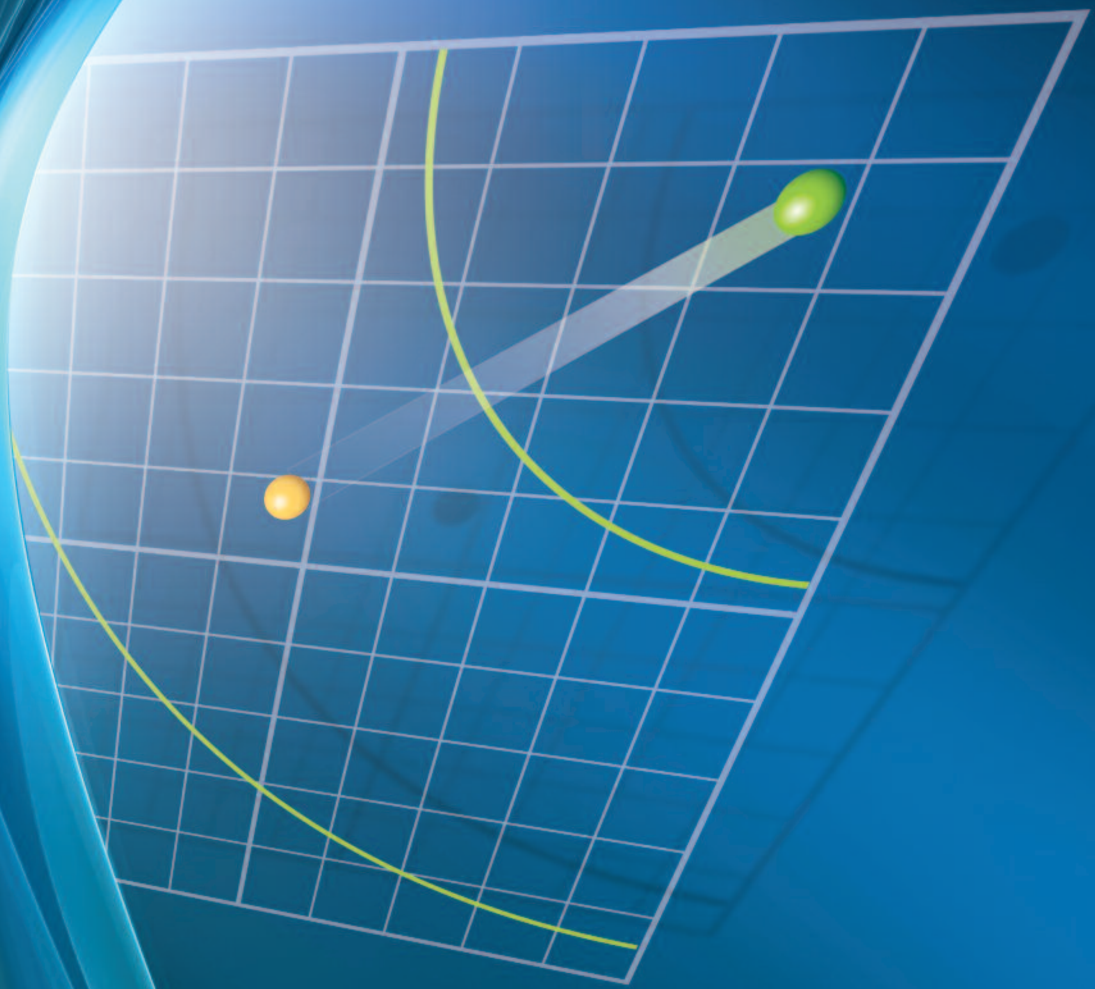
# CANADA:

## Winning as a Sustainable Energy Superpower

### VOLUME II – THE DETAILS



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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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VOLUME II – The Details

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Richard J. Marceau and
Clement W. Bowman

THE CANADIAN ACADEMY OF ENGINEERING
Leadership in Engineering Advice for Canada

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# Introduction to Volume II

Volume I of "Canada: Winning as a Sustainable Energy Superpower" presents an Executive Summary of this two-volume work and provides a short description of Canada's significant opportunities for developing its non-renewable and renewable energy resources.

Volume II develops this theme in greater detail. It provides significant insight on Canada's historically successful "Big Project Innovation Strategy", the scale of its energy resource assets, and what it would mean for Canada to transition from an "energy superstore" to a "sustainable energy superpower". It then describes nine "big projects" which, if undertaken, would embark Canada on a journey of transformation and firmly establish the foundation of it becoming a sustainable energy superpower.

**Chapter 1** presents twelve "big projects" that Canada has undertaken over a 150-year period which have to a large extent defined the nation.

**Chapter 2** projects the vision of Canada as a sustainable energy superpower, and suggests the extent to which this would positively impact Canada's society and economy while enhancing its stature and influence in the world.

**Chapter 3** presents an inventory of Canada's significant renewable and non-renewable energy resource assets, and discusses Canada's capacity to leverage those assets for the benefit of Canadians.

**Chapter 4** presents Canada's extensive hydroelectric potential, both in terms of its large, freshwater drainage basins and its ocean-based tidal opportunities, and identifies projects that could be undertaken in the near- and long-term to reduce Canada's carbon footprint.

**Chapter 5** presents an overview of Canada's provincial electricity systems and, building on the recommendations of Chapter 4, proposes a strategy leading to a national grid which would ultimately connect to a continental grid.

**Chapter 6** reviews Canada's historically successful use of nuclear power for generating electricity, and builds on this to propose a major new initiative employing nuclear power for process heat, in particular for use in Alberta's oil sands, which would contribute significantly to reducing Canada's carbon footprint.

**Chapter 7** presents how Canada can achieve the tremendous economic opportunities by upgrading bitumen from Alberta's oil sands while steadily reducing the environmental impacts on air, land and water.

**Chapter 8** presents Canada's considerable opportunities in developing technologies for coal and biomass gasification which would produce electrical power, hydrogen and high-value chemical products, with much reduced environmental impact.

**Chapter 9** presents Canada's opportunities in developing bio-refineries to produce both bioenergy and bio-chemicals from its extensive forestry and agricultural biomass feedstocks.

**Chapter 10** presents nine "big project" opportunities within an emerging Canadian energy system, and shows how these would enable Canada to progress towards a sustainable energy superpower , building on its energy assets and engineering capability while meeting both economic and social goals.

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# Canada's Big Projects

Clement W. Bowman
Richard J. Marceau

"Every economy needs one great project to keep it functioning properly."

– C.D. Howe

## ABSTRACT

Canada has undertaken numerous significant, large-scale projects over the last 150 years, mainly in the areas of transportation, communication and energy. In this chapter, twelve such projects are briefly described, focusing on the events that drove them and the people who created the vision in each case and inspired the commitment to action.

What were the drivers for these twelve projects? It was rarely economics, certainly not economics as 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 drivers at the time. However, the implementation of these projects changed the business and social landscape of Canada from that time forth. It is especially interesting – and counterintuitive from a normal business perspective – to note that the five projects dealing with energy did not have compelling economics when conceived, or at least economics based on traditional rates of return calculations. Here again, they were driven by a vision that the project would change the nation and open up many new economic opportunities, generating the wealth that is the foundation of the Social Infrastructure that, for some, defines to a large extent what it means to be a Canadian[1].

This observation therefore begs the question: 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 compelling economic drivers for new technologies, entrepreneurs, companies, products and processes on the road to building a very different 21st Century Canada? Additionally, what does it take for visionaries to overcome the objections of the status quo and the risk averse environment that typically stand in the way of major new initiatives? These are the questions that we attempt to answer by considering the specific "big projects" that we describe in this book, through the realizations of past visionaries.

# Introduction

It is safe to say that Canada was built by Visionaries and their visionary projects. As we see in this chapter, Canada has had many of both. Here, we examine the story of twelve Visionaries, who through personal commitment, and by overcoming significant opposition, helped create the Canada we know. It is a story about projects with national impact and their importance in the development of our nation.

## The Canal to Protect Canada

The Rideau Canal was completed in 1832 to provide a secure supply and communications route between Montreal and the British naval base in Kingston. The objective was to bypass the stretch of the St. Lawrence River bordering New York State, a route which would have left British supply ships vulnerable to attack or a blockade of the St. Lawrence River. As many as a thousand workers died from malaria, and other diseases and accidents during blasting. Who supervised its construction?

**The Rideau Canal, Ottawa**

It was Colonel John By of the Royal Engineers who first came to Canada in 1802, working on small locks along the St. Lawrence River. In 1810, he was recalled to England, serving under Wellington in the Peninsular War. After the victory at Waterloo, he was dispatched back to Canada to build the Rideau Canal in 1826. The canal was completed in 1831 with 47 masonry locks and 52 dams, creating a 202 km waterway. The engineering work was carried out by the Royal Engineers, much of this by Colonel By himself. The size of the locks was a major engineering issue and was eventually established by a commission at 134 feet long by 33 feet wide. It has been estimated that 2,000 men worked on the canal each year of its construction. Colonel By was plagued by an initial unrealistic cost estimate of £230,000, and was called before the British Parliament to explain the final cost of £822,000.

Though the canal was conceived and constructed with the defense of Canada in mind, immediately after the canal opened, it played a pivotal role in the early development of Canada, serving as the main travel route for immigrants heading westward into Upper Canada, and for heavy goods (e.g., timber, minerals, grain) from Canada's hinterland heading east to Montreal. Thus, the unintended consequence was economic growth. The canal is cited as the best preserved example of a slackwater canal in North America. In the summer, it continues as a navigable waterway for pleasure craft. In the winter, it is touted as the world's longest skating rink and is integral to the Winterlude festival in the National Capital Region. In 2007 it was inscribed as a UNESCO World Heritage Site, recognizing it as a work of human creative genius.

## The "Longest Bridge in the World"

Opened in 1859, the Victoria Bridge was the first to span the St. Lawrence River, replacing treacherous boat and sleigh crossings of the river. When completed, it was the longest bridge in the world, and was then considered "the 8th wonder of the world". It established Montreal as a continental hub in the North American rail system (as it remains today), greatly facilitating both the trade of goods from Canada's hinterland to United States and European markets, and the passage of people both east and west.

**Victoria Bridge, Montreal**

The bridge is approximately 3 km (2 miles) long, and includes 24 ice-breaking piers. The original deck was a long structural metal tube (i.e., a tubular bridge) made of prefabricated sections. A number of years later, trusses were assembled around the tube, and the original tube was demolished. During the peak of its construction, six steamboats, 72 barges, 3,040 men (of which there were several children between the ages of 8 and 12), 144 horses, and four locomotive engines were required to erect it at a cost of $6,600,000. Its stone piers, part of the original construction, testify to the excellence of its design and the quality of its construction.

Who was the Visionary who selected the location and designed the foundations? It was Thomas C. Keefer, first President of the Canadian Society of Civil Engineers. His design of the foundations for the bridge was called "Keefer's Shoes".

Originally named the Victoria Bridge in honour of Queen Victoria, it was officially rededicated as the Victoria Jubilee Bridge following renovations in 1897. However, it is still commonly referred to by its original name as simply the "Victoria Bridge". The bridge remains in use to this day, carrying both road and rail traffic, with rails in the middle and roadways on both sides, and is actively used by the Canadian National Railway on its Halifax to Montreal main line.

## Uniting Canada – the Canadian Pacific Railway

The Canadian Pacific Railway (CPR) was formed to physically unite Canada and Canadians from coast to coast. Canada's confederation on July 1, 1867 brought four eastern provinces together to form a new country. As part of the deal, Nova Scotia and New Brunswick were promised a railway to link them with the two Central Canadian provinces – Quebec and Ontario. Manitoba joined confederation in 1870. British Columbia, on the west coast, was enticed to join the new confederation in 1871, but only with the promise that a transcontinental railway be built within 10 years to physically link east and west.

**The Last Spike (left)**
**Banff Springs Hotel (right)**

Few images of Canada are as iconic and recognizable as the photo of the driving of the last spike in 1885. Few songs capture Canada's spirit as well as Gordon Lightfoot's 1967 song "Canadian Railroad Trilogy". The sight of a line of over 100 railcars bearing goods laden for Thunder Bay or Vancouver for markets around the world reinforces the fact that Canada is as big as the land, not as small as its population. Pierre Berton called the construction of the Canadian Pacific Railway "The National Dream".

The rocks and muskegs of the Canadian Shield and the mountains of British Columbia created enormous engineering challenges, delays and cost overruns. Who overcame these problems and achieved the vision?

That man was William Cornelius Van Horne. A successful railroad executive in the United States railroad business, Van Horne became CPR general manager in 1882 to oversee construction of the transcontinental railway over the Prairies and through the mountains. Van Horne committed to build 800 km (500 miles) of main line railway in his first year. Floods delayed the start of the 1882 construction season, but at season's end, thanks to 673 km (418 miles) of main line and 177 km (110 miles) of branch line track-laying, the vision of a transcontinental link was within sight.

Construction through the rock and muskeg of the Canadian Shield almost equaled in difficulty the engineering feats of construction through the mountains of British Columbia. Problems in obtaining an adequate work force in British Columbia led to the controversial importation of thousands of Chinese. At the height of the building activity on the Yale to Kamloops Lake section, more than two-thirds, or approximately 9,000 workers, were Chinese.

At the time, the Canadian Pacific Railway was the longest railway ever constructed, most of it in virgin wilderness. Its successful completion, though troubled by political scandal, significant engineering challenges, delays, cost overruns and financial difficulties, was a remarkable accomplishment of both engineering and political will for a country with such a small population, limited means, and difficult geography as Canada. However, the existence of a pan-Canadian, continental railway greatly accelerated the trade of goods from Canada's hinterland to world markets, the settlement and development of Western Canada, the creation of new opportunities which Van Horne seized very early on (e.g., the first national telecommunications subsidiary based on the telegraph, an international shipping line, a luxury hotel business), and the consequent rapid development of Canada's people and economy. Today, the Canadian Pacific Railway owns approximately 22,500 km of track across Canada and into the United States.

## Our National Airline

Canadian Airways Limited began limited intercity air connections in 1930, intending to build the backbone of a private sector national air capability. However, the Canadian Government laid plans in 1935 for Trans-Canada Airlines (TCA), a largely public sector venture and a subsidiary of Canadian National Railways, to provide transcontinental airline service within Canada's borders. Starting with only two passenger aircraft in 1939, TCA instituted its first international routes in 1948, introduced turbine-driven airliners in the 1950s, and was the first airline to use a computer reservation system in 1953, amazing progress for its time in any country.

One man led the struggle to resist the pressure of north-south branch lines between adjacent Canadian and American cities and stimulate east-west connections between Canadian hubs, a nation-building struggle that continues today. Who was that man? This man was Clarence Decatur Howe. He chose most of the original TCA Board members, and personally selected its first President, Philip Johnson, former President of Boeing Aircraft and United Airlines.

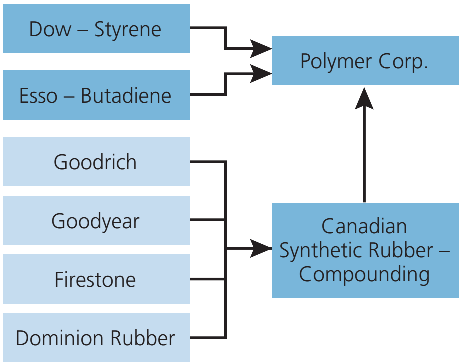
In Canada, the competition between public and private sector airlines continued until 2000, at which time TCA, then called Air Canada, acquired Canadian Airlines, a company that had eventually resulted from the merging of Canadian Pacific Airways and other private sector companies. This practice of reaching into the talent of private industry to staff Canada's emerging crown corporations was a hallmark of C. D. Howe, "Minister of Everything" in Canada for more than 20 years.

Today, Air Canada serves170 destinations on five continents (shown in Figure 1) with 330 aircraft (i.e., from Beechcraft 1900D for regional destinations to the Boeing 777 for international flights), 100 of which are part of its regional fleet. Air Canada now has over more than 23,000 full time equivalent employees, and flies over 11 billion passenger-miles per year.

**Figure 1**
**Air Canada Destinations**

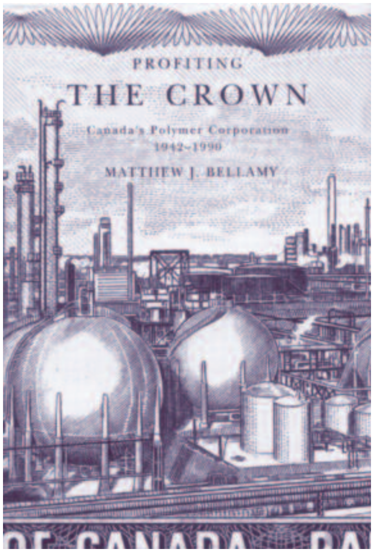
## Synthetic Rubber

Canada's supply of natural rubber was essentially cut off in 1942, at a crucial stage of World War II. The Government developed a plan for building a synthetic rubber plant, using technology never before commercially proven.



Six private companies were persuaded to support the formation of a crown corporation (i.e., Polymer Corporation) to supply synthetic rubber in support of the war effort. By war's end, the plant had produced 95,000 tons of rubber. Who was the man to whom the Government said "It's your job to get rubber!"

It was J.R. Nicholson, Polymer's first General Manager, who conceived and led the project for the first decade. As a result of the "personal service that he gave to his clients", Polymer was highly successful in post-war sales into Europe. There was a consistent instruction from the Federal Government: "operate as a commercial enterprise for the purpose of generating a profit". Polymer Corporation also contributed to Sarnia's emergence as a significant supplier of a large variety of petroleum-based fuels and chemical compounds in the second half of the 20th century.

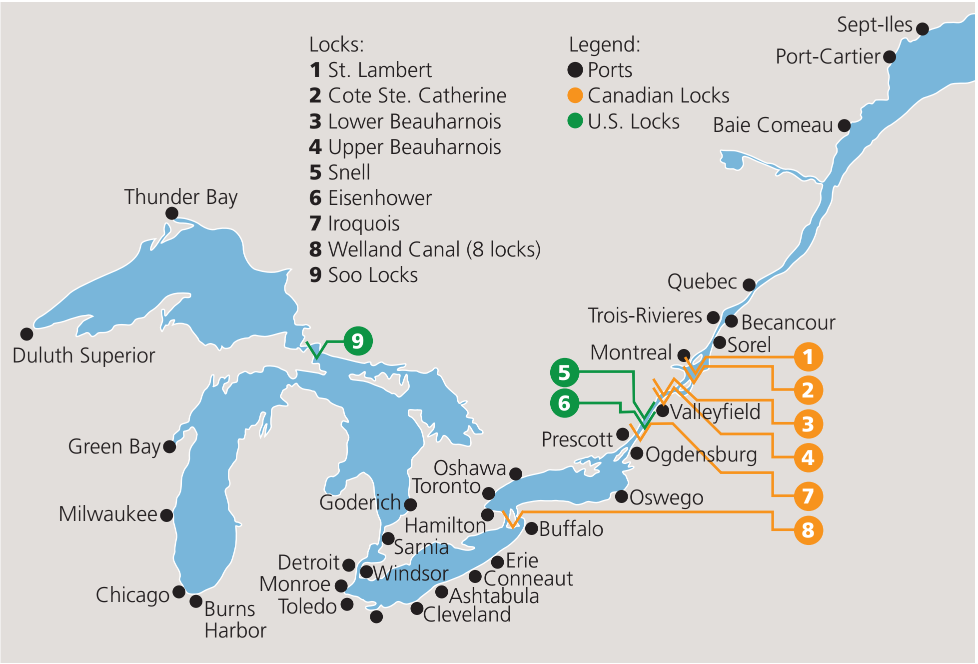


Eventually, the Federal Government recognized this ground-breaking crown corporation by placing its image, for a time, on the back of its ten-dollar bill, becoming as familiar to Canadians as the Parliament Buildings (on the $1 banknote), Moraine Lake (on the $20 banknote), or the RCMP Musical Ride (on the $50 banknote). Now part of the German company Lanxess, it remains one of the world's leading producers of synthetic rubber.

## St. Lawrence Seaway

Similarly to the intercontinental railway, the St. Lawrence Seaway was a project of gigantic proportions – a 3,700 km marine highway that runs between Canada and the United States, from the Atlantic Ocean to the head of the Great Lakes, in the heart of North America. Ranked as one of the outstanding engineering feats of the twentieth century, the St. Lawrence Seaway includes 13 Canadian and 2 U.S. locks, as shown in Figure 2.

**Figure 2**
**From Lake Superior to the Markets of the World**



Although the United States had long resisted the concept since it was first seriously proposed in 1895, a Seaway treaty was finally signed in 1954. The resulting Seaway opened in 1959 at a cost of $470 million, $336 million of which was paid for by the Canadian Government. The project also included the construction of the 2,090 megawatt Moses-Saunders Powerhouse, the world's first international hydroelectric power dam.

Queen Elizabeth II and President Dwight D. Eisenhower formally opened the Seaway with a short cruise aboard the Royal Yacht Britannia. Since 1959, the St. Lawrence Seaway has moved over 2.5 billion metric tons of cargo in 50 years, estimated at more than $375 billion. Nearly 25% of this trade originates from – or is exported to – ports in Europe, South America, the Middle East, and Africa. Virtually every commodity imaginable moves on the Great Lakes Seaway System, exceeding 200 million net tons (180 million metric tons) a year, a significant contribution to Canada's international trade.

Who introduced the bill to Parliament and became the first Seaway President? It was Lionel Chevrier, then Minister of Transport. After leading the St. Lawrence Seaway for four years, he returned to politics serving as Minister in several key portfolios. He resigned from the House of Commons in 1964 to become the Canadian High Commissioner in London. In 1997, Canada Post issued a stamp in his honour.

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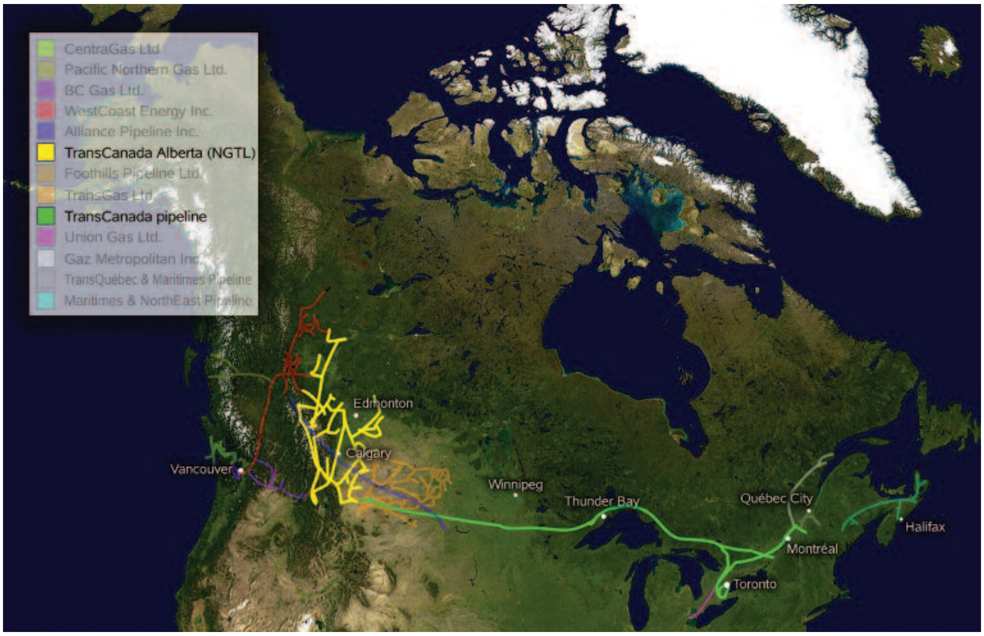
## The TransCanada Pipeline

The Great Canadian Pipeline debate began in 1954 with the goal to ship natural gas from west to east, “through Canada and only in Canada”. Opposition came on many fronts: those supporting north-south links to the United States, those against participation by United States companies in a Canadian resource, and those who simply saw the project as financially unsound. At the time, the pipeline debate in the House of Commons was considered by some to be one of the lowest points in all of Canadian politics. Here is a quote from newspaper media of the time: “… while the Liberal Cabinet, the opposition and the press gazed at the parliamentary wreckage, Trans-Canada got ready to lay pipe across the prairies …”.

Who developed the plan which salvaged the wreck? Once again it was Clarence D. Howe. He committed a lifetime of private and public sector capital to this project. He achieved success, but at the cost of the St. Laurent government losing the next election in dramatic fashion to John Diefenbaker.

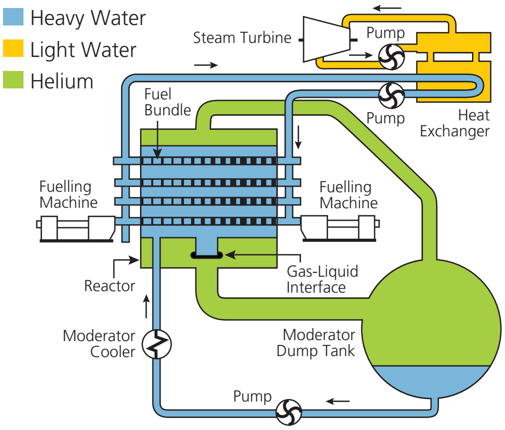
**Figure 3**
**TransCanada Pipeline Network**



Today, TransCanada Pipelines has a network of more than 60,000 kilometers of pipelines, shown in Figure 3, connecting all major gas supply basins in North America, and delivers 15 billion cubic feet of gas per day throughout North America. The company owns, controls or is developing approximately 11,700 megawatts of power generation.

## The CANDU Power Reactor

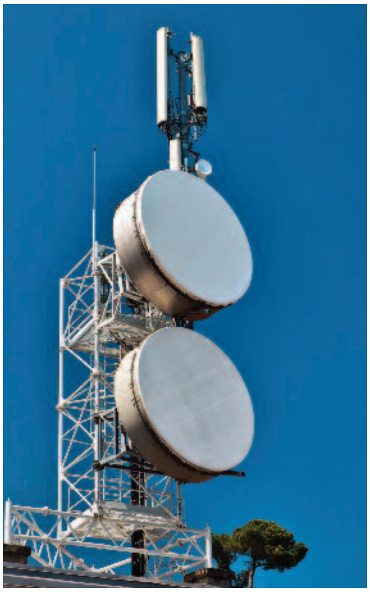
**Figure 4**
**Flow Diagram of the NPD Reactor**



Canada's pursuit of nuclear power dates from 1898 with the appointment of Ernest Rutherford as Professor of Experimental Physics at McGill. But activities expanded dramatically when Canada was chosen to host an international group of scientists in 1942, leading to the construction of the heavy water moderated NRX experimental reactor, the larger research reactor NRU and the first small scale prototype (NPD), the flow diagram of which is shown in Figure 4. The National Research Council (NRC) had responsibility for what was then called the Atomic Energy Project. In 1952, activity was transferred to a crown corporation named Atomic Energy Canada Limited (AECL).

The initial Board of Directors of AECL included representatives from the predecessor of Ontario Power Generation which proved to be essential in getting the first major client on board. There were many people involved in the development of the CANDU high pressure reactor system moderated by heavy water with zirconium alloys as the fuel cladding material. But there was one man who was key in getting the technology ready to be evaluated. That man was Dr. W. B. Lewis, Technical Director of the initial Atomic Energy Project, who had joined the team in 1946. He was a dominant force in Canada in nuclear research and the development of nuclear power until his retirement in 1973.

The commercial history is now well known, with the larger prototype built at Douglas Point in 1967, followed by larger commercial units at Pickering and Darlington, and a number of international sales. In 1987, the Canadian Engineering Centennial Board selected the CANDU reactor as one of the ten most outstanding Canadian engineering accomplishments of the previous century. Twenty-nine commercial CANDU reactors have been built, providing valuable base-generation and low-carbon generating capacity in Canada and abroad. CANDU remains a successful and viable set of designs being marketed in the form of the Enhanced CANDU 6 (EC6) and the somewhat larger Advanced CANDU Reactor (ACR-1000).



## The TransCanada Microwave System


TRANS-CANADA SKYWAY
OPENED JULY 1st, 1958

Northern Electric

Image courtesy of
The Gazette, a division of
Postmedia Network Inc.

After World War II, growth across Canada put a strain on the existing system of long-distance telephone wire lines. Live cross-Canada television broadcasts were also limited. The longest microwave system in the world was completed in 1958, passing signals from Sydney, Nova Scotia to Victoria, British Columbia. 139 towers enabled microwaves to transport telephone, teletype and television signals across 6,275 kilometers in one-fiftieth of a second. Even so, the cost of $50 million and the regional ownership of telephone systems caused several years of bureaucratic delay. Who spearheaded this development from start to finish?

The project was implemented under Bell Canada's President Thomas Wardrope Eadie. The Trans-Canada Microwave System is also recognized as one of the major engineering feats of the last century. The Thomas W. Eadie Medal is an award of the Royal Society of Canada "for contributions in engineering and applied science".

The TransCanada Microwave system allowed significantly increased capacity for telephone, teletype, and television signals. Being able to deliver a live broadcast across the country set the technical foundation for shared events such as "Hockey Night In Canada". By 1966, one microwave channel could carry 1,200 simultaneous telephone calls. By 1971, technical improvements meant that Canada could boast of having the world's first domestic digital microwave network.

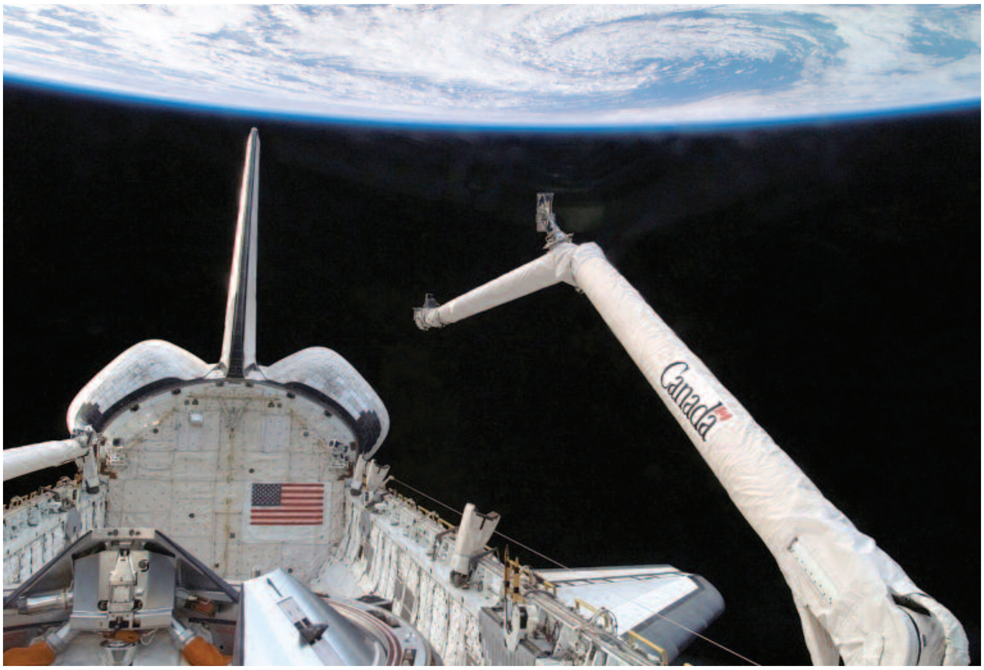
Today, instantaneous cross-country communication is taken for granted with smartphones, free Wi-Fi connections in coffee shops, and so many other ways to be connected with family and friends. Canadians benefit from remote reading of their water and electrical meters at home, the tools to connect with co-workers around the world, and the technological means to run a business from home.

How would Canada conduct its business today, where would Canada's economy be, without this valuable infrastructure?

## Canadian Satellite Launched

With the launching of Alouette I, Canada became the third nation in space after the Union of Soviet Socialist Republics (USSR, the predecessor to what is now Russia) and the United States of America. The introduction of satellites enabled communications to the isolated and sparsely developed northern areas of Canada not reached by the microwave system. Who was the visionary who pioneered this development?

John Herbert Chapman was the pioneer behind the Alouette program, and as Chairman of a government study group, he compiled his findings into "The Chapman Report" which still guides the Canadian space program.



Canada's aerospace industries have now designed and built at least 10 commercial and research satellites, including RADARSAT I, RADARSAT II and MOST. The high performance "storable tubular extendible module" led directly to the development of the "Canadarm" employed on U.S. space shuttle missions, and the International Space Station. One retired Canadarm is being returned to the Canadian Space Agency in recognition of the valuable technology that Canada contributed. Meanwhile, Canadian astronauts continue to have key roles in NASA programs. Chris Hadfield will have a tour of duty in command of the International Space Station in 2012.

Canada has two companies which operate at least one commercial communication satellite. Telesat Canada is now the fourth-largest fixed satellite services provider in the world. It owns a fleet of 13 satellites, has one other satellite under construction, and operates 13 additional satellites for other entities. Ciel Satellite Group is a private Canadian satellite operator, established in 2004, providing services throughout the Americas, and founded to develop Canadian spectrum opportunities while meeting the demand for domestic competitive satellite services.

## Launch of the Oil Sands Industry

**Oil Sands Surface Mining**

Photo courtesy of Suncor Energy

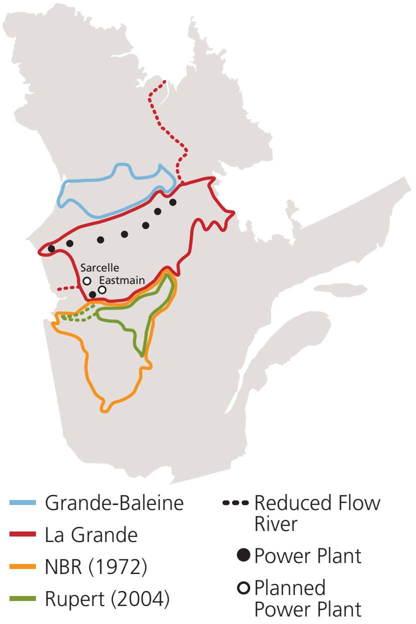
After half a century of failed searches for an expected source of light oil, and a few catastrophic initial commercial trials, one man came forth in 1967 and said to his Board of Directors: "Gentlemen, either you approve our oil sand commercial project or I will handle it myself". His company immediately filed an application with the Alberta Government for the first surface mining oil sand project with the following personal declaration: "I believe in the future of this project and I will put up my money with no reservations if the permit is granted". Who made this promise?

It was J. Howard Pew, Chairman of Sun Oil. He risked his company and his reputation on a first-of-kind project using untried technology. The result: the Great Canadian Oil Sands project – now Suncor. This project now produces approximately 200,000 barrels of oil per day.

The economic impact of the projects following the initial Suncor project on Canada has been significant with respect to any metric. 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. The economic impact of the oil sands is more than just the 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 throughout Canada's 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 James Bay Hydroelectric Power Project

**Figure 5**
**The James Bay Hydropower Resources**



Canada has led the world in the development of numerous hydroelectric power projects, with James Bay in Quebec, Churchill Falls in Labrador, and Nelson River in Manitoba being only a few of many significant examples. Major engineering innovations and achievements resulted in most large Canadian hydroelectric projects, either in the design or construction of dam structures or earthworks, generating stations, or long distance transmission technologies. The James Bay project presented in Figure 5 is an outstanding example, in part because of its numerous innovations in hydraulic engineering, civil engineering, construction engineering and electric power engineering.

The Quebec Government began to plan several large hydroelectric power stations in the early 1970s. In 1975, the Federal and Provincial Governments signed an agreement with the Cree of the James Bay region and the Inuit of northern Quebec for the right to develop the James Bay hydro power resources. The project was undertaken in phases with the first phase completed in 1986, eventually resulting in a current installed capacity of 16,000 megawatts. Several 735 kV AC transmission lines equipped with advanced compensation technologies enhancing their transmission capacity, and one 450 kV DC line, were built to bring the generated power to southern Quebec with links to the U.S. power grid.

Who was the person responsible for launching this mammoth undertaking? It was Robert Bourassa, then Premier of Quebec for whom the first power station is named. A hydroelectric development project on this scale generates not only large economic benefits during its construction phase, but also an ongoing and significant return on investment for generations to come thanks to the renewable nature of rainfall, while producing low-carbon energy.

Thanks to its massive hydroelectric power production, Canada releases only 34 megatonnes of carbon dioxide per exajoule of electrical power, in comparison to the U.S. figure of 162 megatonnes per exajoule.

# Pathway Forward

Is there a common theme for some of these big projects? The Rideau Canal was a secure connection between east and west; between Montreal and Kingston. The Victoria Bridge was a reliable connection from Montreal to key commercial hubs along the eastern seaboard. The Canadian Pacific Railway connected the eastern to the western coasts, allowing immigration of people, and trade of our commercial goods and commodities. Trans Canada Airlines connected people across Canada and now, as Air Canada, connects us to the world. The St. Lawrence Seaway connects the heart of the continent to the world's oceans. The TransCanada Pipeline brings raw materials to sites where they can be upgraded, and on further to where they are valued. The Trans-Canada Microwave System, Alouette I and its successors, connect us, our information, our ideas and our cultures. These big projects have an east-west, or pan-Canadian, theme.

A different view of Canada's big projects has been introduced by Godfrey and McLean in their book "The Canada We Want"[2]. Five National Projects were identified which have defined to a large extent what it means to be a Canadian (right hand column of Table 1). These are now embedded as core values of citizenship in Canada. However, Godfrey and McLean recognize that there has to be another "National Project" to provide the investment needed for these five projects and they introduced a sixth project "Physical Infrastructure" with eight examples. In other words, they acknowledge the organic connection between projects which generate wealth, and projects which require wealth as the foundation of their existence.

As Canada seeks to strengthen its social infrastructure over the coming decades, equal thought needs to be given to both sides of the ledger. Godfrey and McLean have proposed a number of new national projects in the social infrastructure arena including Development Health, Canada's Children, and Educational New Media, all of which will require the new wealth generated by projects such as those identified in other chapters of this book. Although the list of "big projects" on both sides of the ledger may be different, Godfrey's and McLean's three critical ingredients to "get them off the ground"—leadership, vision and resources—are the same for either Physical Infrastructure or Social Infrastructure projects.

**Table 1**
**Canada's Big Projects**

| Physical Infrastructure[3] (Wealth Generating Projects) | Social Infrastructure[4] (Wealth Consuming Projects) |
|---|---|
| Rideau Canal | Public Health Insurance/ Health Care System |
| Victoria Bridge | Education |
| Canadian Pacific Railway | Income Security |
| National Airline | Human Rights |
| Synthetic Rubber (Polymer) | Culture and Research |
| St. Lawrence Seaway | |
| TransCanada Pipeline | |
| TransCanada Microwave System | |
| Canadian Satellites | |
| Alberta Oil Sands | |
| Hydroelectric Power (e.g. James Bay) | |
| Physical Infrastructure[5] | |

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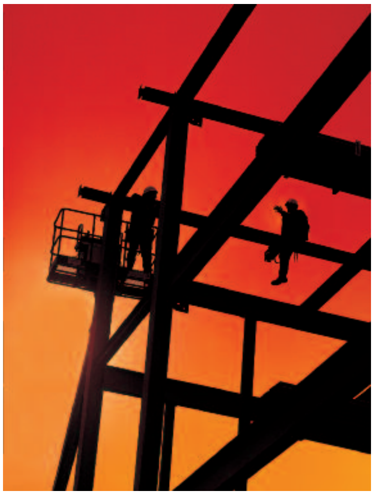
# The Sustainable Energy Superpower Vision

Marshall J. Kern



## ABSTRACT

Canadians are inventors, discoverers, peacekeepers, and builders. A consensus is developing that we are an energy superpower on the world stage. Being a sustainable energy superpower has major implications for Canada. It means that our energy resources must be used wisely, and not impaired for future generations. It also means that we have both the energy resources and the capability to influence world markets.

Our geographic challenges have forced us to learn how to deliver energy from where it is generated to where it is used, from sea to sea. Pipelines have been installed for liquids and gases; rail and the St. Lawrence Seaway for solid fuels. There are a number of north-south electrical transmission lines and corridors which need to be expanded through enhanced east-west connectivity.

To wear the mantle of a Sustainable Energy Superpower, Canada has to have an optimal mix of distributed and centralized energy sources; large, distinctive renewable and non-renewable assets; supplemented with a demonstrated nuclear capability. We already have a pan-Canadian energy distribution network of pipelines and power grids. Our secure, robust energy system has the capability to deliver prosperity and a high quality of life for Canadians. With our energy endowment, we can also “punch above our weight” in international affairs to eliminate energy poverty elsewhere.

As we build a more integrated Canadian energy system, we will make progress in many key areas. We will continue to make advances through big projects. We will resolve competing interests through consensus and collaboration. We will direct and monitor our progress toward sustainable long-term goals.

The vision of Canada as a Sustainable Energy Superpower transcends the scope of any individual company, and crosses the responsibilities of different levels of government. Our common path forward will require political leadership committed to a cooperative and shared goal.

Canada and Canadians, embracing the perception of an environmentally aware land, a peaceable nation, endowed with the natural and human resources needed, can and should strive to bring to reality a vision of Canada as a Sustainable Energy Superpower.

## As We See Ourselves

There is an internationally-held view of Canada as a pristine wilderness. We reinforce this same view ourselves by declaring that we Canadians live in "the Great White North". We have grounded this perception in reality by establishing and expanding National Parks since 1885. We patrol the High Arctic and have extended our sovereignty far into the oceans that bound us. We've put "green-belts" around our cities. We've recently extended protection and limitations on development to a wide swath of boreal forest.

We are stereotypically characterized as polite and courteous; Canadians say "thank you", and "excuse me" and "sorry". We think of ourselves as friends with everyone. We point to the world's longest undefended border as an example of our openness.

**Canadians are inventors, discoverers, peacekeepers, and builders.**

We are inventors, and discoverers who help the world. Examples are Drs. Banting and Best, discovers of insulin, Sir Sandford Fleming, who proposed and championed standard time that is now used in all nations, and Alexander Graham Bell who invented the telephone. Millions of people with diabetes are alive today because of insulin and now the world's population is connected in a global communications network.

As Peacekeepers, Canadians have contributed to missions in troubled spots throughout the world. The actions of our military, diplomatic, and development personnel continue to be praised.

Within Canada, we can look at the mega projects that have shaped the nation, transformed our economy, and ultimately helped define us as a country. A railway stretching to the Pacific Ocean was a national dream that connected and spurred the development of a young Canada. Offshore oil discoveries have propelled Newfoundland and Labrador from "have-not" status into wealth. Medicare rose from a radical idea in Saskatchewan to become a national reality and a fundamental value of being Canadian. Chapter 1 describes big projects that have, to a large extent, defined the Canada that we know.

## A Consensus is Developing

Canada's energy sources have been described in bold, sweeping language. Examples of which are:

**Canada As A Global Energy Leader: Toward Greater Pan-Canadian Collaboration, Ministers of Energy, June 2011**

"Within Canada, there is a large, unique and diverse energy endowment. Canada ranks second in global production of hydro electricity. Canada is also the second largest global producer and exporter of uranium. These are both clean energy sources that are essential to economic development and efforts to address climate change. It has the world's third largest oil reserves. It is the only OECD country with growing oil production and is the world's third largest exporter of natural gas. Canada's nuclear generating stations operate with strong regulatory oversight nationally and adhere to the highest safety standards internationally. We are also leaders in clean electricity with 75% of our power generation coming from non-emitting sources, contributing to both economic and climate change objectives. Notably, the country is well positioned to generate energy from other renewable sources such as wind, solar, geothermal, marine, and biomass. As well, Canada's northern regions are relatively untapped, extremely energy-rich areas, with higher costs of living and where having affordable energy is a challenge. Development of these energy resources will ensure a vibrant northern economy and sustainable communities. These endowments provide an unparalleled economic advantage to secure our place as a global energy leader[1]."

**A Shared Vision For Energy In Canada; The Council of The Federation, 2007**

"Canada is blessed with large quantities of diverse sources of energy, including hydro, wind, solar, oceans (tidal and wave), biomass, uranium, oil, natural gas, coal, oil sands-bitumen, and coal bed methane. Canada is an "energy superpower" on the world stage. We generate more hydro-electric power and produce more uranium than any other country on earth and rank second in natural gas exports. Canada has some of the largest and safest nuclear generating stations in the world and several important nuclear research facilities. With proven oil reserves second only to Saudi Arabia, Canada is the 8th largest oil producer – and growing"[2].

**Canada is an "energy superpower" on the world stage.**

– Council of the Federation

**Clean Growth 2.0, How Canada Can Be A Leader In Energy and Environmental Innovation; Canadian Council of Chief Executives, November 2010**

"Canada is blessed with a wealth of natural resources, which have and will continue to power a great deal of Canada's future prosperity. We have the second largest reserves of oil in the world, are number two in global uranium output, represent the number three natural gas producer in the world and are sitting on coal reserves sufficient for 100 years at current production rates. As well, various parts of the country offer significant potential in new sources of hydroelectricity as well as bio-fuels, wind and tidal power"[3].

These examples are a consensus that energy is markedly different from other sectors of the economy and that the future of Canada will be tied intimately to how well we develop, use and trade our huge energy endowment. Chapter 3 of this book describes our many energy assets and the role of energy corridors that are involved in their development.

## The Meaning of a Sustainable Energy Superpower

"Sustainable" means that we will use our existing energy resources for their best possible value now without impairing their use by future generations.

**Canada can be more than the world's energy superstore.**

An "energy superpower" means the ability to influence world markets in favour of sustainable economic development. This might be exercised by our participation in international treaties, by responsibly exporting our technologies, raw materials and energy, by influencing the market price for commodities and by contributing to the transition to low-carbon energy resources.

Canada's challenge is to establish its role as a "Sustainable Energy Superpower".

The "parade" towards this future has started[4]. We need only look at the statements by business and academic leaders in recent times – seeking collaboration and cooperation for new and renewable energy sources, advocating for better energy transmission, and calling for the recognition of the value of Canada's resources.

Consider as well the white-papers, proposals, debates, and demonstrations calling for changes in the greenhouse gas (GHG) intensity of Canadian society, and real reductions in GHG emissions. There is movement towards a lower-carbon future and towards energy conservation. There is movement towards more diverse sources of renewable and non-renewable energy. There is movement towards collaboration between the levels of government because no single level (municipal, provincial, or federal) has complete jurisdiction over current and future energy resources and currencies.

The Canadian Academy of Engineering, in its work over the past five years[5, 6] investigating Canada's energy pathways, has proposed some measurable definitions in Chapter 10 that could be used to track Canada's progress toward that definition. They include:

- an optimal mix of distributed and centralized energy sources; with large, distinctive renewable and non-renewable assets, supplemented with a demonstrated nuclear capability
- a pan-Canadian energy distribution network (pipelines and power grids)
- creating efficiencies at all points, conserving resources, reducing GHG emissions, meeting expected future international environmental standards
- delivering prosperity and a high quality of life for Canadians
- contributing significantly to the growing international energy demand at competitive prices, and contributing to the alleviation of energy poverty
- creating energy security through robust, reliable systems

Canada can achieve global commercial trade in more than the raw materials of energy—not simply sending Canadian oil, gas, and electricity to the United States. Canada can export and trade in technology, ideas, and expertise. Its international policies can go beyond a north-south dialogue and focus on delivering energy capability as foreign aid to achieve sustainable improvements to poverty levels where a lack of adequate energy infrastructure exists.

Canada is poised to become the Sustainable Energy Superpower that many envision. Some forces are within our control and others are not. Now is the moment to create a vision of a true Sustainable Energy Superpower and make it Canada's reality.

**Canada's energy assets as an integrated system are a work in progress.**

## The Destination and the Pathway

A Canadian Energy Strategy requires a clear vision of the sustainable energy superpower destination. At a meeting of the Energy Ministers in July 2011, the outline and process to achieve a Canadian Energy Strategy was announced. Politicians recognized that the participants are diverse and the route is complex. There may not be clear agreement yet on the definition of Canada as a Sustainable Energy Superpower.

One aspect of Canada's future state, however, is quite clear. It has many opportunities to achieve an optimal mix of energy sources.

The Council of the Federation concisely stated that "Canada is an energy superpower on the world stage". The Council went further to say: "We are one of the few countries in the world that is not only energy-rich, but also fully capable of increasing its energy production in an environmentally and economically sustainable manner. These resources, combined with the intellectual and technological skills possessed by Canadians, have made Canada's domestic and export energy sector one of its biggest economic drivers."

The Waterloo Global Science Institute and the Perimeter Institute hosted an event in June 2011 called the "Equinox Summit"[7]. The communiqué from that event has a vision for 2030 and identifies a set of "technological approaches and implementation steps that have the potential over coming decades to accelerate the transition of our energy systems". A more complete blueprint of steps in six priority areas is being developed now with release expected early in 2012.


**Seven Sisters Generating Station, Manitoba**

What will Canada look like as a Sustainable Energy Superpower?

