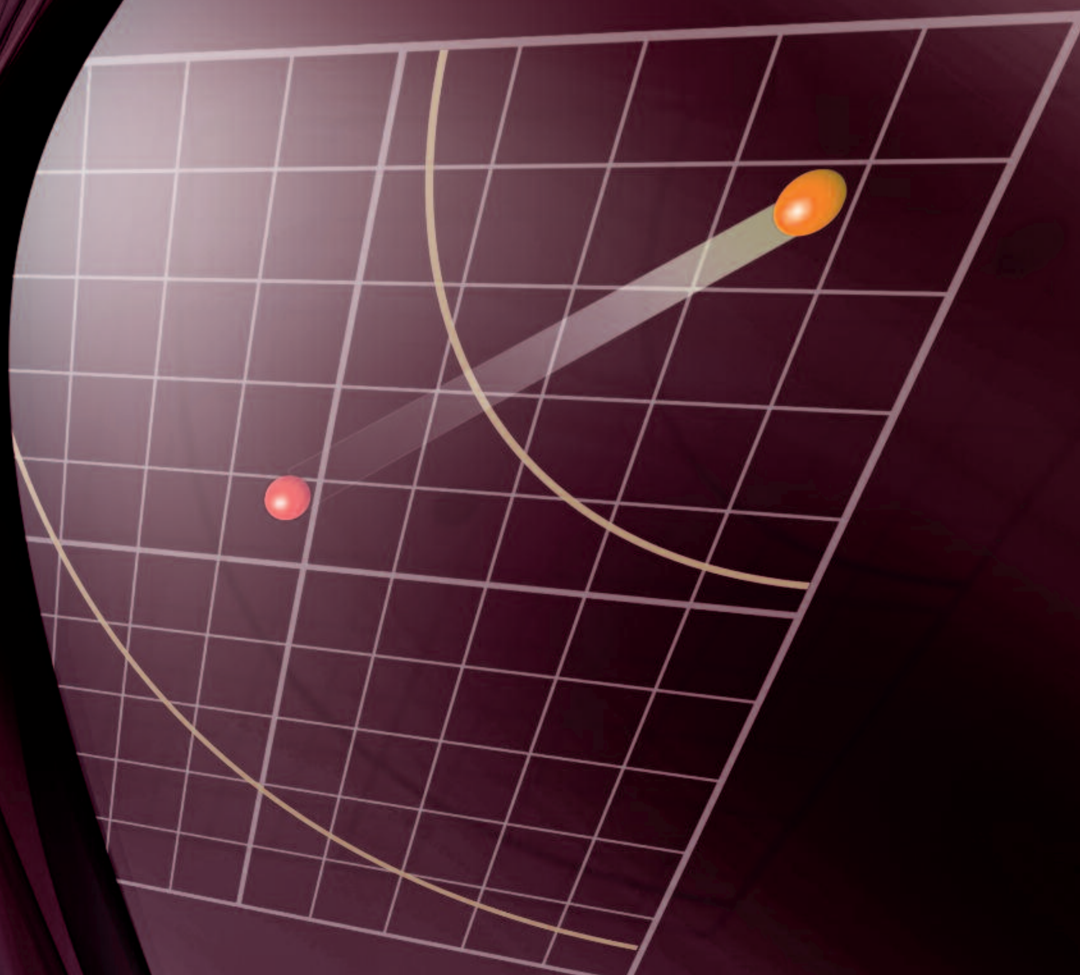
CANADA:

Becoming a Sustainable Energy Powerhouse

FIRST EDITION



A project undertaken by the

Canadian Academy of Engineering

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

Sponsored by

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Energy and Environment Solutions

THE BOWMAN CENTRE

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Edited by
Richard J. Marceau and
Clement W. Bowman

First edition, July 2014

For print copies of this publication, please contact:

Canadian Academy of Engineering
180 Elgin Street, Suite 1402
Ottawa, Ontario K2P 2K3
Tel: 613-235-9056
Fax: 613-235-6861
Email: info@cae-acg.ca

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The Canadian Academy of Engineering
Leadership in Engineering Advice for Canada

L'Académie canadienne du génie
Chef de file en matière d'expertise-conseil en génie pour le Canada

This book, "Canada: Becoming a Sustainable Energy Powerhouse" is the work of many people, some as primary authors, some as sources of information, some as reviewers, and some as Members of the long standing Canadian Academy of Engineering's Energy Pathways Task Force. Whatever their role, they all believed that energy was, and would continue to be, one of the drivers of the Canadian economy and a source of prosperity and jobs. They are identified below.

Authors

Katherine J. Albion
Director, Bowman Centre, Western Sarnia-Lambton Research Park

Gilbert Bennett
Vice-President, Lower Churchill, Nalcor Energy

Clement W. Bowman
FCAE, Chairman, CAE Energy Pathways Task Force

Terri Chu
Project Analyst, FVB Energy Inc.

F. Pierre Gingras
Hydroelectricity Specialist, Hydro-Québec (retired)

Marshall J. Kern
Product Stewardship Expertise Centre Leader, Dow Chemical Canada (retired)

Richard J. Marceau
FCAE, Vice-President (Research), Memorial University of Newfoundland; President, Canadian Academy of Engineering

Daniel A. Meneley
Adjunct Professor, University of Ontario Institute of Technology

Jatin Nathwani
Executive Director, Waterloo Institute for Sustainable Energy (WISE), University of Waterloo

Walter F. Petryschuk
FCAE, Associate, Bowman Centre, Western Sarnia-Lambton Research Park; Site Director, Suncor Sarnia Refinery (retired)

Mary Ellen Richardson
President, Mary Ellen Richardson Inc.

Marlena Rogowska
Urban and Regional Planner

Mark Shrimpton
Principal, Stantec Consulting Ltd.

Jim Stanford
Economist, Unifor; Globe and Mail Columnist

Donald E. Wood
Associate, Bowman Centre, Western Sarnia-Lambton Research Park; Vice President, Logistics and Business Development, Polysar (retired)

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AlbertaInnovates: Energy and Environment Solutions

Our goal is to help Alberta become a global leader in sustainable energy production and exceptional water management. We work with our partners to identify critical technology gaps and apply world-class innovation management strategies and research to develop solutions for the biggest challenges facing Alberta's energy and environment sector.

THEBOWMANCENTRE

Bowman Centre, Western Sarnia-Lambton Research Park

Our goal is to catalyze the implementation of new "big energy projects," representing the Canadian Innovation Strategy for the current half century. Our focus is on the generation of value-added products and services from Canada's hydrocarbon and biomass feedstocks for the improvement of Canada's GDP and the generation of jobs.

Contributors

Bruce Ander
President & CEO, Markham District Energy

Ed Brost
President, JE&M Consulting Ltd.

Bruce Cater
Refinery Economics, Suncor (retired)

Zhewen Chen
Manager, Program Development and Partnerships, Waterloo Institute for Sustainable Energy, University of Waterloo

Duke du Plessis
Senior Advisor, Alberta Innovates: Energy and Environment Solutions

Richard Damecour
CEO, FVB Energy Inc.

Steve Dorey
Chair, Energy Council of Canada's Studies Committee

Dana Feltham
Stantec Consulting Ltd.

Raymond Gosine
FCAE, Associate Vice-President (Research), Memorial University of Newfoundland

H. Clarke Henry
Research Manager, Imperial Oil (retired)

Ken Hicks
Department of Finance, Government of Newfoundland and Labrador

Terrence Hoffman
Emeritus Professor of Chemical Engineering, McMaster University; Principal Chemical Engineer, Polysar Ltd. (retired)

Eddy Isaacs
FCAE, President/CEO, Alberta Innovates: Energy and Environment Solutions

John Kramers
CEO, ProGrid Evaluation Solutions

Larry MacDonald
CFO, Nova Chemicals (retired)

Aung N. Oo
Commercialization Engineer, Bowman Centre, Western Sarnia-Lambton Research Park

Surindar Singh
Executive Director, Renewables & Emerging Technologies, Alberta Innovates: Energy and Environment Solutions

Kirk M. Wilson
Senior Vice President and Head, Bayer Technology Services Americas, Bayer Business and Technology Services, LLC. (retired)

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Preface


Richard J. Marceau


Clement W. Bowman

We have worked together over the past nine years, to the fullest extent that our respective "day jobs" permitted. We started with an understanding that energy is an important sector of the Canadian economy and of life in this country. Our understanding has now evolved into a belief that energy is the only pathway to Canadian economic and social well-being in this current half century. We also believe that energy presents a unique opportunity of bringing greater unity to our country in spirit, thought and action, in a way that has challenged Canadians for decades.

This leads us to propose the following three goals for unleashing unparalleled opportunity for all Canadians over the next half century:

- Add value to Canada's energy exports, extending our country's value chain and strengthening our innovation ecosystem.
- Contribute to reducing North America's carbon footprint, such as being the lowest-cost producer of low-GHG electricity.
- Contribute to the increasing global energy demand, recognizing Canada's massive energy endowment.

In our 2012 book entitled "Canada: Winning as a Sustainable Energy Superpower" sponsored by the Canadian Academy of Engineering, we demonstrated how Canada's aspirations of global energy leadership are well within its grasp.

In this new book, also sponsored by the Canadian Academy of Engineering, "Canada: Becoming a Sustainable Energy Powerhouse," we take the next step and present a plan for making this a reality.

Prime Minister Stephen Harper, July 2006: "[Investors] ... have recognized Canada's emergence as a global energy powerhouse – the emerging 'energy superpower' our government intends to build."

Peter Lougheed, March 2007: "I just find it completely unacceptable that our resource involves shipping jobs down the pipeline with bitumen to the United States..."

Jim Prentice, May 2012: "The era of nation-building is far from over. Canada still has enormous untapped resource wealth, and planned megaprojects across the country hold out the promise of unlocking that potential and securing new markets for Canadian energy."

Frank McKenna, May 2013: Canada is seeing "value destruction of a scale we've never witnessed before in this country."

Jim Stanford, May 2013: "Canadians are asking is there not more for us in the world economy than just digging stuff out of the ground?" "The pejorative term of 'hewers of wood and drawers of water' now has been expanded... to 'hewers of wood, drawers of water, and scrapers of tar'."

Thomas Mulcair, December 2013: "Canada's natural resources are a tremendous blessing, and our energy sector is the motor of the Canadian economy."

Brian Mulroney, April 2014 (addressing Canada as a resource superpower): "The question is not 'Why?' but rather 'Why not?'"

To this end, we have brought together experts from across the country to chart the way forward to the incredible opportunities open to all Canadians. Other prominent Canadians share our enthusiasm, as evidenced by the quotes in the side-bar.

We hope that you agree with our plan. We especially hope that you will partner with us to make it a reality. It indeed comes down to "Why not"?

Richard J. Marceau
PEng, PhD, FCAE
President, The Canadian Academy of Engineering
Vice-President (Research), Memorial University of Newfoundland

Clement W. Bowman
C.M. PEng, PhD, HCIC, FCAE
Chair, The Canadian Academy of Engineering Energy Pathways Task Force

Executive Summary

CANADA'S THREE ENERGY CHALLENGES

- Add value to Canada's energy exports, extending our country's value chain and strengthening our innovation ecosystem.
- Contribute to reducing North America's carbon footprint, by becoming the lowest-cost producer of low-GHG electricity.
- Contribute to the increasing global energy demand, recognizing Canada's massive energy endowment.

CANADA'S INNOVATION STRATEGY

- Big national-scale projects.
- Led by visionaries.
- Implemented by private/public sector collaboration.

NINE PROPOSED BIG PROJECTS

- For Implementation this half century.
- Substantial increase in energy production.
- Carbon content of energy input reduced from 86% to 61%.

As presented at the 2011 World Energy Congress in Montreal, our planet faces two civilization-changing challenges in this century: access to energy by the 2 billion people who have limited or no access to energy, and climate change. With Canada's unique endowment of energy sources, both renewable and non-renewable, the nation has the capacity - some would say the responsibility - of contributing to the resolution of both of these challenges. To provide greater opportunity to its people and strengthen its long-term financial sustainability, Canada has an additional major challenge; that of capturing greater value from its natural resources by upgrading them to higher value products, thus capturing added wealth and jobs. This book presents a roadmap depicting how Canada can meet these three challenges through 'big projects'.

In our previous book, "Canada: Winning as a Sustainable Energy Superpower," sponsored by the Canadian Academy of Engineering, we described the significant impact that twelve previous national projects had in creating the Canada we now know. Wide-reaching projects of this nature have, in fact, constituted the key Canadian innovation strategy, releasing a torrent of new entrepreneurial activity and new technology. In each case, the resulting "innovation ecosystem" developed value chains and supply chains which brought these projects to fruition, and lifted Canada's national technological and business foundation to a new level of capability and performance. How were these big projects launched and how were they financed? They were launched by visionaries who overcame critical obstacles at crucial times. Eight of the endeavours were launched as crown corporations by various governments, but also actively involved the private sector in their implementation. Five of these have since been divested to the private sector. Four were launched as private sector initiatives, but with a significant portion of the risk shared by governments, through a variety of incentives, including equity. Nine of the twelve large-scale projects are now fully private-sector enterprises. All twelve were successful, and continue to generate incredible value.

The message here is clear: big, nation-building projects often take decades to reach commercial fruition and are not jobs for single companies and a single set of shareholders. They are national projects serving a long-term national interest. This is clearly the view of energy experts who gathered at the "Bitumen – Adding Value" conference (May 21-22, 2013), sponsored by the Canadian Academy of Engineering. In their Communiqué (discussed fully in Chapter 3), they stated that "Canada should launch national-scale energy projects as the foundation of its energy strategy and its pathway to sustainable wealth creation and jobs." A "Call for Action" was the theme of keynote presentations by the Honourable Frank McKenna (Deputy Chair, TD Bank Group), Senator Elaine McCoy, and Dr. Jim Stanford (Economist, Unifor).

What are the most compelling new energy projects that should now be carried out in Canada? In our previous book, "Canada: Winning as a Sustainable Energy Superpower," nine big energy projects were proposed for implementation between now and 2050 as a continuation of Canada's ongoing nation building.

In this follow-up book, "Canada: Becoming a Sustainable Energy Powerhouse," **Chapter 1** examines how these nine new big projects would impact both Canada's energy production and carbon footprint if they were implemented, as suggested, between now and 2050. As pointed out in this chapter, these new energy ventures would increase the amount of energy-related products that Canada could produce and export by 85%, and decrease the carbon content of its energy input from 86% to 61%. Clearly, Canada has the ability to be a sustainable energy powerhouse for the foreseeable future.

The next four chapters (Chapters 2 to 5) examine Canada's progress in adding value to its natural resources.

IMPACT OF DRAMATIC INCREASE IN RESOURCE EXTRACTION

- Canada again returning to reliance on extracting and exporting unprocessed resources.
- Policies needed to increase value-add upstream and downstream, and to minimize damage to other export industries.

Chapter 2 describes the fundamental structural transformation of Canada's economy resulting from the dramatic expansion of petroleum extraction since the year 2000. Canada is once again primarily reliant on extracting resource wealth from the ground beneath our feet. We export that wealth to others who transform it, manipulate it, and add value to it – importing it back in the forms of advanced products and services. Because of this, policy-makers should aim to develop and implement policies which maximize the economic benefits (and minimize the environmental and social costs) of Canada's petroleum and other non-renewable resources. Examples of such policies would be measures to,)a) boost Canadian value-add content in inputs to petroleum and other resource sectors, (b) increase Canadian processing and manufacturing of our resource commodities after they are extracted, and (c) support and protect other value-added export industries (with no direct connection to resources) from being damaged by the macroeconomic side-effects of the resource boom.

ACTION ON VALUE-ADD

- Eight-statement strategy from energy leaders.
- Bitumen upgrading a major current opportunity.
- Sarnia-Lambton upgrader a logical next step.

Chapter 3 provides additional value-added policy suggestions from participants at the May 2013 "Bitumen – Adding Value" conference organized by the Canadian Academy of Engineering. The consensus was captured in eight communiqué statements which outlined strategies and tactics to dramatically change Canada's value-added performance. Bitumen upgrading was clearly identified as a current, significant opportunity for adding value to Canada's massive bitumen resource, offering one of those few historic opportunities to reverse the country's trajectory of exporting its raw natural resources with little or no added value to the domestic economy.

Chapter 4 builds on the conclusions of Chapter 3, and provides a case study for a potential bitumen upgrading project in southwestern Ontario, providing access to markets in the central and eastern United States and Canada, and global markets via the St. Lawrence Seaway. This project, led by the Academy's Energy Pathways Task Force, is under review by several potential commercial partners, with the logical next step being a feasibility study on project design and product slate.

ENERGY IN NEWFOUNDLAND AND LABRADOR

- Case study of an energy-driven innovation ecosystem having a transformative effect on the provincial economy.

Chapter 5 describes the dramatic emergence of the Newfoundland offshore petroleum industry, illustrating the impact of a provincial megaproject not only on its host province, but the country as a whole. The result is the creation of a new economic sector serving local, national and international markets, increased business confidence, a highly entrepreneurial environment, new industrial investment, and significantly enhanced government revenues. This is a clear 21st-century example of the emergence of a high value-added innovation ecosystem arising from "big projects," resulting in the transformation of both the economy and the social structure of the host region. This shows that Canada's nation-building "big project innovation strategy" is as relevant today as it was at the birth of Confederation!

The next five chapters (Chapters 6 to 10) drill deeper into Canada's energy opportunities, such as the establishment of a national electricity grid which would enable Canada to be the premier low-cost provider of low-carbon electricity to North America, and the establishment district energy systems for more optimal delivery of municipal thermal energy requirements.

CANADA'S HUGE ELECTRIC POWER POTENTIAL

- New interconnected grid with regional hubs would make Canada a low-cost supplier of low-carbon electricity to the continent, resulting in a major decrease in North America's greenhouse gas emissions.

Chapter 6 presents an opportunity for Canada to achieve a ten- to twenty-fold increase in clean electricity trade with the United States over the next 30 to 50 years, compared to current levels of about $2 billion per year. This would deliver on goals of enhanced energy security and substantial reduction of greenhouse gases (GHGs) on a continental scale. New interconnections and transmission links acting as "regional hubs" between provinces and neighbouring states would be required to meet these goals. Canada's low-carbon electricity advantage, fully integrated with energy trade and climate change policies of Canada and the US, represents a major "big project" opportunity. A dramatic shift in thinking and support for a national energy strategy will be required that has, at its fulcrum, large-scale cross border inter-regional trade in electricity.

REALIZATION OF CANADA'S HYDROELECTRIC POTENTIAL

- Muskrat Falls is already underway.
- Mackenzie River is ready for detailed engineering evaluation.

Chapter 7 describes another ground-breaking "big project" currently underway in the Province of Newfoundland and Labrador; the Muskrat Falls hydroelectric power development. It incorporates a major, low-carbon, hydroelectric development on Labrador's Churchill River coupled to overhead and undersea high voltage AC and DC transmission lines. It will deliver power from Labrador, under the Strait of Belle Isle, through Newfoundland, then under the Gulf of St. Lawrence River to Nova Scotia. At the time of commissioning, this will be one of the most complex transmission systems in the world, and will open new avenues for integrating low-carbon hydroelectric power to continental power grids.

Chapter 8 presents the conclusions of one of the first complete studies dedicated to harnessing the Northwest Territories' Mackenzie River potential for hydroelectric development. This project is enormous by any standard, similar in scale to Quebec's James Bay Hydroelectric Complex. Describing flows of up to 9,000 cubic meters per second, steep shorelines avoiding wide-area submersion, and large lakes acting as flow regulation reservoirs, this chapter depicts a practical implementation scenario for harnessing the Mackenzie River's potential, with an overall capacity slightly greater than 13,000 MW. The chapter describes key features of the project, including an upstream water control structure and six downstream powerhouses. The Mackenzie River hydroelectric complex would help the provinces of Alberta and Saskatchewan transition from high-carbon footprint thermal generating stations to low-carbon hydroelectric power stations as the thermal generating stations of these two provinces approach the end of their useful life spans.

PATHWAY FOR NUCLEAR ENERGY

- Large nuclear sites generating both electricity and steam offer the unique opportunity of supplying low-carbon electricity to the grid, and steam for producing a broad range of value-added, energy-intensive products.

Chapter 9 proposes the concept of large nuclear generating sites producing both bulk electricity and process steam, for use by adjacent industrial parks consisting of high-affinity, energy-intensive plant operations. A key feature of this concept is that of the "energy cascade" in which the inputs and outputs of different industrial activities would be both complementary and mutually supportive. Ontario's Bruce Energy Centre is an example of this concept. Canada's fully established fission energy system (CANDU) would be the backbone of this development, with the required resources of expertise, fuel and other materials fully available within Canada.

DISTRICT ENERGY POTENTIAL

- Thermal grids in cities can dramatically reduce dependence on electricity grids and conventional energy delivery systems.
- Emerging Canadian know-how in partnership with existing international technology providers present a significant business opportunity.

Chapter 10 explores the potential – and presents the pathway forward – for a dramatic decrease in energy dependence from electricity grids and conventional energy delivery systems for home and business space heating and cooling, through the establishment of District Energy (DE) thermal grids in Canada's major cities. Thermal energy use represents roughly one third of all energy consumed in the country. Nearly all of this energy is now provided by high-grade energy sources (e.g., electricity, natural gas, oil, etc.), which are inherently inefficient for maintaining building temperatures between 20 and 23 degrees Celsius. This chapter provides a description of District Energy Systems and how communities inside Canada, and in the international arena, have successfully deployed district energy solutions to meet their energy needs while increasing flexibility in the choice of energy resource, decreasing operating costs, and lowering carbon footprint. It also points the way to significant new opportunities for Canadian know-how and business in developing this area in Canada and abroad.

The Canadian Academy of Engineering is committed to pursuing and promoting its ongoing work on sustainable energy development, an initiative launched in 2005. The actions described in this book will contribute to Canada's three urgent nation-building energy objectives: contributing to global energy demand, reducing North America's carbon footprint, and adding value to our raw resources.

As an ongoing task, the Energy Pathways Task Force will monitor Canada's progress in capturing the energy opportunities presented in this book.

1

Canada 2050: Roadmap to an Energy Powerhouse

Richard J. Marceau
Clement W. Bowman

ABSTRACT

In this chapter, we explore how the nine energy projects proposed in "Canada: Winning as a Sustainable Energy Superpower" would increase the amount of energy-related products that Canada could export, and significantly raise the proportion of renewable and non-GHG-emitting energy sources in the total energy mix. These projects would also dramatically increase the added value of the energy products that Canada uses and exports, reversing Canada's current trend presented in Chapter 2 of this book. Chapters 3 and 4 emphasize the urgency and opportunity of upgrading bitumen in Canada's strategy of moving up the value chain, while subsequent chapters identify other important energy opportunities.

The three objectives of increasing energy production, decreasing the carbon content of our energy mix and adding value prior to export are the key energy challenges that Canada faces in this century. The nine "big energy projects" proposed by the Canadian Academy of Engineering (CAE) would significantly contribute to these goals, and position Canada as a "sustainable energy powerhouse."

Introduction

Canada was created on the shoulders of "big projects" which provided the nation-building infrastructure that is the foundation of its wealth today. Massive, pioneering projects such as the Victoria Bridge, the Canadian Pacific Railway, the St. Lawrence Seaway, and the large hydroelectric complexes found in many provinces remain the foundation of much of today's economic potential. The TransCanada Microwave system, Canadian satellites, the CANDU nuclear power technology, the Alberta oil sands, the

Victoria Bridge, Montreal

Hibernia project and many more were the result of visionary undertakings, in each case transforming Canada's opportunities for the foreseeable future. These projects were undertaken as private/public sector partnerships with governments providing leadership and sharing risks through a variety of incentives, including equity where necessary. The message here is clear: big projects, sometimes taking decades to bring to commercial fruition, often in the midst of significant controversy, are not jobs for single companies and a single set of shareholders responding to current market conditions. Nations have more control over their future than leaving themselves open to market forces: Canada is living proof of this!

As we look towards the future, Canadians must learn from past failures and develop their massive energy resources more strategically. Unfortunately, over the past 70 years, Canada's ability to maintain world-class leadership has diminished, as evidenced in a variety of areas. Examples include industries as diverse as piano manufacturing, television, radio, pulp and paper technology, minerals processing technology, and furniture manufacturing. For a time, its world-class aerospace industry came close to the brink, but Canadians successfully brought it back. Automobile manufacturing, and manufacturing as a whole, is still struggling in Canada, and the jury is still out on whether we will successfully continue to compete in the manufacturing arena. Energy remains an area of immense opportunity. This chapter explores how the nine big projects proposed in "Canada: Winning as a Sustainable Energy Superpower," if implemented by 2050, would transform Canada.

Canada's Current Energy Production

As one of the world's top 10 energy producers and a net energy exporter, Canada plays a key role in providing access to energy for the citizens of our planet. Canada's contribution to global energy production could be substantially increased in a sustainable manner, since Canada is endowed with a wide range of energy sources, including:

- Huge, non-renewable carbon-bearing sources of gas, oil, bitumen and coal,
- Vast uranium and thorium ores, and proven nuclear power technology,
- Massive developed and undeveloped hydroelectric power, and
- Large renewable energy resources from its vast agricultural and forestry residues.

Diverse energy sources, including renewable and non-GHG-emitting, are currently being produced in Canada as shown in Table 1. Table 2 details the current energy generation from biomass resources. This highly significant energy endowment is the basis for suggesting that Canada could ultimately become a sustainable energy superpower. This section quantifies Canada's present energy production in all key categories.

Table 1
Canada's Current Energy Production

Energy Source		Current Production (Industry Units)	Current Production in Million Barrels per Day Fuel Oil Equivalent (M BPD foe)
Conventional Oil		1.58 M BPD	1.58
Oil Sands		2.08 M BPD	2.08
Natural Gas	Conventional Natural Gas	2.19 Trillion Cubic Feet per Year	1.03
	Coal Bed Methane	0.256 Trillion Cubic Feet per Year	0.12
	Tight/Shale Gas	2.263 Trillion Cubic Feet per Year	1.07
Coal		71.17 Million Tonnes	0.70
Nuclear Energy		106,839 GWh 14,320 MW	0.19
Hydroelectric Power Generation		366,096 GWh 76,922 MW	0.68
Solar, Wind, Tidal, Bioenergy	Solar	9,937 GWh 2,456 MW	0.01
	Wind	12,571 GWh 6,637 MW	0.04
	Bioenergy (see Table 2)	217 Pj	0.10
Total			7.60

Table 2
Estimates of Annual Energy Generation from Biomass in Canada[1]

Energy Source	Current Annual Production (Industry Units)	Current Annual Production (in Pj)
Electricity generation from forestry biomass	9,829 GWh	35.38
Heat generation from forestry biomass	21,448 GWh	77.21
Bio-ethanol production	1600 Million Litres	33.79
Bio-diesel production	250 Million Litres	8.93
Wood pellets export	3 Million Tonnes	60.0
Electricity generation from Municipal Solid Waste	81 GWh	0.29
Heat generation from Municipal Solid Waste	469 GWh	1.69
Total – Pj		217.30
Total – million barrels per day fuel oil equivalent (M BPD foe)		0.10

[1] Estimates prepared by the Energy Pathways Task Force

Photo courtesy of Tourism Sarnia-Lambton

Conventional Oil

The first significant discovery of conventional oil was in Oil Springs, Ontario in 1865. Before the village was formed, the indigenous people already knew about the gum beds and used the sticky oil to waterproof their canoes[2]. The place, originally called Black Creek, became the site of North America's first commercial oil well when asphalt producer James Miller Williams set out to dig a water well in 1858 and found free oil instead. Williams' discovery triggered North America's first oil rush and the village's name was changed to Oil Springs that same year. Within a few years, Oil Springs was a bustling town with four thousand residents and, in its peak days, boasted paved roads, horse-drawn buses and street lamps. This led to a world-wide reputation for the drillers and engineers involved. However, the reserves proved to be limited. Today, production continues at a low level using the original equipment, preserving the historical significance of the site.

A huge oil discovery occurred in Leduc, Alberta in 1947[3]. This provided the geological key to Alberta's prolific conventional oil reserves and resulted in a boom in petroleum exploration and development across Western Canada. The discovery transformed the Alberta economy; oil and gas supplanted farming as the primary industry, and resulted in the province becoming one of the richest in the country. Nationally, the discovery allowed Canada to become self-sufficient within a decade and ultimately a major exporter of oil. Canada's current conventional oil production is 1.58 million barrels per day (M BPD).

Oil Sands

Oil sands represent a very different story. The existence of the heavy and viscous bitumen was known by native people and explorers for many decades prior to 1900. The oil sands areas were subjected to extensive survey and early experimentation over many decades. The Alberta government decided to build and test a demonstration bitumen recovery plant at Bitumount Alberta in 1947[4]. Although the recovery process was shown to be commercially viable, large-scale commercial production did not occur until 1967 by Suncor, and a few years later by Syncrude. Production is currently 2.08 M BPD and is likely to at least double by 2030. New production will come from both new mining projects and also a major expansion in in-situ production from the deeply buried deposits representing close to 90% of the total resource. Environmental issues may slow down the pace of production but advances are being made in site restoration and in the development of new processes with less environmental impact. Reducing greenhouse gas emissions will be a continuing challenge. It is believed that there are close to 2 trillion barrels in Alberta's various bituminous deposits.

Natural Gas

The energy equivalent of Canada's current natural gas production of 4.7 trillion cubic feet per year (including conventional natural gas, coal bed methane and tight/shale gas) is higher than that of either conventional oil or oil sands production , equivalent to to 2.22 M BPD foe[5]. Although conventional production appears to have peaked and decreased somewhat, the picture has recently changed with new production expected from coal bed methane, tight gas and shale gas. The emergence of advanced fracturing technology has opened major new gas deposits in both the US and Canada. The major issue for Canada will be the loss of US

2 http://en.wikipedia.org/wiki/Oil_Springs,_Ontario

3 http://en.wikipedia.org/wiki/Leduc_No._1

4 http://en.wikipedia.org/wiki/Bitumount

5 foe – Fuel Oil Equivalent – an index used by the energy industry to compare the size of various energy sources

markets, and the need to shift direction to liquefied natural gas for international markets. Canada will not be running out of natural gas for the foreseeable future. However, environmental concerns in the public arena over the use of fracturing technology will need to be addressed.

Coal

Canada has more energy in coal than oil and gas combined. Coal combustion is used primarily for the production of electricity in both the US and Canada. The level of carbon dioxide produced per unit of energy is much higher from coal combustion than other fossil fuels and the pressure from environmental groups to shift from coal to gas is increasing. However, coal gasification is a technological solution which reduces the greenhouse gas penalty of coal combustion. Coal gasification has the unique ability to simultaneously produce electrical power, hydrogen and high-value chemical and pharmaceutical products. Gasification also has the ability to handle diverse feedstocks, to capture, store, utilize (i.e., for other value-added processes) or sequester carbon dioxide, and to capture sulphur and trace metals. Global coal use will increase dramatically over the next century, and coal gasification demonstration projects should be undertaken based on Canada's low rank coals, utilizing the latest international technology developments and meeting rigorous environmental targets. Current production levels are 71 million tonnes per year, or 0.70 M BPD foe.

Nuclear Energy

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

Nuclear power can be used as a source of heat for a variety of industrial processes, either as stand-alone heat sources or in combination with electricity production, thereby contributing to the reduction of GHG emissions. A specific opportunity is that of applying nuclear energy to in-situ bitumen recovery from Alberta's oil sands, a process that currently uses fossil fuel as a heat source. This would strengthen Canada's position on greenhouse gas abatement by reducing the carbon footprint of the oil sands industry, thereby facilitating further growth.

The amount of nuclear energy that Canada produces is modest at the present time, amounting to approximately 0.19 M BPD foe. However, in view of its vast uranium and thorium deposits, it is essentially unlimited.

Hydroelectric Power Generation

With 73,000 MW of installed hydroelectric generating capacity, producing 366,096 GWh of electrical energy annually (or 0.68 M BPD foe), Canada is a leader in the development and application of advanced hydroelectric power generation and transmission technology. The untapped power in Canada's hydraulic systems, amounting to more than 163,000 MW, is more than double the current installed capacity. Priority areas for development can be found in nearly every province.

The lack of a national power grid results in uneven energy costs across the country and stranded power reserves, not to mention the loss of potential north-south trade opportunities.

A prerequisite for moving ahead with major new hydroelectric projects is the establishment of a Canada-wide high-capacity transmission network, with three objectives:

1. Link new hydroelectric projects to areas of consumption.
2. Interconnect existing provincial networks.
3. Replace thermal power plants at the end of their useful life to reduce Canada's GHG footprint.
4. Seize the opportunity to become North America's premier low-cost provider of low-carbon electricity

Solar, Wind, Tidal and Bioenergy

The current production of energy from solar and wind in Canada is negligible in comparison to other energy sources, and is expected to increase slowly over the next few decades, responding to favorable regional situations and the evolution of more effective technologies and their associated costs. The situation with bioenergy is more promising due to Canada's huge land mass, and agricultural and forestry biomass residues. Current energy produced from biomass amounts to roughly half the energy that Canada derives from nuclear power. As the second largest country in the world and the home to approximately 10% of global forests, Canada can dramatically increase sustainable bioenergy production, following the pathway successfully adoped by Europe.

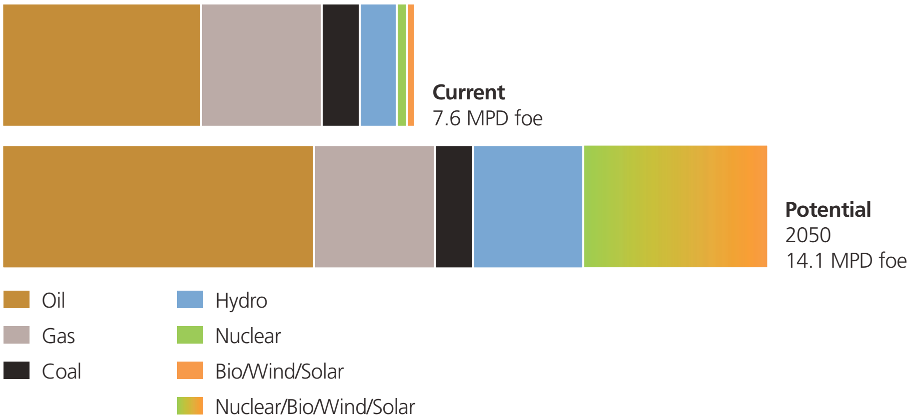
Implementing the CAE "Nine Big Projects"

The previous section provided an overview of Canada's impressive energy endowment. Let us now explore how production from these energy sources could be increased, reducing the carbon content of our overall energy mix and achieving a higher level of value-added upgrading.

The energy resources highlighted in beige in Table 1, contain carbon. The other resources can be considered either low carbon, or carbon neutral. At present, production from the carbon-containing energy sources in Canada represents 86% of the total energy production. The relative contributions of the various energy categories are shown in the top chart in Figure 1.

Considering the potential of Canada's energy resources discussed above, the nine big projects described in "Canada: Winning as a Sustainable Energy Superpower" promise to:

Figure 1
Changes in Energy Productions by Big Projects



- Increase Canada's total energy production, providing greater access to energy for global citizens,
- Enhance the contribution of renewable and non-GHG-emitting energy sources in the total energy mix, contributing to the adaptation to climate change,
- Increase the value of our energy exports by more extensive upgrading, and
- Create long-lasting wealth and energy-related high quality jobs for current and future Canadian generations, positioning Canada as an energy powerhouse.

This section attempts to quantify the benefits associated with implementing the proposed big projects.

Canada's total energy production would significantly increase from its current level of 7.6 M BPD foe if all nine big projects proposed by the Canadian Academy of Engineering (CAE) Energy Pathways Task Force are implemented. A number of different scenarios can be envisaged depending on the actual size and capacity of any one project. As an example of what could be done, the following scenario aims to nearly double Canada's energy production, significantly reduce carbon content, and increase the value of our exports. This scenario is described below, and summarized in Table 3.

Conventional Oil

It is not expected that there will be major new conventional oil discoveries in Alberta. However the extension of the life of existing fields, and the continued development of Atlantic Canada's offshore petroleum industry, should make it likely that the current production level of 1.58 million barrels per day can be maintained for the first half of this century.

Oil Sands

Energy production from Canada's oil sands, one of the largest non-conventional oil resources in the world, is expected to double over the next one to two decades to 4.16 M BPD. The economic impact of doubling oil sands production will be significant for Alberta and for the rest of the country. If a significant portion of the bitumen in this increased production is upgraded inside Canada, an expected $68 billion per year in added value will result (discussed further in Chapters 3 and 4). Our country would become the global centre of excellence for oil sands exploration, development and value-added upgrading.

Table 3
Future Scenario: Implementation of the Nine CAE "Big Projects" by 2050

Energy Source		Current Production (M BPD foe)	Potential Production Mid-century (M BPD foe)	Comments on Change
Conventional Oil		1.58	1.58	Modest new discoveries likely to maintain production level.
Oil Sands		2.08	4.16	Likely to double over next two decades. Hard to predict long term limit.
Natural Gas	Conventional Natural Gas	1.03	2.22	Current markets shrinking, but production could be maintained by developing new markets with LNG exports.
	Coal Bed Methane	0.12		
	Tight/Shale Gas	1.07		
Coal		0.70	0.70	Gasification technology could help retain markets and maintain production.
Nuclear Energy		0.19	1.90	Ample uranium resource for ten-fold or more increase.
Hydroelectric Power Generation		0.68	2.04	Could triple if major sources harnessed.
Solar, Wind, Tidal, Bioenergy	Solar	0.01	1.5	Not expected to be major player in Canada in this half century.
	Wind	0.04		Moderate increase expected, especially if economic storage technology develops.
	Bioenergy	0.10		Agricultural and forestry residues could enable a ten-fold increase.
Total		7.60	14.10	

Natural Gas

Due to the dramatic increase in shale gas production in the United States, it is expected that the export of natural gas from Canada to the US will decrease. However, if the currently planned liquefied natural gas (LNG) big projects to supply Asian markets occur, led by BC, Canada's export of natural gas will likely be maintained at current levels. Investments to build LNG infrastructure will create jobs and the process of liquefaction will increase the value-add of this resource.

Coal

Gasification is considered to be a cleaner process for upgrading coal, one of the largest energy resources in Canada, and for biomass. Investments in technology development and the implementation of advanced gasification technologies for coal and biomass feedstock are recommended. If the coal industry develops new clean technology via the gasification processes, the new technology will be applied as current coal combustion plants reach the end of their expected life span. If this occurs, current production levels and associated jobs can be maintained.

Nuclear Energy

If nuclear energy is used to provide heat energy for the recovery of in-situ bitumen from the oil sands, one of the nine proposed big projects, this would significantly reduce the release of carbon dioxide. This could be accomplished with the application of small modular nuclear reactors, now under development.

Another major nuclear application is the concept of large nuclear generating sites (often termed "nuclear farms") supplying electricity to a national high voltage grid. This would enable the export of low-GHG power to the United States and also could feed both electricity and process steam to adjacent industrial parks comprising energy-intensive industries. This potential contribution to a national grid is described in Chapter 6, and that of nuclear generating sites producing both electricity and steam is described in Chapter 9.

For illustration purposes, a ten -fold increase in nuclear energy generation from Canada's current relatively low level production would represent the energy equivalent of 1.9 M BPD foe. This would certainly be a stretch goal but would represent the energy content only slightly above the current production of conventional oil.

Hydroelectric Power Generation

A three-fold increase in hydroelectric power generation would represent the energy equivalent of 2.04 M BPD foe. In addition to job creation and investment from new hydroelectric power plants, Canada could regain its global expert status in the hydroelectric sector.

Solar, Wind, Tidal and Bioenergy

Bioenergy, still in its infancy, currently produces 0.10 M BPD foe, dwarfing the total from both solar and wind. Biomass resources from Canada's agricultural and forestry sectors could enable a ten-fold increase in Canada's renewable energy production to an energy level equivalent to 1.5 M BPD foe. This would also be a stretch goal, with the energy content equivalent to the current production of conventional oil. Bioenergy would also likely be produced in combination with bio-chemicals and other bio-products. This project could lead to the development of an entirely new industry.

Scenario Summary

The changes in total energy production and the increases in the relative contributions of renewable and non-GHG-emitting energy sources are illustrated in the lower chart of Figure 1.

If all nine big projects are implemented, total energy production would increase by 85%, and the amount of carbon containing sources in our energy mix would decrease from 86% to 61%. All of the proposed additional energy production would be produced at a significantly higher value-added level compared to current production. Additionally, these big projects will create jobs and wealth for Canadians, and position Canada as a sustainable energy powerhouse.

An Alternative Scenario – None of the Nine Big Projects are Implemented

Failure to implement the proposed nine big projects will have significant negative impacts on the current status of Canada as a major energy producer, not to mention its internal social and economic conditions.

- If the oil sands "big project" is not undertaken, the majority of the increase in oil sands production will be upgraded in United States refineries, and the expected $68 billion dollar per year value-added will be captured by those refineries.
- If the currently planned liquefied natural gas (LNG) big projects to supply Asian markets do not occur, Canada's export of natural gas to the United States will likely decrease by 50%, driven by the recent dramatic increases in the US natural gas resources.
- If the coal industry does not develop new clean technology via gasification processes, the use of coal as a power source will continue to diminish as existing power plants reach the end of their lives. In the absence of the development of appropriate coal gasification technology, a 50% decrease in coal production over the next forty years is likely, primarily due to the closure of coal-fired power plants.
- If nuclear heat energy is not applied to the recovery of bitumen from the deeply buried oil sands, the release of carbon dioxide will continue to grow, reflecting the increased bitumen production. If no new nuclear electricity generation capacity is developed, none of the expected benefits arising from the production of additional non-GHG-emitting energy, and the expansion of the nuclear industry will materialize.
- If a national power grid is not established, Canada will not capture the opportunity of being a major exporter of low-GHG electrical power to the continent.
- If no new hydroelectric power generation capacity is developed, none of the expected benefits arising from the production of additional non-GHG-emitting energy, and the expansion of the hydroelectric power industry, will materialize.
- If Canada's bioenergy potential remains undeveloped, none of the expected benefits arising from access to additional GHG-neutral energy, and the emergence of new bio-energy and bio-chemical industries will materialize.

In summary, if none of the big projects are undertaken during the next forty years, Canada will miss the opportunity of being the global energy powerhouse that it presently promises to become. This threat is real, since the US and other countries are exploring both conventional and unconventional energy resources at an unprecedented pace. The negative impacts of not implementing these big projects on GDP and jobs/wealth creation will be substantial, a loss of yearly economic activity on the order of $100 billion dollars, while the impact of doing nothing will not substantially improve the proportion of non-GHG-emitting energy!

The Pathway Forward

Each of the nine big projects described here will contribute in its own way to transition Canada to a sustainable energy powerhouse. The private sector alone is not able to effectively implement these nine nation-building projects. Government must provide a nurturing environment, through vision, leadership, incentives, supportive regulations, and public education programs. Most of the projects will require public-private partnerships, undertaken by the private sector with appropriate risk-sharing incentives. In the past, Canada has proven that it can implement such nation-building projects. With the appropriate government leadership, Canada's energy sector is prepared to seize the opportunities to transform Canada into a world-leading sustainable energy powerhouse.

Biography

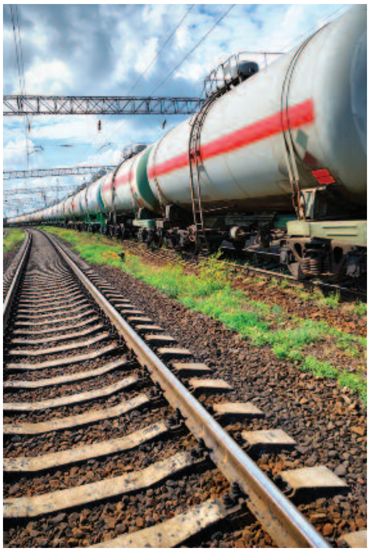
Richard J. Marceau, PEng, FCAE, Vice President (Research), Memorial University: Dr. Richard J. Marceau is the Vice-President (Research) at Memorial University and President of the Canadian Academy of Engineering (2012-2014). He has served as Provost and Vice-President Academic at the University of Ontario Institute of Technology (2005-2013), Dean of the Faculty of Engineering at the Université de Sherbrooke (2001-2004), and Chair of Electrical and Computer Engineering at École Polytechnique de Montréal (2008-2001). Prior to his academic career, he practiced engineering for twelve years, first at MONENCO, then at Hydro-Québec. An active member of his community, he has been invited to participate on numerous committees and board, including as President of the Parkwood Foundation (2009-2013), a National Historic Site and former home of the founder of General Motors of Canada, R.S. McLaughlin. He is a registered Professional Engineer in the Provinces of Newfoundland and Labrador, Ontario and Québec.

C. W. (Clem) Bowman: Dr. C. W. (Clem) Bowman has worked in the energy industry for the past 50 years, in various research, management and executive capacities, including vice-president Esso Petroleum Canada, founding chairman Alberta Oil Sands Technology and Research Authority (AOSTRA), president of the Alberta Research Council, and Presidents of the Canadian Society for Chemical Engineering and Chemical Institute of Canada. Bowman's career contribution to energy technology development led to the 2008 Global Energy International Prize, awarded by Russian President Dmitry Medvedev. In 2010, the University of Western Ontario established the Bowman Centre at their Sarnia-Lambton campus to expand energy technology development. Included in a list of award and recognition was induction into the Canadian Petroleum Hall of Fame in 2013 and granting of an honorary degree by the University of Ontario Institute of Technology in 2013.