- Canada will source reliable and sustainable hydroelectric energy from existing sites and new sites that can be economically developed, and deliver that energy to Canadians across several time zones. The decisions to build new capacity will focus on technical and environmental issues, not political issues. Peak demand in one time zone will be met by off-peak capacity from other time zones. Combined with efficiency, conservation and other demand modification measures, Canada can provide excess energy generation capacity to export markets. These goals are described in Chapters 4 and 5.

- Canada will again address energy security. The apparent diversion of CANDU nuclear technology to the support of a weapons program in India is an example of the need for ongoing diligence in sharing Canadian resources. Canada will continue its role and reputation in the ongoing dialogue with lesser-developed nations towards the use of appropriate energy technologies. In this way Canada will protect its energy interests around the world, whether those interests are for nuclear security, climate change management, or the elimination of energy poverty. The importance of the Canadian nuclear industry is described in Chapter 6.

- Canada will export high-value components of our energy resources, not just harvest the raw materials for others. Fossil fuels will increasingly be refined into high-value chemical products. This is especially important for the Alberta oil sands as discussed in Chapter 7 and also for coal and biomass as described in Chapters 8 and 9.

- Canada will continue to "punch above its weight" in international matters. Canada will hold firmly to the ideal that it is a Peacekeeper nation; that it has earned respect in the international community because of its fair trade practices. Canada will continue to build connections with other countries through trade agreements and through arrangements to support development. These connections will be used to build our nation's reputation as more than a raw materials source, as discussed further in Chapter 10.

It is surprising that this vision of Canada's future has not been a focus of national debate. The major energy issue that has received widespread public attention is the need to reduce carbon dioxide emissions to meet current and expected global warming regulations. Attention on this dimension has been repeatedly captured by the timing of international meetings in Copenhagen and Durban for the Kyoto Protocol. The parallel dimension of creating wealth for the nation over the coming century has not been recognized as a starting point for political debate. Progress toward the vision of being a Sustainable Energy Superpower and addressing these two dimensions has stalled.

# Challenges

## The Geographic Scale of the Nation

Canada's geography is both a challenge and an opportunity.

An obvious challenge is to distribute energy over the vast distances of Canada. Energy sources are scattered from sea to sea to sea. The cities are concentrated along the southern part of the country. How does energy get from where it is generated to where there is demand?

Pipelines have been installed for liquids and gas; rail and the St. Lawrence Seaway for solid fuels. There are a number of north-south electrical transmission lines and corridors. But we have few east-west electrical transmission corridors. A pan-Canadian, continental high-power grid is required to release stranded generation capacity, accept new generation sites, and spread peak demand over multiple time-zones. Chapters 4 and 5 discuss this opportunity in detail.

The vast distances from major energy sources to major demand centres pose technical issues. Matching energy transmission with energy demand can be achieved through improved communication, control and storage capability - key features of an integrated and smart national grid. Canada's energy assets need to be managed as an integrated system.

**CN Railyard at Bedford, Nova Scotia**

## Our Federal System

Some of the most significant challenges to the vision of being a Sustainable Energy Superpower are the obstacles created by Canada's organizational structures. The political construct is one of shared Federal and Provincial responsibilities. The sense of shared nationhood has been allowed to be usurped and distorted into conflicting divisiveness and parochial defensiveness. Overcoming this challenge can be accomplished by individual statesmen and by a collective dismissal of unbending special interest groups. It has been noted by Michael Bourque of the Chemical Industry Alliance of Canada that "most, if not all, of the barriers to new investments are generic. That is, they are barriers to all manufacturers, and it will benefit the whole country to have them removed." [8]

## The Need for an Energy Strategy

Big energy projects create our energy strategy.

Presumably, an Energy Strategy should include a plan for long-term energy investments. Canada does not have a comprehensive strategy which includes new major investments in renewable sources such as tidal, solar or wind energy, hydroelectric, and biomass, and in non-renewable sources such as nuclear, and innovative clean coal commercial plants. Thought should be given to the potentially synergistic "currency" relationship between electricity and hydrogen as the future unfolds. The International Energy Agency has stated that Canada will require $190 billion in investment in the electrical sector alone by 2030. An energy strategy should also outline an optimal mix of distributed and centralized energy sources and a mix of renewable and non-renewable energy generation assets.

Most growth of new Canadian energy sources is from small installations of a local or regional scale. There are subsidization programs to encourage solar panels on roofs of buildings in Ontario. There are approvals for small hydroelectric generation sites in British Colombia. There are demonstration sites for tidal power in the Atlantic Provinces. There are agreements with foreign manufacturers to build wind turbines in Ontario. There are Alberta initiatives to utilize biomass for energy production.

Unfortunately, there is no evidence that Canada has a grand strategy for the development of its huge energy endowment. In this book, we propose that big energy projects should be the major driver of a long-term energy strategy.

## Economics

Canada has weathered the global financial downturn of 2008-09, and appears to be positioned to deliver relatively more GDP growth than other G8 and G20 countries as the global slowdown and various debt crises hit its neighbours. But the finances needed to become a sustainable energy superpower will be a challenge. Collaboration amongst the private sector, the public sector, and the banking establishment will be necessary to bring the vision into reality. There must be acceptance and agreement for financing ambitious major new infrastructure.

**Big energy projects should be the driver of Canada's long-term energy strategy.**

As national or regional projects are launched and because of the scale of spending, there will be a need to recognize the limitations of increasing debt at all three levels of government. Energy pricing will be volatile as markets adjust from dependence on a barrel of oil as a base commodity to other energy criteria. The price volatility will be disruptive which should be more encouraging of conservation and innovation. We probably will not need nor benefit from market-distorting policies of subsidization.

## Competing Interests

There are competing interests through any transition. Energy providers will compete on applied technologies and their commensurate economics for advantages from biomass, hydroelectric, tidal, solar, wind, geothermal, and other sources. Local environmental issues will dictate reasonable constraints on the physical location of generation capacity, transmission or pipeline corridors and the potential expansion of existing energy providers.

## Energy Security

At the St. Petersburg meeting of the G8 leaders, the topic of energy security was limited to non-proliferation of nuclear weapons capability[9]. That was germane to the tensions between India and Pakistan and the concern that nuclear weapons were built using technology from nuclear power plants. For Canada to be a sustainable energy superpower, with both the supply of uranium as a raw material, and CANDU reactor technology to deliver electricity, we must demonstrate vigilance that when nuclear power is used, it is used for peaceful applications, such as those outlined in Chapter 6.

Energy security means interconnection of electrical grids for consistent power delivery, resilience to unplanned outages, and having "robust" capacity to receive and deliver power to meet demand. The technical community has achieved significant agreement on standardizing the equipment and the control systems for existing grids. This must continue as we bring on-line the optimal mix of distributed and centralized renewable and non-renewable sources of energy.

More recently, energy security is being described as a basic human right. Energy security is being compared to the right to clean water, clean air, and food. As the world's population increases, securely delivering enough energy to all is being presented as a great global opportunity. As Canada becomes a sustainable energy superpower, its experience with a mix of energy sources, a national smart grid, and resource conservation, will enable it to engage with other nations as an example of the use of appropriate technology. Canada should continue to develop these capabilities and capacity to serve its own market, and as a sustainable energy superpower contribute to the elimination of energy poverty.

## Protecting the Environment

**Energy is where we must think globally and act locally.**

In the years leading up to the Copenhagen meeting regarding the Kyoto Convention, there were repeated calls for Canada to set GHG emission-reduction targets[10]. Various governments and NGOs issued goals set against baseline dates in the past. There were calls for metrics on everything from energy-intensity, absolute reduction of emissions, and even the carbon footprints of families. All this activity proved how easy it is to be distracted by defining, re-defining and arguing about the criteria.

We must demonstrate how the development and use of our energy assets protect water, land and air quality. Open communication and discussion would be the hallmarks of a progressive approach to moving forward.

Current GHG emissions are based on the current stock of emitters. Some reductions are achievable through changing consumer behaviour. This was demonstrated through the 2008-09 financial emergency and subsequent impact on manufacturing activity. But to achieve a structural and permanent change in GHG emissions, a shift in energy sources to lower-emitting technologies, in addition to applying demand-side changes in behaviour, are necessary. A combination of clear and consistent incentives and appropriate penalties are needed to connect, integrate, and re-capitalize Canada's energy sources and demands. There is an inherent complexity when connecting and integrating energy sources and demands, which should not intimidate or prevent us from achieving an effective integration. Finally, given that significant, industrial-scale processes presently contribute to increased GHG in the atmosphere, a sustainable energy superpower will search for industrial-scale processes which deplete atmospheric GHG while transforming such gases into value-added products.

In our sustainable energy superpower future we will truly be thinking globally and acting locally.

The Alberta oil sands have become the international focal point on air/water/land issues. The magnitude of the challenge and the progress made so far are examined in Chapter 7. Strategies for driving down GHG production through gasification of coal and biomass are considered in Chapter 8. Strategies for transitioning from non-renewable to renewable carbon resources are addressed in Chapter 9.

## Conservation

This old maxim of "waste-not, want-not" is not only valid for energy consumption, it is measurable and demonstrable. For Canada to be a sustainable energy superpower, it must achieve energy efficiency at every node of the integrated energy network, from production to generation to use. Our non-renewable resources should be preserved for future generations to benefit to the maximum extent possible through the utilization of the most effective technologies and the development of new technologies where required.

There is a general understanding that consumers should conserve energy. A promotional slogan from several years ago encouraged the population to think about "nega-watts". First-adopters of conservation practices are already seeing benefits. Some utilities and some companies built a business of reducing the total demand of a facility, and using the savings to fund both the cost of the effort and their profit.

## Monitoring Progress

Monitoring progress by tracking the decisions for new and renewed generating capacity and showing how each decision enhances Canada's progress towards becoming a Sustainable Energy Superpower is important. Government, industry, academia, and NGOs should be involved in monitoring and tracking each decision. This is discussed further in Chapter10.

**A national debate is essential for defining the pathway forward**

# Pathway Forward

Canadians are often identified by the three "C"s of consultation, compromise, and consensus. Canadian politeness is an asset in trying to bring all interested parties together. But inertia can set in as the multiple interests involved in energy supply, transmission, transportation, distribution, and demand, put their own interests ahead of the common goal of becoming a sustainable energy superpower. The challenge of becoming a sustainable energy superpower will require other "C"s, such as conviction, and commitment to action.

The technical and environmental issues of how to distribute the nation's energy wealth, what corridors to follow, how to respectfully conserve natural resources and how to reduce the rate of production of GHG from industrial-scale processes may be controversial. There is a cost to engaging in controversy. But doing nothing will be even costlier.

Many others are looking at the future of energy in Canada and around the world. Through the sharing of more information about its current state, and the opportunities to shape its path forward, there is a reasonable amount of convergence on what must be done immediately.

As this vision of Canada as a Sustainable Energy Superpower transcends the scope of any individual company, and crosses the responsibilities of different levels of government, a common path forward includes political leadership committed to a cooperative and shared goal. Canadians deserve leadership that focuses on the best interests of current and future generations. This must be the purpose of an engaging national public and political discourse and debate. The political and economic commitments require massive and long-term dedication and support for the ultimate goal to be achieved.

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# 3

# Canada’s Energy Assets and Capabilities

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## ABSTRACT

Canada is endowed with significant non-renewable and renewable energy resources which must be exploited sustainably. Canada also has effective energy corridors and a highly trained work force which can develop and implement the next generation of clean energy technologies required to drive an economic and environmentally-sustainable energy sector. 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, hydrogen and electricity. Two examples of this are the Alberta Industrial Heartland and the Sarnia-Lambton Petrochemical and Refining Complex. These corridors have extensive 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.

# Bonanza of Energy Resources

If Canada's energy resources were shared equally, every Canadian family would have a square kilometer of land, 10% of which would have water—on which to grow crops, capture sunlight and wind power, and to extract hydroelectric and geothermal energy. Every Canadian would have 10,000 barrels (bbl) of oil, 20 million cubic feet of natural gas and 18,000 tonnes of coal. Long after other nations have depleted their natural resources, Canada would still be energy rich.

Some believe that these natural resources should be kept for the exclusive use of current and future generations of Canadians, while others would prefer to sell them as quickly as possible and reap the economic rewards. Canadians have debated this issue since 1947, when massive reserves of oil and gas were discovered in Alberta. In the 1950s, the Davis Commission suggested a pragmatic solution – keep at least 30 years of energy reserves for Canadians and export the rest. This was the rationale for the creation of the National Energy Board. Unfortunately, the concept of energy "reserves" was a mirage—such estimates vary with global energy prices, infrastructure and technology. Considering the time value of money, few companies were willing to wait for 30 years for a return on their investment.

In the 1970s, with the rise in global energy prices, the energy resource-rich provinces provided significant equalization payments to the energy-poor provinces. However, this did not stop the federal government in 1979 from imposing the National Energy Program in order to acquire a greater share of the energy revenues from the provinces. Although it was subsequently repealed, it created a sense of alienation among western Canadians, which still persists, and any attempt to develop an integrated national strategy is looked upon with suspicion.

The mid-1980s saw an oil price collapse and the emergence of a North American natural gas bubble. The energy resource-rich provinces struggled to balance budgets; industry moved to areas perceived as higher potential. Although the Soviet Union collapsed, Canadian energy companies did not fare well in Russia and its former satellites.

Natural gas and electricity markets were deregulated and the interest in a national energy strategy waned. Oil and power prices fluctuated widely and global warming became an important issue. Significant parts of the western manufacturing base shifted to Asia. Today, the transition to a low-carbon society is underway. With its enormous reserves of renewable and non-renewable resources, this presents a once-in-a-lifetime opportunity for Canada to become a sustainable energy superpower.

Figure 1 illustrates the huge breadth of the Canadian energy resource base including renewable and non-renewable resources. This figure also shows that each resource delivers an array of energy products and by-products, including petroleum fuel and chemical products, hydrogen, electricity, and carbon dioxide. These commodities are produced in energy corridors, weaving across Canada, highly interconnected and having different roles and importance in each region. The electrical grid and pipeline networks are the important spines of this system. These backbones are supplied by a combination of diverse source facilities dominated by large capital investments. The electrical grid is increasingly supplied by regional, renewable energy sources.

**Figure 1**
**Canada's Resources and 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

Each region of the country has its own unique set of natural resources that can be sustainably developed for energy production. Consequently, it is possible for each province to contribute energy to consumers across the country. Figure 2 shows the distribution of many of Canada's renewable and non-renewable energy resources, including refineries, pipelines and electricity-producing power plants. The eastern provinces have many hydroelectric plants, and are home to Canada's nuclear power plants and many oil refineries. Western Canada, in particular Alberta, has large deposits of oil sands, natural gas and coal. Large oil refineries in Alberta upgrade and refine oil sands bitumen to value-added products. Pipelines cross a major part of the country, to transport raw materials from the west to refineries in eastern Canada and the U.S. Midwest[1]. Capital equipment is transported by rail and road to western Canada from eastern Canada and elsewhere.

**Figure 2**
**Canada's Energy Resources and Capabilities[2]**

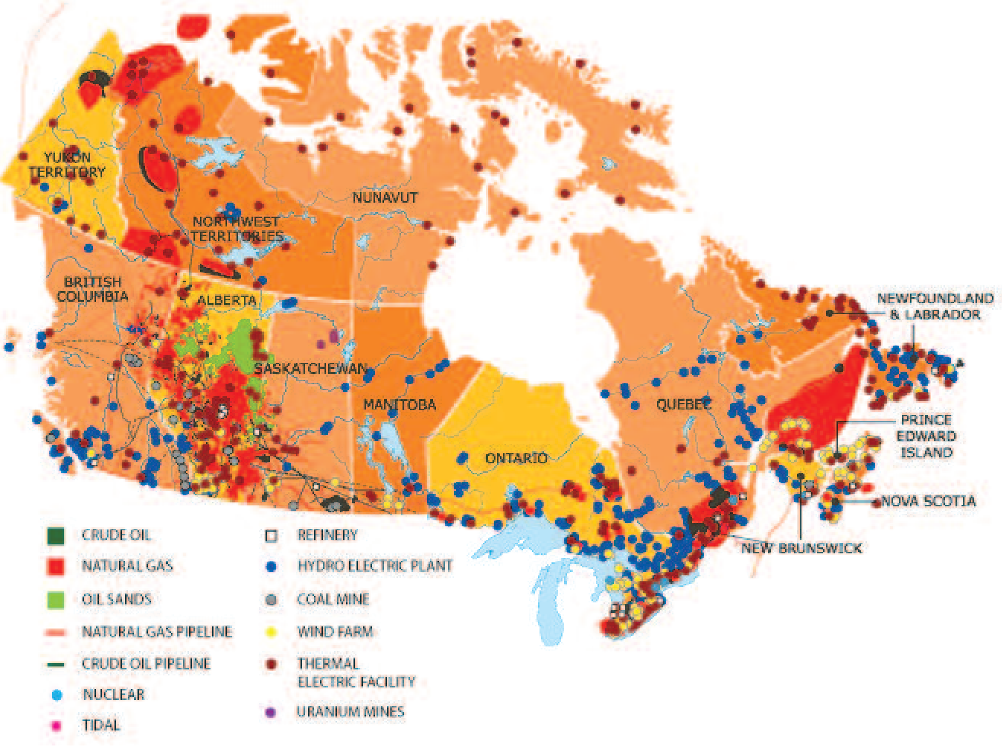


**Figure 3**
**In-Place Energy Resources in Canada, Exajoules (EJ)**

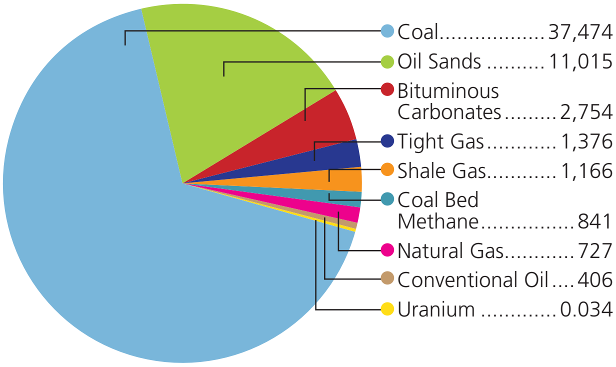
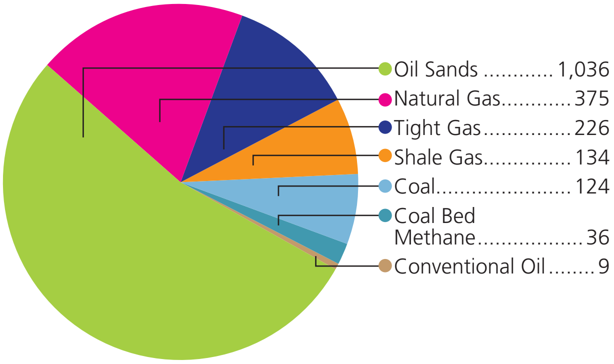


**Figure 4**
**Proven Reserves in Canada, Exajoules (EJ)**



If Canada's massive quantities of energy resources are sustainably developed, the energy will be available for Canadians and others to use for thousands of years. The following section describes Canada's energy resources. Figures 3 and 4 present the energy contained by Canada's non-renewable energy resources through in-place resources and proven reserves, respectively. Table 1 lists the estimated reserves of all of Canada's energy resources.

**Table 1. Estimated Size of Canadian Energy Resources**

| Resource | Current Production | Proven Reserve | | Remaining Ultimate Resources | | In-place Resources | |
|---|---|---|---|---|---|---|---|
| Conventional Oil[1] | 1.08 million BPD | 1.5 billion bbl | 9.2 EJ | 3.9 billion bbl | 24 EJ | 66.3 billion bbl | 406 EJ |
| Oil Sands[1] | 1.47 million BPD | 169.3 billion bbl | 1,036 EJ | 315 billion bbl | 1,928 EJ | 1.8 trillion bbl | 11,015 EJ |
| Bituminous Carbonates | negligible | | | | | 450 billion bbl | 2,754 EJ |
| Natural Gas[14, 15] | 4.91 TCF | 357 TCF | 375 EJ | | | 692 TCF | 727 EJ |
| Coal Bed Methane[16] | 0.2737 TCF | 34-129 TCF | 36-135 EJ | | | 801 TCF | 841 EJ |
| Tight Gas[16] | 1.241 TCF | 215-476 TCF | 226-500 EJ | | | 1,311 TCF | 1,376 EJ |
| Shale Gas[16] | 73 BCF | 128-343 TCF | 134-360 EJ | | | 1,111 TCF | 1,166 EJ |
| Coal[9, 15] | 62.837 million tonnes | 6.6 billion tonnes | 134 EJ | 8.7 billion tonnes | 163 EJ | 2,000 billion tonnes | 37,474 EJ |
| Uranium[10] | 10,174 tonnes | | | 427,000 tonnes | 0.0339 EJ | | |
| Hydro[32, 33] | 73,000 MW | 163,173 MW | | | | | |
| Solar[17, 18] | 19.88 MW | | | | | | |
| Wind[15, 17] | 824 MW | 4,008 MW | | | | | |
| Tidal/Wave[19] | 3-4 MW | 20 MW | | | | | |

## Non-Renewable Energy Resources

### Conventional Oil

While Canadian conventional oil production has been reported to be in decline, this is only from primary and secondary production in established and mature basins. Around 70% of the oil in those basins is known to be still in the reservoirs and is awaiting enhanced oil recovery methods.

In its latest report[3] the National Energy Board expects that due to higher oil prices and the application of horizontal drilling and multi-stage hydraulic fracturing methods to access tight oil, production will increase until 2014. Subsequently, production will decline. However, it will be more gradual than previously projected due to the use of carbon dioxide for enhanced oil recovery.

Additional new deposits will eventually come on-stream from the Arctic and offshore which will require new production technologies to match the unique environments.

As shown in Table 1, the "Ultimate Remaining Potential" is around 1.5 billion bbl in the Western Canadian Sedimentary basin and around 5 billion bbl in the frontier regions.

### Oil Sands

Canada's oil sands are one of the largest hydrocarbon reserves in the world, with the "Ultimate Remaining Potential" of 307 billion bbl. About 20% is recoverable by mining methods and the rest by in situ extraction (see Table 1). The official reserves are approximately 170 billion bbl. These deposits are located in three distinct regions of northern Alberta and cover a total area of 140,200 km$^2$.

The National Energy Board report[3] states, "By 2035, in the Reference Case, oil sands bitumen production is projected to reach 811 thousand m$^3$/d (5.1 million barrels per day (BPD)), three times the production in 2010." It notes, "In 2010, essentially all mined production and about 11% of in situ production was upgraded [within Alberta]."

As bitumen production expands, unless a proactive approach is taken, more and more bitumen could be upgraded outside Canada. Also, an expanded mix of products and new markets need to be developed in order to avoid long-term depressed netbacks on unprocessed bitumen. Canada's pathway to value-added products from oil sands bitumen will focus on improved bitumen characterization, new separation technologies, new catalysts, and the integration of upgrading and refining processes, including gasification. Among different remaining, non-renewable energy resources, about 53% of the proven energy resource is the oil sands (Figure 4). The history of the oil sands development and the current outlook is discussed in Chapter 7.

### Bituminous Carbonates

Some of Alberta's bitumen resources are contained in carbonates rather than sand formations. The Grosmont "Carbonate Triangle" deposits are estimated to have 21% of the oil sands resources in Alberta – but have not been assigned any reserves. This is because they are the most technically challenging. This is not a new realization, as the bituminous carbonates were originally targeted for technology development in the 1970s and 1980s, and did see the development of production pilots with mixed success.

However, the problems encountered 20 years ago during the pilot trials could be solvable today. The industry now has mining and drilling technologies such as continuous miner, horizontal wells,

and well-completion technologies that would increase the likelihood of successful recovery of bitumen from carbonates[4]. Similar carbonate-based oil sands reserves also could exist in Saskatchewan.

### Natural Gas

The National Energy Board estimates the remaining marketable natural gas resources to be between 664 trillion cubic feet (TCF) (Reference Case) and 948 TCF (High Case). This estimate includes "tight gas" (170-333 TCF), coal bed methane (45-64 TCF), shale gas (90-180 TCF) and natural gas from frontier regions (223 TCF).

The Canadian Society for Unconventional Resources estimates[5] the "total gas-in-place resources" at 3,915 TCF, including conventional gas resources (692 TCF), "tight gas" (1,311 TCF), coal bed methane (801 TCF) and shale gas (1,111 TCF).

Another estimate, in Petroleum Technology Alliance Canada's (PTAC) Unconventional Gas Roadmap, suggests that Canada has over 1,500 TCF of coal bed methane in-place, versus about 370 TCF of remaining conventional natural gas potential. Regardless of which of these estimates is correct, it is clear that Canada has considerable natural gas resources.

Even so, while energy experts look upon the twenty-first century as the "Gas Age", the outlook for Canadian natural gas is not that rosy. The United States Energy Information Agency's latest "Energy Outlook" report[6] 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. In the AEO2012 Reference case, net pipeline imports from Canada fall by 62% over the projection period, and net pipeline exports to Mexico grow by 440%." In 2010, the United States produced 21.65 TCF and imported 2.58 TCF, primarily from Canada. In 2035, the projected production is 27.9 TCF with exports of 1.43 TCF; 49% of the production would come from shale gas and 21% from tight gas.

This presents both opportunities as well as threats to Canadian gas producers. The opportunities include the availability of low-cost natural gas for hydrogen, power and process heat production, new pipelines to the west coast, gas-to-liquids production and liquefied natural gas exports. The threats include lower investments, reduced drilling and the potential for precipitous reductions in natural gas royalty revenues.

### Gas Hydrates

Methane hydrates exist in large quantities below permafrost and in sub-sea sediments but are difficult to extract. Estimates of Canadian natural gas volumes in hydrate form range from 1,540 to 28,500 TCF (45 to over 800 trillion $m^3$). If methane can be efficiently extracted from this resource, it provides a vast new source of natural gas. Estimates suggest that the total amount of natural gas captured in hydrates may exceed the combined total of all conventional gas resources including coal, oil and natural gas[7].

Hydrate deposits which are found in Arctic gas formations, in conjunction with free gas, are likely to be developed first. In Russia, free gas is produced from hydrates by de-pressurizing the reservoirs, allowing the hydrate to dissociate.

## Coal

In 2009, there were 22 operating coal mines in Canada; with most large-scale coal mines located in western Canada[8].

Historically, Canada was perceived by the international energy industry to have minor coal reserves, relative to those of the traditionally accepted major coal nations. In fact, our coal resources are world-class[9]. Coal also represents the largest in-place energy resource in Canada (Figure 3).

Alberta is the province with the largest coal resources. The Energy Resources Conservation Board (ERCB) estimates the remaining reserves of all types of coal in Alberta on December 31, 2010, to be 33.3 billion tonnes. Of this amount, 22.7 billion tonnes (or about 68%) is considered recoverable by underground mining methods, and 10.6 billion tonnes by surface mining. In addition the ERCB recognizes an ultimate potential of 620 billion tonnes and ultimate in-place coal resource of 2,000 billion tonnes. Alberta's coal resources are similar in scale to the total coal resources of the United States.

Coal gasification can make this resource a Canadian asset as a future energy source and remove the perception that coal is an environmental liability. It has the potential to reduce emissions of $NO_x$ , $SO_2$, particulates and mercury to very low levels, as well as capture most of the $CO_2$. Gasification and the associated shift reaction convert coal in the presence of oxygen and steam into CO, $CO_2$, and hydrogen..

The hydrogen can be used for generating "clean" power, for refining oil, upgrading bitumen and for producing petrochemicals ("poly-generation") while the carbon dioxide can be captured and used in enhanced oil recovery and coal bed methane applications, sequestered in saline aquifers or employed as feedstock in processes which transform carbon dioxide into value-added products (i.e., accelerated food production, bio-diesel production, etc.). Gasification economics depend on the quality of the coal and little is known about gasifying low rank (quality) Canadian coals. Canada's pathway consists of evaluating and improving known and emerging surface and in situ gasification technologies, and demonstrating commercial readiness for specific Canadian poly-generation applications. Coal gasification is discussed further in Chapter 8.

## Uranium

Canada's uranium reserves are the third largest in the world, after those of Australia and Kazakhstan. In 2009, Canada was the world's second largest uranium producer with a total output of 10,174 tonnes of uranium metal (tU) which represented 20.1% of world production. As of January 1, 2010, Canada's total known uranium resource was approximately 427,000 tU.

Most of Canada's uranium reserves are located in northern Saskatchewan. Canadian uranium deposits have grades that are 10 to 100 times greater than the average grade of uranium mined in other regions of the world. At current production levels, the known uranium deposits will last more than 40 years. However, geological evidence suggests the existence of significant undiscovered deposits in Canada[10].

## Renewable Energy Resources

### Biomass

On an annual basis, the renewable biomass residuals available from forestry, agriculture and related manufacturing industries are equivalent to approximately 25% of the energy Canada derives from fossil fuels. The pine beetle infestation in the forests of British Columbia will add a substantial amount of forest biomass that will need to be disposed of during the next 10-20 years. Marginal agricultural land can be used to produce bioenergy crops in harmony with farming and ranching to maintain a sustainable source of biological energy feedstocks. Proven technologies exist for converting a wide variety of biological feedstocks into a broad range of fuels such as wood pellets, fuel oils, bio-diesel, and ethanol. Canada is well positioned to become a world leader in the production of bio-fuels and other value-added products.

Biomass is considered carbon-neutral, i.e., the amount of carbon released during its combustion is nearly the same as taken up by plants during their growth. This characteristic of biomass contributes enormously to greenhouse gas mitigation. In Western Canada, where power is generated from a large base of hydroelectric, gas fired, and coal-fired plants, the generation of power from straw is not economic. However, it has the "least negative cost" of any base-load, large-scale, green power source available in Alberta. Cost of power from a large-scale, straw-fired, power plant (more than 300 megawatts (MW)) is in the range of C$80- $90 per megawatt hour (MWh)[11]. Location of the biomass plant depends on the comparative costs of transportation of biomass fuel and plant capital and operating costs.

Numerous studies, including a detailed study based on western Canadian straw, confirm that the optimum size of a straw-based power plant is 250 to 450 MW. Small scale power plants, e.g., 25 or 50 MW units, suffer from low thermal efficiency due to higher heat losses and from poor economy of scale. Straw, on a commercial scale, is being used to produce heat and power in several plants in Europe and is also being co-fired with coal.

In combination with an effective municipal waste recycling program, the remaining municipal solid waste (MSW) is largely a mixture of biomass that can be used as a fuel in combined heat and power plants (CHP) to produce electricity and heat. In the past, incinerators were often used in some locations to dispose of MSW. Such incinerators were often shown to operate with excessive emissions (such as sulfur dioxide, nitrogen oxide, carbon dioxide, mercury and especially dioxins), and several incinerators have been shut down.

In contrast, modern waste-to-energy facilities are essentially power plants that use MSW as their source of energy. Modern emissions-control equipment allows waste-to-energy facilities to meet or exceed European and U.S. emissions standards. There are over 400 waste-to-energy facilities operating in Europe, and 89 facilities operating in the U.S. More waste-to-energy facilities are under construction and planned in both locations. A significant number of such facilities exist in Japan. Technology advances that improve the economics are likely to be incremental. Waste-to-energy plants can provide an environmentally friendly and low footprint means of disposing of MSW relative to local or distant landfill options. This pathway can avoid the greenhouse gas (GHG) emissions due to methane gas escaping from landfills, and reduces the emissions from long distance transportation of wastes to available landfill sites. An additional benefit is the production of marketable energy products. This is discussed further in Chapter 9.

## Geothermal

A Geothermal Borehole Thermal Energy System (BTES) is an energy system that stores energy in an underground rock formation contiguous to targeted buildings. Waste heat energy produced from cooling in the summer is stored below ground and used in the winter for heating. In the winter, the waste cold energy produced for heating is stored for cooling use in the following summer. A BTES is most economically attractive for larger scale installations (such as blocks of buildings), with installation in conjunction with original construction.

Mid-depth (< 6,000 m) and deep hot rock (> 6,000 m) geothermal energy resources are potentially very significant sources of moderate temperature (40°C to 180°C) and higher temperature (>180°C) heat. This heat can be used:

- Directly for commercial and industrial processing;
- Potentially for oil sands processing and district heating; or
- For electrical power generation from facilities.

The key features of non-hydrothermal (i.e., non-geyser) type sources of geothermal heat are:

- The requirement for creating new or utilizing existing reservoirs for heating water;
- Transporting the hot fluid from the reservoir;
- Extracting the heat and recycling the fluid back to the reservoir; and
- Removing or stabilizing the salts that are present.

The near-surface technologies are typical of power generation that is currently in use.

## Hydro

According to Statistics Canada, the developed hydroelectric capacity of Canada in 2007 was estimated at approximately 73,000 MW[32]. In 2009, electricity produced from hydropower was estimated to be approximately 585,000 gigawatt-hours (GWh). In comparison to thermal generating stations, Canadian hydropower production is equivalent to the combustion of nearly 125 million tonnes of fossil fuels and it mitigates some 500 million tonnes of greenhouse gas emissions annually. In 2010, Canadian GHG emissions totaled approximately 725 million tonnes, which stresses the importance of hydropower for the environment.

Assuming a cost of $125/bbl and a transportation cost of $50/tonne, the annual hydroelectric production in Canada would have a replacement value, in fuel only, of over $120 billion. The potential for further hydroelectric development in Canada is discussed in Chapter 4.

## Solar

The generation of electricity from photovoltaic (PV) modules installed on the roofs or facades of buildings has further potential to supply power to homes and the electrical grid. There are two classifications:

- Stand-alone systems that are independent of electrical supply grids but require energy storage to ensure an uninterrupted supply; and
- Grid-connected systems in which excess electricity from locally installed PV panels is fed through electrical interconnections for distribution.

In the latter case, when there is insufficient solar energy to meet the local demand, power is drawn directly from the electrical grid, rather than from a battery system.

In Canada, photovoltaic technology has become a preferred form of renewable energy generation technology. In recent years, the rapid growth in the deployment of photovoltaics indicates that the technology is quickly gaining ground[12]. The world's largest solar photovoltaic farm is located in Sarnia, Ontario, with an electricity generating capacity of 80 MW. Additional solar farms are under construction in the Sarnia region.

### Wind

Wind farms consist of an array of factory-built wind turbines and infrastructure to produce electricity and feed it into the electrical grid. Wind turbines are driven by zero-cost, non-polluting fuel: the wind. Technology development in the last 20 years for the rotor, drive train and electrical power conditioning equipment, have made wind power economically competitive, and desirable as a replacement for other forms of generation that are environmentally less benign.

Initial public support has created a regulatory environment where wind farm development is favoured through a relatively rapid permitting and environmental assessment process. Opposition has more recently arisen from citizen groups who have been affected by the proximity to wind farms and advocacy organizations, such as the Ontario Federation of Agriculture[13].

### Tidal/Wave

Canada has only one tidal station in Nova Scotia which has a capacity of 20 MW and produces electricity at 80-100 MWh per day. A dozen Canadian technology companies are working on concept, prototype or pilot approaches. There are about 10 leading international technology companies that are actively considering work in Canada due to resource availability. Canada has excellent research capacity and infrastructure to support the sector. Canada's ocean technology, marine, and power industry can readily deploy in this market. This is an emerging energy opportunity and is further discussed in Chapter 4.

# Canada's Capabilities

If Canada is to become a sustainable energy superpower, it will require the vision and execution of a number of big projects led by two of its major energy corridors: the Alberta Industrial Heartland and the Sarnia-Lambton Petrochemical and Refining Complex. Many of the energy resources discussed above are currently employed or processed in these two corridors.

## Energy Corridors

### The Alberta Industrial Heartland

The Alberta Industrial Heartland (AIH) is one of Canada's largest hydrocarbon processing regions. The AIH is an industrial corridor north-east of Edmonton, comprised of a cluster of more than 40 companies involved in the petrochemical, chemical, oil and gas industries[20]. There is extensive sharing of feedstocks and products, including hydrogen, methane, ethane, ethylene, oxygen and carbon dioxide. This corridor is an integral part of the North American pipeline network and carries oil, natural gas, ethane, and ethylene to processing plants and markets.

AIH facilitates cost effective access to the Alberta oil sands, and has excellent road, rail, air and pipeline connections[21]. The region is focused on bitumen upgrading, with a plan to increase upgrading capacity from 150,000 BPD to 1.7 million BPD by 2017. Over the next decade, the estimated capital expenditure for the area is nearly $65 billion.

The AIH promotes the region as a global leader in processing, manufacturing and eco-industrial development. More than 6,000 people are working in the 582 km$^2$ of the AIH, and future development would be to increase the capacity of bitumen upgrading, pipeline transportation, and petrochemical processing facilities[22].

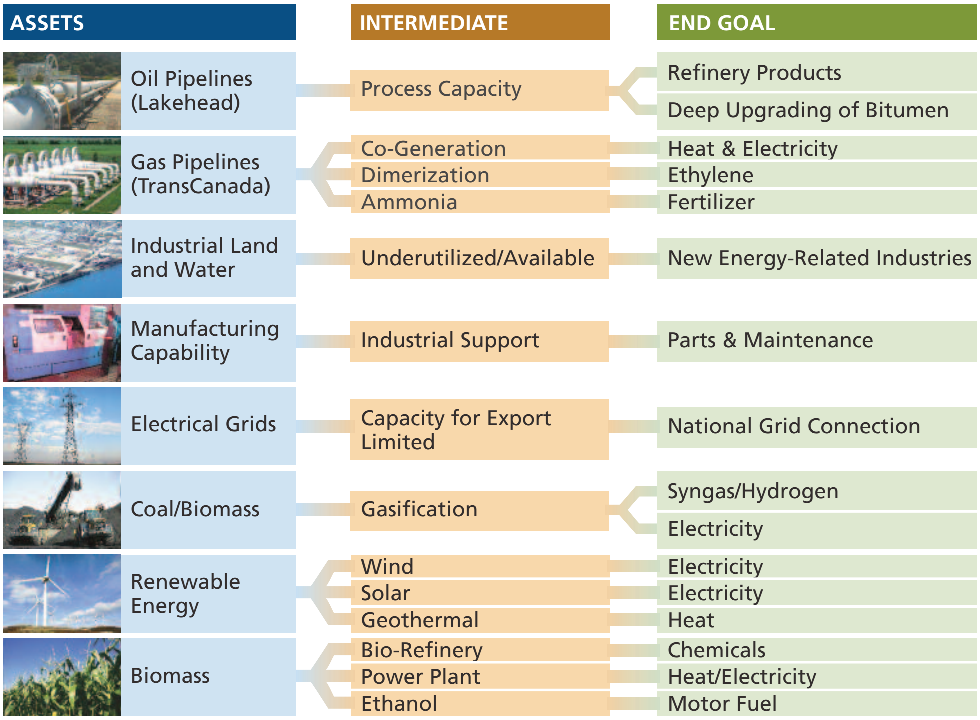
### The Sarnia-Lambton Petrochemical and Refining Complex

North America's first oil field was discovered near Sarnia over 150 years ago and led to the construction of Canada's first oil refineries late in the nineteenth century. In the 1940s, Sarnia was selected as the site for Polymer Corporation (later named Polysar Ltd. in the 1970s), to manufacture synthetic rubber to support the war effort during World War II. Additional petrochemical companies located in the region following the establishment of these early plants. The companies established in the 1940s, such as Polysar, are an example of the collaboration between the public and private sectors on big projects. This has led to the Sarnia-Lambton Petrochemical and Refining Complex becoming the major corridor of integrated petroleum and petrochemical industries, and home to many well-known multinational firms.

Raw materials and transportation are essential, and this Complex has excellent transportation infrastructure. The region is served by a network of highways that connect to the Great Lakes Industrial Corridor, the southern United States, and into Mexico. Products from Sarnia can reach major U.S. markets within 2 days of truck travel. Major pipelines bring crude oil, natural gas, natural gas liquids, and ethane to the Sarnia-Lambton region. Other pipelines carry refinery products to markets across Southern Ontario. The St. Clair River provides cooling and process water and is part of the St. Lawrence Seaway, which connects the heartland of North America with the markets of the world. Within the local Refining and Petrochemical Complex, the companies are highly integrated through a network of pipelines which facilitate the transfer of intermediate products from one company to another, including the co-generation facilities which generate electricity. Figure 5 presents the assets of the Sarnia-Lambton Petrochemical and Refining Complex along with the end product goals.

**St. Clair Ethanol Plant**

**Figure 5**
**Sarnia-Lambton Petrochemical and Refining Complex Assets, Intermediate Products and Value-Added Products**



| ASSETS | INTERMEDIATE | END GOAL |
|---|---|---|
| Oil Pipelines (Lakehead) | Process Capacity | Refinery Products |
| | | Deep Upgrading of Bitumen |
| Gas Pipelines (TransCanada) | Co-Generation | Heat & Electricity |
| | Dimerization | Ethylene |
| | Ammonia | Fertilizer |
| Industrial Land and Water | Underutilized/Available | New Energy-Related Industries |
| Manufacturing Capability | Industrial Support | Parts & Maintenance |
| Electrical Grids | Capacity for Export Limited | National Grid Connection |
| Coal/Biomass | Gasification | Syngas/Hydrogen |
| | | Electricity |
| Renewable Energy | Wind | Electricity |
| | Solar | Electricity |
| | Geothermal | Heat |
| Biomass | Bio-Refinery | Chemicals |
| | Power Plant | Heat/Electricity |
| | Ethanol | Motor Fuel |

Within Sarnia-Lambton, efforts are underway to develop new sectors that have a logical relationship with the community's existing infrastructure, which has traditionally supported the Petrochemical and Refining Complex and the agricultural community. The concept of the "Bio-hybrid Economy", the merger of the hydrocarbon-based economy with the industrial bioeconomy, is strongly supported by various community partners. Within the Bio-hybrid Economy, there is the potential to replace or supplement materials currently produced from petroleum with those made from renewable resources to produce bio-fuels, renewable chemicals, biocomposites and bioplastics. Sarnia-Lambton is home to Suncor Energy's ethanol plant which is North America's largest ethanol-from-corn production facility. There is also a strong focus on development of the Cleantech Sector (solar, wind, fuel cells, batteries, energy conservation). The world's largest photovoltaic solar farm, at 80 MW, is located in Sarnia-Lambton and an additional 40 MW solar farm is currently under construction. As an alternative to traditional petroleum feedstocks, several companies are investigating the use of shale gas as a feedstock in their processes. The source is the Marcellus Shale basin.

## Value-Added Opportunities

The production of value-added products is essential to Canada's economic prosperity. Processing adds value to raw materials and creates wealth for the country. This wealth is lost when raw materials are exported from Canada for processing elsewhere.

The bitumen extracted from the oil sands should be transformed into feedstocks for Canadian petrochemical plants. The oil sands are an excellent resource and opportunity for Canada to produce value-added products. The value-added fuels and chemicals can then be exported to generate jobs, particularly at the higher level of remuneration, and wealth for Canada.

The Sarnia-Lambton Refining and Petrochemical Complex offers a successful model of realizing the potential of building an integrated complex of value-added investments. Tables 2-4[23] provide an example of the value-added products chain in the Sarnia-Lambton Petrochemical and Refining Complex, based on 100 years of history. A core group of companies has grown into a highly connected cluster that shares feedstocks and intermediate products for the production of value-added end products. The products, producer, and end use of the products are presented in these tables.

## Canadian Pipeline Networks

Pipelines are a critical component of Canada's oil, petroleum products and natural gas delivery network. These pipelines transport crude oil and raw natural gas over long distances from the producing regions of Canada to refineries and processing plants. These energy sources are then converted into value-added products, such as gasoline, diesel and commercial-grade natural gas.

**Table 2**
**Petroleum and Petrochemical Products Produced in the Sarnia-Lambton Refining and Petrochemical Complex**

| Product | Producer(s) | End Uses |
|---|---|---|
| Propane, Butane, Iso Butane, Normal | BP Energy; Shell; Suncor | Fuel; Chemical Feedstock |
| Butane, Mixed | Imperial Oil; NOVA Chemicals (Corunna) | Fuel; Chemical Feedstock |
| Hexane | Imperial Oil | Oil Seed Extraction; Polymerization Medium |
| Butylene, Iso | LANXESS | Chemical Intermediate |
| Gasolines, Various Grades | Imperial Oil; Shell; Suncor | Auto and Aviation Fuel |
| Nonene | Imperial Oil | Detergents; Plasticizers |
| Tetramer, Propylene | Imperial Oil | Detergents; Plasticizers |
| Solvents, Petroleum | Imperial Oil; Shell | Paints; Dry Cleaning |
| Kerosene | Imperial Oil; Shell | Fuel |
| Fuel Oil, Various Grades | Imperial Oil; NOVA Chemicals (Corunna); Shell; Suncor | Stove Oil; Furnace Oil; Jet Fuel; Marine Fuel; Production of Carbon Black |
| Lubricating Oil, Various Grades | Imperial Oil | Lubricants for Machinery of all Types |
| Waxes, Petroleum | Imperial Oil | Packaging; Candle Making; Protective Coating |
| Lube Oil Additives | Imperial Oil; Ethyl | Viscosity and Flow Improvers for Motor Oil |
| Coke, Petroleum | Imperial Oil | Fuel |
| Carbon Black | Cabot | Rubber; Plastics; Pigments; Inks |
| Toluene | Imperial Oil; Shell; Suncor | Paints; Explosives; Pesticides |
| Xylene | Imperial Oil; Shell; Suncor | Paints; Pesticides |
| Toluene/Xylene Mixtures | NOVA Chemicals (Corunna) | Paints; Pesticides |
| Isopropyl Alcohol | Shell | Printing Inks; Pharmaceuticals; Cosmetics; Household and Automotive Specialties |
| 2-Ethyl Hexyl Nitrate | Ethyl | Diesel Ignition Improver |
| Cyclopentane | Imperial Oil | Fuel; Solvents |

**Table 3**
**Plastics, Rubbers and Latices Produced in the Sarnia-Lambton Refining and Petrochemical Complex**

| Product | Producer(s) | End Uses |
|---|---|---|
| Polyethylene, Wide Variety of Grades, Densities and Types | Imperial Oil; NOVA Chemicals (Moore & St. Clair River Sites) | Film; Rigid and Flexible Packaging; Pipe and Pipe Coatings; Barrels and Drums; Toys; Shrink Wrap; Wire and Cable Coating |
| Rubber, Butyl | LANXESS | Tire Inner Tubes; Reservoir Linings; Chewing Gum |
| Rubber, Halobutyl | LANXESS | Tubeless Tire Inner Liners; Pharmaceutical Closures; Tire Sidewalls |
| Reactive Polymers | DuPont | Co-extrudable Adhesives for Packaging; Corrosion Protection; Tougheners; Compatibilizers |

**Table 4**
**Inorganic Chemicals Produced in the Sarnia-Lambton Refining and Petrochemical Complex**

| Product | Producer(s) | End Uses |
|---|---|---|
| Anhydrous Ammonia | CF Industries | Fertilizers; Chemical Intermediate; Household Cleaning Compounds; Refrigerant; Pulp and Paper; Plastics; Mining Products |
| Nitric Acid | CF Industries | Industrial Chemicals; Explosives; Metal Refining |
| Urea, Urea Sulphur Coated | CF Industries | Fertilizers; Runway Deicer |
| Aqua Ammonia | CF Industries | Fertilizers; Pulp and Paper; Household Cleansers; Pharmaceuticals |
| Nitrogen Solution Fertilizers | CF Industries | Liquid Fertilizers |
| Carbon Dioxide, Liquefied | Air Liquide Canada; Praxair | Food Freezing; Welding; Carbon Dioxide Lasers; Mould Hardening; Fire Abatement Systems, Beverage Carbonation |
| Argon Liquid | CF Industries | Various industrial processes |
| Hydrogen, Liquid<br>Hydrogen, Compressed Gas | Air Products; Praxair | Petroleum Refining; Metal, Food, Electronic and Pharmaceutical Industries |
| Nitrogen, Compressed Gas | Praxair | Inert Gas |
| Oxygen | Praxair | Steel Making |
| Sulphur | Imperial Oil; Shell; Suncor | Fertilizers; Gunpowder; Chemical Intermediate |

Pipelines are then used to transport the value-added products from refineries and processing plants to large terminals where the products are distributed to homes and businesses.

History has demonstrated that pipelines are the safest and most efficient means of transporting large quantities of crude oil and natural gas over long distances. Large quantities of petroleum products are transported daily, the equivalent of filling 15,000 tanker trucks and 5,000 rail cars, resulting in an environmentally friendlier and much less expensive method of shipping compared to rail or truck. Such transport takes place irrespective of weather conditions. Pipelines also allow for the transport of fuels over terrain not accessible by other modes of transportation.

North America was the first jurisdiction to build a large pipeline infrastructure. Today, North America has the largest and most sophisticated network of crude oil, petroleum products and natural gas pipelines in the world. Continuity of supply to meet the demand for energy

Figure 6
Natural Gas Pipelines in North America[24]

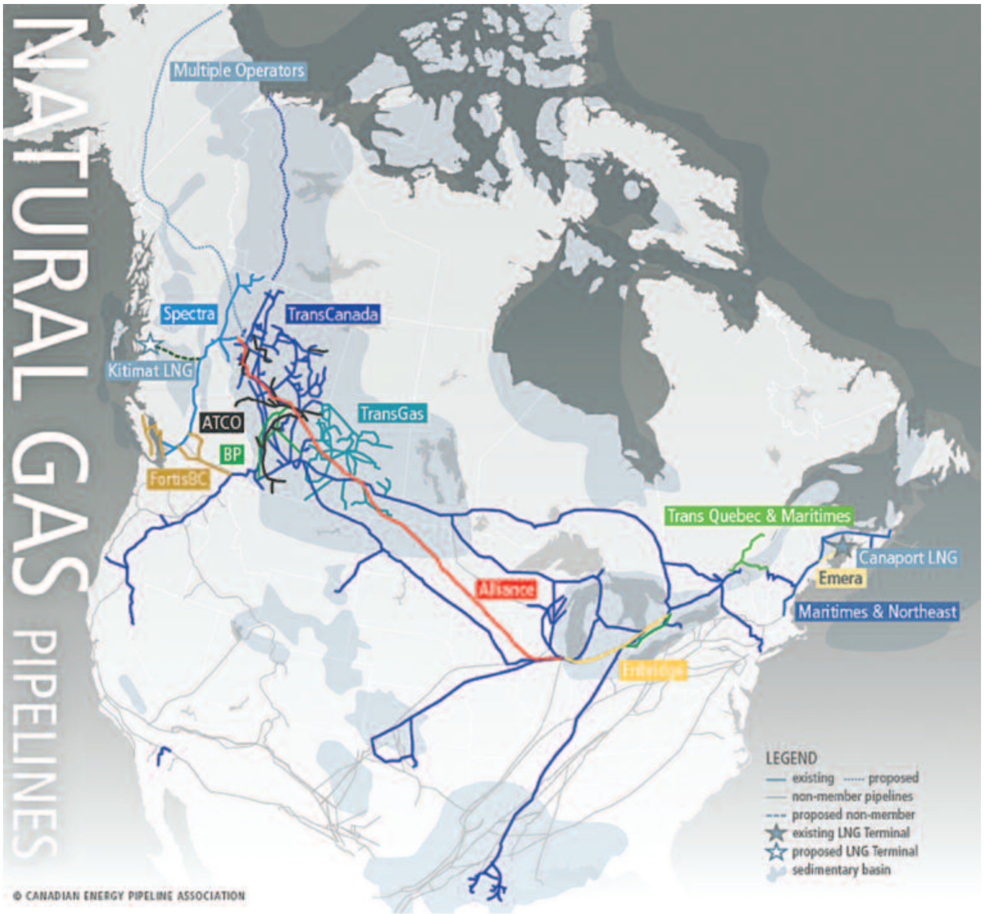


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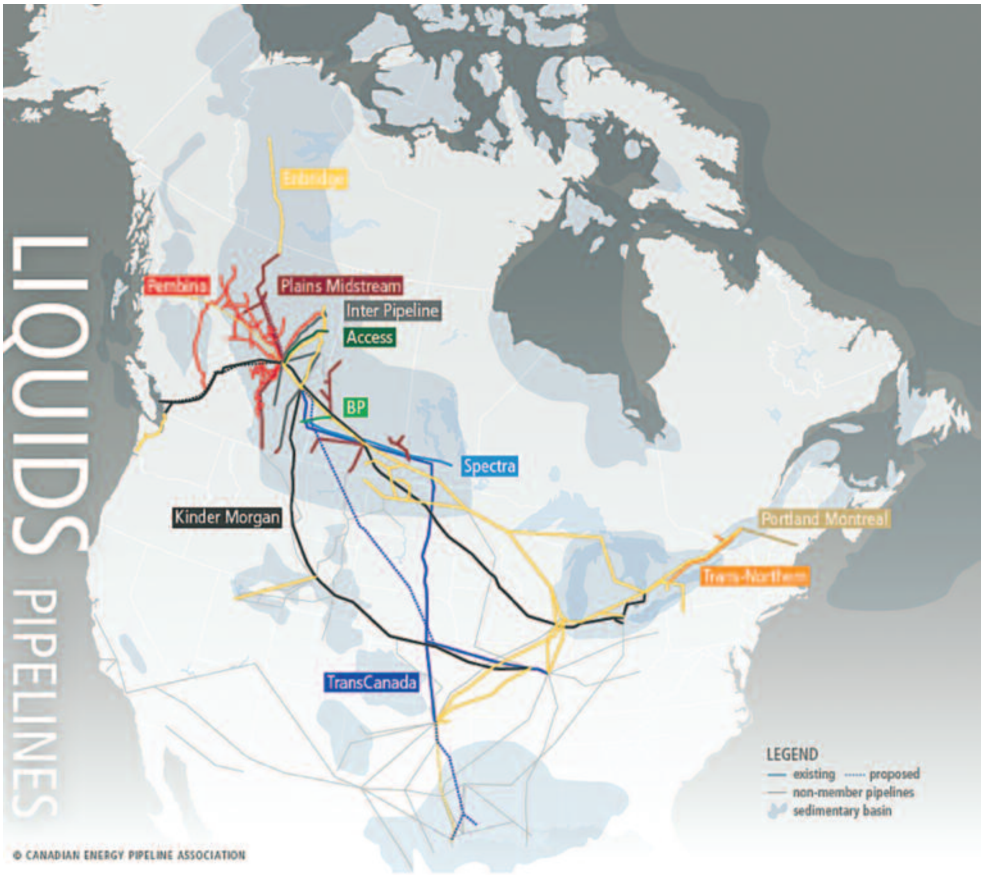
Figure 7
Oil and Liquid Products Pipelines in North America[24]



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commodities is central to the North American energy system. The natural gas and crude oil pipeline systems are shown in Figures 6 and 7, respectively.

Canada's extensive crude oil and natural gas pipeline networks extend over 700,000 km. The network consists of both the pipelines and the associated processing facilities. The heart of the pipeline network is in Western Canada where the majority of the petroleum exploration and production occurs[25].

## Canada's Uranium Corridor

In addition to the petroleum energy corridors, Canada is also fortunate to have a uranium corridor from Saskatchewan to Ontario. Uranium is mined in northern Saskatchewan and transported to Ontario for processing. Canada's uranium facilities for refining and conversion are located in Blind River and Port Hope, respectively. At the world's largest uranium refinery in Blind River, uranium mine concentrates are refined to produce uranium trioxide ($UO_3$). The $UO_3$ is then trucked to the conversion facility at Port Hope, where uranium hexafluoride ($UF_6$) and uranium dioxide ($UO_2$) are produced. Port Hope provides the world's only commercial supply of fuel-grade natural $UO_2$. $UF_6$ from the conversion facility is exported and enriched outside Canada for use in foreign light-water reactors, and $UO_2$ is used to fabricate fuel bundles for CANDU reactors. Approximately 80% of the $UO_3$ is converted to $UF_6$, while the remaining 20% is converted to $UO_2$ [26].

## British Columbia's Hydrogen Highway

The British Columbia Hydrogen Highway was created in 2004 to promote the development, deployment and commercialization of hydrogen and fuel cell powered products[27]. To support the development of new hydrogen markets, seven hydrogen fuelling stations were strategically located to produce and distribute hydrogen fuel for use by the following initiatives:

- **Vancouver fuel cell vehicle program:** to assess the performance of five fuel cell cars operating in "real world" conditions, provide valuable information on vehicle durability, reliability and performance, and allow for the evaluation and improvement of system performance;

- **Hydrogen pick-up trucks:** eight light-duty trucks run on compressed hydrogen gas in modified internal combustion engines;

- **Hydrogen shuttle buses:** three shuttle buses are supercharged and modified to run exclusively on hydrogen fuel;

- **BC Transit:** the world's largest demonstration fleet of fuel cell electric buses is in Whistler; and

- **Fuel cell engine development:** for the emergence of next-generation automotive fuel cells[28].

The infrastructure is based on the use of renewable energy sources such as wind, solar, biomass and the capture of waste hydrogen from co-product streams to produce hydrogen fuel[29].

## Electrical Infrastructure

Canada at present has more electrical connections with the U.S. than it has among all the provinces (34 to the U.S. compared to 31 between the provinces). In addition, the interprovincial connections tend to have limited transfer capabilities whereas many of the connections to the U.S. can transfer quantities equivalent to the output from major hydro or nuclear plants. In 2007, total electricity generation in Canada amounted to 617,470 GWh and the nation consumed 592,161 GWh of electricity. The difference between the generation and consumption was the net export to the U.S.

Several new major interconnections are being considered by various planning authorities, including a project to transfer power from the Lower Churchill Falls project in Labrador to Newfoundland and Nova Scotia by means of submerged HVDC transmission, a line across Confederation Bridge feeding potential expansion in wind power in Prince Edward Island to New Brunswick, and a connection to bring Manitoba hydro power to Ontario. Also there are potential capacity increases between Manitoba and Saskatchewan, Alberta and BC, and Alberta through BC to the U.S. The next step in the evolution of Canada's electrical transmission system is discussed in Chapter 5.

## Canada's Refining Capabilities

Refineries are complex, capital-intensive manufacturing facilities that convert crude oil into a variety of value-added products. The efficiency of refining has improved over the years, along with significant gains in environmental performance. Since the early 1970s, the number of refineries in Canada has decreased, from 40 to 19. However, increases in the capacity of the remaining facilities have offset the reduction in the number of refineries.

Historically, Canada has had "cracking" refineries due to the abundance of domestically produced light sweet crude oil and the strong demand for distillate products. Recently, "coking" capacity has been added since oil sands bitumen has become an important feedstock. Refineries in Western Canada and Ontario anticipate significant changes to their feedstock supplies in the future as they attempt to accommodate a growing share of oil sands bitumen.

Canada's large oil companies focus on the entire process from exploration and production, to refining and distribution. These large companies include Imperial Oil, Suncor Energy, Husky

**Table 5**
**Canadian Refineries and Capacities**

| Company | Location | Capacity (BPD) |
|---|---|---:|
| Husky | Prince George, BC | 12,000 |
| Chevron | Burnaby, BC | 55,000 |
| Imperial Oil | Edmonton, AB | 185,000 |
| Suncor | Edmonton, AB | 135,000 |
| Shell | Scotford, AB | 100,000 |
| Husky | Lloydminster, AB | 29,000 |
| Consumer Co-op | Regina, SK | 100,000 |
| Moose Jaw Refining | Moose Jaw, SK | 14,000 |
| Imperial Oil | Sarnia, ON | 120,000 |
| NOVA Chemicals | Sarnia, ON | 78,000 |
| Shell | Sarnia, ON | 75,000 |
| Suncor | Sarnia, ON | 85,000 |
| Imperial Oil | Nanticoke, ON | 120,000 |
| Suncor | Mississauga, ON | 15,600 |
| Suncor | Montreal, QC | 130,000 |
| Ultramar | Levis, QC | 265,000 |
| Irving Oil | Saint John, NB | 300,000 |
| Imperial Oil | Dartmouth, NS | 89,000 |
| North Atlantic Refining | Come by Chance, NL | 115,000 |
| **Total** | | **2,022,600** |

Energy and Shell. Regional oil companies also contribute to Canada's production of value-added products and include Irving Oil, Ultramar, Chevron and North Atlantic Refining. Although Irving Oil is a regional oil company, it operates the largest refinery in Canada. The capacity of each Canadian refinery in 2010 is shown in Table 5[30]. Actual crude oil refined by Western Canada refineries and Ontario refineries were 551,800 BPD and 362,700 BPD in 2010, respectively.

The demand for oil and petroleum products in Ontario is higher than any other province in Canada due to a large number of manufacturing facilities and a larger number of vehicles. Crude oil and refined petroleum products are used domestically. Canada also exported 2.5 million BPD to the U.S. in 2010, which made Canada the largest supplier of crude oil and petroleum products to the U.S. Continued development of upgrading and refining of bitumen in Canada would ensure that this wealth generating capacity continues in the future.

## CANDU Reactors

The CANDU (CANada Deuterium Uranium) pressurized heavy-water power reactor technology was developed in Canada by Atomic Energy of Canada Limited (AECL). Features of CANDU reactors include:

- Capability to use fuels based on uranium (natural and enriched), thorium or a combination of fuels;
- Low fuel costs since natural uranium does not require enrichment;
- Capability to be refueled while operating under full power, significantly reducing the cost of refueling shut-downs; and

- Safety systems are designed for three levels of backup and are independent of all other components.

Worldwide in 2011, there were 32 CANDU reactors. Canada had 17 of these reactors in operation, and an additional 3 CANDU reactors are expected to return to service in 2012. In Canada, CANDU reactors are located in Ontario, Quebec and New Brunswick. In 2010, they generated approximately 15% of Canada's total electricity production, and nearly 60% of Ontario's electricity[26]. Nuclear power in Canada is discussed further in Chapter 6.

## Challenges

### Environmental Issues

Canada does not have a favourable international reputation with regards to environmental issues in two specific areas:

1. **Oil Sands** – The oil sands are criticized based on the land disturbance impact, GHG emissions and from the release of contaminants into the water system. Substantial progress has been made in restoring the surface lands of mineable oil sand projects; typically, such lands can now be restored to an acceptable and natural-appearing condition. For the 80% of the deposit which is too deep to be recovered by surface mining, the land disturbance is considerably less. GHG emissions are an issue, although major progress has been made through innovation and technical advances. Alberta has recognized the concern of water contamination and is in the process of strengthening monitoring programs and reviewing regulations in this area.
2. **Carbon Dioxide Emissions** - In fact, Canada has very low carbon dioxide emissions in its electricity generation industry. Even when fossil fuel production is included, total Canadian carbon dioxide emissions, on an energy intensity basis, are less than the U.S.

In spite of the advances made to date, the development of new technologies is an inherent requirement to further improve performance. The environmental issues related to the energy sector will need to be resolved before Canada can be recognized as a sustainable energy superpower.

### Electrical Energy Storage

As outlined in Chapter 5, electrical energy storage goals are to level peak demand loads, support modernized base-load generation (nuclear and conventional thermal power plants), and store energy produced by renewable energy sources when such energy cannot be immediately consumed by grid customers. The importance of energy storage grows in response to the challenges of reducing the GHG footprint of electric power generation, transmission and utilization within each provincial grid though, as pointed out in Chapter 5, an interconnected Canada would alleviate this need. Of nine storage technologies:

- Two have long-standing maturity in providing the large capacities required for the central grid service: ponds (traditional hydro reservoir water storage), and pumped hydro storage;

**Table 6**
**Integration of Energy Sources**

| Starting Point | Intermediate | End Goal |
|---|---|---|
| Geothermal | Produces heat<br>Stores heat | Heating and cooling for residential, industrial |
| Hydro power generation | Produces electricity | Electricity for national grid, balances electricity offer and demand |
| Wind power generation | Produces electricity | Electricity for national grid, hydro energy storage |
| Solar power generation | Produces electricity | Electricity for national grid, hydro energy storage |
| Nuclear energy | Produces electricity<br>Produces steam<br>Produces waste heat | Electricity for national grid, in situ oil sands recovery, thermo-chemical hydrogen |
| Coal, Biomass | Produces synthetic gas<br>Produces waste heat | Fuels, chemicals, hydrogen, carbon dioxide, thermo-chemical hydrogen |
| Oil sands bitumen | Deep upgrading<br>Produces waste heat | Fuels, chemicals, carbon dioxide, thermo-chemical hydrogen |
| Natural gas | Conversion processes | Fuels, chemicals, hydrogen, carbon dioxide |
| Carbon dioxide | Solar/Nanocatalysis | Fuels, chemicals, carbon–based products |

- Two newer technologies have demonstration facilities: compressed air storage with electricity recovery using gas turbines (CAES) and molten salt storage of captured solar energy with steam turbines providing electricity recovery;
- Two older energy storage technologies have been used for back-up of the electrical grid: batteries and hydrogen;
- Superconducting magnetic energy storage and electrical capacitors, although fairly new, offer promise; and
- Vehicle-to-grid connections allow parked vehicles to connect to the electrical grid so that electricity can flow between the vehicle battery and the grid. Though offering potential, this remains a controversial topic.

## Pathway Forward

**Figure 8**
**Energy Integration**

Examples of integration:

- Nuclear power to provide thermal energy for the oil sands
- Use of off-peak power to pump water into elevated reservoirs
- Storage of off-peak power as hydrogen
- Thermal or nuclear co-production of electricity and thermochemically-produced hydrogen (from waste heat)
- Coal gasification to produce hydrogen for upgrading oil sands bitumen
- Employing carbon dioxide for the accelerated production of food and other value-added products

## Integration of Energy Sources

In 2006, the report entitled Powerful Connections: Priorities and Directions in Energy Science and Technology in Canada recommended an integrated systems approach to the development of Canada's many energy sources. It called for a dedicated commitment by all stakeholders to provide the financial and innovative resources to put Canada in a world leadership position in sustainable energy development[31].

The full potential of Canada's energy resource abundance can only be realized by managing Canada's energy resources and currencies as a system, in which the challenges of one energy source can be resolved by integration with the benefits of another. This concept has only been applied in a few specific cases, and few systematic studies on integration have been carried out. There are many energy integration possibilities in the Canadian energy system by the linkage of sources, products and by-products. Examples of these are shown in Table 6.

What does integration mean? The interconnection must occur either in co-processing or in the co-mingling of products and services, as illustrated in Figure 8 through the following examples.

A structure for a Canadian energy system, which would include options for integrating energy sources, products and co-products to resolve the economic and environmental issues, is now required by industry. These issues include the need to:

- Develop clean coal technology
- Obtain a sustainable source of hydrogen
- Achieve a major reduction in greenhouse gas emissions
- Develop a viable bioenergy industry
- Resolve the intermittency of renewable energy sources
- Overcome the barriers facing the oil sands industry
- Complete our energy corridors through the establishment of high-capacity east-west power and pipeline grids
- Develop creative processes which transform carbon dioxide into value-added products and help reduce the concentration of atmospheric carbon dioxide.

Many of these challenges are beyond the capacity of individual companies and will likely need the support and collaboration of a number of private and public sector organizations.

## Regional Collaboration

Another form of integration would involve improved collaboration among energy regions of Canada. Specific examples would be:

1. Transporting bitumen by pipeline from Alberta to Ontario for upgrading in the Sarnia-Lambton Refining and Petrochemical Complex;

2. Implementation of a multi-reactor nuclear power park in a remote region of Canada to meet the power needs across Canada via a high voltage national grid;

3. Improving the business case for bioenergy projects by better access to other time zones via an interconnected provincial grid; and

4. Multi-province development of hydroelectric power from regional water basins.

Past forms of interprovincial collaboration have been in the form of big projects, and could now be accelerated by launching new, big projects in areas such as the above described examples.

## Conclusion

Canada's energy resources, its skilled labour force and its established energy corridor infrastructure provide the foundation for Canada to become a sustainable energy superpower. Canada has a demonstrated history of changing the nature of the country through big projects led by visionaries and strong leaders. Highly skilled engineers are ready to implement Canada's next big energy projects.

This will result in jobs and prosperity for generations to come.

**Sarnia-Lambton Refining and Petrochemical Complex**

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# 4

# Hydroelectricity

F. Pierre Gingras

## ABSTRACT

Hydroelectric development in Canada has continued unabated since 1881. Progress in the efficient use of electricity since 1990 has reduced the pace of development of new hydropower, but given the untapped potential and slower pace of the nuclear and wind industry development, it is quite possible that Canada is at the dawn of a new rush for this "white gold".

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, resulting in more electrical energy being sold to the United States than between provinces. For example, 75% of the electrical energy sold by Hydro-Quebec to out-of-province buyers is exported to the United States.

A prerequisite for moving ahead with major new hydroelectric projects is the establishment of a Canada-wide transmission network, with three objectives: a) link new hydroelectric projects to areas of consumption, b) interconnect existing provincial networks and c) replace aging thermal power plants to reduce Canada's greenhouse gas footprint. The high variability in the price of electricity across Canada could be corrected with improved interprovincial connections.

Environmental issues received extensive attention in hydroelectric projects initiated during the 1970s. There are now extensive catalogues and checklists of best practices 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:

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

Tidal Energy: The tides of the Bay of Fundy present a particularly attractive "renewables" opportunity with a potential of 6,700 MW. 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 implementation of appropriate flood-control infrastructure would structure the St. Lawrence River – Great Lakes basin as a waterfall consisting of some ten reservoirs, and offer 1,000 MW of additional hydroelectric potential. A necessary companion project to maintain river level involves intercepting the Bell and Waswanipi Rivers in the Matagami area, 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 contribute to protecting 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, more commonly referred to as the Great Whale (Grande Baleine) Complex, would offer the opportunity of developing 5,000 MW of hydroelectric potential.

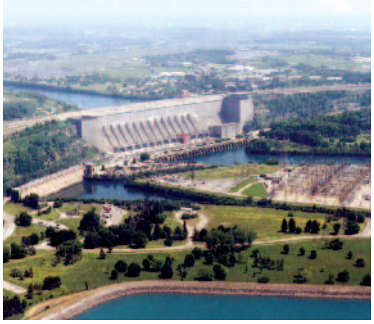
Western Half of Canada: The Western half of Canada presents a theoretical potential of 91,000 MW. This massive hydraulic potential poses a major difficulty in that the key watersheds, those of the Mackenzie, Churchill and Thelon Rivers, cover several or all of the Western Provinces and the Northwest Territories. 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 are known to 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.

# Current State of Hydroelectricity

## History and Context

In this land of lakes and rivers that is Canada, the development of the hydropower potential began quickly. Commissioning of the first plant, Chutes de la Chaudière in Ottawa occurred in 1881, quickly followed by Chutes Montmorency in 1885. In 1892, a plant went into operation on the Lachine Canal in Montreal, soon followed by the Bow River plant in Calgary in 1893. In 1897 came the Lachine Rapids plant in Lachine, Quebec, and the Chambly plant in 1899. Ontario, Newfoundland and British Columbia completed their first hydroelectric plants in 1898 at a time when Sir Adam Beck became fascinated by the possibilities offered by Niagara Falls.

In 1900, the first major hydroelectric plant went into production along the St. Maurice River at Shawinigan, Quebec, beginning construction of a complex whose progressive development would continue nonstop until the nineteen forties, involving nine major dams and power plants at such places as Grand'Mère (1915), and Réservoir Gouin (1918), and Beaumont in 1958.



**Sir Adam Beck Hydroelectric Project**

Photo by Andrew C. Porteus, courtesy of the Niagara Falls (Ontario) Public Library

In Ontario, the commissioning of the Sir Adam Beck plant at Niagara Falls in 1922 was an undisputed sign of things to come. By this time, the site by site approach of developing hydroelectric power plants had given way to the planning of entire complexes, namely along the Ottawa River in Ontario, and the Péribonka, Saguenay and Gatineau rivers in Quebec. Many of these projects, now over a century old, such as Shawinigan – 2 dating from 1911, are impressive even by today's standards.

The Second World War served only to accelerate the development of hydropower. For example, in 1943, a power plant the size of Shipshaw (nearly 900 MW) was built in only eighteen months! A period of great prosperity immediately followed the Second World War with the arrival of the "baby boomers".During this period, most provinces established a crown corporation capable of tackling large projects. In Quebec, construction of the Bersimis complex was initiated, followed by the Manicouagan and Outardes complexes (which continued until the late nineteen eighties), and in 1972, the James Bay complex. In Newfoundland and Labrador, work on the Churchill Falls complex was begun in 1968 and completed in 1974. Manitoba developed the Nelson River (including Kettle, Limestone, Long Spruce) from 1970 to 1980. British Columbia developed impressive complexes along the Peace River (Bennett and Peace Canyon dams) in 1968 and the Columbia River (12 sites including Revelstoke and Mica dams) from 1973 to 1984. Meanwhile, Ontario, short on rivers suitable for large hydropower development, turned to nuclear power. In 1968, New Brunswick commissioned the Mataquac project, its only major hydroelectric site.

The 1990s marked a significant slowdown of hydroelectric development. In Quebec, the focus was the completion of large complexes already undertaken, including the development of the Eastmain project and the Rupert diversion of the La Grande complex (2010), the Toulnustouc plant on the Manicouagan, and the last site of the Péribonka River. Work also started on the lower North Shore, ending with the development of the Ste-Marguerite River (2007).

Does the end of the twentieth century signal the end of hydroelectric development, or simply a pause? Growing concerns since the 1970s have challenged the environmental sustainability of hydropower, but the hydropower industry has responded vigorously by working on correcting its excesses and developing the benefits of hydropower. Since then, the scope of the studies undertaken and the knowledge gained are of a magnitude matched by few industries.

Canada still has enormous hydropower potential to be developed. Hydroelectric power remains one of the cleanest sources of energy, and is generally recognized as the most environmentally-sustainable and renewable. To unlock this potential, Canada needs to move its thinking to a national and continental scale.

## Developed and Available Hydroelectric Power Potential

According to the Canadian Hydropower Association, the hydroelectric potential theoretically available in Canada is estimated at approximately 236,610 MW, as illustrated in Table 1.

**Table 1**
**Canada's Hydroelectric Potential (2007)**[1, 2]

| | In Service MW | Available MW |
|---|---:|---:|
| Yukon | 78 | 17,664 |
| Northwest Territories | 25 | 11,524 |
| Nunavut | 0 | 4,307 |
| | | **33,495** |
| British Columbia | 12,609 | 33,137 |
| Alberta | 909 | 11,775 |
| Saskatchewan | 855 | 3,955 |
| Manitoba | 5,029 | 8,785 |
| | | **57,652** |
| Ontario | 8,350 | 10,270 |
| Quebec | 37,459 | 44,100 |
| New Brunswick | 923 | 614 |
| Nova Scotia | 404 | 8,499 (tidal) |
| Prince Edward Island | 0 | 3 |
| Newfoundland-Labrador | 6,796 | 8,540 |
| | **73,447** | **163,173** |
| **Total** | | **236,620** |

### Developed Hydroelectric Potential

Table 1 shows that in 2007 the installed hydropower capacity was 73,447 MW. By the end of 2011, this installed capacity was on the order of 76,000 MW. For example, in Quebe alone, the addition of new power plants on the Eastmain, Upper St. Maurice and Péribonka Rivers added more than 1,500 MW. An overview of all major works in service as of early 2011 is provided at the end of this chapter.

After thirty years of operation, a complete renovation of turbine-alternator units is generally required, offering two distinct opportunities: a) increasing unit efficiency through improvements in technology, and b) adding units for increased overall power plant output. Power plant capacity is generally upgraded by substituting existing turbines with units offering greater peak output, though power plant expansion resulting in the addition of units is not uncommon. Installed capacity can sometimes be increased by approximately 10% with each new generation, translating in significantly enhanced return on investment.

The significance of hydropower can be appreciated by considering that a typical fuel oil or bunker-driven thermal power plant consumes 2,500 U.S. tons of fuel annually and emits approximately

10,000 tons of greenhouse gases per MW of plant capacity, though such statistics vary with age, combustion technology, plant efficiency, and type of fuel. Canadian hydropower electricity generation, on average, is therefore equivalent to the annual combustion of some 125 million tons of fuel and the emission of some 500 million tons of greenhouse gases, based on a load factor of 65%. In 2010, greenhouse gas emission in Canada was approximately 725 million tons, which underscores the importance of hydropower for the environment.

From an economic perspective, hydroelectric power generation avoids the purchase of 125 million tons of fuel per year, or some 912 million barrels (2.5 million barrels per day, assuming that a ton of oil represents 7.3 barrels, though this may vary up to 9 barrels). Assuming a cost of $125 per barrel and a transportation cost of $50 per ton, Canada's annual hydroelectric power output represents a replacement value, in fuel only, of over $120 billion! Clearly, hydroelectricity remains one of the most profitable and desirable of all energy sources.

## Differences Between Real and Theoretical Hydropower Potential

The purpose of this section is not to further address the estimate of theoretically estimated hydropower potential, but to identify the various aspects which influence this estimate and must be taken into account.

Certain sites prove unacceptable for environmental reasons, and must be removed from the overall estimates. Such sites include wetlands that are particularly rich from a biological standpoint, regions which protect wildlife, and populated habitats. Other sites are excluded due to technical constraints leading to unacceptable costs, such as high-risk geological conditions in the foundation, or the unavailability of backfill.

Hydrological and hydraulic conditions, such as winter flow conditions involving the excessive generation of frazil ice, and unique flow conditions resulting from regional physical characteristics must also be taken into account. For example, the vast marshes and wetlands of northern Ontario are due to river flows up to four times lower than in northern Quebec in proportion to the size of the watershed. The possibility of creating reservoirs to regulate flows and/or provide greater flexibility in generation scheduling are yet other factors which can be taken into account. The lack of physical access to potential sites, and the need for new transmission infrastructure to link up to existing power grids, impact project profitability and/or project execution timelines.

Finally, the acceptability of any project remains to be seen for populations directly affected by any project, including First Nations, and the political and economic interests of all stakeholders must be taken into account.

The only way to determine one's true hydropower potential is to conduct an initial feasibility study of the most interesting sites, river by river, and site by site. Each provincial electricity authority should be capable of fielding a team of professionals which performs such initial site surveys, resulting in an ongoing catalogue of potential projects, and ensuring the long-term strategic management of each province's hydropower energy resources.

Even so, normal changes in energy costs, construction costs, technology, access to transmission infrastructure, and the existence of appropriate road networks render these studies "perishable", to the point of having to update them regularly, at least for the most promising sites. For example, during the 1960s and 1970s, the increased cost of labour and the high efficiency of earth-moving equipment steered the evolution of dam engineering toward embankment dams rather than concrete dams.

Hydroelectricity is no different from other forms of energy resources in that it requires some form of prospecting. In other words, a hydroelectric company is the same as an oil company: no exploration, no future! Once a site has been identified, the goal is to define its relative profitability.

## Installed Electricity-Generating Capacity

Table 2 shows the installed electricity-generating capacity of each province. This Table highlights the large proportion of electrical energy derived from heat, gas, coal or oil, on the order of 29% or nearly 35,500 MW. Further study would likely show that more than half of existing facilities have been operating for over thirty years, that they are relatively inefficient by present standards, contribute to air pollution, produce significant quantities of GHG, and are at the end of their useful life. The replacement of Canada's thermal electricity-generating power plants by low-GHG, sustainable hydropower represents a significant opportunity for reducing Canada's carbon footprint and improving air quality, though the latest and most efficient thermal plants could be retained to meet peak demand requirements.

**Table 2**
**Installed Electricity-Generating Capacity by Province[2]**

| Province | Thermal MW | Total MW |
|---|---|---|
| Newfoundland and Labrador | 557 | 7,353 |
| Nova Scotia | 2,006 | 2,463 |
| New Brunswick | 2,932* | 4,535 |
| Quebec | 2,508* | 41,018 |
| Ontario | 11,414* | 32,166 |
| Manitoba | 494 | 5,627 |
| Saskatchewan | 2,853 | 3,879 |
| Alberta | 10,503 | 11,851 |
| British Columbia | 2,223 | 14,832 |
|  | **35,490 MW (28.7%)** | **123,724 MW** |

*Excluding nuclear

## Hydropower: Complementary Technologies

New, complementary hydropower technologies are presently in various stages of development. A review of these is given here, including marine turbines, tidal plants, plants using "wave energy", and pumping stations.

**Marine turbine power plants** are built around large turbines, submerged in ocean currents or streams. Trials have been ongoing for over four decades. An advanced development program is underway in the Montreal area where a 250 kW prototype was set up by the firm RSW in the summer of 2010. The key advantage of this technology lies in the fact there are no civil works. There has also been some consideration of a project of approximately ten turbines that would be submerged in the St. Clair River, downstream of the city of Sarnia.

**Tidal power plants** use the rising tide to fill their "tank" or forebay. The "La Rance" plant in France is the recognized prototype for tidal power plants since the early nineteen seventies, where

La Rance Tidal Power Plant in France

tidal currents in both directions drive bulb-type generating units, a type of turbine particularly suitable for low heads. The stakes are much higher in Canada where the Bay of Fundy, between Nova Scotia and New Brunswick, generates the highest tides in the world, at a height of 19.26 meters (63 feet), for a potential installed capacity of over 5,300 MW. Studies of this site have spanned the past three decades, and a 20 MW project has successfully been implemented at Annapolis. The tides of Ungava Bay are the second highest in the world, at a maximum height of 16.3 meters (53 feet). In the "Northern Plan" put forward by the Quebec Government in 2010, some of the most important iron deposits in the world are known to be located just a few hundred miles from Ungava Bay, strengthening the case for both opportunities. New roads, rail linkages and power lines are also in planning stages for the region.

**Wave power plants** are designed to recover wave energy. Though still in its infancy, the technology presently offers a variety of prototypes. One approach makes it possible for waves to fill a tank whose outlet is equipped with a turbine. Another attempts to exploit the vertical displacement of floats. A third leverages the movement between long floating elements to operate a hydraulic mechanism. To date, there are no marketable applications.

Finally, **pumping stations** are similar to classic hydropower plants, but differ in that the forebay, with no natural incoming water supply, is filled using the generating units themselves as pumps, in off-peak periods. These plants are only used to produce power during peak demand periods, with some loss of energy, about 10 %. The study of each project must compare the cost of this peak energy to that of other types of plants such as gas turbines. Only very large networks justify the creation of such power plants. In the event of a Canada-wide network, such projects could offer unique energy-storage opportunities. An excellent site for such a project is at Paugan, located about fifty miles north of Ottawa, for which a preliminary study was carried out by Hydro-Quebec in the late nineteen seventies. A capacity of up to 4,000 MW could be installed at this site.

## Dawn of a New White Gold Rush?

Compared to petroleum, often referred to as "black gold", hydroelectric potential is often called "white gold". Given the estimated hydropower potential of Table 1, environmental concerns related to greenhouse gases, the unfulfilled promises of the wind industry and uncertain government policy in relation to nuclear power, it is quite possible that Canada is at the dawn of a new "rush" for this white gold.

Significant improvements in demand-side energy efficiency since 1990 have contributed to slowing the pace of hydroelectric development, but the power needs of a growing society remain undiminished. Continued advancements in the fields of environmental protection and electrical transmission make it possible to ensure environmentally-sustainable development while overcoming vast distances, and open new areas of Canada through the development of hydropower, as was done a century before.

Few other energy resources are as abundant, clean, renewable and sustainable. The development of some 40,000 to 50,000 MW over the next two or three decades – of a theoretical potential of approximately 163,000 MW – is a realistic goal, equivalent to an endless daily production on the order of 2 million barrels of oil! A detailed examination of this potential is provided in the section of this chapter entitled "Potential Major Projects".

**La Grande 1 Power Station of the James Bay Complex**

# Hydropower: Environment and Society

## Context

During the nineteen seventies, public opinion gradually mobilized to protect the environment, objecting more systematically to indiscriminate human interventions on the world that we live in, especially when faced with undetermined outcomes. Large-scale hydroelectric developments were quick to attract attention.

It was in this context that the La Grande complex was built, a project the size of a typical European country, or 350,000 square kilometers. Because of its scale, the scope of environmental impact assessments made it, for three decades, the worldwide hydropower environmental research laboratory of choice. The final environmental report, "Summary of Knowledge Acquired in Northern Environments from 1970 to 2000"[3] represents a significant milestone in environmental knowledge related to hydroelectric power developments.

This report is essentially a manual on the types of environmental protection measures that need to be implemented for hydroelectric power developments. Unfortunately, it spends too little time on the fact that a large number of studies were conducted on issues that never materialized, based primarily on apprehensions. However, the key conclusion is that hydroelectric power development can be realized while respecting both the environment and the local and/or First Nations communities involved. The report bears witness to the integration of environmental knowledge and hydroelectric power development in the form of intervention catalogues or checklists, development measures, audits, corrective works, analyses, procedures and safeguards to be put in place, at least in the Canadian context.

### Approval Process and Consultation

The approval process for major projects at both the federal and provincial levels have the advantage of being well established. The list of specific concerns to be studied is now fairly well known, and the negotiation processes with local and/or First Nations communities can also now rely on established practices. Past agreements can be used as references, especially with regard to the recognition of the rights of these communities and the specific terms that have been found mutually acceptable. It is now conceivable that such actions take place in parallel with engineering design activities, thereby significantly reducing the time required for project implementation.

## Versatility of the Projects

### Regional Infrastructure

Hydroelectric projects have many other complementary aspects. They require the availability of a road network, and the creation of an entirely new road network can open regions to other economic development opportunities such as logging, tourism and mining. They also require new transportation infrastructure, such as airports and/or seaports where available. Finally, public service infrastructure on the construction site, such as family villages with schools, medical clinics, fire and safety services, can be designed from the outset to be permanent, and allow sustainable employment for the long-term.

### Reservoirs and Natural Environments

The implementation of many major projects involves the creation of a reservoir. Such a reservoir will require the redevelopment of the natural environment, not its destruction. Initially, the reservoir will be designed with the aim of enhancing the environment, including such possibilities as the development of spawning grounds and wetlands, and outdoor amenities such as beaches, campgrounds, boat launchings, observation points, etc. Harvesting of wood prior to watering is an important though expensive measure which can delay project implementation.

Yet, long before such measures were identified and methodically applied, reservoirs and other hydroelectric developments were successfully completed. The Gouin, Baskatong, Kipawa and Lac Taureau reservoirs in Quebec are all among the busiest fishing grounds in the province, if not in Canada, and drive the livelihood of dozens of outfitting operations. The area immediately downstream of the Carillon plant is also a very busy fishing site, located on the immediate outskirts of Montreal, one of Canada's largest metropolitan areas. Finally, the largest hydroelectric power plant in Ontario leverages the potential of Niagara Falls, even though the Falls remain one of the most famous tourist sites in Canada.

### Flood Control

The construction of a reservoir makes it possible to accumulate surplus water flow from spring and fall, thereby preventing significant flood damage. In Canada, and particularly in Quebec, the volume of water from spring thaw can often account for 50% of annual totals, making it possible to accumulate a large water reserve without adversely altering the flow conditions of the river for the following ten months. Additionally, in times of need, such a reserve allows for a continuous minimum flow, thereby providing drinking water or avoiding catastrophic periods of low water for the environment. Finally, such a reserve makes it possible to redirect a substantial portion of water to another river basin without significant impact on the original river environment. Capturing the potential of two or more rivers can also reduce the environmental impact on a single river. In some cases, the operation of reservoirs ensures minimal navigation conditions, such as in the case of the St. Lawrence Seaway.

## Climate Change


**Lake Huron and St. Clair River**

It appears that each of Canada's watersheds has begun to feel the impact of climate change. More and more, these changes will affect how existing hydroelectric structures can be used, and sometimes even change the role of these structures, especially to mitigate or control greater flood or drought periods. Similar changes may arise with the need to manage the drinking water supply in some regions, as in the case of the Great Lakes. In Western Canada, the melting of glaciers will result in a significant reduction of water inputs in the near future.

Experts predict a gradual drying of the Great Lakes region[11] by some 20 to 30%, which corresponds to a decrease of flow rates on the order of 1,000 to 1,500 cubic meters per second in the St. Clair River at Sarnia, the outlet point of Lake Huron. Already, the level of lakes Michigan and Huron are lower by about two feet or 60 centimeters, which, considering the area of 114,000 square kilometers for these two lakes, represents a volume of about 68.4 cubic km, equivalent to almost six months of flow for the St. Clair River. This flow reduction will affect the productivity of the power plants all along the St. Lawrence River and the Great Lakes, most notably at Niagara, Cornwall and Beauharnois.

Conversely, it appears that the water which evaporates from the Great Lakes due to climate change will likely fall on Quebec, adding some 15% to the flow of the Ottawa River. Two hydraulic complexes have been proposed to both compensate for this situation and take advantage of opportunities which arise, as follows:

- The first aims to complete the development of the St. Lawrence River-Great Lakes basin by means of four or five new hydraulic control infrastructures, resulting in ten successive reservoirs where the management of water levels would no longer be accomplished by releasing flows, due to the fact that the water volume required for such releases is diminishing. To the already controlled basins of Lake Superior, Lake Erie, Lake Ontario and Lake St. François, new control dams would be added in the Sarnia area to control lakes Michigan and Huron, in the Lachine Rapids area to control the level of Lake St. Louis, and in the Montreal area for the Laprairie basin. Finally, two more dams would need to be built in the general areas of Sorel and Portneuf to control the downstream part of the St. Lawrence River, a section nearly 300 km long between Montreal and Quebec City. Altogether, the cost of this project is approximately $5 billion, largely justified by the environmental protection of 18,000 km of shoreline and at least 1,000 square kilometers of invaluable wetlands.
- The second project, "Northern Waters"[4, 5], involves diverting an average flow of 800 cubic meters per second towards the St. Lawrence River by intercepting two major rivers at Matagami. These waters would be pumped a height of 53 meters along the Bell River, where they would then be released into the Ottawa River, and thereupon flow through existing power plants, upgraded to yield an additional peak capacity of 2,950 MW and a net energy gain of 14.6 TWh. Even if this project is not undertaken, approximately 60% of its total $14 billion cost is still required for renovating existing infrastructures. While protecting the James Bay watershed from flash floods, this project would supply the St. Lawrence River basin with needed additional flow, preventing its waters from becoming too stagnant due to the diminishing Great Lakes water flow.

These projects are described in greater detail below in the section entitled "Potential Major Projects". In Western Canada, similar studies should urgently be considered to address the long-term challenge of accelerated glacier thaw.

### Fresh Water and Sea Levels

The operation of hydroelectric facilities may increasingly need to take into account the corollary water management needs of nearby populated areas, especially in the Great Lakes region. The principles of water management that predicate transforming the St. Lawrence River – Great Lakes basin into ten successive reservoirs may need to be applied elsewhere where drying effects are expected due to climate change, especially in the plains of Alberta and Saskatchewan.

In Egypt, work presently underway aims to create a second valley along the Nile in addition to diverting a significant portion of the freshwater supply to a canal along the coast of Gaza. In China, a diversion system 800 km in length is planned to feed a dry region. In Russia, the diversion of the upstream basin of some rivers leading to the Arctic Ocean is presently being considered to bring water to the nearly-dry Aral Sea. Many other examples exist, demonstrating the priceless value of fresh water. This could also be true of some rivers in the northern Prairie Provinces which may also need to be diverted south, at least in part.

Could it be that the best way not to run out of fresh water is to use it rather than let it go into the sea, especially given concern over rising sea levels?

## Exporting Water?

This question comes up periodically. On the one hand, with the anticipated effects of drying-up due to climate change, both in the Great Lakes and the Prairies, the logical answer is seemingly not to export. On the other hand, on its own, Quebec discharges 40,000 cubic meters of fresh water per second into the sea, enough to supply all of humanity.

Also, how can we, and more importantly how dare we, prohibit the export of water faced with a population in need, for example, in the Great Lakes region? Since "water is life," as environmentalists are fond to point out, what right do we have to refuse to share with others?[9]

The answer lies in the reconfiguration of the St. Lawrence River-Great Lakes basin into ten consecutive reservoirs, resulting in the management of water levels being essentially independent of the management of the water flows. This project can solve the problems of fresh water availability for the entire Great Lakes region.

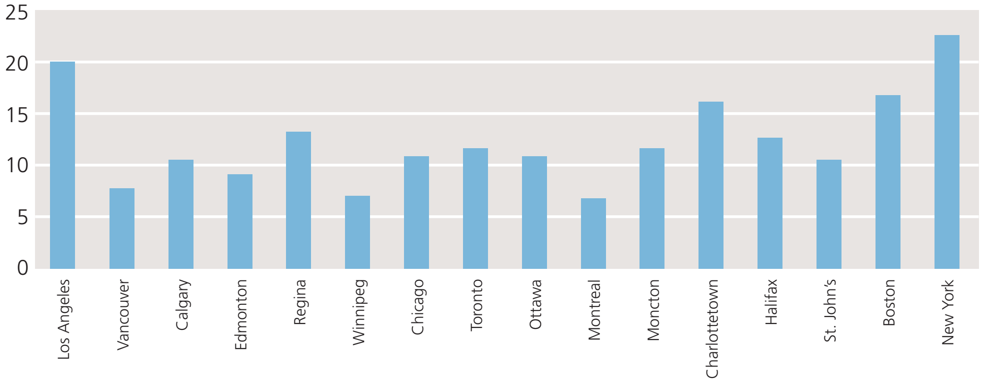
## The Cost of Electricity

Because of the complexity of the shared jurisdiction of energy between the governments of Canada and the provinces, long-term planning leaves much to be desired. Currently, there are more electrical interconnections between provincial and U.S. electricity networks than between provincial grids.

Though the market retail price of energy appears to be higher in the United States, the wholesale market is far more volatile as a result of the development of shale gas, and U.S. claims of hydropower not being a clean energy resource.

In Ontario, the push either for decommissioning coal plants or modifying them for biomass or natural gas combustion, combined with the need either for extensive renovations or the decommissioning of some nuclear power plants, and finally the high cost of programs intended to stimulate wind and solar electricity generation, are driving energy costs upwards. Though electricity rates are significantly higher in Ontario than British Columbia and Quebec, the latter is negotiating a price between 6 to 8 cents in the U.S. market for the output of the "La Romaine complex" presently under construction. Figure 1 provides the 2011 electricity rates of key Canadian and U.S. cities.

**Figure 1**
**2011 Electricity Rates of Key Canadian and U.S. Cities**



Unfortunately, there is a lack of convergent vision between federal and provincial governments in Canada. Thoughtful planning at the national level would stimulate economic opportunity throughout the country, enhance synergies in the upgrading of all of Canada's energy resources, develop hydropower at a rate comparable to that of the nineteen seventies and eighties and, over time, contribute to lower electricity rates, and significantly reduce Canada's GHG footprint.

# Potential Major Projects

## Inventory of Potential Projects

A summary inventory of hydroelectric projects either pending or presently under serious consideration shows a hydroelectric potential of 28,000 to 32,000 MW (Table 3). This is somewhat equivalent to Canada's current installed thermal power plant capacity of about 35,500 MW, which could be replaced to reduce greenhouse gas emissions on the order of 175 million tons annually, more than 23% of all of Canada's 734 million tons of GHG emissions in 2010. This estimate is based on a factor of 10,000 tons of greenhouse gases emitted per MW produced on an annual basis, corrected for a 66% production time factor.

**Table 3**
**Hydroelectric Projects Either Pending or Under Serious Consideration**

| Province | Site | MW |
|---|---|---|
| Manitoba<br>Potential projects, 4,915 MW | Burntwood River (3 sites) | 680 |
| | Nelson River 6 sites) | 3,990 |
| | Upper Churchill (2 sites) | 245 |
| | Lower Churchill | To be studied |
| Quebec<br>Potential projects, approximately 19,000 MW | Lower North Shore (Romaine, Petit-Mécatina and others) | 4,000 |
| | Secondary Potential (40 to 50 plants of 50 to 100 MW) | 5,000 |
| | James Bay (Great Whale and secondary potential) | 5,000 |
| | Nottaway Broadbank (excluding the Rupert which is diverted) | 5,200 |
| | St. Lawrence (Montreal, Beauharnois, others) | 1,000 |
| Newfoundland and Labrador | Lower Churchill (Gull Island. Muskrat Falls, secondary sites) | 4,000 |
| Nova Scotia<br>Tidal potential (40% load factor) | Comberland Basin | 1,400 |
| | Cobequid Bay | 5,300 |

With regard to projects located in Manitoba, there may be some merit in reconsidering the drainage basins of the most important Prairie Province rivers so as not to overlook potential synergies. However, before projects far removed from load centres can be implemented, there is a prerequisite: the completion of a pan-Canadian, continental transmission network.

## The Essential Prerequisite

In order to undertake the construction of a new "generation" of hydroelectric projects across Canada, projects that are physically scattered across the country and far removed from populated areas, it is essential to have a transmission strategy. Chapter 5 presents the concept of a pan-Canadian, continental high-capacity transmission network interconnecting distant hydroelectric power complexes to provincial power grids, and the provincial grids among themselves. The proposed network would simultaneously contribute to significant reductions in Canada's carbon footprint and find economic justification by achieving the following three objectives:

a. Permit the phasing-out of older, high-GHG electricity generating power plants which would normally need to be renovated or replaced (thereby reducing Canada's carbon footprint);

b. Enable the phasing-in and interconnection of new, low-GHG electricity generating power plants to those networks formerly served by thermal power plants; and

c. Interconnect existing provincial networks, thereby offering intermittent renewables access to wider markets and enhanced profitability.

Chapter 5, based on previous work[6, 7], proposes a technological scenario to achieve these objectives, and provides an estimate of the cost of such a project.