2

Adding Value to Canada's Petroleum Wealth: A National Economic and Environmental Priority

Jim Stanford



ABSTRACT

For some, there is nothing wrong with Canada becoming increasingly dependent on the extraction and export of raw resources. Merely extracting the resource, in this world view, is all the "value-added" that is needed. This approach implies that unexploited natural resources are value-less and hence "wasted," and that it is, in fact, preferable to focus on extraction and allow other nations to do the work of innovation, engineering, design, and manufacturing required to convert our raw resources into value-added products and services. Fortunately, most Canadians appreciate the risks – economic, environmental, geopolitical – of our country becoming a mere source of raw materials for other, more developed economies, who then process those resources and sell us back the (more expensive) finished products. They want something bigger for our country: an economy based on talent, innovation, ingenuity, and productivity. With active attention paid to ensuring that resource industries contribute, rather than detract, from the prospects of other value-added sectors, Canada's resource wealth could become a stepping stone toward a more diversified, prosperous, and sustainable economic future.

In this chapter, we begin by reviewing several empirical indications of Canada's growing and dangerous reliance on raw resource extraction and export, and our resulting national specialization at the very bottom rungs of the value-added ladder. Next, we consider some broader risks and consequences of this growing resource-dependence, including stagnant productivity and innovation, future economic instability, and environmental degradation. Following this, we consider in detail the economic evidence regarding the negative spillover effects of the petroleum boom (experienced largely through an over-valued exchange rate) onto non-resource export industries. Finally, we conclude with some preliminary proposals for enhancing the value-added linkages and spin-offs associated with Canada's petroleum industry.

Introduction: Canada's Structural U-Turn

The dramatic expansion of petroleum extraction since the turn of the 21st Century has sparked a fundamental structural transformation of Canada's economy. Booming investment and employment in new petroleum projects in northern Alberta has been the most important driver of this growth. There are many economic and fiscal benefits generated by the petroleum boom including new jobs, incomes, exports, and tax revenues. But there are many challenges and problems associated with the unbridled expansion of this sector too. It is important for policy-makers to examine both sides of the ledger, and to develop and implement policies which maximize the benefits for Canadians (and minimize the costs) of our important non-renewable resources. In particular, proactive efforts to increase Canadian value-added content throughout the value chain of our economy, even as our production of resources grows, would enhance the net benefits to Canadians from resource extraction. Measures to this end could include boosting Canadian content in inputs to petroleum and other resource sectors; increasing Canadian processing and manufacturing of our resource commodities after they are extracted; and being careful to support and protect other value-added export industries (with no direct connection to resources) from being damaged by the macroeconomic side-effects of the resource boom.

Of course, as a resource-rich and relatively sparsely populated country, Canada has always depended on resource industries as the first step in economic development. Successive waves of resource development, oriented toward export markets, motivated corresponding waves of settlement, transportation development, and government. Fish, furs, timber, wheat, minerals, and now petroleum were the industries (called "staples" by economic historians) that led the way through these successive chapters of our national economic history.

The leading role of resource industries in the economic development of Canada is a historical fact. But Canadians have been traditionally concerned, and rightly so, with the potential downside of unthinking resource-dependence. Historians and economists (including

pioneering thinkers like W.A. Mackintosh, Harold Innis, and Mel Watkins) described how each successive wave of staples-led development shaped the resulting pattern of economic, political and social development – and not always for the better. It was possible for Canada to become caught in a "staples trap," in which the dominance of a particular form of resource extraction and export inadvertently undermined our ability to develop and diversify a full-fledged modern economy.[1]

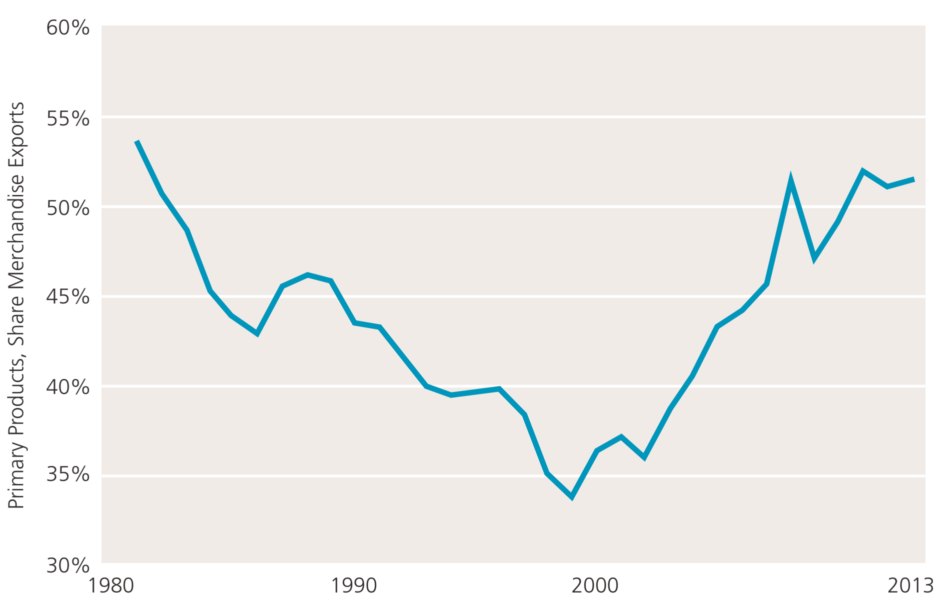
To counteract this risk, economic policy-makers since Confederation were preoccupied with measures to supplement resource industries by nurturing a more diverse "value-added" economy. Instead of simply extracting and exporting raw resources as fast as possible, and then using the resulting export revenues to pay for necessary imports (of manufactures and other value-added products), Canada should develop more value-added industries of our own. This would contribute to greater prosperity, productivity, and stability. It would also expand the range of vocations available to Canadians. Examples of policies aimed at expanding the value-added diversity of Canada's economy included the early National Policy of tariffs to support domestic industry, the Canada-U.S. Auto Pact of 1965, various sector-focused strategies to develop key industries (like aerospace and telecommunications equipment), and limits placed on incoming foreign investment (especially in resource industries).

For some decades after World War II, those strategies seemed to be paying off. The share of Canada's merchandise exports which consisted of unprocessed or barely processed resources declined, eventually outweighed by valuable exports of automotive products, aerospace products, and other technology-intensive, high-value exports. By the 1990s it was no longer accurate to describe Canada as "hewers of wood and drawers of water." Foreign ownership as a share of Canadian GDP also declined (reaching a historic low in the mid-1980s).

Beginning around the turn of the century, however, this historic structural progress in building a more diversified, developed, and autonomous economy began to unravel. This historic about-face is illustrated vividly by the dramatic U-shape of Figure 1. It calculates the share of total Canadian merchandise exports accounted for by four primary sectors: agriculture and fishing, forestry, minerals, and energy. That share declined steadily during the postwar era,

Figure 1
Reliance on Primary Exports

Source: Author's calculations from Industry Canada, Strategis database. Primary sectors include agriculture and fishing, forestry, mining, and energy.



[1] See Watkins (1963) for the classic statement of the dangers of the "staples trap." The commentaries compiled in Stanford, ed. (2014) reflect on the lasting relevance of this analysis for Canada's present economic juncture.

and by the end of the twentieth century (famously defined as "Canada's Century" by Sir Wilfred Laurier) barely one-third of Canada's total exports originated in these basic resource-dependent sectors. That year Canada ranked as the fourth largest assembler of motor vehicles in the world – an astounding achievement for a country of our size. We punched above our weight in several other high-value, technology-intensive sectors as well. Business innovation (measured, for example, by business R&D spending as a share of GDP) reached its highest level ever. It seemed that Canadians were poised to escape our resource-dominated history.

But after 2000, all that progress was reversed, and dramatically. World commodity prices surged, whetting the appetites of investors for Canada's resource riches – especially for our petroleum. At the same time the prospects for Canada's value-added industries dimmed, for various reasons. The 9-11 terrorist attacks produced a short-lived recession in the U.S., and a more lasting change in national consciousness there (including a thickening of the Canada-U.S. border, and a renewed "America-first" attitude on the part of political leaders). Companies which had led the way in Canada's value-added transformation (from North American-based automakers to Northern Telecom) faltered. The take-off of the Canadian currency (which appreciated by 65 percent in five years, beginning in 2002) made Canadian-made products and services fantastically expensive in the eyes of the rest of the world. Foreign capital surged back into Canada; an unprecedented frenzy of takeovers of iconic Canadian firms (Stelco, Inco, Falconbridge, Alcan, Algoma, IPSCO, and more) added a stunning $112 billion to the stockpile of foreign direct investment here in just two years (2006 and 2007). But once the commodity price cycle turned down (as it inevitably does), most of those takeovers went sour.

Table 1
Canada's Economic Complexity Score 1980-2010

	Score	Ranking
1980	1.731	6
1990	1.066	21
2000	1.112	21
2010	0.760	29

Source: Observatory of Economic Complexity, MIT, http://atlas.media.mit.edu/rankings/country/.

Today those four primary sectors (agriculture, forestry, minerals, and energy) once again account for a clear majority of total merchandise exports, and the qualitative regression in the composition of our exports is continuing. In essence, Canada has "undeveloped." Much like a Third World country (although, to be sure, with more income, more democracy, and more productivity), Canada is once again primarily reliant on extracting resource wealth from the ground beneath our feet. We export that wealth to others who transform it, manipulate it, and add value to it – importing it back in the forms of advanced products and services.

An interesting project based at Harvard University, called the Economic Complexity Observatory, tries to quantify the level of complexity and development of different countries, on the basis of a composite measure of each country's exports, imports, production, and technology. Canada's absolute score and relative ranking on this index have both plummeted, as summarized in Table 1. The rapid expansion in petroleum extraction and export is not the only factor in this trend.[2] But it is clear that growing dependence on raw resource extraction is reshaping Canada's entire economy, and reducing our stature in the world as a source of knowledge, innovation, and productivity.

Should we worry about the visible deindustrialization and growing resource-dependence of Canada's economy? I think we should. While there are many immediate opportunities created from resource-driven expansion, there are many risks and costs, as well. These include:

- A stunted role in world trade: Canada is becoming pigeon-holed into supplying raw resources to other countries, to the detriment of other value-added activities (like manufacturing and tradable services).

[2] The successful industrialization of many emerging market economies in recent years is another factor which has affected the relative complexity of Canada and some other OECD countries. But the fall in Canada's relative ranking has been relatively steep; in 2010 Canada ranked by far the lowest of any G7 economies according to this measure, and within the lowest quarter of all OECD countries.

- Perpetual economic uncertainty, with regions and even the entire national economy held hostage to the inevitable ups and downs of resource prices and profits.
- Poor innovation and productivity performance associated with the growing concentration of economic activity in resource extraction, and the corresponding decline of manufacturing.
- Massive costs, usually subsidized by government, of economic infrastructure required for resource extraction and export (including railways, ports, and pipelines). This expensive infrastructure becomes a sunk cost which in turn compels even faster extraction and export of resources to amortize their heavy costs.
- An unbalanced political culture, in which super-profitable resource companies are able to exert disproportionate influence over economic and social policy.
- Growing influence for foreign companies, which have invested huge amounts of capital in resource extraction and export and which wield tremendous influence as a result.
- The environmental consequences (both local and global) of irresponsible management of non-renewable resources. Chief among these concerns today, of course, is the threat of global climate change. Canada's petroleum boom holds major consequences for our national role in addressing this top-priority issue.

In light of these risks and drawbacks, it would be prudent for Canadians to consider whether we are managing the exploitation of our resource wealth in the best way possible. Yes, resource industries are important. They have always been crucial sources of jobs and incomes for Canadians, and they will always play a central role in Canada's economy. After all, all economic activity begins with the necessary raw materials and inputs we harvest from nature. But we need to perform that work in a more deliberate, strategic, responsible, and sustainable manner. Instead of confining our national economic destiny to simple extraction, we need to emphasize and develop our capacity to add value to our own resources. We need to see resource extraction – sustainable and responsible – as just the first step in the value-added chain, rather than as the all-consuming goal in its own right.

We can leverage more Canadian jobs both "upstream" (through more Canadian-sourced inputs to resource projects) and "downstream" (through more Canadian refining, processing, and manufacturing of our produced resources). But this will only happen on the strength of deliberate strategies to link petroleum production to value-added activity. We need a national energy strategy to redirect energy production to meeting the needs of Canadians, and leverage those upstream and downstream value-added opportunities – instead of focusing on the extraction and export of raw energy. At the same time, we also need proactive efforts to manage the economic, fiscal, and environmental side-effects of the resource boom, and to support other Canadian industries capable of producing value-added goods and services for the world market. Those are the major planks of a strategy to reverse the visible regression in our economic structure since the onset of the petroleum boom.

The remainder of this chapter is organized in the following sections. First, we review several empirical indications of Canada's growing and dangerous reliance on raw resource extraction and export, and our resulting national specialization in primary products. Second, we consider some broader risks and consequences of this growing resource-dependence: including stagnant productivity and innovation, future economic instability, and environmental degradation. Third, we consider in detail economic evidence regarding the negative spillover effects of the petroleum boom (experienced largely through an over-valued exchange rate) onto non-resource export industries. This phenomenon is commonly called "Dutch disease," but I will argue for a different terminology. Finally, the article concludes with some preliminary proposals for enhancing the value-added linkages and spin-offs associated with Canada's petroleum industry.

Describing Canada's Lopsided Trajectory

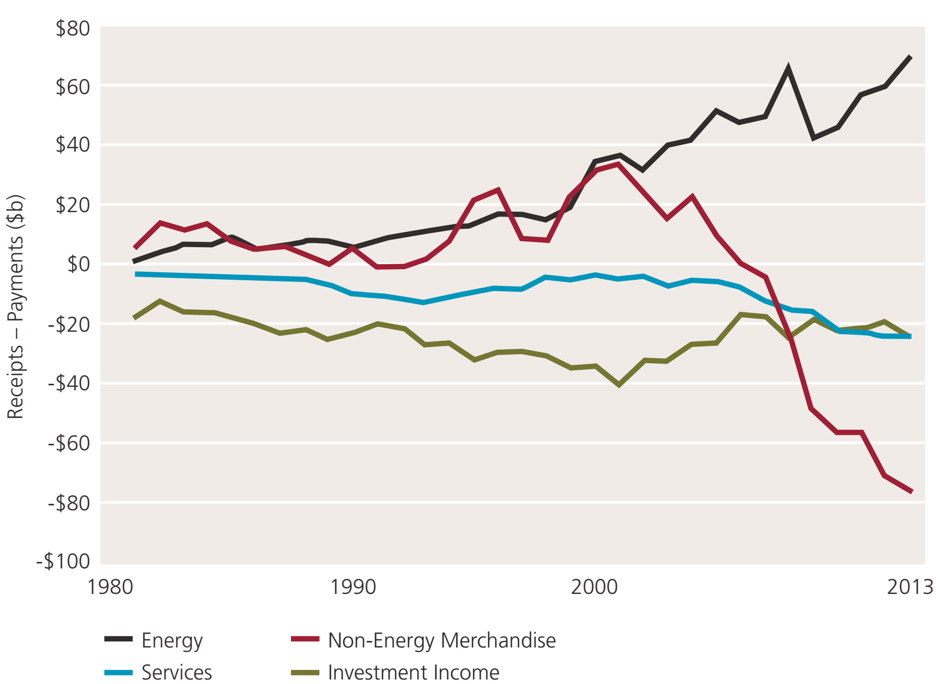
Canada's worrisome reliance on extraction and exports of unprocessed resources (and especially petroleum) is visible in a wide range of statistical indicators. Together they paint a clear picture of a national economy that fundamentally shifted direction, both quantitatively and qualitatively, beginning shortly after the turn of the century.

Figure 2 describes a Jekyll-and-Hyde dichotomy in Canada's international trade performance. Since 2002, when the petroleum boom took off, Canada has enjoyed a large and growing trade surplus in energy products. That surplus reached almost $70 billion in 2013, an all-time record. This should underpin robust success in our international affairs, right? Wrong. Unfortunately, Canada's trade performance in all non-energy products has deteriorated even more rapidly than our petroleum exports have grown.

Canada also enjoyed a trade surplus in non-energy merchandise until 2005. In other words, until then Canada's export portfolio was very diversified, generating positive net export earnings across the whole range of goods we produce (both energy and non-energy). But the two lines diverged when the energy export boom kicked into high gear. Canada quickly slid into a deficit in non-energy merchandise, and that deficit grew steadily – reaching a record of $76 billion in 2013. In short, the more energy we export, the less of everything else we export. That worrisome side-effect of our growing resource-dependence cannot be ignored.

Figure 2
Major External Balances

Source: Author's calculations from Statistics Canada CANSIM Tables 376-0107 and 376-0101.



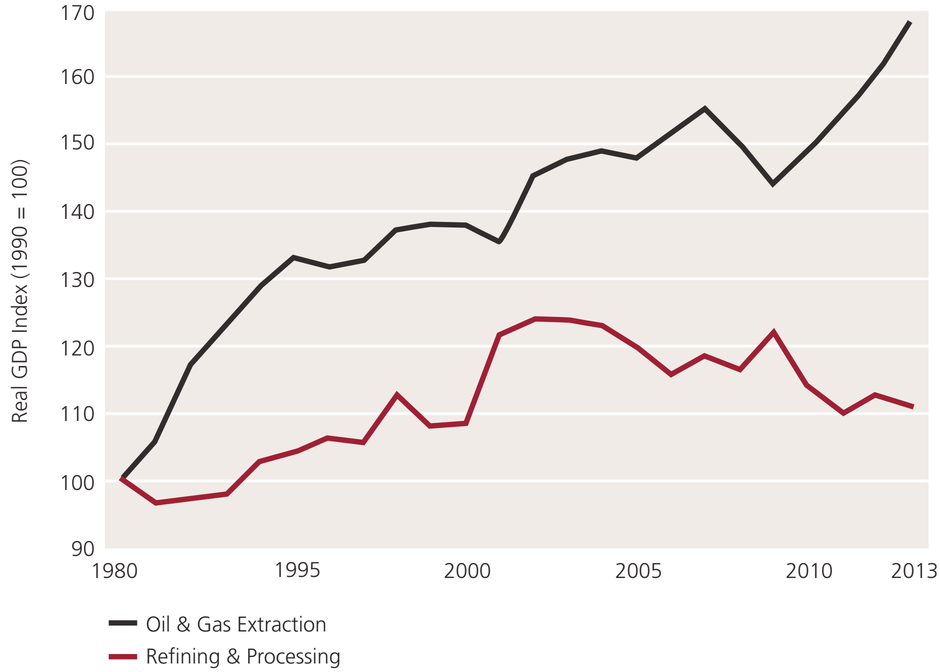
The other components of our international balance of payments remain firmly in the red as well. Our trade deficit in services reached $25 billion in 2013. It is not unusual for Canada to have a trade deficit in services, but it was traditionally quite small. Since 2002, however, our trade performance in services (which are often heralded as the "next frontier" of globalization) has deteriorated dramatically. This is partly due to the dramatic increase in the Canadian dollar, which makes Canadian-made services seem very expensive to foreign customers. Net outflows of investment income (resulting in part from the growth of foreign investment in Canada) produce another chronic drain on the national balance of payments. Put it all together, and Canada has been experiencing a large and now-chronic deficit on its balance of payments that has totalled around $60 billion in recent years. Whereas we once were able to successfully export both resources and value-added products to the rest of the world, our capacities have become increasingly concentrated in resources (especially energy). Even our huge trade surplus in energy products is not enough to offset growing deficits in non-energy merchandise, services, and investment income. We are learning the hard way that we need more than oil to pay our way in world trade.

Even within the broad category of energy exports, Canada's trade has become deindustrialized as we move further and further toward the low-value end of the economic continuum. Most petroleum-producing jurisdictions, in an effort to capture more of the value-added potential of their non-renewable resources, invest heavily in developing upgrading, refining, and petrochemical capacities. Typically, strong policy interventions are used to expand this value-added activity: for example, through requirements for domestic processing, limits on exports of unrefined resources, the use of fiscal subsidies to encourage downstream investments, and even the direct allocation of public equity capital to refining and petrochemical projects. Even in Canada this has been a traditional priority – for example, as with Alberta's effort to nurture a domestic petrochemical industry in the 1970s. In recent years, however, the importance of adding downstream value to our petroleum production has largely faded from the radar screens of policy-makers. Petroleum companies are now given free rein to export the energy they produce in any form. Indeed, the integrated global producers that account for a large share of Canadian petroleum output naturally prefer to refine their feedstock in their own refineries (often located in the U.S.). In this way, corporate decisions regarding what is cheapest or most profitable can easily diverge from broader cost-benefit calculations about what produces most value for Canada.

As a result, the refining and petrochemical end of Canada's petroleum business has lagged far behind the extraction end. In fact, by some measures there has been no growth in petroleum refining and processing at all – in sharp contrast to the dramatic expansion in petroleum extraction. Figure 3, for example, indicates the trend of real output (measured by GDP) in oil and gas extraction and petroleum products manufacturing, using 1990 as the base. Extraction has grown steadily and dramatically (up by 70 percent, in real terms, over that period). Initially, in the 1990s, refining and processing activity also grew, but at a much slower pace. With the take-off in global prices (and the Canadian exchange rate) in the early 2000s, however, even that growth was reversed. Real GDP in the petroleum products sector has since declined by 10 percent, even as the extraction boom accelerated. This decline could get worse, given the fragile prospects facing Canadian refineries in several locations (including B.C., Quebec, and Newfoundland), where security of supply and other challenges are jeopardizing their long-run viability. More positively, some new investments are being made in upgrading (largely in

Figure 3
Extraction vs. Value-Added: GDP

Source: Author's calculations from Statistics Canada CANSIM Table 379-0004 and 379-0031.



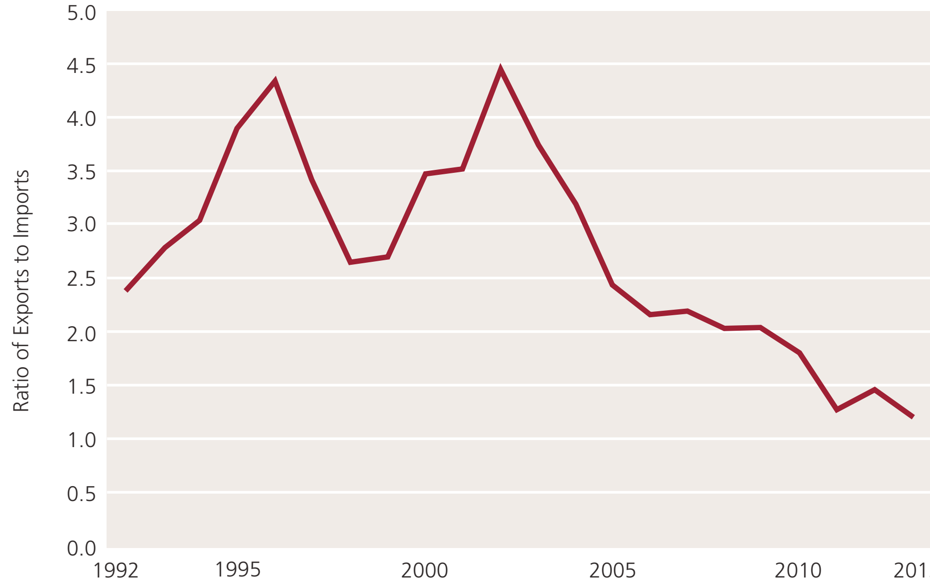
Western Canada), but not enough to reverse the overall trend. Therefore, the stagnation, at best, of Canada's petroleum products sector continues, even as our production of raw petroleum has exploded. This is a damning indicator of the failure of our energy policy to capture the value-added opportunities arising from our own non-renewable resources.

The lack of attention provided to downstream activity in the context of the overall boom is also readily visible in our flagging international trade performance in that end of the business. One would think that, as a leading global petroleum producer, Canada would naturally also be successful in international petroleum products trade. But Canada's status in this regard is increasingly in question. Changes in the regional patterns of energy supply and demand within North America have resulted in Canada becoming a major importer of petroleum products (both from offshore and from the U.S.). Petroleum product imports have exploded five-fold (in nominal dollars) since 2004, mostly destined for consumers in eastern Canada. Canada's exports of refined products, on the other hand, only doubled during the same time (driven solely by higher prices, not increased real output).

The curious result is that Canada now barely exports as much refined petroleum products as it imports, as illustrated in Figure 4. The ratio of exports to imports in this important value-added sector has plunged from over 4-to-1 early in this century, to just 1.2-to-1 in 2013. Relatively minor additional shifts in supply patterns (or, worse yet, the possible closure of one or more Canadian refineries) could easily tip this balance into the red. What an incredible irony that Canada, a dominant source of global petroleum, could soon become a net importer of refined petroleum products. The jobs, incomes, and innovation potential associated with manufacturing our own petroleum, are all given up to foreign suppliers. Meanwhile, as we continue to pump as much unrefined product into foreign markets as possible (for now, only to the U.S.), the earned price of those exports is suppressed by regional supply gluts and the lower quality of the product. The faster we export unrefined product, the lower its price becomes. By focusing so exclusively on extracting and exporting a base product, we dig ourselves into a bigger and bigger hole. We are left needing to exploit increasing volumes

Figure 4
Refined Petroleum Product Trade

Source: Author's calculations from Industry Canada, Strategis database.



of raw resource just to pay for our imports (even imports of products refined from our own feedstock).

It is not just downstream where the failure of Canada to maximize the value-added potential of our petroleum resources is so painfully evident. Upstream too, the lack of attention and creativity of our energy policy is reflected in a growing reliance on foreign suppliers for enormous purchases of lucrative, value-added inputs to the resource industry itself. Too much of the economic stimulus resulting from resource investments leaks out of Canada's economy through imports of machinery, equipment, and supplies. Input-output studies indicate that the dominant supply chain feeding new resource projects in northern Alberta runs north-south, much more than it runs east-west. Too much of the resulting economic stimulus is experienced in the U.S., rather than in Canada (whether that is Alberta or other provinces). For example, according to the Canadian Energy Research Institute, the spin-off economic benefits from bitumen production in Alberta are 5 times larger in the U.S., than in Canadian provinces outside of Alberta (see Clarke et al., 2013, pp. 80-81; and Honarvar et al., 2011). The more we spend on capital equipment and other inputs to petroleum extraction, the more we import, and the bigger our trade deficit becomes.

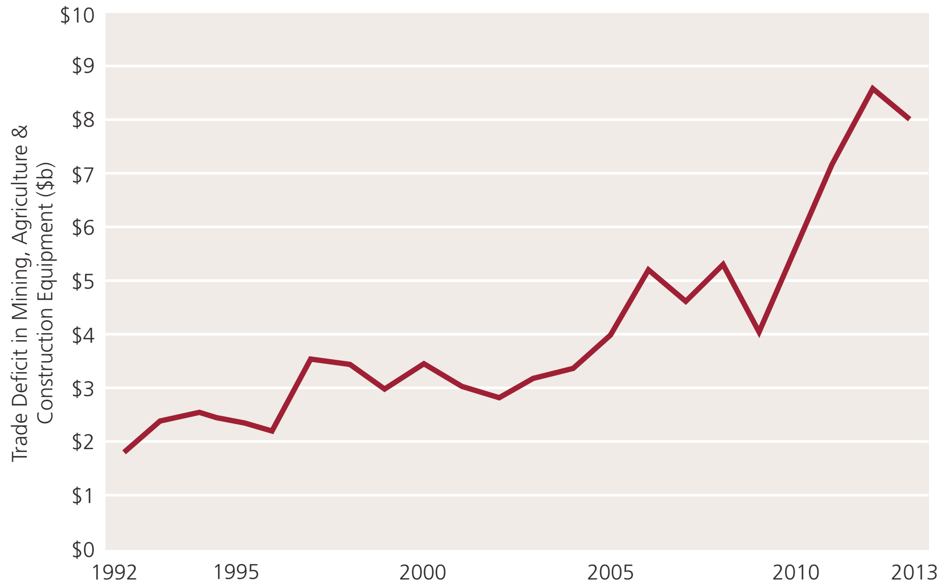
Figure 5, for example, illustrates the dramatic expansion of Canada's trade deficit in construction and mining equipment. Canada has always had an underdeveloped heavy machinery manufacturing sector, but important production facilities here, and a determined effort by policy-makers to expand our footprint in this vital sector,[3] at least kept us in the game. That has all changed. Resource investments have increased Canadian demand for high-cost, high-value heavy equipment. But at the same time, Canadian production of construction and mining equipment has declined – battered by exactly the same forces that have hammered the rest of the manufacturing sector. The resulting gap between demand and domestic supply produces an enormous trade deficit. The deficit in construction and mining equipment alone reached almost $9 billion by 2012, and has roughly tripled since the petroleum boom took off.

Indeed, no better symbol of the weaknesses of the domestic linkages (and the failure of domestic policy to strengthen those linkages) could be provided than the case of Caterpillar.

[3] Economists have long recognized the strategic importance of capital equipment and machinery manufacturing, given its link to domestic productivity, the regional concentration of learning effects and other spill-overs, and the constant innovation and product differentiation which characterize these industries. See Wolfe and Lucas (2005) for more discussion.

Figure 5
Canada's Trade Deficit in Mining Equipment

Source: Author's calculations from Industry Canada, Strategis database.



This U.S. machinery giant sells billions of dollars of equipment to Canadian resource projects. Yet the company closed its only Canadian manufacturing operations in 2012 and 2013. One of these closures generated considerable public attention: the shuttering of its London, Ont., locomotive plant (following a failed attempt to enforce a 50 percent cut in wages on union members there). The other was less reported, but equally ruthless: the closure of Caterpillar's non-union tunnelling equipment factory in Toronto (where workers were not unionized, and hence the company did not go through the high-profile charade of demanding large cuts in compensation). These actions have not deterred Canadian resource producers from sending even more business to Caterpillar – and why should this not be the case, if Canadian governments make no effort to connect the dots between Caterpillar's enormous resource-driven business, and the company's own manufacturing activity here. Being host to many large resource projects should give Canada a "home market advantage" in developing and producing capital equipment tailored to the unique requirements of our resource sector. But without a deliberate strategy, this opportunity will be wasted, and our reliance on foreigners to do this expensive, innovative work will only continue.

In short, both upstream and downstream, it is clear that Canada is squandering unique opportunities to lever our resource wealth into a more well-rounded form of economic development. Even within the resource sector itself, we are ignoring obvious openings to stimulate more made-in-Canada production (both producing valuable inputs to resource projects, and processing and manufacturing our own resources once they are pulled from the ground).

The Risks of Resource-Dependence

The evidence is clear that Canada's economy, and Canada's international trade, is becoming increasingly concentrated in the extraction and export of unprocessed resources – and that the take-off of the petroleum industry beginning around 2002 has accelerated that process dramatically. There are many reasons why this growing concentration should concern Canadians, and why policy-makers, instead of uncritically celebrating this boom for its immediate economic benefits, should consider ways to manage and plan the expansion, and support as much Canadian value-added as possible.

For example, Canada's national business innovation performance has long been a source of national and international concern.[4] And Canada is getting worse in this regard, not better. Business investment in research development has declined by one-third as a share of GDP since the turn of the century – even as the petroleum boom was gathering momentum. The private sector invested just 0.8 percent of GDP in R&D in 2013 (down from 1.3 percent in 2001). That's the lowest R&D intensity since Statistics Canada began collecting these data. Canada now badly underperforms other industrial countries (and even some emerging market economies) in R&D spending, and the decline in R&D spending (relative to GDP) has been bigger in Canada over the last decade than in any other OECD economy. In other words, our innovation effort and performance has been deteriorating, even as the importance of innovative capacity to long-run productivity and competitiveness is increasingly recognized.

The petroleum-driven structural change in the Canadian economy has been an important part of the deterioration of overall innovation performance during the last decade. Petroleum companies and other resource-extraction businesses do conduct R&D, but significantly less as a share of the industry's GDP than the rest of the economy. Hence, the expanded relative importance of extraction activities will automatically be associated with a decline in overall innovation effort. The related contraction of the manufacturing sector (discussed further below) has a similar effect, since manufacturing is the strongest source of R&D spending. The manufacturing sector in Canada typically invests around 4 percent of GDP in R&D activity, versus only 0.6 percent for the petroleum and mining industries, so a reorientation of Canadian economic activity from manufacturing toward resource extraction will inevitably produce poorer R&D outcomes. That lack of innovation, in turn, then reinforces our economic reliance on the straight extraction of raw resources (since the less we invest in innovation, the less competitive we are in international trade in value-added products).

The impact of the resource boom on national productivity performance is another drawback of our growing dependence on the extraction and export of raw resources. Productivity in resource extraction tends to decline over time, as the most readily available reserves of desired minerals are harvested first – requiring more capital and labour effort to exploit less lucrative deposits.[5] This effect can be offset to some extent by progress in extraction technologies. The tremendous effort (including expenditure of energy) required to extract bitumen is an extreme example of this fundamental "Ricardian" problem in resource industries. Since the turn of the century, Canada's labour productivity has grown at the anemic rate of 0.6 percent per year: putting us 29th among the 34 countries of the OECD, with less than half the average rate of productivity growth in the industrialized world. Resource extraction is certainly profitable (especially when global commodity prices are high), but its productivity declines over time – and this poses significant long-term economic risks to any country which places a growing share of its economic eggs in this particular basket. So as the composition of the economy shifts in favour of resource industries, each of which experiences diminishing returns, overall composite productivity performance suffers accordingly.

The unplanned, "gold rush"-like approach to investment in new resource projects (especially in northern Alberta) further undermines productivity. Mammoth, helter-skelter capital spending, with little attention paid to infrastructure, bottlenecks, and labour supply planning, regularly

4 See Council of Canadian Academies (2013) for a useful overview of the evidence and causes.

5 See Stanford (2011) for more discussion of this relationship between resource extraction and productivity.

produces huge cost overruns and other problems in those new projects, and negative outcomes in terms of realized productivity.

Research by Sharpe (2013) confirms the negative impact of growing resource dependence on national productivity. Average labour productivity in mineral and oil and gas extraction has been declining since the turn of the century at the rapid pace of over 5 percent per year, giving this sector the dubious distinction of making the largest negative contribution to Canada's overall productivity performance. The growing share of national output accounted for by pure extraction activities thus has been an important factor in Canada's miserable overall productivity record.

Undue reliance on the export of unprocessed commodities also poses substantial risks to the national economy, in the event of negative shifts in global demand, technology, or prices for those particular products. Indeed, the past history of Canada's staples-driven economic development features many examples of industries (and regions) wiped out by changes in global demand for the products concerned. In some cases the staples industry disappeared because of the exhaustion of supplies. But in other cases the decline reflected changes in foreign technology and tastes, which undermined demand for the staple export in ways over which Canada had no control – then necessitating a painful restructuring.[6] To take a vivid example, Canada no longer exports beaver pelts, and not because we ran out of beavers. Rather, foreign demand for the product disappeared due to changes in taste and technology. Foreign appetite for our other staple exports, including petroleum, is equally unpredictable. For many reasons (technological, environmental, and geopolitical) the strength of global demand for Canada's petroleum output cannot be taken for granted. This risk is not eliminated by merely trying to diversify the destinations of our exports of raw petroleum. Basic prudence would suggest that we should diversify our economic portfolio to reduce the potential damage from future cycles in demand, prices, and activity.

Even business leaders in Canada express concern about the increasingly resource-dependent nature of Canada's economic direction – even though many of those leaders are personally employed in resource-related companies. For example, in a recent survey of CEOs conducted by the Globe and Mail, nearly two-thirds agreed with the statement that Canada is too reliant on commodities, and needs more diversification (Blackwell, 2014). One technology CEO expressed his concern bluntly: "We have become more hewers of wood and drawers of water than we were. There is no doubt in my mind that we have created more risk in our economic environment."

The consequences of the petroleum boom for Canada's international environmental citizenship provide another reason to reconsider the current trajectory. Our resource policies (and, indeed, all economic policy) must now be evaluated in light of our overarching need to limit and reduce greenhouse gas pollution. The environmental problems associated with bitumen production are well-known, including both localized effects (tailings ponds, water pollution, and land reclamation issues) and emissions of greenhouse gases (since bitumen production is itself very energy intensive, it releases more carbon dioxide in extraction and processing than conventional oil). Pressed by regulators and public opinion alike, the petroleum industry has been working to reduce the emissions-intensity of production, but those efforts are being swamped by the dramatic expansion in the sheer scale of production (which some forecasts expect to triple over the next two decades). According to the federal

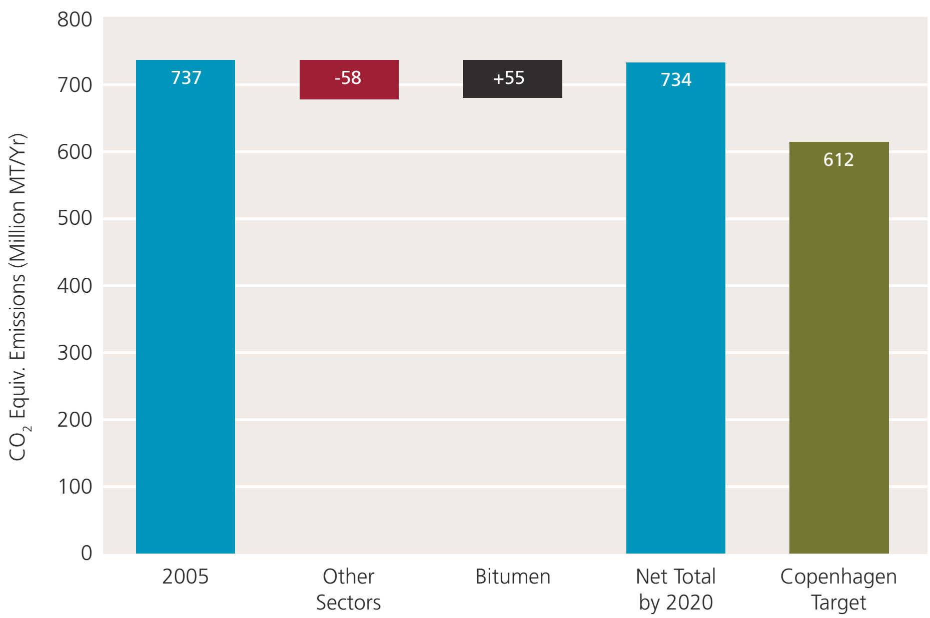
[6] Haley (2011) discusses the dimensions of these risks, and highlights the continuing relevance of this problem – especially regarding environmental factors which will inevitably affect the demand for Canadian energy staples in the future.

government's own forecasts (Environment Canada, 2013), the resulting growth in bitumen-related emissions will almost completely offset the decline in greenhouse gas emissions achieved from all other sectors in Canada from 2005 through 2020 (see Figure 6). That will leave Canada far away from its stated Copenhagen commitments. The rapid expansion of bitumen production is by far the largest single source of new greenhouse gas emissions in Canada. Unless offset by dramatic reductions in emissions from other sectors (something that is far-fetched in the absence of any binding national climate change targets), environmental constraints will inevitably curb future growth in petroleum output and hence threaten the value of sunk capital. Even financial investors are becoming more cognizant of the environmental limits on future bitumen extraction (see, for example, Leach 2014).

It is clear that the sheer physical quantity of resource extraction, and bitumen production in particular, will need to be constrained by the need to limit greenhouse gas pollution. So if the quantity of resource extraction necessarily will be limited, it becomes all the more important to ensure that Canada's economy derives the most benefit possible from the limited volume of resources which can be produced. This reaffirms the emphasis on maximizing the value-added opportunities associated with resource extraction – both upstream and downstream.

Figure 6
Wasted Opportunity

Source: Author's calculations from Environment Canada (2013), p. 21, 24.



Diseases: "Dutch" and Others

Canada's deteriorating value-added performance is not solely due to our failure to maximize the value-added spin-offs that could have been associated with the growth in resource extraction. The damage to our value-added potential goes further, because that resource boom itself has indirectly and inadvertently damaged the prospects of other value-adding sectors of the economy. In other words, not only are we failing to maximize the spin-off benefits to value-added industries from the resource boom, we are also failing to mitigate the collateral damage from the resource expansion to other sectors which do contribute to Canada's economic productivity, diversification, and innovation.

The most important channel for this negative collateral damage on other tradable industries has been through the exchange rate. For various reasons, the rapid expansion in petroleum production and export was associated with the dramatic appreciation of the Canadian dollar, also beginning in 2002. That badly undermined Canadian production and exports of non-resource tradable products – including manufacturing, of course, but other tradable industries as well (such as tourism and tradable services).

This phenomenon is commonly called "Dutch disease" in popular discourse (so-named by the Economist magazine in 1977 to describe the evolution of the Dutch economy following the discovery of North Sea gas there some years earlier). In my view, that term is more confusing than illuminating – all the more so in light of the heated debates that have occurred in Canada over this issue in recent years. Indeed, the Dutch and Canadian experiences with deindustrialization were very different – not least because the downturn in Dutch manufacturing exports that followed the North Sea discoveries was modest and temporary, compared to the more dramatic and long-lasting erosion of Canada's manufacturing sector. I prefer a more descriptive phrase, "resource-led deindustrialization," to refer to the phenomenon whereby value-added industries are crowded out by a resource boom. There are many potential channels for this effect,[7] but the impact of resource extraction and export on the exchange rate is clearly the most important.

The composite hypothesis of resource-led deindustrialization depends on two distinct sub-hypotheses. First, it needs to be shown that the expansion of natural resource exports (and petroleum in particular) pushes up the value of the exchange rate. Second, it needs to be shown that exchange rate appreciation in turn causes contraction in the scale of production and export of non-resource-based tradable industries – including, but not limited to, manufacturing. Other tradable industries affected by exchange rate appreciation include services exports and tourism. Both of these propositions would seem relatively common-sense and uncontroversial when expressed independently. For example, few Bay Street traders would question that the high price of oil, and Canada's growing presence in the global oil industry, was an important factor in the rise of the dollar beginning in 2002. Similarly, few manufacturing analysts would question that the dramatic rise in the dollar had something to do with the accelerating decline in Canadian manufacturing activity, output, and exports. In neither case does the causal relationship need to be exclusive: that is, other factors may also contribute to the rise in the dollar and/or the contraction of manufacturing. To sustain the hypothesis of resource-led deindustrialization, we merely need to accept that both factors are relevant.

Put these two seemingly innocuous sub-hypotheses together, however, and the explosive political implications begin to distort the nature of analysis and discourse. Suggesting that the expansion of an export-oriented petroleum industry (concentrated in the west of Canada) has anything to do with the troubles of manufacturing (concentrated in central Canada) raises uncomfortable questions and conflicts. Some economic and political commentators would rather not talk about the issue at all.

For example, when former Ontario Premier Dalton McGuinty and Federal NDP leader Thomas Mulcair independently suggested in 2012 that Canada's manufacturing industry was experiencing negative side-effects related to the speed and scale of the resource expansion, they were met with a daunting and highly-politicized reaction. Both were accused of being

[7] If capital and labour markets were constrained on the supply side, then a resource boom could crowd out other sectors simply by bidding up the price of those inputs and facilitating their reallocation away from other sectors. That type of restructuring would hardly be a problem, however, since owners of capital and labour (even in declining sectors) would experience rising incomes, and no difficulty finding alternative employment. In Canada's recent experience, it is clear that neither employment nor investment are constrained by supply, and the impact of the resource expansion on other sectors has been experienced through other, less benign channels.

unpatriotic and divisive. Both were vilified by financial columnists (especially, but not exclusively, those in Western papers). Ontarians were told to stop blaming Albertans for their problems (as if such a simplistic us-against-them counterpoint was the essence of the argument). McGuinty and Mulcair moved to defuse the storm, largely retracted their comments, and the lesson was made clear: there is little political space in mainstream dialogue in Canada to even suggest there is any economic downside whatsoever to untrammeled resource expansion. One commentator (Cross 2013b) went so far as to declare (perhaps prematurely) the demise of the whole theory: "The notion of Dutch disease (that a booming resource sector leads to a higher exchange rate that depresses manufacturing) has been so dis-credited even politicians shy away from its use." It is likely true that politicians, given the experience of McGuinty and Mulcair, do indeed shy away from invoking this concept. But that hardly proves that their argument is wrong.

I have reviewed a dozen recent published studies examining the link between the petroleum export boom and the decline of manufacturing in Canada since 2002. I consider what each study says about each of the two sub-hypotheses described above: the impact of the petroleum boom on the value of the Canadian dollar, and the impact of the higher Canadian dollar on manufacturing activity in Canada. The findings of this review are summarized in Table 2.

Table 2
Previous Research on Resource-Driven Deindustrialization in Canada

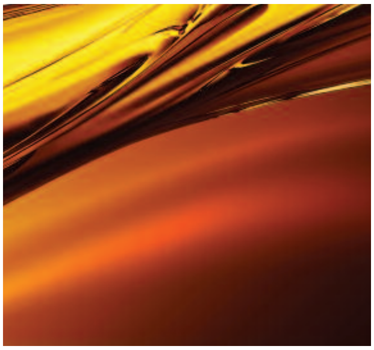
Source: Adapted from Clarke et al. (2013), pp. 73-87.

"n.a." indicates that the source in question did not address this issue.

Source	Link Between Oil Price / Oil Expansion and Appreciation of $C?	Link Between Appreciating $C and Decline of Canadian Manufacturing?
Bank of Canada (2012)	✔	✔
Beine et al. (2009)	✔	✔
Burt et al. (Conference Board, 2012)	n.a.	n.a.
Clarke et al. (CCPA, 2013).	✔	✔
Cross (Macdonald-Laurier, 2013)	✔	✖
Honarvar et al. (CERI, 2011)	n.a.	n.a.
IMF (2013)	✔	✔
Lemphers and Woynillowicz (Pembina, 2012)	✔	✔
OECD (2012)	✔	✔
Shakeri et al. (IRPP, 2012)	✔	✔
Spiro (Mowat, 2013)	✔	✔
Tal and Exarhos (CIBC, 2014).	n.a.	✔

Not every one of these published works comments explicitly on each of the two links in the logical chain required to sustain the composite deindustrialization hypothesis. For example, two much-reported studies estimating the spin-off benefits of bitumen investments for other regions and other industries in Canada (Burt et al. 2012, and Honevar et al. 2011) make no commentary on either of those two issues. Instead, these two studies each utilize a fixed-coefficient input-output model (benchmarked to Statistics Canada's 2006 input-output matrix for Honevar et al., and 2008 for Burt et al.) to track through the indirect effects. This approach assumes fixed relative prices and a fixed exchange rate. Neither of these reports, therefore, can shed light on whether or not the resource boom has had any negative side-effects on the competitiveness, and hence output, of those other sectors.[8]

[8] Moreover, both of those studies find the interprovincial and intersectoral stimulus from major bitumen investments to be surprisingly small, and much smaller than the spin-off spending generated in the U.S. economy by those investments. See Clarke et al. (2013), Appendix 1, for a more detailed discussion.



Of the other studies listed in Table 2, all but one confirm that the run-up in oil prices, and the corresponding expansion of investment, production, and exports in Canada's petroleum industry, has been a significant factor (not necessarily the only factor) in the sharp appreciation of the Canadian dollar since 2002. The only exception is the work of Tal and Exarhos (2014), who did not attempt to explain the causes of the dollar's appreciation, but rather focused only on its consequences.

Regarding the second sub-hypothesis, all but one of the remaining studies (again, other than the two input-output models) also confirmed that the appreciation of the Canadian dollar was a significant factor (again, not the only factor) in the contraction of Canadian manufacturing. The only exception in this case was the report by Cross (2013a), who, surprisingly, actually denied that any such contraction in manufacturing has, in fact, occurred. Cross measured the size of the manufacturing sector on the basis of nominal sales (rather than more conventional measures such as real value-added or employment), and concluded that overall manufacturing output was stable through the decade of Canadian-dollar appreciation (with sectors enjoying growing sales offsetting those experiencing falling sales). On this basis, Cross concludes that deindustrialization has not occurred.[9] He is the only author among the twelve surveyed to argue that manufacturing has not declined. Most other analysts would conclude from the loss of employment (down by 600,000 positions in Canada since 2001) and real value-added (which declined 14 percent between 2004 and 2013)[10] that manufacturing has indeed experienced a contraction.

The strong majority of research surveyed and summarized in Table 2, therefore, confirms both sub-hypotheses in the theory that the petroleum boom, primarily through its impact on the exchange rate, has indeed had a negative impact on manufacturing (and other tradable sectors, as well). Research confirms that the rapid expansion of petroleum production and export has been a major factor in the appreciation of the dollar, and also that the stronger exchange rate has predictably undermined investment and export opportunities in other trade-sensitive sectors. Only one cell in the matrix depicted in Table 2 (namely, Cross's argument that the high dollar has not damaged the manufacturing sector, which has enjoyed stable aggregate nominal sales) reflects the presence of counter-evidence to either of the two sub-hypotheses embedded in the composite hypothesis of resource-driven deindustrialization. Eight of the twelve studies confirm both links in that logical chain, two confirm one of the two links, and the remaining two (the input-output studies) do not comment on either link.

Published economic research, therefore, confirms that the resource boom has had an important set of unintended side-effects on the well-being of other sectors in Canada's economy. This hardly implies that the petroleum industry should somehow be vilified or "shut down." Instead of pretending that these unintended side-effects do not exist (or, worse yet, suggesting that it is somehow "un-Canadian" to even discuss them), surely it is more effective to recognize that there are both costs and benefits to the petroleum boom. The expansion of petroleum extraction and export has created potential and opportunity, but also risk and challenge. The goal of policy should be to actively enhance the benefits and reduce the costs of this fundamental change in Canada's economic structure, thus achieving a higher net benefit outcome for Canadians. Efforts to enhance the Canadian value-added associated with resource developments (both upstream and downstream) would certainly constitute one important component of such a policy framework.

[9] The use of nominal sales as a measure of total industry output is questionable given the impact of inflation on nominal values. Two of the most resilient sub-sectors identified by Cross (food manufacturing and petroleum refining) were also the ones experiencing the fastest nominal inflation, which should not be misinterpreted as evidence of "growth" in any real sense.

[10] In 2000 manufacturing accounted for 16 percent of Canada's GDP at factor cost; by 2013 that had declined to 10 percent. While manufacturing tends to decline gradually as a share of GDP in the industrialized countries, the decline in Canada has been much faster since 2000, and to a lower level, than in other OECD countries. And in Canada there has also been a decline in absolute real manufacturing output which has not been experienced in most other OECD countries.

The precise "transmission mechanism" linking the petroleum boom to the exchange rate merits further discussion. Casual observers might assume that the impact is experienced through a generalized improvement in trade performance (measured by the current account balance), driven by vibrant petroleum exports. But this is clearly not the case. As noted above, Canada's overall trade balance has deteriorated markedly in the last several years, and remains mired in a deep and chronic deficit. Including services and investment income, Canada's current account deficit now regularly exceeds three percent of GDP (leading to an annual accumulation in international indebtedness of equal proportion).

The link between petroleum and the exchange rate is not experienced through trade flows, but rather through capital and asset markets.[11] Part of the effect is due to fleeting speculative capital flows, as financial traders internalize (rightly or wrongly) the assumption that the Canadian currency is a "petro-dollar," and hence determine their speculative positions in light of their expectations of changes in petroleum markets. This belief can become self-fulfilling, and during periods of exuberant expectations it can push the dollar far higher than real fundamentals would justify. The transmission mechanism between the petroleum boom and the Canadian dollar is also experienced through longer-run capital inflows associated with the growth of foreign direct investment in Canada's oil patch. The historic surge in incoming FDI (focused on resource-related industries) in 2006 and 2007 was associated with the most dramatic upswing in the dollar. Continuing foreign investment in the oil patch[12] has reinforced this overvaluation.

Canada represents a rare opportunity for private energy companies to invest in new sources of petroleum supply, since over 80 percent of the world's oil reserves are owned by state-owned enterprises, and over half of the remainder is located in Canada (see Hussain, 2012). This unique private access to a strategic non-renewable resource is another factor explaining the intense interest by foreign investors in ownership of Canadian petroleum assets. A better understanding of the precise ways in which the petroleum expansion translated into a rising Canadian dollar can also inform policy responses to the problem. For example, if incoming FDI interest is a key factor supporting the dollar at high levels despite Canada's large and accumulating current account deficit, then limits on foreign takeovers of resource assets and resource companies would help to break that link and presumably facilitate a softening of the dollar. The fact that the Canadian dollar declined significantly in 2013, following the announcement by the federal government of new limits on foreign state-owned ownership in the bitumen industry, is consistent with this hypothesis.

The reversal of the Canadian dollar through 2013 and 2014 reduced its value by over 10 percent compared to the U.S. dollar. But even at reduced levels (in the range of 90 cents U.S. at time of writing) the dollar's retreat is incomplete. According to the Organization for Economic Cooperation and Development, the purchasing power parity equilibrium level for the Canadian dollar is 81 cents (U.S.).[13] Even at 90 cents (U.S.), therefore, the exchange rate is still approximately 10 percent too high (and still making Canadian-made goods and services appear 10 percent too expensive in global markets). However, even this partial reversal will eventually enhance the competitiveness of non-resource exporters (with an expected time lag[14]) and lead to some improvement in non-resource trade performance. Even resource exporters benefit from a lower dollar (since it enhances the landed value of export earnings). This partial decline in the dollar reflects a negative shift in investor expectations about

[11] Economists have long recognized that the exchange rate is a primarily financial variable, not predictably determined by factors in the real economy.

[12] A recent estimate suggests that foreign investors own over 70 percent of the equity in Canada's bitumen production, including both Canadian subsidiaries of foreign firms, and foreign minority ownership of Canadian-based bitumen producers. See Forest Ethics Advocacy (2012).

[13] See OECD, "Purchasing Power Parities for GDP," available at OECD.stat.

[14] It typically takes 1-2 years for the effects of exchange rate adjustments to be reflected in production and employment decisions, and even longer for fixed capital spending.

Canada's general economic recovery, the expected "tapering" of quantitative easing by U.S. monetary authorities, the recent softening of global commodity prices (and expectations of future price changes), and a realization by investors that Canada's bitumen expansion faces many risks and constraints (economic and otherwise). The softer dollar will assist many export industries, but it cannot bring back all the non-resource jobs lost during the dollar's upswing. Moreover, many firms will wonder if the dollar might shoot upward again in the future (if and when oil prices strengthen further). Given the inaction of Canadian policy-makers (in government and the Bank of Canada) when the dollar took off after 2002, this is a reasonable concern, and it may serve to inhibit the rebound in investment in manufacturing and other trade-sensitive activities.

Nevertheless, the recent decline of the Canadian dollar has been almost universally welcomed by economic analysts who expect it to have an eventual and significant positive impact on exports (which has been the weakest component of national GDP performance). This is ironic, given the intense debate which erupted when the dollar was high, over whether or not this appreciation had any negative implications for the rest of the economy or not. If resource-driven deindustrialization does not exist, and the high dollar was not the cause of Canadian manufacturing problems, then why do economists now so energetically welcome the dollar's decline?

The erosion of manufacturing in Canada was far faster over the past decade than was experienced in most other OECD countries. It was not inevitable, and has had major negative effects on Canada's productivity, investment, incomes, and exports. Moreover, the decline in other export industries in the era of over-valuation (including tourism and tradable services) shows this is not solely a manufacturing issue. All trade-sensitive industries (including petroleum itself) have been damaged by the sharp currency appreciation which was so clearly a side-effect of the petroleum expansion. Notwithstanding the over-heated political rhetoric that was sparked by the issue, policy-makers should think about ways to ensure that this unfortunate experience is not repeated in the future.

Toward a More Diversified Economy

As a major petroleum producer, Canada is squandering the opportunity to generate additional jobs, incomes, and exports from petroleum production (keeping in mind that the level of petroleum extraction must be managed, as well, in light of both economic and environmental considerations). We need a proactive strategy to maximize forward and backward linkages from petroleum extraction to other value-added sectors. In this way, resource production can support (rather than undermine) broader economic development goals. "Less extraction and more value-added" is a motto which summarizes this philosophy. Applied to the petroleum industry, this approach would feature several key policy measures:

- Active efforts are needed to boost Canadian-content in the machinery, capital, and services which are purchased as inputs to resource projects. Given the enormous capital investments being made in new projects (especially bitumen), the industrial spin-offs to other Canadian sectors have been far from optimal. Capturing those spin-off benefits requires planning and encouragement, rather than simply assuming that a rising bitumen tide will automatically lift all boats.

Sarnia-Lambton Refining and Petrochemical Complex

- Active strategies to maximize industrial spin-offs from resource projects across Canada would also help to overcome the regional inequalities and divisions which are a feature of the current unplanned approach. Potential enmity between resource-producing and resource-consuming regions could be short-circuited quickly by deliberate and effective measures to enhance the purchase of capital equipment and other inputs from other provinces.
- Exports of raw petroleum should be discouraged or limited by regulation. Instead, policy should encourage (or even mandate) more made-in-Canada upgrading, refining, and petrochemical activity, to add as much value as possible to our non-renewable resource – and to avoid driving down received export prices through our own excess shipments of lower-grade bitumen.
- Enhancing the value to Canadians of our own resource also implies investments in infrastructure to allow the matching of Canadian supplies with Canadian end-users. Canada's refining and petrochemical industries face challenging global pressures which threaten the future of important refinery operations in several parts of Canada. Ensuring a secure source of Canadian supply to these crucial facilities would help to preserve these facilities and their high-value jobs, as well as to strengthen Canada's net trade performance in refined petroleum products.
- An ambitious value-added policy for Canada also requires proactive measures to support continued investment, production, exports, and innovation in export-oriented value-added industries that have nothing to do with petroleum. Active industrial strategies to enhance Canada's footprint in key high-value industries (learning from the successful experience of other countries which have followed this approach, like Germany, Korea, and Scandinavia) will be important in ensuring that Canada's resource wealth does not result in an unbalanced economic structure.[15]
- Proactive measures to manage the macroeconomic side-effects of regionally concentrated resource expansion will also be important to improving the net benefits to Canadians from petroleum production. This includes measures to ensure the Canadian dollar remains at levels that are compatible with Canadian competitiveness. Fiscal measures to ensure that the benefits of resource production are shared widely through the country will also be important.

With active attention paid to ensuring that resource industries contribute, rather than detract from, the prospects of other value-added sectors in Canada, our resource wealth could become a stepping stone toward a more diversified, prosperous, and sustainable economic future.

In contrast to this optimistic vision, some proponents of a more narrowly "extractivist" economic strategy actually celebrate Canada's renewed focus on raw resource extraction as an efficient reflection of our natural "comparative advantage." For them, there is nothing wrong with Canada becoming increasingly dependent on the extraction and export of raw resources. Government should not interfere with the drive to extract and export non-renewable resources such as petroleum, since the profit-seeking activity of the oil industry somehow reflects the real benefits and opportunity costs of the various opportunities for using our scarce capital, labour, and ingenuity. Merely extracting the resource, in this world view, is all the "value-added" that we need. For example, Trevor Tombe, an economist at the University of Calgary and author of a recent report celebrating Canada's raw energy exports, made this case

[15] See Stanford (2012) for more discussion of this policy direction.

bluntly: "The value you're adding is in extracting the resource itself. It has no value a kilometre below the surface, but it has value when it's brought to the surface. When you take resources from below the surface and move it up to the surface and ship it to where the demand is, that is creating value." (Smith, 2014). This approach implies that unexploited natural resources are value-less and hence "wasted," and that it is in fact preferable to focus on extraction and to allow other nations to do the work of innovation, engineering, design, and manufacturing required to convert our raw resources into value-added products and services.

Most Canadians would reject this stunted vision for Canada's economic future. Most Canadians immediately appreciate the risks – economic, environmental, geopolitical – of our country becoming a mere source of raw materials for other, more developed economies, who then process those resources and sell us back the (more expensive) finished products. Most Canadians want something bigger for our country: an economy based on talent, innovation, ingenuity, and productivity. I believe that the vision of building a more diversified, value-added economy is one that would generate strong excitement and support. We don't need to throw out any babies with the bath water; we can be grateful for the unique opportunities that Canada's resource wealth provides. But we must be more deliberate and proactive in ensuring we manage that wealth wisely, as a stepping stone to a developed, prosperous, and sustainable economy.

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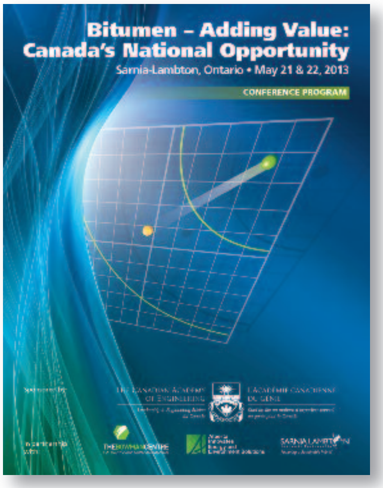
Biography

Jim Stanford is an economist with Unifor, Canada's largest private sector trade union. He received his Ph.D. in Economics in 1995 from the New School for Social Research in New York, and also holds economics degrees from Cambridge University and the University of Calgary. Jim is the author of "Economics for Everyone,"published in 2008 by Pluto Press and the Canadian Centre for Policy Alternatives. He writes an economics column for the "Globe and Mail," and is a member of CBC TV's regular National News economics panel, "The Bottom Line." He lives inToronto with his partner and two daughters.

3

Bitumen – Adding Value: Canada's National Opportunity

Katherine J. Albion
Marshall J. Kern
Walter F. Petryschuk



ABSTRACT

The conference "Bitumen – Adding Value: Canada's National Opportunity," was initiated and sponsored by the Bowman Centre at the Western Sarnia-Lambton Research Park, in partnership with Alberta Innovates – Energy and Environment Solutions, Sarnia-Lambton Economic Partnership and the Canadian Academy of Engineering. The conference brought together representatives from the private sector, the political scene at three levels of government, as well as labour, lobby groups, agencies and technical professionals (contributors shown on page 46).

The purpose of the conference was to focus on oil sands bitumen with a view towards enhancing the discourse about adding value to Canada's resources, specifically that of bitumen extraction and additional value-added processing in Canada.The goal was to stem the loss of wealth inherent in exporting the raw resource. This chapter focuses on the views and perspectives of the many contributors who participated in the conference's five sessions. The keynote presentations were highlighted by the Honourable Frank McKenna, Deputy Chair of the TD Bank Group, and Dr. Jim Stanford, Economist for Unifor. In addition, a key address was made by the Honourable Senator Elaine McCoy from Alberta. A further key address came from Mr. Kirk Bailey, President of Kushog Consulting, and former executive of Suncor Energy Ltd., addressing the perspective of the private sector from a position of his active involvement in oil sands development.

Conference Contributors

Mr. Kirk Bailey
Former Executive Vice President of Suncor's Oil Sands Business Unit and Vice President of Suncor's Sarnia Refinery; Consultant

The Honourable Bob Bailey
Member of Provincial Parliament, Sarnia-Lambton Riding

Mr. Bob Bleaney
Vice President External Relations, Canadian Association of Petroleum Producers

Dr. Clem Bowman
Founder, The Bowman Centre and Chair of the Energy Pathways Task Force

Dr. Duke du Plessis
Senior Advisor, Alberta Innovates: Energy and Environment Solutions

Mr. Ray Fillion
President, Sarnia and District Labour Council

Mr. Brian Love
Assistant Deputy Minister, Ontario Ministry of Economic Development, Trade and Employment

Dr. Richard Marceau
President, The Canadian Academy of Engineering

Mr. John Margeson
Vice President, Chemistry Industry Association of Canada

Senator Elaine McCoy
Progressive Conservative, Alberta

Mr. Gil McGowan
President, Alberta Federation of Labour

The Honourable Frank McKenna
Deputy Chair, TD Bank Group

Mr. Justin Riemer
Assistant Deputy Minister, Alberta Ministry of Enterprise and Advanced Education, Economic Competitiveness Division

Dr. Jim Stanford
Economist, Unifor

Mr. Don Wood
Associate, Bowman Centre & Consultant

Introduction

To launch the conference proceedings, Drs. Clem Bowman and Richard Marceau examined the historical evolution of Canada and its economic development, and put forward a vision for Canada based on Big Projects. Big Projects have been the fundamental means by which nation-building has taken place through a basic cooperation and collaboration of the private sector and government. Investment economics have a requirement of a return on capital and was concluded not to be the deciding factor in the initiation of these projects which shaped the nation. With consideration of value-addition to resources as the main theme, perspectives from the provincial representatives were followed by the chemical producers' representative and discussions of potential markets and refining viability.

The second day of this gathering dealt primarily with bridging the economic impact of oil sands development with the realities of geography, national economics and interprovincial trade, as well as environmental considerations. The labour and small business communities of Sarnia-Lambton took the opportunity to communicate their respective attributes and capacities to support any significant capital investment slated to enhance the capture of full value for oil sands bitumen by locally processing it to fuels and chemicals.

It is apparent from the content expressed during the conduct of this conference, and offered by renowned and singularly eminent individuals from many walks of life, that there is much concern about the lack of clearly defined policies and a framework for creating a Pan-Canadian effort to maximize the potential wealth of oil sands bitumen. This chapter captures these contributions in a summarized and succinct way with a view towards addressing the possibilities that are on Canada's horizon.

The Last Spike

Conference Communiqué

The following set of statements represents the consensus conclusions of the conference.

1. Lack of access to international pricing for Canada's oil products represents a value destruction of $20 to $30 billion per year.
2. An expanded pan-Canadian pipeline network is key to accessing both domestic and growing global markets.
3. Canada should launch national-scale energy projects as the foundation of its energy strategy and its pathway to sustainable wealth creation and jobs.
4. The Ontario and Alberta governments commit to dramatically enhance their value-added collaboration to improve energy supply chain opportunities, to enhance transportation networks and to develop new energy-efficient and environmentally-advanced technology.
5. A Sarnia-Lambton bitumen upgrading project to produce refinery ready crudes was identified as a high priority national-scale project, with a call for action, with strong support by a committed region.
6. Delegates urged Canada to shift to a more diversified value-added economy, away from its historic staple-based economy.
7. An Alberta Government/Industry study is being launched to identify pathways to increase the competiveness of oil sand products in North American and International markets.
8. New technology is key for the long term sustainable development of Canada's natural resources. (The COSIA initiative was identified as an example of the commitment of oil companies to collaborate and share advances in improving environmental performance).

Background to Conference Communiqué Statements

The following sections contain the background discussions of the conclusions that led to the eight communique statements.

1. Lack of access to international pricing for Canada's oil products represents a value destruction of $20 to $30 billion per year.

Value Destruction: According to the Honourable Frank McKenna, Canada is seeing "value destruction of a scale we've never witnessed before in this country." The lack of take-away pipeline capacity means Canada is captive to a single purchaser, and this purchaser does what all purchasers do in a monopoly situation: gives Canada a discount to the benchmark price of oil. "The result of that has been an enormous economic and fiscal catastrophe for Canada." It is a catastrophe that Canadians don't speak of, because the magnitude of what is taking place is not appreciated. TD Economics Group estimates that:

- $25 to $30 billion in value will be destroyed in 2013,
- $276 billion will be lost in taxes by 2025, and
- $1.3 trillion will be lost in GDP by 2025.

The amount of money lost is so staggering that it is overwhelming, and must be reduced to meaningful terms. The Hon. Frank McKenna said this represents thousands of nursing and teaching jobs, new schools, better highways, better healthcare, and more money for those in need. "Any fraction of that amount of money that we are vapourizing every day would make the life better of every single Canadian."

The Call: Frank McKenna issued a call not just for a value-added national energy infrastructure, but a call to create a symbol that will make Canada a better country. "This country could lead the world in growth if we could just get off the launching pad some of the exciting projects that we are capable of delivering." All Canadians must be part of the solution to build a national energy infrastructure from coast to coast. "So it brings the country together and I think that represents probably the most important value-added components of all." A pipeline from sea-to-sea will demonstrate that Canada is a country where provincial boundaries are not toll booths, where Canadians are working together to enhance the well-being of every citizen in this country.

The History: Dr. Jim Stanford shared the observation that Canada's economic history can be traced "from beavers to bitumen". Canada has a long history of exploiting staples, or natural resource-based products, for export. Canada sold staples in unprocessed or barely-processed forms to more advanced trading partners and, in turn, imported manufactured goods. Canada's earliest history is based on fishing and the fur trade. Later, timber was cut and exported, or processed to paper and exported. Canada continues to export grains, minerals, forestry products, energy, and petroleum products such as bitumen. Now, approximately two-thirds of all exports are unprocessed. "Canadians are asking is there not more for us in the world economy than just digging stuff out of the ground?" To answer this question, Dr. Stanford stated that "we have to be thoughtful about making the most of our resource base." The problem of over-reliance on staples production and a resulting structural underdevelopment of our national economy has been with Canadians since Confederation. The cycles of staples extraction and export have marked the chapters of the country's national economic history.

The Economics: Dr. Stanford added that resource development and export has costs as well as benefits to Canadians. Canada has seen these economic cycles and mechanisms in the staples industries in the past. Dr. Stanford has worked with the Canadian Centre for Policy Alternatives to understand the current so-called "Bitumen Cliff." Their report[1] states that there are declining exports from other Canadian merchandise and service sectors. This has contributed to a cumulative current account deficit of over $150 billion since 2008. The "Bitumen Cliff" report goes further to state that the country's resource dependence has negative implications for innovation, and productivity growth.

[1] Canadian Centre for Policy Alternatives: The Bitumen Cliff (2013), Tony Clarke, Diana Gibson, Brendan Haley, and Jim Stanford

Potential Policies: Dr. Stanford drew several conclusions. He stated that there is nothing automatic about the flow of oil sands benefits to research and development, nor to the economic activity of the other provinces. It was determined that interprovincial economic activity spin-offs from Alberta developments are surprisingly weak. "We have to go out and seek them. We have to put in place policy levers to maximize them." He emphasized that the long-run implications of resource dependence are serious and include economic impacts, environmental concerns, and geopolitical influence. This was confirmed by Senator Elaine McCoy, who explained Canada's current position in the world economy: Canada ranks third in the world for oil reserves, after Saudi Arabia and Venezuela. But Canada is sixth in the world for annual oil production. Sen. McCoy drew from a Senate report[2] to state that Canada is in this position because the country has not become a global trader. To become a global trader requires an attitudinal shift and a reconfiguration of the way Canadians view their country and its behaviour.

A Labour Perspective: Mr. Gil McGowan posed a challenge to create a new consensus of what Albertans and Canadians can do to add value to Canada's resources. Canadians cannot allow others, such as "Big Oil", to continue to create a consensus for Canada. When there is a conflict between the positions of industry and the expectations of the public, the broad public interest must trump narrow private interests. Mr. McGowan also added that former Alberta Premier Peter Lougheed was correct, and Albertans must "think like owners", such that owners should never let others make all the important decisions regarding their assets. In this regard, Mr. McGowan pointed to the experience of Norway and the development of North Sea oilfields. The Norwegian developments occurred within a framework that the oilfields are a public resource. The development of this public resource would be public policy that recognized the public interest, and is strengthened by public participation. Policy must not shy away from public participation and even public ownership to ensure that public interest goals are met, Mr. McGowan concluded "the oil sands are one of Canada's most important public resources. We need a clear public policy framework that ensures it is developed in the Canadian public interest."

2. An expanded pan-Canadian pipeline network is key to accessing both domestic and growing global markets.

Senate Perspective: Sen. McCoy brought two priorities from the Senate Report "Now or Never" supporting the conclusion that an expanded pan-Canadian pipeline network is key for access to both domestic and growing global markets. The priorities are:

1. **Canada must strive for collaborative energy leadership.**
   The federal, provincial, territorial and municipal governments, industry, environmental groups and Aboriginal leaders need to come together to chart a course for responsible development and marketing of Canada's energy resources.

2. **Advance nation-building through energy infrastructure.**
   Canada must modernize and expand its electricity systems and oil and gas pipelines to connect regions and diversify export markets to further strengthen the national economy.

[2] "Now or Never" The Standing Senate Committee on Energy, the Environment and Natural Resources: July 2012

Pipeline Discussion: Mr. Kirk Bailey emphasized that while concerns about the economy are mainly expressed by Canadians, there are international concerns about the environmental impacts of the oil sands. These concerns centre on pipelines, greenhouse gas emissions, water use, and land impacts. Recent evidence and historical experience continue to support the assertion that pipelines are the safest way to transport crude oil. The next best alternative is rail. While this does not mean that leaks from either pipelines or rail are acceptable, it confirms that the safest way forward is to continue pipeline capacity growth.

Several contributors noted that, in the midst of the bitumen value destruction, there is a huge pipeline debate in Canada. Canada has had pipeline debates before, such as the Trans-Canada pipeline debate and the MacKenzie Valley pipeline debate. The current debate is different because it is a proxy for other issues such as Aboriginal land claims, the rights of provinces, and the development of the oil sands. This has led to the emotion of the debate being magnified a hundred-fold by vested interests. The specific case of the proposed West-to-East Energy Pipeline project was brought forward because of its significant impacts:

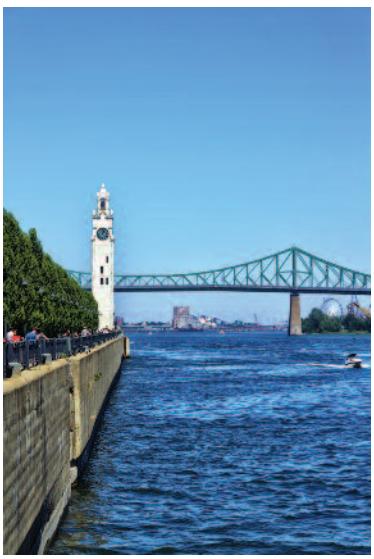
- A ship takes 9 days less to reach Mumbai, India from New Brunswick than from the Pacific coast. This is one of the huge market opportunities off the East coast of Canada.
- Over 5,700 direct construction jobs in New Brunswick and Quebec, and more jobs to move the product through terminals and shipping facilities are at stake.
- If the West-to-East pipeline can be built to Montreal, there is an even bigger opportunity for upgrading more of our petroleum. It just makes sense that if more processing occurs in Canada, then more jobs and wealth stay in Canada.
- Moving the oil from Alberta to the west coast or east coast allows for the transport of oil to the skilled workers. This leads to the distribution of the demand for human resources around the country.

Policy Considerations: Dr. Stanford urged adoption of several policy levers including one to target higher Canadian value-added content both upstream in the extraction of staples, and downstream in the upgrading and processing of raw materials through to final manufacturing. This includes the consumption of Canadian bitumen. Another policy lever is to have a pro-active national strategy to expand interprovincial links. Pipelines are an example of the interprovincial links and the flow of raw materials to the end users.

Mr. Bob Bleaney shared recent data on global crude oil reserves by country. Canada is at the top of a list of 14 countries for openness and attention given to environmental rigour and stewardship of the resource. Canada's petroleum producers have a number of initiatives underway to continue to improve environmental performance. These efforts address production, the integrity and operation of pipelines, and protection of marine environments with the prevention of spills and improved abilities to respond and recover oil from spills.

3. Canada should launch national-scale energy projects as the foundation of its energy strategy and its pathway to sustainable wealth creation and jobs.

Economic and Social Balance: Dr. Stanford urged that active management of resource developments is essential to increase the benefits to all Canadians, and to reduce economic and social costs. There is an opportunity to enhance national net benefits from both sides of the equation. The first key policy priority Dr. Stanford put forward was to constrain the pace of development consistent with Canada's environmental and economic objectives. He pointed out that former Alberta Premier Peter Lougheed also called for this. Dr. Stanford added that resource development is a tremendous source of potential opportunity for Canadians, but the country must be smart and proactive about how the resource is used. He added, "I am heartened by the fact that we are meeting here together, all of us stakeholders, business, labour, government, community, with the goal of trying to do that."



Markets and Government: The cost of doing nothing is the destruction of health care, education and many other services Canadians hold dear. Canada is a country of dialogue and consensus. Economic theories tell Canadians the markets should find, finance and profit from adding value to our resources. As history has proven, however, this is not the case. If it were not for government intervention, Canada would not have had the Hibernia oil field, the Churchill Falls hydro-electric development, the St. Lawrence Seaway, and even the Oil Sand developments. There are times government has to give a helping push. Governments can give a legal licence to operate and Canadian society gives a social licence after reaching a consensus on key issues. There is a need for a clear call to the federal government to launch national-scale energy projects as the foundation of its energy strategy and its pathway to sustainable wealth creation and jobs.

BIG Projects: Dr. Bowman and Dr. Marceau examined 12 past Big Projects in Canada, to understand the driving forces and the financial structures that led to their launch. Two forms of partnerships were identified as significant to the launch of the projects: the first form of partnership involved the establishment of crown corporations – seven of the twelve big projects involved this model, and in five of these projects, the government has since divested fully to the private sector. The second form of partnership is that of a private sector company entering the market with the negotiated support of a range of government risk sharing mechanisms, such as technology support, pioneer project grants, tax policies, and even equity participation. Four of the big projects involved this type of partnership.

Additional commonalities of Big Projects include:

1. Big Projects are nation-wide, or enable connections between Canadians in the east and the west. None of the projects have a north to south, nor export focus.
2. Big Projects have been used, or have become, symbols of nation-building.

For decades it has been commonly known that Canada has strengths in basic and applied research. Canada's weakness has been crossing the chasm from research to successful commercialization. Big Projects are the enablers of transitioning Canadian research to successful commercial applications. Canada must now identify champions to execute the next Big Projects, such as bitumen upgraders for Lambton County, Montreal, St. John and Kitimat. Based on prior public and private sector risk sharing examples, a suitable financial architecture can be established.

4. The Ontario and Alberta governments commit to dramatically enhance their value-added collaboration to improve energy supply chain opportunities, to enhance transportation networks and to develop new energy efficient and environmentally advanced technology.

Pan-Canada: The base case of goods and services flow from Ontario to Alberta is:

- $8.4 billion of goods in 2010, and
- $16.0 billion of services in 2010 (more than doubled since 1999)[3].

This conference called on the Ontario and Alberta governments to dramatically enhance these figures.

Mr. Justin Reimer and Mr. Brian Love addressed the topic of value-added collaborations between Alberta and Ontario. Mr. Reimer referred to the report "Fuel for Thought"[4] published by the Conference Board of Canada. It indicated that nearly one-third of the domestic inputs for oil sands investment are from outside Alberta, and 15% of the domestic inputs come from Ontario. This investment translates into direct and indirect jobs, including the manufacturing industries in Ontario.

Mr. Love referred to a Canadian Energy Research Institute report[5] which projected annual sales of Ontario products and services to the oil sands could potentially surpass most of Ontario's traditional international export markets. It is expected that approximately 80% of the oil sands reserves will be developed by in situ or drilling technologies. This will demand the sophisticated engineering and manufacturing capabilities which exist in Ontario.

Mr. Reimer emphasized that oil sands production facilities are increasingly engineered for modular construction, shipping, and assembly. This provides many advantages including capital cost savings, Canadian sources of materials, and the use of Canadian skilled labour. Currently, there are logistics limitations regarding the size of modules that can be moved from Ontario to Alberta. Innovations in module construction, as well as improvements of the transportation corridors, will support the growth of modular facilities. Mr. Love added that Ontario offers a number of advantages, compared to international suppliers, for collaboration with Alberta. These include no foreign exchange, cross-border or customs issues. There are no language or cultural barriers between the two provinces. Ontario offers top-notch manufacturing, quality, and labour standards. As well, there is a large existing manufacturing capacity, with potential for growth.

Mr. Reimer offered that there are four areas of policy collaboration between Alberta and Ontario in the areas of transportation, manufacturing, technology, and also in value-added

[3] "National and provincial-territorial input-output tables, 2010"; CANSIM 386-0003, released November 8, 2013

[4] "Fuel for Thought: The Economic Benefits of Oil Sands Investment for Canada's Regions"; The Conference Board of Canada report by Alan Arcand, Michael Burt, Todd A. Crawford: October 2012

[5] Canadian Energy Research Institute (CERI) Study No. 125, Aug 20122, A Decade of Staged Oil Sands Growth (2010-2020)

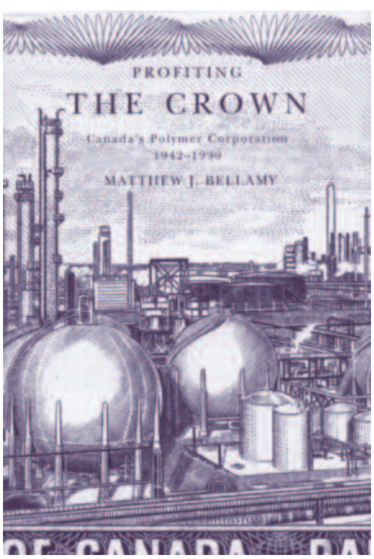
upgrading and refining facilities. In addition to all the business-to-business collaboration that is well-established, the provincial governments are already collaborating in other areas. An example of a government program is the "Energy Connections – Oil Sands" program[6] which engages Ontario manufacturers directly with Alberta project owners, engineering procurement companies, and tier-one suppliers.

Mr. Reimer noted "our two provinces are pillars of the petrochemical industry", and this point was confirmed by Mr. John Margeson of the Chemistry Industry Association of Canada. Alberta and Ontario are the home of many key participants in the Canadian downstream chemical industry, which is the fourth largest amongst all domestic manufacturing industries. Chemical product exports rank second among all manufacturing industries.

The Canadian chemical industry links Canada's rich resource endowment to recognizable value-added manufacturing products used in construction, textiles, electronics, and other day-to-day goods. Petrochemical products are a higher value-added end product for bitumen than fuels. The value of petrochemicals can be four times greater than the value of bitumen, while further manufacturing to raw materials for consumer goods can generate products valued at over five times greater than the value of bitumen.

While the Canadian chemicals industry has had limited investment in new capacity over the past 10 years, it is now poised for growth. The situation has changed due to new government policies as well as changes in feedstocks. The emergence of Sarnia as a bio-hybrid chemistry cluster is also an advantage.

The history of the Canadian chemical industry is defined by step-changes in growth driven by government policy or strategic decisions. Mr. Margeson gave three examples of decisions, starting in 1915 in Quebec, when acetone was first produced to supply the munitions industry. This decision catalyzed the growth of the chemical industry in Quebec. The second example was the manufacture of synthetic rubber in Sarnia during World War II. This strategic decision laid the foundation for the Chemical Valley in Sarnia. The final example is Alberta, where in 1974 the government influenced companies to use ethane to produce ethylene. Now, two world-scale petrochemical clusters exist in Alberta.



Several speakers indicated that the inter-provincial benefits of the oil sands are limited now, but there are opportunities. Mr. Reimer was clear that "these benefits can only be realized if we take a strategic, collaborative, and intentional approach." He went on to challenge the conference participants to do something "to optimize the value of this resource for Alberta, Ontario, and Canada".

Labour's Views: The perspective and situation of labour in Sarnia and Lambton was presented by Mr. Ray Fillion, President of the Sarnia and District Labour Council. He confirmed that Sarnia has the capabilities to fulfill Alberta's needs for skilled trades and available labour. The Labour Council works diligently with its membership to assure that there is a match between the demand for labour, and the availability of skilled trades. There have been many recent examples of how the Labour Council has drawn workers from outside the region to meet the timelines of local projects. A unique advantage brought forward by the

[6] This is an ongoing effort with the Canadian Manufacturers and Exporters (CME) comprised of regular conferences and trade shows to bring businesses in Alberta and Ontario together.

local labour movement, supported by the government and industry, is the opportunity to have project agreements which assure steady work without any interruptions during the term of the project agreement. Another local strength is the ongoing education of members through the Sarnia-Lambton Industrial Education Co-operative. This effort avoids expensive duplication of training, and delivers current and world-class education. The result is an exceptional safety record in Sarnia-Lambton.

5. A Sarnia-Lambton bitumen upgrading project to produce refinery ready crudes was identified as a high priority national-scale project, with a call for action, with strong support by a committed region.

Case Study: Mr. Don Wood examined the business case for an upgrader in Sarnia-Lambton. A hypothesis was proposed that a Sarnia-Lambton upgrader is viable. This hypothesis was evaluated by examining the following six essential and supporting conditions.

1. Capture of the value-added will benefit all Canadians.
2. Bitumen is deliverable through existing pipelines.
3. All stakeholders will be advantaged.
4. Production will be globally competitive and markets are available.
5. A social license is obtainable.
6. The project is financeable via single proponent or multiple partners.

The development of a business case has continued from the date of the conference to the publishing of this book and has confirmed the validity of these conditions. The details of the business case are presented in chapter 4 of this book.

6. Delegates urged Canada to shift to a more diversified value-added economy, away from its historic staple-based economy.

Dr. Stanford explained that dependence on staples leads to a number of concerns. In general, staples are globally traded commodities with volatile price and demand cycles. Dr. Stanford reminded conference attendees that resources, such as the cod fishery on the east coast, will eventually run out. Value-adding jobs in the many processing industries are located abroad instead of in Canada, and the extraction of staples in Canada is both capital and infrastructure intense. There can be a disproportionate reliance on foreign capital, as seen recently with foreign ownership of companies in the oil sands. Due to the significance of the oil sands on the domestic economy, companies in the staples extraction industry may have disproportionate political influence.

Canada has witnessed wave after wave of interest in the country's abundant natural resources and has not captured their full value in Canada. Dr. Stanford clarified this by stating, "that problem of over-reliance on staples production and a resulting under-development of our national economy has been with us since Confederation. The cycles of staples extraction and export have defined our national economic history. The pejorative term of "hewers of wood

and drawers of water" now has been expanded in the current decade to "hewers of wood, drawers of water, and scrapers of tar."

Dr. Stanford asserted that, "We have to be thoughtful about making the most of our resource base," to allow workers to add value to the economy, as well as be part of their communities. On this point Mr. Bob Bailey added, "I think a big part of being a responsible political leader is to have these men and women at home every night with their children." Mr. McGowan added that jobs at upgrading sites are not remote, so workers get home each day, and that is important to the labour movement. Frank McKenna emphasized these points by saying, "So it brings the country together and I think that represents probably the most important of the value-added components of all." Mr. Kirk Bailey added that Canada can reduce exposure to boom-and-bust commodity price cycles where success is dictated by global pricing by investing in innovative value-adding processing of resources into competitive products.

Fundamentally, if Canadians are to realize the value of the country's resources, Canadians must heed the advice of Sen. McCoy, who urged that the time is "now or never." Sen. McCoy mused, that even if Canada does not seize the opportunity to become a global trader in diversified markets and products, then Canadians will continue with safe, peaceful and rewarding lives. However, Canada has a national opportunity to go beyond seeking simple "access to markets" for our raw materials. This applies not only to the oil industry, but also to other Canadian industries such as Ontario's manufacturing base, and the British Columbian forest products industry.

Reviewing recent research, Dr. Stanford concludes that there is strong evidence of resource-driven deindustrialization in Canada. "This doesn't mean that we have to leave everything in the ground – that's not what I've argued nor what most participants in this debate have argued. What it does mean is that we have to be cognizant of the risks of resource-driven deindustrialization and take policy measures to look at it." Dr. Stanford elaborates on this important topic in Chapter 2 of this book.

7. An Alberta Government/Industry study is being launched to identify pathways to increase the competiveness of oil sand products in North American and International markets.

Today's oil sands export products fall into two main categories of crude oils: diluted bitumen (dilbit) and Synthetic Crude Oils (SCO). Various blends of these products are also marketed. Bitumen-derived refinery feedstocks have several challenges that impact their marketability, including market value, growth potential and the overall competitive position in US and international markets. Several government initiated studies have been carried out to understand the challenges and opportunities in different markets. A study conducted by the Institute of Energy Economics Japan (IEEJ) examined the marketability of various oil sands products in Asian Countries[7].

More recently AI-EES working in partnership with other government departments and industry has embarked on a phased investigation of the competitiveness of oil sands products in North American and international markets. Phase 1, completed in 2012, examined how

[7] Marketability of Oil Sands Products in Asian Countries; Prepared for: The Alberta Government by: The Institute of Energy Economics, Japan (IEEJ), March 2007

various quality levels impact competitiveness in PADD II refineries[8]. The study's findings highlighted the importance of reducing vacuum residue and TAN through lower cost partial upgrading to improve the market value of dilbit products while also reducing diluent requirements for pipeline transport. The suitability of different quality improvement technologies (thermal conversion, hydro conversion, solvent deasphalting) were identified. The methodology used to quantify the impact of vacuum residue, TAN, sulphur, aromatics and basic nitrogen was described.

Phase 2, started in February 2014 by Alberta and Saskatchewan in partnership with six oil sands operators, will first identify what crude qualities are valued by different world refinery regions and markets, and then determine the infrastructure and technologies needed to produce crudes suitable for these markets. The suitability of dilbit and partially upgraded pipelinable bitumen products in Asian and North American markets will be evaluated. The study is being carried out under the direction of a government-industry steering committee.

8. New technology is key for the long term sustainable development of Canada's natural resources. (The COSIA initiative was identified as an example of the commitment of oil companies to collaborate and share advances in improving environmental performance).

Environmental Considerations: In 2012, the Canadian Oil Sands Innovation Alliance (COSIA) was created. This alliance allows the sharing of intellectual property to find alternatives to reduce the volumes of water and steam used in oil sands operations. There are also efforts to improve the recycling of water, and allow for faster land reclamation. These efforts have resulted in a significant reduction in the GHG emission footprint of the products from the oil sands.