## Major Potential Hydroelectricity Projects

### Lower Churchill

The Churchill Falls power station (5,428 MW) has been in operation since the early nineteen seventies. Gull Island (1,711 MW at 76% load factor) and Muskrat Falls (824 MW at 74% load factor) have been known and studied extensively since the nineteen sixties. What is not known is whether there is a possibility to add a number of additional projects to this 7,760 MW complex, such as diversions from the upstream basin of the Georges River (Figure 2), or a 275 MW plant to the Lobstick flood-control structure, thus bringing the capacity of this complex to some 8,500 MW at a 75% load factor.

In the Quebec government's "Northern Plan"[8], three other mining complexes are proposed 100 to 150 km north of Schefferville and within 200 km of Ungava Bay, thereby increasing the attractiveness of several tidal power plant developments. Additionally, the entire Georges River would become attractive for hydroelectric development.

The development of mines north of Schefferville may require the construction of a second railway to Sept-Iles, all of which could greatly facilitate the implementation of hydroelectric generating plants on the rivers of the region, including the Georges River, transmission corridors, and tidal power plants in Ungava Bay.

The implementation of the Lower Churchill complex requires building two EHV transmission lines of 1,300 km to reach areas of high consumption. The integration of these lines within a pan-Canadian continental power system, as proposed in Chapter 5, would help replace the coal and fuel-powered thermal power plants of the Atlantic Provinces and Ontario, and contribute to meeting the growth of electricity demand. According to an announcement made November 18, 2011, the government of Canada appears to have approved the guaranty of loans for the Muskrat Falls project, including a line to Newfoundland and Nova Scotia including two undersea links.

Unfortunately, the Provinces of Quebec and Newfoundland and Labrador have significant political barriers to overcome before they come to an agreement to their mutual benefit in developing hydropower and other resources in Labrador. On the one hand, Quebec has never accepted the Privy Council of London's decision to carve away Labrador from Quebec in 1927, while

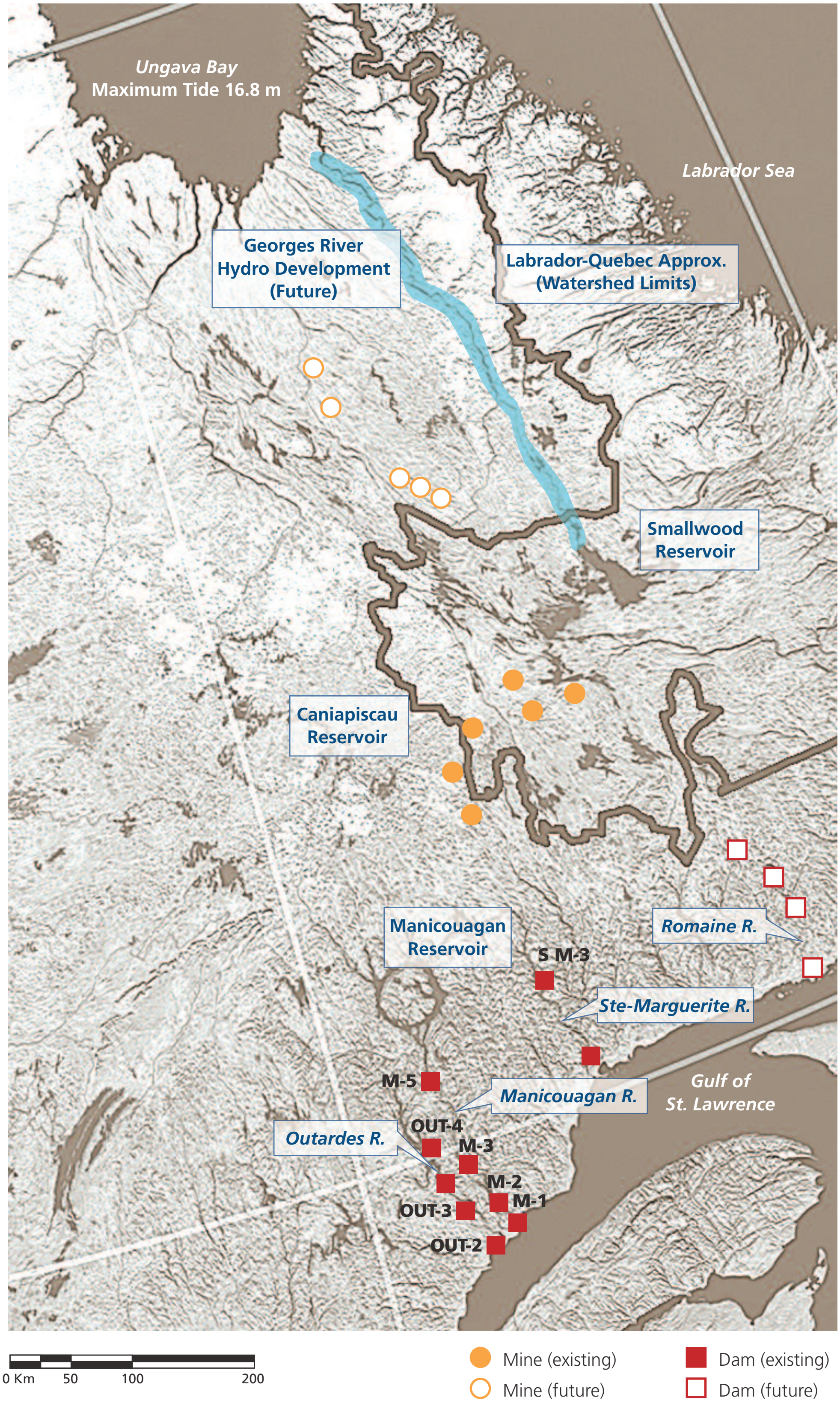


**Figure 2**
**Ungava Bay to St. Lawrence River Development Projects**

Map of Eastern Quebec and Labrador identifying Anticipated Major Mining and Hydroelectric Developments

Newfoundlanders bitterly resent its exclusive, long-term agreement with Quebec to sell virtually the entire output of the Churchill Falls generating station at a discount price until 2041. Quebecers should be consoled by the observation that the size of their province, limited to the southern third until 1898, was doubled twice, first in 1898, and again in 1912; while Newfoundland and Labrador should recognize that without the Churchill Falls agreement, there would likely be no hydropower development in Labrador, and that developments on the order of 3,500 to 5,000 MW are not a cheap consolation prize.

In the longer term, the key is greater collaboration among regions and provinces. Missing only are political vision and leadership.

## Tidal Energy

Bay of Fundy

Since the nineteen seventies, the Province of Nova Scotia has been evaluating the enormous tidal power potential of 6,700 MW of the Bay of Fundy, where tides are the highest in the world, at a height of 63 feet or 19.25 meters. In the early nineteen eighties, a pilot project of 20 MW was implemented at Annapolis.

If the profitability of this project could be analyzed in the context of a Canadian market, considering the current and future cost of energy, particularly in Ontario, it is quite possible that its development would begin in the short or medium term.

Ungava Bay, in turn, has the second highest tides in the world, at 53 feet or 16.4 meters, and has a multitude of bays suitable for the installation of tidal power stations. It is quite possible that this region is even more favourable than the Bay of Fundy from the perspective of harnessing tidal power.

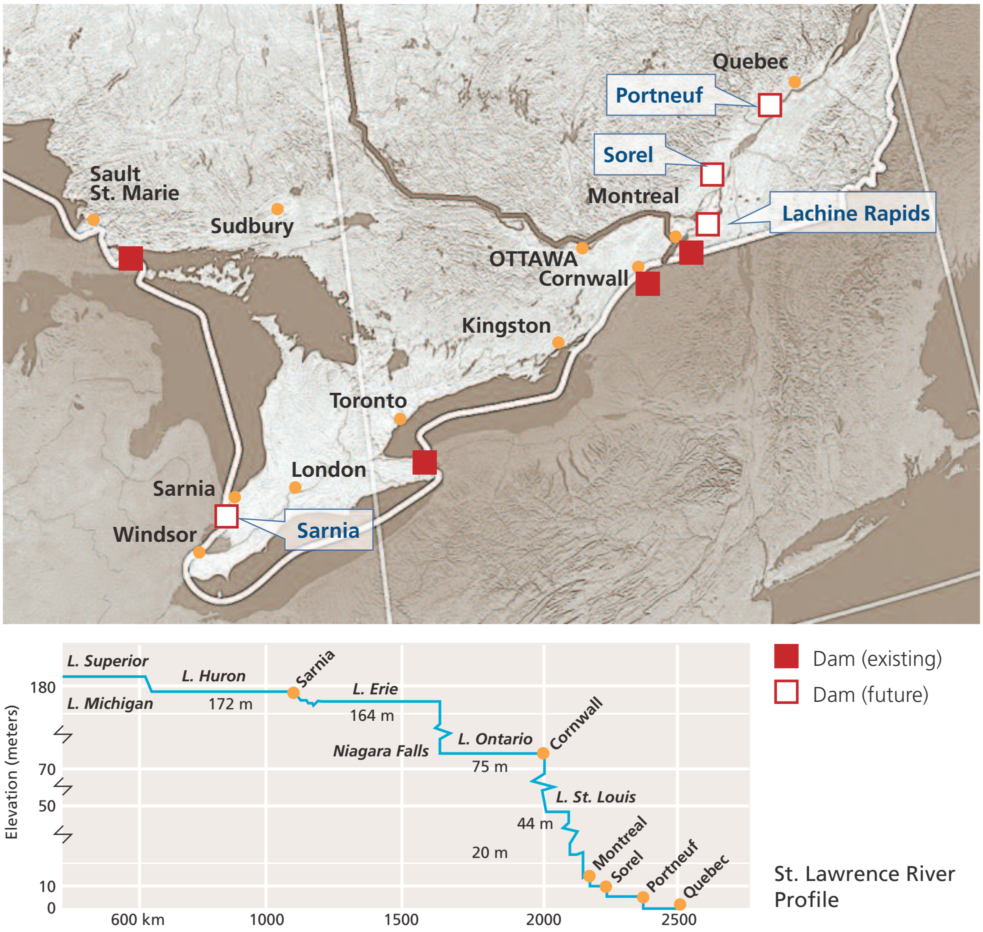
## The St. Lawrence River Basin and the "Northern Waters" Complex

The hydroelectric industry has indirectly been involved in the profound changes presently underway in the hydrology of the basin of the St. Lawrence River. Experts in climate change[11] foresee a reduced intake of about 20 to 30% in the Great Lakes, corresponding to 1,000 to 1,500 cubic meters per second in Sarnia and, possibly up to 2,000 cubic meters per second at Cornwall. In addition to reducing the electricity-generating capacity of all the key power plants found at Niagara, Cornwall and Beauharnois, this water flow reduction is likely to have significant impact on the St. Lawrence River shoreline, including the drying up of presently wet sections.

In its downstream portion between Montreal and Quebec, the riverbed is often shallow, apart from a main centre channel where the Seaway right-of-way is located due to dredging. This centre channel acts as a drainage channel, adding to the difficulty of managing water levels. How does one protect the environmental quality of over 18,000 kilometers of shoreline, much of it inhabited, and more than 1,000 square kilometers of very rich wetlands? Until recently, upstream water was released to increase water levels but, in the near future, such releases will no longer be possible, as the water to do so is diminishing.

Figure 3 illustrates the author's recently proposed alternative recommending a series of flood-control infrastructures which would structure the entire St. Lawrence – Great Lakes basin much like a waterfall consisting of some ten reservoirs. The lakes and reservoirs already controlled are those of Lake Superior, Lake Erie, Lake Ontario and Lake St. François. The infrastructures to be added would be located in the Sarnia area for the management of lakes Michigan and Huron, in the Lachine Rapids area for the management of Lake St. Louis, in the Montreal area for the Laprairie basin, and in

**Figure 3**
**Map of the St. Lawrence River – Great Lakes Basin Including Proposed Developments for Enhanced Water Level and Flow Control**



the general area of the cities of Sorel and Portneuf for the downstream portion of the St. Lawrence River. The St. Lawrence River-Great Lakes basin represents one of the most densely populated regions of Canada. New infrastructure, such as shown in Figure 3, may be required to prevent extensive modifications of water levels due to climate change along thousands of kilometers of shoreline. This will involve extensive consultations among local populations, First Nations, St. Lawrence Seaway authorities, the International Joint Commission, and many other stakeholders.

Thus, level management would essentially become independent of flow management. Without significant impact on the environment, part of the water inputs could be employed to meet the drinking water needs of the population of the entire St. Lawrence River – Great Lakes basin. The flow of 100 cubic meters per second is sufficient to allocate 100 gallons per person per day to a population of 20 million people. The project cost for these five infrastructures is estimated at about $5 billion.

## The "Northern Waters" Complex

To avoid creating large areas of standing water in the river, new water supplies must be added to the St. Lawrence River. Figure 4 illustrates the only valid proposal to date for diverting water to the St. Lawrence River. This proposal, the "Northern Waters" project[4, 5], recommends intercepting 800 cubic metres of water per second from the Bell and Waswanipi rivers in the Matagami area, and pumping it a head of 53 meters into the Ottawa River basin. This additional contribution to the Ottawa River, along with its 300 meters of head, offers an additional generating potential of nearly

3,000 MW in existing powerhouses (whose capacity would need to be enhanced), and an energy surplus of 14.6 TWh on Ontario's eastern border. The project leverages existing river beds while total flows would never exceed the natural flood flows of these rivers. The project cost is estimated at $14 billion, to which should be subtracted the investment required to bring existing facilities up to date with the most recent safety standards and allow them to deal with anticipated increased flood flows due to climate change. The project would still allow the development of a residual potential of about 1,800 MW on the Nottaway River, in the James Bay basin.

**Figure 4**
**Northern Waters Project**[4]

In this proposal, the Waswanipi and Bell Rivers are diverted from James Bay to the St. Lawrence River by pumping 800 cubic metres of water per second up a 53 meter head into the Ottawa River basin, thereby providing an additional 3,000 MW potential along the Ottawa River, and drinking water for up to 150 million people. The cost of this project is estimated at 15 billion dollars.

## James Bay

The La Grande Complex is already benefiting from the contributions of the Caniapiscau and Eastmain rivers, and more recently, the Rupert River. Other rivers in the region have been studied, and plans are in a very detailed final design stage. Among these rivers are the Great Whale (i.e., Grande Baleine) River, and the Nottaway and Broadback rivers (Figure 5).

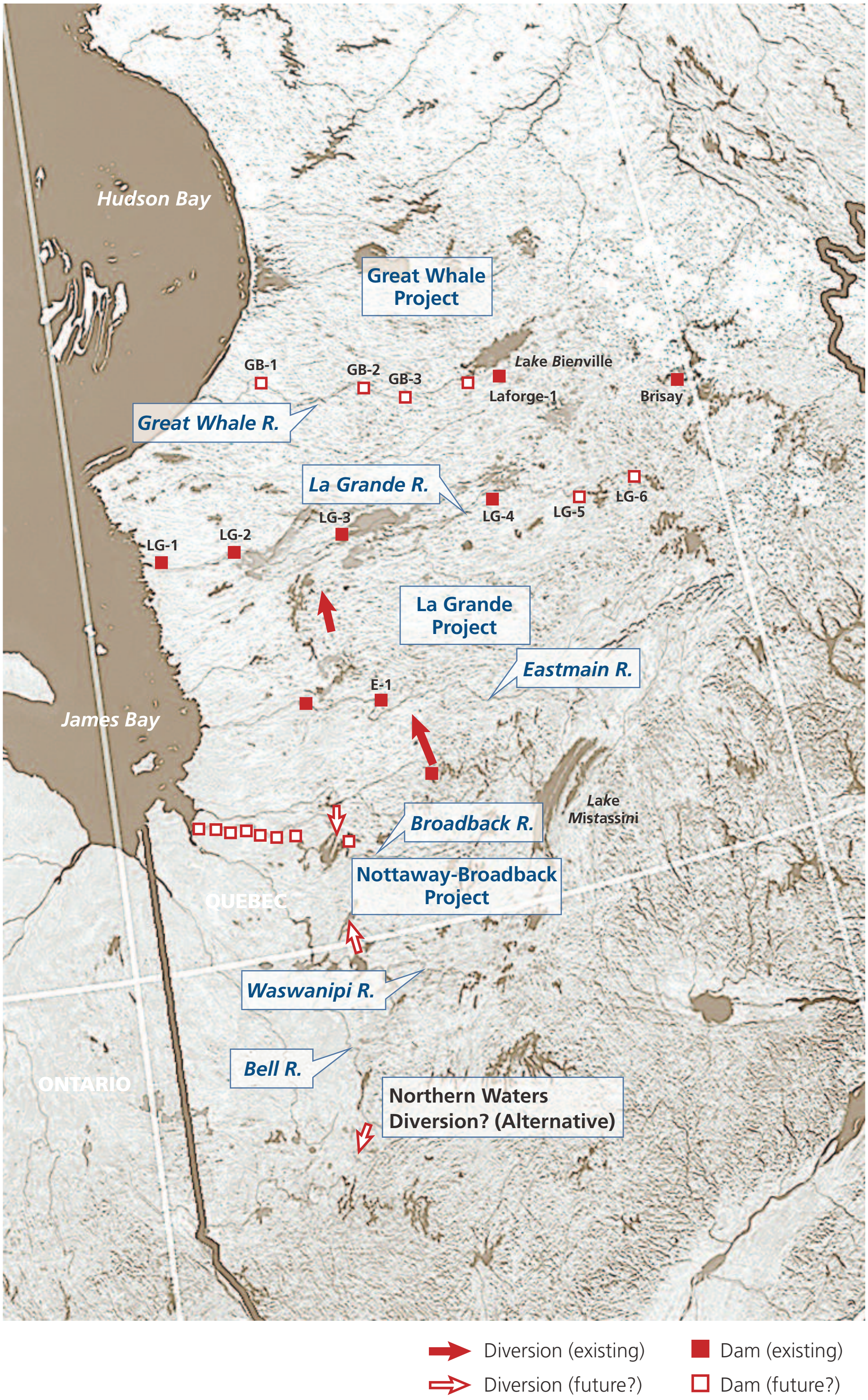


**Figure 5**
**Map of the James Bay Area in Western Quebec Indicating the Location of the La Grande, Great Whale (Grande Baleine) and Nottaway-Broadback Projects**

**South of the La Grande complex**, it is still possible to achieve what remains of the Nottaway-Broadback-Rupert complex. The Nottaway and Broadback rivers would yet allow the installation of a dozen plants having a combined capacity of approximately 3,200 MW. However, a choice needs to be made between this project and the proposed "Northern Waters" scheme as they draw from the same water supply. A Nottaway-Broadback complex would likely have much more environmental impact and be more expensive to realize than comparable projects without solving the problem of the drying-up of the St. Lawrence River.

**North of the La Grande complex,** there could be another hydroelectric complex on the Great Whale River, whose advanced studies were halted in 1995. This project remains very interesting, with a potential installed capacity of 2,900 MW. Its layout may need to be revised to reduce environmental impacts, including the extent of the flooded areas of the Bienville Reservoir.

The completion of the La Grande complex has made this area accessible and connected to a proven, reliable and extensive EHV transmission network. More than a dozen smaller sites therefore become interesting, such as sites in the upstream part of the La Grande River, the Eastmain River and several tributaries. The downstream part of the diversion of the Rupert River still offers a potential of 500 MW. On the whole, there remains the potential for secondary developments on the order of 3,000 MW.

### Western Half of Canada

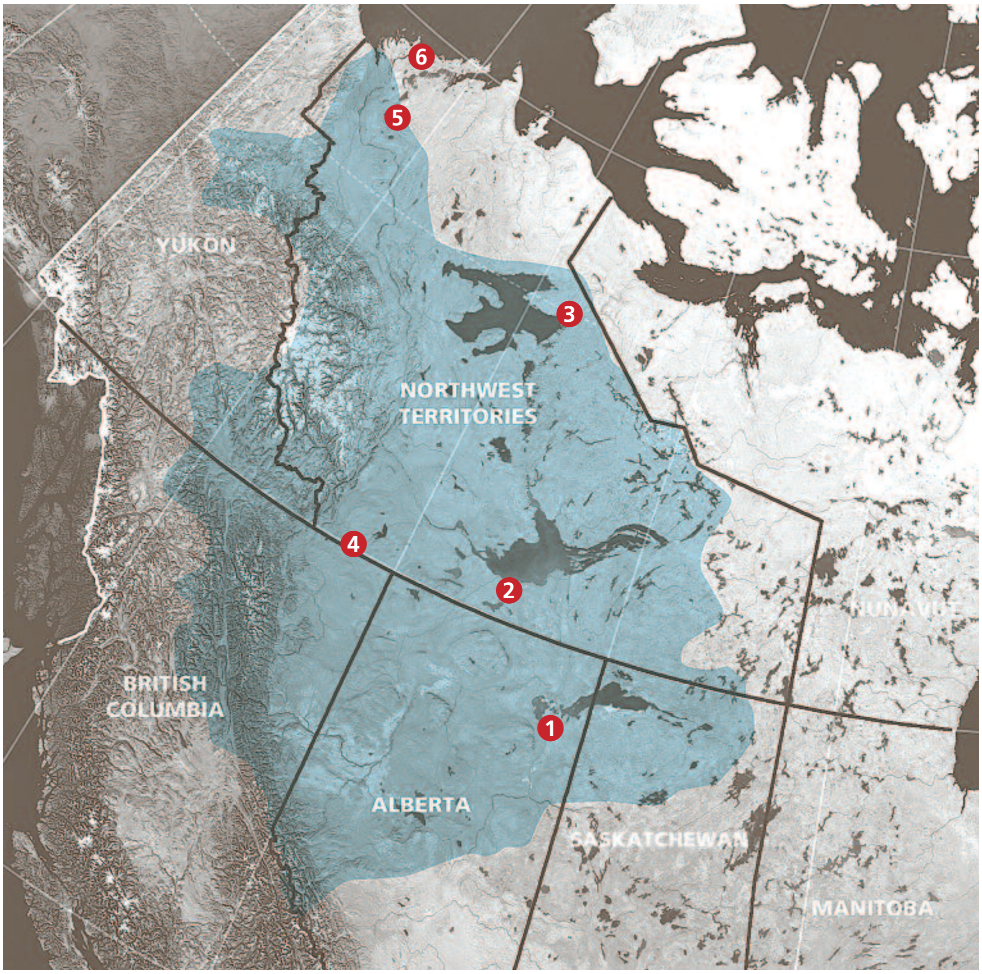
**Mackenzie River**

The western half of Canada, according to estimates by the Canadian Hydropower Association, possesses a vast theoretical potential of 91,000 MW. This potential poses a major difficulty in that key watersheds, including those of the Mackenzie, Churchill and Thelon rivers, often cover all or several of the Prairie Provinces. A deepened understanding of the interdependence of any project on other projects in the same complex, including reservoir volumes, flow rates, equipment capacities and levels of water control, can only arise from a comprehensive and integrated study of these complex hydraulic systems. Additionally, a detailed study of the topography suggesting possible diversions from one basin to another and even partial diversions from the Arctic basin to the Hudson Bay watershed, limiting the quantities of "hot water" discharged northward, could alleviate some of the effects of warming.

The initial data are exceptionally promising. For example, the average flow at the mouth of the Mackenzie River is 9,700 cubic meters per second, more than the St. Lawrence River at Montreal. As illustrated in Figure 6, the Mackenzie River has a drainage basin of 1,805,200 sq. km. It is connected to several large lakes, such as Great Slave Lake (28,528 sq. km) and Great Bear Lake (31,328 sq. km), which could easily be employed as reservoirs. In the Lower McKenzie River, downstream of the Athabasca and Great Slave lakes, a hydroelectric complex of some 14,000 MW,

**Figure 6**
**Mackenzie River Drainage Basin**

This map shows the Mackenzie River drainage basin, including the Athabasca, Slave and Peace Rivers, which could be leveraged to create a large hydroelectric complex spanning three provinces and the Northwest Territories.



| | Mackenzie River Drainage Basin | Basin Area (sq. km.) | Flow (CMS) | Elevation (m) |
|---|---|---|---|---|
| 1 | Lake Athabasca | 7,850 | | 209 |
| 2 | Great Slave Lake | 28,568 | | 156 |
| 3 | Great Bear Lake | 31,153 | | 186 |
| 4 | Fort Providence | 970,000 | 4,835 | |
| 5 | Arctic Red River | 1,660,000 | 9,119 | |
| 6 | Reindeer Station | 1,805,000 | 9,700 | |

***Sometimes truth is stranger than fiction…***

*In Quebec, in the second half of the sixties, while building the Manic-Outardes hydroelectric complex, Hydro-Quebec focused its studies on the Nottaway, Broadback and Rupert rivers though they were characterized by huge swampy areas. These large rivers had the sole advantage of being located immediately north of the Abitibi. Two engineers, Rousseau and Warren, took the initiative to look beyond these three rivers and outlined a vision of what would become the La Grande complex, where "there was both bedrock and high vertical drops, not just high flow rates." Having the ear of Premier Robert Bourassa, the two projects were put in competition, and the James Bay project was born!*

with a load factor of 80%, could be built. With a general arrangement of 11 projects of a height of 20 meters each, without submerging any important surface of land, it could be regulated managing the Athabasca and Great Slave lakes alone, within their natural boundaries. This project alone is already of a scale comparable to the James Bay Project. The upper part of the basin could then be study independently.

It must be emphasized that the study of such large complexes should not only consider hydropower generation potential but also aim to offset the effects of the drying-up of the Prairies due to climate change, including the melting of glaciers that currently feed this river system. Exceptional floods as experienced in 2011 by Manitobans could also be managed to some extent.

The scale of these projects is such that they may extend beyond five jurisdictions. An initial study is required to outline possible alternatives in addition to raising needed public interest. It would make sense for the Government of Canada to assume leadership for such a study.

## Recommendations

This chapter has attempted to highlight some of Canada's tremendous, as yet untapped hydroelectric and tidal power development opportunities. While much remains to be accomplished in the way of environmental assessments, negotiations with First Nations, consultations with local populations and other key stakeholders (e.g., St. Lawrence Seaway authorities, etc.), not to mention detailed engineering design, the following are promising projects identified for near-term development:

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

**Tidal Energy:** The tides of the Bay of Fundy present a particularly attractive "renewables" opportunity with a potential of 6,700 MW. 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 implementation of appropriate flood-control infrastructure would structure the St. Lawrence River-Great Lakes basin as a waterfall consisting of some ten reservoirs, and offer 1,000 MW of additional hydroelectric potential. A necessary companion project to maintain river level involves intercepting the Bell and Waswanipi Rivers in the Matagami area, 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 contribute to protecting 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, more commonly referred to as the Great Whale (Grande Baleine) Complex, would offer the opportunity of developing 5,000 MW of 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, those of the Mackenzie, Churchill and Thelon Rivers, cover several or all of the Western Provinces and the Northwest Territories. 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 are known to 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.

For these projects to be economically justifiable, it is essential to undertake the creation of a high-capacity, pan-Canadian, continental power grid - as discussed in the next chapter - which would enable phasing out – over time - of Canada's high-GHG thermal power plants nearing the end of their normal life cycle, and permit phasing in of the low-GHG electricity produced by these projects.

To facilitate moving forward on these projects, it would also be helpful for the Canadian Government to undertake topography and hydrometric surveys, especially in the Western half of Canada and the Northwest Territories, Yukon and Nunavut, through its Ministry of Natural Resources, to develop a scale mapping of 1:20.000. The existing mapping at a scale of 1:50.000 from the ministry is insufficient for present-day economic development and environmental studies.

**St. Lawrence River**

## APPENDIX A

## Key Hydroelectric Power Stations in Operation in Canada[2, 10]

| Province | Region | Major Plants | MW |
|---|---|---|---|
| British Columbia 14,832 MW, Hydroelectricity – 12,609 MW | Lower Mainland Network (10 plants – 1,065 MW) | Bridge River | 460 |
| | | Buntzen | 72 |
| | | Cheakmus | 158 |
| | | Stave Falls | 91 |
| | | Ruskin | 105 |
| | | Wahleach | 64 |
| | Columbia Network (12 plants) | Revelstoke | 2,416 |
| | | Mica | 1,740 (2,805 projected) |
| | Peace River Network (2 plants- 3,424 MW) | Bennett Dam | 2,730 (GR Shrum) |
| | | Peace Canyon | 694 |
| | Vancouver Island Network (7 plants) | Strathcona | 65 |
| | | Ladore | 47 |
| | | John Hart | 126 |
| Alberta 11,851 MW Hydroelectricity – 909 MW | | Brazeau (hydroelectric) | 355 |
| | | Bow River (hydroelectric) 13 sites | 800 |
| Saskatchewan 3,879 MW Hydroelectricity – 855 MW | | Coteau Creek | 186 |
| | | Nipawin | 255 |
| | | E B Campbell | 288 |
| | | Island Falls | 101 |
| | | Crume | 92 |
| | | Athabasca System | 23 (3 plants) |
| Manitoba 5,627 MW Hydroelectricity - 5,029 MW | Winnipeg River | Great Falls | 131 |
| | | Seven Sisters | 165 |
| | | Pine Falls | 89 |
| | | Pointe du Bois | 78 |
| | Nelson River | Jenpeg | 132 |
| | | Kelsey | 250 |
| | | Kettle | 1,220 |
| | | Limestone | 1,340 |
| | | Long Spruce | 1,010 |
| | Saskatchewan River | Grand Rapids | 479 |
| Ontario 32,166 MW Hydroelectricity – 8,350 MW | Central Group | 29 plants | 300 |
| | North-East Group | 13 plants | 1,000 |
| | North-West Group | 11 plants | 680 |
| | Ottawa St. Lawrence Group | 10 plants | 2,576 |
| | Niagara Group | 4 plants (Including Sir Adam Beck No. 1 and 2 and new power tunnel) | 2,439 |
| Quebec 41,018 MW Hydroelectricity – 37,459 MW | Hydro-Quebec | La Grande Complex | 17,295 |
| | | Manic-Outardes Complex | 7,958 |
| | | Bersimis Complex | 2,047 |
| | | St-Maurice Complex | 1,825 |
| | | Beauharnois | 1,911 |
| | ALCAN | | 2,576 |
| New Brunswick 4,535 MW Hydroelectricity – 923 MW | | Mactaquac | 672 |
| | | Beechwood | 113 |
| | | Grand Falls | 66 |
| | | Tobique | 20 |
| | | Sisson | 9 |
| | | Tinker Dam | 34.5 |
| | | Nepisiquit Falls | 11 |
| | | St-Georges Dam | 15 |
| Nova Scotia 2,463 MW Hydroelectricity - 404 MW | | 33 plants | 360 |
| | | Annapolis Tidal Power | 20 |
| Newfoundland 7,353 MW Hydroelectricity – 6,796 MW | | Churchill Falls | 5,428 |
| | | Baie d’Espoir | 604 |
| | | Cat Arm | 127 |
| | | Granite | 40 |
| | | Hinds Lake | 75 |
| | | Paradise River | 8 |
| | | Upper Salmon | 84 |
| | | Star Lake | 18.4 |
| | | Private Plants (2) | 66 |

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### Helpful Web Sites:

B.C. Hydro
Hydro-Québec
Manitoba Hydro
New Brunswick Hydro
Newfoundland and Labrador Hydro
Nova Scotia Hydro
OPG Ontario Power Generation
Saskatchewan Hydro

## 5

# Interconnecting Canada

Richard J. Marceau
Clement W. Bowman
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## ABSTRACT

Canada's electricity system was designed and built historically 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 greenhouse gas (GHG) emitting capacity, mainly hydro and nuclear. Of the remaining high-GHG-emitting capacity, 65% of this is over 30 years old.

The interconnection of existing provincial grids through a new high-capacity transmission system would enable significant reductions in Canada's carbon footprint by incorporating distant hydroelectric and tidal low-GHG-emitting 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 and thereby reduce power costs in some markets, enhance energy storage capability and provide strategic security advantages through a high-capacity transmission backbone.

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, considered here, 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 some enhancement. Even so, such a project is found to be 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.

## The Opportunity

In Canada's original electricity system design, there was limited emphasis on provincial interconnections. Economics for new interconnections have historically favored north-south connections to the U.S. The climate change imperative and the potential for new low greenhouse (GHG) emitting generation are important signals that the situation has changed. The International Energy Agency has estimated that Canada's electricity sector will require $U.S. 190 billion in new investment from now to 2030. This may be the time to consider strategic national electrical infrastructure investments.

The current situation regarding electrical transmission systems can be described as follows:

- Canada is moving towards a national position on the question of climate change and GHGs.
- The Canadian Chamber of Commerce has noted[1] that "a substantial amount of Canada's power potential is stranded because there is no transmission grid to tap that power and ship it to market".
- Newfoundland and Labrador Hydro has stated that[2] "… without sustained action on a strong east-west grid that will support this country's growing demand for clean energy, Canadians may find themselves squandering a key competitive advantage …"
- The United States is investigating several inter-regional connections to add to their grids, driven in large part by planned expansion of renewable energy. These include reinforcing the north-south intertie in the Western states to provide power for Nevada and California, and connections from the Great Plains with load centers to the east and west.

A National Advisory Panel on Sustainable Energy Science and Technology has stressed the importance of seeing the Canadian energy sector as "an integrated system with strong interdependence between producers and users of energy"[3]. This provides urgency in examining the interconnection of electricity with other energy "currencies" of Canada's major energy corridors.

The technology available has changed considerably since the current Canadian electrical system was put in place. Two specific advances are the use of extra- and ultra- high voltage AC and DC transmission and the potential for energy storage; both are examined in this chapter. The U.S. Department of Energy "Roadmap"[4] describes another important technology objective, namely the need for analytical tools as well as techniques to overlay next generation technologies onto the existing grid. More sophisticated control strategies are also needed, such as the asymmetric operation of transmission corridors.

In addition to specific technology changes, there has been a decrease in the enrolment of students in electric power engineering programs across Canada. Combined with the expected retirement of practitioners active in this field, including university faculty members and instructors, this leads to a major concern regarding Canada's ability to undertake ambitious new electric power projects if they are too long delayed.

As we shall see later in this chapter, the strategy of replacing ageing high-GHG generation by means of a cluster of distant hydroelectric and tidal power stations in several provinces, connected among themselves and to their provincial grids, may well offer the first practical economic and environmental strategy for interconnecting and integrating Canada's electric power networks.

History has shown the value in building infrastructure not just for immediate short-term needs but preparing for game changing future needs. A Toronto example began circa 1910, when architect Edmond Burke and engineer Thomas Taylor designed the Bloor-Danforth viaduct to span the Don Valley. They anticipated that, before the close of the just opened-century, Toronto would build a subway system requiring a Don Valley crossing. So they designed and built the bridge with a lower deck to accommodate subway trains. The decks for a "future" subway added but a modest increase to the construction cost. But when the first trains on the Bloor-Danforth line crossed the Don Valley in 1954, this was a reminder of our forefathers' foresight.

Given Canada's abundant capacities of hydropower in combination with a foreseeable more electricity-intensive economy (including a greater contribution to the transportation of people and goods), Canada should aim to reduce its net GHG emissions while delivering a sustainable competitive advantage, for which an integrated and comprehensive national electrical grid would represent a significant asset. The above factors make this an important time to examine the Canadian electrical industry and its relation to Canada's energy future.

## Overview of the Electrical Industry in Canada

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 30 years old, providing opportunities for replacement with lower-GHG-emitting technology, (e.g. hydro, wind, solar, biomass and fossil fuels with carbon capture). The ratio of low to high-GHG-emitting generation for each province is given in Figure 1.

All provinces, except Ontario, have their peak demands in winter. This suggests that an interconnected grid would allow Ontario to reduce its peak load generating capacity in summer by a shift in power from provinces to the east or west. Due to the number of time zones within our nation, the real-time national load requirement indicates excess capacity in hours 3 to 7 which could be shifted one or two time zones to match provincial loads, or captured by improved storage technology. Quebec has a significant excess capacity from hours 13 to 18 which could be shifted east or west, or south to a U.S. grid which peaks in the summer overall. These lags in load requirements are captured in Figure 2 whereby all loads are set to Atlantic Time.

Although responsibility for electrical power is that of provincial governments, there are an increasing number of participants in the generation/transmission system, with more participation by the private sector. This increases the complexity and difficulty of developing a coordinated national strategy and plan. However, with this increased number of players, it may provide opportunities to develop a strategy that is more than the sum of regional projects.

**Figure 1**
**Electrical Generation (GWh) in Canada – 2007**[5]

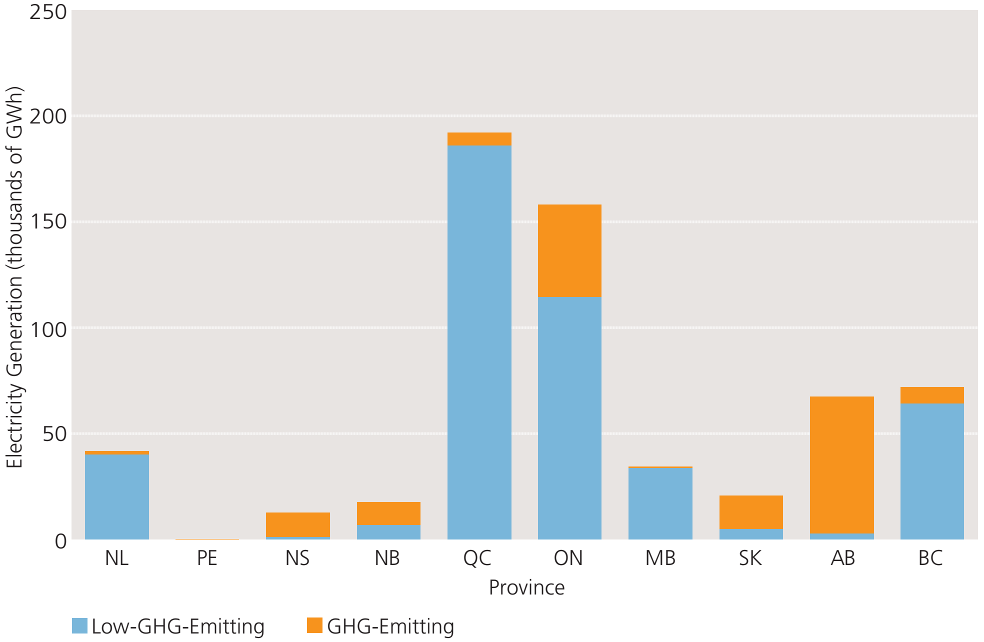
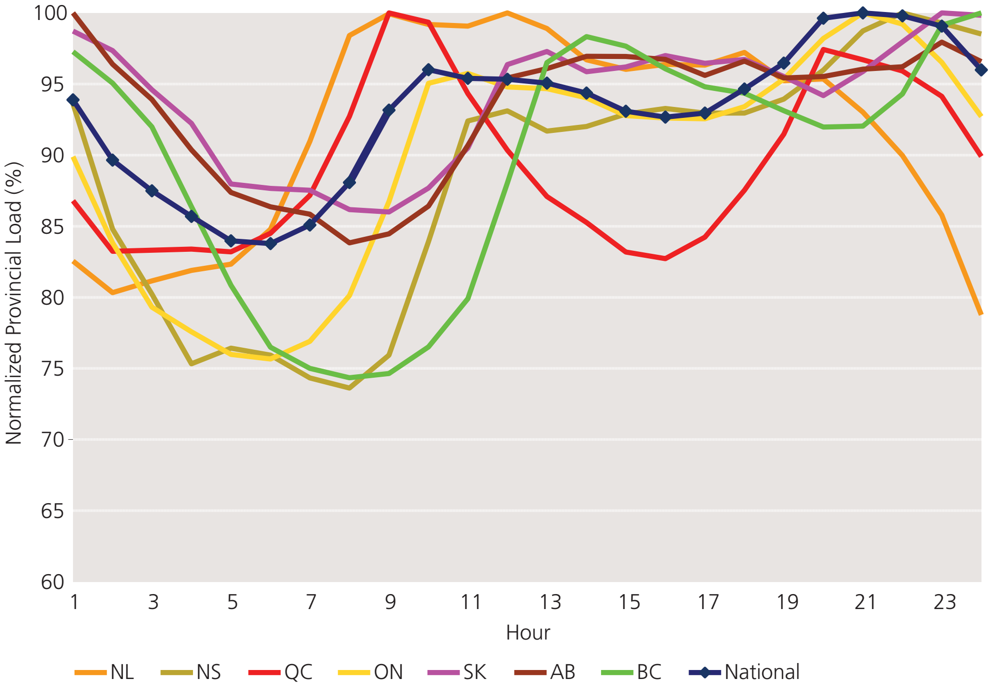


**Figure 2**
**Hourly Load Variation (%) Over 24 Hours**[6]



It is also significant that there is a commonality of goals across the country, such as increasing the use of low-GHG emission technologies, ensuring reliable and secure energy supplies, maintaining consistency with North American transmission standards, and expanding the development of renewable energy sources. There are opportunities for collaboration on specific objectives, for example: the development of low-GHG emission technology for fossil fuels in Nova Scotia, New Brunswick, Ontario, Saskatchewan, and Alberta; the development of additional hydro storage and other storage technologies in Newfoundland and Labrador, Quebec, Ontario, Manitoba and British Columbia; facilitating an interconnection between Manitoba and Ontario which would encourage the flow of low-GHG electricity in either direction between eastern and western networks; participation in international programs on advanced nuclear reactors by Quebec, Ontario and New Brunswick; load sharing across the country by improved high-capacity long distance transmission and/or export to a continental market.

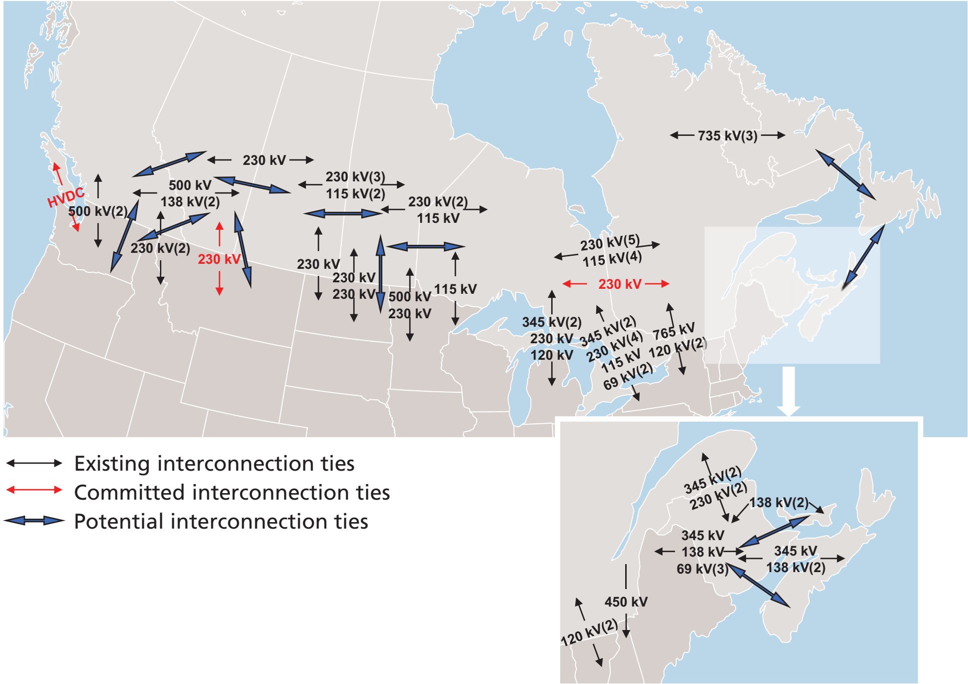
## Existing and Planned Interconnection Projects

Canada at present has more electrical connections with the U.S. than it has among all the provinces (34 to the U.S. compared to 31 among provinces). In addition, the interprovincial connections tend to have small transfer capabilities whereas many of the connections to the U.S. can transfer quantities equivalent to the output from major hydro or nuclear plants.

Several new major interconnections are being considered by various planning authorities, including a project to transfer power from the Lower Churchill Falls project in Labrador to Newfoundland and Nova Scotia by means of submerged HVDC transmission, a line across Confederation Bridge feeding potential expansion in wind power in Prince Edward Island to New Brunswick, a connection to bring Manitoba hydro power to Ontario, potential for capacity increases in the connections between Manitoba and Saskatchewan, a second Alberta-BC interconnection and a new line from Fort McMurray Alberta through BC to the U.S. The existing, committed and potential interconnections are shown in Figure 3.

New interconnection projects will continue to be justified on the basis of the respective economics of each interconnection. It would seem reasonable to consider undertaking a strategic evaluation of a strengthened east-west grid capacity with the above interconnections forming important and key links. Opportunities for distributed regional renewable energy sources to tie into the grid would increase the attendant opportunities to bring such renewable energy sources to wider markets through an appropriately interconnected network of provincial grids.

**Figure 3**
**Existing, Committed and Potential Interconnection Lines between Jurisdictions**



It is not hard to visualize that the committed and potential interconnections shown in Figure 3 could evolve into a future national east-west grid. But it would be prudent to ensure that new interconnections have the "head room" to meet potential future requirements (as was done with the Bloor-Danforth viaduct). However, each project moves forward on its own economic merits (which precludes the notion of "head room" to some degree), independently of any other project. Unfortunately, none of these projects are part of any larger systemic analysis and design.

Canada's release of GHG per exajoule of electrical power is 34 megatonnes versus 162 in the U.S. Canada's electrical generating capacity is one of the lowest GHG-emitting in the world, with over 70% of its capacity derived from non-GHG-emitting technology.

Rights of Way for power lines are highly constrained in both the U.S and Canada. The various enhanced or new interconnections that have been proposed will give rise to different issues on power line location. There may be considerable value in exploring the use of existing pipeline rights of way as potential rights-of-way candidates for electric power transmission, thereby aiming for multiple usages of existing rights of way.

## Hydro Power Potential

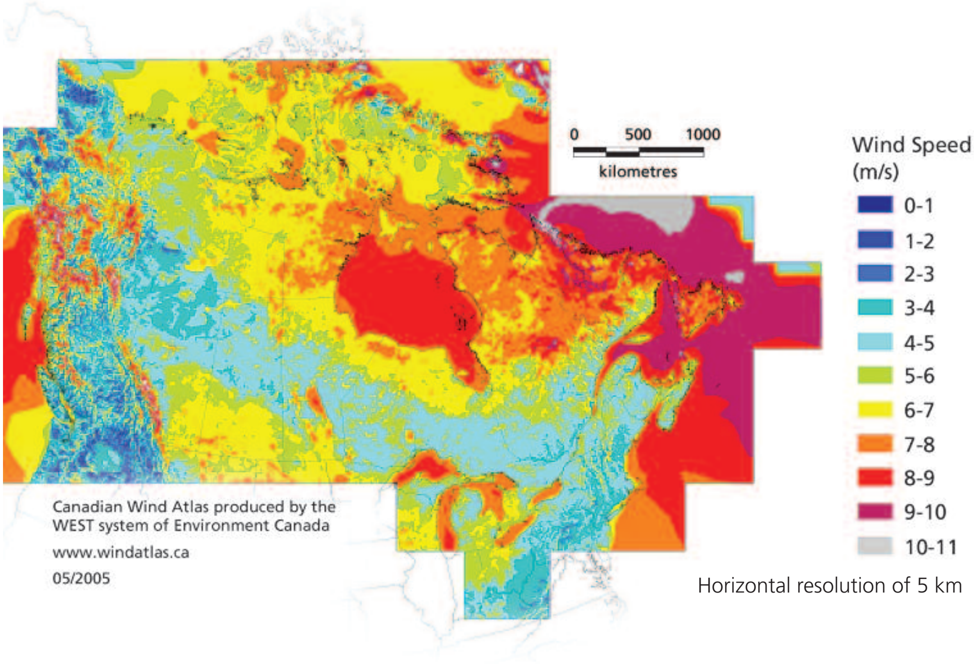
Hydroelectric power is a major Canadian strength and now provides about 57% of Canada's electrical energy production (approximately 73,000 MW generating capacity) and there is the technical potential to more than double this as illustrated in Table 1. Hydro power is site specific and usually involves long transmission lines to load centres[8]. Seasonal variability and storage are key factors in hydro site design. As indicated in Chapter 4, Canada has the ability to significantly increase its electrical generating capacity by harnessing clean, dispatchable and exportable hydropower that brings with it an immense, sustainable, competitive advantage.