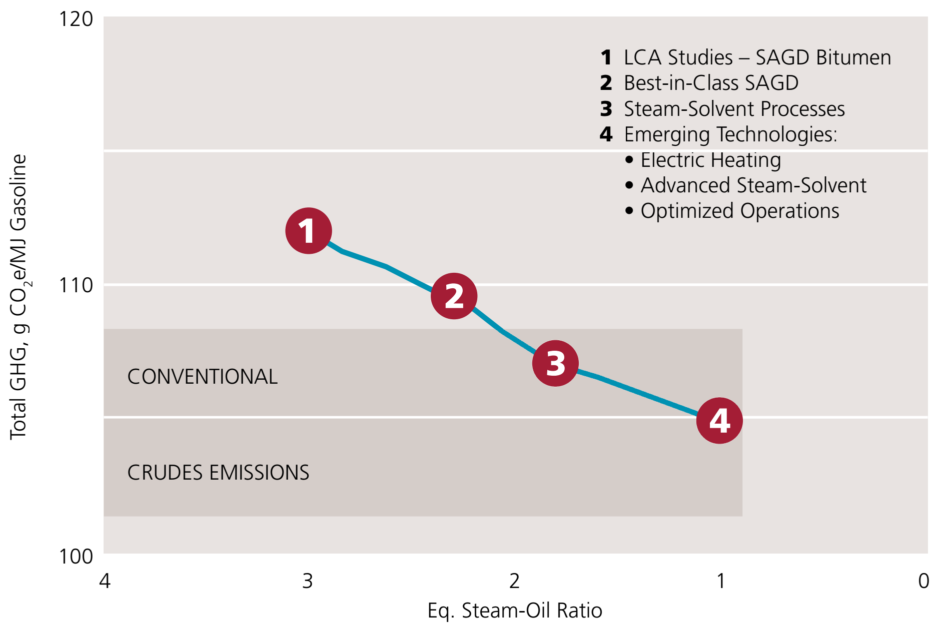
A comparison of full life-cycle GHG emissions shows that the most recent in situ oil sands production produces 5% more kilograms of CO_2 equivalent per barrel of refined product than the average barrel of oil refined in the US. The most recent production from mined oil sands has only 2% more. Dr. du Plessis presented a chart at the conference which showed the effect of different technologies on the amount of greenhouse gas emissions produced. As efficiency improvements occur in the Steam Assisted Gravity Drainage (SAGD) process, the steam required to oil produced ratio has improved. With the introduction of steam/solvent processes, as well as the optimization of operations, the steam to oil ratio continues to decline. A number of emerging technologies, such as electric heating, advanced steam/solvent systems, and the further optimization of operations, will continue the downward trend. This also leads to a reduction in GHG emissions since steam production generates more GHG emissions than conventional crude production processes. The trend of improving efficiencies in the steam to oil ratio, along with the concurrent decrease in GHG emissions, positions oil sands production close to conventional oil production in terms of emissions production intensity.

The environmental impact of the oil sands and the current downstream industry is recognizable, measureable, and reported. Dr. Stanford reminded the audience of the ongoing

[8] Technology Opportunities to Improve the Competitiveness of Alberta's Oil Sands for U.S. Refineries, conducted by Jacobs Consultancy for Alberta Innovates-Energy and Environment Solutions, October 2012

need to hold the industry accountable for environmental impacts. Mr. Reimer added, "We place a very high value on our environment and we are taking significant measures to protect it." Several examples of efficiency improvements and reductions in GHG intensity were presented by Dr. du Plessis (Figure 1).

Figure 1
Reductions in Greenhouse Gas Emissions from Bitumen Recovery



Many speakers asserted that technology innovations, and capturing value in Canada, reduces the environmental impact of bitumen extraction and processing. Mr. Bleaney added, "By virtue of these efforts we've been able to significantly improve the GHG footprint of the product from the oil sands."

Call to Action

It is demonstrated that Canada's Energy Strategy is already being acted upon. Such a strategy is not a document, but it is the way that interested parties are getting together and figuring out ways to move our country forward. There are engaged discussions and debates underway across Canada: where energy sources are found, along the pipelines and corridors that transport it, where oil products are refined and processed, as well as within governments and amongst stakeholders such as First Nations and environmental groups. These discussions will change the current perception of Canadians as "hewers of wood, drawers of water, and scrapers of tar."

While the discussions and debates are healthy, and typically the way that Canadians achieve consensus, there must be urgency directed towards a common goal of nation-building. Canadians must be thoughtful about the pace of resource development and Canada's role in maximizing the value of its resources.

All the analysis is available. It is leadership that is needed. Who will push the button?

Biography

Dr. Katherine Albion is the Director of the Bowman Centre, located at the Western Sarnia-Lambton Research Park. Dr. Albion joined the Western Research Park in 2008, as the Commercialization and Research Engineer. Katherine is a graduate of Western University, where she received a Bachelor's Degree in Biochemical and Environmental Engineering, and was awarded a PhD in Chemical Engineering. Her PhD research involved the development of non-invasive acoustic flow monitoring techniques for pneumatic and hydraulic transport pipelines. As Director of the Bowman Centre, Dr. Albion is responsible for the research and small business centre at the Research Park, where she works with industry, entrepreneurs, and academic researchers to advance and commercialize their technologies and processes. Since joining the Research Park, Katherine has co-authored Academy reports focused on the development of renewable and sustainable energy technologies identified as having a significant impact on the future of Canada's energy supply. She has also made energy presentations to the private and public sectors, including the Federal Conservative Energy Caucus in Ottawa.

Marshall Kern is an Associate at The Bowman Centre. He is a corporate director in the healthcare sector, and a conference speaker on governance processes. He teaches ethics through the Nipissing University School of Business. Marshall completed a career with Dow Chemical; leaving from a global position where he was recognized with the company's highest honour for his environmental commitment.

Walter F. Petryschuk was born outside the Point Pelee National Park in the most southerly part of Canada. Raised on a farm, his schooling included a one-room elementary facility, his secondary education was in Leamington, attending the University of Toronto for his Bachelor's degree and McMaster University for his Masters and Doctorate degrees in Chemical Engineering. His professional career led to plant and site management of Polysar Corporation's facilities and Suncor's refinery in Sarnia and the presidency of the Sun-Canadian Pipeline. Subsequently, he was responsible for McMaster University's spin-off start-up, the Management of Technology and Innovation Institute, and ended as Director General of the National Research Council's manufacturing technology institutes in London and Vancouver. He is currently a volunteer contributor as Associate, the Bowman Centre.

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Responding to the Call to Action: The Case for a Sarnia-Lambton Bitumen Upgrader Refinery

Donald E. Wood

ABSTRACT

The oil sand industry was initially launched by a few large multi-national oil companies with surface-mining operations who produced and upgraded the bitumen in Alberta. Today, a broad mix of oil sand companies produces bitumen from both surface-mining operations and 'in situ' thermal processes, such as steam-assisted gravity drainage (SAGD). Some of these companies have refineries in the United States and, for corporate economic reasons, have opted to pipeline the raw bitumen to these refineries for upgrading to value-added products. However, there are an increasing number of independent companies that produce bitumen without an internal capacity to produce high-value finished products. These companies would clearly benefit from additional upgrading capacity in Canada.

Ontario's Sarnia-Lambton region offers a unique and early opportunity to increase Canada's bitumen upgrading capacity, using existing pipeline networks to safely deliver the bitumen. The refinery would produce high-value products on the threshold of one of the world's largest energy market, the US Midwest. The St. Lawrence Seaway would provide ready access to global markets.

A team of pro bono ex-senior executives and recent retirees was assembled from Bayer, Imperial Oil, Nova Chemicals, Polysar, Shell, and Suncor to provide greater definition for this opportunity. The team identified the fact that benefits from this major project would accrue to all Canadians. Bitumen producers obtain the benefits of downstream integration. The Sarnia-Lambton community would spearhead the effort to develop the project. Alberta would gain a new market for 100,000 BPD of bitumen with more stable revenue. Ontario would receive a major increase in employment, though benefits would eventually be spread across Canada. From a national perspective, Canada would capture the value-added with a significant increase in export revenue.

An acceptable Return on Investment (ROI) can be achieved if the new upgrader is built to produce gasoline, diesel and other value-added petroleum products. At current prices the value-added is $2.5 billion per year, an additional $45 per barrel of diluted bitumen. Capital Expenditure (CAPEX) is expected to be in the order of $10 billion.

The team has recognized that for this opportunity to be realized, a corporate champion will be needed, ideally from the ranks of experienced refiners with the skills to market the product. A financial feasibility study was determined to be the next step.

Introduction

Chapter 3, which summarized the "Bitumen – Adding Value: Canada's National Opportunity" Conference held in Sarnia in May 2013, presented the case that Canada can capture enormous wealth by upgrading its raw natural resources to value-added products. Four communiqués from that conference are highly relevant to the subject of this chapter:

1. Delegates urged Canada to shift to a more diversified value-added economy, diverting from its historic staple-based economy.
2. Canada should launch national-scale energy projects as the foundation of its energy strategy and its pathway to sustainable wealth creation and jobs.
3. The Ontario and Alberta governments should commit to dramatically enhancing their value-added collaboration to improve energy supply chain opportunities, to enhance transportation networks and to develop new energy-efficient and environmentally advanced technology.
4. A Sarnia-Lambton bitumen upgrading project to produce refinery ready crudes was identified as a high priority national-scale project, with a call for action, with strong support by a committed region.

The Hypothesis

The momentum behind the project continued. The Sarnia-Lambton Research Park's Bowman Centre next assembled a team of executives with petroleum industry experience to study the viability of the project. They gathered at the Sarnia-Lambton Research Park to respond to the Call to Action that had emerged from the Sarnia Conference. This team hypothesized that a Sarnia-Lambton bitumen upgrader refinery is viable for six major reasons.

First, the value added will benefit all Canadians: a strong economic stimulus locally, higher employment and taxes for Ontario, new markets for Alberta, and a significant increase in export revenue for the country as a whole. Secondly, they identified the ability to deliver bitumen through existing pipelines, and pointed to the advantages accruing to all stakeholders. They recognized that production will be globally competitive, and cited Sarnia's proximity to American and global markets through its advantageous location on the St. Lawrence Seaway. They stated that a social license is available as a result of strong local support and, finally, they deemed the project to be financeable by means of either a single proponent or multiple partners.

The actual financial performance of the Marathon Detroit refinery was cited as an example[1], as shown in Figure 1. Market pricing from 2012 and 2013 indicates that this project is making Earnings before Interest, Taxes, Depreciation & Amortization (EBITDA)[2] returns of 15 to 20% on CAPEX. Since this refinery is only 100 kilometers from Sarnia, this represents a strong indication that a Sarnia- Lambton project could also be profitable, either as a new stand-alone upgrader or as an add-on to an existing refinery.

[1] Marathon September 2013 Investor Presentation

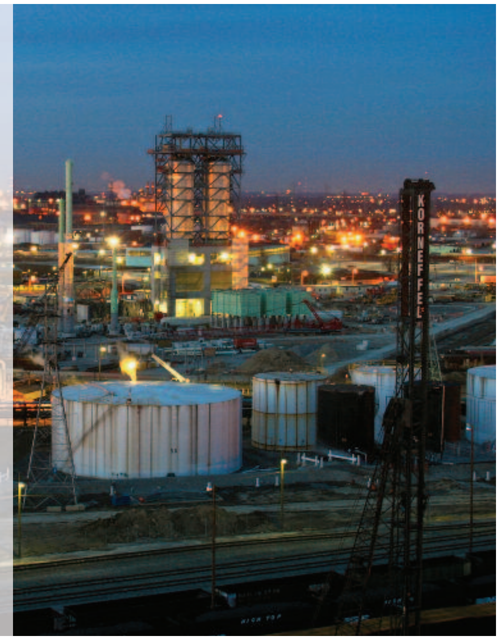
[2] Earnings Before Interest, Taxes, Depreciation and Amortization

Figure 1
Detroit Heavy Oil Upgrade Project

Detroit Heavy Oil Upgrade Project

- Increased heavy oil capacity from 20,000 BPCD to 100,000 BPCD
  – 28,000 BPCD delayed Coker
  – 36,000 BPCD Distillate Hydrotreater (DHT)
- Crude capacity increased ~14,000 BPCD
- Discounted Canadian crude
- Investment: $2.2 billion* project
- Estimated incremental annual EBITDA based on:
  – 2006-2010 Prices: ~$200 million
  – 2011 Prices: ~$350 million
- Operated at design capacity YTD 2013

*Excludes capitalized interest



The Project Concept

The oil sand industry was initially launched by a few large multi-national oil companies with surface-mining operations who produced and upgraded the bitumen in Canada. There is now a broad mix of oil sand companies who produce bitumen from both surface-mining operations and in situ thermal processes, such as SAGD. Some of these companies have refineries in the United States and, for corporate economic reasons, have opted to pipeline the raw bitumen to these refineries for upgrading to value-added products. They have no incentive to build facilities to upgrade bitumen in Canada and would have limited interest in participating in the Sarnia-Lambton upgrader project proposed in this chapter. However, there are an increasing number of independent companies that produce bitumen without an internal capacity to produce high-value finished products. These companies would clearly benefit from participating in the Sarnia-Lambton project outlined in this chapter.

In the current environment, Alberta crude oil producers have both a marketing problem and a transportation problem. In the United States, the supply and marketing of crude oil is undergoing unprecedented rebirth, transformation and growth with the rapid development of light sweet crude oil from shale sources by horizontal drilling and fracturing. Much of this supply is situated in locations not served by pipelines. This has created a surplus of domestic light crude oil often sold at discounted prices, with which the Alberta bitumen producers must compete for access to refinery capacity. Furthermore, in Canada, the rapid development of bitumen supply in Alberta has outpaced the development of pipeline capacity to take it to market. Many bitumen producers, particularly those using the thermal and SAGD processes, are spread around the northeastern section of the province not served by pipelines. These producers are developing options to ship by rail, but the long-term viability of this route is questionable. All these factors have led to lower and variable bitumen prices, recently discounted by as much as $40 per BBL. By producing gasoline, ULS diesel, and fuel products, all of this discount can be recovered, and additional value obtained. The purpose of this project is to help secure the long-term market for bitumen and to realize the full value for the resource.

Since Sarnia-Lambton is served by pipelines from Alberta, with production costs competitive to the US Gulf coast and unrivalled access to the US Midwest market, this project represents a unique opportunity for Canada. A team of pro bono ex-senior executives and recent retirees has been assembled from Bayer, Imperial Oil, Nova Chemicals, Polysar, Shell, and Suncor to pursue this opportunity.

The Project Principles

The following principles were used to guide the project through its various phases.

1. Build and assemble local support through involvement throughout the process
2. Maintain current Alberta bitumen/heavy oil processing at Sarnia's Imperial Oil, Shell or Suncor refineries
3. Establish a significant project size – 100,000 BPCD bitumen (~150,000 BPCD dilbit)
4. Involve existing Sarnia refiners where possible
5. Leverage existing infrastructure
6. Review with Alberta bitumen producers and stakeholders

Why Sarnia-Lambton?

Sarnia-Lambton has grown from its earlier days in the 1860's as the processing location for the first oil discoveries in the Petrolia and Oil Springs areas of Lambton County. The community has supported over 40 refining, petrochemical, bio-industrial and associated plants since then, as illustrated in Figure 2. There are major refining and petrochemical facilities in the region including three refineries owned by Imperial Oil (~120,000 BPCD), Shell Oil (~80,000 BPCD) and Suncor (80,000 BPCD), and world-scale ethylene plants with polymer plant derivatives operated by Esso Chemical, Nova Chemical and LanXess.

All of these facilities have access to shipping on the St. Clair River, part of the St. Lawrence Seaway, giving access to international and mid-continental markets by pipeline, marine, rail, and truck.

Figure 2
Sarnia Refinery Complex

The Project Deliverables

The main driver behind a Sarnia-Lambton bitumen upgrader is the objective of maximizing value-added to bitumen in Canada. In order to be considered a successful project there are several requirements that must be achieved. First, the project must provide a return to investors/partners while defining itself as an internationally competitive gasoline, diesel and fuels exporter. The project must also leverage existing petroleum refining capacity and infrastructure by either adding capacity to one of the three existing refineries or by adding a new facility that would be integrated with existing infrastructure. Finally, the project must meet societal expectations for environmental and social performance.

The Projected Benefits

For Canada

A world class upgrader refinery keeps value-added processing in Canada. This project is sized at 150,000 BPCD diluted bitumen (dilbit) feed and represents an increase in annual fuel product[3] exports of over $6 billion, over 30% if operating in 2013, and a 1½ % increase in total Canadian exports.[4] The project revenues would be in excess of $6 billion at current crude oil values. The primary plant assets are estimated to be about $10 billion.

For Alberta

The market for 100,000 BPCD of bitumen represents a significant advantage to stakeholders in Alberta. The emergence of abundant new crude oil supplies produced by horizontal drilling and fracturing shale oil formations from new locations has destabilized the conventional crude oil market in North America. It has given much more power to the refiner customers and represents market diversification. Participation directly in the fuels market is very different from selling bitumen at whatever price the refiner is willing to pay. The upgrader refinery opportunity would enable access to the refining value-added with the effect of downstream integration. A Sarnia-Lambton upgrader refinery would provide for new and different access to the market, and it would enable participation in the mid-continent US PADD[5] 2 gasoline and fuels market. It should be noted that this market consumes about 3.5 million BPCD of oil directly and a further 0.5 million BPCD of product imports. Such participation as a player in the marketing of the products would give strategic access to critical information for the planning and marketing of bitumen and bitumen-sourced crude oils. It would also help to capture the value-added to the benefit of the stakeholders, through enabling the effect of a fully integrated oil company.

An upgrader refinery would also moderate variations in revenue. During the period from 2011 through 2013, the netbacks to Alberta on sales of synthetic crude oil suffered a discount from the conventional crude oil market by up to $40 per BBL This has followed the swings in West Texas Intermediate (WTI) prices, and has been impacted by the new supplies of oil from the shale oil fields, primarily the Bakken-Three Forks, and Eagle Ford fields. Meanwhile gasoline, diesel, distillate and fuel products have tracked the European Brent/ICE prices, with much more moderate price swings. Price changes in this market are much smaller with a lower risk of error in generating a revenue forecast or a royalty income forecast.

3 Assumes project capacity of 100,000 BPCD of bitumen processed.

4 Patricia Mohr, Scotia Bank, Oil and Gas Dominates Canadian Economy 2013.

5 Petroleum Administration for Defense Districts.

The Sarnia-Lambton refinery upgrader opportunity would provide market access sooner than other alternatives. The major unknowns in this timeline are the minor increase in capacity in Enbridge Line 6B or Line 5, and obtaining the social license to build the upgrader refinery.

For Ontario

The major benefits to Ontario relate to jobs, products and wealth generation. During the construction of the upgrader refinery, construction trades employment to build the $10 billion capital cost facility is projected to engage about 5,000 workers for two years. It would require supplies from across Ontario and generate services and activity throughout the entire Province, including the production of primary materials like steel, and the manufacture of equipment and pipe.

The plant and business operations will employ approximately 500 engineering, operating, maintenance, and business management staff on an ongoing basis. Direct support employment after construction is likely to equate to 1,000 to 1,500 additional high quality jobs.

The primary products from this project would be ultra-low sulphur diesel fuel, distillate, gasoline, and aviation fuel. In addition, it would make feedstocks for high value petrochemicals. The value of the exports from this project in 2013 dollars represents 1½ % of total Canadian exports, making a significant positive contribution to value-added creation in Canada.

For the Operator/Investor

The processing and marketing fees would represent a benefit to the operator and the investors. The value-added capture is estimated to exceed $2.5 billion per year at current prices of crude oil and products, netted back to the plant in Sarnia-Lambton. This can be applied to the ROI of the investors after paying operating and maintenance costs. The size of the value-added capture indicates that there will be a return sufficient to attract investors or, alternatively, to support a business model providing a tolling fee for the owner(s) of the bitumen.

For Sarnia-Lambton

This project would provide a major stimulus to Sarnia-Lambton. The region is well suited to host such a project, and expansion opportunities would flow from the support needs of the project related to maintenance, plant turnarounds, upgrades, and debottlenecking.

The upgrader would provide raw materials for other high value-added products as well as finished fuels and access to global markets via pipeline, rail and marine transportation.

Bitumen Production

The outlook for new bitumen production has changed considerably in the past few years. The current Alberta government policy is to use BRIK (Bitumen Royalty In Kind) barrels to support worthy projects (http://www.energy.alberta.ca/includes/3435.asp).

The TCPL[6] Energy East pipeline project proposes to convert part of the underutilized Trans Canada Pipelines Ltd. (TCPL) mainline natural gas system, which is all within Canada's borders, and to add a new pipeline in eastern Canada to ship 1.1 million BPCD of oil from Alberta and Saskatchewan to refineries in Ontario, Quebec, the Atlantic seaboard and international markets. The Alberta Petroleum Marketing Commission (APMC)[7] has committed to a 20-year "take or pay" transportation service agreement to move Alberta crude oil to eastern Canada and beyond, designed to obtain a fair netback for Alberta crude oil based on a world price.

6 Trans Canada Pipeline.

7 Alberta Petroleum Marketing Commission.

The NorthWest Redwater Refinery Project[8] is owned 50/50 by NorthWest Upgrading Inc. and Canadian Natural Resources Ltd. The first phase of the refinery project will have processing capacity of 78,600 BPCD of bitumen blend feedstock and will be operational in 2017. APMC has signed a processing agreement which is based upon a 30 year tolling arrangement. APMC will provide 75% of the required bitumen blend feedstock. Condensate will be recovered and the bitumen will be processed into diesel, vacuum gas oil and Liquified Petroleum Gases (LPGs). APMC will retain ownership of the condensate and refined products, which will be sold into the local and export markets.

Table 1 is a project list ranked by new production in the 2018 to 2025 period.

Table 2 is a prospect list ranked by production, fit, and possible interest.

Table 1
Prospect List Ranked by New Production Planned 2018-2025

Source: (http://www.albertacanada.com/business/statistics/oil-sands-quarterly.aspx, and corporate websites)

	New BPCD 2018-2025	Comments
Cenovus	520,000	• Have JV in 2 refineries with Phillips 66 • Might be good fit in fuels market
Brion	225,000	• No current production • PetroChina funded
Athabaska	193,000	• No current production • Financed via Brion
CNRL	170,000	Invested in NWU
Teck Resources	162,000	• Unknown but could be interested in an outlet • Miner, used to big projects, fast acting
Statoil	120,000	
Sunshine Oil Sands	110,000	
Total E&P	107,000	
BP	70,000	• Have done deals with Husky both upstream and downstream
Husky	55,000	• Would be a good fit as both supplier and refinery partner
MEG Energy	41,000	2020 will have ~200,000 BPCD

Table 2
Prospect List Ranked by Production, Fit, and Possible Interest

	New BPCD 2018-2025	Comments
Cenovus	520,000	• Have JV in 2 refineries with Phillips 66, Wood River and Borger • Opportunity for Philips to increase market share in PADD II? • Might be good fit in fuels market
Brion	225,000	• No current production • PetroChina Oil funded
Athabaska	193,000	• No current production • Financed via Brion
Teck Resources	162,000	• Unknown but could be interested in an outlet • Miner, used to big projects
Statoil	120,000	
Husky	55,000	• Would be a good fit as both supplier and refinery partner • Possible fit in fuels market
MEG Energy	41,000	• 2020 will have ~200,000 BPCD

[8] Northwest Partnership website http://www.nwrpartnership.com.

Deliverable Bitumen

Enbridge presented the following information at the Canaccord Genuity Infrastructure Conference which was held in Toronto in September 2012. Unlike other prospective bitumen destinations where no pipelines exist, Enbridge has two lines, shown in Figure 3, which at the time of commitment may require only minor capacity expansion. The company expects that such expansion will be relatively inexpensive.

Sarnia-Lambton is now served by line 5 and line 6B with a total capacity of over 800,000 BPCD.

Line 9 reversal and expansion is planned to take away 300,000 BPCD. Line 6B expansion is in the Enbridge 2016 CAPEX plan. The current tariff is approximately $5.50 per barrel from Hardisty, Alberta to Sarnia-Lambton.

Figure 3
Enbridge Pipeline Systems

Sarnia-Lambton Area Advantages

Sarnia-Lambton is situated at a strategic location on the Ontario/Michigan border. Half of the Canadian and American populations live within 500 miles – a day's drive! It is one hour to Detroit, three hours to Toronto, and five hours to Chicago. Sarnia-Lambton is connected on the Ontario 400 series highways and to the USA Interstate highway system – Interstate 94 starts at the Bluewater Bridge. The Chris Hadfield International Airport is located 9 KM from the Sarnia city centre. In addition, Sarnia-Lambton offers affordable housing, short commutes to and from work, as well as outstanding recreational amenities.

This region includes the city of Sarnia and ten municipalities in Lambton County (see Figure 4), and offers many attractive features for such a project. First, Sarnia-Lambton, which is located at approximately the same latitude as Oregon, has a population of 129,000 with a labour force of 62,000 workers. A surplus number of these workers are skilled in the construction trades. There is an adjacent labour force of 300,000 workers within a 100 KM radius of Sarnia-Lambton, including highly educated engineers, process operators and

Figure 4
Sarnia-Lambton Region

technical tradesmen with refinery and chemical plant maintenance turnaround expertise. There are also excellent labour-management relationships in the region which would provide for continuity of services for the project. The construction safety record is excellent, on an order of magnitude higher than the provincial average.

There is serviced land zoned for heavy industry and the available sites for industrial development are highly disturbed (i.e. not pristine forest) and present little risk of ecological or archeological impacts. The St. Clair River can be an abundant source of clean cold water as long as the water is used responsibly.

Businesses in the region are now making refinery type process modules in Sarnia, for plants in Alberta and Nova Scotia. These include Heat Recovery Steam Generators (HRSG[9]s), pressure vessels and distillation towers. Local industry supports the Sarnia-Lambton bio-industrial complex of over 35 diverse manufacturing and emerging technology sectors. The region is also home to the industry-oriented Lambton College.

There are three operating refineries and five major petrochemical plants in Sarnia-Lambton and a range of infrastructure, and brown field and green field sites with heavy industrial zoning are available. Sarnia-Lambton sits above a deep saline aquifer that may be suitable for stored CO_2 should carbon capture and sequestration become part of the project scope.

An Energy Transportation and Storage Hub

The existing pipeline web in Sarnia-Lambton connects storage, product distribution pipelines and refineries in order to move oil, intermediates, natural gas liquids (NGLs), and refined products to a range of storage and distribution infrastructure. These include salt caverns and above ground storage facilities, product distribution pipelines, deep water docks, a CN Rail Tunnel and the Bluewater Bridge which connects Sarnia to Port Huron, Michigan and to marine, rail and truck loading facilities. The area is also located above underground salt layers at depths of 600 to 800 meters.

This is storage and distribution infrastructure comparable to that existing along the US Gulf Coast. The Houston ship channel/Galveston Bay area has crude supply from pipelines and offshore production facilities and distribution of products by pipeline and by marine. Thirty miles north of Houston is the Mont Bellvieu NGL cavern storage system. A further 200 miles

[9] Heat Recovery Steam Generators, a component in cogeneration and in combined cycle power plants.

to the east in Erath, Louisiana is the Henry Hub, a major natural gas price reference point. Sarnia-Lambton has the same facility advantages, but all within a 50 x 50 km area.

The Dawn Natural Gas Storage Hub

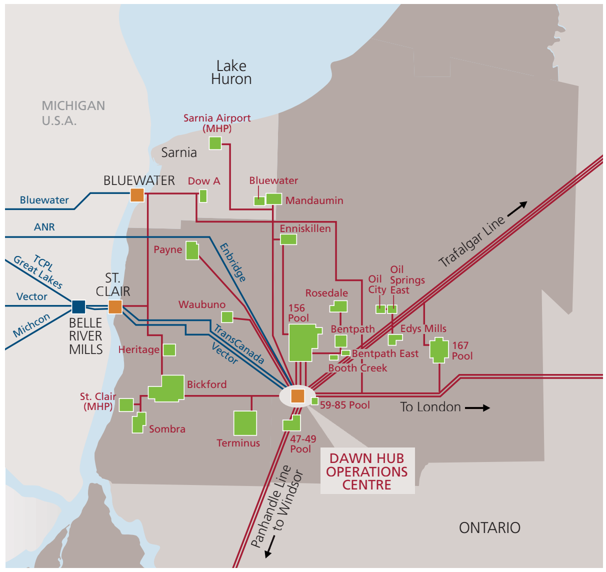


Figure 5
Dawn Natural Gas Storage Site

The Dawn Hub (Figure 5) encompasses the junction of major natural gas transmission lines over a large natural gas storage system. Some notable features of the Hub include high deliverability pinnacle reefs which have been developed for storage and are connected to major transmission lines and river crossings to enable off peak storage and high deliverability rates during peak demand periods. The Hub is the preferred location in which to store the gas from the transmission lines in order to serve markets in the Midwest.

The Hub offers a competitive advantage to a local refinery for energy, and for feedstock for making low cost hydrogen. There is an available supply of electrical power to candidate industrial sites and there is access water for cooling and for processing (e.g. to manufacture hydrogen). Responsible water use and conservation, however, will be critical to societal acceptance of the project.

A key material required to upgrade bitumen is hydrogen, usually made from natural gas by steam methane reforming. Natural gas for hydrogen production and fuel is available from the Marcellus shale from nearby Pennsylvania, at a cost which is competitive to US Gulf Coast refiners, and at one quarter to one half the cost found at European and Asian locations.

This area is an oil and gas field with operations dating back to the 1860's. The red and blue lines represent high pressure transmission and storage connection lines. The green boxes represent storage pools.

Pipelines and Storage

These pipeline systems (see Figure 6) were built to support the Imperial Oil, Suncor, and Shell refineries, and the Dow Chemical, Polysar (now Nova Chemicals) and LanXess complexes. The system enables operators to receive, store, and exchange crude oil, NGLs, brine, and intermediates, and to ship out gasoline, diesel, fuel products, petrochemicals, and polymers. Over 100 pipelines are in place and routinely move crude oil, NGL/LPGs, naphtha, raffinates, distillates, gasoline, hydrogen, olefins, aromatics, brine, and water. There is also substantial underground salt cavern storage capacity in the area, as well as pipelines connected under the St. Clair River to a commercial storage operation at Marysville, Michigan. The

Figure 6
Pipeline and Storage Facilities

The coloured lines show pipeline corridors containing multiple lines in each.

pipeline system delivers gasoline, diesel, and other refined fuel products to major Midwest markets. There is marine loading capability for both barges for distribution through the Great Lakes and the St. Lawrence Seaway system, and ocean vessels to global markets. The storage systems are also connected to load rail and trucks for product distribution to Midwest markets.

Globally Competitive with Accessible Markets

In 2009, the United States became a net exporter of gasoline and refined products (exports minus imports, Figure 7). When the imports on the US east coast (primarily from Canadian refineries) are removed, actual exports from the USGC in 2012 averaged 2,430,000 BPCD, with 2013 indications projected slightly higher.

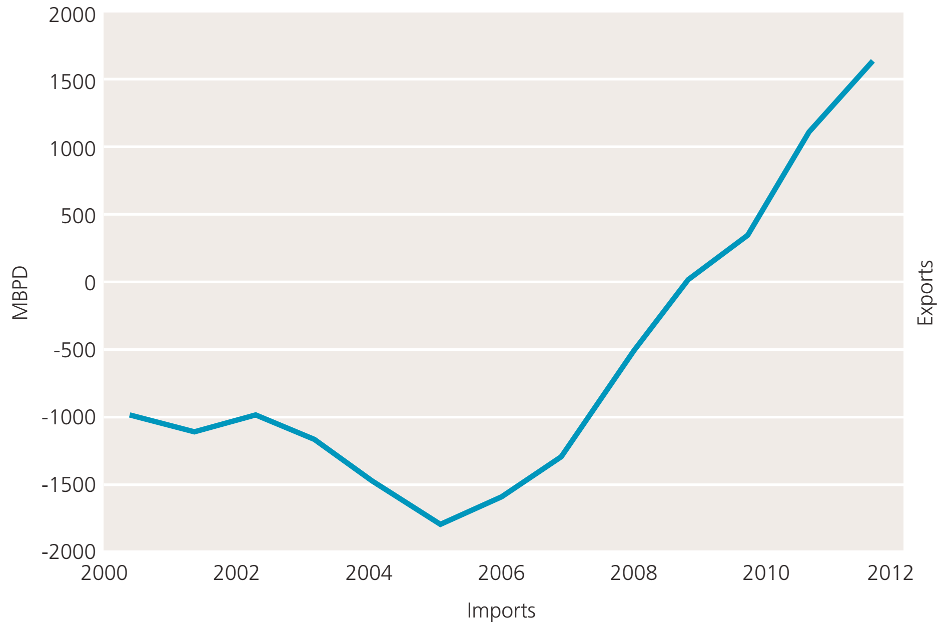
The US Gulf Coast refiners' exports into the Atlantic Basin markets surged, enabled by "advantaged" competitive crude and super competitive natural gas costs. Sarnia-Lambton product sales would represent about 5% of the current US Gulf Coast exports.

Atlantic Basin refinery closures since 2008 totaled 4,000,000 BPCD of crude running capacity, including the shutdown of refineries in Aruba and St. Croix, reduced operating rates due to political intervention in Venezuela, and the shutdown of 1,000,000 BPCD of European capacities, including many low complexity refineries.

BRENT/ICE European markets became the pricing basis in early 2011 (Figure 8). Prior to that the US gasoline prices tracked the US WTI crude oil price postings.

Figure 7
US Imports/Exports

VALERO – HOWARD WEIL Energy Conference, March 20, 2013.

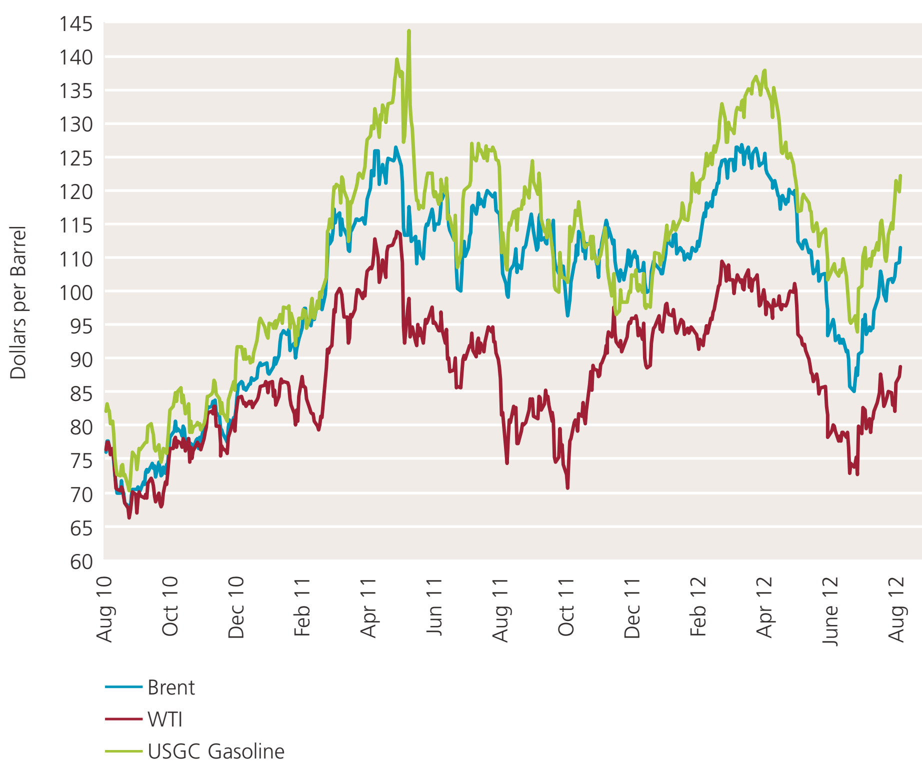


With the emergence of significant US Gulf Coast exports demonstrating the capability to compete in these markets, price netback levels were established that had to be met by US domestic buyers. It is important to note that US gasoline and distillate prices are set by netbacks from export gasoline and diesel sales priced based on Atlantic Basin crude oil costs – Brent/ICE.

While the crude oil price differential between Brent/ICE and US WTI closed in summer of 2013 due to softness in the European economy, the gap opened again in the fourth quarter of 2013.

Figure 8
USGC Gasoline Pricing Basis

(Source – Marathon Petroleum Corporation, Barclays CEO Energy/Power Conference Sept 4-6, 2012).



The US PADD 2 Midwest market is a major importer of gasoline, diesel, and fuel products (Figure 9).

The PADD 2 market has approximately 3.5 million BPCD refining capacity, with a 4.0 million BPCD market demand, per US EIA[10] data. Imports into the market, primarily from the US Gulf Coast refineries, correspond to 13% of the PADD 2 gasoline, diesel and fuel products' demand. This is per the Marathon Petroleum Corporation Business Update, December 2012, and confirmed by the Valero presentation at the Howard Weil Energy Conference, March 20, 2013.

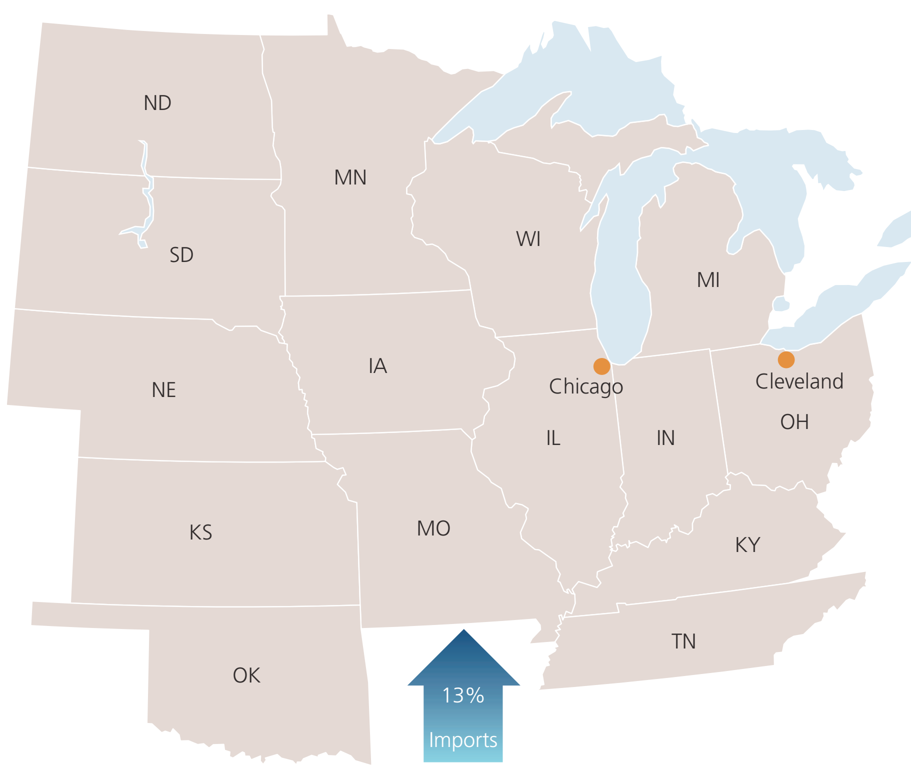
A Sarnia-Lambton refinery upgrader processing 150,000 BPCD of diluted bitumen would represent about 3.5% of this market. A new Sarnia-Lambton refinery upgrader using locally available natural gas from the Marcellus shale for hydrogen production and fuels would be cost competitive with the US Gulf Coast refineries. Product distribution costs by product pipeline from the US Gulf Coast to this market are about $2.00 per BBL. Distribution costs from Sarnia-Lambton by marine barge and pipeline would be equal to or lower than the distribution costs from the US Gulf Coast refineries.

A Sarnia-Lambton refinery upgrader would have additional markets including those adjacent to US PADD 2, and markets in Ontario and along the US East Coast. For eight months of the year there would also be marine access to world markets.

It is important to consider that the US Gulf Coast refiner has access to substantial additional export markets, and it would be indifferent on a pricing basis in terms of selling into the PADD 2 market or to the world market.

Clearly the participation of a refiner marketer as a stakeholder in the project is desirable.

Figure 9
US PADD 2 Midwest Market



[10] Energy Information Administration

The Social License

The Sarnia-Lambton area and community have a history of supporting development based on crude oil; a history dating back to the 1860s discovery at nearby Petrolia and Oil Springs (Figure 10). This led to the development of the refinery now owned by Imperial Oil and was prior to the availability of crude oil from Alberta. Sarnia was selected as the eastern terminus of the first crude oil line from Alberta to Ontario. Early transparent two-way responsive dialogue with local stakeholders and consultation with First Nations communities will be essential to the success of the project.

Figure 10
Oil Museum at Oil Springs, Site of the First Commercial Oil Well in North America (1858)

The presentation made to the Oil Sands Symposium on December 4th, 2013 was reviewed by key stakeholders as it was being developed, and input was included from local construction trades; the Sarnia Lambton Industrial Association, refinery and major plant managements, the Sarnia Construction Association, and municipal, county, provincial and federal elected representatives. All provided valuable input from their perspectives and all were supportive.

Local issues will need to be addressed and local firms have excellent experience in working with the range of stakeholders in the project. We now have in the community locally based firms that are experienced in this type of consultation. There are nine First Nations groups within 100 km of the project and they will need to be meaningfully involved in the project. Issues involving First Nations peoples, as well as their businesses, will need to be addressed..

The goal of building confidence in the project and obtaining the social license to proceed will be aided by the incorporation of the latest proven technologies. Process selection will consider the best match of stakeholder supplier synthetic crude oil quality, market demand and social license considerations. Water use will be minimized, and the design will incorporate zero liquid waste discharge from the site or to the watershed and St. Clair River. The project will use the latest process design, energy efficiency and emissions control technology to ensure minimizing discharges to the atmosphere as well as minimizing the GHG footprint.

Obtaining a social license will involve work and consultation; however, the objective is achievable given the extraordinary support for the project from the local community.

Financing

The project is financeable, likely with partners. Using publicly available information, the three local refineries were analyzed to identify possibilities for modifications to process diluted bitumen. No clear fit was identified. To provide options to attract a refining partner, the analysis was based on a grassroots bitumen upgrading refinery of conventional design.

The project design leverages existing unused infrastructure. There are two "brown field" sites available. These are the Dow plant site, now owned by TransAlta, and the Polysar plant site, now owned by LanXess. These properties are available, border the St. Clair River with docks still in place, and have utilities readily available. Nova Chemicals is converting its Corunna petrochemical refinery to ethane and propane feed stocks from the Marcellus shale fields. This leaves crude oil atmospheric and vacuum distillation towers unused, along with crude oil pipelines and onsite storage It also leaves multiple pipelines connecting to the Shell and Suncor refineries, the LanXess site, and to product pipelines to markets, all unused. Access to underground salt cavern storage is also available. It is assumed that a new facility will make optimal use of this infrastructure.

The design elements for the upgrader refinery include a feed stream of 150,000 BPCD of diluted bitumen (dilbit) with 30% diluent, and 70% bitumen. Additionally, a number of process units would be required. These include an Atmospheric and Vacuum Distillation unit, Coker and Hydrocracking units. A Hydrogen Plant would be required, together with a Sulphuric Acid Alkylation unit, Intermediate and Product Hydrotreaters, and units for BTX extraction and Isomerization. A Catalytic Reformer unit would be required, as well as a Gas Plant and Sulphur Recovery unit.

Product streams that would be produced by the project include:

a. 9,000 BPCD Liquified Petroleum gases
b. 5,000 BPCD Jet Fuel
c. 7,000 BPCD Aromatic solvents (BTX)
d. 70,000 BPCD Gasoline
e. 44,000 BPCD Low Sulphur Diesel
f. 1300 BPCD Heavy Fuel Oil
g. 600 TPD Sulphur
h. 2,900 TPD Petroleum Coke
i. Gasoline/Diesel (G/D) ratio: 1.5

The Capital Cost Estimate, Class 5 Magnitude, equates to $8.6 billion in Canadian funds. For discussion purposes, a CAPEX of $10 billion Canadian funds has been assumed. The estimate is based upon current Greenfield site, process unit capacity factored estimates, and a Sarnia/ US. Gulf Coast cost ratio of 1.33. A contingency of 30% has been factored, as well as a Canadian/ US rate of exchange of $1.05.

No detailed feasibility studies have been undertaken to date. It was recognized that the combination of partners in the project would undertake their own feasibility studies to determine the optimum design, considering their supply and marketing positions and their perspective on design considerations needed to obtain the social contract for the facility. This basic design is well understood by refiners, and represents an understandable starting point.

Value-Added Capture

Using an assumed input of 150,000 BPCD of dilbit and the refinery configuration and product slate outlined above, a value added calculation can be easily projected. The first step is to assume a West Texas Intermediate (WTI) crude oil price of $100 per BBL. If the diluted bitumen is sold to a US Gulf Coast refinery, there is a pipeline transportation cost of $7.35 per BBL. There is also a quality differential which has varied from time to time, and which has been assumed as $20 per BBL, based upon the IHS CERA study Alberta Upgrading, March 2013, Table 2, and multiple other studies. This gives a netback to Hardisty, AB of $73.65 per BBL. The Enbridge Pipeline transportation tariff from Hardisty to Sarnia is $5.50 per BBL, which lands the dilbit mix in Sarnia at an input cost of $78.15 per BBL. The weighted average netback of the product slate yielded by the refinery design, based on an analysis done by the Bowman Centre for 2011 is $123.98 per BBL. This gives a value added capture of $45.83 per BBL or $2.5 billion per year, or over $62 billion over $25 years.

The export potential of this project is significant to Canada[11]. Refined products exports from this refinery upgrader would be valued at over $6 billion Canadian funds, or 1.5% of the total 2012 Canadian products exported valued at over $400 billion. This would also correspond to 30% of total 2012 Canadian refined product export of over $20 billion.

The Path Forward

There will be eleven Alberta bitumen producers coming on stream between 2018 and 2025, with a total production of over 1.5 million BPCD. An initial analysis suggests that participation in a Sarnia-Lambton Upgrader might fit the interests of seven of these companies, totaling over 1.2 million BPCD of bitumen production.

A corporate champion, however, is required for the Sarnia-Lambton Upgrader. Ideally the champion would be an experienced refiner that knows how to build and operate refineries and is experienced in marketing the products, ideally with a PADD 2 market position.

The energy world is dominated by super international oil companies, and national oil companies like Total, Statoil, Aramco, Pemex, Petrobras, IPIC, and YPF to name a few. Canada, Alberta and Ontario need to be involved and supportive of the project to help to level the playing field.

There are many levers that government partners can pull to enable financing. One very promising lever is BRIK (Alberta Bitumen Royalty In Kind) barrels to support worthy projects. The NW Upgrader project has a commitment of BRIK barrels for 30 years, while the Alberta Petroleum Marketing Commission has committed barrels to the TransCanada Energy East project for 20 years.

A financial feasibility study is the next step for this project. The Bowman Centre is following the "Call to Action" to proactively take this business case to potential corporate partners to try to convert this into a feasibility study that fits with the partners' business interests.

The creation of a bitumen upgrader refinery in Sarnia-Lambton is one of the "big picture, big project" undertakings that can begin to recharge Canada's pursuit of recapturing our national image as a sustainable energy powerhouse.

Sarnia-Lambton was there at the beginning of North America's oil industry. The men of the Aamjiwnaang First Nation saw it first, seeping from the sticky gum beds near Oil Spring's Black Creek. This was followed by the continent's first oil wells, and the construction of Sarnia's Chemical Valley, where the oil refineries and production of synthetic rubber helped to lead the Allies to victory in WW II. The people of Sarnia-Lambton are ready, willing, and able once again to do their part in this new national quest.

[11] Patricia Mohr, Vice President, Scotia Bank, Canada's Merchant Trade in Oil & Gas 2012

Biography

Donald E. Wood, B.Sc. (RMC), B.A.Sc. (U of Toronto), is Associate and Advisory Board member of the Sarnia-based Bowman Centre, and is president of his own consulting firm. He has had 45 years experience in the energy and petrochemical industries, including natural gas utility (Union Gas), petrochemical refinery restructuring (Polysar Limited, retired Vice President Logistics and Business Development), greenhouse gas capture, conversion and management (Marsulex, retired senior operating Vice President), merger and acquisitions (15 M&A projects completed). His efforts in the Sarnia-Lambton region have helped medium-sized organizations assess strategic alternatives. On a broader front, he has acted on behalf of owners and been involved within many mergers, joint venture establishments, divestitures and acquisitions, and acquisition integrations.

Co-Authors and Support Team

Clement Bowman, C.M., PhD, PEng, HCIC, FCAE: Founder, The Bowman Centre for Technology Commercialization; Past Chairperson of the Alberta Oil Sands Technology and Research Authority (AOSTRA)

Walter F. Petryschuk, PhD, PEng, FCIC, FCAE: Associate, The Bowman Centre for Technology Commercialization; Retired – Manager, Suncor Sarnia; Retired – Sarnia Site Manager, Polysar Ltd.

Bruce Cater: Retired – Refinery Economics, Suncor

Kirk M. Wilson: Retired – Senior Vice President and Head of Bayer Technology Services Americas, Bayer Business and Technology Services, LLC.

Ed Brost: President, JE&M Consulting Ltd.

Terrence Hoffman, PhD, FCIC, FEIC: Emeritus Professor of Chemical Engineering, McMaster University; Retired – Principal Chemical Engineer, Polysar Ltd.; Retired – Senior R&D Technology Leader, Polysar Ltd.

Larry MacDonald: Retired – CFO, Nova Chemicals

List of Abbreviations

APMC ....Alberta Petroleum Marketing Commission
BBL ....Barrel (oil barrel)
BPD ....Barrel (oil) per day
BPCD ....Barrels (oil) per Calendar Day
BRENT/ICE........Brent/Intercontinental Exchange (European)
BRIK ....Bitumen Royalty In Kind
BTX.................Benzene, Toluene and Xylene
CAPEX ....Capital Expense
CN ....Canadian National (rail)
COSIA ....Canadian Oil Sands Innovation Alliance
Dilbit ....Diluted bitumen (diluted with naphtha or similar light hydrocarbon)
DHT ....Distillate Hydrotreater
EBITDA ....Earnings Before Interest, Taxes, Depreciation and Amortization
EIA..................Energy Information Administration (US)
FCC ....Fluidized Catalytic Cracking
G/D.................Gasoline to Distillate (ratio)
HRSG ....Heat Recovery Steam Generator
ISBL.................Inside Battery Limit
LPG ....Liquefied Petroleum Gas
LTPD................Long Ton per Day
MBPD ....Thousand Barrels per Day (“M” refers to 1000 in Imperial system
MTD ....Metric Tonne per Day
NGL ....Natural Gas Liquids
NWU ....Northweast Upgrader
OSBL................Outside Battery Limit
OPEX ....Operating Expense
PADD ....Petroleum Administration Defense District
ROI ....Return on Investment
PSA..................Pressure Swing Absorber
Synbit ....Bitumen diluted with synthetic crude oil
TCPL ....Trans Canada Pipelines Ltd.
YTD ....Year to date
TPD..................Ton (Tonne) per day
UDEX...............Union Dow Extractor
USGC ....United States Gulf Coast
WCS ....Western Canadian Synthetic
WTI..................West Texas Intermediate

5

The Case of the Dramatic Emergence of Newfoundland & Labrador's Petroleum Industry

Mark Shrimpton

ABSTRACT

The first oil discovery was made on the Grand Banks in 1979 and the first oil development project commenced in 1990. Since then the offshore oil and gas industry has, at an increasing pace, transformed the Newfoundland and Labrador economy. It has not simply provided government revenues and an additional economic sector, but has delivered: new industrial investment and capabilities, training and education, increased business confidence, innovation and entrepreneurship, and success working in other industries and other markets at local, national and international levels. This chapter summarizes the growth of the offshore oil and gas industry in Newfoundland and Labrador, describes its effects on the economy, and then outlines industry-related initiatives in the areas of infrastructure, education, training and R&D. This is followed by a description of the ways in which a number of Newfoundland and Labrador companies have prospered through work in this very demanding industry.

This chapter provides a dramatic and ongoing case study of the effects of megaprojects on one province, and thereby on Canada as a whole. Dependent as it was on the confluence of natural resource potential, private-sector enterprise and investment, and strategic government support for, and leveraging of, the economic benefits from industrial development, it is an excellent example of the creation of a high value-added innovation ecosystem from "big projects," resulting in the transformation of the economy and society of the host region.

Introduction

The history of Newfoundland and Labrador for the last 120 years has largely been concerned with addressing economic challenges. As the Dominion of Newfoundland (with similar jurisdictional status to its neighbour, the Dominion of Canada), then under rule by the Commission of Government after the Dominion became bankrupt in the 1930s, and finally as Canada's tenth province after 1949, the urgent priority has been to create employment, business and government revenues. This has been in response to a wide range of economic, social, health, demographic and other issues, including unemployment, poverty, poor nutrition and out-migration. The initiatives included investment in economic development studies and structures (e.g. royal commissions and the Economic Recovery Commission), transportation infrastructure (e.g. a trans-island railway and "roads to resources"), hydro developments (e.g. Churchill Falls), fisheries and forestry initiatives, and business attraction (e.g., a boot factory, a steel mill, the Come-by-Chance refinery, and a huge cucumber greenhouse complex near St. John's) (Letto 1998).

None of these initiatives brought more than limited or short-term economic growth to Newfoundland and Labrador. However, in 1977 the then Minister of Mines and Energy, Brian Peckford, laid the foundation for the establishment of an offshore oil and gas industry. Based on the Norwegian model, this saw an emphasis on benefits initially enacted in provincial legislation and then, after the settlement of a federal-provincial dispute as to jurisdiction over offshore mineral resources, in the 1985 Atlantic Accord. This set up a Canada-Newfoundland Offshore Petroleum Board (later renamed Canada-Newfoundland and Labrador Offshore Petroleum Board) with jurisdiction over offshore activity. One of the main requirements for the approval of any activity was the submission of a satisfactory Benefits Plan, designed 'to provide an opportunity for businesses and persons in Newfoundland and Canada to participate on a competitive basis in the economic opportunities generated by any offshore oil and gas activity' (CNLOPB 2006). These plans must commit to benefits-related policies and procedures in the areas of project management, procurement and contracting, employment and training, research and development (R&D) and diversity.[1]

[1] Since the 2000s, the Government of Newfoundland and Labrador has increasingly adopted aspects of this approach to the approvals process for large onshore resource development projects.

The first oil discovery was made on the Grand Banks in 1979 and the first oil development project commenced in 1990. Since then, the offshore oil and gas industry has, at an increasing pace, transformed the Newfoundland and Labrador economy. It has not simply provided government revenues and an additional economic sector, but has delivered: new industrial investment and capabilities; increased business confidence, innovation and entrepreneurship; training and education; and success working in other industries and other markets at local, national and international levels. As such, the offshore oil and gas industry provides a dramatic and ongoing case study of the effects of megaprojects on one province, and thereby on Canada as a whole.

This chapter summarizes the growth of the offshore oil and gas industry on Newfoundland and Labrador and goes on to describe its effects on the economy and on industry-related initiatives in the areas of infrastructure, education and training infrastructure, and R&D. This is followed by a series of case studies of Newfoundland and Labrador companies that have worked within the industry. Much of the material is drawn from studies of Newfoundland and Labrador's socio-economic benefits from the petroleum industry between 1999 and 2002 (Community Resource Services Ltd. 2003), 2003 and 2004 (Jacques Whitford 2005), 2005 and 2007 (Stantec 2009) and especially 2008 and 2010 (Stantec 2012). The preparation of an update for the 2010-2012 period is in progress.

It should be noted that the focus here is on the effects of offshore oil and gas activity itself; this chapter does not document the taxes and royalties the industry pays (for example, a total payment of $2.4 billion to the Government of Newfoundland and Labrador in the 2010-2011 fiscal year) or the major financial contributions oil companies make to local charities and community groups.

The Growth of the Offshore Oil and Gas Industry

Offshore petroleum activity in Newfoundland and Labrador began in 1963, and the first exploration well was drilled in 1966. In the 50 years that have followed this initial work, the industry has experienced fluctuating levels of exploration, development and production activity. In the first case, the pace of exploration has differed in response to varying levels of success, changing oil prices, and the availability of government support (e.g. federal Petroleum Incentive Plan grants in the 1970s). Exploration, including both drilling and seismic activity, peaked in the early-1980s, with minor other peaks in the mid-1990s and late 2000s. This exploration led to the discovery of the Hibernia oilfield in 1979, the Hebron field in 1981, and the Terra Nova and White Rose fields in 1984.

However, the first development activity did not occur until 1990, after the Hibernia Development Agreement was signed between Mobil Oil, its partners, and the federal and provincial governments. Because of low oil prices at the time, the development of the Hibernia field was not commercial; the Government of Canada intervened to facilitate the development of the Hibernia project and hence new industry as an economic development initiative. The agreement involved a federal contribution of $1 billion and loan guarantees. The federal government subsequently took an 8.5% working interest in Hibernia, after Gulf Oil had to withdraw. This stake, held by the Canada Hibernia Holding Corporation, has proved to be a very remunerative federal investment.

Since then, three major Grand Banks oilfields have been successfully developed:

- **Hibernia:** The approximately $5.2-billion development of this field by Mobil Oil (now ExxonMobil), including the construction of a concrete gravity based structure (GBS) and some topsides components at Bull Arm, Trinity Bay, started in 1990. The GBS and topsides were mated in early 1997, and the complete platform was towed to the field in time for first oil production in November 1997.
- **Terra Nova:** In 1998, Petro-Canada (now Suncor) decided to develop the Terra Nova field using a floating production storage and offloading (FPSO) vessel with a South Korean-built hull, but with much of the topsides fabrication and installation occurring at Bull Arm. The FPSO arrived at the field in August 2001 and produced first oil in January 2002. The total Terra Nova pre-production capital expenditures were approximately $2.8 billion.
- **White Rose:** Husky Energy's work developing this field started in 2002. Like Terra Nova, White Rose uses an FPSO with a hull built in South Korea. However, much of the topsides fabrication and installation work occurred in Marystown, Placentia Bay, while some fabrication work and the testing of some sub-sea components took place at Bull Arm. The project had a total capital cost of approximately $2.35 billion and first oil was produced in late 2005.

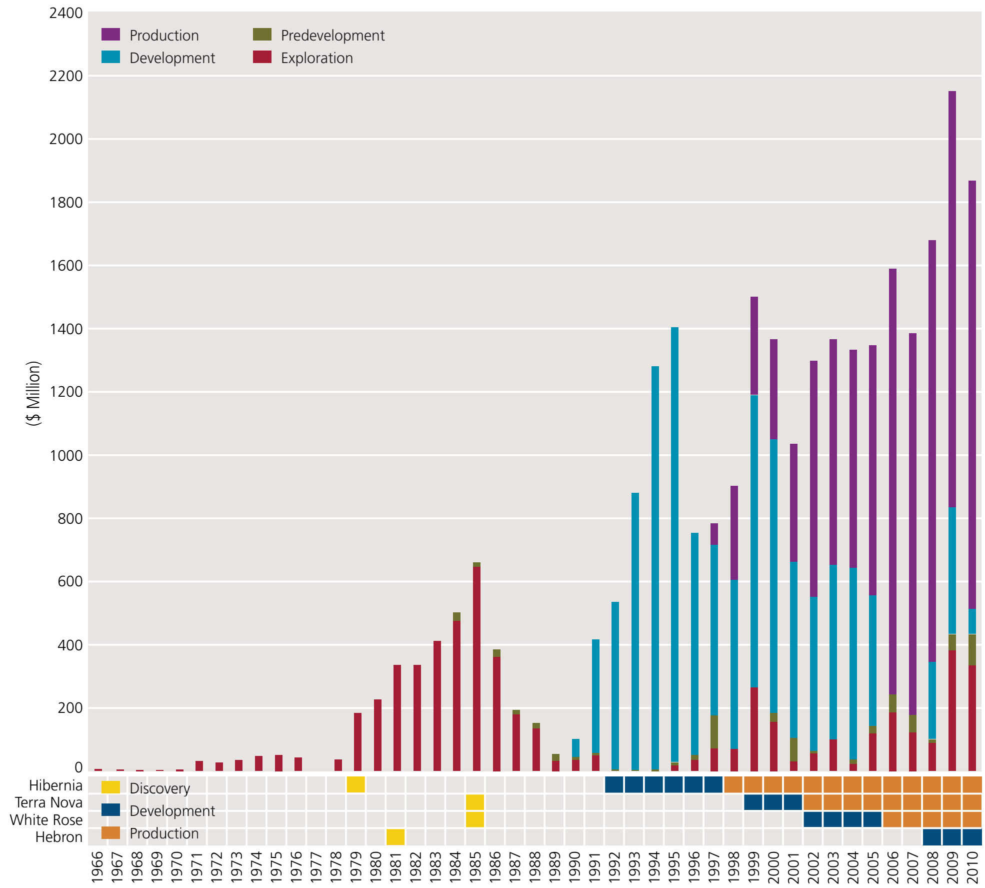
A fourth major oilfield and a satellite field are currently under development. The construction of ExxonMobil's Hebron GBS and topsides began at Bull Arm in 2013, with an estimated total cost of $14 billion. Production is targeted to commence in 2017 and expected to continue until at least 2047. Work on Husky Energy's $2.3 billion White Rose Extension Project, which will see the first North American use of a concrete well-head platform, recently started near Placentia in Eastern Newfoundland. The presence of this structure in the field will reduce the drilling and production costs, and thus increase the viability of various other satellite developments in the White Rose area. The fact that the graving dock for the platform construction is designed to be reusable would reduce the costs of any future similar well-head platforms.

The satellite field developments, such as North Amethyst (a satellite of the Husky's White Rose field) and Hibernia South (a satellite of the ExxonMobil Hibernia field), are often almost overlooked as components of Newfoundland and Labrador industry growth. The $1.3-billion North Amethyst development provides an example of how such a project can result in substantial benefits to the local industry. In addition to exceeding original estimates of 1.6 million person-hours taking place in Newfoundland and Labrador, all subsea engineering took place within the province. It is also noteworthy that, with less than four years between discovery and development, the North Amethyst project saw a drastic reduction from previous development timelines in the province.

The growth in the scale of total oil industry expenditures in Newfoundland and Labrador, as shown in Figure 1, has been impressive. Fluctuating exploration figures have been supplemented, post-1990, with very large but similarly variable development spending to construct and commission offshore facilities. Since 1997, production-related expenditures have seen a steady and relatively predictable increase. Total expenditures rose to a record $2.36 billion in 2011 and then jumped again to $2.89 billion, including $1.68 billion in production expenditures, in 2012.

Figure 1
Newfoundland and Labrador Offshore Petroleum Activity and Area Expenditures, 1966-2010

Source: C-NLOPB



Since 2008, the Government of Newfoundland and Labrador has become directly involved in the industry by taking an equity position in a number of projects. In that year the province, represented by Nalcor, finalized the purchase of a 4.9 percent working interest in the Hebron project, and in 2009 it took a 5.0 percent interest in the White Rose Growth Project, which includes the North Amethyst, West White Rose and South White Rose Extension fields. In 2010, Nalcor acquired a 10 percent working interest in the Hibernia Southern Extension project, which includes two new licences, as well as an area of the main field covered by a separate licence.

The pace of Newfoundland and Labrador offshore oil and gas activity is expected to continue, especially given Statoil's Bay du Nord oil discovery in the Flemish Pass Basin in 2013. The estimated recoverable reserves of between 300 and 600 million barrels make it comparable in size to, or larger than, the fields already in production. Bay du Nord, in conjunction with Statoil's earlier Mizzen and Harpoon discoveries in the same basin (the former with an estimated 100 to 200 million recoverable barrels, the latter still under evaluation), led the company to make an early 2014 commitment to a new multi-year drilling program. In 2013 Husky Energy also made major commitments in terms of both drilling (taking a five-year lease of the rig West Mira commencing in 2015), and its onshore presence (becoming the anchor tenant for the new 351 Water Street office tower in downtown St. John's).

Companies have also acquired land rights to large amounts of offshore acreage. This involves them making exploration activity commitments and, as of March 31, 2013, there were $1.2 billion in commitments, secured by deposits valued at $291 million (CNLOPB 2013).

In June 2013, Scott Tessier, Chair of the CNLOPB, indicated that the Board was expecting a 33% increase in the number of applications for approvals and authorizations in 2013, making it the busiest year on record, with a further approximate 25% increase expected in 2014.

It is worth noting that the industry is also looking at using Newfoundland and Labrador as a centre for activity in more northerly and Arctic waters, an area of increasing interest to the oil industry given large reserve estimates and the shrinking of the ice surface. For example, Husky Energy is using St. John's as the operational centre for its exploration work in Western Greenland.

Economic Benefits

Total offshore petroleum industry expenditures (i.e., capital plus operating costs) in Newfoundland and Labrador over the 2002-2010 period peaked at $2.2 billion in 2009, comprised of over $1.4 billion in capital costs and over $0.7 billion in operating costs. Operating costs have generally grown steadily, from $230 to $280 million between 2002 and 2005, $600 to $620 million in 2006 and 2007, and about $700 million from 2008 to 2010. As was noted above, total expenditures reached a record $2.89 billion in 2012.

A substantial portion of the local benefits from the offshore petroleum industry activity accrues to companies providing goods and services to oil companies. On average, these indirect linkages account for total annual direct and indirect nominal GDP impacts of approximately $7.6 billion, and annual direct and indirect employment impacts averaging approximately 9,200 person-years.

Data on direct and indirect economic impacts provide key inputs to simulations of the overall effects of the offshore petroleum industry on the economy of the province, using the Department of Finance's Newfoundland and Labrador Econometric Model (NALEM) (Table 1).

Over the 2002-2010 period, the GDP impacts (i.e. the business and labour income earned within the geographic boundaries of the province) increased steadily to a peak in 2008 and then decreased sharply from 28.3 percent of the total GDP (Real GDP chained) to 25.1 percent in 2010 as a result of the global economic downturn. Aside from these impacts, the overall pattern of change in total impacts reflects the increased development activity and relatively stable production costs.

Much of the business income earned in Newfoundland and Labrador's offshore petroleum industry accrues to non-resident companies. Therefore, business income directly related to the industry generally would not accrue to residents and is not reflected in the personal income impact. Personal income impacts, primarily wages and salaries, reflect only income received by provincial residents. Consequently, the personal income impacts are smaller than the GDP impacts.

Personal income from the offshore petroleum industry was $955 million per year higher during the 2002-2010 period and represented 6.7 percent of total personal income in Newfoundland and Labrador. Personal income from the industry declined between 2004

Table 1
Total Economic Impacts Related to the Offshore Petroleum Industry in Newfoundland and Labrador

	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
GDP ($ Millions)	4,144	5,138	5,833	7,267	8,141	10,261	12,875	7,668	8762	7,788
Share of Total (%)	27.7	31.1	32.8	35.8	35.2	38.6	44.3	33.3	33.3	34.8
Real GDP Chained ($ Millions)	4,088	4,710	4,439	4,537	4,641	5,356	5,117	4,345	4,365	4,622
Share of Total (%)	27.3	29.6	28.2	28.1	27.9	29.4	28.3	26.4	25.1	27.8
Personal Income ($ Millions)	663	957	979	930	935	866	986	1152	1130	955
Share of Total (%)	5.6	7.7	7.6	7.0	6.7	5.9	6.3	6.9	6.5	6.7
Labour Income ($ Millions)	497	718	734	698	701	650	739	864	848	717
Share of Total (%)	6.9	9.4	9.2	8.4	8.1	7.0	7.5	8.0	7.5	8.0
Other Income ($ Millions)	166	239	245	233	234	217	246	288	283	239
Share of Total (%)	3.5	5.0	5.0	4.7	4.5	3.9	4.3	4.8	4.6	4.5
Disposable income ($ Millions)	522	752	766	726	738	681	779	923	911	755
Share of Total (%)	5.6	7.7	7.6	7.0	6.7	5.9	6.3	6.9	6.5	6.7
Retail Sales ($ Millions)	292	421	429	407	413	381	436	517	510	423
Share of Total (%)	5.4	7.3	7.5	7.0	6.9	5.8	6.2	7.3	6.9	6.7
Housing Starts	104	150	153	145	148	136	156	185	182	151
Share of Total (%)	4.3	5.6	5.3	5.8	6.6	5.1	4.8	6.0	5.1	5.4
Employment ('000s)	11.0	14.5	13.6	13.4	13.5	12.0	12.9	14.0	12.8	13.1
Share of Total (%)	5.3	6.9	6.4	6.3	6.3	5.6	5.9	6.6	5.8	6.1
Labour Force ('000s)	7.5	10.8	9.7	1.0	10.6	9.1	9.8	10.9	9.8	9.8
Share of Total (%)	3.0	4.3	3.8	4.0	4.2	3.6	3.9	4.3	3.8	3.9
Unemployment Rate (%)	-2.0	-2.3	-2.3	-2.1	-1.9	-1.7	-1.8	-2.0	-1.8	-2.0
Population ('000s)	12.6	18.0	16.1	16.6	17.7	15.1	16.4	18.2	16.4	16.3
Share of Total (%)	2.4	3.5	3.1	3.2	3.5	3.0	3.2	3.6	3.2	3.2

and 2007, partially due to completion of White Rose project construction activity. However, it increased after 2007 due to strong wage growth and increased activity related to the development of North Amethyst and Hibernia South, and in 2010 the total personal income attributed to the offshore petroleum industry was $1.1 billion, or 6.5 percent of total income.

Personal income effects mainly reflect the boost to labour income resulting from the offshore petroleum industry's high-wage jobs, as well as labour income from spinoff employment (indirect and induced). Annual disposable income increased from $497 million in 2002 to $848 million in 2010, an increase of 71 percent. Consumer spending in the form of retail sales also increased by approximately 75 percent between 2002 and 2010.

The estimated annual employment impact averaged approximately 13,000 person-years over the 2002-2010 period, representing 6.1 percent of all provincial employment. On average, the unemployment rate was 1.9 percentage points lower as a result. The decline in unemployment would have been greater except that increased employment, higher average wages and higher population encouraged more labour force participation. The rise in the labour force was approximately two-thirds as large as the gain in employment. The increased demand for labour also contributed to a substantial population increase as a result of diminished out-migration and some in-migration, with the latter including large numbers of returning Newfoundlanders and Labradorians.

The offshore petroleum industry is thus making a very substantial contribution to the Newfoundland and Labrador economy, particularly in relation to GDP and employment. The GDP contribution from oil production will likely decline in the near future as the most productive current reserves have been depleted and overall production levels are expected to fall in the medium term. However, other production-related benefits such as employment and personal income are not expected to be affected by the production declines. In addition, development and then production impacts are expected to increase as construction activity ramps up as a result of the Hebron and satellite field developments.

Infrastructure, Education and Training, and Research and Development

Infrastructure

The ongoing development of the Newfoundland and Labrador offshore petroleum industry is supported by, and has made a substantial contribution to, infrastructure development in Newfoundland and Labrador. Over the long term, the availability of such infrastructure reduces the costs of development, increases the likelihood of additional petroleum industry investment in Atlantic Canada, increases the province's ability to be involved in the industry's construction, fabrication and operations activities, and ultimately increases Newfoundland and Labrador's participation in the industry. Some of this infrastructure has also contributed to the diversification of Newfoundland and Labrador's business community. For example, many Newfoundland and Labrador companies have successfully leveraged harsh environment engineering expertise developed in provincial facilities to gain additional experience by working in Arctic environments.

This section illustrates this development of new infrastructure, based primarily on examples reported in a study of the effects of the offshore petroleum industry during the 2008-2010 period. This timeframe saw continued development and growth in supporting infrastructure for the Newfoundland and Labrador offshore petroleum industry. This was in support of increased production, exploration, and drilling activity, and is evident in activity among local companies, as well as the supporting government, institutional and transportation infrastructure.

For example, in 2010 Memorial University opened an Autonomous Ocean Systems Laboratory to advance harsh environment research capacity. The laboratory provides uniquely designed space to researchers, including undergraduate and graduate students, providing a catalyst for research on autonomous ocean systems in ice-covered and otherwise harsh environments. The laboratory was established with support from the Research and Development Corporation of Newfoundland and Labrador (RDC) Canada Research Chair program and the Canada Foundation for Innovation. Also in 2010, a partnership between Chevron Canada, Memorial University and the RDC resulted in the announcement of an agreement to build a new Process Engineering Design and Research Laboratory on Memorial University's St. John's campus.

The 2008-2010 period also saw the Marine Institute of Memorial University open a new marine base in Holyrood. It was designed to be a focal point for a variety of oil and gas industry-related research and educational activities, including such areas as ocean technology, fisheries, marine environment, diving, offshore safety and survival, oil spill response, oceanography and marine biology. The same period saw the Marine Institute purchase new ocean-mapping equipment in support of its ocean technology programs. The equipment, including multi-beam sonar, a sub-bottom profile, will support programs such as the new joint Diploma of Technology/Bachelor of Technology in Ocean Mapping and enable the Marine Institute to conduct applied research in ocean mapping. Applications include determining pipeline routes for offshore oil production and identifying safer routes for vessel traffic. In 2010, the Marine Institute purchased a wave piercing catamaran, the MV Atlanticat, to provide a marine platform to deploy research equipment. This vessel was funded through a $1.5-million investment from the provincial government and Memorial University, and has increased research and training capacity for the Marine Institute.

The period also saw continued private-sector investment in infrastructure. For example, Pennecon Energy Marine Base invested more than $3.5 million in infrastructure development at its Bay Bulls facility. In addition to the installation of a concrete caisson that expanded its dock space from 60 m to 90 m, Pennecon increased warehouse space by approximately 1,021 m^2 (11,000 ft^2) and expanded its secure laydown area.


Photo courtesy of Memorial University

Education and Training

The 2008-2010 period saw further advances in education and training, in addition to the infrastructure investments described above. For example, C-CORE, a separately incorporated research and development (R&D) corporation at Memorial University specializing in cold oceans engineering, matched funding from the provincial government's Department of Industry, Trade and Rural Development to provide work-terms and internships to new graduates pursuing careers in geotechnical engineering. In total, C-CORE employed 33 work-term and other undergraduate students and the organization's total 2008-2010 investment in students was $323,429. C-CORE's contribution to develop the province's base of expertise in this field also extended to a partnership with Memorial University to cost-share a Chair in Geotechnical Engineering, allowing Memorial University to attract a senior Professor to the province to develop new academic programs within the Faculty of Engineering.

Undergraduate enrollment in the Faculty of Engineering and Applied Science at Memorial University grew steadily over the study period, with 1,039 students in 2008, 1,128 in 2009 and 1,203 in 2010. During this period, the Faculty awarded 480 undergraduate engineering degrees and there was a rapid increase in the number of graduate students, many engaged in petroleum industry-related work. Approximately 400 Memorial co-op students are placed with oil and gas companies each year. These are mostly engineering students, but also include business students.

Also during this period, the College of the North Atlantic vocational school increased the intake into the Process Operator Engineering Technology Program at its St. John's campus through its oil and gas funding. This three-year program has an annual capacity of 20 students and previously had an alternate year intake. In 2010, a new three-year co-op program in Chemical Process Engineering Technology was introduced with an annual capacity of 24 students.

Research and Development

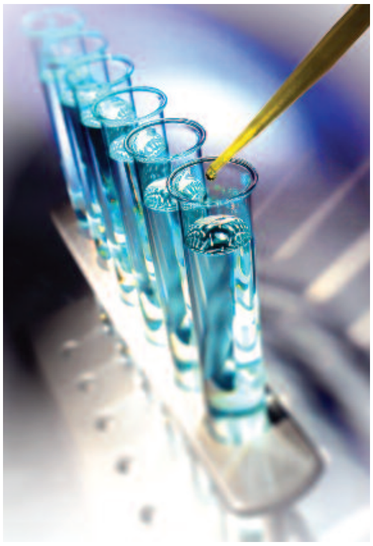
Research and development is an area of high activity in the provincial offshore petroleum industry, with industry, educational institutions, and research organizations providing support for the advancement of industry locally, as well as providing a mechanism for the transfer of local expertise into international markets.

The 2008-2010 period saw this continue with a number of major R&D initiatives. For example, in 2009 Memorial University announced a partnership with the American Bureau of Shipping to create a new Harsh Environment Technology Centre. Responding to a demand for ice class guidance for offshore structures in harsh environments, the new centre is designed to support the development of technologies for ships and offshore structures operating in harsh environments, particularly the Arctic. Applied research will be conducted to study vessels and units operating in ice covered waters, low temperature environments, and severe wave and wind climates.

The Institute for Ocean Technology (IOT), now part of the National Research Council's (NRC's) Ocean, Coastal and River Engineering Institute, was involved in a number of projects either directly related to, or with applications in, the offshore petroleum industry. For example, working with Memorial University and other NRC institutes, the IOT took the lead in the Escape, Evacuation and Rescue Project. This has tested different lifeboat hull designs in pack ice and wave conditions as well as conducting tests of marine safety systems in extreme environments to update safety equipment guidelines, while transferring research data and new technologies to the private sector. With funding from Transport Canada and Natural Resource Canada's Program on Energy Research and Development, the IOT has also been involved in a survival research project concerning the effects of wind and waves on the thermal regulation of people in immersion suits. The results of this study will be incorporated into any future review of regulations for marine safety and survival equipment.

Petroleum Research Newfoundland and Labrador (PRNL) (formerly Petroleum Research Atlantic Canada [PRAC]) is an industry-funded federally-incorporated not-for-profit agency that facilitates R&D development projects with application in both the Newfoundland and Labrador offshore sites, and in Arctic areas such as Greenland, where Newfoundland and Labrador companies have begun to operate in support of exploration activities. During the 2008-2010 period, PRNL awarded approximately $1.8 million in funding to companies and institutions undertaking research with application in the offshore petroleum industry. With PRNL funding, Memorial University's Ocean Engineering Research Centre (OERC) and the IOT became engaged in a project building on a related undertaking Ice Data Analysis and Mechanics for Design Load Estimation previously funded by industry (Husky, Petro-Canada, and Chevron Canada Resources), NRC, PRAC, and the National Sciences and Engineering Research Council of Canada (NSERC). This project studied ice composition, structural design, and iceberg impact modelling to examine ways of minimizing the risks of damage caused by icebergs. The study also incorporated risk analysis and probability into the larger challenge of operating offshore structures in iceberg-busy waters.

Petroleum Research Newfoundland and Labrador also funded studies in reservoir characterization and health, safety and environment. The latter included funding provided to Virtual Marine Technologies, in partnership with OERC, and Marine Institute's Centre for



Marine Simulation (MI-CMS), to develop a virtual trainer and curriculum to expand upon the existing live boat training program.

The RDC of Newfoundland and Labrador also made important R&D investments, funding several projects through the Industrial Research and Innovation Fund (IRIF). In 2008, a five-year, $3.7 million, Advanced Exploration Drilling Technology project was initiated by a partnership that includes ACOA, RDC, Husky Energy and Suncor. This applied research project is undertaking an experimental and numerical investigation of vibration-assisted rotary drilling leading to the development of a prototype drilling tool.

In 2010, RDC invested more than $400,000 in research into the use of underwater vehicles in extreme environments, such as the Arctic. This funding was provided through the Leverage R&D component of the IRIF which enables researchers to leverage additional funding from other sources such as NSERC. Additional funding for research in the design, navigation and control of Autonomous Ocean Systems was provided through the Ignite R&D portion of the IRIF.

In 2009, with a $500,000 investment from the Wood Group, an Aberdeen-based energy services company, and an additional $500,000 in support from RDC through the IRIF, Memorial University established the Wood Group Chair in Arctic and Cold Region Engineering. The objective of the chair is the development of technology for application in Arctic and cold region oil and gas development, specifically pipeline design, construction and operations in northern regions.

Early in 2010, Chevron Canada announced that the Chevron Corporation had selected Memorial University to join its University Partnership Program (UPP). Memorial is the first university in Canada selected for this program, which includes approximately 100 universities and colleges worldwide. In late 2010, Chevron and RDC also announced the creation of the Chevron Chair in Petroleum Engineering with a $500,000 investment from Chevron and an additional $500,000 in support from RDC through the IRIF. The chair establishes, promotes and focuses research and teaching in petroleum engineering with the objective of petroleum engineering capability within the current undergraduate programs.

Additional R&D work undertaken by such private-sector and non-profit companies as Oceanic, C-CORE, PAL and VMT is described in the company case studies that follow.

Company Case Studies

The success of the offshore petroleum industry in Newfoundland and Labrador is both a result of, and exemplified by, the success of local companies. This section summarizes the involvement of a range of such companies with this very demanding industry, and explains how this has led them to develop new goods and services, hire new personnel, provide them with further training, acquire new facilities and equipment, and improve quality, health, safety and environmental policies and practices. It also demonstrates the ways in which the resultant increases in experience and capabilities have led to them winning petroleum industry work in other jurisdictions, and undertaking work in other industries at local, national, and international levels.

One of the most striking examples is the **Cahill Group**. Founded in 1953, it grew out of a small electrical company, focused on residential work. In 1991, it successfully bid on electrical work on the initial Bull Arm Hibernia construction site work camp. Building on that opportunity, it went on to work on the construction site swimming pool and gym, the Hibernia topsides, and the final Hibernia hook-up, and it is still undertaking offshore work on the Hibernia platform. It has expanded into a range of electrical, mechanical installation, industrial mechanical and pipe fabrication work, including the construction of a White Rose FPSO topsides module, additional Terra Nova FPSO accommodations, and subsea manifolds for the North Amethyst satellite development. The Cahill Group now provides a wide range of electrical and instrumentation, mechanical, piping and instrumentation services.

Based on its success in Newfoundland and Labrador, 2005 saw the company make a strategic decision to expand to Alberta. It has successfully bid sophisticated work on oil sands projects, benefitting from the rigorous quality and other systems it had put in place in Newfoundland and Labrador to address exacting offshore petroleum industry requirements, and allowing the company to build its capacity, resources and balance sheet and to help deal with cyclical variations in demand in both provinces. The company has also undertaken a range of oil industry work in the Maritimes, including on ExxonMobil's Sable Gas project and the Irving Oil refinery in Saint John, New Brunswick.

The Cahill Group's locally-developed capabilities and resources have also allowed it to expand into non-oil industry activity, including work on the Voisey's Bay mine and Long Harbour minerals processing projects (through alliances with such companies as ABB, P. Kiewit and Black Macdonald), the Newfoundland Refinery, and Iron Ore Company of Canada's iron ore mine in western Labrador. Strategic partnerships have also assisted in capturing further oil industry work; for example, with Aker and SNC-Lavalin in undertaking Husky Energy maintenance and modifications work. Outside of Newfoundland and Labrador, the Cahill Group has assisted in the construction of waste and water treatment plants across Atlantic Canada, and it is responsible for the electrical and instrumentation, mechanical and piping work on the Wuskwatim hydro project in Manitoba.

In 2010, the Cahill Group moved its corporate office to the redeveloped St. Bride's College, now renamed as The Tower Corporate Campus at Waterford Valley in St. John's. The company has come full circle with the purchase of the property; in the late 1960s, GJ Cahill was selected as the sole contractor for the installation of the electrical systems for the construction of The Sisters of Mercy's St. Bride's College, one of the largest institutional projects of the time. The 12,000 m^2 Tower Corporate Campus is now the home to many of the companies involved in the Hebron project.

A number of other companies are engaged in petroleum industry-related construction and fabrication activity. For example, **C&W Offshore** provides custom or client design steel and aluminum fabrication, and undertakes some piping work. It was incorporated in 2004 on the basis of opportunities that the company president identified while he was working in Texas. It was soon fabricating subsea components for the White Rose project for Technip, as well as undertaking specialist work for drilling company GlobalSantaFe. In order to achieve this success, the company had initially to introduce quality and safety standards much more rigorous than were common in metal fabrication in the Province at the time.

Subsequent oil industry work has included the fabrication of lifeboat decks for a drilling rig (for TransOcean), subsea assemblies for Husky Energy's North Amethyst satellite development (for Technip), custom ROV components (for Oceaneering) and components for the Hibernia gas lift (for Wood Group/PSN). C&W Offshore has also undertaken work for projects outside Newfoundland and Labrador, both for the oil industry, in the form of ROV and launch recovery system components for a company in Morgan City, Louisiana, and for the mining industry, fabricating steel tanks for a mine in the Northwest Territories. Overall, the oil industry accounts for over 95 percent of C&W's business. It now occupies a custom-built 1,500 m^2 building, including a 1,100 m^2 fabrication space with a 50 tonne crane, in Mount Pearl.

In support of offshore petroleum construction and fabrication activity, **Pennecon Energy** has developed and operates a Marine Base in Bay Bulls, approximately 30 km south of St. John's. It provides a service facility for a wide range of marine operations, which have included such oil industry activity as drilling rig servicing, rock dumping, chain inspection, pipe inspection and other support for a range of offshore construction and maintenance projects. The clients for this work have included Husky Energy, Technip, Tideway, Transocean, Rowan and GlobalSantaFe. This work has seen a progressive expansion and improvement in the Marine Base, with increased ocean frontage, water depth, bollards and crane pads, and the construction of an office/warehouse, an encapsulated sewer system and a garage. These have helped attract work on both oil and non-oil industry activity, with the latter including work on fishing vessels and the transshipment of wind turbines. However, the oil industry still provides approximately 90 percent of the base's business.

Marine activity is also the focus of oil industry work by **A. Harvey Group**. Founded in the 1860s, it first became involved in offshore petroleum activity in the 1960s, acting as ships agents and customs brokers, and providing crewing, for drillships engaged in exploration off Labrador. While St. John's Harbour was once the home of a number of single-operator supply bases, increased asset sharing has led to A. Harvey becoming the main provider to the oil companies operating in the Newfoundland and Labrador offshore sites. Its Offshore Marine Base encompasses almost five hectares of waterfront property. It can accommodate five offshore supply vessels, providing fuel and water via pipeline, drilling bulks, 24 hour-security, and a heavy lift crane capable of 44-tonne lift. A. Harvey has been active in offshore logistics since the start of exploration, with experience in vessel operations, cargo planning, safe rigging and slinging practices, container repairs and certification, heavy lift management, freight forwarding, oil spill response, and crane and equipment maintenance.

As demonstrated above, a number of Newfoundland and Labrador companies are working directly for the industry developing and delivering the results of R&D activity. For example, **C-CORE** was founded in 1975 under a five-year Devonian Foundation grant to address challenges facing oil and gas development offshore Newfoundland and Labrador and other ice-prone regions. It was incorporated as a federal non-profit in 1992, and has become a major international player in the fields of remote sensing, ice engineering and geotechnical engineering.

As a key contributor to Memorial University's research capacity, C-CORE undertakes more than 100 R&D projects annually, as single client or multi-participant joint industry projects, and works with the oil and gas industry to define R&D priorities to meet the requirements of this sector. It is committed to building Newfoundland and Labrador's knowledge base for offshore engineering, particularly ice and geotechnical engineering aspects, and to further acceptance of new engineering concepts for oil and gas development. This knowledge base includes unique familiarity with Atlantic Canada and a growing understanding of engineering considerations for such other harsh cold-ocean environments as the Barents, Beaufort and Caspian Seas. C-CORE successfully worked with industry to secure funding and other support for long-term R&D addressing barriers to development of hydrocarbon resources in Arctic and other ice and iceberg prone regions.

C-CORE has branch offices in Ottawa, Halifax and Calgary and is active on every continent, providing research-based advisory services and technology solutions to clients in the natural resource, energy, security and transportation sectors. In 2010, oil industry work accounted for 60 to 70 percent of its turnover, with 20 percent directly concerned with the Newfoundland and Labrador offshore sites.

Since 1993, **Oceanic**'s researchers, engineers, and technical personnel, working with one of the world's most comprehensive collections of hydrodynamic research facilities, have made the company a world leader in commercial R&D. Developing out of Marineering in an alliance with the NRC, based around the IOT, Oceanic emerged as an independent entity in 1998. Marineering had undertaken a range of work in the oil industry, including evaluation studies for Global Marine, Noble Drilling and for the Terra Nova FPSO in the late 1990s. There was then a lull in Oceanic's local oil industry work until it undertook studies for the White Rose project (examining green water impacts, combined wind, current and wave loads, and the effectiveness of disconnectable moorings for the SeaRose FPSO) and subsequent work on the Hebron GBS and Hibernia offshore loading system. Based on its early local FPSO work, Oceanic has gone on to work on more than 60 FPSO-related projects worldwide for clients such as ExxonMobil, Husky Energy, Single Buoy Moorings, Suncor, Technip and Woodside Energy. The company's work has reached as far as the Tatar Strait, the South China Sea, the Sea of Okhotsk, Australia, Brazil, Italy and West Africa.

Oceanic's range of physical modeling and numerical simulation research has included: sea-keeping studies (with one or more floating or fixed structures); free running and captive ship manoeuvering tests; evaluations of current loads on moored structures; hull resistance in level and pack ice as well as in open water; ship performance in ridged ice; and ice abrasion studies. In recent years the oil industry has been responsible for approximately 70 percent of Oceanic's business, of which approximately 70 percent is in export markets. In 2011, Oceanic became part of the J. D. Irving Limited Group of Companies, providing new opportunities for growth in the oil and gas industry, in Newfoundland and Labrador, nationally, and internationally.

The aviation sector is also important to, and a beneficiary of, the oil industry. **Provincial Aerospace** (PAL) started life in 1974 as a St. John's flying school with less than 10 employees but, primarily thanks to opportunities presented by the oil industry, it has developed into a global leader in aerospace and defence. It now provides highly tailored airborne and maritime surveillance solutions, including custom aircraft design and modification, mission system design and integration, and mission operations, training and support. It has more than 900 employees, approximately 750 of them in Newfoundland and Labrador, with domestic operating bases in Newfoundland and Labrador, Nova Scotia and British Columbia, and

Photo courtesy of Provincial Aerospace Ltd.

“Provincial Aerospace Limited, in St. John’s, Newfoundland and Labrador, has grown from its origins as a small flight school to being a world leader in maritime and airport surveillance. The company now employs 900 people, sells to 30 countries and has operating bases in the Caribbean and Middle East.

Again, success is rooted in local strengths and global demand. In this case, Provincial Aerospace built upon its hard-won expertise in flying and navigating in difficult Maritime weather conditions to develop leading-edge aerospace engineering. The local know-how was the basis for a global service, with the value added by innovation.”

David Johnston
Governor General of Canada
November 18, 2011

international bases in Barbados, Trinidad and Tobago, Netherlands Antilles, and the United Arab Emirates (UAE).

The company’s involvements with the oil industry started with ice surveillance flights in the early 1980s. The requirement for this service grew as the industry’s activity increased and in the wake of the sinking of the Ocean Ranger drilling rig with 84 fatalities in February 1982, which resulted in greater safety-related requirements, including in the area of ice response. This provided a challenge to which PAL responded by adapting military anti-submarine technology to ice surveillance in a harsh environment. This also saw PAL moving away from simple ice data collection to ice management and coordinating appropriate responses.

With the lull in oil industry exploration activity in the late 1980s, PAL used its oil-related expertise to diversify into fisheries monitoring, which provided greater business stability. PAL has subsequently further extended its operations into products and services related to sovereignty protection, search and rescue, maritime security, environmental management, pollution detection and monitoring, drug interdiction and smuggling, customs and immigration patrol, disaster relief and general law enforcement. This has included, for example, a 2009 $370-million contract with the UAE for the design, modification, and integration of two Dash-8 Q300 aircraft as well as training and integrated logistics support. A feature of the UAE program is the incorporation of design innovations that PAL developed over its 25 year history modifying and operating maritime patrol aircraft. The company continues to explore the use of new technologies and innovations, and is currently moving forward with commercial applications of military drone technology

Notwithstanding this diversification, the oil industry is still directly or indirectly responsible for approximately 70 percent of PAL’s aerospace and defence work. This includes work in Newfoundland and Labrador, the Maritimes, and internationally, with the last including supporting Cairn Energy, Husky Energy and Shell exploration programs in Greenland.