**Table 1**
**Hydro and Tidal Power Generation: Present & Untapped Potential (MW)**[7, 8]

| | In Service MW | Available MW |
|---|---:|---:|
| Yukon | 78 | 17,664 |
| Northwest Territories | 25 | 11,524 |
| Nunavut | 0 | 4,307 |
| | | **33,495** |
| British Columbia | 12,609 | 33,137 |
| Alberta | 909 | 11,775 |
| Saskatchewan | 855 | 3,955 |
| Manitoba | 5,029 | 8,785 |
| | | **57,652** |
| Ontario | 8,350 | 10,270 |
| Quebec | 37,459 | 44,100 |
| New Brunswick | 923 | 614 |
| Nova Scotia | 404 | 8,499 (tidal) |
| Prince Edward Island | 0 | 3 |
| Newfoundland-Labrador | 6,796 | 8,540 |
| | **73,447** | **163,173** |
| **Total** | | **236,620** |

Wind power provides about 0.5% of Canada's electrical power. The availability of higher quality (i.e. higher average wind speed and lower cost) potential is site specific. High quality potential sites are widely distributed. Most are located near the Great Lakes and coastal regions as well as northern Ontario and Quebec but some are found in the Great Plains and British Columbia (Figure 5). Short-term variations are large and make balancing supply more difficult. Interconnecting dispersed wind farms can alleviate the variability, while on a seasonal basis wind tends to complement hydro. A national or continentally interconnected grid would enable each wind farm to operate at its optimum output level. Canada has abundant opportunities for creating synergies between wind and hydro generation, particularly in northern Ontario and Quebec through shared transmission corridors for both types of renewable energy sources.

**Figure 5**
**Canada's Wind Power Potential – Mean Wind Speed (m/s) at 50 m Above Ground**



Canadian Wind Atlas produced by the WEST system of Environment Canada
www.windatlas.ca
05/2005

Horizontal resolution of 5 km

## Nuclear Power

After years in the doldrums, over the last decade, nuclear power has experienced something of a rebirth world-wide. This is in part a consequence of concerns over climate change. The emissions of GHGs resulting from generating electricity with nuclear power are indirect (mostly in the plant construction process) and small. Also, the development of reactors employing new types of fuels, such as Thorium, or reutilizing "spent" fuel continues to advance.

However, this nuclear renaissance is full of uncertainties. Beyond the habitual issue of determining the full cost of generating electricity from nuclear power, the tragic shutdown of the Fukushima power plant in Japan in 2011, due to the near-simultaneous occurrence of an earthquake and tsunami, has again caused some nations to seriously question their commitment to nuclear power. In Canada, the June 2011 sale of Atomic Energy of Canada Ltd's reactor business—the traditional supplier of CANDU technology to the world—by Canada's Federal Government to SNC-Lavalin has introduced yet another element of uncertainty to Canada's nuclear industry, although this may lead to greater standardization of CANDU power plant design and capacity.

To these uncertainties and risks must be added the relatively large size of individual plants, both in terms of MW installed and the investment required. Risks and size combine to make it difficult to finance new nuclear capacity. One approach to mitigating this problem, especially in the near-term, is to spread the costs and risks among more than one investor. Such parceling and diversification of risk can be done in various ways institutionally. In physical terms, it is likely to mean a wider market area for the plant's output.

When a longer term perspective is taken, another point emerges. Not only are individual nuclear plants usually larger than their fossil fuel counterparts, there is a greater tendency to cluster plants at specific sites. Future expansion is likely to reinforce this tendency – pioneering analyses in the 1970-80s led by Alvin Weinberg in Oak Ridge suggested that very substantial nuclear capacity could be added, overall, in the existing sites. At the time, such "nuclear parks" (on the order of 10 GW) were advocated in order to bring together the requisite know how to deal with low probability emergencies and to facilitate the safe handling of the flows of nuclear fuel and wastes. Another possibility is to aim to develop clusters of nuclear power plants in isolated locations, where environmental studies and authorizations would be obtained for the cluster rather than on a plant-by-plant basis. The fact that nuclear sites are, for all practical purposes, permanent structures is another factor leading to clustering.

In Canada the potential application of nuclear energy for Alberta is being investigated by a variety of groups, including the University of Calgary, the Petroleum Technology Alliance Canada (with industry and government support), and the Alberta Research Council in collaboration with the Idaho National Laboratory. Potential applications include using nuclear reactors to provide utility electrical operations, process heat for producing the steam employed in the in situ thermal recovery of bitumen from oil sands, and for the production of hydrogen and oxygen used by bitumen refiners.

## Coal-Derived Power

Coal combustion now generates one-fifth of Canada's electrical supply, compared to 50% to 80% in other energy intensive economies. Ontario has committed to phase out coal combustion, and the Federal Government has issued draft regulations on the shutdown of coal plants when they reach the end of their economic life[9]. This opens up an opportunity for new more environmentally benign technology. The GHG footprint of coal can be reduced significantly by gasifying coal with steam and oxygen, and capturing and sequestering the concentrated stream of carbon dioxide, at the cost of reduced energy efficiency. Successful coal gasification would be a platform technology for application to a wide variety of high-carbon fossil fuel and biomass feedstocks.

Gasification involves the reactions of carbon-based fuels with steam and oxygen to produce electricity, hydrogen and other value-added products. Although commercial in other countries, it has not been demonstrated for Canadian low rank coals and biomass, and has not been integrated with carbon dioxide capture, transportation, storage and use technologies. Hydrogen is needed now for upgrading hydrogen-deficient fossil fuels. Gasification technology is proven but not economic in Canada under present conditions. Demonstration scale projects including $CO_2$ capture using Canadian low rank coals and coke, and next generation technology improvements are needed. While gasification will largely be regional using coal, a successful demonstration project could lead to a platform for gasification of biomass country-wide. This is discussed further in Chapter 8.

## Demand Side Issues

The Smart Grid concept is under intensive study and has two applications:

1. Interactions with consumers to reduce consumption or flatten the load; and
2. Managing power generation and power line assets to improve reliability.

It would not appear to have a major influence on the need for greater connectivity between provincial grids, but would impact on the design, operation and control of existing grids.

The main contender for electricity use in transportation is the Plug-in Hybrid (batteries charged from the grid at night with an onboard fuel powered battery charger to extend range). Analysis suggests that the likely increase in power demand even with rapid introduction of the Plug-in Hybrid would not be large, if linked with Smart Grid technology.

Air pollution is another major health and environmental problem throughout the growing metropolises globally, including Canadian cities. The problems arise primarily from the use of coal and automobiles. Power generation from hydro, nuclear and renewables in conjunction with the adoption of electric vehicles are vital to the health of Canadian citizens living in large urban environments.

The U.S. expects to have increased electrical trade inside the country as a result of new interregional connections. It is not as yet planning any significant increase in import of electrical power from either Canada or Mexico, as shown in Table 2. However, if Canada had enhanced grid interconnections with the U.S. grid network, it would have a strong argument to support a major increase in the sale of low-GHG electrical power to the U.S.

**Table 2**
**U.S. International Trade in Electricity, Recent and Projected (TWh)[10]**

| | 2006 | 2007 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|
| Imports from Canada and Mexico | | | | | |
| Firm Power[a] | 14 | 16 | 17 | 7 | 0 |
| Economy[b] | 29 | 36 | 29 | 31 | 46 |
| *Total* | *42* | *51* | *46* | *39* | *46* |
| Exports to Canada and Mexico | | | | | |
| Firm Power[a] | 3 | 4 | 1 | 1 | 0 |
| Economy[b] | 21 | 16 | 21 | 20 | 19 |
| *Total* | *25* | *20* | *21* | *21* | *19* |
| Net Exchange with Canada and Mexico | | | | | |
| Firm Power[a] | 10 | 12 | 16 | 7 | 0 |
| Economy[b] | 7 | 19 | 9 | 11 | 27 |
| *Total* | *18* | *31* | *24* | *18* | *28* |
| **Total U.S. Net Generation to the Grid** | **3906** | **4004** | **4042** | **4396** | **4859** |

a Firm Power Sales are capacity sales, meaning the delivery of the power is scheduled as part of the normal operating conditions of the affected electric systems.

b Economy Sales are subject to curtailment or cessation of delivery by the supplier in accordance with prior agreements or under specified conditions.

# Energy Storage Technologies

Energy storage goals are to level peak demand loads, support modernized base-load generation (nuclear and coal), and store energy produced by renewable energy sources when such energy cannot be immediately consumed by grid customers. The importance of energy storage grows in response to the challenges of reducing the GHG footprint of electric power generation, transmission and utilization. This section provides a brief overview and analysis of existing electric energy storage options.

## Traditional Hydroelectric Storage ("Ponding")

This involves reducing river flow through a hydroelectric installation, thereby storing water behind the dam for later generation. This method has a long and successful history of storing large amounts of electricity in a reservoir, which is of special significance to an interconnected grid. Hydroelectricity is already the spine of the Canadian electric system, supplying 58% of the country's electrical needs whether for base-load, peak load, or export. Ponding is identified as the most important storage technology due to the future need for more base-load generation, the massive unexploited hydro power available in Canada's North (see Chapter 4) in close proximity to large wind resources, and the ability to divide the costs of high-capacity, long transmission construction between hydro and wind power operators, while creating transmission corridors to allow further wind power installation. Unfortunately, information on the energy storage capacity in Canada's hydroelectric system is not publicly available.

## Pumped Hydroelectric Storage

This involves elevating and storing water in large reservoirs for later hydro generation, on daily, weekly, and seasonal cycles. It is similar to "ponding" in the use of the gravitational potential of water, but the need for pumping introduces some inefficiency relative to traditional hydro. Pumped storage has the ability to fit either a large central grid or smaller regional grids. A number of sites in Canada lend themselves to a 2 to 4 GW capacity. For large-scale solar and wind generation to work effectively and economically, traditional hydroelectric reservoir storage and pumped hydro represent proven, reliable and cost-effective energy storage technologies.

## Compressed Air Storage (CAES)

This involves compression of air and storage in underground caverns for later electricity generation in turbines. CAES is dependent to a large extent on geology for the right geological formations to store the compressed air. A large central grid would allow more transmission lines to reach the suitable formations, something smaller regional grids cannot do. The technology is relatively mature, and represents an alternative to traditional reservoirs or pumped hydro where such appropriate sites are unavailable. A project is presently under study on the Saskatchewan/Alberta border.

## Molten Salt Storage

This involves storage of solar heat in salts such as sodium and potassium nitrates, with later heating of water to generate steam for electricity generation. It is mainly used in unison with concentrated solar power (CSP), and therefore not very feasible in the Canadian context.

## Hydrogen Energy Storage

Production of hydrogen, storage, and later power generation has too low an overall efficiency (< 25%) to be considered for large stationary applications. Hydrogen could be produced by electrolysis during off-peak periods and stored for use by industrial processes as a chemical feedstock. However, if the demonstration of thermochemically-produced hydrogen from the waste heat of nuclear power plants is successful, this will likely transform the economics of hydrogen as an energy currency for electric power generation and other potential applications.

## Battery Energy Storage

Battery energy storage could have four main uses in a grid system:

1. Time shifting or leveling the intermittency of smaller distributed renewable power sources;
2. Short-term peak shaving for base-loads (with flow batteries);
3. Improvement of power quality at problematic nodes; and
4. Providing short-term uninterrupted power supply and bridging between power outages and generator start-up, at modest power levels or discharge times.

## Superconducting Magnetic Energy Storage (SMES)

In this case, energy is stored in the magnetic field of a current circulating in a superconducting material, and discharged in short bursts of about 10 seconds. SMES can be used in regional grids to control instantaneous power surges or sags caused by the intermittency of renewable sources, and in large centralized grids as a power quality insurer at grid nodes on long transmission lines.

## Electrochemical Capacitors

This involves the separation of charge on surfaces separated by an electrolyte. They can be used at transmission nodes to offset power sags and as bridging power between power outages and generator start-up. The ability to maintain power quality gives capacitors a role in integrating various power generation sources.

## Electric Vehicle to Grid (V2G) Storage

This represents the ability of passenger cars to absorb electrical power from the grid in off-peak periods and return some of that power in peak periods. A cautious estimate of the near-term impact is that the Canadian electric car population could deliver on the order of 1% of daily demand to the grid in the evening. Although it would have minimal contribution to the base-load demand, it could reduce the peak load problem by providing a distributed storage capability near demand locations. The life expectancy of batteries has been raised as an issue. The principles behind the technology are sound and the major hurdles lie in the field of regulation, commercial arrangements, and incentives.

Storage technologies can have an important role either regionally or nationally in helping match supply with the load, and therefore allowing intermittent renewable resources to be more fully exploited. However, many of the available technologies are not mature to the extent of helping in real-time balance of power and generation, while fast-acting storage technology prototypes remain expensive and limited in capacity. Hydroelectric power could aid a national grid by increasing both the base and peak load generation and the practice of "ponding" is the eminent player among the available storage technologies, in all evaluated attributes. Pumped Hydro and Compressed Air Energy Storage would also have application for a national grid, albeit with more difficulty. Batteries, Capacitors, and Superconducting Magnetic Storage would be important tools in aiding the design of a national grid, but not necessarily contributing large storage capacities or power levels. Production of hydrogen from electricity would normally be a one-way street to a chemical raw material due to low conversion efficiencies, though the emergence of hydrogen produced thermo-chemically may well provide an opportunity to review this conclusion. Molten salts, although very favourable in CSP application, has presently little relevance for Canada. Finally, V2G technology is very promising but largely dependent on consumer adoption and effective regulatory practices.

## High Voltage Transmission Technologies

Technologies and equipment are available to transport bulk electricity over long distances, in particular high voltage DC and AC transmission. There are a variety of options now available to transmission planners to strengthen existing grids, increase transmission capacity and provide high-power interconnections to large neighbouring networks without sacrificing either power system security in normal utility operations, or the long-term power system reliability of interconnected systems.

### High Voltage Alternating Current (HVAC) Transmission

The majority of the electrical power is transmitted by means of AC lines and a number of improvements have been made. Voltages of up to 765 kV are currently used for bulk power transfer of up to 3000 MW. Technologies for voltages of up to 1200 kV are being developed. Stability and voltage control are two key operating factors that need to be carefully considered. New devices,

called Flexible AC Transmission System (FACTS) devices, are available that can enhance transmission system performance and increase transmission capacity. These comprise thyristor-based devices, including the static Var compensator and the thyristor controlled series capacitor, and force commutated based systems, including the static synchronous compensator, the static synchronous series compensator and the unified power flow controller. Issues include AC system strength, temporary overvoltages, commutation failure, and fault recovery. Ultra high voltage FACTS systems, with high bulk transmission capabilities, and ratings of up to 800 kV, 6000 MW, are being developed and installed at the present time. These systems extend the capabilities of existing transmission systems.

## High Voltage Direct Current (HVDC) Conventional Transmission Technologies

Conventional line commutated systems are based on thyristor technologies, with typical voltages of up to 500 kV, and bulk power transfer capability of up to 3000 MW. Technical issues include converter configurations (monopolar, bipolar, multi-terminal), valve ratings, reactive power requirements, grounding electrode design and reliability.

## High Voltage Direct Current (HVDC) Transmission Technologies Using Voltage Source Converters (VSC)

These systems are based on force commutated devices, with typical voltages above 300 kV, and bipolar power transfer levels of 1100 MW now possible. They use mostly cable systems, with overhead transmission being developed. Advantages include full real and reactive power control, and the capability of feeding any type of load. Technical issues include the converter configurations (two level and multi-level), device ratings, transformers, cables, AC filters and reliability. Performance issues include real and reactive power control, AC faults, DC faults, overloads, and environmental aspects.

## Applications of HVDC Transmission

Features and advantages of HVDC transmission include capability of bulk power transmission across long distances, improved utilization of existing infrastructure, interconnection of asynchronous systems, integration of remote energy resources, infeed to congested load areas and supply of isolated loads.

At the present time, conventional Line Commutated Converter (LCC) HVDC is a mature technology with proven application in bulk power transfers over long distances, typically over 1000 km, interconnection of asynchronous AC systems, and long cable transmission systems. Conventional LCC HVDC has the disadvantages of the associated reactive power compensation requirements, dependence on the AC system strength for performance, and not being easily tapped along the transmission line. Newer Voltage Source Converter (VSC) HVDC technology addresses these issues and others, along with providing a means of independent control of converter real and reactive power. VSC technology has advanced quickly and continues to, with overhead line applications now being possible. As the power transfer capabilities of VSC converters continue to increase, it is expected that the application of VSC technology will continue to increase, including the development of multi-terminal VSC HVDC based systems.

# Pathway Forward

In the 20th century, the interconnection of Canada's disparate networks into a single operating power system was a dream, more of a "nice to have" rather than a "have to have", where the technology for accomplishing this dream was at best in its nascent stages, and the return on investment was more qualitative than quantitative.

As we enter the second decade of the 21st century, the high-power technologies needed to implement continental power systems are proven and mature. Some control and operational challenges will no doubt emerge as the integration of hundreds of Gigawatts of electrical and mechanical machinery on a continental scale, through multiple time zones, is undertaken for the first time. However, the successful operation of telecommunications networks on global scale, and of large power systems today, provide the confidence that continental power systems can be successfully implemented.

As previously stated, 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 30 years old, representing an opportunity for replacement with lower-GHG-emitting technology, (e.g. hydro, tidal, wind, solar biomass and fossil fuels with carbon capture). A second observation is that Canada needs to implement strategies for achieving significant reductions to its carbon footprint to combat climate change. In conjunction, these two observations circumscribe a new opportunity for Canada to interconnect its provincial grids according to the following three-step strategy:

1. Develop the known potential of several distant hydroelectric and tidal power sites identified in Chapter 4 (see Table 4 on page 87);
2. Interconnect the resultant hydroelectric and tidal power stations among themselves and to provincial grids with the objective of progressively replacing thermal generation;
3. Strengthen existing networks to facilitate the integration, transmission, distribution and reliability of power from other renewable sources.

**Table 3**
**Canada's Fossil Fuel Generating Capacity (2007)[7]**

| Province | Thermal MW | Total MW |
|---|---|---|
| Newfoundland and Labrador | 557 | 7,353 |
| Nova Scotia | 2,006 | 2,463 |
| New Brunswick | 2,932* | 4,535 |
| Quebec | 2,508* | 41,018 |
| Ontario | 11,414* | 32,166 |
| Manitoba | 494 | 5,627 |
| Saskatchewan | 2,853 | 3,879 |
| Alberta | 10,503 | 11,851 |
| British Columbia | 2,223 | 14,832 |
|  | **35,490 MW (28.7%)** | **123,724 MW** |

*Excluding nuclear

As an example of how this strategy could applied, let us consider a low-GHG pan-Canadian transmission and interconnection scenario, as illustrated in Figure 6, and as described below.

**Table 4**
**Candidate Phase-in Hydroelectric and Tidal Generating Stations**

| Province | Site | MW |
|---|---|---|
| Manitoba<br>Potential projects, 4,915 MW | Burntwood River (3 sites) | 680 |
| | Nelson River 6 sites) | 3,990 |
| | Upper Churchill (2 sites) | 245 |
| | Lower Churchill | To be studied |
| Quebec<br>Potential projects, approximately 19,000 MW | Lower North Shore (Romaine, Petit-Mécatina and others) | 4,000 |
| | Secondary Potential (40 to 50 plants of 50 to 100 MW) | 5,000 |
| | James Bay (Great Whale and secondary potential) | 5,000 |
| | Nottaway Broadbank (excluding the Rupert which is diverted) | 5,200 |
| | St. Lawrence (Montreal, Beauharnois, others) | 1,000 |
| Newfoundland and Labrador<br>4,000 MW | Lower Churchill (Gull Island. Muskrat Falls, secondary sites) | 4,000 |
| Nova Scotia, 6,700 MW<br>Tidal potential (40% load factor) | Comberland Basin | 1,400 |
| | Cobequid Bay | 5,300 |

**Figure 6**
**Illustrative 735 kV Pan-Canadian Transmission and Interconnection Scenario***

| | | | |
|---|---|---|---|
| **A** | Lower Churchill River – Quebec | 2 lines | 1,100 km |
| **B** | Quebec – Fredericton | 2 lines | 1,000 km |
| **C** | Lower Churchill River – St John's | 1 line | 900 km |
| **D** | Fredericton – Halifax | 1 line | 700 km |
| **E** | Nelson River – Winnipeg | 3 lines | 800 km |
| **F** | Winnipeg – Regina – Saskatoon – Edmonton – Langdon | 1 line | 1,600 km |
| **G** | Winnipeg – Sudbury – Toronto | 1 line | 1,700 km |
| **H** | James Bay – Sudbury – Toronto | 2 lines | 1,400 km |
| **J** | Baie Comeau – Montréal – Toronto | 1 line | 1,200 km |
| **K** | Montréal – Ottawa – Toronto | 1 line | 500 km |
| **L** | Edmonton – Calgary – Vancouver | 1 line | 1,000 km |
| | | | Total: 17,000 km |

All km values approximate

The following comments highlight this scenario:

1. **Objective:** To reduce Canada's carbon footprint by means of an illustrative pan-Canadian transmission and interconnection scenario.
2. **Economic Driver:** The economic driver is the replacement of fossil fuel thermal generation located in Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba and Saskatchewan as they approach the end of their normal operating life time. Some of these can be retained as backup and peak power plants. The hydroelectric and tidal power plants identified in Table 4 are brought on-line as selected thermal power plants are phased out. The phased-in hydro and tidal power is delivered to appropriate provincial grids by means of a transmission and interconnection network such as that of Figure 6. Each provincial grid aiming to phase out fossil fuel thermal power plants delivers this low-GHG power to its respective distribution networks through appropriately strengthened existing transmission networks. Phase-out of targeted thermal power stations occurs over decades with the concurrent planning, construction, commissioning and phase-in of targeted hydroelectric and tidal power stations. Operators of the fossil fuel power plants slated for phase-out could be investors in the proposed hydroelectric or tidal power plants and their attendant transmission and interconnection infrastructure.
3. **Illustrative Network Scenario:** As an example of how the above provincial networks incorporating thermal power plants could phase-in power from the distant hydro and tidal sites of Table 4, and for purposes of preliminary cost estimation, a 735 kV transmission infrastructure is shown in Figure 6. The number of 735 kV transmission lines exiting the phased-in power stations of Table 4 is obtained on the basis of approximately 2,000 MVA per line, and the total number of lines is suitable for transmitting the output of each power station. The number of the transmission lines entering each provincial grid corresponds to the total thermal generating capacity needing to be replaced by low-GHG hydroelectric power plants. The illustrated network stretches through Alberta along two corridors: the first links up with Alberta's Langdon-Cranbrook 500 kV interconnection with British Columbia, and the second stretches through BC up to Vancouver, offering the opportunity of replacing approximately 2 GW of thermal generating capacity in Alberta from hydroelectric developments in either British Columbia or Manitoba. If Alberta's entire fleet of thermal power plants (i.e., more than 10 GW) was phased out in coming decades as appropriate hydroelectric capacity was phased in from Northern Alberta, the Yukon or the Northwest Territories (see Chapter 4), this network would need significant redesign.
4. **Illustrative Construction Scenario:** The network of Figure 6 can be constructed within 17 years at a rate of ~1,000 km of line per year. Though a thorough study of different transmission alternatives is advisable due to evolving technology, 735 kV transmission technology, pioneered in Canada, has demonstrated remarkable economic and reliability performance over the past 45 years, similarly to its close cousin, the U.S. 765 kV voltage class technology. Over 11,000 km of 735 kV transmission exists today in Quebec, and costs can be estimated with a high degree of confidence. In 1987, Canada's Engineering Centennial year, 735 kV transmission was celebrated as one of the ten greatest Canadian engineering feats of the preceding century.
5. **Additional Advantages:** The illustrative network scenario of Figure 6 does two things: it interconnects all provinces, and provides an incentive for provincial networks to strengthen their existing networks (through compensation and other strategies) to facilitate the flow of solar and

wind power across provincial boundaries, or through the existing or proposed interconnections of Figure 3.

6. **Possible Extension:** An additional 3,000 km of lines could connect the Athabasca oil sands to this network at Fort McMurray, contributing to further reductions of GHG, if oil sands recovery and upgrading processes were electrified to a higher degree than they are today.
7. **Preliminary Cost of Hydroelectric and Tidal Developments:** Estimating the construction costs of 35 GW of hydroelectric and tidal power stations at approximately 1.5 B$/GW, this represents an investment of $52.5 billion in low-GHG generating facilities. These construction costs would be distributed over two decades.
8. **Preliminary Cost of Transmission and Interconnection Infrastructure:** The cost of 17,000 km of transmission and interconnection infrastructure at 1.5 M$/km, excluding switching stations and compensation equipment, represents an estimated investment of $25.5 billion. This amounts to constructing a 735 kV transmission system only slightly larger than that of Hydro-Quebec's existing system. These costs would also be distributed over two decades.
9. **Preliminary Cost of Switching and Compensation Equipment:** The cost of switching stations and compensation equipment is estimated to be approximately the same cost as that of the line infrastructure, i.e. $25.5 billion, again distributed over two decades.
10. **Preliminary Cost of Project:** A pre-feasibility cost estimate of this project is approximately $104 billion, spread over a construction and commissioning period of approximately 20 years.
11. **GHG Reduction:** The replacement of the fossil fuel thermal power plants by hydroelectric and tidal power plants—as described in item 2 above—eliminates more than 80 million tons/yr of GHG emissions in Canada, approximately six times the GHG emissions of the oil sands transformation industry, representing approximately 12% of all GHG emissions in Canada.

This scenario proposes an economically sound strategy for addressing the need for reducing Canada's GHG production. What clearly emerges is that the high-power generation and transmission technologies needed to implement the proposed power stations, transmission infrastructure and compensation, are available today. Construction and equipment costs can appropriately be staggered to ensure a timely return on investment from the moment individual units are commissioned.

Existing system control and telecommunications technologies ensuring real time adequacy, security, reliability, generation pricing and economic dispatching may need to be enhanced to cover multiple systems and time zones on a continental scale. Even so, this project is very much within the range of current power technology, and represents a modest scale-up of past Canadian achievements in the electricity industry.

An interconnected Canada would not need to rely exclusively on energy storage for leveraging intermittent renewable electric power, as surplus power could be transferred more easily from one region to where it is needed, with appropriate system controls in place. Also, a more tightly coupled grid would likely contribute to increased voltage and angular stability, thus reducing the probability of blackouts and their attendant costs to the economy[11]. Finally, considering that hydroelectricity in Canada has historically been less expensive than electricity from other sources, this strategy may contribute to curbing the growth of electricity rates across the nation.

The main obstacle remains the political will to commit to such an objective, and then to craft a workable financial architecture and business model which spreads both risk and return on investment among all stakeholders. The Strengths, Weaknesses, Opportunities and Threats (i.e., SWOT) analysis of Table 5 summarizes these observations.

**Table 5**
**SWOT Analysis of the Proposed 735 kV Pan-Canadian Transmission and Interconnection Scenario**

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| • Facilitates the phase-out of high-GHG thermal power plants<br>• Facilitates the phase-in of low-GHG distant hydro and tidal power sites to provincial grids<br>• Facilitates the flow of other low-GHG renewable power to electricity markets<br>• Facilitates the flow of low-GHG power across time zones<br>• Employs proven high-power generation and transmission technologies, with known costs and performance characteristics, relatively low implementation risks, and predictable project management timelines<br>• Reduces Canada's GHG emissions significantly | • High cost of project: approximately $104 billion over 20 years<br>• Buy-in of Canadian government and all Canadian provinces not yet secured<br>• Cooperation among all provincial electricity players not yet secured<br>• Financial architecture and business model which spreads both risk and return on investment among all stakeholders to be determined<br>• Additional transmission technologies may be required in view of system requirements, provincial conditions and economic opportunities (e.g., high-voltage direct current transmission, "back-to-back" interconnections, etc.) | • Reduces the growth of long-term electricity rates across Canada<br>• Pioneers the development of new control and telecommunications technologies for continental power grids<br>• Markets the technologies for continental power grids<br>• Enables U.S. power flows across state boundaries through Canada<br>• Facilitates development of other northern, isolated hydroelectric sites in provinces and territories | • The lack of a national energy framework or policy to guide large projects in the electricity sector for Canada<br>• The lack of buy-in of all Canadian governments, both federal, provincial and territorial<br>• The continued interest of U.S. utilities to work on the feasibility of their own continental grid |

## Conclusion

As evidenced in this chapter, power system technologies have now achieved the level of technical and economic maturity permitting the design and implementation of continental power systems. This chapter, which updates previously published work by the Canadian Academy of Engineering's Energy Pathways Task Force[12], shows that the implementation of a Canadian continental power system would permit low-GHG hydroelectric and tidal power to replace high-GHG electricity generation in many parts of Canada and contribute significantly to reducing Canada's carbon footprint. Improved provincial interconnectivity would also allow the large hour by hour load variation across the country to be met without each region having to build full peak load capacity. Other advantages include facilitating the transfer of power of wind and solar electric power between provinces, enhancing energy storage capability, reducing energy costs by the receiving province(s), and opening new markets for stranded power generation.

This project's main obstacle remains the national will to make the first step on the road to a significant reduction of Canada's GHG footprint. This first step requires the commitment to replacing aged, high-GHG fossil fuel power plants by new, low-GHG hydroelectric and tidal power plants. This first step then takes Canadians on a journey to constructing the world's first continental power system.

**Pine Falls, Manitoba**

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# 6

# Nuclear Energy

John Stewart

## ABSTRACT

In its first fifty years, Canada's development of nuclear technology was dominated by a few publicly owned companies and by 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/irradiation, energy supply, uranium mining, materials science) and the science and technology networks that support them.

The largest of these clusters—energy supply—offers the world considerable potential as a way to reduce greenhouse gas emissions, and as a source of industrial process heat. These two opportunities would complement each other in Canada if nuclear technology were applied 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 process would ultimately require a technology development initiative of the type and scope that made the oil sands an economically viable resource decades ago. Such a process requires visionaries, public-private collaborations, 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 successful energy technology developments.

## The Opportunity

Chapters 3 and 7 indicate that Western Canada's oil sands resource consists of approximately 1.6 trillion barrels of bitumen, of which over 300 billion barrels are expected to be recoverable. This is more than the estimated reserves of oil in Saudi Arabia. When upgraded, this bitumen is a successful replacement for conventional crude oil; it can also be a major source of feedstock for producing chemicals and lubricants.

Capturing more of the value of this resource within the Canadian economy is of great interest to many in policy circles. So would the recovery of bitumen in ways that mitigate greenhouse gas emissions and conserve cleaner fossil fuels. Among the options for the latter would be to apply nuclear power in place of natural gas to generate the heat needed for bitumen recovery.

There are diverse examples of nuclear energy being used for process heat applications such as smelting minerals, desalinating seawater, and heating buildings in addition to electricity generation. Presently, innovators in the oil sands industry are occupied with closer-to-deployment technical advances, and there is currently little of the nuclear reactor industry supply chain available in Western Canada. Even so, there are various new nuclear reactor technologies available or on the horizon (e.g., Generation III and IV reactors, small modular reactors and others) that promise to make nuclear power options even safer and more versatile than they currently are, as well as easier to finance.

**Four Reactor CANDU Darlington Plant, Ontario Power Generation**

## The Champions and Visionaries

The development of the oil sands has not been easy. The sector has repeatedly faced difficult technical and economic challenges. Each time, visionaries have taken the industry to a new level of performance. While private industry was the main driver and investor, public sector actors played a significant role, notably the Alberta Research Council and the Alberta Oil Sands Technology and Research Authority (AOSTRA – 1974-2000). Backed by industry consensus and assisted by economic policy through such measures as royalty and tax adjustments, these public sector champions enabled the development of the oil industry that Canada has today – our largest export earner and a huge wealth generator for the private and public sectors. Those champions and visionaries were the source of decisive nation-building industry growth.

**W.B. Lewis**

In addition to its bitumen reserves, western Canada also has large and rich uranium deposits. Canada was a participant in Allied nuclear research projects during the Second World War, and nuclear technology's development in Canada from the 1940s until the 1990s was dominated by collaboration among a few publicly owned "champion" players (i.e., Eldorado, Atomic Energy of Canada Ltd or AECL, Ontario Hydro), and by a visionary physicist, W.B. Lewis (1908-1987).

W. B. Lewis was recruited to direct Canada's National Research Council Atomic Energy Laboratory in 1946.

Convinced that nuclear energy could be used economically for generating electricity, Lewis fostered collaboration between two Crown corporations, Atomic Energy of Canada Limited (AECL) and Ontario Hydro that led to the development of the CANDU, an all-Canadian nuclear power reactor system. Lewis was at the centre of all major planning and decisions for the project, from the conceptual phase, through proposal developments and construction, to the successful commercialization of the reactor in Canada as well as its export abroad.

Responding to the energy cost shocks of the 1970s, Lewis argued that the energy that could be harnessed from nuclear fission was enough to sustain the energy needs of the world's population for thousands of centuries. In 1981, Dr. Lewis was awarded the Fermi Award for outstanding lifetime contributions to energy science research.

## Power Generation

CANDU's application to commercial power generation, beginning in 1962, and now five decades old, has been characterized by excellent engineering and safety, and high reliability in operation, producing affordable base-load power that currently meets over 15% of Canada's electricity demand and more than half of Ontario's. Considering that it has been developed and marketed independently by a small country and only for civilian uses, the fact that the CANDU design has been sold in six other countries against substantial U.S., Japanese and European competition is a remarkable technological and commercial success story. Twenty-nine commercial CANDU reactors have been built, and CANDU remains a successful and viable set of designs. They are now being marketed in the form of the Enhanced CANDU 6 (EC6) and the somewhat larger Advanced CANDU Reactor (ACR-1000).

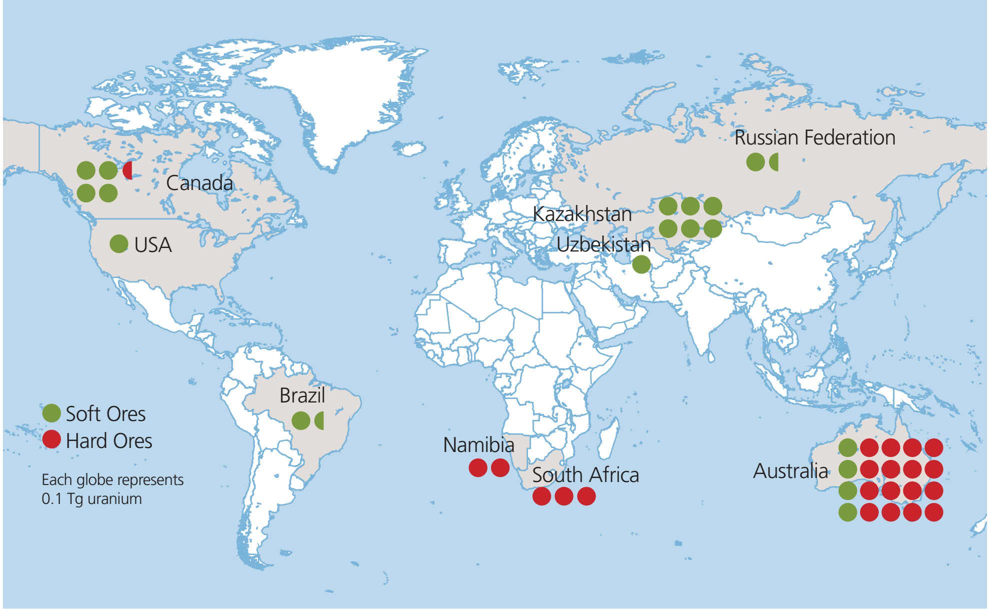
Nuclear generating plants currently produce more than half of Ontario's electricity, and the provincial government's Long-Term Energy Plan anticipates that this role for nuclear will be maintained over the next twenty years. Currently, the Plan calls for addition of two new units at the Darlington Nuclear Generating Station east of Toronto, and for the mid-life refurbishment of ten existing reactors in Ontario. CANDU units are also installed in New Brunswick (where a mid-life refurbishment is nearing completion) and in Quebec (where a refurbishment decision is due in the near future).

Refurbishing CANDUs at mid-life is popular among utilities that operate the units, as it is a minimal-carbon-emissions option that generates large numbers of highly skilled, highly paid jobs for several years. Independent research shows that refurbishing these nuclear units is one of the most effective ways to use public dollars to reduce carbon emissions, maintain generating capacity, and create jobs.[1] The refurbishment option further improves the economics of the CANDU reactor technology, by spreading capital and financing costs of the original build over two or three additional decades of plant life.

## Fuel Supply and Options

Canada has large deposits of uranium, particularly in northern Saskatchewan, and is the second largest uranium producer and exporter after Kazakhstan as shown in Figure 1. Uranium mining creates about 5,000 jobs in Canada. In Saskatchewan, the uranium mining industry is the leading employer of aboriginal people, and in 2010 it generated nearly $150 million in taxes and royalty revenues for the provincial government.

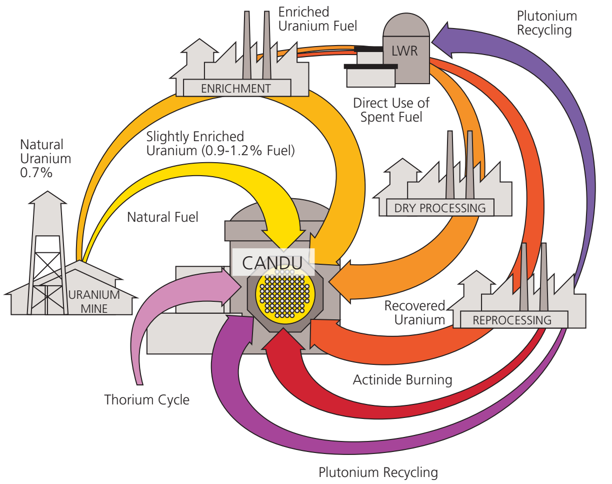
**Figure 1**
**Canada's uranium resources in global perspective**[2]



Approximately 85% of Canada's uranium yield is exported, chiefly to the United States, the European Union and Japan, generating hundreds of millions of dollars annually in revenue.

CANDU reactors burn natural grade uranium fuel, so enrichment facilities are not required for nuclear power generation in Canada. Canada's uranium refining facility in Blind River, Ontario, owned and operated by Cameco, is the largest such facility in the world. Cameco also owns and operates Canada's uranium conversion facility in Port Hope, Ontario. Fuel bundles for CANDU reactors are manufactured in Port Hope and Peterborough, Ontario and exported to the CANDU fleet worldwide.

**Figure 2**
**The CANDU Reactor Technology Supports Diverse Possible Fuel Cycles – with Natural Grade Uranium Fuel Currently Being the Norm**[3]



# Spent Fuel Management

The price paid for nuclear-generated power in Ontario includes a provision to cover the cost of spent fuel management and plant decommissioning. After half a century of using nuclear energy in Canada, the total amount of used nuclear fuel in this country could be stacked to fill one soccer field to the height of an average adult.

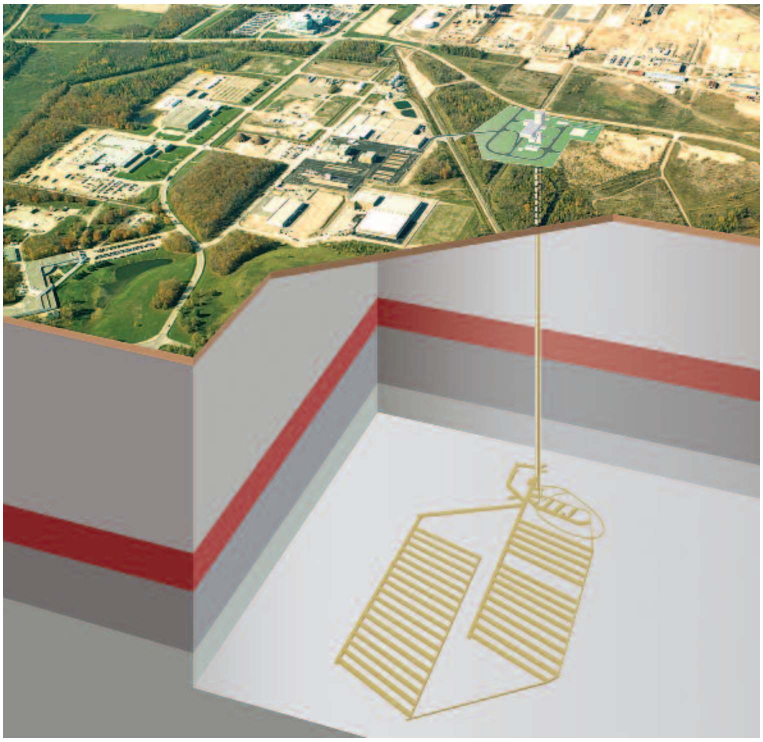
Canada's used nuclear fuel is managed at licensed interim storage facilities at nuclear generation facilities. After being removed from the reactor, used nuclear fuel is stored in water-filled pools for 7 to 10 years, giving it time to cool down and reduce its radioactivity. The fuel bundles are then put into "dry storage," large concrete containers that protect the bundles, prevent radiation from escaping, and continue the cooling process.

Security measures ensure that there is no threat to public health from stored used fuel, and no member of the Canadian public has been harmed as a result of radiation from used fuel or from nuclear power facilities.

Storage is managed by the utilities that own the fuel, and monitored, regulated and licensed by the Canadian Nuclear Safety Commission in direct cooperation with the International Atomic Energy Agency. In the future, most of this used fuel could be reprocessed to make new nuclear fuel, reducing the amount of final waste to a small fraction of the current volume.

In 2002, the Nuclear Waste Management Organization (NWMO) was established to consult with Canadians on a management approach for the long-term care of Canada's used nuclear fuel. In 2007, the Government of Canada accepted the NWMO's recommendation for an Adaptive Phased Management approach, a long-term plan that is now being implemented by the NWMO.

**Figure 3**
**An Artist's Rendering of NWMO's Proposed Deep Geological Repository (DGR) Project**[4]



Part of NWMO's plan will be a Deep Geological Repository (DGR) project. This involves the construction of a deep geological repository and a national centre of expertise in an informed and willing host community. Several communities in Saskatchewan and Ontario have expressed interest in hosting this long-term asset.

## The New Structure of Canada's Nuclear Industry

In recent years the landscape in Canada's nuclear industry has evolved significantly, as a number of new and newly privatized players have emerged from the fertile environment fostered by the early partnership of Crown corporations:

- Former federally-owned uranium mining firm Eldorado Nuclear was folded into a new firm, Cameco, that now has multinational operations. Uranium mining has become a large and dynamic part of Canada's mining scene as well as a major employer of aboriginal workers.
- The businesses now known as Nordion and Best Theratronics were privatized out of AECL in 1991 and 1998 respectively. They now form the heart of Canada's globally successful nuclear health and medical industry.
- After building three major nuclear generating stations from the 1960s to the 1990's, Ontario Hydro's power generating operations became Ontario Power Generation, and a new entity, Bruce Power Limited Partnership, became the licensed operator of the eight-reactor Bruce nuclear power plant in 2001.
- In 2011, AECL's commercial reactor division was acquired by Candu Energy Inc, a wholly owned subsidiary of SNC-Lavalin.

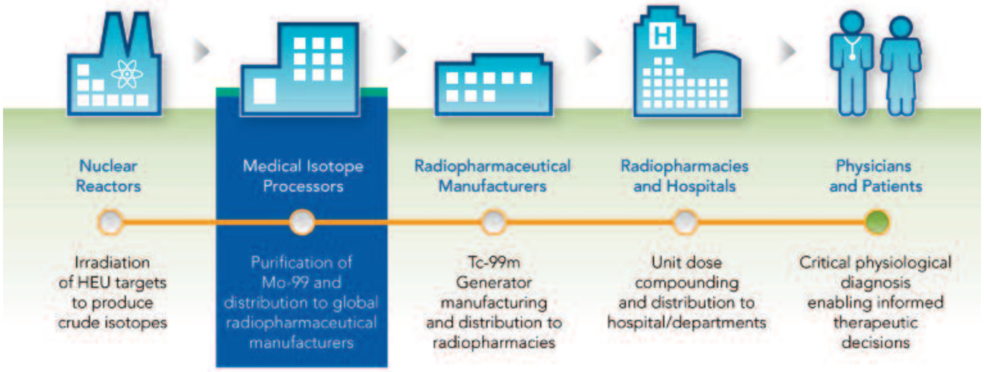
As a result of this evolution, the Canadian nuclear industry is greatly different from a few decades ago, with significant private sector investment.

## Benefits to Canadians of Nuclear Technologies

Uranium mining and power generation from nuclear reactors have delivered great benefits over the past several decades in the form of large amounts of clean, minimal-emission power and highly paid, highly skilled jobs. At the same time, there are various other, non-energy ways that nuclear technologies deliver benefits to Canadians as shown in Figure 4. All of these technologies share a common ecosystem of scientific and technological facilities, tools and expertise in many locations across Canada.

Radioactive isotopes are used to diagnose cancerous tumours and other medical conditions. Targeted radiation therapy is used to cure many of these conditions. Irradiation systems improve food safety, and sterilize bandages and many other medical products and devices. These processes and devices, many of them pioneered in Canada, bring immense benefits not just to Canadians but worldwide, by lengthening lives and reducing food-related illnesses and infections.

**Figure 4**
**Canadians Continue to Lead in the Development of Nuclear Medicine, with Worldwide Benefits[5]**



The science and technology ecosystem fostered by nuclear industries is Canada-wide and contributes to the capacities of Canada's innovation system as a whole, and thus to the productivity and standard of living of all Canadians. It includes the TRIUMF particle research facility in Vancouver, Canadian Light Source in Saskatoon, McMaster University's nuclear engineering establishment in Hamilton, the University of Ontario Institute of Technology's (UOIT) recently inaugurated Energy Systems and Nuclear Science Research Centre, AECL's Nuclear Laboratories, and a network of over 30 other universities and institutes.

While this nuclear science and technology learning and research infrastructure supports the continued safe and efficient operation of the existing nuclear reactor fleet and the ongoing development of highly skilled human capital, it also serves many other functions, including providing an indispensable knowledge resource to the nuclear regulator (i.e., the Canadian Nuclear Safety Commission) and to the Canadian government's competence and credibility on international nuclear issues. The regulator and the government have very limited in-house scientific resources. They need recourse to expertise in other Canadian organizations so that they can regulate confidently and fulfil the public policymaking mission.

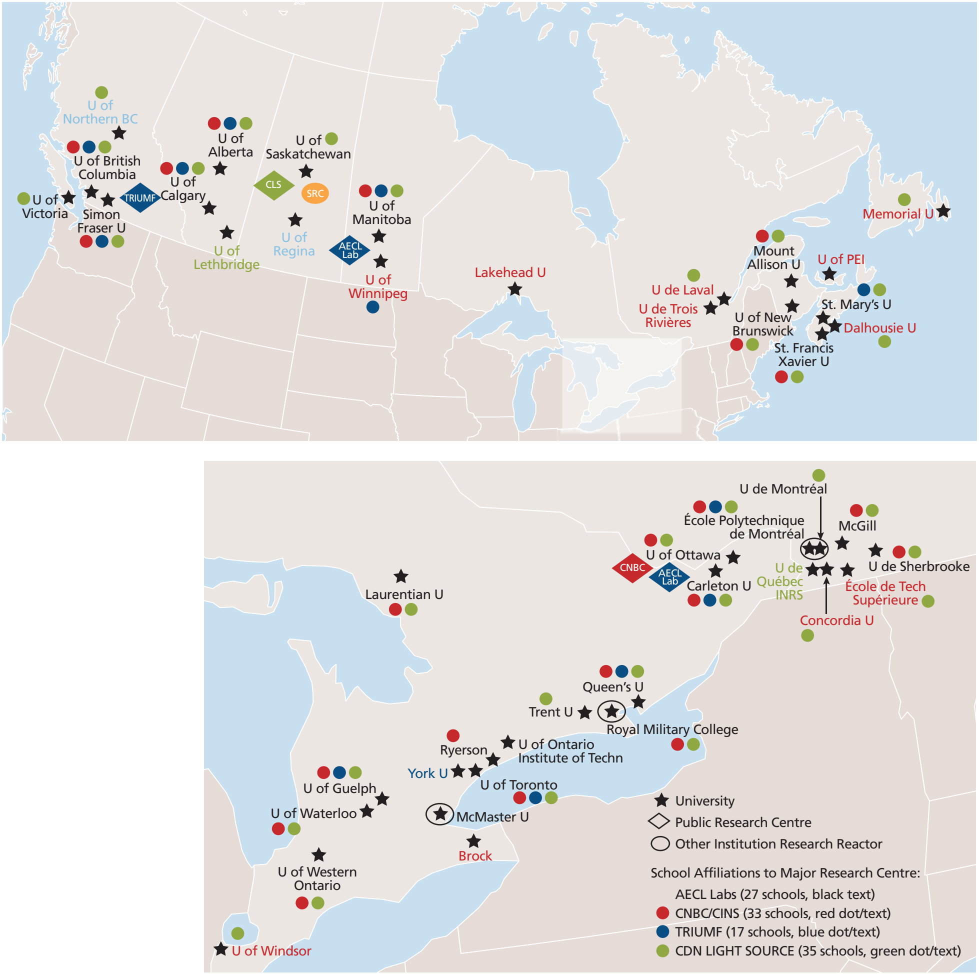


**Figure 5**
**The Publicly Funded Side of Canada's Nuclear Science and Technology Ecosystem (Private Facilities are not Shown)[6]**

Nuclear science and technology supports innovation in the whole economy, particularly through materials science. Neutron beam testing, which can only be done with major research infrastructure, allows testing of parts and materials made of innovative alloys and composites that are essential in most advanced manufacturing.