Virtual Marine Technology (VMT) is a more recent Newfoundland and Labrador-based technology company, a simulation specialist that grew out of Memorial University and the IOT. It was founded in 2004 as a result of offshore petroleum industry interest in having a lifeboat simulator developed. It is engaged in lifeboat, fast response craft and electronic navigation simulation for the oil, defence and commercial shipping industries. This includes the development and sales of hardware, software and teaching curriculum. VMT is also investigating links to the gaming industry, and pursuing business opportunities in foreign markets, including Mexico, and building on relationships that it has established with major international corporations working in aviation (e.g., CAE, a Canadian world leader in providing simulation and modelling technologies and integrated training solutions for the civil aviation industry) and defence (e.g., Lockheed Martin).

The wide range of other oil industry services provided locally includes those of **PF Collins**, a St. John’s-based family business. Newfoundland was still a colony of Great Britain when PF Collins was appointed the Customs Broker for Newfoundland in 1921. St. John’s was the key port of entry for Newfoundland at the time, and PF Collins participated in the development of Newfoundland’s first industries and helped arrange the movement of imported goods to points around the island. After Confederation in 1949, Newfoundland’s trading patterns and transportation systems changed significantly, providing new opportunities. The company participated in early industrial developments such as the pulp and paper mills, the U.S. military bases built during the Second World War, refineries at Holyrood and Come-By-Chance, and the Churchill Falls hydro project.

In the 1970s, the company initiated its involvement in offshore petroleum exploration. Working with operators and government legislators, the company implemented many operational procedures to accommodate the then "customs free zone" on the Continental Shelf. As the company continued to grow, it expanded its services and capabilities and its international network of agents and affiliates. At the same time, the company initiated an extensive program to incorporate the latest advances in technology and automation, and it expanded into Nova Scotia and Alberta. PF Collins now provides custom brokerage, freight services, warehouse and distribution services, project logistics, project administration, marine agency services, immigration consulting, and compliance consulting services. Company managers are proud of the fact that more than half of its personnel, including many in senior positions, are women.

The founder of St. John's-based **Atlantic Offshore Medical Services** (AOMS) began working with a commercial diving company in the late 1970s, leading to his establishing AOMS in 1978 and success in capturing work on the Hibernia project. AOMS offers harsh environment occupational health and emergency medical services, both onshore and offshore. They include the assessment of occupational health and safety practices, pre-employment examinations, health surveillance programs, periodic medical examinations, independent medical examinations, disability management programs, workplace drug testing, occupational therapy, vaccinations and immunizations. AOMS also provides response teams for medical emergencies at remote sites, and it has extensive experience in setting up medical services for offshore drilling rigs.

The company has provided its services to all the oil companies operating in the Newfoundland and Labrador offshore, and to the Come-by-Chance oil refinery. It also has a Halifax-based Nova Scotia affiliate which has supported the Sable Gas and Deep Panuke offshore gas projects. Drawing on its Newfoundland and Labrador-developed expertise, AOMS has also provided medical support for the Sunrise (Husky Energy), Kearl (ExxonMobil) and Albian Sands oil sands projects in Alberta. The company has used its oil industry-based expertise to expand into other sectors, working for such organizations as workers compensation commissions in both Newfoundland and Labrador and Nova Scotia, and the cities of St. John's and Mount Pearl. However, the oil industry is still responsible for about two-thirds of company revenues.

East Coast Catering (ECC) was established in St. John's in 1984, largely on the basis of perceived opportunities related to offshore oil exploration. The company now operates in seven Canadian provinces and in Ireland, and it is the dominant workforce catering service provider to the offshore petroleum industry in Atlantic Canada, supporting three of the region's four producing projects and many of the drilling rigs operating in the region. ECC's oil industry clients include or have included ExxonMobil, Suncor, Husky Energy, Canship Ugland, Transocean, GlobalSantaFe, Petrodrill, Sedco and Rigco. It has also provided camp facilities for drilling rig refit work at Bull Arm in Eastern Newfoundland.

The company has long recognized that the oil industry is very demanding in the areas of safety and training. However, the adoption of such standards for the oil industry has been beneficial in bidding work in both that industry and historically less-demanding sectors, helping the company to expand into other jurisdictions and to get work on mining, hydro and other projects. In the former case, ECC operates four camps associated with onshore oil activity in Alberta and British Columbia.

In an early example of work in other industries, ECC provided accommodations, catering and housekeeping services at the Hope Brook gold mine in southwestern Newfoundland in the 1990s. The company has subsequently provided similar services for the construction and/or operation of Vale's Voisey's Bay mine and Long Harbour minerals processing project, mining projects in Western Labrador, Ontario, Manitoba, British Columbia and Northwest Territories, and a number of hydro projects in Newfoundland and Labrador. ECC also provided workforce accommodations for the Confederation Bridge construction project in PEI, and East Coast (Ireland) Limited has operated accommodations for asylum seekers for the Irish Department of Justice since 2002.

Smaller Newfoundland and Labrador companies provide a range of specialist services to the industry. For example, **Strategic Concepts** was originally established in 1990 to assist small businesses with business planning and marketing. However, the company principals soon recognized that there were opportunities associated with forecasting and demonstrating the economic impacts of major resource development projects. Strategic Concepts has subsequently expanded its offerings to include: cash flow and economic impacts analysis; strategic advice re advancing projects; the provision of software to monitor project benefits and commitments; specialist studies, such as project labour requirements and supply; and the negotiation and implementation of Impact and Benefits Agreements.

The local oil industry clients for Strategic Concepts services have included ExxonMobil, Chevron and Husky Energy, and local success has led to its benefits monitoring software being adopted for projects elsewhere in Canada, including the Mackenzie Valley Gas Pipeline and Kearl oil sands projects for ExxonMobil and the Surmont oil sands and Parson's Lake gas projects for ConocoPhillips. However, non-oil projects, such as the Vale's Voisey's Bay mine in Labrador, have become increasingly important to the extent that, at times, work for the oil industry has only been responsible for 20 to 25 percent of the company's turnover.

In another example of a small specialist company working in the oil and other industries, **Canning & Pitt** was established in 1991, primarily to support the Hibernia development project in its relations with fisheries interests. Since that time it has worked for such companies as Husky Energy, Suncor, ConocoPhillips, Hebron, WesternGeco, PGS and GXT, developing and supporting operational management plans and compensation programs, providing consultation services, and assisting in the development of environmental assessments. This has included seismic-related work in Nova Scotia, the Beaufort Sea, and Greenland. While the oil industry accounts for approximately 80 to 85 percent of the company's business, it has diversified into work on minerals processing and subsea transmission line projects.

The oil industry supply and service sector is not just comprised of companies engaged in industry-specific activity. For example, **Greg Locke** was originally a freelance photographer and reporter, working for the Globe and Mail, Maclean's and other newspapers and magazines.

He increasingly became involved in corporate photography for such companies as Ford, Toyota and Imperial Oil, while based in Ottawa. Greg moved back to Newfoundland in 1988 and in the 1990s he became involved in local photography for the oil industry, including documenting the Hibernia construction site preparation for HMDC. This led to work for Chevron, Petro-Canada, GJ Cahill, Texas Instruments, Schlumberger, Baker Hughes, and other companies engaged in oil activity. Greg's recent work has included what he calls "engineering telemedicine," photographing damaged offshore equipment for evaluation by experts onshore.

Working in such a demanding industry has driven Greg's professional development, further expanding his business. For example, he has had to acquire suitable equipment for working offshore (where, for example, flash cannot be used because it might set off sensors) and to maintain current safety training certification for working offshore. These have helped Greg get work at other types of industrial sites, within and outside the province, including work for such companies as Teck-Cominco, Sandwell Engineering, and Schneider Electric. The importance of the oil industry to Greg Locke has been quite variable, representing between 10 and 60 percent of his total business income.

While St. John's is the Province's largest city, the centre of oil industry management, regulation and R&D, and the location of the main marine supply base and helibase for offshore activity, not all oil industry business occurs there. For example, the construction of the Hibernia, Terra Nova, White Rose, North Amethyst and Hebron projects, and rig mobilization and refurbishment work, has mostly been concentrated around the Isthmus of Avalon and in Marystown. Work on the White Rose Extension Project is primarily occurring near Placentia, and the transshipment of Grand Banks' oil occurs at a terminal near Arnold's Cove on Placentia Bay.

Some supply and service companies are also located outside of the St. John's region. For example, **Dynamic Air Shelters** is based in Grand Bank on the Burin Peninsula, approximately 360 km by road west of St. John's. It evolved from Calgary-based Aero Dynamics Inflatable Shelters Inc., which originally focused on designing and manufacturing inflatable shelters for promotional events. Involvement with the oil and gas industry had an important influence on product development, and it was through the industry that it first began working in Newfoundland and Labrador in 2002, leading to it moving its manufacturing operations to Grand Bank in 2004.

The company began engineering and testing its shelters for explosion resistance in response to petroleum industry demand. A turning point came when the company demonstrated that its structures could withstand pressures from an explosion of up to four pounds per square inch (psi), with later tests concluding that they would likely withstand a blast of nine or ten psi. The product is now being used on work sites for offices, warehouses and lunchrooms, with the company becoming heavily involved with the oil industry internationally, producing structures for refineries and other sites across North America, the Caribbean and Australia.

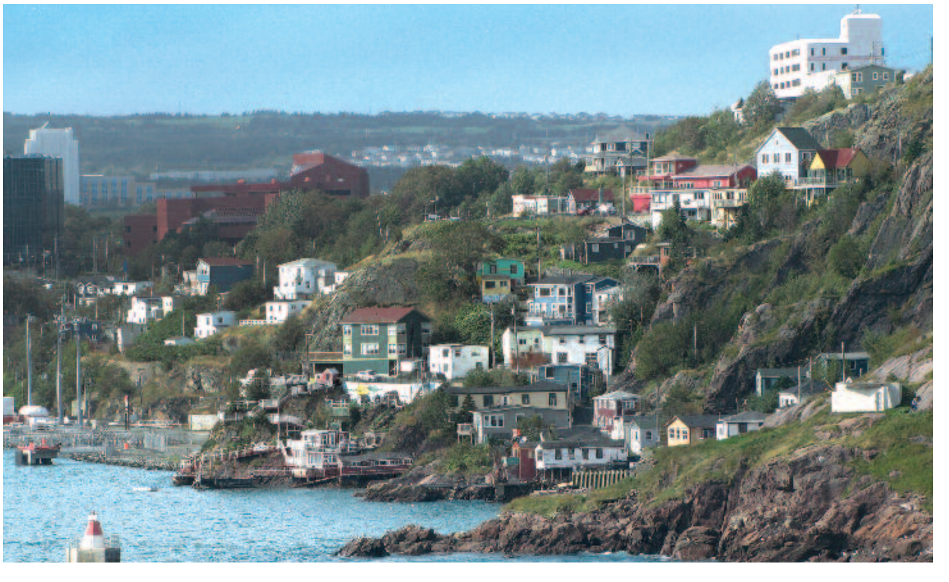
Contracts with oil and gas companies represent about half of its sales; however, engineering and manufacturing capabilities developed to meet oil industry requirements have helped Dynamic sell its products to the construction and fabrication industries. The company has also worked with the Canadian Armed Forces to provide protective structures for use in military operations. About a quarter of its business comes from construction and fabrication projects, many of which are linked to the oil and gas industry, while the remaining quarter is split between military applications, promotional structures, and emergency response shelters.

Conclusion

Thanks to a combination of natural resource potential and private-sector enterprise and investment, the past twenty years have seen a dramatic increase in Newfoundland and Labrador offshore petroleum industry activity and expenditures. Although total oil production volumes have recently decreased as the three main existing fields mature, additional investments in satellite fields and enhanced recovery have begun to offset these declines. With continued exploration and with the development of the Hebron field and the White Rose Extension project underway, the industry is making investments that will extend production into the second half of this century, and is contributing to a thriving and expanding innovation ecosystem.

As of 2010, this still relatively new industry was responsible for approximately 33 percent of provincial Real GDP and resulted in the average personal income being 6.5 percent higher, the unemployment rate being 1.8 percent lower, and the province's population being 16,400 larger, than they would have been without the industry. Thanks in part to strategic government support for, and leveraging of the economic benefits from, the offshore oil industry, Newfoundland and Labrador has also been transformed into a "have" province, as Atlantic Canada's only contributor to, rather than recipient of, equalization payments. The industry has also driven the growth of the St. John's region as a cosmopolitan centre of business, educational, recreational and cultural activity. Future oil industry activity, and associated additional investments in infrastructure, education, training, R&D and business growth in Newfoundland and Labrador seems certain to deliver further economic growth and diversification.

St. John's, Newfoundland and Labrador



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Biography

Mark Shrimpton (Principal, Stantec Consulting Ltd.) has over 30 years' experience assessing, planning and managing the socio-economic impacts of large natural resource and infrastructure projects. He has played a lead role in preparing requirements studies, impact assessments and benefits plans for petroleum, mining, hydro and transportation projects in Canada, and assisted project proponents, governments, regulators, industry groups and non-governmental organizations in the US, Greenland, Iceland, the Faroe Islands, the UK, France, Argentina, the Falkland Islands and Australia. He has also undertaken policy-related studies of resource development activity, including for the US Minerals Management Service and UN International Labour Office, and he is a member of the Pool of Experts for the UN Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic aspects, focusing on offshore petroleum activity.

Mark has published and presented widely on his research, including conference presentations in Canada, the US, Norway, Denmark, Greenland, Iceland, the Faroe Islands, the UK, France, Lithuania, Russia, Malaysia and Australia. In addition to his consulting work, Mark holds Professional Associate positions with the Leslie Harris Centre for Policy and Regional Development and the Faculty of Business Administration, at Memorial University.

Acknowledgements:

A large number of people contributed to the reports on which this chapter is based, but special mention must be made of **Ken Hicks** (Department of Finance, Government of Newfoundland and Labrador) and of **Dana Feltham** and the other members of the Stantec Consulting Ltd. socio-economic team in St. John's.

6

Canada's Low Carbon Electricity Advantage: Unlocking the Potential of Inter-Regional Trade

Jatin Nathwani

ABSTRACT

The goals of energy security and substantial reduction of GHGs on a continent-wide scale are achievable through enhanced electricity trade utilizing Canada's low carbon electricity advantage and significant reductions in fossil fuel use (primarily coal) in the North American energy system. A ten to twenty-fold increase in clean electricity trade from current levels of about $2 billion per year would be required to deliver on such lofty goals, but the transition can be achieved over the next 30-50 years through development of the necessary transmission infrastructure.

Major expansion of electricity trade between the US and Canada, buttressed by interconnections and transmission links acting as "regional hubs" between provinces and neighbouring states is part of the plan to meet the goals. Trade—as opposed to regulations and targets—is a powerful arbiter of mutual benefit and perhaps a more promising pathway to a lower carbon energy future for North America.

Lined up against a vision of expanded electricity trade are a number of formidable forces. The weight of history is one; geography, long distances and large investment costs are others; but the most difficult aspect is the political calculus of the day that conspires against a long view of an energy trade strategy searching to realize the fullest potential of clean electricity from Canada. The paradigm of "province wide self-sufficiency" dominates the public discourse and is prevalent in regulatory and system planning decisions. Support for expansion of electricity generation and transmission facilities – on a vastly increased scale – as part of a deliberate national "export driven" strategy is either limited or all too often met with derision or outright hostility.

Twinning Canada's electricity trade strategy with climate change goals – through high value electricity production and transmission - has the potential to deliver economic prosperity with a much lower national carbon footprint. Whether a "shadow" price on carbon emerges through regulations, an effective cap-and trade-regime or a tax, the

economic rationale for specific investments will pivot on a price that internalizes the economic cost of emissions. Currently, the lack of a high enough price signal for carbon emissions, combined with expectations that low natural gas prices will prevail, presents barriers to investment decisions for an alternate future. Beyond pricing of carbon, strong policies and commitments to incent investments in transmission and interconnections may be necessary to pave the way for enhanced trade.

A dramatic shift in thinking and support for a national energy strategy is required that has, at its fulcrum, large-scale cross border inter-regional trade in electricity. The national strategic opportunity is for Canada's low carbon electricity advantage to become fully integrated with energy trade and climate change policies of Canada and the US synchronized for mutual benefit.

Introduction

Is there an economic opportunity for Canada to promote trade in electricity based on its existing clean energy advantage? If so, can electricity trade become a central force in helping decarbonize the North American energy system through large-scale expansion? Can a carbon mitigation strategy deliver a cost effective solution compared with other options on a scale large enough and timelines meaningful enough to make a difference to the threat of climate change?

It is widely recognized that the transition from a fossil fuel-based energy system to a low-carbon energy system will be a slow process spanning decades. Resource availability and forecasts of scarcity or abundance of fossil fuels (coal, oil, and gas) at the right price is one factor. However, emerging constraints on carbon emissions—either through stringent regulations, a carbon tax or a cap-and-trade regime, will put an upward pressure on electricity prices in those jurisdictions where coal is dominant.

In the short term, low prices of natural gas will be driven by the US shale gas boom. In the medium to long term, electricity prices and profits will be determined by the rate of substitution of non-carbon generation and the advantage will shift to these resources because they will not attract a carbon penalty. The rate of change will undoubtedly vary across regions depending upon the existing supply mix, the strength of policy interventions and the specific stringency of environmental compliance requirements (i.e. GHG prices or abatement costs) and broader macro-economic factors.

It is in this context that we investigate whether enhanced electricity trade between Canada and the US offers a strategic environmental and economic advantage that would benefit the entire North American economy and accelerate the process of low-carbon development in a meaningful way.

The interconnected electricity system between Canada and the US, with significant further enhancements, has the potential to become a powerful regional asset to allow a vast number of distant and dispersed generation sources (hydro, wind, nuclear, bioenergy, geothermal) to play an active part in an integrated market that is responsive to the challenge of decarbonizing the North American energy economy. With more than 17 GW of new generation capacity under construction or at advanced planning stages and nearly 34 GW proposed, especially in the major exporting provinces of Manitoba, Ontario, Quebec, Newfoundland and BC (Baker et al. 2011), Canada can begin to envision clean electricity trade as the primary driver for pushing coal out of the North American energy mix over a 50-70 year time frame.

A helpful geographical perspective can be gained by considering Europe; for example, there is a striking similarity between Denmark and Ontario with two major hydro producers (Norway and Sweden) to the north and east and a major coal-based system (Germany) to the south. For Denmark, regional integration became a key factor in making high-level wind generation practical. Denmark has interconnections with its neighbours equal to about 80% of its generating capacity. The North Sea underwater grid, currently under development to connect offshore wind projects, will further enhance linkage among Norway, Sweden, Denmark, Holland, Germany and France.

In the present Canadian context, a fundamental problem is that the planning processes for electricity system expansion remain paralyzed within the context of a "provincial self-sufficiency" argument, and justification for capital investments in the grid is subject to the criteria of meeting "own" needs, province by province. Trade and export of electricity as part of a deliberate strategy to address the climate change challenge is neither part of the discussion nor an explicit consideration in the planning processes or approvals. The consequence is that integration of regional markets is constrained by limits on interconnections and the system is not geared to advance large-scale trade comparable in scale and scope to energy trade through pipelines. Recognition of electricity exports as a "manufactured" high value-added product with a large potential for delivering economic prosperity is not part of the public discourse.

Several recent studies, including Carr (2010), the Canadian Academy of Engineering (2010), the Pembina Institute (2009), and Bernard (2003), provide comprehensive reviews of the state of inter-provincial trade in Canada. A compelling rationale exists for increased electricity trade from several perspectives that include short-term operational and long-term planning benefits, untapped international and inter-provincial synergies and effective utilization of national renewable energy resources.

As noted by Carr, "while trade cannot happen without appropriate transmission infrastructure, it must be concluded that any infrastructure deficit is the result rather than the cause of limited trading potential" (Carr 2010). Such an infrastructure deficit arises from policy constraints and lack of a coherent national framework. This echoes the view as argued by Blue (2009) that the "federal government should empower the National Energy Board to regulate transmission access on provincial electricity systems including the authority to order a provincial utility to construct new facilities, for the purpose of creating a truly national electricity system and facilitating inter-provincial and international electricity sale."

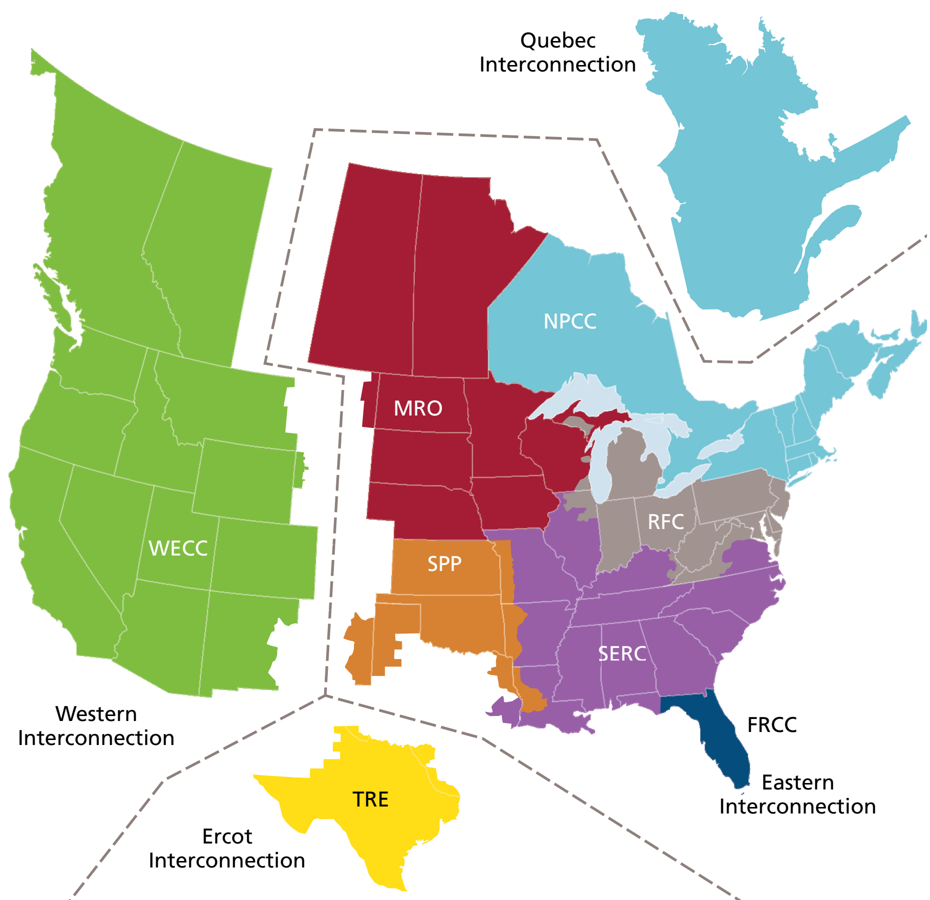
Historical Context

The existing interconnection between Canada and the US, which has its roots in historical developments, is an artifact of geography and history. Ever since the Northeast Blackout of 1965, reliability has been the primary focus in the design, development, and operation of the interconnected grid.

The three principal electric networks in North America are the Eastern Interconnection, the Western Interconnection and the Electric Reliability Council of Texas (ERCOT) Interconnection. The Hydro Quebec system is distinct from these three systems but is connected to Ontario, New York and New England by DC interconnections. Each of these operates synchronously and each can be viewed as a single machine comprising many connected generators. The three interconnections are independent in that they are not synchronized with each other, but are linked through limited direct current (DC) ties. The Eastern and Western Interconnections are linked to the electrical grids in Canada. The Eastern Interconnection is the largest synchronous electrical system in the world comprising more than 60% of the circuit length of the transmission lines.

The map below shows the North American Electric Reliability Corporation (NERC) Interconnections and its networks and regions. The entire system has some 211,000 miles (340,000 km) of high-voltage transmission lines and serves 334 million people (North American Electric Reliability Corporation 2012).

Figure 1
Networks and Regions within the NERC Interconnections (North American Electric Reliability Corporation 2012)



Power can flow from James Bay in Northern Quebec or from anywhere in Ontario as far south as Florida or through any of the contiguous states such as Michigan, Ohio or Pennsylvania within the Eastern Interconnection.

The benefits, delivered through the interconnections across a vast geography, have been widely recognized in terms of provision of emergency support, reserve sharing, improved reliability and mitigation of supply risk. Over the past four decades, the system has delivered impressive results in its capability to withstand unanticipated disturbances of bulk power production in the network.

After the 2003 Blackout, however, the North American Electric Reliability Council (NERC) was reformulated from what was effectively a voluntary organization to a self-funding quasi-governmental organization operating under delegated authority from the Federal Energy Regulatory Commission (Cooper 2011). This change has resulted in NERC reliability standards moving from being voluntary to becoming mandatory and enforceable standards through compliance.

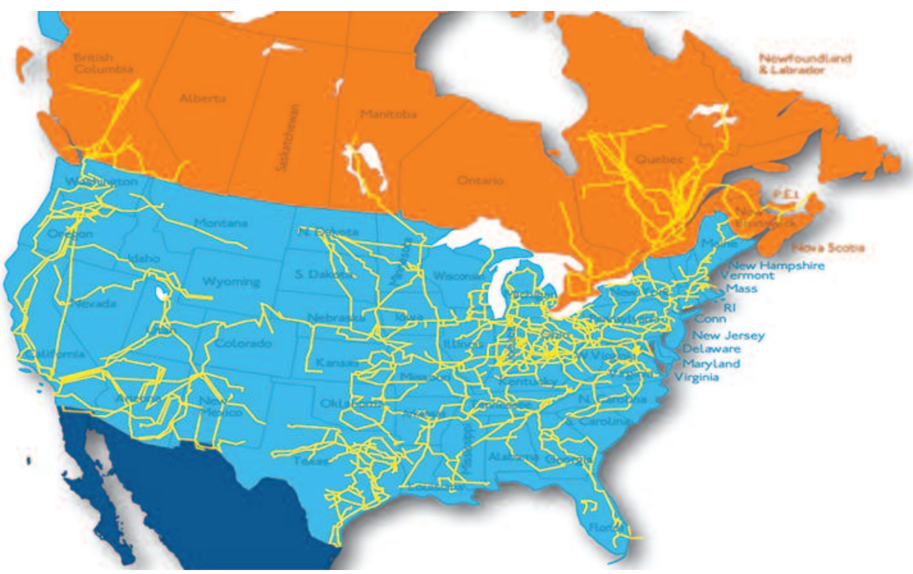
What Role for Electricity Trade?

Even though the historical roots of the North American grid can be traced to the paradigm of reliability as the primary determinant, it is worthwhile to explore how this vast interconnected system of wires and generators over a large geography, operating as a synchronous machine, can also be used to lower energy costs and reduce greenhouse gas emissions on a continent-wide scale. Figure 2 below shows the extensive nature of the high voltage electricity transmission system on the continental scale.

Figure 2
Major US-Canada Transmission Interconnections

(Canadian Electricity Association 2011)

Map copyright CEA
Lines shown are 345 kV and above.
There are numerous interconnections between Canada and the U.S. under 345 kV that do not appear on this map.



This extensive network of existing assets and its potential to shape the broader climate change policy and the political discourse on a strategy for enhancing inter-regional electricity trade has not been explored fully. A national strategy to promote significant expansion of electricity trade, perhaps by ten to twenty-fold or higher, would test this central premise and help to identify limitations of the existing infrastructure and to answer practical questions such as:

- Is access to lower cost supply from distant resources feasible?
- Would trade reduce price volatility and how would it benefit consumers?
- Is it possible to exploit energy storage capabilities and peak shaving opportunities on a diurnal and seasonal basis and what would be the scale of such an opportunity?
- Does seasonal diversity of demand and generation resource offer the possibility of arbitrage and lower costs across regions?
- Do the "levelized cost of energy" (LCOE) and the newer concept of "levelized avoided cost of energy" (LACE) provide a reasonable indicator of the different cost and value of generation technologies?
- If significant reductions of carbon emissions are to be achieved on a continent-wide scale, does inter-regional electricity trade offer better prospects for cost effective carbon mitigation compared to investments in carbon capture and sequestration (CCS) technologies?

Export Markets to Drive Regional Integration

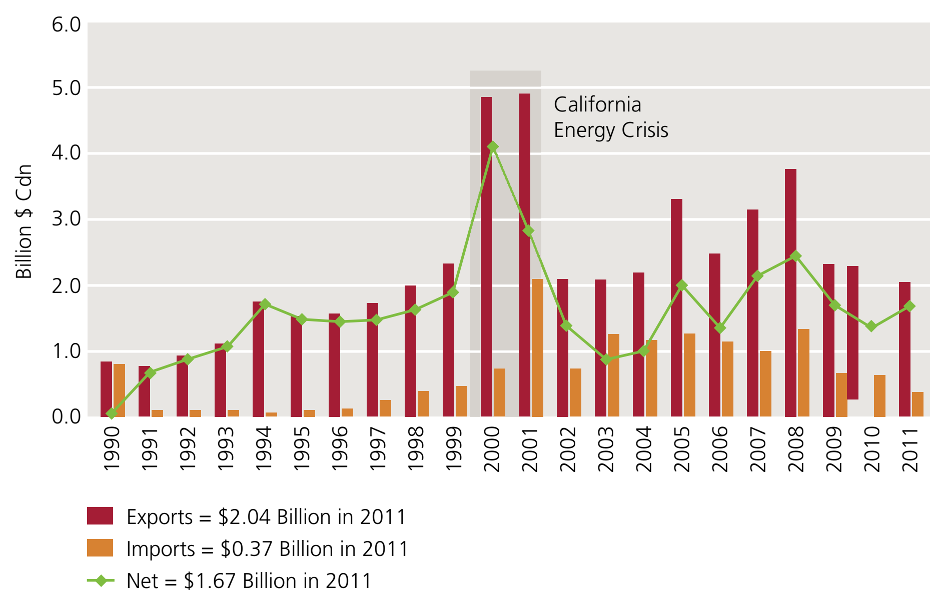
Canada is the largest supplier to the US of oil, and Canada's crude and natural gas exports to the US were valued at $101.9 billion in 2011 (Office of the United States Trade Representative 2012). The current level of electricity trade, by the standards of overall energy trade, is at best anemic. According to the National Energy Board (see Figure 3), the export volume of Canadian electricity to the US in 2011 amounted to 51.4 TWh, valued at $2.04 billion dollars, whereas import volume reached 14.6 TWh at $0.37 billion. Net exports were 36.8 TWh totaling $1.67 billion in revenue (Canadian Electricity Association 2011; National Energy Board 2013).

Electricity is a high value energy product and a large proportion of Canada's electrical generation has a low carbon emission profile. If the potential for clean energy exports from Canada is vast, why are electricity exports not higher?

Most of the Canada-US electricity trade occurs via interconnections between the provinces of British Columbia, Manitoba, Ontario, Quebec and New Brunswick and neighbouring US

Figure 3
US-Canada Electricity Trade Revenue, 1990-2011

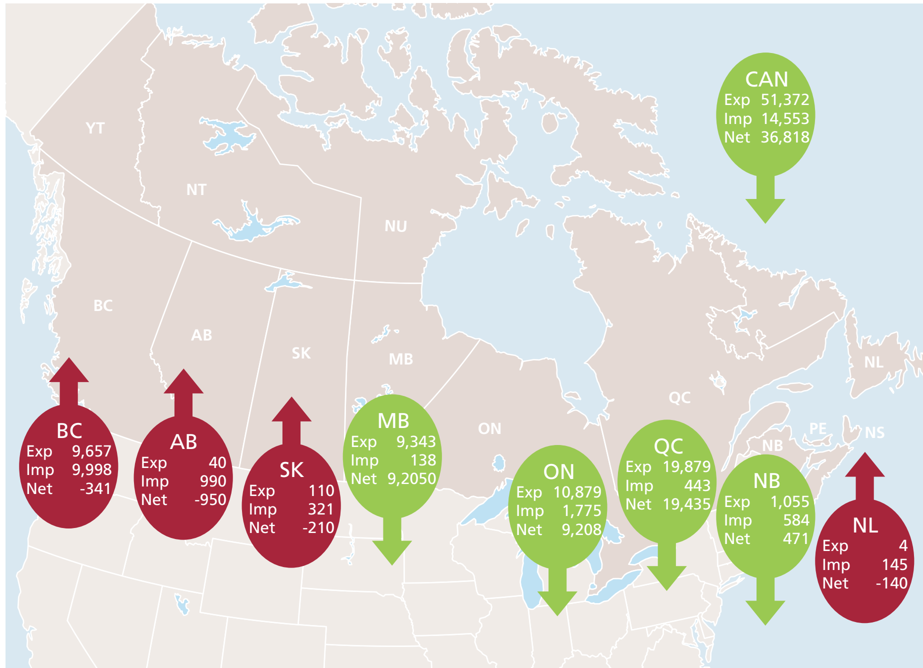
(Canadian Electricity Association 2011)



states. The existing flow of power from Canadian hydro sites goes to a limited number of US states. Historically, much of the trade was limited by long-term fixed rate contracts (i.e. Quebec into New England states) and a limited ability to take advantage of peak markets (see Figure 4).

Figure 4
US-Canada Electricity Trade by Province, 2011 (GWh)

(Canadian Electricity Association 2011; National Energy Board 2013)



With the opening of the markets, sales of electricity currently are through the interactions of power markets (Ontario with New York, Midwest ISO; Manitoba with MISO as well; Quebec with New York, Ontario and New England). The creation of open markets in Ontario and in the Northeast US has resulted in significant changes in how these transactions take place. While Alberta, Nova Scotia, and Newfoundland and Labrador currently do not have direct access to US markets but could rely on interprovincial transmission lines for indirect access, developments currently underway will change the situation for these provinces.

Although the direction of the market structures to promote and enable electricity trade is evolving positively, insufficient attention has been paid to the development of the necessary infrastructure to foster electricity trade on a very large scale. For example, developing inter-regional trading hubs could make a significant positive difference in climate change policies.

Figure 5 shows the major transmission arteries between Canada and the US. Note that the large majority of Quebec exports go to Vermont and New England. Access to the Great Lakes region is limited for Quebec except through Ontario. Similarly, 90% of Manitoba exports go to a single market—Minnesota, which makes Manitoba a captive provider.

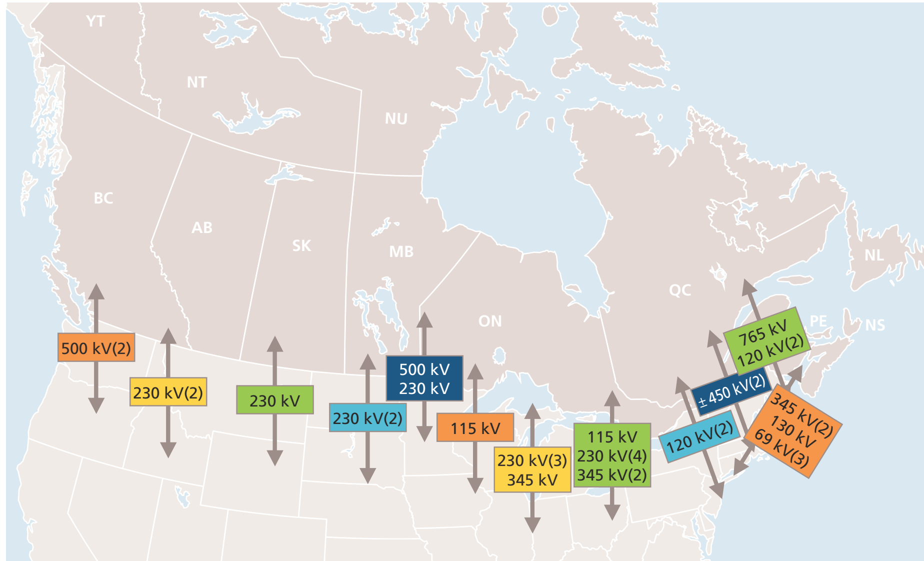
If a deliberate strategy for increased international and interprovincial exports of clean electricity was to be adopted by provincial, state and the federal governments, then there would be good potential for reducing carbon emissions in the North American context through inter-regional trade[1].

The economic case would rest on the development of cleaner non-carbon emitting generation resources in Canada and the United States, but realization of benefits would occur through

[1] We note that in the US, the best wind resources tend to be in states far from large markets, so expanded inter-regional trade is also beneficial within the US national context but it does require a clear regulatory framework to foster investments in transmission that takes into account regional wide benefits.

Figure 5
Major US-Canada Transmission Interconnections

(Canadian Electricity Association 2011)



trade on a continent-wide scale made possible by the transmission network. Such an approach – as distinct from arduous negotiations about regulations, or carbon taxes or emission targets – would also introduce more flexibility and ensure reliability of the system. For cost-effective investments, either in generation or transmission assets, a price on carbon would be necessary for optimal decisions.

Canada's Clean Energy: A Strategic Environmental Advantage

As the threat of anthropogenic climate change increasingly becomes a concern for policy makers, the need for economy-wide decarbonization becomes urgent. In this case, clean energy (in the form of electricity from low-carbon energy sources) trade between Canada and the US offers a strategic environmental advantage from a North American perspective.

Evidence of Canada's clean electricity advantage is found in the existing installed capacity of the generation supply mix and the low level of greenhouse gas emissions from the generation output. Figure 6 shows the installed base of generation capacity (in GW).

Figure 7 illustrates the significant differences in the mix of generation supplies between the US and Canada on the basis of actual generation (in TWh) as reflected in the capacity utilization of the installed generation base. Whereas Canada has over 75% clean non-carbon energy (nuclear, wind and hydro) in the mix, the US has only a little over 30%. Coal fire plants account for 18% of electricity generation in Canada compared to 44.8% in the US—a 14.8% increase from its 2009 level (Canadian Electricity Association 2011) and Ontario is on track to becoming coal-free by 2014. Canada's electricity generation contributed 14.2% of the country's total GHG emissions in contrast to the US electric power sector, which accounts for 33.1% of that country's total GHG emissions.

The abundance of clean energy resources puts Canada in a strong position to expand its low-carbon generation export portfolio. Canada releases 0.122 Mt of CO_2 per TWh[2] of electricity generation compared to 0.58 Mt of CO_2 per TWh of electricity in the US (approximately 5

[2] Alternatively: Canada's emissions = 34 Mt CO_2 per EJ and US = 162 Mt per EJ. 1 EJ = 1018 J = 277.7 TWh

Figure 6
2011 Installed Generation Capacity in Canada and the US

(Center for Energy 2012; Independent Electricity System Operator 2012b; US Energy Information Administration 2012b).

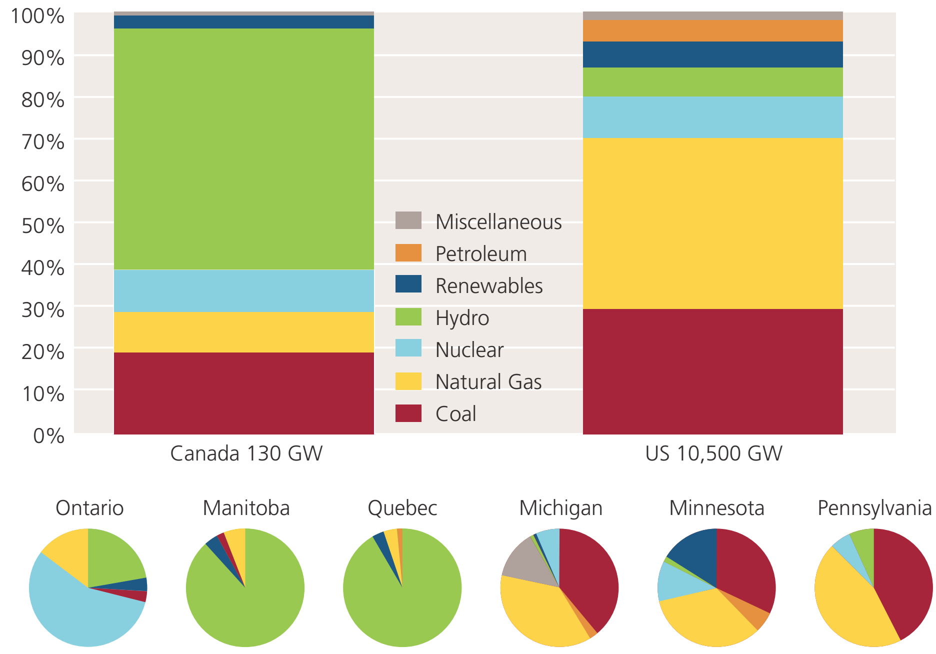
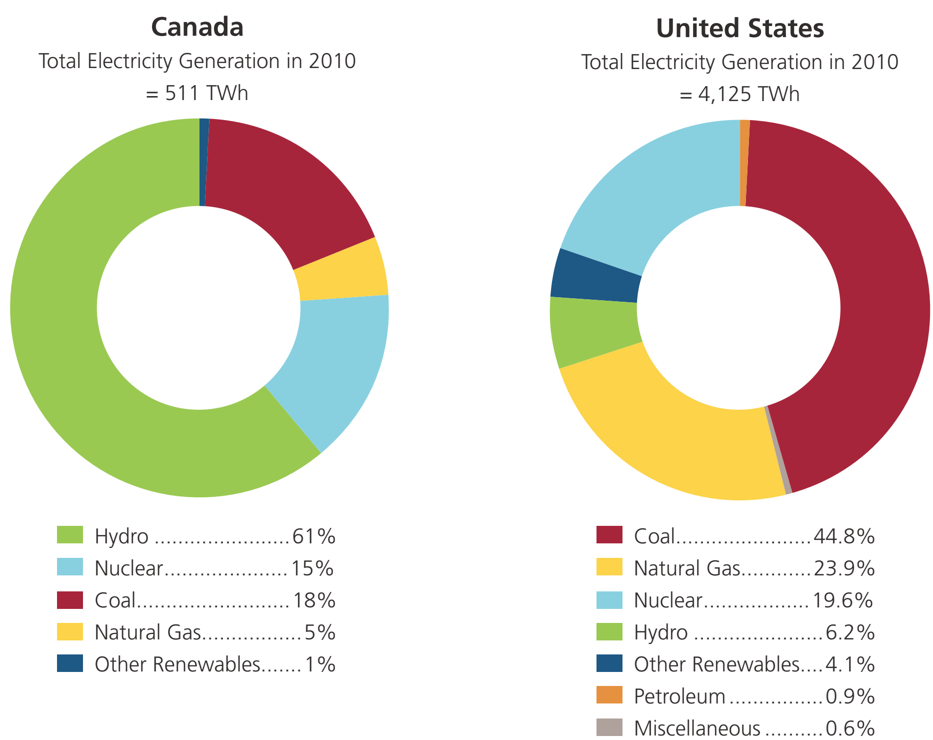


Figure 7
Electricity Generation in the US and Canada by Fuel Type, 2010

(Canadian Electricity Association 2011)



times higher). Of these resources, hydro, wind and nuclear power are established forms of electricity generation in many regions of Canada. Canada's large natural resource endowment, especially hydropower, coupled with much broader regional development in the coming decades, provides the economic impetus for a robust trade based on price differentials against carbon sources if GHG emissions were appropriately priced.

Canada ranks second globally in hydropower production and third in installed capacity. Hydropower provides 60% of the country's electricity, with an installed capacity of 70,858 megawatts. Canada's hydropower maximum technical potential is 7.44 EJ and the economic potential is estimated at 1.93 EJ (International Institute for Applied Systems Analysis 2012).

Investments of nearly $50 billion (Tal and Shenfeld 2011) in large hydro projects are under active consideration and the potential installed capacity projections to 2025 from these large power projects in Canada is 15,000 MW (Goodman 2010 – see Table 1). Projects include:

- Site C project on the Peace River in British Columbia;
- The Conawapa generating station on the lower Nelson River; and
- Gull Island (I/S post 2020) and Muskrat Falls (I/S 2017) on the Lower Churchill in Labrador;
- Eastmain A, Sarcelle, Romaine, Petit Mecatina in Quebec

These new projects would still only tap a small proportion of Canada's unused hydro potential which is estimated at 163,000 MW (Canadian Hydropower Association 2008). While the top producing provinces are Quebec, British Columbia, Manitoba, Ontario and Newfoundland and Labrador, hydropower is easily accessible to nearly all regions in Canada

The Canadian energy advantage is dependent on existing transmission inter-ties that link hydro plants with the US market. Large-scale trade is contingent on future expansion of the transmission capacity.

Table 1
Potential Large Hydroelectric Power Projects in Canada, 2009-25

(Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

Province	Project	MW	Possible In-service Date
Newfoundland and Labrador	Muskrat Falls	824	2017+
	Gull Island	2250	2020+
Quebec	Eastmain A & Sacrelle	918	2012
	Romaine	1500	2015+
	Petit Mecatina	1500	2020+
Manitoba	Wuskwatim	200	2011
	Gull	600	2020+
	Keeyask	695	2020+
	Conawapa	1485	2025+
Alberta	Slave River	1800	2020+
British Columbia	Revelstoke Unit 5	500	2011
	Mica Units 5 and 6	1000	2015
	Peace "C"	900	2020+
	Plutonic Power	1000	2015

Canada also has high-quality wind resources and most areas of the country have pockets of economically viable wind. Ontario, Quebec and Alberta are leading provinces in wind development, with strong public policy commitments. Canada's wind resources offer a stronger economic proposition in terms of cost-effectiveness because the vast and readily accessible hydropower can provide storage capacity to complement wind power's variability and intermittency.