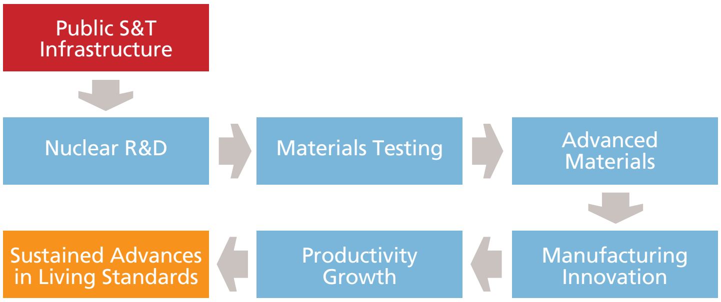
The National Research Council's Canadian Neutron Beam Centre at Chalk River, Ontario and the Canadian Light Source in Saskatoon are essential elements of a complementary suite of facilities needed for materials research.

In aerospace, where it is critical to find the proper balance between weight and reliability, the NRC's Canadian Neutron Beam Centre at Chalk River has used neutrons to probe materials to examine residual stresses in components from all over the aircraft structure: turbine discs, compressors and spools, landing gear, airframe structural components, hull skins, rivets, and fasteners.

Nuclear science also allows study of the crystal structures of new materials for such purposes as lithium-ion battery improvements, hydrogen-storage and fuel cells, and coatings for medical implants.

Other examples of industries that deal with advanced materials, and benefit from access to neutron beams in Canada, include pharmaceuticals and medical devices, environmental technologies, automotive fuel producers, producers of metals, composites and plastics, advanced electronics, food processing, electric power distribution, advanced polymer producers, oil recovery, paint and adhesives, and coatings for hardening of tools.

**Figure 6**
**How Nuclear Science and Technology Connects to Canadians' Standards of Living[7]**



Since advanced materials are essential in modern manufacturing, and since manufacturing is the source of much productivity growth, having these capabilities in Canada directly supports advances in national productivity and in the standard of living of Canadian families.

These capabilities depend to a significant degree on public funding of research and development infrastructure —specialized facilities, tools, instruments, and highly qualified personnel that are accessible by users in industry, government and academia. Public funding is required for these facilities because, while this infrastructure is of high value to the economy, and private industry will pay for access to it, there is little evidence that private industry anywhere in the world will build it independently. Such infrastructure is clearly a public good.

## The Nuclear Industry and its Impact on Canada's Economy, Reputation and International Influence

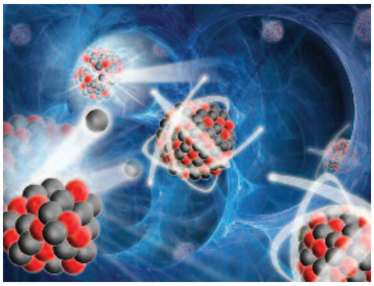
There are both obvious and less obvious ways in which civilian nuclear technology translates into increased economic strength for Canada, and the growth of its reputation and influence abroad.

The obvious ways are mainly through foreign transactions. First, there are exports that are directly related to nuclear. Canada sells reactor designs, uranium, isotopes, and other goods and services to non-Canadians. Uranium and radioisotopes were worth over C$2 billion in export revenue to Canada in 2010. Being a supplier of choice in these areas directly strengthens Canada's ability to negotiate when it pursues a variety of international objectives.[8]

Second, there is the diplomacy directly related to nuclear issues. The Canadian Government's representatives are better able to protect the interests of Canadians and others in talks on international nuclear safety and non-proliferation when they have access to Canada's own nuclear science and technology expertise.

While such "transactions and diplomacy" effects contribute to the growth of Canada's gross domestic product in parallel with its credibility, reputation and influence in international affairs, there are less obvious, but equally high impact ways in which Canada is strengthened through a strong nuclear industry. This involves its ability to add value to other sectors of the economy as in the following examples:

- Canada's electric power supply, particularly in Ontario (where nuclear provides more than half of all power), is affordable, reliable, and clean because of nuclear. Because all sectors use electric power, this strengthens the entire economy and contributes to a lower-GHG-emitting energy system. As a result, energy-consuming industries such as auto manufacturers are more willing to locate in Canada because we make use of nuclear power. If it becomes more costly to emit greenhouse gases – for example, as a result of carbon pricing initiatives by government – this effect grows.
- Progressive changes in technology (e.g., wind and solar generation feeding back into the grid, or the widespread adoption of electric vehicles) are easier to implement in an economy with reliable, affordable base-load power. This in turn improves innovative capacity in our energy system. New energy sources cannot exist in a vacuum; they are best accommodated within a balanced, diverse supply mix that provides reliable, affordable base-load electricity to complement intermittent sources such as wind and solar.



- Nuclear technology's contribution to materials science, and thus to advanced design and manufacturing capacity (as described in the previous section). This is another non-obvious but pervasive way in which nuclear technology strengthens the economy as a whole. While it now employs far fewer workers than the service sector, manufacturing continues to be the key source of innovation, growth, and productivity advances in modern economies. Without advanced design and manufacturing capabilities, Canadians must resign themselves to slower growth and lower living standards.

These points are, in effect, arguments for maintaining and growing the role of nuclear energy, science and technology in Canada's economy. Doing so builds strengths that are already present while contributing to international influence, energy security, innovation and economic growth.

What yet-to-be-deployed uses of nuclear technology would add to these national strengths, or build new ones?

In Canada's case, there is an often-mentioned, but insufficiently championed answer: using nuclear energy in new ways, to provide low-carbon energy for applications such as natural resource extraction, and heating and powering remote communities that currently rely on burning fossil fuels.

# The Vision and the Opportunity

As noted in Chapter 7 where the opportunity of further developing Alberta's oil sands resource is addressed, Alberta already has a long tradition of visioning and public-championing a far-from-deployment energy technology. Bringing the oil sands to large-scale commercial operation required decades of effort, with active involvement from both business visionaries and the provincial government, and that experience is still part of the province's collective, living memory. While it is less clear whether there are sufficiently large players with the patience and the risk appetite to do something similar in the nuclear power area, this idea has tentatively been investigated over the years. Carbon mitigation was a major driver for these investigations. So was the fact that fuel cost is a very small percentage of nuclear power costs, but a very high percentage of gas-fired power costs, making nuclear energy investments an effective hedge against future increases in fossil fuel prices, as well as against the prospective cost of GHG emissions.

While there is room for more detailed investigation, currently deployed reactor designs would face a number of challenges in their application to bitumen recovery in the oil sands. They require large, permanent installations with large support staffs, and need to be shut down periodically for maintenance and/or refueling. There are also questions about whether the steam they produce would be of adequate temperature and pressure for oil sands operations (where steam would need to be piped some distance to the oil sand deposits). Even with these challenges, a 2003 study suggests that conventional nuclear technology would be approximately competitive with natural gas.[9]

Newer reactor designs such as the Enhanced CANDU 6, the Advanced CANDU Reactor (ACR-1000), and other so-called Generation 3 and 4 reactors, some of which are close to deployment but have not yet established multi-year track records in operation, are expected to advance the safety and economics of nuclear energy. Also, several small modular reactor (SMR) designs are being promoted—in varying degrees of proximity to deployment—with promises of further reductions in the financing, building and maintenance costs of nuclear energy and its applicability to non-power uses. These promised advances are mainly based on SMRs' portability, modularity, steam characteristics, and maintenance needs.

With a number of newer reactor technologies now undergoing "pre-licensing vendor design reviews" with the primary regulator (the Canadian Nuclear Safety Commission), the menu of options for using reactors in an application like the oil sands has grown significantly. As a result there is considerably more scope than there was in 2003 for a serious, objective evaluation of the possibilities. The purpose of such an evaluation would be, not the actual implementation of any technology, but rather to identify feasible technologies and increase the degree of certainty around

**CANDU 6 Schematic[10]**

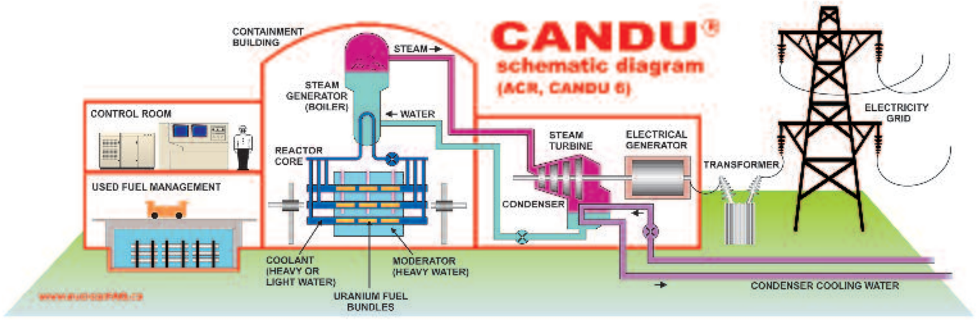


**Table 1**
**Possible Suitability of Small Modular Reactor (SMR) Designs for Bitumen Extraction from Oil Sands**[11]

| | |
|---|---|
| **Design and construction:** | Modular design, assembled and fuelled in a factory environment |
| | Transported to site by rail, barge, or large truck |
| | Integral design needs less supporting infrastructure |
| **Operations:** | Runs without refueling for approx. 10-year life of a Steam-Assisted Gravity Drainage (SAGD) field |
| | Appropriate temperature and pressure for SAGD oil sands extraction from small fields |
| **Economics:** | Projected to be roughly competitive with gas |
| | Cogeneration of thermal and electrical energy |
| **Mobility and decommissioning:** | Refueling and maintenance occur in controlled, central facility |
| | Transportable to a new location at end of oilfield's life |
| **Environmental:** | No GHG emissions |
| | Site returns to greenfield state within one year of shutdown |

their economics so that—where appropriate—business models could be developed with some confidence.

## Current Attitudes

Alberta's Provincial Energy Strategy[12] recognizes that Canada's main fossil fuel resource-rich province is entering a future where emissions of carbon into the atmosphere will be constrained. It also stresses the role of technology in realizing its vision for the province's energy future, as follows:

- Alberta will be "a global energy leader, recognized as a responsible world-class energy supplier, an energy technology champion, a sophisticated energy consumer, and a solid global environmental citizen."
- Alberta "will continue to reduce greenhouse gas emissions per barrel of production by improving our energy efficiency and by developing new technologies."
- "Alberta's energy future relies heavily on technology" and "we need a clean solution for energy production."

While Albertans, like most Canadians, may be conceptually open to the idea that ambitious technological changes may be needed or warranted, mobilizing actual investment dollars for unproven technologies is much more difficult. So is mobilizing support for the idea that public-private collaborations may be necessary to push those technologies toward commercial deployment.

## Regulatory and Licensing Issues

In addition to the usual work nuclear industry regulators do to anticipate new reactor designs, there is growing work in both Canada and the United States on how to regulate and license small modular reactors. Issues being identified in the U.S. include specifics such as annual fees, siting, staffing, physical security, safeguards, liability insurance, applicability of existing licensing requirements, manufacturing licenses, source term and dose calculations, risk-informed regulation, and decommissioning funding.

**Some Alberta Viewpoints on Applying Nuclear Technology to In Situ Bitumen Extraction**

Paraphrased from CNA interviews, mid-2011

Conversations with a number of industry experts in Alberta in mid-2011 elicited the following views, among others:

"Since we looked at nuclear three to five years ago, we've just been letting the nuclear industry know that there continues to be market demand here. When they advance the technology, we might be interested. It's too far from deployment right now."

"Electrified in situ extraction of bitumen from oil sands could be as little as five years away. If that technology option were realized, the consequent need for electric power would be huge -- but by then the province won't even have enough electricity for residential use, let alone large-scale industrial needs. Nuclear will be the likely option because it's the alternative with no greenhouse gases. But it takes time to develop that option."

"If the economics of nuclear in the oil sands were good, and if that were demonstrated with an actual plant, then public acceptance would tend to follow. The chances are best in a remote location, maybe replacing a 450 MW gas plant somewhere."

"The oil industry is actually quite risk-averse. They need to see a new technology demonstrated before they'll invest in it. They need to see a few years' track record for one of these small reactor designs."

"Coal and gas are abundant and cheap here, at least for now. Those are vested interests with lots of provincial government support. That's why there's so much investment in finding ways to sequester the carbon they produce. Not everybody believes that sequestration is the best answer for all this carbon. But why should the province help nuclear, an outside industry, rather than coal or gas?"

"If the perfect reactor came along today, it would do us no good, since Alberta so far has no provincial policy framework on nuclear."

"The province needs to get involved in preparing for this. The first step could be to inform the conversation by having universities do some more detailed studies."

The issues are similar in Canada. An important and positive difference is that these issues can be addressed within the Canadian regulatory framework without requiring changes in the regulations. The main regulator, the Canadian Nuclear Safety Commission (CNSC), has taken early steps to prepare the groundwork for licensing SMRs, and has stated that they expect that SMRs can be licensed in Canada in significantly less time than would be required in the U.S. The CNSC has even invited suppliers of SMRs to apply for pre-licensing design review, and one of those reviews has begun[13].

The CNSC has indicated that SMRs will be licensed for operation more quickly than larger nuclear plants, i.e. in about six years rather than nine years. This tightening of the timeframe would be mainly achieved by doing the environmental assessment, the site preparation license, and the construction license in parallel.

While there are many uncertainties around the issues that need to be addressed to successfully license an SMR in Canada, this proactive stance by the main regulator is a very positive sign.

## Synergies Among Technologies, and the Case for Public-Private Collaboration

As shown above, the future benefits to Canada of its assets in the nuclear industry need not be tied to one technology used in one application such as electricity generation. Rather, the benefits may lie in developing strength nationally out of the synergies among a set of technology clusters (medical diagnosis/treatment, food safety/sterilization, energy supply, uranium mining, materials science). Having expertise in some of these clusters makes it easier for Canada to be good at the others. And having affordable, reliable energy supply makes all other economic sectors more competitive.

Of the nuclear technology clusters, nuclear energy supply and materials science are the two that most clearly call for some degree of public-sector encouragement. Nuclear as an energy source offers vast potential as a way to reduce greenhouse gas emissions, and as a source of industrial process heat. These two opportunities would complement each other if and when nuclear is applied to in situ bitumen extraction from Western Canada's oil sands—a process that currently uses fossil fuel and that suffers from widespread negative public perceptions as being "dirty." This would strengthen Canada's position as a sustainable energy superpower by conserving natural gas, mitigating the oil sands' carbon emissions, and simultaneously facilitating new economic pathways for bitumen extraction.

This application could require a multi-stakeholder technology development process like those that made the oil sands economically viable in the first place. While a policy environment that puts a price on carbon emissions would be helpful in this and many other dimensions of energy technology development, the application of any nuclear reactor design to the oil sands would still appear unlikely to occur in the next decade without a significant public-private collaboration, driven by an industry consensus to proceed, and supported by long-term backing from a public sector champion.

The public champion is needed to support the assumption of risks that offer long-term payoffs for both Alberta and Canada, and in which individual private firms are willing to participate, but are not ready to accept unassisted. A public champion can succeed where tax credits might fail because the public champion provides a coordinating role and a measure of patience and durability to the long-term effort. This is comparable to the risks that the Alberta Research Council, AOSTRA and others had to take on decades ago—backed by industry consensus and assisted by economic policy through measures such as royalty and tax adjustments—to make the oil sands an economic resource.

## Conclusion

The application of nuclear technology to oil sands bitumen recovery processes will ultimately require a multi-stakeholder technology development initiative of the type and scope which originally made such processes economically viable decades ago. To do so, a significant public-private collaboration is required to explore the technical possibilities and narrow down the range of options for applying nuclear technology to in situ oil sands operations. The benefit of that effort would be to allow the costs of various technical pathways to be determined with greater confidence and enable the nuclear industry to participate fully in making Canada a sustainable energy superpower.

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8. Note: Health applications of nuclear technology have produced major advances in diagnosis (e.g. locating tumours), treatment (radiation therapies), efficient sterilization of bandages and other products, and preventing food-borne illness. These technologies, largely pioneered in Canada, create high-salaried, high-skilled jobs for Canadians, help them to live longer and more productively, and are being disseminated around the world where they can deliver similar benefits to much larger populations. The opportunity to brand these globally as being Canadian technologies could be more fully developed to build Canada's image and goodwill abroad.
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## 7

# Oil Sands of Alberta

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Surindar Singh
Walter Petryschuk

## ABSTRACT

The Alberta oil sands contain at least 1.6 trillion barrels of bitumen, of which 300 billion barrels is expected to be recoverable, larger than the oil reserves in Saudi Arabia. About 10-20% of this is recoverable by surface mining; the balance requires in situ recovery processes. The oil sands have faced major challenges over the past 80 years, and five visionaries stand out as heroic figures who faced and overcame technical, political and economic hurdles at critical periods. The economic impact on Canada has been huge. 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. The economic impact of the oil sands is more than just the 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 both the environment and the need to find economic and societally acceptable sources for the large amounts of hydrogen needed to upgrade the raw bitumen. The industry has made progress in reducing its environmental impact, with significant reductions in fresh water use, and in dramatically reducing the time to restore disturbed lands to close to original conditions. However, industry is falling behind in capturing the full value of the resources; 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 fuel and chemical products, the country will forfeit $60 billion per year in economic activity by the end of this decade. Our future prosperity will be strongly dependent on reversing this trajectory.

# The Opportunity

The Canadian oil sands occur over a 140,000 square kilometre area of Alberta, Canada (Figure 1), covered by overburden ranging in depth from a few metres to 800 metres[1]. About 10 to 20% of the resource can be surface-mined; the balance is too deeply buried and must be recovered by in situ recovery techniques. The oil sands are unique, since there is a film of water between the bitumen and sand particles. Other heavy oil deposits around the world do not have this film of water and are much more difficult to extract as a result. Unlike most paraffinic conventional crude oils, bitumen in the oil sands are naphthenic and amenable to reaction at relatively low temperatures, unlike many heavy tar-like residues throughout the world that have been subjected to severe oxidation processes.

**Figure 1**
**Canadian Oil Sands**

Two geological cross sections are shown in Figure 2, illustrating the location of the oil sands relative to the underlying Devonian carbonate formation[2]. Although the geographic extent of the resource is small, the resource is huge (Table 1), with approximately 1.6 trillion barrels of bitumen in place. Over 300 billion barrels are expected to be recoverable. The latter figure is larger than the estimated reserves in Saudi Arabia[3].

# The Visionaries Behind the Opportunity

The development of the oil sands has not been easy. The sector has faced seemingly insurmountable challenges at five critical junctures: in 1928, 1948, 1967, 1972, and 1975. Each time, visionaries have taken the industry to a new level of performance[4].

The first was Dr. Karl Clark of the Alberta Research Council. By 1928, after many drilling attempts, it became obvious that there was no huge pool of conventional oil underlying the oil sands. This made it clear that the oil sands had to be used as they are – bitumen in a sand/clay matrix. Clark, using equipment that would be considered primitive in today's high tech environment, developed a process to extract bitumen from the sand. He elucidated the process mechanism which has been corroborated many times by future researchers[5]. This Hot Water Extraction (HWE) process is the basis of the current surface-mined processes that are used today. One of his major findings was the effect of pH on the process, as illustrated in Figure 3.

**Figure 2**
**Geological Cross Sections of Oil Sands Deposits**

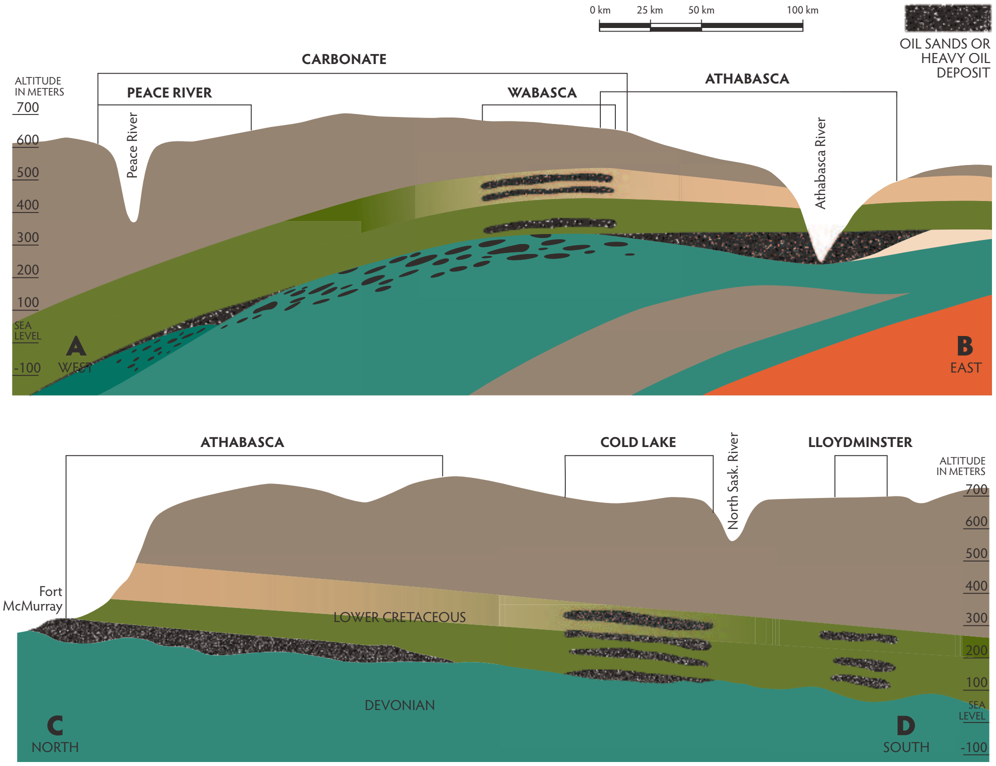
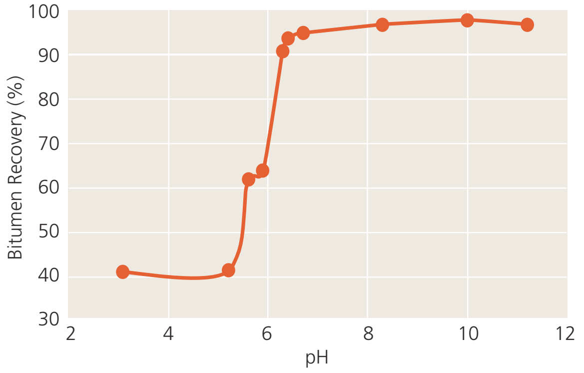


**Table 1**
**Oil Sands Resource**

| | Billion Barrels |
|---|---|
| Total In-Place Resource | 1629 |
| Established Reserves | 175 |
| Ultimate Reserves | 310 |
| Expected Annual Production within 10 Years | 1 |
| Saudi Arabia Reserves (Oil and Gas Journal – January 2006) | 266 |

**Figure 3**
**Effect of pH on Bitumen Recovery**

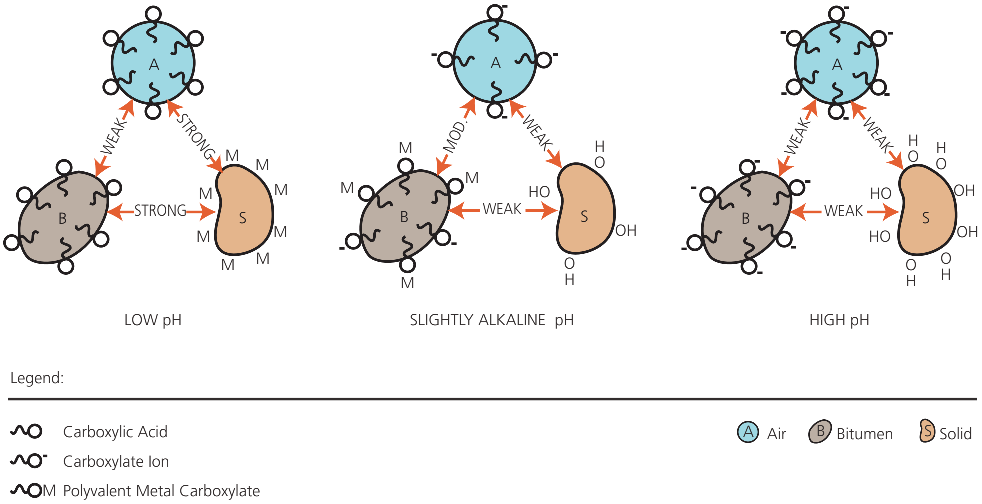


Data extracted from Reference 2

The role of the various ionic species in the interaction of the bitumen, clays and air was the subject of many later investigators, as illustrated in Figure 4.

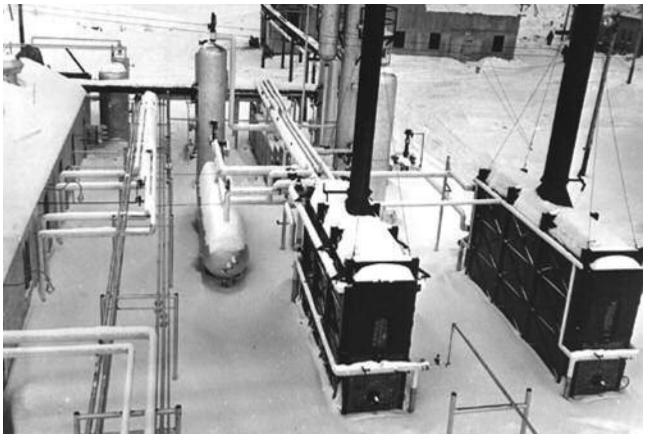
The second visionary was former Alberta Premier, Earnest Manning. By 1948, there had been a pattern of early-decade failed commercial attempts at extracting bitumen, not one of which used Clark's HWE process. Manning knew that the government had to do something to protect the reputation of this major resource. He commissioned a HWE demonstration plant at Bitumount,

**Figure 4**
**The Role of Ionic Species**



80 km north of Fort McMurray. This was a significant initiative for the time – the entire Alberta legislature visited the plant in 1949. An independent evaluation of the project was carried out by Sydney Blair, father of Alberta oil man, Bob Blair. It was an impressive report and is still worth studying. Blair concluded simply that "the oil sands were commercially viable and could compete on the world market". Manning maintained a life-long belief in the importance of the oil sands to Canada.

**Blair Report and the Bitumount Plant**



REPORT

ALBERTA
BITUMINOUS SANDS

S. M. BLAIR

**Oil Sands Surface Mining[25]**

The third visionary was J. Howard Pew, Chairman of the Sun Oil Company. 1967 was another critical period in the oil sands. The Alberta Government confirmed that it would only provide permits for small projects and as result, private support was shaky. Facing serious concerns from Board Members, Pew said, "Gentlemen, either you approve this project or I will handle it myself." Shortly after, the Sun Oil Company filed an application to the Energy Resources Conservation Board for a 31,500 barrels per day (BPD) project, later amended to 45,000 BPD of a sweet Synthetic Crude Oil (SCO). A letter from Pew was read during the government hearing on this project, "I believe in the future of this project and I will put up my money with no reservations if the permit is granted." An astonished attendee at that meeting said that this statement changed the atmosphere at the meeting. It led to the Great Canadian Oil Sands Project, now known as Suncor.

**Syncrude Plant**

The fourth visionary was Frank Spragins, Chairman of Syncrude. In the early 1970s, the second oil sands initiative, Syncrude Canada Limited, was put on hold after losing some of its original sponsors. Spragins was frustrated that world oil prices never caught up to the projected project costs – it always seemed to be a half a dollar or so less than what was required for a viable commercial project (50 cents in today's terms now seems insignificant). Spragins established the first dedicated oil sands research laboratory, remained optimistic and kept anxious participants on board. As a very important contribution, he developed a long-term strategy for upgrading bitumen. He had a huge display board in his office with a plethora of organic and inorganic products that could be derived from the oil sands. The display board no longer exists, but the ideas behind it certainly do.

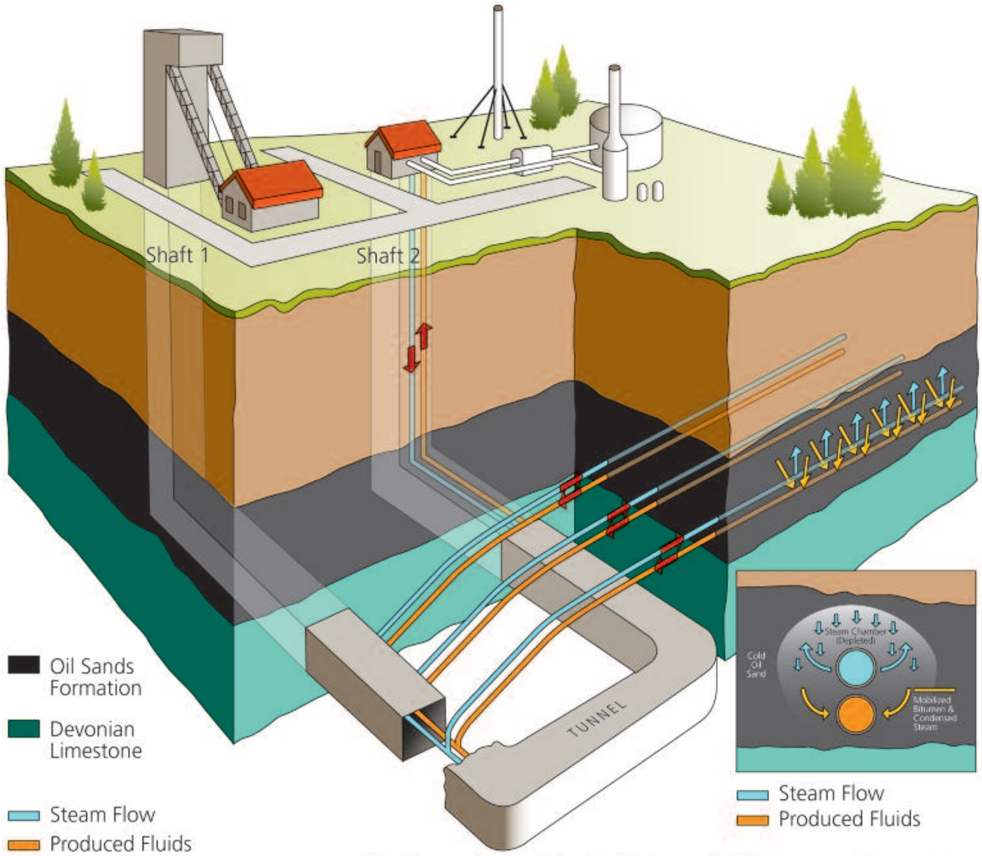
In 1973, Spragin's vision was fulfilled with help from a fifth visionary, Alberta Premier, Peter Lougheed. Lougheed agreed to have the province retain the right to 20% of the venture, secure an 80% equity position in the pipeline from Fort McMurray to Edmonton and 50% ownership of the project's power provider[6]. In addition, Lougheed established that the province should receive 50% of the venture's profit by way of a royalty, instead of a percentage of the production value. Today, Syncrude produces over 300,000 BPD of SCO, and has significant expansion plans.

In the first half of the 1970s, work on bitumen recovery from the deeply buried oil sands had stalled. There was no demonstrated technology available for the Peace River, Wabasca and the deeply buried Athabasca deposits. Imperial Oil was making limited progress in the Cold Lake deposit but in general, there were few multinational oil companies with active lease development plans. The oil companies believed that they had more prospective international opportunities. As a result, under Lougheed's leadership, the Alberta government established the Alberta Oil Sands Technology and Research Authority (AOSTRA) in 1974, with a mandate to develop commercially viable in situ recovery technologies. AOSTRA had a $100 million technology development fund, which grew to a $1 billion public/private sector investment over the next decade (equivalent to $3 billion in today's dollars[7]). This was the signal for multinational oil companies to launch many new demonstration projects in all the oil sand deposits.

AOSTRA was a visionary undertaking, reversing the conventional role that technology developed with public funds should be freely available to the public. Recognizing that freely available technology was of no value to anyone, new technology developed with AOSTRA support was owned by AOSTRA, on behalf of the crown. That technology was made available to all companies for payment of a fee, that fee being essentially what they would have paid to become a member of the group that developed the technology. The majority of AOSTRA projects were co-funded with private sector partners[8].

Drilling horizontal wells from a shaft and tunnel was one project for which industry support was not forthcoming. Industry was skeptical about it being commercially viable but AOSTRA demonstrated the technology in an Underground Test Facility (Figure 5), which led to the development of the Steam-Assisted Gravity Drainage (SAGD) process. SAGD recovers bitumen

**Figure 5**
**Underground Test Facility**



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

that is too deep for surface mining and too shallow for cyclic steam injection. Dr. Roger Butler, at that time working with AOSTRA, developed the concept of a pair of horizontal wells —an upper well to inject steam and a lower well to collect the heated oil draining from the upper steam chamber. This is the general approach that has been used in all subsequent SAGD projects[9]. One of the major ancillary impacts of AOSTRA was a major expansion in Alberta's scientific, engineering and entrepreneurial talent. At the recent Summit of the Americas in Trinidad, the AOSTRA model was proposed for energy development, which went against conventional wisdom of the role of government.

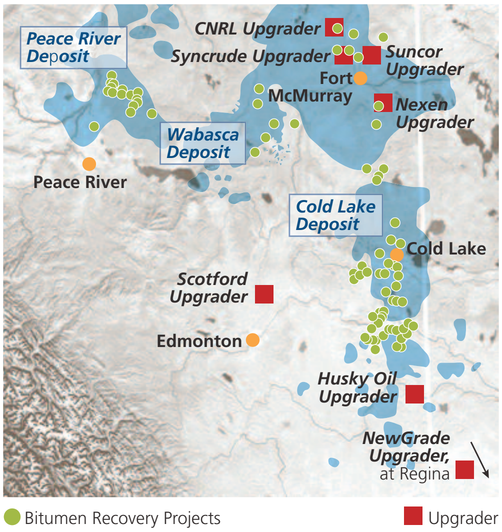
Today, the opportunities are unlimited yet the challenges facing the oil sands sector are significant. Who will be the next visionaries?

## Production

Commercial SCO production from surface-mined oil sands started in 1967 and soon reached 40,000 BPD. By 1985, total SCO production had increased to 165,000 BPD. In 2009, total SCO production was more than 600,000 BPD and bitumen production from surface-mined oil sands was 140,000 BPD. In 2009, total production was 740,000 BPD[10].

In 1967, in situ bitumen production, from experimental schemes and field pilots, was 724 BPD. By 1985, it had increased to 7,800 BPD. After the commercialization of SAGD, production increased sharply. In 2009, in situ bitumen production was 570,000 BPD.

**Figure 6**
**Oil Sands Projects**



In 2009, total SCO and bitumen production from surface-mined and in situ recovery processes was 1.3 million BPD. By 2030, production is projected to be between 3 million BPD and 5 million BPD.

Figure 6 shows the location of about 75 bitumen recovery projects underway in 2010, and the location of six of the seven Canadian upgraders[11]. The production of raw bitumen exceeds the capacity of Canadian upgraders and an increasing percentage of the bitumen is diluted and sent by pipeline to U.S. refineries.

## Economic impact

The capital expenditures on oil sands projects since commercial development began are close to $120 billion and in recent years, new investment has averaged about $15 billion per year (Table 2). The economic impact of the oil sands is more than just the 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 rate of more than $10 billion per year in recent years. The royalties paid to the Alberta government total over $17 billion[12].

The Canadian Energy Research Institute estimates that over the next 25 years, capital investment would be $218 billion, royalties would be $184 billion and revenues would be approximately $736 billion[13].

The early pioneers, during their pursuit of "black gold", could never have anticipated the massive impact of this sector on the Canadian economy. It provides a significant competitive advantage and is an important key to Canada emerging as an energy superpower.

**Table 2**
**Capital Expenditures, Operating Costs and Royalties**

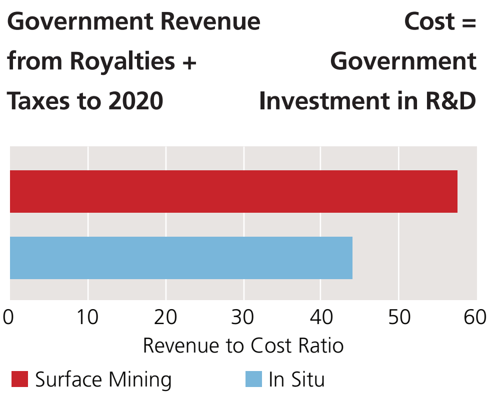
| Year | Capital | Operating | Royalties | Total |
|---|---|---|---|---|
| Pre 1997 | 13,740 | 24,658 | 3,105 | 41,503 |
| 1997 | 1,915 | 1,665 | 270 | 3,849 |
| 1998 | 1,543 | 1,654 | 67 | 3,264 |
| 1999 | 2,372 | 1,784 | 269 | 4,425 |
| 2000 | 4,223 | 2,289 | 816 | 7,328 |
| 2001 | 5,907 | 2,753 | 265 | 8,926 |
| 2002 | 6,751 | 2,557 | 182 | 9,490 |
| 2003 | 5,048 | 3,794 | 274 | 9,117 |
| 2004 | 6,183 | 4,341 | 769 | 11,293 |
| 2005 | 10,437 | 6,305 | 819 | 17,561 |
| 2006 | 14,337 | 8,051 | 2,187 | 24,575 |
| 2007 | 18,065 | 8,135 | 2,716 | 28,916 |
| 2008 | 18,113 | 11,105 | 3,545 | 32,763 |
| 2009 | 11,227 | 11,781 | 2,110 | 25,119 |
| Total | 119,861 | 90,874 | 17,394 | 228,128 |

# Impact on Alberta

An economic analysis of the impact of the oil sands industry by the Canadian Energy Research Institute (CERI) showed that this sector provides benefits across Canada and the United States[14]. The CERI study showed that the cumulative impact for 2000-2020 on Alberta's Gross Domestic Product would be $633 billion. Alberta government revenues would be $44 billion (or 36% of the total government revenues) and the jobs created during this period would be 3.6 million person years (or 56% of the total jobs created).

The Alberta Chamber of Resources (ACR) task force on resource development[15] has noted that the Alberta resource sector in total, in which the oil sands are a major component, are technology intensive and have shaped a thriving knowledge economy in Alberta, which has more than 75,000 professional engineers, geoscientists and technologists – one of the highest per capita concentrations in the world. The "size of the prize" over the next decade is $700 billion in incremental GDP, just under four million person-years of employment and over $110 billion in provincial government revenue. The ACR Task Force also stressed the priority of extending the value-chain to promote economic diversification. The importance of upgrading is discussed further in the last section of this chapter.

**Figure 7**
**Wealth Generating Potential of Oil Sands Innovation**



The wealth generating potential[16] of the oil sands is clearly evident in the growth of Alberta Government revenues compared to government R&D costs, as shown in Figure 7.

On February 28, 2011 the Alberta Minister of Finance, Lloyd Snelgrove, was quoted as saying that Alberta doesn't need to consider a provincial sales tax until oil sands revenues are exhausted, someday far into the future[17].

## Resource Rent Royalty Framework

A royalty system was introduced in 1930, when Alberta first gained ownership of its natural resources. This system has evolved over time, in response to changes in the production and quality of the natural resources, and other factors such as major shifts in oil prices. Different royalty systems were put in place for conventional oil, natural gas and oil sands.

Prior to 1997, individual Crown Agreements establishing royalty terms were separately negotiated with each oil sands project developer. This acknowledged the diverse oil sands reservoir quality and the effort required to recover and upgrade the bitumen. However, it did not provide certainty about the royalty treatment for future projects or ensure a level playing field across all projects.

In 1997, a generic royalty regime was put in place to provide certainty about the royalty treatment and to accelerate the development of new commercial oil sands plants[18]. Under this scheme two royalty rates were set:

- **Before Payout:** A royalty rate of 1% of the project's gross revenue applies before "payout" – before the developer has made profit equal to the capital invested in the project, plus an allowance equal to the long-term government bond interest rate, to recognize financing costs during the construction period.

- **After Payout:** The royalty rate after payout would be the greater of:
  – 25% of the project's net revenue (gross revenue minus allowable costs); or
  – 1% of the project's gross revenue.

In September 2007, the final report of the Alberta Royalty Review panel recommended a new generic royalty regime, based on the principle that royalty rates should vary with the bitumen prices. In January 2009, the Alberta government introduced a new royalty framework[19], under which the royalty rates are dependent on the United States West Texas Intermediate (WTI) crude oil price, in Canadian dollars – the higher this price, the higher the royalty rate. As WTI prices escalate from C$55 per barrel to C$120 per barrel:

- **Before Payout:** the royalty rate increases progressively from 1 to 9%

- **After Payout:** the royalty rate increases progressively from 25 to 40%

Therefore, below a WTI price of C$55/barrel, the royalty rates are identical to the previous royalty regime. Above C$120/barrel, the royalty rate is 9% before payout and 40% after payout.

The Alberta government is entitled to take its royalty share of bitumen production-in-kind, as it does currently for conventional oil production[20].

## Economic Impact on Rest of Canada

The CERI study showed that the cumulative impact for 2000-2020 on the Rest of Canada's (i.e., excluding Alberta) Gross Domestic Product would be $155 billion. Federal government revenues would be $51 billion (or 41% of the total government revenues) and the jobs created in the rest of Canada during this period would be 1.8 million person years (or 27% of the total jobs created).

Today, every dollar invested in the oil sands creates about $9 in economic activity – $6 in Alberta and $3 elsewhere in Canada, the United States and around the world. The impact of both the investment and the income associated with people who make the materials, goods, and services used by the oil sands sector generate significant taxes to all government levels in Canada.

These taxes and royalties ultimately support health care, roads, education, arts and culture, and the national infrastructure that underscores Canadian's high quality of life. The economic impact appears to be as enduring as it is far-reaching.

## Economic Impact on United States of America

On February 10, 2011, in a written statement to the U.S. House Committee on Energy and Commerce, Alberta's representative in Washington D.C., Gary Mar, made the following observations[21]:

- Growing oil production in the Western Canadian province of Alberta provides a key alternative to U.S. oil imports from less secure and reliable sources.

- Most of this production growth will come from the ongoing development of oil sands resources. This development offers benefits to the U.S. beyond energy and national security, including economic growth, jobs, and socially and environmentally responsible energy production.
- Canada is already the largest supplier of oil to the U.S., accounting for almost one-quarter of U.S. imports, and expanded production from Alberta's oil sands offers the potential for this proportion to increase.
- American companies are not only major investors in the oil sands, but many U.S. businesses throughout the country benefit from supplying goods and services required for ongoing oil sands operations and expansion.
- Alberta's oil sands industry is one of the most regulated in the world, with strict legislation and standards to protect air, land, water, and wildlife and manage greenhouse gas (GHG) emissions.

Referring to a CERI study[22] Mar stated that, over the next 15 years, oil sands development would boost U.S. Gross Domestic Product by an average of $31 billion per year, creating over 624,000 jobs, with just over half of these jobs being created in the next four years.

The United States is a natural market for Canadian oil, as a result of an extensive and expanding pipeline network. Canada's position as the number one foreign supplier of oil to the United States is often unrecognized. Canada's share of U.S. oil imports rose from 15% in 1998 to 19% in 2008, underscoring the deep economic and trading relationship between the two neighbors, as well as the critical role of energy in that bond. In a high growth scenario the oil sands would supply 37% of U.S. oil imports by 2035—far more than any other foreign supplier. Greater Canadian oil exports to the United States result in fewer imports from elsewhere in the world than would otherwise be the case—shortening supply lines  and ensuring reliability of supply, among other advantages.

## Asian Markets

Although the United States has always been the preferred market for Canadian oil, a 2005 Purvin & Gertz Inc. study[23] for the Alberta government concluded that the Canadian oil sands could become a significant supplier of crudes to the Asian markets. The diesel-rich bitumen components are better aligned with Asian markets, where the bitumen could possibly be sold for higher prices, resulting in better returns for the producers and higher royalties for government.

In recent years, three proposals – Enbridge's "Northern Gateway Pipeline", Kinder Morgan's "Trans Mountain Pipeline" and Canadian National's "Pipeline-On-Rail", have been made for bitumen transportation from Alberta to the West Coast. These systems would open new markets in coastal U.S., as well as overseas. While the Premiers of Alberta, British Columbia and Saskatchewan have recognized the opportunity and support these initiatives, they face strong opposition from environmentalists, fishermen and aboriginal groups. However, it is most likely that such a transportation infrastructure will be initiated during this decade, because of the Asian investment being currently made in the oil sands.

The Japanese have had a stake in the oil sands for several decades and have been involved in developing new recovery technologies. Recently, China, South Korea and Thailand have bought into commercial oil sands projects and other Asian countries are actively pursuing opportunities. As stated in a February 3, 2011 article by Ernst & Young, "Heightened foreign investment in Canada's unconventional oil and gas industry will be driven primarily by Asian markets."

The reasons include volatile and rising oil prices, a stable financial and regulatory environment in Canada, huge reserves, vast expertise and a well-established infrastructure. Another reason is that if the United States and Europe decide to penalize or prevent SCO and bitumen imports (as some have threatened to do), Canada would have to find new markets elsewhere.

Access to Asian markets, however, means that Canada will need to overcome several challenges.

## Environmental Challenges

The oil sands are facing new challenges in the first quarter of the twenty-first century related to the environment and the need for hydrogen. The latter has been produced to date from natural gas, itself a relatively high quality commodity. When the first oil sands mining projects started in the 1970s, air and water were free and the technology decisions at that time reflected this situation. Few had linked global warming to man-made carbon dioxide emissions – and water was in plentiful supply. New technologies are now being developed for reducing the use of water, restoring the landscape scarred from the surface mining of bitumen, and using less energy to force deeply buried bitumen to the surface in what are referred to as in situ processes. The deeply buried deposit now uses technology (SAGD) which has a much lower land and water disturbance and that technology is being progressively improved over time. Technology for capturing and storing the carbon dioxide in underground formations is also being actively pursued.

### Tailings Ponds

In the bitumen recovery process used by current surfacing mining oil sands plants, based on the Clark Hot Water process, the fine clay materials remain dispersed in the water phase. Due to their electrical charge (zeta potential) they do not settle with the heavy sand particles and can remain in suspension for many years, a serious problem experienced by all surface mine operators. There are three broad approaches which have been studied to mitigate this problem:

1. Addition of flocculants to agglomerate the fine particles (polyvalent metal ions such as calcium and magnesium were among the first tested to neutralize the negative charge on the particles).
2. Electrophoresis to remove the electrical charge (e.g. the Ritter process, U.S. Patent 4,501,648)
3. Hydrocloning or centrifuging to use gravity to accelerate the rate of settling.

The seriousness of the tailings pond problem was recognized by Great Canadian Oil Sands (GCOS), now Suncor, based on their pilot plant operations in 1965. Dr. Frederick Camp reported, "GCOS predicted the existence of a previously unexpected complication in tailings disposal which has come to be called the pond water problem."[24] He further stated that, "while the pond water problem is an inherent defect of the hot water extraction process, it need not be a permanent defect." Camp described progress that was being made during the 1970s at minimizing or eliminating the problem. The tailings ponds have continued to be a serious problem for all subsequent mining projects. For example, the oil slick on their surfaces kills migrating fowl that may land on these ponds. Although oil sands companies have set up elaborate systems for preventing this from happening, they are not fail-safe; in recent years, there have been two instances of such occurrences. Another continuing concern is the potential leakage through the dikes of the tailing ponds. In 2010, the Alberta Government through Directive 74 has established a number of long-term objectives with the goal of minimizing and eventually eliminating the long-term storage of fluid tailings and the creation of a trafficable landscape at the earliest opportunity.

Previous technology reviews, as well as a current review, are examining specific processes for handling the tailings stream and these are being evaluated and tested by oil sands operators. It is likely that such technologies will soon be implemented and the tailings issue will be a less serious problem for surface mining operations.

The TRO™ process is an example of an approach for managing the tailing streams developed by Suncor Energy[25] as illustrated in Figure 8. The fine tailings stream is mixed with a polymer flocculent and deposited in thin layers over sand banks with shallow slopes. The solid material rapidly loses water allowing for reclamation at an earlier time compared to traditional settling processes.

The tailings problem is not an issue for in situ producers.