Whereas Table 2 shows both the current installed capacity and near term forecast, there is far more potential for wind in Labrador and other regions of Canada. For example, large scale development of wind with complementary development of hydro at Lower Churchill would be economically feasible if the storage capacity that hydro offers can be integrated with the variable output of wind.

Finally, Canada maintains a strong presence in nuclear power development, with significant technological achievements in the development of the CANDU (CANadian Deuterium

Table 2
Wind Capacity in Canada, 2009 and 2020 (Forecast)

(Goodman 2010)

Province	Wind Capacity, MW December 2009	Wind Capacity, MW 2020 (Forecast
British Columbia	102	1,000-2,000
Alberta	590	2,000-3,000
Saskatchewan	171	300-500
Manitoba	104	600-1,200
Ontario	1,168	3,000-4,000
Quebec	659	4,000-5,000
New Brunswick	195	400-500
Prince Edward Island	164	200-300
Nova Scotia	110	300-400
Newfoundland and Labrador	55	100-200
Canada	3,319	11,900-17,100

Uranium) nuclear reactor. CANDU technology offers high fuel efficiency and flexibility due to its fuel-capability uniqueness and characteristics such as on-power fuelling, high neutron economy, core tailoring, compact fuel bundle, and versatile pressure tube design. In the Canadian context, nuclear power becomes a particularly intriguing peaking resource when combined with hydropower where geography permits.

Nuclear power has the potential to be part of a broader energy solution beyond the domestic market. Whereas nuclear power faces challenges in terms of high upfront capital cost, on a levelized cost of energy it would remain competitive against fossil resources if carbon emissions were fully priced. Hydro resources are already attractive economically as generation alternatives to coal and natural gas in some regions, and availability of storage capacity can enhance competitiveness of wind resources.

Transmission Expansion and Inter-regional Trade

Clean new "renewable" or "non-carbon" forms of generation from Canada are a piece in the bigger puzzle of a low carbon energy future for the North American economy. The primary opportunity, contingent on a strong policy framework in support of interprovincial and international trade, arises from regional integration with transmission expansion possibilities.

As early as 1999, policy makers recognized the challenges of creating a competitive market for electricity generation in the U.S. and initiated FERC issued Order 2000 to centralize coordination and control of electricity transmission companies into regional transmission organizations (RTOs). Implicit in the order was a clear recognition that operation and control across a broader geography would more efficiently utilize a larger generation resource base, relieve local transmission congestion issues and remove transmission "rate pancaking" that hampers the continued development of wholesale energy markets.

"Order No. 2000 is a critical step toward broad market reforms in bulk power markets. It is about operating the nation's greatest energy network – high voltage transmission lines – on a regional basis, with few economic or operational impediments to trade, a high level of transparency and ease of entry and exit."

James J. Hoecker, Former FERC Chairman, FERC news release, (December 15, 1999)

The importance of expanded access to and from neighbouring regions to support competitive electricity markets has been clearly recognized through various restructurings of the electricity sector around the world.

The concept of expanded transmission capacity and interconnections as part of an inter-regional electricity trading "Hub" creates a wide range of benefits, principally, through lower prices, improved reliability and positive environmental impact.

Lower Prices

The most significant benefit from an inter-regional trading "Hub" is a more efficient use of generation resources across a broader geography. By strengthening the transmission interconnections and removing inter-regional bottlenecks, the market (and utilities) can more efficiently operate generating resources to meet the hour-by-hour needs of customers across a larger region. Aggregating the generation units would allow the market to utilize limited but valuable resources during periods of high demand (e.g., storable hydro) and to make better use of the operating characteristics of individual plants (i.e., run base-load plants as base-load without having to "back-down" the units during off-peak hours). Without adequate transmission investment, these units would remain isolated or inaccessible within their immediate locations

Reducing Congestion Costs

Congestion costs are largely driven by local imbalances between supply and demand that are exacerbated by transmission constraints. By improving access to new markets and facilitating larger scale energy transfers, the Hub will help reduce inter-regional congestion costs that underlie market price differentials. Ultimately, decreased congestion results in lower prices to consumers.

Reducing Price Volatility by Diversifying the Supply Base

Local supply and demand imbalances also contribute to price volatility. Competitive markets that are more physically isolated tend to experience greater volatility in price than those with greater resource diversity and supply liquidity. By creating greater access to generating resources throughout the region, local imbalances can be mitigated as more competitors participate in meeting energy requirements.

Increased interconnectivity also allows a broader geographic region to benefit from access to a more diverse portfolio of generation sources. Interconnections can provide a hedge against outages, equipment failures, and fuel price volatility arising from extreme weather events or bottlenecks in the supply chain for any particular fuel source. Over the past decade, for example, natural gas prices have exhibited sufficient price volatility to suggest unpredictable reversals of low price forecasts. By providing access to a greater mix of generating resources, energy providers can protect against rising natural gas prices (and periodic spikes in the prices of other fuels) and thereby lower the overall cost to consumers.

Improved Reliability

The future cannot be predicted with certainty and thus a robust network helps mitigate the risks associated with unforeseen events. For example, when a large portion of Ontario's nuclear fleet went down for safety reasons in 1997, the transmission infrastructure protected the citizens of Ontario from rolling brownouts and blackouts. Similarly, during the 1998 ice storm, Ontario's interconnectedness helped reduce the impact of severe energy shortages. Without the inter-ties to surrounding regions, far more than 230,000 households would have lost power as downed transmission lines isolated certain generators from the rest of the grid.

Although the ability to mitigate the impact of a major contingency in the past does not necessarily guarantee energy system security in the future, system planners in various jurisdictions have recognized the values of flexibility and strength that existing regional interconnections provide to enhance reliability. Leveraging a neighbour's assets in times of crisis is good practice. The ability to provide protection by any one utility across a region is a positive, but unintended, consequence of an inter-regional electricity trade system that improves the general robustness of the grid.

Positive Environmental Impact

An inter-regional electricity "Hub" provides significant environmental benefits through a more efficient use of regional generating resources. By substituting low-emission Canadian hydro and nuclear for high emission thermal generation, aggregate regional emissions are reduced significantly.

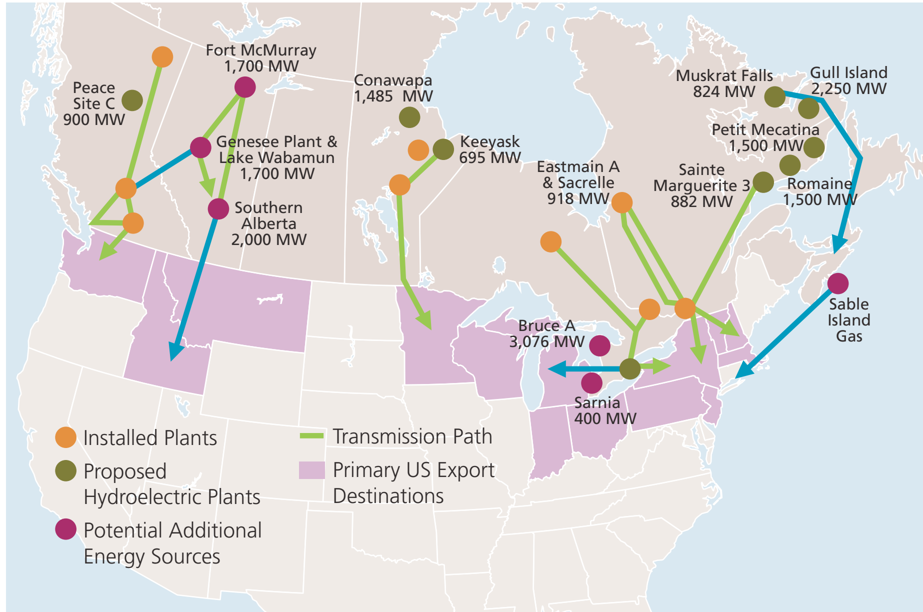
As the markets for emissions trading develop, Ontario, and Canada as a whole may be able to realize the financial upside of cleaner electricity resources. In doing so, generators avoid costs associated with the purchase of environmental "pollution credits" and additional equipment required for abatement.

Enhancing Canadian Regional Integration

Low-carbon generation projects, when developed, would be connected into the high voltage grid in order to deliver their power to markets through strong regional integration. Projects to link remote renewable generation (mostly hydro) with major markets are currently being developed in Canada. The concept of regional integration opportunities, on a continent-wide scale, is shown in Figure 8.

Integration on a vast geographic scale can also unlock lower cost supply by reducing price volatility. For example, it offers opportunities for peak shaving through the utilization of seasonal diversity between regions. In the US-Canadian context, seasonal factors are particularly relevant, given that Canada generally has a winter-peaking electricity system while the US has a summer-peaking system. Similar complementarities exist between Ontario, now a summer peaking system, and Quebec, Manitoba and Newfoundland – all winter peaking systems. Stronger interprovincial connections would create the capacity for arbitrage between off-peak and on-peak prices on a seasonal and diurnal basis. This would allow utilities to better manage their resources and optimize their operational needs by meeting their peak demand

Figure 8
Regional Integration Opportunities[3]



without having to construct new generation and transmission facilities. Because export prices tend to be higher than price points that can be achieved domestically, private energy providers can maximize economic profits and, in the case of Canadian Crown corporations, the benefit to domestic customers would be through lower power rates (Goodman 2010).

With greater integration of renewable energy sources, the handicap associated with the characteristic output of intermittent and dispersed resources such as solar and wind could be overcome in an interconnected system that also presents opportunities for exploitation of large-scale hydro energy storage. Development of cost-effective storage on a large scale – exploiting Canada's geographic advantage to the fullest for hydro storage capacity – has the potential to reduce the overall costs of variable wind generation because an inter-regional electricity trading market would have the capacity to optimize and manage temporal and spatial variations across large distances through peak-shaving and load following. Hydro storage coupled with wind generation on a large scale, in effect, would allow wind generation to "mimic" characteristics of baseload generation.

Addressing constraints in transmission networks could diversify access, increase the value of potential generation investment, and ensure network readiness for large volume of trade.

The recently announced Atlantic project to develop and link Labrador's Lower Churchill hydro-electric capacity via an underwater DC link to Newfoundland with a second underwater DC link between Newfoundland and Nova Scotia and on to New Brunswick and New England is one example (Figure 9). This DC link to Nova Scotia is also a clear example of how clean hydro power can displace coal based generation in Nova Scotia. A new DC back-to-back link between Ontario and Quebec that allows clean power transmission into Ontario to meet peak demands, and to offset variability in wind production and transfer of off-peak base load from Ontario back into Quebec to save valuable hydropower, is another example.

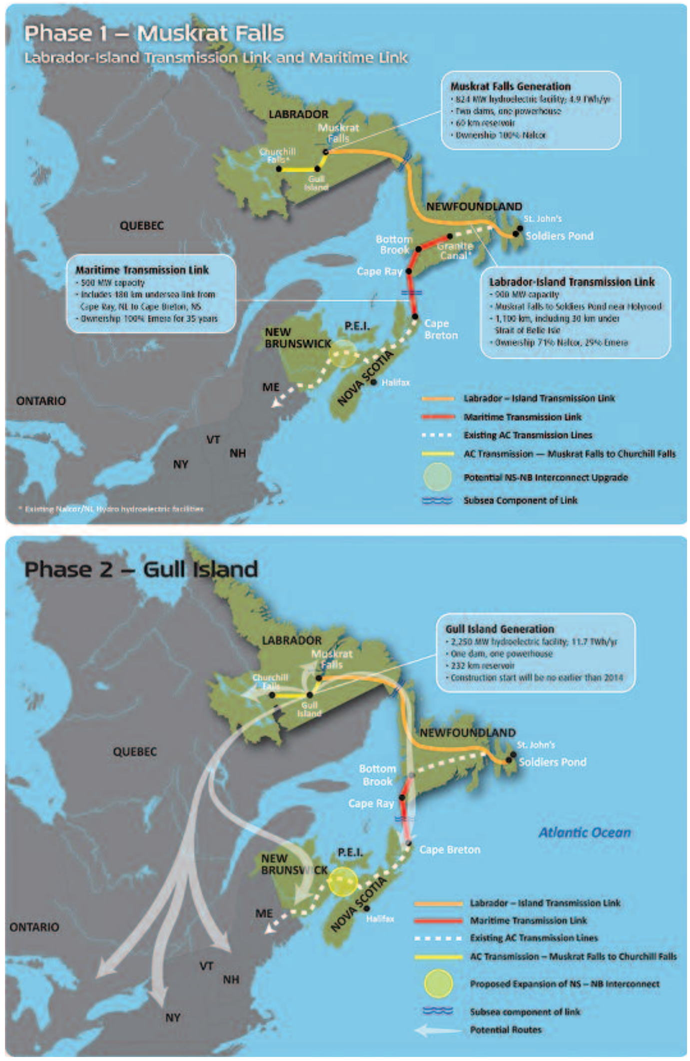
Additional examples include: the British Columbia and Alberta links; expansion of the British Columbia grid into Northwestern BC to serve mining development and to connect to hydro potential in Yukon and Alaska to the British Columbia system; regional integration between Saskatchewan and Manitoba; and New Brunswick's efforts to build itself into an energy hub

[3] Adapted by the author from various sources: (Goodman 2010; Hydro Quebec 2013; Manitoba Hydro 2013; Nalcor Energy 2013)

Figure 9
Phase 1 and 2 of the Lower Churchill Project.

(Nalcor Energy 2013)

Further details on the Muskrat Falls project are provided in Chapter 7.



for eastern North America, trading hydro power, nuclear power and natural gas throughout the region. The development of hydro resources in Manitoba (i.e., the Conawapa project) with access through Ontario and to the US markets further south would provide Manitoba with an alternate path to the existing link into Minnesota. The Montana-Alberta Tie-Line (MATL) power transmission project (a 300 MW, 230-kilovolt kV transmission line) would support ongoing development of a rich wind-powered generation resource and allow much-needed energy to flow in both directions, ensuring more reliable supplies of electricity into the US Northwest and Alberta.

The recently completed back-to-back DC link between Ontario and Quebec can save valuable hydro power by allowing clean power transmission into Ontario to meet peak demands, to offset variability in wind production, and to ship off peak base load from Ontario back into Quebec. Expanded back-to-back interconnections between the two provinces could allow further development of these opportunities, together with expanded wheeling of power into the Great Lakes states, to replace coal-fired generation.

Ontario's Geographic Advantage

Ontario is a large Canadian province adjacent to the US industrial heartland. It has the ideal geographic, policy and existing transmission infrastructure to play an important role as an energy-trading hub for the Great Lakes regions.

The province is situated between two hydro-rich provinces with its population concentrated in the Greater Golden Horseshoe region of Lake Ontario. It relies on nuclear as the primary baseload source of power and is on track to meet the closure of coal as a generation source by

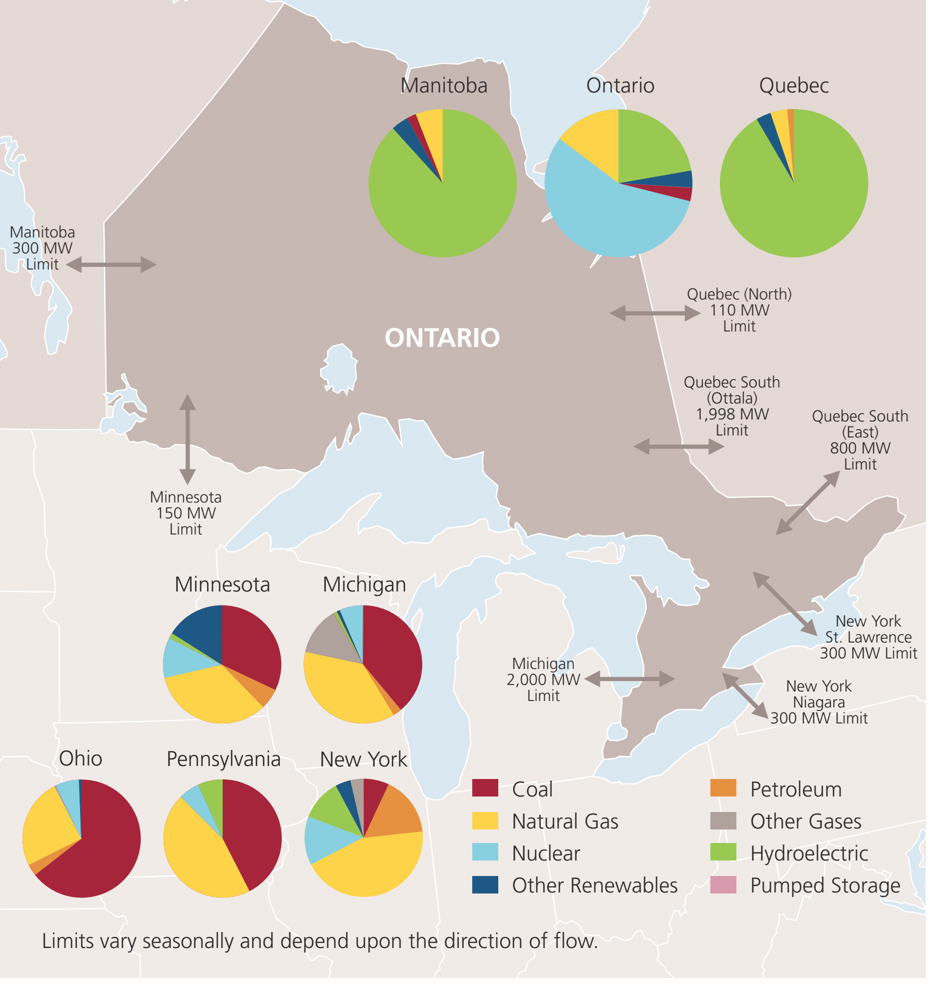
2014. Of all the provinces, Ontario is the most highly connected to neighbouring states and provinces. As shown in Figure 10, Ontario has a diversity of energy supply resources with seventeen interconnections (or circuits) at nine locations with neighbouring jurisdictions.

From a geographic perspective, there is a striking similarity between Denmark and Ontario with two major hydro producers (Norway and Sweden) to the north and east, as well as a major coal-based system (Germany) to the south. For Denmark, it became clear that regional integration was key to making high-level wind generation practical. Denmark has interconnections with its neighbours equal to about 80% of its generating capacity. In stark contrast, Ontario has about 20%. The North Sea underwater grid is currently under development to connect offshore wind projects and significantly enhance linkage among Norway, Sweden, Denmark, Holland, Germany and France.

The principal value of interconnections between multiple markets is not limited to the enhancement of trade flows between one province and a neighbouring state. Interconnections between multiple markets offer generators pathways for electricity access to more diverse markets. Low-cost generators can benefit from greater exports to US states in the Midwest and south of Ontario by displacing less efficient generators (ie. high-cost peaking plants) from the market. More efficient use of generators on both sides of the border and effective utilization of the storage capacity of the Quebec system would lower prices, reduce price volatility, enhance reliability and improve the environmental benefits.

Figure 10
Ontario Interconnections

(Center for Energy 2012; Independent Electricity System Operator 2012a, 2012b)



Price Regimes and Costs

Realization of the environmental benefits needs a strong economic premise, and it is important to consider the regional and state price regimes along the North-South neighbouring states within the Eastern Interconnection.

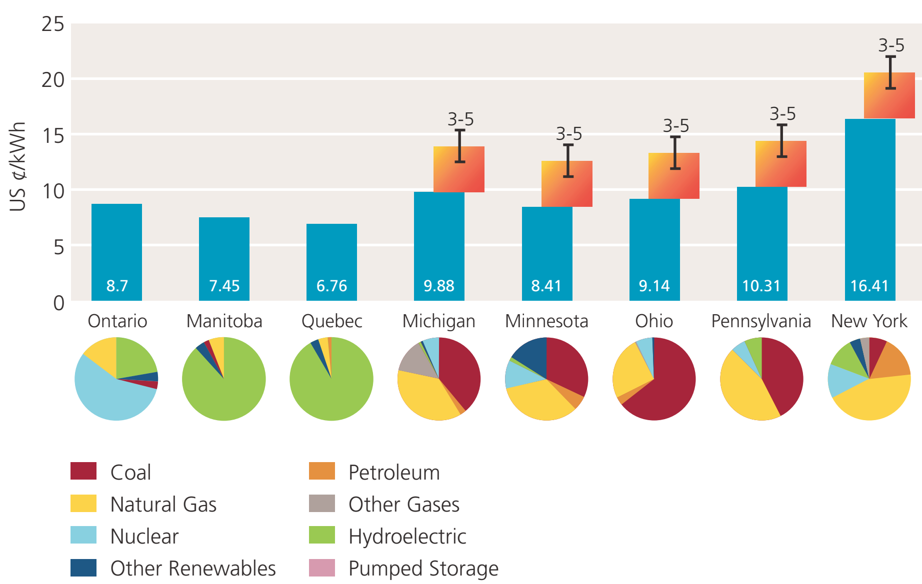
Electricity prices are linked to the supply mix. For those jurisdictions where fossil resources are dominant, the prices tend to be on the lower end of the spectrum. Upward pressures on prices arising from a carbon penalty, however, would change that evaluation. Companies with large emissions must find ways to meet regulations and may find supply of clean power from Canada attractive. Given that there is no established mechanism for pricing carbon, there are additional costs – anywhere from 3-5 cents per kWh – that would emerge for each jurisdiction depending on the role of coal in its generation mix.

Surrounding Ontario are the states more heavily dependent on fossil resources and most vulnerable to the impacts arising from the Federal Environmental Protection Agency (EPA) regulations on carbon. The EPA, under Obama's renewed presidency, seems politically ready to take on the responsibility to regulate GHG emissions in the US under the Clean Air Act (CAA). A consensus is emerging on the need for a "price" on carbon and the failure to put cap-and-trade legislation on a firm footing in the US has shifted the focus to EPA regulations. Recent presidential pronouncements provide one indication of commitment to the climate change policy; the closing of the Las Brisas coal power plant, owned by Chase Power in Texas, may foreshadow a strong regulatory commitment from the agency to decarbonization and several utility executives have indicated a commitment to full phase-out of coal fired generation.

Figure 11 is a snapshot of current prices which are indicative of regional pricing on average. Market prices are set hourly and are dynamic with large variations during a year and prices vary from location to location. Broadly, the price regimes reflect the cost to the consumers

Figure 11
Comparison of Electricity Prices and Energy Mix in Major North American Cities[4]

(Center for Energy 2012; Hydro Quebec 2012; Independent Electricity System Operator 2012b; Ontario Energy Board 2013; US Energy Information Administration 2012b)



[4] Regulated Price Plan (RPP) in Ontario includes two tiers of pricing, with 7.4 cents/kWh on the lower-tier and 8.7 cents/kWh on the higher-tier. Current tier threshold is 1,000 kWh per month in the winter and 600 kWh per month during summer. www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices

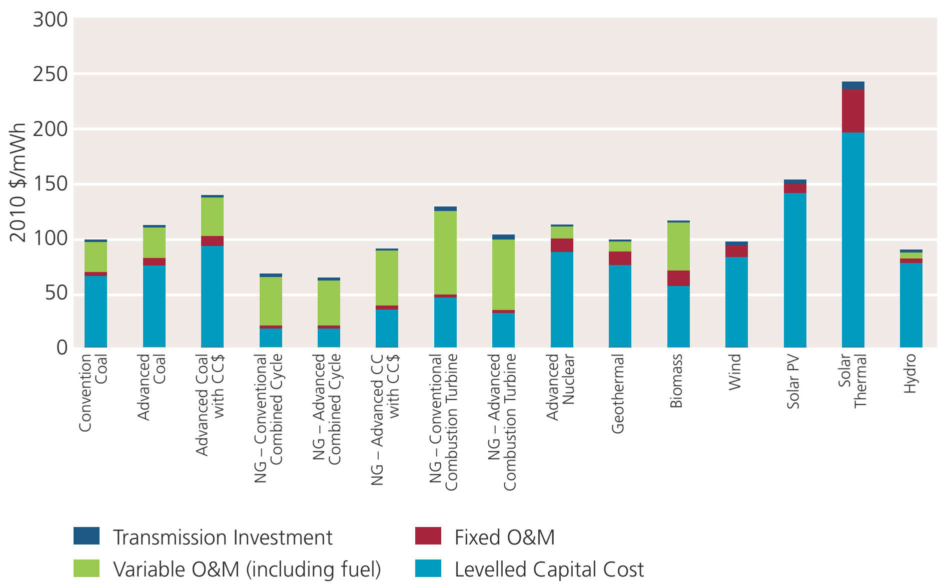
based on the existing base of generation assets – some new, some old and the overall supply mix in the jurisdiction. The price differentials across the provinces and the states are partly determined by the geography (i.e. natural resource endowment) and history: decisions that were made a number of decades ago to develop large hydropower projects continue to yield low cost energy to consumers in Quebec, Manitoba and BC.

For decisions about the future, however, the economic rationale for the development of specific projects will be determined on the basis of incremental costs for the next megawatt of generation capacity.

Figure 12 illustrates the costs of different generation options. The "levelized cost of energy" (LCOE)[5] is a convenient summary measure of the overall competitiveness of different generation technologies and it represents the per kWh cost (in real dollars) of building and operating a facility over an assumed financial life and duty cycle. It is important to note, however, that actual plant investment decisions are affected not only by the specific technological and regional characteristics of a project but by other factors, such as the cost of financing, the cost of regulatory approvals, and available policy incentives.

Figure 12
US Average Levelized Costs for Plants Entering Service in 2017

(US Energy Information Administration 2012a)



The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity is needed, also affects the investment decision. The existing resource mix in a region can directly affect the economic viability of a new investment through its effect on the economics surrounding the displacement of existing resources. For example, a wind resource that would primarily displace existing natural gas generation will usually have a different value than one that would displace existing coal generation (US Energy Information Administration 2012a) based on the unit cost of gas versus coal generation.

A related investment decision factor is the capacity value which corresponds to the value of a generating unit to the system: units that can follow demand (dispatchable technologies) generally have more value to a system than less flexible units (non-dispatchable technologies) or those whose operation is tied to the availability of an intermittent resource. A caution in interpreting the LCOE data is the influence of policy-related factors, such as investment or production tax credits for specified generation sources, that can impact investment decisions.

[5] LCOE: Key inputs include capital costs, fuel costs, fixed and variable OM&A costs, financing costs and a utilization rate for each plant type (US Energy Information Administration 2012a).

Recently, the EIA has developed a metric to provide a more useful tool for comparative analysis (EIA, 2013). The "levelized avoided cost of energy" (LACE) is based on the system value of a generation resource and is derived from the "avoided cost" or the cost of displaced energy and capacity and is presented in "levelized" terms. Similar to the LCOE, which is an estimate of the revenue requirements for a given resource, LACE is an estimate of the revenues available to that resource through an assessment of the generation displaced, on a time-of-day and seasonal basis, and the need for additional generation or capacity resources. A comparison of LCOE to LACE for any given technology provides a quick, intuitive indicator of economic attractiveness; projects have a positive net economic value when LACE is greater than LCOE.

Whereas specific investment decisions would require detailed analysis, Canada's non-carbon generation technologies will have a clear advantage and can provide a cost-effective pathway for displacing coal over a wide range of scenarios if an effective carbon pricing regime were put in place.

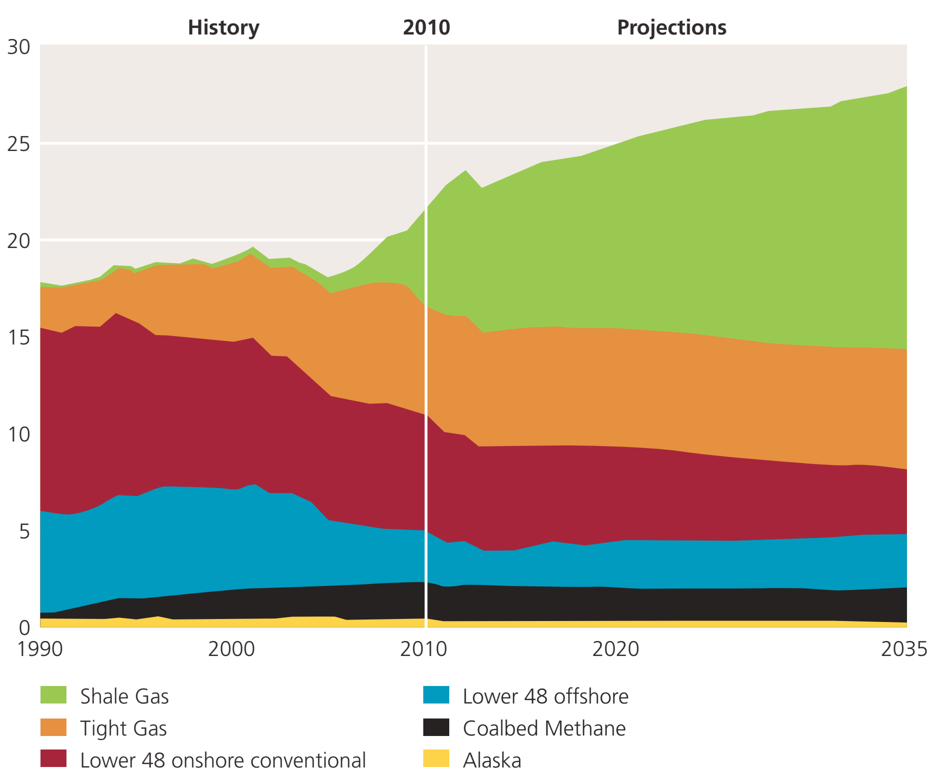
Shale Gas Impacts

No energy story is complete without including natural gas in the mix. It has been argued that the low prices of natural gas, driven by the current US shale gas boom, fundamentally changes the pivot point for investment decisions related to energy infrastructure. In the short term, the market dynamics suggest that this is the case and the current glut of gas is an effective and a profitable substitute for reducing coal generation and its associated GHG burden.

The increase in natural gas production results primarily from the continued development of shale gas resources, as shown in Figure 13.

Figure 13
Natural Gas Production by Source, 1990-2035
(Trillion Cubic Feet)

(US Energy Information Administration 2012a)



Shale gas is expected to become the largest contributor to production growth and it is forecasted to account for 49% of total U.S. natural gas production by 2035, more than double its 23% share in 2010. Estimated proven and unproven shale gas resources amount to a combined 542 trillion cubic feet, out of a total U.S. resource of 2,203 trillion cubic feet. Estimates of shale gas well productivity remain uncertain.

At 2012 price levels, natural gas prices are below average replacement cost. As indicated by the latest US EIA price forecasts for the longer term, natural gas prices are expected to rise with the marginal cost of production at a rate of 2.1% per year from 2010 through 2035 to an annual average of $7.37 per million BTU (2010 dollars) in 2035. (US Energy Information Administration 2012a)

The rate at which natural gas prices will change depends on two important factors: the future rate of macroeconomic growth and the expected cumulative production of shale gas wells over their lifetimes—the estimated ultimate recovery (EUR per well – see Figure 14). Alternative cases with different assumptions for these factors are shown in Figure 15. Higher rates of economic growth lead to increased consumption of natural gas, causing more rapid depletion of natural gas resources and a more rapid increase in the cost of developing new incremental natural gas production. Conversely, lower rates of economic growth lead to lower levels of natural gas consumption and, ultimately, a slower increase in the cost of developing new production.

For the low EUR case, recovery is decreased by 50%. The uncertainties associated with future shale gas well recovery rates will remain an important determinant of future prices. Changes in well recovery rates affect the long-run marginal cost of shale gas production, which in turn affects both natural gas prices and the volumes of new shale gas production developed.

Figure 14
Annual Average Henry Hub Spot Natural Gas Prices, 1990-2035

(2010 Dollars per Million BTU).

Natural gas prices are expected to rise with the marginal cost of production.

(US Energy Information Administration 2012a)

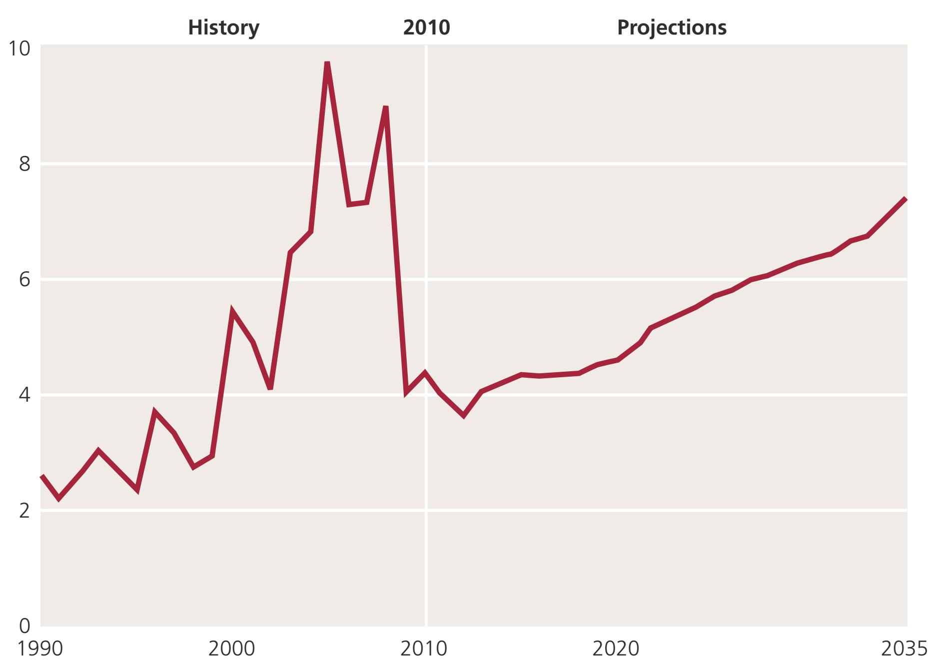
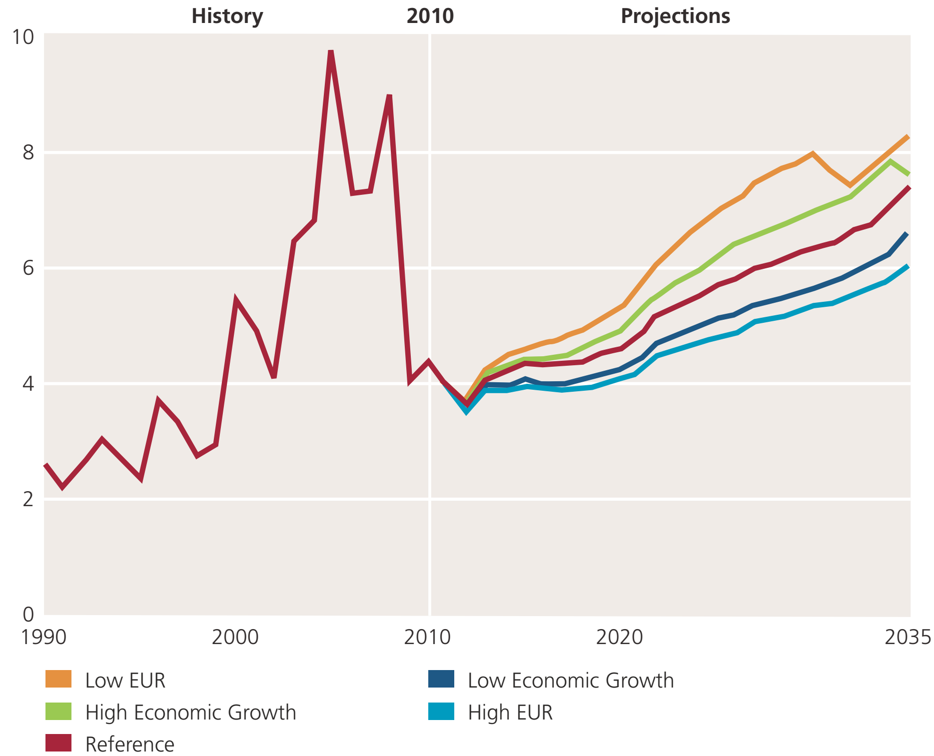


Figure 15
Annual Average Henry Hub Spot Natural Gas Prices in Five Cases, 1990-2035
(2010 Dollars per Million BTU)

Natural gas prices vary with economic growth and shale gas well recovery rates.

(US Energy Information Administration 2012a)



Coal Production and Emissions

U.S. coal production varies across the six cases of Figure 18, reflecting different assumptions about the costs of producing and transporting coal, the outlook for economic growth, the outlook for world oil prices, and possible restrictions on GHG emissions. As shown in the GHG15 case (Figure 16), where a CO_2 emissions price that grows to \$44 per metric ton in 2035 is assumed, actions to restrict or reduce GHG emissions can significantly affect the outlook for US coal production.

From 2010 to 2035, changes in total annual coal production across the cases (excluding the GHG15 case) range from a decrease of 1% to an increase of 26%.

On average, energy-related CO_2 emissions decline by 0.1% per year from 2005 to 2035, compared with an average increase of 0.9% per year from 1980 to 2005. Growing use of renewable energy technologies and fuels, efficiency improvements, slower growth in electricity demand, and more use of natural gas all contribute to a projection that ensures energy-related CO_2 emissions remain below 2005 levels through to 2035, when they are projected to total 5,758 million metric tons. The important point to note is that carbon dioxide emission levels to 2035 and beyond to 2050 and for the rest of the century would need to be substantially lower to mitigate the threat to climate change.

If the above estimates of the forecast of energy-related GHG emissions by the EIA to 2035 were to prevail, then the ability to limit the rise in temperature to a maximum 2-3 degree warming to stabilize impacts on the climate would not be feasible. Associated with a 2-3 degree warming of the climate is an emission reduction requirement of 50% by 2050 and 80% through to the end of the century. This makes for a compelling case for a dramatic shift in thinking towards an energy market that thrives on cleaner, non-carbon sources of supply.

Figure 16
U.S. Total Coal Production in Six Cases, 2010, 2020, and 2035
(Quadrillion BTU).

(US Energy Information Administration 2012a)

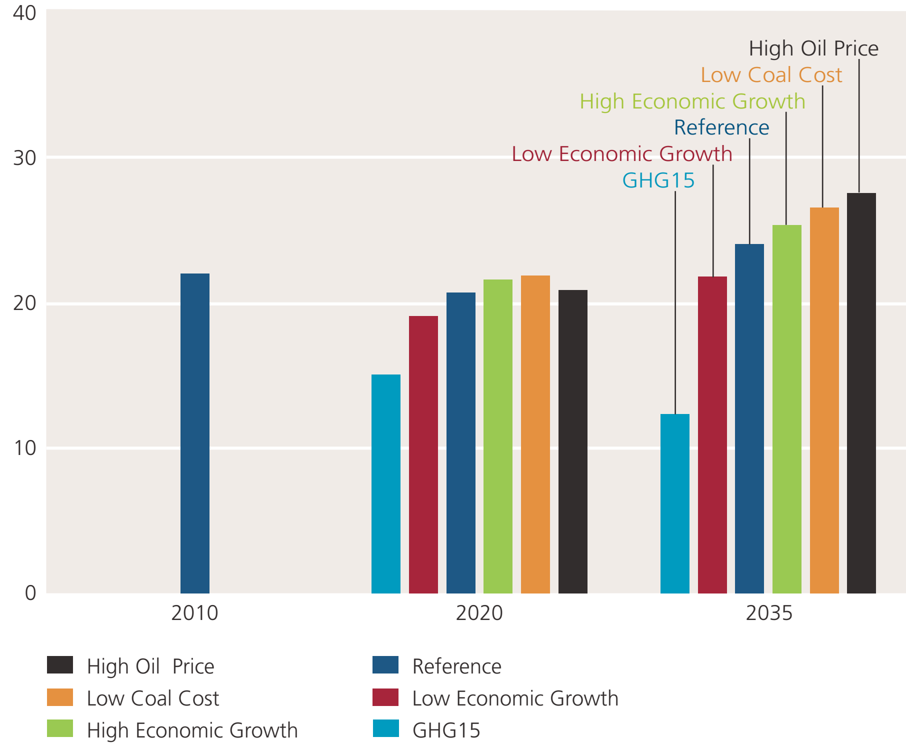
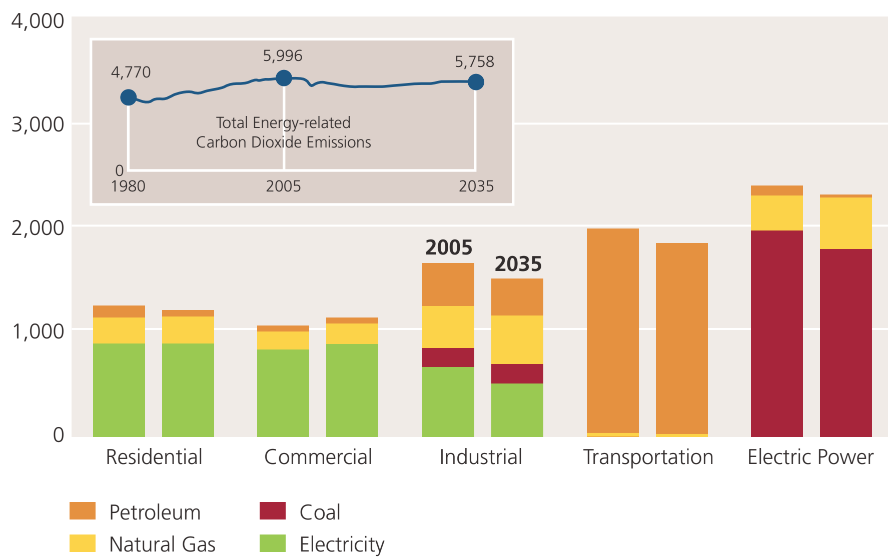


Figure 17
U.S. Energy-related CO_2 emissions by sector and fuel, 2005 and 2035 (Million Metric Tons).

(US Energy EIA 2012a)



In the medium to long term, electricity prices and profits will be determined by the rate of substitution of non-carbon generation—with some ongoing role for shale gas—and the advantage will shift to those resources with a lower carbon penalty. As is shown in Figure 17, a carbon penalty of $44 per metric ton translates into a significant reduction in coal production. The rate of change will undoubtedly vary across regions depending upon the existing supply mix, the stringency of environmental compliance requirements (i.e. GHG prices or abatement costs), general economic conditions and natural gas prices.

While Canada is well-equipped with clean energy capacity that is economically attractive for export, trading of electricity in the North American context would not make sense if it brings inefficiency, higher power prices, decreased reliability or creates large environmental liabilities.

Canada's clean electricity advantage can be realized through new transmission upgrades that would increase the available markets for Canadian generation in the US Northeast and to the south and west of Ontario. Such transmission upgrades would also offer a good possibility for optimizing power flows that can exploit diurnal and seasonal arbitrage through storage of hydro resources. Production from different generation resources can be brought into alignment and optimized for cost and environmental performance even if the generation resources are spread over a large area. The adequacy of transmission capability becomes a key facet of how this can be achieved on a continent-wide scale. This promise needs to be explored fully.

Summary and Conclusions

In this chapter, it is argued that Canada's low carbon electricity advantage is capable of making a major contribution to the reduction of greenhouse gases (GHGs) on a continent-wide scale through a strategy that has, at its core, the promotion of inter-regional trade in electricity. Large scale trade in electricity, across provincial and national boundaries, is a cost effective mechanism for alignment of Canada's climate change policies required for a transition to a low-carbon energy economy.

Enhanced electricity trade – an increase from present levels by ten to twenty-fold or higher to a level greater than $40 billion per year – between Canada and the US offers a strategic environmental and economical advantage that would benefit the entire North American economy. Such an epochal change is conceivable over a 30-50 year time frame consistent with the time lines for achieving a low carbon energy economy.

Realizing the full potential of clean electricity exports from Canada to the US through an expanded power grid requires the provinces, states and federal government to establish a clear policy framework and specific mechanisms to reduce barriers to investment and to the development and approval of specific projects. Upgrades to the existing interconnections and transmission system would be necessary to overcome the current limits to large-scale trade.

Electricity generation is a "high value" manufactured good that has the promise and potential of delivering large economic benefits through inter-regional trade enabled by transmission and interconnections.

To achieve such a goal, however, will require a dramatic shift away from the "provincial self-sufficiency paradigm" to a coherent national energy strategy. Congruent with climate change policies, large scale electricity trade is a promising pathway to a lower carbon energy future for North America. This is in contrast to a climate change policy focused primarily on regulations, targets and treaties.

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Biography

Professor **Jatin Nathwani** is the founding Executive Director, Waterloo Institute for Sustainable Energy (WISE). The Institute comprises 95 plus faculty members drawn from all the six faculties at the University of Waterloo. As the Executive Director, he provides leadership to the Institute's research and development efforts to foster the development of large-scale multi-disciplinary research projects in close collaboration with business, industry, government and civil society groups. The vision of the Institute is simple: clean energy, accessible and affordable for all. His current focus is on energy policy developments to enable the social and technological innovations required for the transition of the global energy system to a lower carbon energy economy for long term sustainability. Energy research at WISE spans the full range of renewable energy technologies, energy storage, smart energy networks, sustainable mobility and ICT for micro-power and off-grid access. For additional information, please see: www.wise.uwaterloo.ca. Prof. Nathwani's experience in the Canadian energy sector includes corporate planning and strategy, sector policy developments, regulatory affairs, innovation and R&D linkages and long term plans for the energy sector. He has advised the Ontario Power Authority and the Ministry of Energy on evolving electricity sector issues. Prof. Nathwani serves on several Boards at the provincial and national levels and has appeared frequently in the media (print, TV, radio) and has over 100 publications related to energy and risk management, including seven books.