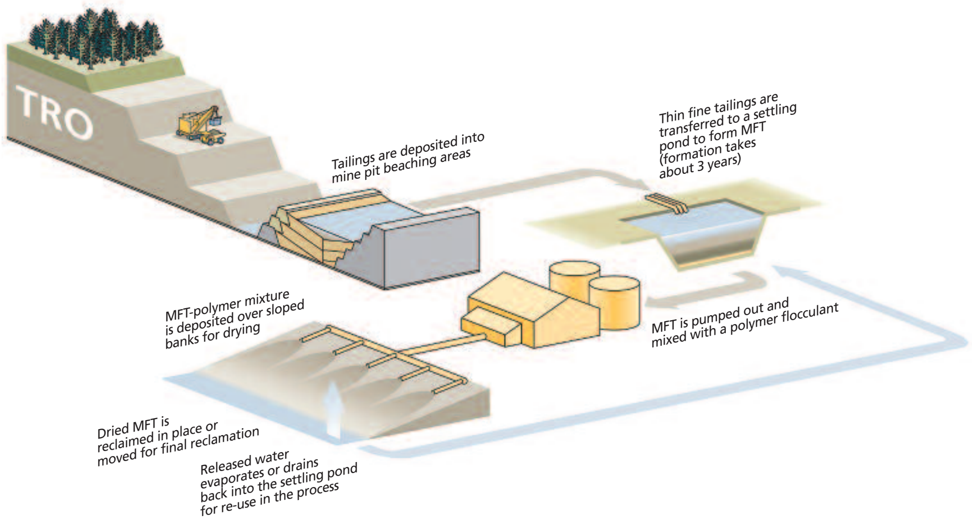


**Figure 8**
**TRO Process**

## Water

According to the Canadian Association of Petroleum Producers (CAPP), net fresh water use accounts for approximately four barrels of water for every barrel of oil produced by mining operations, with about two to three of these barrels drawn from the Athabasca River[26]. In situ operations require roughly 0.5 barrels for every barrel of oil produced (no water is directly drawn from the Athabasca River). Forty-five percent of the water used by in situ oil sands developments is saline water from deep underground zones.

CAPP estimates that the approved surface mining would use about 2.2% of the natural flow of the Athabasca River. By 2020 less than 0.5% of Alberta's current water allocation will be required by the in situ oil sands industry, which by then will be producing roughly 40% of Canada's crude oil. However, environmental groups claim that high water consumption by the oil sands threatens the quality and quantity of water available to Saskatchewan and the Northwest Territories and this concern must be addressed.

In 2010, Professor David Schindler of the University of Alberta published a paper[27] which claimed that oil sands development is contaminating the Athabasca River watershed, by both airborne and waterborne pathways. He found that seven "priority pollutants" were at levels that exceed government guidelines for the protection of aquatic life. While the initial response was that this comes from eroding oil sands deposits along the riverbank, the government appointed an independent panel to review Dr. Schindler's claims. The panel concluded that more study is needed before there is a definitive answer on how much industrial pollution affects the river, and recommended a more coordinated system for pollutant monitoring[28].

## Carbon Dioxide

Anthropogenic carbon dioxide emissions into the atmosphere contribute to global warming; however, it is not clear how much and how quickly, since no direct, quantifiable causal relationship has been established. Even so, the United Nations Intergovernmental Panel on Climate Change has urged nations to take action to curtail the growth of these emissions. Most of this growth is happening in China, India and other developing nations, mainly because of new coal-fired power plants and the growth in personal transportation.

Carbon dioxide emissions from oil sands production are generally estimated, not measured. Such estimations are complex in that there are many individual factors that need to be taken into account, such as depth of the deposit, the type of recovery and upgrading process, and the source of the hydrogen used for upgrading. In 2008, $CO_2$ emissions from oil sands production and upgrading were estimated at about 35 million tonnes per year[29]. Even if oil sand production increased three-fold in the next decade, its contribution to global emissions would be less than 0.3%. Nevertheless, oil sand extraction processes have attracted close scrutiny by environmental groups.

Thermal-based oil sands processes have slightly higher carbon dioxide emissions than conventional oil processes. The average oil sands $CO_2$ emissions intensities are in the order of 0.51 tonnes/cubic metre of bitumen (80.8 kilograms/barrel). Mining, production and upgrading result in 0.66 tonnes/cubic metre of bitumen (104.9 kilograms/barrel), and in situ production produce 0.3 tonnes/cubic metre of bitumen (47.5 kilograms/barrel). The emission intensity also varies throughout the lifetime of steam-assisted in situ processes, where the steam/oil ratio is high during its initial stages and then stabilizes to a value of 3 or lower. Most California heavy oil reservoirs have a steam-oil ratio of 5 or higher.

In the near to medium term, there is high potential for reducing GHG emissions from oil sands production through efficiency improvements. In oil sands mining operations, improved process reliability can lower energy consumption per unit of oil sands processed, thereby reducing life-cycle GHG emissions. For in situ operations, reducing the amount of steam required to produce each barrel of oil sands reaps rewards in decreased energy use and decreased life-cycle GHG emissions. This objective is consistent with advances in technology and efficiency achieved in recent years. The average amount of steam used today per unit of output is half what it was in 2000. The technology is expected to continue improving.

Carbon Capture and Storage (CCS) is being actively researched in Alberta as an approach to reduce $CO_2$ emissions. This involves capturing $CO_2$ from large point-sources, such as electric power plants, and storing it underground in geological formations. $CO_2$ can also be used to enhance the recovery of oil, natural gas and coal bed methane. Canada has important options for geological storage in the depleted or underutilized pore space of the mature Western Canadian Sedimentary Basin (located in northeastern British Columbia, Alberta, Southern Saskatchewan and southwestern Manitoba). Canada has considerable expertise and experience in acid gas ($CO_2$ and hydrogen sulfide) injection, which is sometimes co-produced with methane. During the past two decades, around fifty acid gas injection projects have stored around 3 million tonnes of $CO_2$ deep underground in Alberta.

The Government of Alberta has developed a Climate Change Strategic Plan[30], with three thrusts – Carbon Capture and Storage, Energy Efficiency Improvements and Renewable Energy. It has created a $2 billion Carbon Capture and Storage Fund and four field CCS projects are planned, which would enable Alberta to begin sequestering up to 5 million tonnes of $CO_2$ by 2015. Two of these projects involve the upgrading of bitumen, however, extension of CCS directly to the oil sands region will require the building of pipelines to transport $CO_2$ from Fort McMurray to the depleted oil fields in Central Alberta. One such pipeline is in the planning stage. Using a collaborative approach among industry, government and the research community it is expected that 10 million tonnes of $CO_2$ could be sequestered per year by 2020. These projects alone will not allow Alberta to achieve its emissions reduction target of 20 million tonnes per year by 2020.

Reducing carbon dioxide emissions will remain a major challenge for Alberta and its plans to expand production from the oil sands. There is a need to intensify research in processes which will extract $CO_2$ from the atmosphere on an industrial-scale, and transform such $CO_2$ into value-added products which will sequester carbon in their own right.

## Other Challenges

In addition to the need for market diversification, improvements in energy efficiency and environmental mitigation, there are other challenges facing the oil sands industry, including the increasing demand for natural gas – for power, process heat and hydrogen production – and fluctuating world oil prices.

### Natural Gas

In past years, there was concern that there might be a shortage of natural gas, as conventional gas production declines, while oil sands production increases. This concern has been mitigated, due to increased production from non-conventional sources, especially shale gas. The United States Energy Information Agency, in its latest long-term supply report, projects that by 2030, shale gas would provide 45% of the U.S. demand for natural gas, while Canadian gas exports would decline significantly. In other words, there would be no natural gas shortages in the foreseeable future.

However, the oil sands industry continues to look for alternatives to natural gas, such as geothermal energy, nuclear power, coal gasification and bio-hydrogen.

### Fluctuating Oil Prices

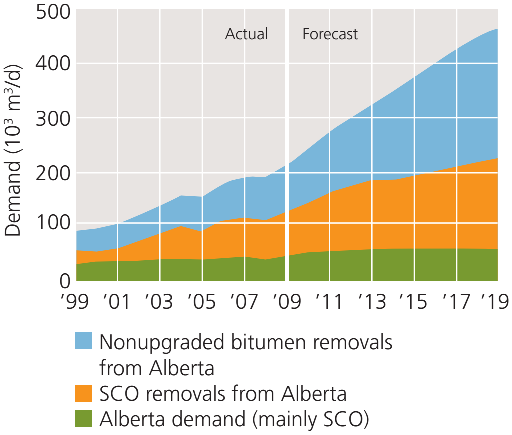
Since it is the marginal supplier of crude oil, the oil sands industry is very susceptible to the volatility in world oil prices and the price differentials between conventional and heavy oil. When prices are high, there is a flurry of new project announcements but when prices fall, even existing oil sands projects are adversely affected.

There are no easy solutions to this problem, yet the most recent studies suggest that world oil production has peaked – and crude oil demand will be increasingly greater than oil supply. While there still might be short-term fluctuations, the long-term oil price trend will likely be upward.

## Pathway Forward – Superpower or Superstore?

Canada has a historic reputation as a hewer of wood and a drawer of water, exporting raw low-value commodities with the upgrading to value-added products taking place in other countries.

**Figure 9**
**Oil Sands Demand and Disposition Projections**



We should ensure that this does not happen in the oil sands industry, keeping in mind Frank Spragins' vision for the development of upgraded products. When the oil sands industry began in the last quarter of the past century, 100% of the raw bitumen was upgraded in Canada to Synthetic Crude Oil (SCO). It is now approximately 70% and is predicted to diminish to 50% by 2019 as a result of the transfer of raw bitumen outside Canada (Figure 9).

A strategy and plan is needed to reverse this trend. Upgrading converts heavy oil and bitumen into products that are similar to and can be blended with lighter crude oils for conversion to transportation fuels in conventional refineries. The most common upgrading methods involve coking or thermal cracking followed by hydrogen addition (hydro-cracking and hydro-processing) in the presence of catalysts. Coking removes carbon in the form of petroleum coke that can be used for other industrial applications and power generation. Hydro-cracking is a catalytic conversion process which cracks or breaks down mainly aromatic molecules. Hydro-processing, also performed catalytically, removes impurities bound in the oil molecules such as metals, sulphur and nitrogen. Hydrogen acts to stabilize the products by adding to the unsaturated molecules. The final product of upgrading is known as a synthetic crude oil (SCO) that has many desirable features and compares favorably with conventional crudes.

Current commercial hydro-cracking processes use catalysts supported in a fixed or an ebullated bed to transfer hydrogen and stabilize the cracked molecules. The big challenge is to deal with the impurities found in heavy crudes as they deactivate or poison the catalyst over time. Many efforts are made to remove contaminants and increase yields while ensuring higher activity and longer life expectancy of catalysts. This includes the use of separation methods such as distillation, solvent de-asphalting, supercritical solvent de-asphalting, and combined membrane separation and catalytic conversion. An emerging innovation involves the use of molecular sized additives dissolved or dispersed directly in the heavy oil or bitumen (slurry-phase hydrocracking) to improve conversion, reduce fouling and achieve high yields. This technology can typically be retrofitted into existing refineries.

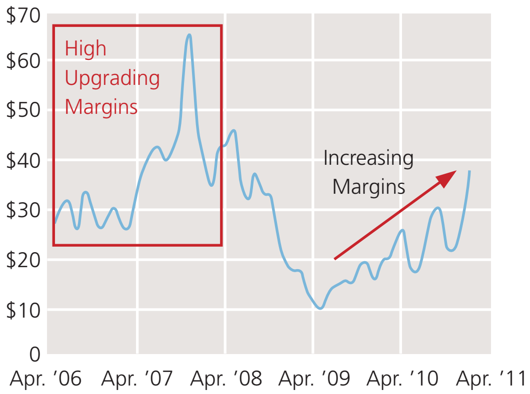
Alberta has made an important start on developing novel, less energy-intensive upgrading technologies through its $100 million Hydrocarbon Upgrading Demonstration program [31]. One hundred technologies were screened leading to the evaluation of 17 technology configurations, ranging from early stage concepts to more mature, ready for demonstration processes. As a result, the following technologies were scaled up, using Alberta feedstocks:

- **ETX Cross-flow Coking:** Advanced coking with less coke, higher liquid production and better hydrogen retention;
- **UOP – Statoil Slurry Phase Hydrocracking:** High conversion primary upgrading technology with gas oil and lighter yields of greater than 90%;
- **Nova Chemicals:** Advanced secondary upgrading technologies to produce petrochemical feedstocks from bitumen-derived gas oils;
- **Great Point Energy:** Single-stage catalytic gasification for producing synthetic natural gas;
- **Pratt & Whitney Rocketdyne:** Large capacity entrained flow gasification using rocket engine technology to reduce the capital cost of gasification.

Next-Generation Upgrading technology development is continuing at the National Centre for Upgrading Technology in Devon, Alberta, which seeks "to develop new and improved bitumen and heavy oil upgrading technologies that are less energy intensive, produce fewer GHG emissions, and result in higher quality, cleaner fuels at lower costs[32]." This upgrading work needs to be accelerated and the more promising approaches demonstrated under commercially-relevant conditions.

## Incentive for Upgrading in Canada

**Figure 10**
**Price Differential Between Synthetic Crude Oil and Diluted Bitumen Increasing**
($2011 basis, posted Edmonton Basis, through January, 2011)

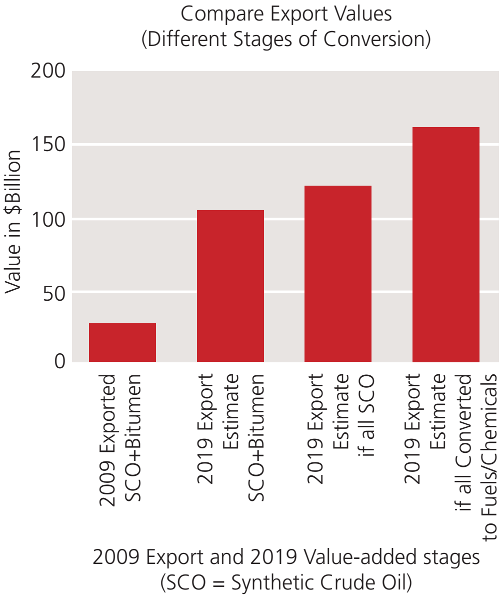


The price differential between synthetic crude oil and a mixture of bitumen and a diluent is shown in Figure 10[33]. Rapid increases in the differential occurred in the mid part of the past decade, and then rapidly diminished to about $10 per barrel. There has been a steady increase in the last few years, which is improving the case for upgrading.

Alberta's Energy Resources Conservation Board has estimated, in its 2010 update, bitumen production in the province will reach 3.2 million barrels per day by 2019, compared to actual production averaging 1.49 barrels per day in 2009. The consequences of such a significant growth are the commensurate potentials in upgrading and refining this basic feedstock to added-value products such as synthetic crude oil, fuels and chemicals. It is further estimated that about 80% of this production will leave Alberta – some for Eastern Canada but the majority for export to the U.S.

The value of this exported product, a combination of SCO and bitumen, is estimated to be about $103 billion per year in 2019 at current product price ratios and 2011 dollars. If the bitumen were

**Figure 11**
**Substantial Incentive for Upgrading in Canada**



to be fully upgraded to synthetic crude oil then the value would increase to $121 billion per year. If the SCO were to be further refined to fuels and chemicals, the estimated product value would increase to $161 billion per year. Thus, by converting the feedstock to chemicals such as ethylene, propylene, polymerized materials or derivative downstream products, an additional $60 billion per year (based on fuel value) would likely be added over and above the base value of the source bitumen. This is illustrated in Figure 11 over the decade 2009-2019.

It is recognized that Alberta-based firms will invest in some upgrading facilities during the coming decade but the anticipated export will carry with it the potential of losing the $60 billion per year value to firms located in the U.S. refining and market areas. With this export of bitumen will be the export of tens of thousands of potential jobs created by upgrading and refining in Canada along with a significant, positive impact on the Gross Domestic Product and the wealth of Canada. This is especially true when considering the multiplier effect of the money circulation associated with such investments.

In 2009 the Alberta government, recognizing the incentive for upgrading in Canada, initiated the Bitumen-Royalty-In-Kind (BRIK) initiative, with three objectives:

- **Foster value-added oil sands development:** Alberta could strategically use its royalty bitumen barrels to stimulate value-added activities, such as upgrading and petrochemical development. The resultant incremental investment would create economic activity and jobs from capital project construction and operations. This would positively impact Alberta's long-term economic sustainability and diversify the product portfolio produced in Alberta while allowing the province to hedge its bitumen commodity risk.
- **Enhance the transparency and liquidity in the bitumen market:** The BRIK program includes a market design to facilitate more buyers and sellers of bitumen and a more transparent and liquid market. This will help assist Alberta in getting full value for its royalties.
- **Share in the differential gains and risks, between SCO and bitumen:** Historically, there has been a considerable differential between the price of bitumen and SCO. By assuming some risk and cost associated with processing, Alberta could obtain increased revenue compared with taking cash based on bitumen pricing.

In February 2011, the government announced that the first BRIK project was the North West Upgrading/Canadian Natural Resources Limited Partnership that would lead to construction of a new bitumen refinery in Alberta's Industrial Heartland, northeast of Edmonton.

Canada's energy corridors, such as the Alberta Industrial Heartland and the Sarnia-Lambton Refining and Petrochemical Complex, have enormous capacity to expand to meet expected upgrading requirements. Single-company short-term evaluations that indicate that it is more economical to ship the bitumen, and the jobs, outside the country do not take into account the long-term strategic advantage to Canada in building its own value-added industries.

## Conclusion

Over the past 100 years, the oil sands have progressed from a geological curiosity to become an important contributor to Canada's economic prosperity. It has faced major technical and economic challenges which have been overcome by the determination and actions of many visionaries. Even so, the oils sands now face new challenges, related to air, land and water impacts. The industry has made progress in reducing its GHG emissions, its use of fresh water, and in dramatically reducing the time to restore disturbed lands to close to original conditions. However, the industry is falling behind in capturing the full value of the resource.

Bitumen from the oil sands is not a leftover fossil fuel residue or tar. It is a geologically new hydrocarbon with a unique chemical structure. It is a potential feedstock for chemicals, lubricants and of course a replacement for conventional crude oil. By 2019, 50% of the bitumen will be upgraded outside Canada. Limited progress has been made in the development of technologies to produce high-value products, based on the unique properties of the resource. New "big projects" to upgrade bitumen to innovative value-added fuel and chemical products could translate into $60 billion per year of additional economic activity by the end of this decade. Canada's future prosperity is strongly dependent on private-private partnerships to seize this unique opportunity.

**The Athabasca River near its Source, the Columbia Ice Field**

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# 8

# Coal and Biomass Gasification

Aung N. Oo

## ABSTRACT

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 proven in-place coal resources, which will provide more than 100 years of production at current production rates. Additionally, about 2 trillion tonnes of coal resources have been identified in Canada. Gasification, a proven and commercial technology, is likely the most promising alternative conversion technique to direct combustion of coal from an environmental perspective as it represents a versatile way to convert coal 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 readily and economically available.

There are approximately 150 gasification plants operating worldwide, and they use coal as their major feedstock. Chemicals represent approximately 45% of total gasification products followed by liquid transportation fuels, about 38% of total. Electric power and gaseous fuels are also important products of gasification. It is important to capitalize on the learning and the latest developments of 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 sequestration, 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 a sustainable energy superpower, Canada should master the efficient utilization of coal resources in an environmentally responsible manner. Providing resources to the research and development of new gasification technologies, and sharing the risk with industry in scaling-up the new technologies, are essential actions for effectively utilizing coal resources.

# Introduction

Coal is the most widely used fuel for electricity generation in North America due to its abundance and favourable economics. However, concerns regarding the emissions from coal-fired power plants and related climate change and public health issues have led to the consideration of alternative energy conversion techniques to conventional direct combustion. If coal can be used in a manner which greatly minimizes its impact on the environment, this ample resource could provide energy and many other products while contributing to greater competitiveness in an increasingly integrated world economy.

The demonstration of the first coal gasification technologies was initiated in the U.K., France, U.S. and Germany in the late 1700s and early 1800s. The first commercial coal gas manufacturers were the London and Westminster Gas Light and Coke Company, established in 1812 in the U.K., and the Gas Light Company of Baltimore, established in 1816 in the U.S. The first German gas plant was built in Hannover in 1825, and by 1870 there were 340 plants in Germany making gas from coal, wood, peat and other materials. In the 1850s, almost every reasonably sized western city had a gas plant to provide for street lighting. Major advancements in coal gasification occurred in the 1860s, but the well-known high-pressure "Lurgi" gasification process was developed in Germany in the first half of the 20th century. Since then, gasification technologies have continually progressed in terms of technical and environmental performance[1,2].

Gasification is likely the most promising alternative conversion technique to the direct combustion of coal. Gasification is a versatile thermo-chemical process for converting coal simultaneously into electricity, heat, hydrogen, and other synthetic gases. Gasification can not only break down coal but also biomass such as wood, agricultural residues and municipal solid wastes. The development of flexible gasification systems for dual fuels (i.e., coal and biomass) could be an attractive technical option for countries like Canada, where both coal and biomass are readily available.

Electricity and heat generation through coal gasification exhibit a number of environmental advantages over conventional coal-fired power plants, including lower levels of $NO_x$, $SO_x$ and particulate matter emissions, easier capture of the sulphur contained in coal, and greater thermal efficiency with Integrated Gasification Combined Cycle (IGCC) technology[3]. Coal gasification plants are commercially in operation around the world, and the technology continues to improve. Gasification could potentially play an important role in future integrated facilities which would not only generate heat and electricity but also produce building block chemicals to produce a wide range of products from locally available resources while minimizing environmental impacts.

# The Opportunity

## Abundant Coal Resources

Coal is the world's most abundant and widely distributed fossil fuel. The International Energy Agency estimates that the world's total proven recoverable coal reserves are 935 billion tonnes spread over more than 70 countries[3]. At its current production rate, this coal reserve will last for more than 140 years, which is significantly longer than the proven reserves of oil and gas. Coal is also the most economical energy resource in many countries. Coal has been used to generate heat and power for hundreds of years, and represented the most important source of primary energy in the world until the late 1960s. Today, close to 90% of the world's total coal production is consumed for electric power generation. Coal-fired electric power generation currently provides more than 40% of global electricity, and accounts for 15.5% of Canada's total electricity output. The International Energy Agency estimated that the world's total coal use was approximately 6,800 million tonnes in 2008.

The major coal producing countries are identified in Table 1. Though Canada is a mid-size coal producer, Canada's coal mining sector plays an important role in the Canadian economy as a provider of about 10% of the country's primary energy. The Canadian coal mining industry is the direct employer of close to 6,000 people, the instigator of many more indirect jobs across the country, and contributes more than $1 billion to Canada's gross domestic product. Canada is a net exporter of coal, and holds 8.7 billion tonnes of proven in-place coal resources, including 6.6 billion

**Table 1**
**The World's Major Coal Producing Countries, 2008 Production[4] (Million Tonnes)**

| Rank | Country | Coal Production, 2008 |
|---|---|---|
| 1 | China | 2,761.4 |
| 2 | United States | 1,075.2 |
| 3 | India | 521.7 |
| 4 | Australia | 397.8 |
| 5 | Russia | 323.1 |
| 7 | Indonesia | 284.2 |
| 6 | South Africa | 235.8 |
| 8 | Germany | 194.5 |
| 9 | Poland | 143.9 |
| 10 | Kazakhstan | 108.7 |
| 11 | Turkey | 78.6 |
| 12 | Colombia | 75.7 |
| 13 | Canada | 67.8 |
| 14 | Greece | 65.7 |
| 15 | Czech Republic | 60.2 |

tonnes of proven recoverable coal reserves, which would provide more than 100 years of production at current production rates. Additionally, about 2 trillion tonnes of other coal resources have been identified in Canada[3,5,6].

Coal resources in Canada are well distributed throughout the country. British Columbia, Alberta and Saskatchewan have the largest known reserves and resources in Canada that are actively mined. Coal is also mined in Nova Scotia and New Brunswick. Coal reserves and resources have been identified in the Yukon, Ontario, Newfoundland and Labrador, Northwest Territories and Nunavut, but these resources are not currently mined.

Coal is a significant source of pollution when employed by means of conventional direct combustion technologies. However, this plentiful natural resource can play a significant role in the global energy mix for decades to come if it is used in a manner which is more environmentally acceptable. The development of clean coal technologies, including gasification, could be of critical importance in exploiting this abundant resource for energy security and other benefits. As a net coal exporter, Canada could significantly gain by participating in the development of next generation coal gasification technologies. This could lead to the establishment of value-added industries using local coal as a feedstock and the development of Canadian coal resources to their full potential.

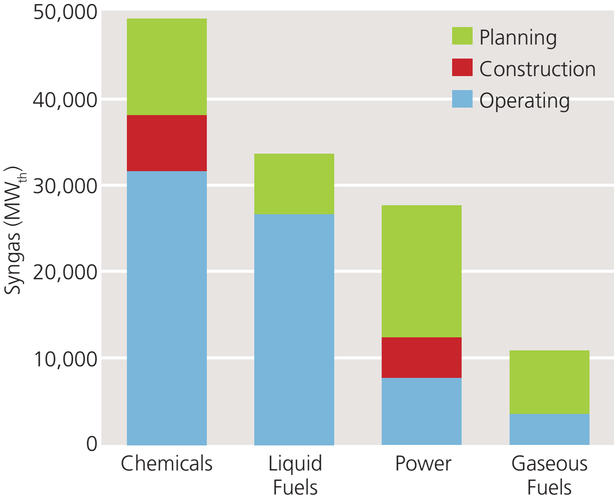
## Gasification: Commercial and Progressing Technology

Coal gasification has been in commercial operation for decades around the world. The U.S. Department of Energy's (DOE) 2010 Worldwide Gasification Database[7] shows that the current gasification capacity has grown to 70,817 megawatts thermal ($MW_{th}$) of synthetic gas (i.e., commonly referred to as syngas, and composed mainly of carbon dioxide and hydrogen) output at 144 operating plants representing a total of 412 gasifiers. The database also shows that 11 plants, with 17 gasifiers, are presently under construction, and an additional 37 plants, with 76 gasifiers, are in planning stages to become operational between 2011 and 2016. The majority of these plants will use coal as the feedstock. The additional planned capacity from all new 2011-2016 plants is 51,288 $MW_{th}$, an increase of more than 72%. If this growth is realized, worldwide capacity by 2016 will be 122,106 $MW_{th}$ of syngas capacity, from 192 plants and 505 gasifiers. The database is summarized in Table 2.

Chemicals, especially methanol-based, are the most widely generated products from syngas in coal gasification. Major marketable chemicals derived from methanol through coal gasification are formaldehyde, fuel additives, and acetic acid[8]. Figure 1 gives product distributions from gasification systems worldwide. Chemicals represent approximately 45% of total gasification products followed by liquid transportation fuels, about 38% of the total. Electric power and gaseous fuels are also important products of gasification, representing 11% and 6%, respectively, of the total. There are no commercial coal gasification plants operating in Canada at present. However, an advanced gasification project is currently under development by Swan Hills Synfuels in Alberta. The project will use In Situ Coal Gasification (ISCG) to tap deep, unmineable coal to produce syngas that will be processed in a conventional gas plant to remove $CO_2$ as a byproduct stream. The syngas will then be used in a combined cycle power generation station to generate electricity. The Swan Hills ISCG/Power Project is 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 located in the Swan Hills/Whitecourt area of Alberta. The full-scale $1.5 billion project is expected to commence service in 2015[9].

Technology improvements in terms of increased conversion efficiency, effective syngas cleaning systems and better environmental performance are gradually incorporated into new gasification systems. Technology development is expected to continue in countries like China where crude oil is an import commodity and coal resources are relatively abundant and inexpensive for producing chemicals and liquid transportation fuels. The progress of this commercial technology, combined with increasing crude oil prices, could gradually improve the economic feasibility of coal gasification in Canada.

**Figure 1**
**Product Distribution of Worldwide Gasification[7]**



## Integrated Processing with Biomass

As shown in Table 2, biomass currently accounts for a small percentage of total global gasification feedstocks. However, countries like Canada with significant biomass resources should consider the next generation gasification systems, as conceptualized in Figure 2, to process diverse feedstocks. Anthracite, which is the most aged coal, is mainly used for metallurgical applications such as producing steel. Anthracite could be too expensive to be gasified to produce chemicals and fuels in Canada, where competing oil and gas resources are relatively readily available. Lignite and bituminous coals are, therefore, major feedstocks for gasification systems. The chemical properties of these less aged coals are relatively similar to that of biomass, and integrated processing with biomass is feasible and could be an attractive option for Canada.

As shown in Figure 2, an array of products can be obtained from integrated coal and biomass gasification. Bio-based industry advocates have been promoting the bio-refinery concept to produce fuels, chemicals, heat, power and other commodities from biomass feedstocks for some time. Integrated coal and biomass gasification, therefore, offers an opportunity to incorporate proven and commercial coal gasification technologies into an emerging bio-based sector. The development of integrated coal and biomass gasification systems would not only help the emergence of a new bio-based industry but also lead to the more effective utilization of Canadian coal resources.

**Table 2**
**Summary of Worldwide Gasification Database**[7]

| Feedstock | | Operating 2010 | Under Construction 2010 | Planned 2011-2016 | Totals |
|---|---|---|---|---|---|
| **Coal** | Syngas Capacity ($MW_{th}$) | 36,315 | 10,857 | 28,376 | 75,548 |
| | Gasifiers | 201 | 17 | 58 | 276 |
| | Plants | 53 | 11 | 29 | 93 |
| **Petroleum** | Syngas Capacity ($MW_{th}$) | 17,938 | | | 17,938 |
| | Gasifiers | 138 | | | 138 |
| | Plants | 56 | | | 56 |
| **Gas** | Syngas Capacity ($MW_{th}$) | 15,281 | | | 15,281 |
| | Gasifiers | 59 | | | 59 |
| | Plants | 23 | | | 23 |
| **Petcoke** | Syngas Capacity ($MW_{th}$) | 911 | | 12,027 | 12,938 |
| | Gasifiers | 5 | | 16 | 21 |
| | Plants | 3 | | 6 | 9 |
| **Biomass/Waste** | Syngas Capacity ($MW_{th}$) | 373 | | 29 | 402 |
| | Gasifiers | 9 | | 2 | 11 |
| | Plants | 9 | | 2 | 11 |
| | **Total Syngas Capacity ($MW_{th}$)** | **70,817** | **10,857** | **40,432** | **122,106** |
| | **Total Gasifiers** | **412** | **17** | **76** | **505** |
| | **Total Plants** | **144** | **11** | **37** | **192** |

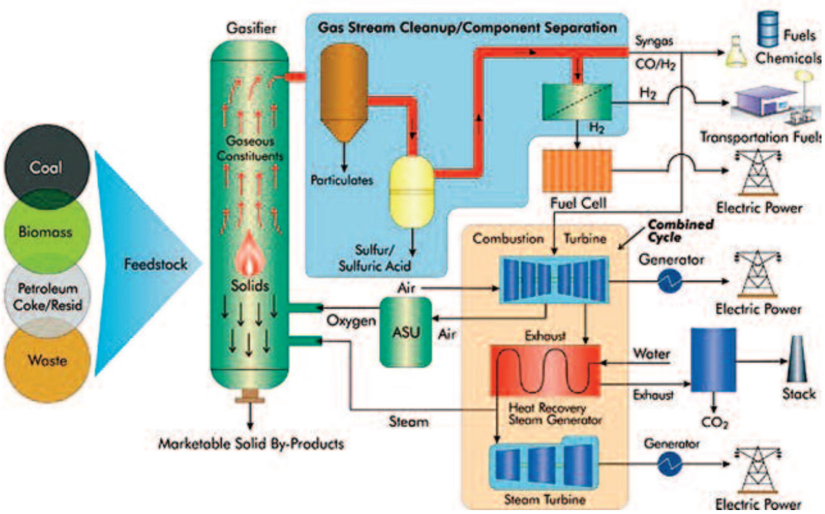


**Figure 2**
**Next Generation Gasification System for Diverse Feedstocks**[10]

# Challenges

## Technology Development

Since coal is the most abundant energy source and provides 40% of global electricity, technology improvements in coal power generation are still a major focus of some countries, especially in the United States. Integrated Gasification Combined Cycle (IGCC) power plants with $CO_2$ capture capability are considered to be future clean, secure and affordable electricity generation alternatives. The areas of technology development in IGCC plants include the processing of syngas for increased efficiency of $CO_2$ capture and sulphur stream separation, improving the performance of syngas coolers, increasing the lifespan of refractories, and optimizing the sorbent/catalyst design for low-rank coals. Six particularly noteworthy industry/government

collaborative projects recently funded by the U.S. Department of Energy (DOE) to advance IGCC technologies are summarized below[11].

- Electric Power Research Institute, Inc. (Palo Alto, California)—Slurries of liquid carbon dioxide and low-rank coal can potentially lower the cost and increase the efficiency of IGCC power plants with carbon capture. The Electric Power Research Institute (EPRI) will confirm the potential advantages of these slurries by conducting plant-wide technical and economic simulations, developing a preliminary design and cost estimate of a slurry preparation and mixing system, and performing laboratory tests for increasing the knowledge and understanding of maximum solids loading capability for three coals. EPRI will team with Dooher Institute of Physics and Energy (Garden City, New York), WorleyParsons Group, Inc. (Houston, Texas), Columbia University (New York), and ATS Rheosystems/REOLOGICA (Bordentown, New Jersey).
- TDA Research, Inc. (Wheat Ridge, Colorado)—Teaming with the University of California at Irvine, Southern Company (Birmingham, Atlanta), and ConocoPhillips (Houston, Texas), TDA Research will demonstrate the technical and economic viability of a new IGCC power plant designed to efficiently process low-rank coals. The plant uses an integrated $CO_2$ scrubber/water gas shift (WGS) catalyst to capture more than 90% of the $CO_2$ emissions, while increasing the cost of electricity by less than 10% compared to a plant with no carbon capture. The team will optimize the sorbent/catalyst and process design, and assess the efficacy of the integrated WGS catalyst/$CO_2$ capture system, first in bench-scale experiments and then in a slipstream field demonstration using actual coal-derived synthesis gas. The results will feed into a techno-economic analysis to estimate the impact of the WGS catalyst/$CO_2$ capture system on the thermal efficiency of the plant and cost of electricity.
- General Electric Company (Houston, Texas)—The use of the nation's large reserves of low-cost, low-rank coals in IGCC systems is currently limited by the capabilities of available coal feed systems. General Electric and partner Eastman Chemical Company (Kingsport, Tennessee) will evaluate and demonstrate the benefits of novel dry-feed technologies to effectively, reliably, and economically feed low-rank coal into commercial IGCC systems. Investigators will complete comparative techno-economic studies of two IGCC power plant cases, one without and one with advanced dry feed technologies. The study will focus on IGCC systems with 90% carbon capture, but the dry feed system will be applicable to all IGCC power generating plants and other industries requiring pressurized syngas.
- Air Products and Chemicals, Inc. (Allentown, Pennsylvania)—Downstream processing of syngas for $CO_2$ capture requires separation of the crude stream into the desired products (hydrogen and carbon monoxide), a sulfur stream (primarily hydrogen sulfide), and sequestration-ready $CO_2$. Air Products has developed a three-step process to accomplish this separation at lower cost and greater efficiency than currently available technologies. Working with the Energy and Environmental Research Center at the University of North Dakota, Air Products and Chemicals will extensively test the process and use the results to generate a high-level pilot process design and to prepare a techno-economic assessment to evaluate the applicability of the technology to plants using low-rank coals.
- Reaction Engineering International (REI) (Salt Lake City, Utah)—In an IGCC plant, syngas coolers—heat exchangers located between the coal gasifier and the combustion turbine—offer high efficiency, but their reliability is generally lower than other process equipment in the

gasification island. Downtime events associated with the syngas cooler are typically a result of ash deposits. REI, along with researchers from the University of Utah, will evaluate ash deposition and plugging in industrially relevant syngas cooler designs and evaluate methods to mitigate fouling and plugging. Improving the performance of the syngas cooler through reduced plugging and fouling will improve the reliability, availability and maintainability of IGCC plants.

- General Electric Company (Houston, Texas)—General Electric and partner Eastman Chemical Company (Kingsport, Tennessee) will work on the following four tasks, which were selected based on their broad applicability to the IGCC industry to better benefit the public: integrated operations philosophy, modularization of gasification/IGCC plant, active fouling removal, and continuous slag handling.

## Environmental Issues

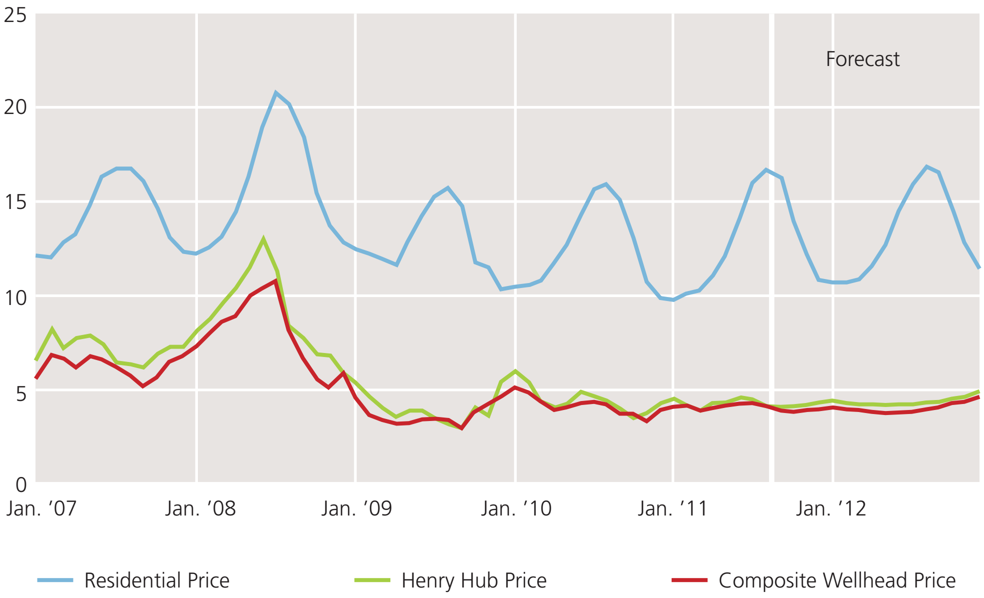
The environmental issues associated with coal gasification begin at coal mines. For coal deposits near the earth's surface, open pit or strip mining techniques are used. For coal deposits located deep in the ground, a combination of vertical and horizontal shafts from the surface provide access to the coal resources. There are environmental concerns for both open pit and deep mining methods. However, land reclamation and soil remediation techniques are increasingly effective in managing the negative impact of coal mining.

While the environmental performance of coal gasification systems are significantly better than conventional direct combustion systems, concerns remain. Coal contains most naturally occurring chemical elements in trace amounts, with specific elements and their concentrations dependent upon the rank of the coal and its geological origins[12]. Potentially toxic trace metals, metal compounds and organic matter components can be released during gasification and pose environmental and human health risks, depending upon their abundance, physicochemical forms, toxicity, and their ultimate disposal. Most of these trace metals either remain with the slag/bottom ash or are removed from the syngas in downstream process equipment[13]. The trace metals of greatest environmental concern are arsenic, boron, cadmium, mercury, and selenium. Mercury is a problematic element for both conventional combustion and gasification, since it has a low boiling point of ~ 350 °C and remains in the vapour phase during the energy conversion. The separation of these trace metals from the exhaust stream is required to reduce the negative environmental impacts of coal gasification.

## Competing with Natural Gas

As mentioned before, the gasification of coal or biomass produces syngas, which mainly contains carbon monoxide and hydrogen. These syngas components can also be generated from natural gas, essentially composed of methane, through the steam reforming process. The economics of coal gasification therefore greatly depend on the price of natural gas, the competing hydrocarbon resource. As shown in Figure 3, the price of natural gas significantly dropped in 2008, and hasn't recovered since. Advanced exploration techniques have considerably increased the economic reserve of natural gas, mainly composed of deep shale gas. The current price of natural gas is less than \$4/GJ and the long-term projection is approximately \$ 6/GJ. The low-rank coals are available at ~ \$3/GJ. Another prominent advantage of natural gas is the better environmental performance from exploration to final energy conversion.

**Figure 3**
**Price of Natural Gas and Short-Term Outlook[14]**
**(Dollars per Thousand Cubic Feet)**



Capital and operating costs associated with gasification systems also hamper the economics of coal gasification at the present time. To compete with natural gas in the medium- to long-term, the economics of coal gasification need to be substantially improved. This requires research and development in the areas of new reactor technologies, the ability to process diverse feedstocks, finding less expensive sorbents/catalysts, and the economic recovery and sale of sulphur, ash and trace metals in coal.

## Pathway Forward

Coal—abundantly available in Canada—should be considered a strategic energy source. This resource could play an essential role in diversifying the energy mix of the country and providing an economic competitive edge for Canadian industry in the medium- to long-term. The goals suggested by Natural Resources Canada in its clean coal technology roadmap are[15]:

- A national leader, proactive in the research and development of clean coal technologies;
- A champion of achieving top environmental performance standards using the best available commercial technology in its operations;
- A good local citizen, viewed as environmentally responsible and committed to the health and welfare of communities in Canada and globally;
- A part of the solution to develop sustainable energy sources by building a fleet of clean coal plants that provide power to the nation; and
- Able to adapt and integrate leading technology into Canadian research and development and demonstrations.

These goals and the roadmap should serve as guidelines in expanding the contribution of coal in the Canadian energy mix. To become a sustainable energy superpower, Canada should able to utilize this strategic hydrocarbon resource in an efficient and environmentally friendly manner. This requires the following actions:

- Develop guidelines for coal mining and soil remediation requirements to minimize negative environmental impacts;

- Fund basic research and development for integrated coal and biomass gasification technologies;
- Capitalize on the latest global advancement in gasification technologies by collaborating with international firms to improve these technologies for the Canadian context;
- Share the risk with industry in commercializing the gasification systems, especially in technology scale-up;
- Collaborate with the chemicals industry to produce high-value chemicals from coal and biomass gasification systems;
- Develop and commercialize carbon capture and sequestration and other technologies which could make the environmental performance of coal comparable to that of other hydrocarbon resources; and
- Formulate the long-term goal of developing clean coal technologies and integrate emerging technologies into demonstration and commercial systems.

Canada could be a leader and the international technology provider for the effective utilization of coal and biomass through gasification, producing electricity, heat, and chemical feedstocks with minimum environmental impact. Mastering the efficient and clean use of this, the most abundant of energy resources, would move Canada closer to the goal of becoming a sustainable energy superpower.

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# 9

# Bioenergy

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## ABSTRACT

Approximately 10% of world's forests, a total of 450 million hectares, is in Canada, and the total agricultural land in Canada represents an additional 67.5 million hectares. The Canadian forestry industry currently has an over-capacity of approximately 12 million tonnes of lumber due to the recent downtown in the U.S. housing sector; approximately 4.75 million dry tonnes of wood residues are also available annually from the Canadian forestry industry; and the mountain pine beetle (MPB) infestation of British Columbia has caused massive damage to trees, affecting approximately 10 million hectares of forests and resulting in approximately 385 million tonnes of additional biomass available for harvesting over the next decade. Additionally, Canadian farms produce over 100 million tonnes of grains, beans and hays annually, and it is estimated that over 30 million tonnes of agricultural residuals such as straws and corn stover can be sustainably harvested for energy applications. Finally, there could be approximately 15 million dry tonnes of biomass from the municipal solid waste streams. Clearly, Canada's biomass resources are enormous, and could be used sustainably.

The development of bio-refineries where bioenergy, bio-chemicals and other bio-products are produced from diverse biomass feedstocks, could lead to the emergence of a significant bio-economy sector in Canada. Integrated development options include the conversion of pulp and paper mills into bio-refineries, and the product diversification of sugar-based and cellulosic ethanol plants. The challenges of the bioenergy sector include technology improvements, meeting the increasingly stringent environmental regulations, and the scarcity of funding for scaling-up of technologies. The fundamental requirement in the pathway forward for developing bioenergy is to incorporate sustainability principles in every segment of the value chain. Business incubation support and sustainability guidelines are of critical importance for properly developing this sector in Canada.

# Introduction

Canada is endowed with abundant natural resources such as oil, gas, uranium, hydro, minerals, and biomass. As the second largest country in the world, Canada has enormous biomass resources from its large forests and well-developed agricultural lands. Various biomass feedstocks can be used to produce a wide range of commodities, including fuels, chemicals, foods, energy and other consumer products. Although Canada is currently producing different forms of energy from biomass resources, it lags far behind European countries in terms of a per capita or per resource basis. Reasons for this include the availability of relatively inexpensive fossil energy resources, environmental issues associated with bio-fuel production and biomass combustion, public perception of the food versus fuel issue, and sustainability concerns.

Given the scale of its biomass resources, Canadian forestry and agricultural sectors can sustainably provide foods, fuels and other commodities. Experts agree that Canada, the U.S., and Brazil are the most promising countries to develop a large-scale bio-refinery sector due to their sustainable resources. A bio-refinery is a facility where a number of bio-based fuels, energy, chemicals and commodities are produced, and distributed bio-refineries are considered the preferred bio-economy development model. The economics of bio-refineries improve when bioenergy is produced in conjunction with other commodities from diverse biomass feedstocks.

Bioenergy can play a greater role in the overall energy mix and in reducing greenhouse gases (GHG) in Canada. An integrated development option based on the distributed bio-refinery model could lead to the emergence of a bio-economy sector, employing domestic biomass feedstocks, and creating numerous manufacturing job opportunities. However, the emergence of a strong bioenergy sector faces numerous challenges, including developing and commercializing suitable energy conversion technologies for domestic biomass feedstocks, minimizing environmental impacts, and competing with traditional fossil energy resources, all of which require prudent policy and planning, not to mention a pragmatic approach.

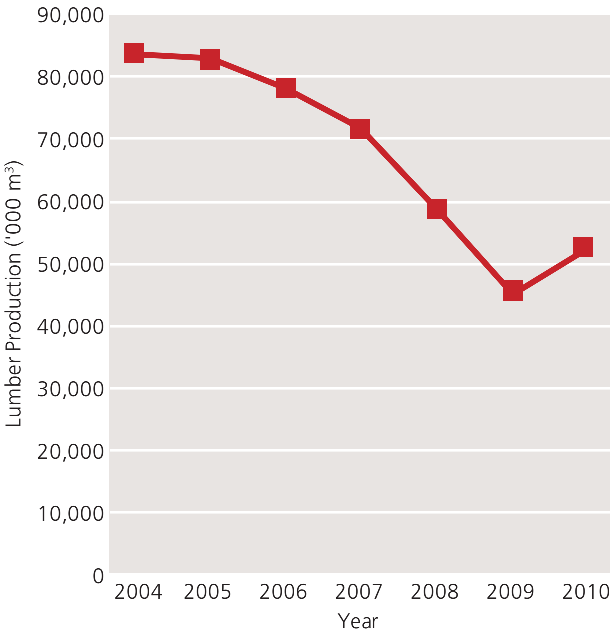
# The Opportunity

## Resource Base

### Canadian Forests

Forests are a major source of biomass in Canada. Though Canada has only 0.4% of the world's population, it possesses approximately 10% of its forests[1]. Canada is the second largest country in the world, with almost 1,000 million hectares, and with 45% of the land covered by the forests. Although timber production has declined due to the struggling United States housing sector, Canada is still the largest timber and wood pellets exporter[2]. Figure 1 shows recent Canadian lumber production data, and the details for each province are provided in Table 1. The Canadian forestry industry currently has an over-capacity of 30 million $m^3$ (approximately 12 million tonnes) if the 2004 production figure is considered as a benchmark. The woody biomass from this excess capacity represents a sustainable source of biomass feedstock and a considerable opportunity for the development of bio-based fuels, energy and chemicals.

**Figure 1**
**Canadian Lumber Production[3]**



The Canadian forestry industry produces a substantial amount of wood residues such as bark, shavings, and sawdust from pulping and milling processes. Other residues such as tops, branches and leaves are also generated annually in the forests or at the roadside from harvesting and thinning operations. Some wood residues, over 80% of the total produced, are currently used for onsite energy generation or sold to independent power producers, board and pellet manufacturers, and to farmers for animal bedding, and landscapers for garden beds. The surplus residues are incinerated in British Columbia, Alberta and Manitoba, as required by the regulations in these provinces. The excess residues are accumulated, known as historic hog piles, at mill sites in other provinces. At 2004 lumber production levels, the Canadian forestry industry generated approximately 2.75 million dry tonnes of surplus wood residues from lumber mills annually[4].

**Table 1**
**Lumber Production in Canada by Province ('000 m$^3$)[3]**

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---:|---:|---:|---:|---:|---:|---:|
| British Columbia | 39,205 | 41,014 | 41,050 | 36,677 | 28,192 | 22,975 | 26,758 |
| Alberta | 8,053 | 7,362 | 6,782 | 7,853 | 7,358 | 6,644 | 7,386 |
| Saskatchewan | 1,184 | 749 | 479 | 200 | 0 | 0 | 0 |
| Manitoba | 637 | 700 | 459 | 200 | 0 | 0 | 0 |
| Ontario | 8,728 | 9,104 | 8,493 | 7,753 | 5,509 | 3,542 | 3,480 |
| Quebec | 19,883 | 18,607 | 16,126 | 14,588 | 12,401 | 9,433 | 11,668 |
| New Brunswick | 4,039 | 3,797 | 3,525 | 3,349 | 2,408 | 1,934 | 2,420 |
| Nova Scotia | 1,785 | 1,557 | 1,308 | 1,224 | 817 | 540 | 864 |
| Canada | 83,514 | 82,890 | 78,222 | 71,844 | 58,693 | 45,068 | 52,576 |

Historic hog piles can also provide significant quantities of biomass for energy and other uses. Bradley[4] estimates that over two million dry tonnes of wood residues/year can be mined from hog piles for ten years as shown in Table 2. Altogether, with annually generated lumber mill residues, approximately 4.75 million dry tonnes of wood residues/year are available from the Canadian forestry industry over the next decade.

**Table 2**
**Wood Residues in Historic Hog Piles ('000 Dry Tonnes)[4]**

| | Estimated Quantity in Hog Piles | Usable Quantity in Ten Years | Annual Quantity if Mined for 10 years |
|---|---:|---:|---:|
| Saskatchewan | 2,900 | 2,900 | 290 |
| Ontario | 19,371 | 11,604 | 1,160 |
| Quebec | 11,710 | 5,251 | 525 |
| New Brunswick | 300 | 257 | 26 |
| Nova Scotia | 213 | 148 | 15 |
| Prince Edward Island | 30 | 30 | 3 |
| Newfoundland and Labrador | 235 | 188 | 19 |
| Canada | 34,759 | 20,378 | 2,038 |

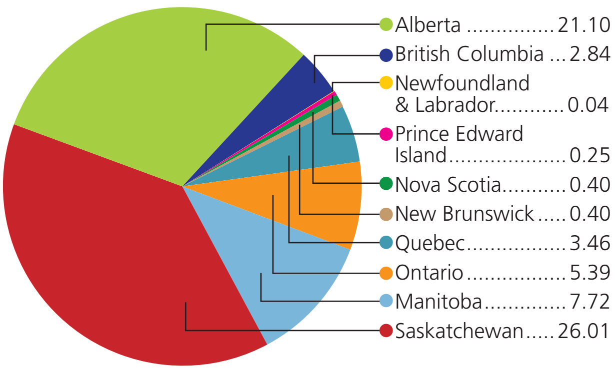
In addition to the excess capacity of the Canadian forestry industry and mill residues, the mountain pine beetle (MPB) infestation has caused considerable damage to trees in British Columbia, affecting approximately 10 million hectares of forests, and resulting in 960 million m$^3$ (approximately 385 million tonnes) of biomass available for harvesting over the next decade[5]. The MPB infested trees have been a source of wood pellets exported from British Columbia to Europe, and could be an important feedstock for Canadian bioenergy and bio-fuel production.

## Agriculture Sector

Canada has 67.5 million hectares of agricultural land, representing 6.8% of its total surface. As shown in Figure 2, two western provinces, namely Alberta and Saskatchewan, dominate Canadian farm land area. Canadian farmers produce a wide range of field crops, including wheat, canola, soybeans, corn and tame hay, and some special crops such as lentils, sunflower seed and dry peas. Farm production of major crops is given in Table 3. Some grain corn and canola are currently used to produce bio-ethanol and bio-diesel, respectively. The large agricultural land in Canada can also accommodate specialty industrial crops and other purpose-grown crops such as miscanthus and switchgrass for energy and other applications. Approximately 15% of the agricultural land in

Ontario, identified as marginal, can be used to grow energy crops and sustainably produce 8.75 million tonnes/year of biomass for power generation[6].

**Figure 2**
**Agricultural Land in Million Hectares in Canadian Provinces[7]**



The Canadian agricultural sector also produces significant tonnages of residues such as corn stover and straws as by-products every year. The majority of agricultural residues should be left in fields to maintain soil organic matter (SOM). However, some residues can be harvested or removed from the field for energy use and other applications. Based on a SOM balance model, a total of 2.8 million tonnes of agricultural residues could have been sustainably harvested in 2009 in Ontario without degrading the soil[8]. This quantity represents approximately 20% of the total above ground agricultural residues produced in Ontario. By applying the same harvestable residues to farm area ratio, a total of over 30 million tonnes of agricultural residues could be sustainably harvested from Canadian farms for energy and other applications. Improvements in crop yields due to genetic advancements would gradually increase the sustainably harvestable quantity of agricultural residues. Canada's livestock farms also produce 58 million tonnes of manure annually which, if made available for biogas production through the anaerobic digestion process, would generate approximately 65 PJ of biogas, equivalent in energy content to 3.5 million dry tonnes of wood biomass[9].

**Table 3**
**Canadian Production of Major Field Crops and Special Crops ('000 tonnes)[7]**

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| **Field Crops** | | | | | |
| Wheat | 25,265 | 20,054 | 28,611 | 26,848 | 23,167 |
| Canola | 9,000 | 9,601 | 12,643 | 12,417 | 11,866 |
| Barley | 9,573 | 10,984 | 11,781 | 9,517 | 7,605 |
| Oats | 3,852 | 4,696 | 4,273 | 2,906 | 2,298 |
| Flaxseed | 989 | 634 | 861 | 930 | 423 |
| Rye | 383 | 252 | 316 | 281 | 216 |
| Soybeans | 3,466 | 2,696 | 3,336 | 3,507 | 4,345 |
| Grain corn | 8,990 | 11,649 | 10,592 | 9,561 | 11,715 |
| Tame hay | 29,966 | 30,217 | 30,432 | 25,022 | 32,681 |
| **Special Crops** | | | | | |
| Canary seed | 133 | 162 | 196 | 159 | 111 |
| Lentils | 693 | 734 | 1,043 | 1,510 | 1,947 |
| Sunflower seed | 157 | 125 | 112 | 102 | 68 |
| Mustard seed | 108 | 123 | 161 | 208 | 187 |
| Dry peas | 2,520 | 2,935 | 3,571 | 3,379 | 2,862 |

### Municipal Waste Biomass

Canadians produce approximately 1,031 kg of waste per person according to 2008 Statistics Canada data[10]. Of this, 777 kg went to landfills or was incinerated while only 254 kg was diverted from landfill. This amount of waste per capita going to landfills is relatively high in comparison with some European countries. For instance, less than 150 kg of waste per person went to landfills in Germany. Assuming 75% of landfill waste is combustible and a moisture of content of 25%, there is a potential 14.5 million dry tonnes of biomass-equivalent available from municipal waste in Canada which could be directed to the production of energy.

## Bioenergy, Chemicals and Products

Direct combustion of raw or densified biomass for heat and power applications is the most straightforward use of biomass for energy. Biomass feedstocks for energy use only is not likely an attractive option due to the current low price of natural gas and the potential abundant supply of shale gas in North America. However, production of low-volume high-value chemicals and other products from biomass with bioenergy as a co-product could be financial feasible. There has been an increasing interest in the production of value-added chemicals from Canadian field crops, in addition to liquid bio-fuels. For instance, Soy 20/20 in Ontario has identified a number of industrial, cosmetic and nutriceutical products potentially manufactured using specialty soybeans as feedstock[11]. Figure 3 shows conversion processes, which could be integrated with bioenergy generation, to produce a range of end-products from different biomass feedstocks. Utilizing municipal solid waste as a feedstock is desirable for the promotion of alternatives to landfill, and to integrate energy applications. The Waste-to-Biofuels Facility under construction in Edmonton will be the world's first industrial-scale municipal waste-to-bio-fuels plant once it is completed in 2012. The $80 million facility will be owned and operated by Enerkem Alberta Biofuels. It will convert 100,000 tonnes of municipal solid waste into 36 million litres of bio-fuels annually and help reduce Alberta's carbon dioxide footprint by six million tonnes over the next 25 years[12].

The liquid bio-fuel industry which produces ethanol and bio-diesel is gradually expanding, primarily due to regulatory supports such as mandatory blending rates by the federal and provincial governments. The feedstocks for producing bio-fuels are currently food-based but are expected to shift to non-food biomass, such as agricultural residues and municipal wastes, as new technologies emerge. Companies which produce bio-chemicals have been rapidly growing, and the recent successful fund raising and Initial Public Offerings (IPO) of new bio-chemicals firms such as Gevo,

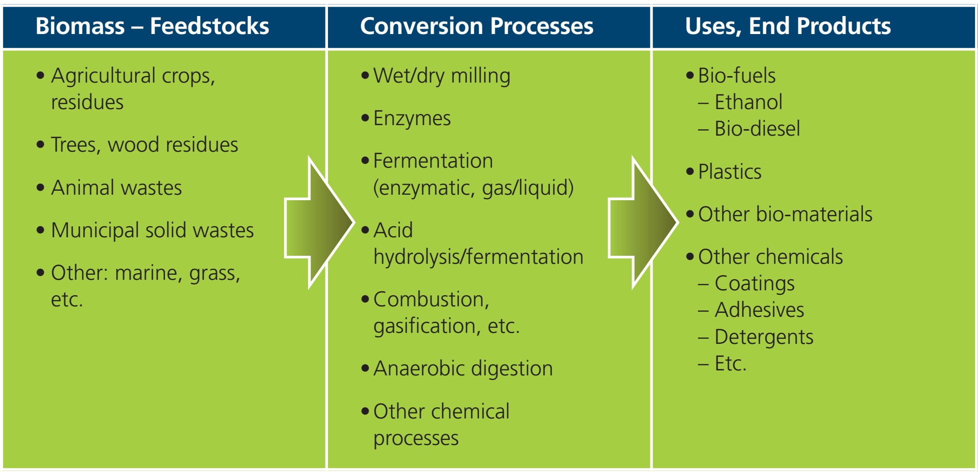


**Figure 3**
**Biomass Feedstocks, Conversion Process and Products[13]**

**Biomass – Feedstocks**

- Agricultural crops, residues
- Trees, wood residues
- Animal wastes
- Municipal solid wastes
- Other: marine, grass, etc.

**Conversion Processes**

- Wet/dry milling
- Enzymes
- Fermentation (enzymatic, gas/liquid)
- Acid hydrolysis/fermentation
- Combustion, gasification, etc.
- Anaerobic digestion
- Other chemical processes

**Uses, End Products**

- Bio-fuels
  – Ethanol
  – Bio-diesel
- Plastics
- Other bio-materials
- Other chemicals
  – Coatings
  – Adhesives
  – Detergents
  – Etc.

Bioamber and Solazyme suggest that there is a growing interest in bio-based fuels and chemicals. Bio-plastics and bio-composite materials are also increasingly replacing higher carbon footprint materials. Ford motor company, Walmart and the Coca-Cola company are large corporations presently leading the creation of markets for bio-based materials.

## Integrated Development Options

Pulp and paper mills are potential candidates for conversion to modern bio-refineries due to their existing infrastructure and experience in handling biomass feedstocks and chemicals, and generating heat and power in conjunction with other products. A number of chemicals and products can be manufactured from forestry biomass: examples of such products are high quality lignin, chemicals and ethanol from both hardwood and softwood species produced by Canadian companies such as Lignol, one of the leading corporations in this area. With declining pulp and paper demand and the struggling housing market in the U.S., the forestry feedstock-based bio-refinery model has a great potential to revive the Canadian forestry industry. In this regard, FP Innovations is a Canadian organization leading the optimization of the Canadian forestry sector value chain and the development of new products and market opportunities.

Cellulosic ethanol with fibres/lignin as co-products is an emerging model for agricultural biomass feedstocks, both purpose-grown or residue-driven. The Danish company Inbicon is advancing its bio-refining technology for producing ethanol and fibres/lignin from wheat straw. A demonstration plant is planned in the U.S. Midwest. ZeaChem Inc. has developed a cellulose-based bio-refinery platform capable of producing advanced ethanol, fuels and chemicals, and recently announced a binding multi-year joint development agreement with Procter & Gamble. Integrating bio-refineries with agricultural activities requiring substantial heat resources, such as vegetable greenhouses or food processing facilities or district heating, could also improve the financial viability of projects, and create rural jobs and economic growth.

Conversion of coal-fired power plants to biomass power generation could also create distributed fuel processing units, i.e., biomass pellet mills in most cases, in nearby regions. For instance, if Ontario Power Generation's Nanticoke power generating station is converted to biomass, this will require two million tonnes of biomass pellets annually from about 15 pellet mills across Ontario. The pellet mills would provide a foundation for future bio-refineries, and further integration with food processing and vegetable greenhouse operations. All the systemic benefits resulting from the displacement of coal in power generation should be assessed and implemented as an integrated solution.

Perennial energy crops such as miscanthus and switchgrass provide annual biomass for 15-20 years once they are established. The massive root systems of these perennial crops increase soil porosity, add soil organic matter, reduce erosion, and offer environmental benefits such as biodiversity and carbon sequestration. Growing perennial energy crops on marginal lands, therefore, represents an integrated development opportunity for biomass feedstocks and soil improvement. The governments of the United Kingdom and United States have respectively been providing incentives for farmers to grow miscanthus and switchgrass on set-aside or marginal lands.

# Bioenergy Challenges

## Technology Development

Bioenergy conversion technologies can be categorized as follows:

a. Direct combustion processes;

b. Thermo-chemical processes; and

c. Bio-chemical processes.

Direct combustion processes employ a wide range of feedstocks, such as wood chips, sawdust, bark, black liquor, straw, municipal solid waste, etc. Direct combustion furnaces are used for the production of heat and/or power. Although the direct combustion of biomass is one the oldest bioenergy conversion techniques, increasingly stringent environmental regulations demand technology improvements. In 2009, the city of Montreal banned the installation of wood-burning appliances, stoves and fireplaces in all new residences or as replacements in existing homes[14]. Particulate emissions from biomass combustion are a major concern in small-scale furnace applications such as residential bioenergy applications. Large-scale users considering the replacement of coal with biomass or co-firing, such as power utilities, are also facing technical challenges[15]. Risk management in handling and storage of biomass fuels and corrosive chemicals in agricultural biomass are major barriers to large-scale bioenergy applications.

Thermo-chemical conversion processes include pyrolysis, gasification, carbonization and catalytic liquefaction. These processes convert the original biomass feedstock, usually under controlled temperature and in an oxygen-deprived environment, into more convenient forms of higher energy density products such as bio-oils or synthetic gases. These products can be used to generate heat and/or power, or to manufacture bio-based chemicals through further refining. The high acidity of pyrolysis oil, the impurity of gasification products, the emissions from carbonization processes, and the high costs of liquefaction catalysts are areas requiring improvement.

The major bio-chemical conversion processes for converting biomass into biogas or bio-ethanol are, respectively, anaerobic digestion and fermentation. The use of micro-organisms for the production of ethanol or biogas is a relatively mature technology. Technology improvements are necessary for the cleaning of the anaerobic biogas before feeding into gas engines to extend their life expectancy. The development of new enzymes and hydrolysis techniques in ethanol production are key areas of technology improvement for increasing conversion efficiency, and reducing production costs.

## Sustainability and Environmental Issues

If biomass feedstocks are used for energy applications without considering sustainability, the negative impacts on the environment could be similar or even more pronounced than the use of conventional hydrocarbon fuels. The major concerns in the development of bioenergy are:

a. Land use conflict;
b. Deforestation and loss of biodiversity;
c. Soil degradation;
d. Water use and contamination; and
e. Socio-economic issues such as negative impacts on human health.

Growing energy crops on prime agricultural land, or producing ethanol from corn, and bio-diesel from canola, are facing public scrutiny with regards to food versus fuel concerns. Cutting forests in Brazil for bio-fuel crops is considered alarming for reasons of deforestation, their potential contribution to changes in weather patterns, and related negative impacts. The loss of biodiversity from deforestation, and the intensive cultivation of a few bio-fuel crops could also have devastating effects on the environment, and all living beings in general. When agricultural residues, such as corn stovers, are removed from the soil beyond a sustainable quantity, soil degradation—due to the loss of soil organic matter—could be a serious issue in the long-term productivity of agricultural land.

If energy crops or other bio-fuel crops require a substantial amount of water, chemicals and fertilizers, this could lead to the contamination of lakes, rivers and water systems. The creation of aquatic dead zones by chemicals contained in the water run-off of agricultural land has arisen as a severe environmental problem, threatening aquatic creatures and the complete food chain. The storage and handling of biomass requires careful design and proper industry standards to reduce potential harmful impacts on human health. Accidents related to the spontaneous combustion of biomass in storage have been reported, and risk mitigation measures are important.

## Commercialization Risk

Although there has been significant research and development work on bioenergy conversion and bio-refining technologies, commercialization activities are relatively slow, especially in Canada in comparison to the United States and Europe. The major risk areas in commercializing bio-based technologies include:

a. Lack of financing in technology scale-up;
b. Regulatory barriers;
c. Uncertainties in feedstock availability and pricing; and
d. Strong competition from conventional hydrocarbon products.

The scale-up of bioenergy conversion and bio-refining technologies to the pilot unit and demonstration stage are capital-intensive, and can exceed $100 million. Venture capital investments in bio-fuel and alternative technologies peaked in 2007, and dropped by approximately 50% in 2009[16]. The recent IPO activities of bio-based firms seem encouraging, though perceived and actual risks remain in financing technology scale-up. Regulatory barriers include the approval of new bio-fuel crops from appropriate agricultural authorities, permit requirements, and the lack of streamlined process for all regulatory approvals.

Secure, long-term supply, and stable pricing of feedstocks is a major concern of bio-based firms. Availability of sustainable feedstocks usually dictates the location of bio-based energy generation and manufacturing facilities which are sometimes distant from markets, and the lack of adequate transportation and handling infrastructures represents an additional commercialization risk. As mentioned before, a major threat to the development of a bio-based economy is strong competition from the well-developed, conventional petrochemical industry, whose diverse range of products derived from non-renewable hydrocarbon resources provides a significant competitive advantage with respect to emerging bio-based competition. Over the long run, bio-based energy and products need to be comparable in terms of cost and performance with petroleum-based energy and products, a significant challenge at the present time.

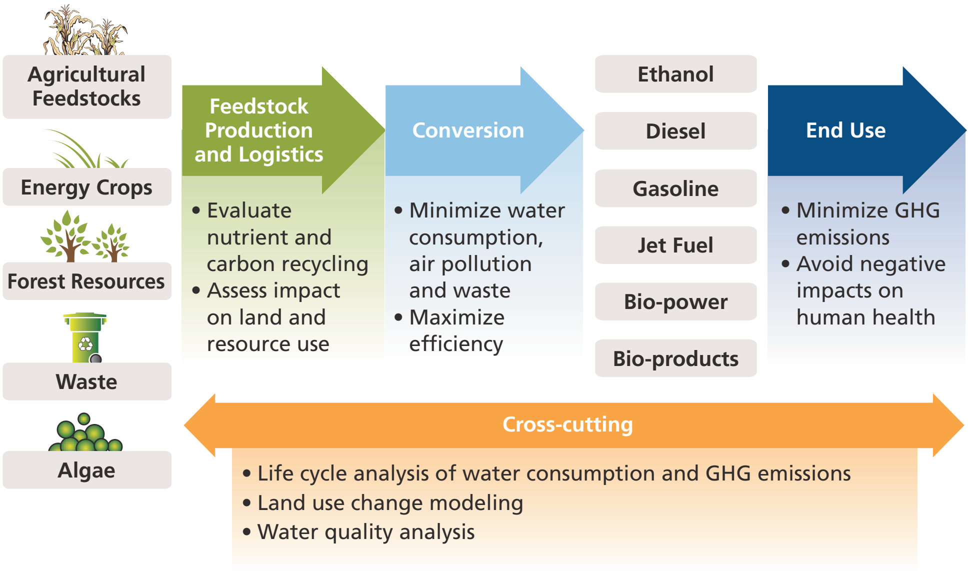
## Pathway Forward

The fundamental requirement in developing a bioenergy industry is to incorporate sustainability doctrines in every segment of the value chain as shown in Figure 4. This will ensure the maximization of renewable benefits from biomass, and the minimization of negative impacts on land, water, air and all living beings.

The pathway forward to increase the share of bioenergy in Canada's overall energy mix requires the following actions:

- Develop sustainability guidelines for harvesting forestry and agricultural biomass;
- Fund the research and development of bio-refining technologies;
- Create effective leverage funding mechanisms to share the risk of scaling-up of technologies;
- Provide business incubation support for the commercialization of bioenergy conversion and bio-based technologies/products;
- Build transportation and other infrastructure to optimally locate bio-refining clusters;
- Identify the potential of integrating biomass feedstocks into existing petro-chemical industry processes;
- Streamline regulatory approval processes, from growing new crops to granting permits for the bio-based industry;
- Develop industry health and safety standards for bio-based industries in consultation with agricultural communities, industries and other stakeholders;

**Figure 4**
**Development of Bioenergy and Bio-products and Sustainability Principles**[17]



- Encourage and provide necessary assistance to venture capital firms interested in bioenergy and renewable technologies;
- Invest in product development and market research for bioenergy, chemicals and products, and disseminate information;
- Assess the integrated development potential of bioenergy and other emerging industries;
- Create incentives for bio-based energy, chemicals and products with clear exit strategies to assist the launch of the bio-based economy; and
- Incrementally develop mechanisms, both voluntary and mandatory, for bio-based industries to claim carbon credits from their products/processes.

Canada's abundant biomass resources are an incentive for developing a vibrant bio-economy sector. However, this needs supportive government policies and initiatives, well-designed incentives, public education, and collaboration among all stakeholders. If all these elements are in place, bioenergy, as a part of an integrated and sustainable development effort, can contribute significantly to Canada's overall energy mix and to the reduction of Canada's carbon footprint.

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# 10

# Imagining Our Energy Future

Katherine J. Albion
Richard J. Marceau
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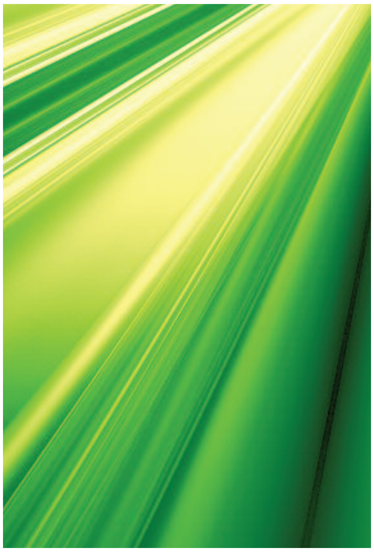


## ABSTRACT

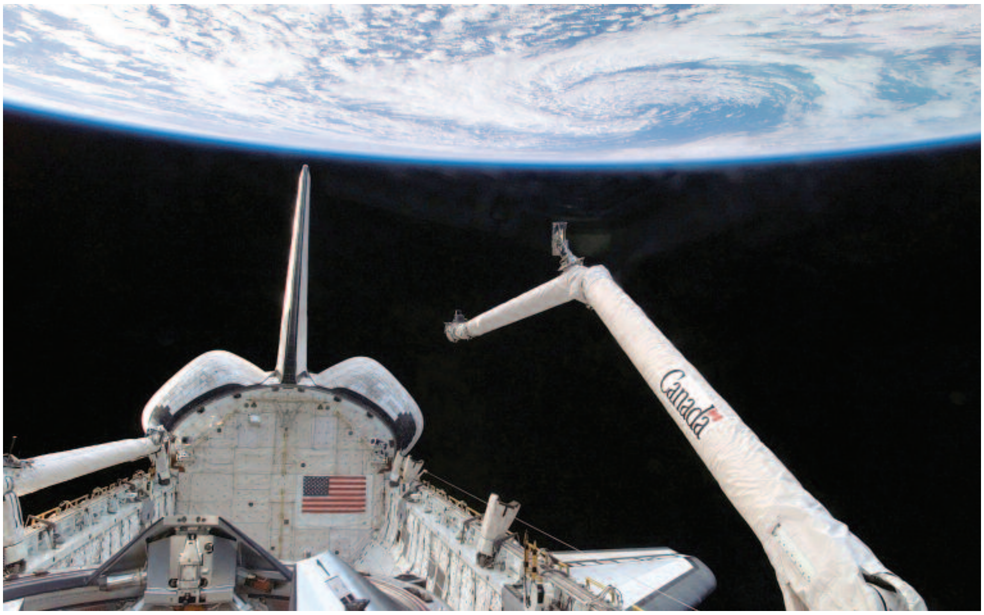
Canada has a history of challenges related to technology commercialization. In the 1970s, Senator Maurice Lamontagne chaired a Special Senate Committee which proposed "A Science Policy for Canada" to address Canada's inability to cross the commercialization chasm[1]. Forty years later, the Canadian commercialization 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.

History shows that Canada is most innovative when striving to complete a large national project. "Big projects" provide Canadian inventors, innovators and entrepreneurs with the razor-sharp focus required to make a particular national vision a reality, and move Canada's performance to a higher level. History also shows that, without a big project, Canada is challenged in commercializing its technologies and reaping the attendant benefits. Canada is most productive when a big project is underway, backed by consensus and vision, with an array of new, innovative technologies under development.

Nine big projects have been identified in this book as "candidate big projects" for Canada to undertake over the next few decades. These recommended projects will maximize the value of Canadian energy assets, capitalize on its other valuable assets—its world-class scientists, engineers, technologists and researchers, its world-class research infrastructure, and some of the best research funding in the world—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 40 years, and continued prosperity for Canadians long into the future.

# Canada's Commercialization Challenge

Canada is challenged with regards to commercialization. In the 1970s, Senator Maurice Lamontagne chaired a Special Senate Committee which proposed "A Science Policy for Canada"[1]. This series of reports addressed Canada's apparent poor performance in crossing the commercialization chasm, and provided recommendations designed to resolve the dilemma. Over the years, Canada's federal and provincial governments have created numerous research and commercialization programs, as well as tax credits, regarded as some of the most generous in the world, to assist with the development and commercialization of Canadian technologies. Unfortunately, these programs have not significantly improved Canada's commercialization record.



The current situation recalls that of the 1970s. Recently published reports continue to rank Canada behind its G7 partners in terms of innovation and productivity. In 2010, the Federal Government ordered a review of Federal support to research and development which resulted in numerous recommendations[2] convergent with many other recent studies, including that of the Canadian Council of Academies[3] and the Science and Technology Innovation Council[4]. New programs and funding aimed to correct the commercialization situation have yet to produce significant results.

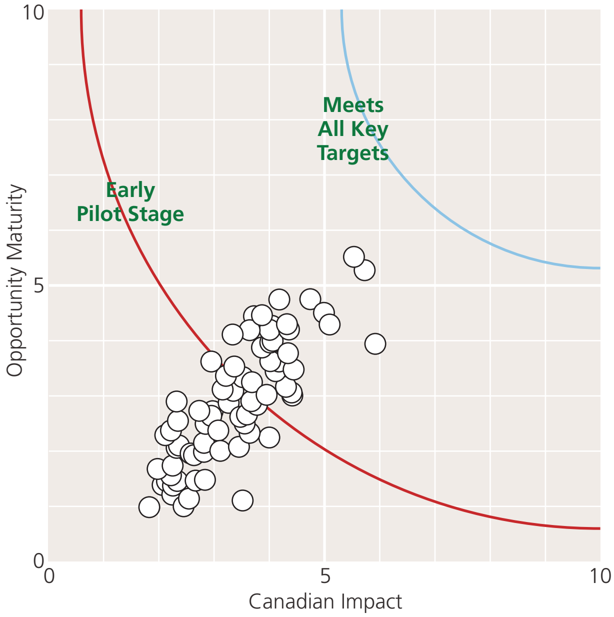
# Measuring the Commercialization Challenge

A 2009 report prepared by the Canadian Academy of Engineering reviewed more than 80 energy technology projects under development by Canadian universities, government laboratories, industry and energy associations. These energy projects were evaluated on the basis of factors believed to be necessary for the successful commercial deployment of the technology[5] (Table 1). Figure 1 illustrates the results of this study as a cluster of points in the lower left quadrant, and confirms that Canadian researchers have innovative ideas and projects, but that these projects are small scale and have yet to cross the commercialization chasm[6]. To move projects across the chasm, Canada must implement an innovation strategy better suited to the Canadian environment.

**Table 1**
**Evaluation Criteria to Determine the Commercialization Status of Various Energy Technologies**

| Opportunity Maturity | Enablers | Canadian Impact |
|---|---|---|
| Science | Funding | Economic |
| Technology | Collaboration | Environment |
| | | Sustainability |

**Figure 1**
**Commercialization Status of 80 Energy Technology Research and Development Projects Underway in Canada in 2009**



# Canada's Successful Innovation Strategy – Big Projects

Canada's history has shown it to be at its most innovative and productive when a large, focused, national project was underway, supported by vision and consensus, with an array of new, innovative technologies under development that were required for project completion. As evidenced in Chapter 1, the construction and subsequent operational phases of Canada's "big projects" have driven innovation, sparked successful entrepreneurship and enterprise, accelerated economic activity and job creation, and resulted in the generation of new wealth, increased GPD and a higher quality of life for its population over many generations.

In the past, many factors have driven Canada to resort to "big projects": a small, sparsely distributed population over an immense geographical landscape; the need to establish its sovereignty and protect its borders; the need to create a sense of unity across the nation; the need to provide communications and trade infrastructure between distant centres; and the need to develop opportunity and competitive advantages for its people. Canada has lived in the shadow of an emerging world power (i.e., the United States in the 19th century), or in partnership with an established world power (i.e., the British Empire in the 19th century; the United States in the 20th and 21st century). These factors, in combination with limited financial resources, have forced successive Canadian governments to have a sharp focus on what was needed to build a nation, and Canada's response to these needs has been its "big projects".

Canada's "Big Project Innovation Strategy" provides a very different window for assessing Canada's innovation record. Big projects offer home-grown technologies and entrepreneurs the opportunity to enjoy early market success, and provide a strong foundation for the later development of export markets for unique services and products. The "Big Project Innovation Strategy" is the nation-building strategy that has been spectacularly successful in developing Canada's economic infrastructure in the past, and may still be its most effective strategy for continuing Canada's economic development in the future. Many of the historical drivers of "big projects" in the 19th and 20th centuries remain true of Canada's strategic environment in the 21st century.

Canada's "Big Project Innovation Strategy", applied to the energy sector, is the strategy for transforming Canada into the world's first true sustainable, environmentally-sound, energy superpower. Canada is fortunate to possess massive supplies of non-renewable and renewable energy resources, and these formidable assets are complemented by other, equally valuable, unique strengths:

1. A strong banking system, possibly the strongest in the world at the present time, and a sound economy;
2. A highly ranked post-secondary education system which graduates both highly skilled workers, and highly qualified personnel;
3. World-class scientists, engineers, project managers, technologists and technicians with the abilities to develop the next generation of energy technologies and implement big projects; and
4. Proven industrial capacity and capability to design, manage, build, commission and deliver large, nation-building projects.

In between "big projects", many new ideas and innovations continue to arise from Canada's R&D ecosystem, but the path from "laboratory" to "market" is uneven. The innovation model of research, development, venture capital, entrepreneurship and commercialization more generally associated with the United States has positively impacted the Canadian innovation ecosystem, but less than elsewhere. Due to its history, large size and relatively low population, Canada's most successful innovation strategy has been that of initiating and implementing "big projects".

## Pathway Forward – Big Projects

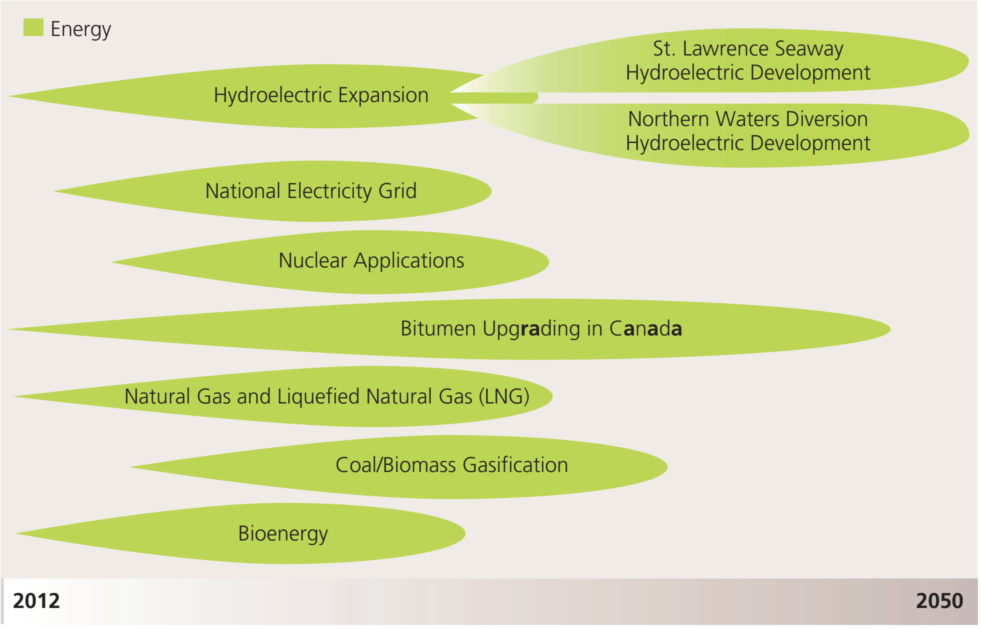
Canada generates a portion of its wealth through the export of raw materials for processing in other regions of the world. This has been the case since the first days of Canada's settlement, when explorers shipped animal furs back to Europe, and has contributed to Canada's reputation as "a hewer of wood and a drawer of water"[7].

As documented in Chapter 1, Canada has had a successful history of implementing large, nation-building projects which share many characteristics, including:

- Intense public scrutiny, discussion and debate;
- Completion over many years;
- Creation of a large number of jobs;
- Public and private sector partnerships and financing;
- Investments more than recovered as projects became profitable; and
- Economic stimulus of entire regions[8].

The Canadian Academy of Engineering, through discussions with many energy experts, has identified a number of big projects that have the potential to propel Canada towards its goal of becoming a sustainable, environmentally-sound, energy superpower. These nation-building projects are shown in Figure 2 in one possible implementation scenario.

**Figure 2**
**Canada's Big Projects for 2012 to 2050**

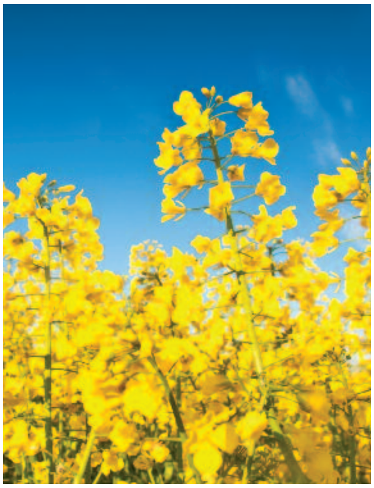


The recommended big projects from 2012 to 2050 are as follows:

1. Hydroelectric Expansion – Develop hydro and tidal power resources to effectively double Canada's hydroelectric power generating capacity, and significantly lower the quantity of greenhouse gases (GHG) produced each year. Sites amounting to nearly 35 GW of hydroelectric capacity have been identified for near-term development;
2. St. Lawrence Seaway Water Management and Hydroelectric Development – Construct additional hydraulic infrastructure for water level and flow management in the St. Lawrence River – Great Lakes watershed while creating additional hydroelectric generating capacity on the order of 1 GW;
3. Northern Water Diversion Hydroelectric Development – Divert fresh water from the James Bay watershed to the St. Lawrence River through the Ottawa River, increasing the latter's

hydroelectric generating capacity by 3 GW while contributing to re-establish water levels in the St. Lawrence River and offering drinking water for up to 150 million people;

4. National Electricity Grid – Connect eastern and western Canada by means of a new, high-capacity transmission system to replace high-GHG thermal generation with distant low-GHG hydroelectric and tidal generation, liberate stranded power, improve market access for electrical power for intermittent renewables such as wind and solar power plants, share power across time zones, and significantly reduce Canada's carbon footprint;
5. Nuclear Applications – Provide thermal energy for oil sands bitumen recovery and processing, while decreasing the quantity of greenhouse gas emissions generated;
6. Bitumen Upgrading in Canada – Provide a $60 billion per year benefit to Canada that is lost if raw bitumen is shipped out of the country for upgrading in other countries;
7. Liquefied Natural Gas – Seize a major opportunity to develop Canada's capacity to export liquefied natural gas to world markets. Government and industry need to capture this opportunity by reducing policy and technology barriers;
8. Coal/Biomass Gasification – Produce large quantities of energy and chemicals from Canada's proven coal reserves and from sustainably harvested biomass;
9. Bioenergy – Support bioenergy projects and seize a significant economic opportunity to develop Canada's enormous biomass potential.


**Canola, Grown for Conversion to Bio-diesel**

Canada is fortunate to have the ability to undertake these remarkable projects. CIBC analysts have estimated that for every $1 billion invested in the electricity sector alone, over 1,000 jobs are created[9]. This analysis also shows that big projects in hydroelectricity and the oil sands alone could lead to the creation of over 1 million jobs in the next 20 years. A unique feature is that such jobs can be created in Canada while many countries are headed towards another recession. Investments in large energy projects generate revenues following project completion, thereby reimbursing project capital costs, financing costs[10], and generating a significant return on investment over time.

## Measuring Canada's Progress

Canada's opportunity to be a world leader in the energy sector does not exist in any other economic sector. Its leadership position in such areas as forest products, pulp and paper, mining and minerals processing, and electronics and automotive manufacturing has diminished. Canada has missed past opportunities. Countries around the world are knowledgeable of Canada's remarkable energy resource endowment, and are watching to see if – and especially how – its resources are developed. What are Canada's options?

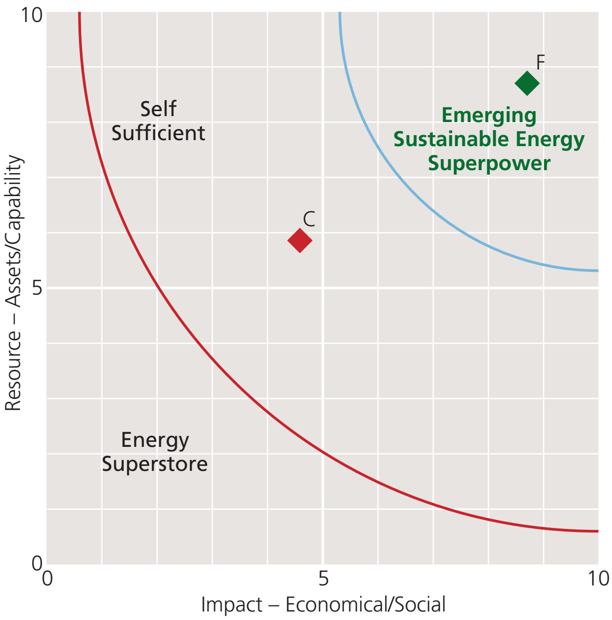
In 2009, the Canadian Academy of Engineering Energy Pathways Task Force undertook an evaluation of Canada's current status towards becoming an energy superpower[11]. The evaluation was conducted on the basis of the nine criteria listed in Table 2. The first and third columns contain criteria that describe Canadian resources and their impact on Canada, respectively. The second column contains criteria that link the Resources criteria to the Impact criteria.

Figure 3 illustrates Canada's positioning in terms of these criteria. Canada's current position – shown as point "C" in this chart – is calculated[5] based on the progress it has made in the economic

**Table 2**
**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 |

**Figure 3**
**Canada's Energy Superpower Trajectory – Current and Future States**



development of its fossil fuels, renewable energy sources (in particular hydroelectric) and nuclear power (and related technologies), and reflects its relatively low and decreasing greenhouse gas emissions when measured on an intensity basis. Also, such progress has been achieved in large part due to past big projects. Its potential future state "F" is an estimate of Canada's position if the big projects described in this book are successfully undertaken and completed, putting it on the trajectory to becoming a sustainable energy superpower.

Based on these observations, Canada has three possible choices:

1. Continue to sell its raw energy resources (bitumen, uranium, etc.) into international markets, acting as an energy superstore;

2. Upgrade its energy assets in an environmentally-responsible and sustainable manner to meet its own needs for fuels and chemical products, essentially becoming self-sufficient; or

3. Upgrade its energy assets in an environmentally-responsible and sustainable manner, become a significant supplier of the world's energy currencies and needs, influence the world in transitioning from high-carbon to low-carbon energy currencies, and be recognized as a sustainable energy superpower.

All three future scenarios remain possible. However, only the last can have paradigm-shifting impact on Canada as a nation. Canada must decide which future it wishes to achieve.

# Imagining Deeper into Canada's Energy Future

The nine big projects proposed in this book will generate two types of opportunities:

a. Opportunities directly related to the construction and ongoing operation of these big projects; and

b. Opportunities arising from these projects as enablers of future initiatives in a highly integrated and optimized energy system.

This book's preceding chapters have detailed the considerable direct opportunities arising from the nine proposed big projects. Significant indirect opportunities will also arise, due to the "enabling characteristic" of these projects. For example, the creation of a national electricity grid enables the creation of large wind, solar and/or nuclear generating farms in the far north which could work in tandem with hydroelectric reservoirs to create additional generating capacity, while storing energy in hydroelectric power plant reservoirs when appropriate. Such energy storage could also happen in the form of hydrogen, strengthening the place of hydrogen as the combustion fuel of choice, and opening the future to the concept of hydricity where only two dominant energy currencies, non-carbon-based, serve the world's energy needs: electricity and hydrogen.

The development of a highly integrated and optimized energy system will also fundamentally alter our view of carbon dioxide. Carbon dioxide will be understood to be a valuable commodity feedstock for new, value-added processes and products, not only a waste product in the combustion of carbon-based energy resources. There is growing evidence that this shift has begun[15,16]; someday, industrial-scale carbon-fixation processes producing a variety of value-added products may well contribute to reversing the accumulation of atmospheric carbon. Finally, a highly efficient, integrated and low-carbon Canadian energy system would likely include the aggressive expansion of district energy systems and geothermal systems. These future opportunities are discussed briefly below.

## Wind, Solar and/or Nuclear Power Generation Parks

Once a national grid is established, it is possible to consider the creation of large wind, solar and/or nuclear power generation parks (e.g., in isolated regions such as the far north) which could work in tandem with hydroelectric reservoirs to serve as a combination of base and intermittent power generating capacity, and to store energy in hydroelectric power station reservoirs when appropriate.

One aspect of this is that the approval processes for new nuclear power plants are increasingly challenging due to opposition from those closest to the proposed sites. Another is that large wind-based electricity generating projects have also begun to encounter significant opposition close to population centres, while wind and solar farms tend to complement each other from an operational perspective. Already, for such projects, many years of study and promotion are required with no guarantee of success, even after the expenditure of a large amount of money and time, especially in the case of nuclear power plants. In the nuclear area especially, these challenges, and issues arising from the recent Fukushima disaster, are discouraging power companies and regional authorities around the world from considering the construction of new base-load nuclear power plants.

An alternative approach would be to consider obtaining approval for the construction of a pre-determined number of wind generators, solar generators and/or nuclear reactors at a single site in a relatively remote region, with a high-capacity transmission corridor linking such generation to distant, high population urban centres. This would facilitate the concentration of all necessary support services in a single region, reduce the cost of producing power and contribute to more uniform power costs across the country. There would only need to be one comprehensive environmental study. This idea is presently under consideration by several countries: for example, the Indian cabinet has reserved two potential sites for a nuclear park, and the Los Alamos National Laboratory in the United States suggested in 2004 that an array of high temperature nuclear reactors be built underground and connected to a continental super grid[12].

## Coupling of Hydrogen and Electricity (Hydricity)

Hydrogen and electricity are "dual currencies" as they allow—in principle—for energy conversion in both directions, and need not be associated with carbon-based energy resources. Electricity can be used to produce hydrogen sustainably by electrolysis from electricity generated from hydroelectric, wind, solar or nuclear power, either to store energy or to strengthen hydrogen as the combustion fuel of choice in a large variety of existing applications, while maintaining considerable intrinsic value as a chemical intermediate. Second, hydrogen can also be produced thermo-chemically, either from waste heat or a dedicated source such as nuclear power, thereby favouring synergies in Canada's energy system and optimizing its efficiency. Finally, hydrogen can be used to generate electricity on demand. But like foreign monetary currency exchanges, there are losses associated with each conversion. As a result, converting back and forth is not cost-effective unless there is an intermediate change in currency value during the period between exchanges.

An innovative view of this is proposed by David Scott[13,14] who notes that our future civilization need only resort to one electronic currency (electricity) and one protonic currency (hydrogen), and describes the synergies between them as follows:

- Hydrogen can serve as a transportation fuel or a material feedstock. Electricity has tremendous barriers for these applications;
- Electricity can be used to transmit, process and store information. Hydrogen cannot;
- Hydrogen can be stored in enormous quantities. Electricity cannot (at least not yet); and
- Electricity can transport energy without moving material. Hydrogen cannot.

## Carbon Dioxide as a Raw Material

Canada suffers from an inaccurate media perception of its environmental record in relation to carbon dioxide emissions. For example, it is not widely known that Canada's carbon dioxide emissions are less than those of the United States on an energy output basis. Canada possesses a large share of the world's energy assets and its total emissions necessarily reflect this, unless a conscious decision is made not to share this endowment. Canada is presently addressing the carbon dioxide challenge in many innovative ways. For example, in Alberta, billions of dollars are being spent on projects to capture and sequester carbon dioxide. Ontario had some of the cleanest burning coal plants in North America due to the installation of advanced scrubbing technologies. The province is now converting its coal-fired power plants to alternative fuels to further reduce net carbon dioxide production.

Canadian industries are developing innovative uses for carbon dioxide. Many of these new methods use carbon dioxide as a feedstock for the production of energy through biological processes. If industrial processes utilizing carbon dioxide to create value-added products can become widespread, such processes could contribute to the reversal of the concentration of greenhouse gases in the atmosphere. Two industries in southern Ontario are particularly creative with regards to the use of carbon dioxide.


**Envirofresh Farms, Courtright**

In Courtright, Ontario, CF Industries manufactures nitrogen fertilizer products, and in the process, generates a very pure stream of carbon dioxide. CF Industries partnered with local entrepreneurs to construct a 25 acre greenhouse dedicated to the production of sweet peppers. Excess low grade heat and the pure carbon dioxide stream from CF Industries are piped to the greenhouse, located next to the manufacturing plant, to provide a growing atmosphere for the pepper plants. Not only does the carbon dioxide provide the food required for the pepper plants to grow, it is also used to control any pest infestations in the greenhouse by increasing the carbon dioxide levels overnight. Since the opening of the greenhouse, the pepper yields have been excellent and future expansion is planned. This use of carbon dioxide is an ideal approach to produce energy – through the production of food. Canada has a strong agricultural sector. Integration of the refining sector with the agricultural and manufacturing sectors will not only decrease Canada's carbon dioxide emissions, but will also increase productivity in other areas of the Canadian economy.

St. Mary's Cement produces cement, concrete products and aggregates for the construction industry in Ontario. Located at the manufacturing plant in St. Mary's is a demonstration facility where carbon dioxide is used for the production of algae. Carbon dioxide is produced in the cement manufacturing process and some of the stream is diverted to promote algae growth. In return, the algae release oxygen, and produce algal oil which the cement company plans to convert to bio-fuels for use in their truck fleet. St. Mary's Cement also recycles excess heat in the process. Following the extraction of algal oil from the algae cell, the residual cell material is dried using this excess heat, and the dried residual cell material is burned as fuel in the cement kilns. Consequently, this use of carbon dioxide creates different forms of energy—as a transportation fuel and fuel for the cement kiln[15].

## District Energy

Policy makers across Canada are faced with the coincident challenges of urban intensification, growing energy demands, aging energy infrastructure and rising replacement costs for new and refurbished energy services. Finding new innovative approaches to meeting community energy demand, while also meeting environmental and energy efficiency imperatives, are goals shared by many stakeholders. District energy solutions involve well-understood and well-applied technologies, have had positive economic, energy and environmental results in many jurisdictions, and have contributed to energy, economic and environmental sustainability in countries around the world. In Canada, district energy systems have not gained significant market penetration, but the potential and interest are growing. District energy systems would significantly contribute to efficiencies in a more highly integrated Canadian energy system, and would more readily interconnect with such heat-based energy systems as geothermal energy systems.

## Conclusion

Canada has massive energy resources that can be developed sustainably, in the interest of its own people, and people around the world. It has a sound banking system, a highly skilled technical, project management and business workforce, world-class universities and research personnel and infrastructure, companies experienced in the management and delivery of nation-building projects, and a proven innovation strategy based on "big projects". In the past, "big projects" have provided the focus and impetus for taking Canadian technology to another level, thereby providing the foundation for developing new markets. They can do so again.

Nine big projects have been identified in this book as "candidate big projects" for Canada to undertake over the next few decades. These projects can maximize the value of Canadian energy assets and propel Canada to the status of a sustainable energy superpower. The benefits will result in sustained and significant job creation over the next 40 years, continued prosperity for Canadians long into the future, and a significant reduction of Canada's carbon footprint. Let us have the vision to embark on this journey.

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