7

The Muskrat Falls Project Development

Gilbert Bennett

ABSTRACT

In the 2012 Edition of "Canada: Winning as a Sustainable Energy Superpower," three fundamental objectives for the Canadian electrical energy system were identified:

- Achieving a major reduction in greenhouse gas emissions
- Resolving the intermittency of renewable energy sources
- Completing our energy corridors through the establishment of high-capacity east-west power and pipeline grids

A key observation was also made:

"*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 …*" (vol. 2, page 45)

The Muskrat Falls development in Newfoundland and Labrador, along with associated transmission development in Atlantic Canada, demonstrates that these challenges can be fully addressed, and that support and collaboration are essential elements of this success.

As a result of these projects, Newfoundland will no longer be an electrical island and the province's hydroelectric resources will be fully integrated. Storage will be available throughout the system which will increase flexibility and optimize market deliveries. Interconnection of the Newfoundland and Labrador system with that of the Maritime Provinces will provide opportunities for broader reserve sharing, load following and regulation services. The integration of renewables can be pursued on a regional basis. With the completion of the projects, a firm transmission path will be available from Newfoundland and Labrador through Nova Scotia, New Brunswick, and into New England. This path will enable new export opportunities throughout the region.

The development of Muskrat Falls is the result of collaboration and co-operation among Atlantic Canada governments and provincial energy companies, along with the Government of Canada, and sets the stage for the future transformation of Atlantic Canada's electricity system.

Introduction

The hydroelectric developments at Gull Island and Muskrat Falls on the Churchill River in central Labrador have a long history. The Churchill River was a traditional travel route, and archaeological investigation at Muskrat Falls has produced artifacts that date back over 3,000 years.

Gull Island and Muskrat Falls were seen as natural next steps for hydroelectric generation after the development of Churchill Falls. These downstream sites were straightforward developments, and could rely on the storage and regulation provided by the upstream facility.

To British Newfoundland Corporation (Brinco), the principal shareholder in Churchill Falls (Labrador) Corporation, the development of the lower Churchill sites were the natural next locations for development after the completion of the Churchill Falls hydroelectric development. Brinco had undertaken engineering studies for the Gull Island and Muskrat Falls sites (Figure 1), along with early studies for high voltage direct current (HVdc) transmission through Newfoundland, Nova Scotia, and into New England. These alternatives were not economical at the time.

During the 1970s, a concerted effort to develop the lower Churchill was advanced. A federal-provincial (NL) crown corporation, Lower Churchill Development Corporation (LCDC), was established. Studies for both Gull Island and Muskrat Falls were advanced, various HVdc transmission configurations were considered, and in 1980, LCDC recommended that the development of Muskrat Falls and an HVdc transmission system to Newfoundland's Avalon Peninsula be pursued.

Unfortunately, the project could not be economically justified at the time[1], and terms for financing and federal support could not be established.

Further efforts to advance the lower Churchill in 1998 and 2002 were made with Hydro-Québec but, in each case, market access, commercial negotiations, interest rates, and

Figure 1
The Provinces of Atlantic Canada

[1] A combination of crippling interest rates and relatively inexpensive oil rendered the project uneconomical in the late 1970s.

aboriginal relations precluded the development of the lower Churchill. These factors, combined with the long-standing inequity of the Churchill Falls power contract, have strained relations between Newfoundland and Labrador and Quebec. Another important factor stalling development of the lower Churchill was the impact of the development of Churchill Falls on the traditional lifestyle of the Labrador Innu, and the inability to reach an agreement addressing those impacts and the impacts of the lower Churchill development.

Newfoundland and Labrador's Energy Plan

In September 2007, the Government of Newfoundland and Labrador released its Energy Plan. The plan underscored the importance of energy development to Newfoundland and Labrador. Newfoundland and Labrador holds a veritable "energy warehouse"' of non-renewable and renewable resources in quantities far beyond those necessary for its own needs, which the Government of Newfoundland and Labrador committed to be developed in the best interests of the people of Newfoundland and Labrador (Figure 2).

Newfoundland and Labrador's crown-owned energy corporation, Nalcor Energy, was established in 2008 to participate in all aspects of the energy sector. Its vision:

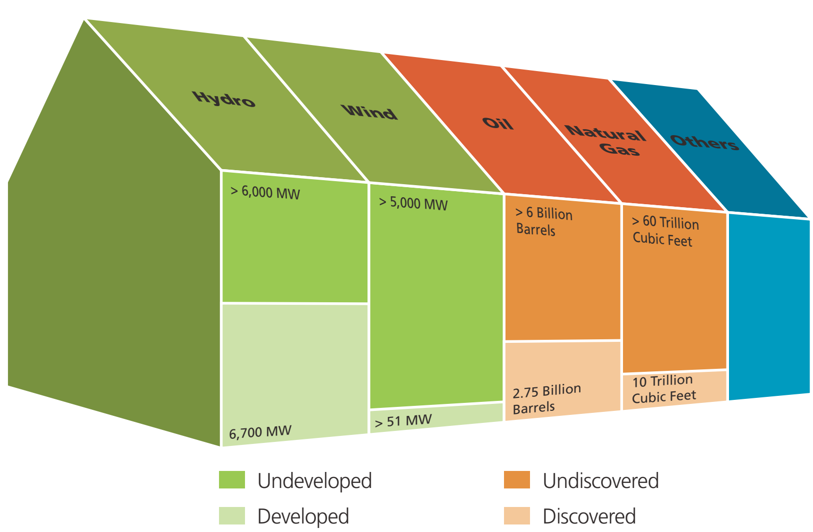
"To build a bright economic future for successive generations of Newfoundlanders and Labradorians" speaks to the need to consider long-term – both development horizon and benefits considerations – as well as the importance of the energy sector to the province's economy.

The Energy Plan recognizes two key themes:

1. The importance of the province's energy resources to the province's economy
2. The need to leverage the province's benefits derived from non-renewable resources to sustain a renewable future

These themes translate into Nalcor's lead role in the lower Churchill development. From 2005 to 2010, a comprehensive planning effort was undertaken for moving it forward, and a multi-discipline project team was established. Six primary objectives were set:

Figure 2
Newfoundland and Labrador's Renewable and Non-renewable Energy Resources



1. Develop a team, practices, and capabilities for megaproject execution
2. Complete the engineering design work necessary for all project components
3. Steward the generation and transmission projects through the environmental assessment process
4. Complete aboriginal negotiations and consultations
5. Develop a financing strategy
6. Develop a commercial framework to support the business case for the investment

The results of these efforts were evident with the November 18, 2010 announcement by the Government of Newfoundland and Labrador that terms for the development of Muskrat Falls and associated transmission infrastructure had been reached by Nalcor Energy and Emera Inc. of Nova Scotia.

The Project Components

The major elements of the development include (Figure 3):

a. The construction of an 824 MW hydroelectric generating facility at Muskrat Falls,

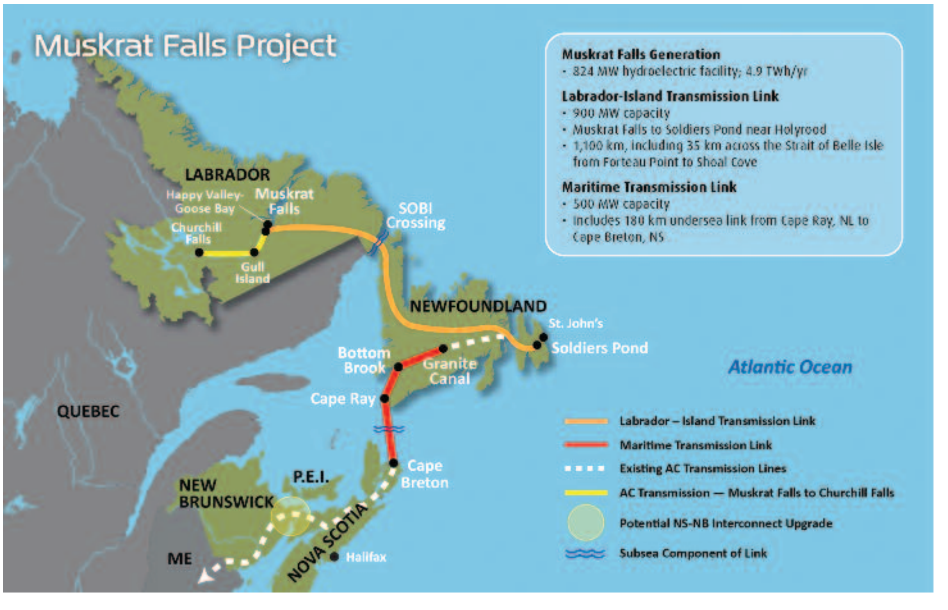
b. The construction of a pair of 250 km, 315 kV transmission lines between Muskrat Falls and Churchill Falls, NL (the Labrador Transmission Asset),

c. The construction of an 1,100 km, 900 MW HVdc transmission link between Muskrat Falls and Soldier's Pond, 30 km from St. John's, NL (the Labrador Island Transmission Link), and

d. The construction of a 500 MW HVdc transmission link between Bottom Brook on the west coast of Newfoundland and Cape Breton, NS (the Maritime Link)

The development also includes ac transmission system upgrades to both the Newfoundland and Labrador, and Nova Scotia transmission systems.

Figure 3
The Muskrat Falls Project Components



The commercial underpinnings of the development, however, clearly establish long-term benefits for both Newfoundland and Labrador, and Nova Scotia electricity customers, and establish a foundation for further opportunities for regional benefits.

Newfoundland and Labrador's Electrical Options

A key factor leading to the development of Muskrat Falls was an evaluation of the lowest cost electricity supply option for the island of Newfoundland. While approximately 80% of Newfoundland's electricity supply is derived from hydroelectric generation, including generating facilities at Bay d'Espoir, Cat Arm, Upper Salmon River, Hinds Lake, and Granite Canal, the largest and most attractive generation sources have been developed, and thermal generation will dominate Newfoundland's future electricity supply. Newfoundland's electrical system is isolated from North America, and opportunities for integrating non-dispatchable renewables such as wind are limited.

An optimized portfolio of generation expansion alternatives with the island of Newfoundland operating on an isolated basis (Newfoundland's Isolated Island Alternative) was compared to an optimized portfolio that included Muskrat Falls and the Labrador-Island Transmission Link (Newfoundland's Interconnected Island Alternative). The Interconnected Island Alternative demonstrated a $2.4 billion[2] cumulative present worth preference over the Isolated Island Alternative.

Muskrat Falls, however, will provide substantially more energy than will be required by the island of Newfoundland, and efforts to develop value for this surplus focused on Nova Scotia.

Nova Scotia's Energy Outlook

Nova Scotia is heavily dependent on thermal generation, with thermal alternatives making up 80% of the energy supply in that province. In 2010, the Government of Nova Scotia introduced legislation requiring that 25% of Nova Scotia's energy supply be derived from renewable alternatives by 2015, growing to 40% in 2020. Energy from Muskrat Falls qualified for inclusion under Nova Scotia's regulations. With a surplus of energy from Muskrat Falls and a market for renewable energy in Nova Scotia, Nalcor and Emera turned their attention to developing a technical solution to deliver energy from Muskrat Falls and to develop a business case for that solution.

In some jurisdictions, renewable portfolio standards are sometimes limited to only include domestic projects, and the Government of Nova Scotia's decision to qualify imported energy as a renewable source was a key factor in facilitating this regional project, as energy supplied from Muskrat Falls was demonstrated as the lowest-cost means of meeting Nova Scotia's renewable energy targets.

Canada's Support

Requests for support of the lower Churchill development have been made by successive governments of Newfoundland and Labrador, and on November 30, 2012, Prime Minister Harper announced Canada's commitment to a federal loan guarantee for the projects. The loan guarantee was predicated on it demonstrating benefits not just for Newfoundland and Labrador, but on a regional basis to Atlantic Canada.

[2] This analysis, completed in October 2012, was based on the Project obtaining a loan guarantee from the Government of Canada, which was ultimately obtained.

Over a period of two years following the announcement of the term sheet, Nalcor, Emera, the Governments of Newfoundland and Labrador and Nova Scotia, and the Government of Canada concluded the work activities, approvals, and negotiations necessary to enable construction of the projects, and on December 17, 2012, the projects were sanctioned for construction.

The Facilities and Assets

By mid 2014, engineering design and financing have been concluded; the characteristics and features of the various facilities have been established. Each of the project components can be described as a megaproject in its own right.

Muskrat Falls

The scale of work at the Muskrat Falls site is evident with the completion of site excavation. Over 2.2 million cubic metres of rock were removed in 2013 from the powerhouse and spillway locations in preparation for construction of the respective concrete structures (Figure 4).

Figure 4
Site of Muskrat Falls Powerhouse and Spillway (2013)

The powerhouse and spillway structures will require the placement of 560,000 cubic metres of conventional concrete, and the dams at site will require another 200,000 cubic metres of roller compacted concrete (RCC); all in all enough concrete to construct five offshore petroleum gravity base structures.

While the Muskrat Falls site is not complex as large hydroelectric projects go, it does offer unique challenges, particularly when considering the effort required to place the necessary concrete quantities in a timely manner. The entire powerhouse site will be enclosed under a structure that creates a controlled environment and provides coverage by overhead cranes over the entire site. This will provide better working conditions and improved productivity over working outdoors during the Labrador winter.

The Muskrat Falls facility will be equipped with four 206 MW (229 MVA) turbine – generator sets. The turbines are Kaplan units, and are among the largest Kaplan turbines in the world (Figure 5).

Figure 5
Turbine Blade and Stay Ring Fabrication

Transmission Lines

As illustrated in Figure 3, the transmission facilities for the project are extensive, and over 2,000 km of transmission lines are required to integrate the Muskrat Falls facility into the Newfoundland and Labrador transmission system, and to interconnect with the Nova Scotia system.

Labrador Transmission

This system consists of a pair of 315 kV ac transmission lines between Muskrat Falls and Churchill Falls. Each line is approximately 250 km, and generally parallels the Trans Labrador Highway. The interconnection will enable water management between the Muskrat Falls and Churchill Falls facilities, as Newfoundland and Labrador legislation requires producers on a river system within the province to coordinate their production so as to optimize the use of water. This coordination between Churchill Falls and Muskrat Falls will require that energy be transferred between the two generating facilities. The transmission interconnection is also required in order to ensure stability of the Newfoundland and Labrador electrical system.

The project also includes the construction of a new switchyard at Muskrat Falls to interconnect the generating plant, HVdc converter station, and transmission lines, as well as a new 735 kV/315 kV switchyard at Churchill Falls to interconnect the new transmission lines to the existing facilities at Churchill Falls.

Labrador – Island Transmission Link

While the Labrador – Island Transmission Link is not the longest High Voltage (HVdc) transmission line in the world, and numerous systems operate at higher voltages and transmit more power, the link between Labrador and Newfoundland has a number of design and construction considerations that have created unique engineering and construction challenges.

Approximately 1,100 km long, the line traverses central and southern Labrador, crosses the Strait of Belle Isle, and Newfoundland's Northern Peninsula on its way from Muskrat Falls to Soldiers Pond, just outside St. John's.

With the long distance, underwater crossing, and need to interconnect the relatively weak Newfoundland electrical system to Labrador, HVdc technology is a natural choice. The system incorporates unique features in order to maintain a high level of reliability:

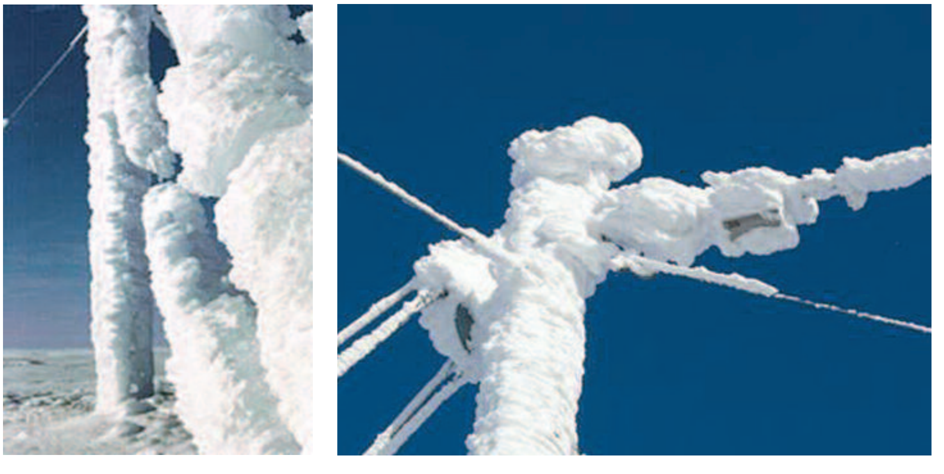
- While the system will operate as a bipole transmitting 450 MW per pole, the system is designed to operate as a 900 MW monopole for short periods to ensure stable operation of the Newfoundland system during a permanent pole fault. This provides sufficient time to reconfigure the island system after a fault.
- High-inertia synchronous condensers will be included in the island system in order for the system to ride through temporary (both pole and bipole) faults. The synchronous condensers, located at Soldier's Pond, will provide 525 MVAR of reactive power for the system, and 3,675 MW-s of system inertia for the Newfoundland electrical system.

Given the transmission requirements for the HVdc system, a conventional line commutated converter (LCC) will be implemented for the Labrador – Island Transmission Link. The dc system voltage will be 350 kV.

The 1,100 km long HVdc transmission line traverses areas with particularly severe meteorological conditions. Notable locations include coastal areas in Labrador and northern Newfoundland, the Long Range Mountains[3], and Newfoundland's Avalon Peninsula. Each of these areas presents situations where extreme wind and ice conditions will be encountered, and the transmission line design must withstand these severe conditions.

Thirteen different wind and ice loading zones have been established for the line. The meteorological design criteria are based on the results of decades of operational experience, measured conditions at local weather stations along the route, measurements taken from test spans in known high loading areas, as well as applicable design standards for high voltage transmission lines. The most severe conditions along the route will be in the Long Range Mountains, where the line will be required to withstand either continuous winds of 180 km/h or 135 mm radial rime ice loads (Figure 6).

Figure 6
Long Range Mountains Meteorological Test Site Under Winter Icing Conditions

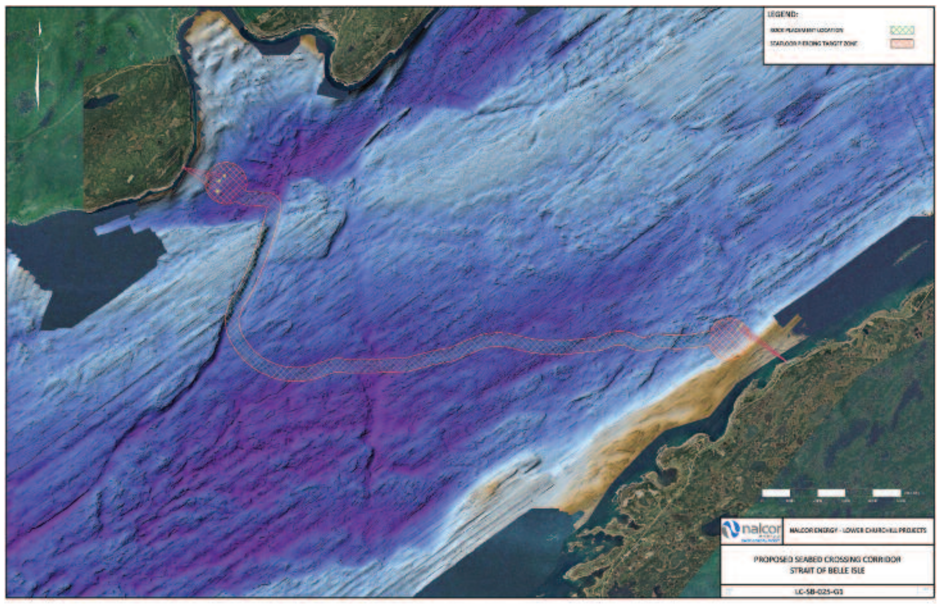


[3] The Long Range Mountains on Newfoundland's Northern Peninsula are the northeastern extent of the Appalachian Mountain Range.

The transmission line will also be required to cross the 19 km wide Strait of Belle Isle between Newfoundland and Labrador. The potential for damage to the cables from icebergs in the strait is a key design feature that separates the Strait of Belle Isle crossing from most other electrical cable crossings.

The design approach to address this issue has been a topic of study since the earliest days of planning for the project, and various concepts (including tunneling and seabed trenching) have been proposed in pre-feasibility studies for the project. Field investigations, including bathymetric, seismic and drill programs, ultimately narrowed the crossing options to two: a tunnel crossing and a protected seabed crossing (Figure 7).

Figure 7
Strait of Belle Isle Subsea Crossing Route



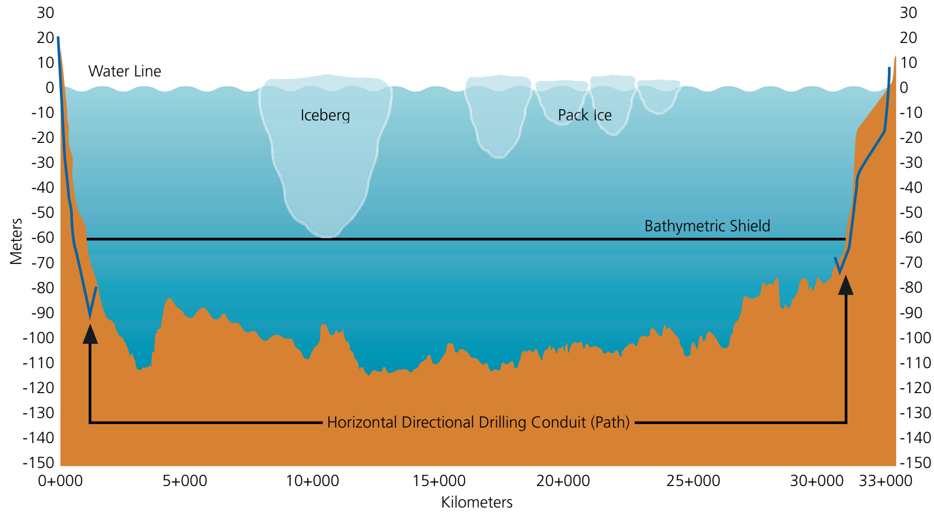
The installation and protection of subsea structures have been important design considerations for Memorial University's Centre for Cold Ocean Resources Engineering (C-CORE), which concluded that the risk from iceberg damage would be mitigated if the cables were protected to a water depth of 70 metres or greater. Horizontal directional drilling (HDD) was identified as a protection method, and the feasibility of this approach was confirmed with the completion of a test bore at site.

The HDD bores are up to 2,050 metres long, and extend to a depth of 70 metres on the Newfoundland side of the strait and to 75 metres water depth on the Labrador side (Figure 8). Once placed on the seabed, the cables will be protected by a rock berm.

Maritime Link

The Maritime Link will provide an interconnection between Newfoundland and Labrador Hydro's Bottom Brook terminal station on the west coast of Newfoundland, and Nova Scotia Power's terminal station at Woodbine, near Sydney, Nova Scotia. This HVdc system will operate at 200 kV, and will have a rated capacity of 500 MW. The HVdc system has been specified as a Voltage Source Converter (VSC), which will better interconnect the Nova Scotia and western Newfoundland electrical systems with less extensive system upgrades than a line commutated converter.

Figure 8
Strait of Belle Isle Bathymetric Profile



Project Benefits

Optimizing benefits from resource development is a fundamental theme for the Government of Newfoundland and Labrador as well as the Government of Nova Scotia. Both governments have established benefits strategies to achieve this goal. The principal objectives of both strategies are to prioritize employment during construction, and to ensure the local supply community has full and fair access to project opportunities.

Employment

The employment requirements for the projects are substantial; construction of Muskrat Falls, the Labrador Transmission Assets, and the Labrador-Island Transmission Link will require 9,100 person-years of direct employment, and construction of the Maritime Link will require another 1,200 person-years. On a national scale, and when indirect and induced economic activities are considered, 59,500 person-years of employment activity are associated with the projects.

Over 5,800 person-years of direct employment will occur in Labrador, and increasing workforce capability has been a key initiative for the project team. The Labrador Aboriginal Training Partnership (LATP) has been established to coordinate training programs for aboriginal residents of Labrador. With the support of the Government of Canada and the Government of Newfoundland and Labrador, and the participation of Innu Nation, Nunatsiavut Government, and the NunatuKavut Community Council, over 500 aboriginal workers have participated in training programs to prepare for project employment.

Early into the second year of construction, Labrador residents comprise 40% of the 1,000 strong project workforce in Labrador, and 20% of the workforce identifies as a member of one of the Labrador aboriginal groups.

Throughout the five year construction period, the workforce requirements will peak at over 3,100 workers and require over 70 different trades and professions, as illustrated in Table 1.

Table 1
Muskrat Falls Project Workforce Requirements
(Number of Workers)

	2013	2014	2015	2016	2017
Management	34	56	79	45	19
Business Support Services & Administration	148	169	176	144	72
Engineering & Geosciences	126	146	188	120	45
Technologists & Technicians	102	112	126	99	64
Researchers & Scientists	13	10	10	7	4
Inspectors	35	61	89	40	9
Site Services	110	242	344	216	90
Truck Drivers	69	73	99	43	14
Logging, Forestry & Mining	78	103	95	37	1
Heavy Equipment & Crane Operators	194	210	335	176	29
Structural Trades	35	93	162	61	11
Electrical Trades	59	232	440	313	81
Construction Labourers	219	278	464	257	34
Carpentry Trades	59	150	314	155	27
Other Trades	35	35	51	29	5
Mechanical Trades	84	122	215	158	55
Totals	1400	2091	3186	1898	557

Business Opportunities

Although the electrical industry is highly globalized, and key equipment is sourced from specialized suppliers, enabling the local supply community is an important objective. The project team has worked with chambers of commerce, economic development associations, and contractor organizations to communicate both opportunities and expectations to the supplier community.

During the first 15 months of construction, over $420 million has been spent with Newfoundland and Labrador-based businesses.

On a provincial scale, total expenditures in Newfoundland and Labrador (including wages, salaries, and payments to Newfoundland and Labrador-based businesses) are expected to exceed $1.9 billion.

Supply Chain

The project draws on a global supply chain for material, equipment, and contractor capability. With project procurement almost two thirds complete, the suppliers and contractors for the projects represent major players around the world (Figure 9).

Procurement activities are continuing, and contract award information is available at the project's website at muskratfalls.nalcorenergy.com.

Figure 9
Key Muskrat Falls Project Suppliers

As of April 2014, Major suppliers include:	
Andritz Hydro Canada:	Turbine / generator sets and hydromechanical equipment
Nexans	Submarine cable, Labrador Island Link and Maritime Link
Midal	HVac conductors
General Cable	Hvdc conductors
Sa Ra	HVac transmission structures
Jyoti	HVdc transmission structures
As of April 2014, the major construction contractors include:	
Valard Construction	HVac transmission line construction
Astaldi	Powerhouse civil works
IKC-ONE L.P.	Muskrat Falls Powerhouse/Spillway Excavation
Liannu L.P.	Muskrat Falls Accommodations Complex and Access Road
Labrador Catering L.P.	Catering Services
Johnson's Construction	Reservoir and Right of Way Clearing
HJ O'Connell Construction	Soldiers Pond Earthworks

Future Development in Labrador

While the construction benefits for regional economies are substantial and long-term, the development of Muskrat Falls will establish a capability for further resource development in the region. The key enablers are:

- Increased human resource capability. The training and experience gained by hundreds of workers in Labrador will better enable them to benefit from future development in the region. From mining to construction to future energy development, the skills and experience gained on Muskrat Falls will increase capability in the region.
- Increased business capability. The local business community will also acquire increased capacity and experience with the project, and will be better able to serve the requirements of future developments in the region.
- Increased regional infrastructure. The completion of the projects will increase the power supply in the region and extend power transmission capability in the region. Both of these are essential elements for future development. Communications infrastructure in Labrador has been established for the project, and the installation of fibre optic transmission facilities will further improve infrastructure in Labrador.

Conclusion

While the development of Muskrat Falls is the least-cost supply option for both Newfoundland and Labrador and Nova Scotia, the project sets the stage for transformation of the Atlantic Canada electrical system, and paves the way for further large-scale renewable energy development in the region. Further development will be enabled by:

Development of Transmission Interconnection

Newfoundland will no longer be an electrical island. With the interconnection of Newfoundland and Labrador, energy resources throughout the province can be developed to meet domestic needs or for export markets, and transmission paths are available between Newfoundland and Labrador, between Labrador and Quebec, and from Newfoundland to Nova Scotia, and on to the Maritime Provinces and New England (Figure 10).

Figure 10
Potential Electricity Export Routes from Newfoundland and Labrador

Integrated Hydroelectric Operations for Newfoundland and Labrador

A further benefit of the transmission interconnection of Newfoundland and Labrador is that the province's hydroelectric resources are integrated. While Newfoundland and Labrador legislation requires that facilities on a river system be operated on an integrated basis, the transmission interconnection permits all of Newfoundland and Labrador's hydro resources to be operated as an integrated system.

While the Churchill Falls reservoir holds the equivalent of approximately 22 TWh of storage, the major reservoirs on the island hold the equivalent of approximately 2.5 TWh of storage. This greatly increases the flexibility of the provincial hydroelectric system, as storage will be available throughout the system to optimize market deliveries.

Renewable Integration

Building on storage flexibility and transmission interconnections, the level of non-dispatchable renewable generation on the Newfoundland and Labrador system can be dramatically increased. The integration ability of the existing Newfoundland system is constrained by its isolation and limited frequency regulation capability. Both of these constraints are eliminated with the interconnection to Muskrat Falls via the HVdc link. Operating as a rapid acting frequency controller, the HVdc link will provide regulation for the island system, and the wide operating range of the Muskrat Falls Kaplan units (from 50% to 98%) will enable significant levels of variable resources to be added to the Newfoundland and Labrador electrical system.

Regional Integration

The capabilities of the region are enhanced through the interconnection of the Newfoundland and Labrador system with that of the Maritime Provinces. Opportunities for broader reserve sharing, load following and regulation services, and renewable integration can be pursued on a regional basis.

Export Opportunities

With the completion of the projects, a firm transmission path will be available from Newfoundland and Labrador through Nova Scotia, New Brunswick, and into New England. This path will enable new export opportunities throughout the region, and given that Canadian generation resources are required to meet winter peaks in their domestic markets, renewable resources backed by firm capacity will be available to take advantage of New England market requirements during their summer peaks.

These opportunities, combined with the ability to import off peak energy through regional interconnections open a host of market opportunities.

Biography

Gilbert Bennett joined Nalcor Energy in May 2005 and he is responsible for the development of Phase 1 of the Lower Churchill Project - Muskrat Falls Project. The lower Churchill River is one of the most attractive undeveloped hydroelectric sites in North America and is a key component of the province's energy warehouse. The Muskrat Falls hydroelectric development on the lower Churchill River in Labrador includes construction of an 824 megawatt (MW) hydroelectric generating facility and more than 1,500 km of associated transmission lines that will deliver electricity to homes and businesses in Newfoundland and Labrador, Atlantic Canada and Northeastern United States. The development of Muskrat Falls will provide a clean, renewable source of electricity to meet the province's growing energy demands. It will provide Newfoundland and Labrador homes and businesses with stable electricity rates well into the future, and will be a valuable power-producing asset for the province well into the future. In addition, the development will help Canada's efforts to reduce greenhouse gas emissions. Gilbert Bennett is a former Vice President of 360networks Canada, and has served in a number of senior engineering and operations roles with GT Group Telecom Services, Cable Atlantic and Newfoundland Telephone/Aliant. He has a Bachelor of Engineering (Electrical) degree from Memorial University of Newfoundland, is a member of the Professional Engineers and Geoscientists of Newfoundland and Labrador, and is a member of the Memorial University Board of Regents, the College of the North Atlantic Board of Governors, and the Canadian Hydropower Association.

8

The Mackenzie River Hydroelectric Complex – Concept Study

F. Pierre Gingras

ABSTRACT

This chapter provides an overview of a recent study of the potential of harnessing the Northwest Territories' Mackenzie River for hydroelectric development. By any standard, the proposed project is enormous; similar in scale to Quebec's enormous James Bay Hydroelectric Complex. This chapter also describes a practical implementation scenario for realizing the Mackenzie River's significant hydroelectric potential, with an overall capacity slightly greater than 13,000 MW, assuming 80% availability. Characterized by flows of up to 9,000 cubic metres per second, steep shorelines avoiding wide-area submersion, and large lakes acting as flow regulation reservoirs, the Mackenzie River project includes an upstream water control structure, six downstream powerhouses, and 10,000 km of transmission lines to bring the power to Edmonton. The complex would produce some 92 million MWh yearly, equivalent to producing 525,000 barrels of fuel per day. This clean energy could be used to assist Alberta (10,000 MW) and Saskatchewan (3,000 MW) to transition from high-carbon footprint thermal generating stations to low-carbon hydroelectric power stations as thermal generating stations approach the end of their expected life spans.

Introduction

The Mackenzie River is 1,738 kilometres long and Canada's longest river. Its watershed encompasses the Eastern slopes of the Rocky Mountains, and the northern half of the plains of Alberta and Saskatchewan, while its waters cut across the Northwest Territories as they work their way to the Beaufort Sea. At its mouth in the Beaufort Sea, its average annual flow is of 9,910 cubic metres per second (CMS). However, the Mackenzie River really bears this name only from Great Slave Lake to the sea, over a distance of 1,400 kilometres (Figure 1).

From Great Slave Lake to the village of Artic Red River (which marks the river's final approach to the Beaufort Sea), its waters run slowly at the bottom of a three to ten kilometre-wide valley, between two very high mountain ranges (Figure 2). The steep riverbanks which characterize this region offer the opportunity of building a cascade of low-head hydroelectric projects, as low as 22 to 27 metres high, with little significant flooding of lands. At first sight, the total lack of rapids in this region could mean difficult geological conditions on the riverbed, such as significant overburden depth, but this needs to be confirmed.

Downstream of Artic Red River village, the river flows into a large wetland area, approximately 200 kilometres long by 100 kilometres wide, where the river separates into a multitude of

Figure 1
Map of the Proposed Mackenzie River Hydroelectric Complex

Figure 2
Site of the Mackenzie – 2 Project ("Bassin des Murailles")
Note the steep riverbank typical of the Mackenzie River landscape.

smaller rivers, only three of which are navigable up to the Beaufort Sea, though offering the opportunity for ships from Alaska and the Bering Straits to be serviced. These wetlands are of critical importance to the environment, for example, being a major beluga "breeding ground."

The population of the Northwest Territories consists of some 40,000 people, with more than 20,000 living in the town of Yellowknife. The Governor, appointed by the Government of Canada, is assisted by a locally-elected Council. If the Mackenzie River's potential is to be harnessed as proposed in this chapter, its electricity-generating capacity far exceeds the needs of the Northwest Territories at the present time. The Mackenzie River Hydroelectric Complex is a "big project," appropriate from the perspective of Canada aspiring to become a sustainable energy powerhouse.

Project Characteristics

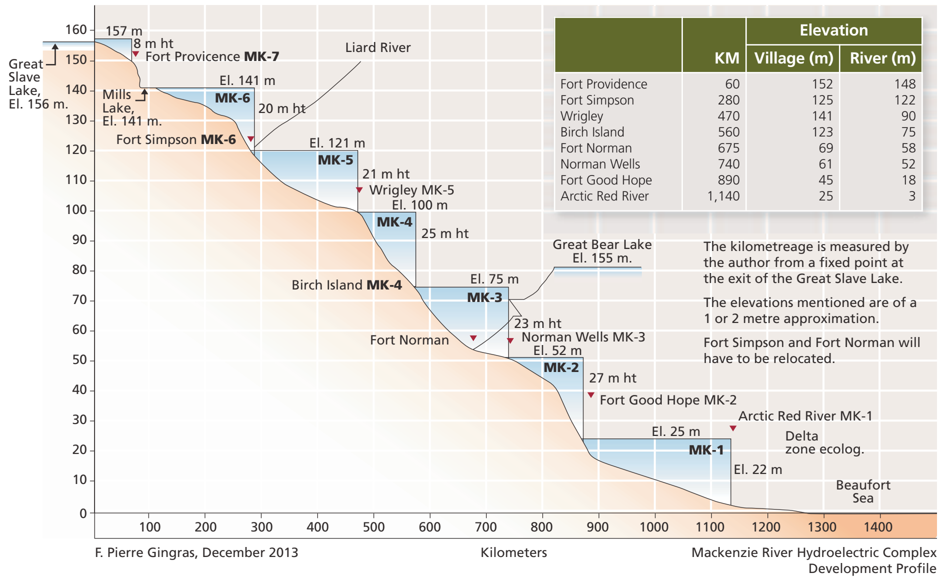
The Mackenzie River presents several unique characteristics. First and foremost is the fact that its riverbanks are generally so steep, from 15 to 40 metres, that dams of 20 to 30 metres would flood only a very limited area, despite the river's enormous power generating potential. The particular implementation proposed here consists of seven individual projects, including one water control structure and six run-of-the-river electric power generating stations, harnessing a combined head of 138 m, and representing a capacity of over 13,000 MW (Figure 3). Additional projects may also be envisaged on the Great Bear, Liard and Slave Rivers, though not considered here, the latter being particularly delicate from an environmental perspective.

Hydrology

At its mouth, the average flow of the Mackenzie River is 9,910 cubic metres per second (CMS) while at the Great Slave Lake discharge, it is 4,835 CMS. Between these two points, several large rivers flow into the Mackenzie River, in particular, the Liard River at Fort Simpson, which contributes a non-regulated flow of 2,434 CMS.

Great Slave Lake covers an area of some 28,568 square kilometres, and contains an active reserve of water of some 57 cubic kilometres in the marling between elevations 155 and 157 m. This represents approximately 37% of the Mackenzie River's annual flow at the lake's discharge, or 25% of the flow at Fort Simpson (i.e., downstream of the confluence of the Liard and Mackenzie Rivers). As a result, water levels need only be managed within one metre variations about its average elevation at 156 m, that is to say, within its natural marling to have sufficient flow regulation capacity for the entire downstream complex.

Figure 3
Mackenzie River Profile – 156 m Head over 1,200 km (Project Head: 138 m)



Hydrology

	Basin Km²	Average Flow CMS
Fort Providence, Mack-7	970,000	4,825
Liard River	277,100	1,926
Providence at Simpson	42,500	295
Fort Simpson Mack-6	1,290,000	7,046
Fort Simpson at Wrigley	56,400	392
Wrigley, Mack-5	1,346,400	7,438
Wrigley at Keele	21,600	150
Redstone River	18,000	125
Birch Island, Mack-4	1,386,000	7,703
Keele River	21,800	151
Keele at Fort Norman	5,800	41
Great Bear River	156,800	1,089
Fort Norman, Mack-3	1,570,400	8,994
Mountain River	14,800	103
Fort Norman at Fort Good Hope	16,700	116
Fort Good Hope, Mack-2	1,601,900	9,213
F. Good Hope at Arctic Red River	47,700	331
Arctic Red River, Mack-1	1,649,600	9,544
Peele River	28,400	197
Delta Mackenzie	10,200	71
Estimated Total	1,688,200	9,812
Mackenzie River, Downstream of Fort Providence, Total	835,200 (164 km)	5,085

Geology

Knowledge of the overburden depth on the Mackenzie River riverbed remains the only key unknown needing further clarification, and recognition drilling must be considered a top priority at each proposed site. Indeed, this 1,200 kilometre long, flat-bottomed valley of 3 to 10 kilometres width, whose river is 1 to 2 kilometres wide on average, suggests significant overburden, mainly due to the lack of rapids from Great Slave Lake to the Beaufort Sea, despite an overall drop of 156 metres (Figure 3). Based on known drillings and past bridge construction at various sites, it seems realistic to consider a 5 to 6 m water depth, and a 6 to 8 m overburden depth as normal everywhere. Permafrost is present everywhere.

Environment

Although it is possible to propose a design for this complex consisting of only three or four dams for harnessing the Mackenzie River's potential, surely less expensive to build, the implementation scenario proposed here deliberately aims to minimize the flooding of lands by means of seven smaller, run-of-the-river generating station projects. The reservoir or forebay of each project is contained within steep shore banks in almost every case. The highest dam proposed here has a height of 27 metres. This scenario also avoids any development downstream of "Artic Red River" due to the environmental importance of the wetlands found there.

Each proposed generating station incorporates hydraulic structures facilitating the flow of fish, such as fish elevators, fish scales, etc. Several fish spawning grounds will also result from the construction of dams.

At each construction site, a new worker village will be added to an existing village, and industrial installations will need to be built. These installations are designed to remain in place at the end of construction.

This proposed complex is entirely located in the Northwest Territories, with a population of 40,000, located mainly in the town of Yellowknife. As a result, only a small number of people will be affected directly, and where they are, they can be compensated for any inconvenience. The completion of the proposed complex would open an important corridor toward the Beaufort Sea. In addition to the main road presently under construction, an airport, village and campsite will be built in each community hosting a hydroelectric power generating station, including an electric power grid, and community and industrial services. Moreover, it is in the interest of contractors to hire workers within these local communities, reducing the cost of transportation to and from worksite, and contributing to building the pool of highly qualified workers within the Northwest Territories.

Design Criteria

Load Factor

A load factor of 80% was retained for two main reasons. First, a lower load factor of 60%, such as that employed in Quebec's James Bay complex, would have required a larger reservoir capacity for each individual power station, resulting in the flooding of a wider geographic area. The second rests on the assumption that it is best to maximize energy output while minimizing power output in order to lower overall project costs. In other words, if the same amount of energy is to be delivered, at a lower load factor (i.e., 60%), this means that the same amount of energy is delivered in a shorter period of time, resulting in higher power generating and transmission capacity across the board. Clearly, this assumption will need to be reviewed over the next years. However, it is generally considered more profitable for peak power demands to be addressed locally, rather than by oversizing generating and transmission capacity over thousands of kilometres.

Powerhouse Design

The six proposed powerhouses are almost identical. For the purposes of this study and preliminary cost estimation, the James Bay Hydroelectric Complex' La Grande-1 powerhouse design was employed as the basic template for each one , with only the number of units (18 to 24) and the height of the water intake being adapted to every site's unique characteristics (Table 1). The turbines are assumed to be of the Kaplan Type, functioning at low speed to protect fish, with a nominal flow of 500 CMS each. All 138 Kaplan turbines are assumed to be identical for ease of procurement, maintenance and costs.

Table 1
Powerhouse Characteristics
Kaplan turbines, 500 MCS, 23 m head, 103.5 MW
(Ref. La Grande – 1)

	Basin Km^2	Av. Flow (CMS)	Design flow 80% (CMS)	Head (m.)	MW	No. of Turbines
Fort Providence, Mack – 7	970,000	4,825	6,031	9	—	
Fort Simpson Mack – 6	1,290,000	7,046	8,807	20	1,622	18
Wrigley, Mack – 5	1,346,400	7,438	9,297	21	1,798	19
Birch Island, Mack – 4	1,386,000	7,703	9,628	25	2,140	19
Norman Wells, Mack – 3	1,570,400	8,994	11,242	23	2,383	23
Fort Good Hope, Mack – 2	1,601,900	9,213	11,516	27	2,798	23
Artic Red River, Mack – 1	1,649,600	9,544	11,930	22	2,379	24
Total				138	13,120	138

Spillway Design

The powerhouse spillways are designed to be equipped with 2,000 CMS capacity gates, 12 metres wide x 20 metres high, similar to the La Grande – 1 spillway gates. The number of gates needed in each case is 15 to 29, depending on the estimated flow at each site (Table 2). Each gate is equipped with its own winch, and each spillway pass is equipped with slots for a set of stop logs, upstream and downstream of the pass. For several powerhouses, the tailrace of the passes will be concreted at the end, to lower the cofferdam elevation.

Table 2
Spillway Characteristics
Gates : 12 m wide x 20 m high,
2,000 CMS/pass
(ref. La Grande – 1)

	Average Flow (CMS)	Spring Flood (CMS)	No. of Gates
Fort Providence, Mack – 7	4,825	28,950	15
Fort Simpson, Mack – 6	7,046	42,276	22
Wrigley, Mack – 5	7,438	44,628	23
Birch Island , Mack – 4	7,864	47,184	24
Norman Weels, Mack – 3	8,994	53,964	27
Fort Good Hope, Mack – 2	9,213	55,278	28
Artic Red River, Mack – 1	9,544	57,264	29

Dams and Cofferdams

Assuming approximately 5 metres of water and 6 to 10 metres of overburden over the bedrock, the cofferdams are integrated to the dam itself. The dams are of the gravel-fill type. Asphalt cores could be used to hasten the construction schedule.

The cofferdams will be built employing a massive fill of boulders, covered by a gravel filter on the outside made watertight with till or clay. Usually built in a second construction phase while the river is diverted by the spillway, the upstream cofferdam is usually some five to seven metres higher than the downstream one.

The dams being of rather low height, the outside slopes will be 3 to 1 (vertical), meaning that it will be acceptable to leave the overburden in place under the structure, except under the core itself. The final choice on site for each individual generating station project will likely depend on whether the powerhouse and spillway can be constructed simultaneously in the first phase, saving one to two years on construction time.

Navigation Locks

A navigation lock is assumed at each site, 15 metres wide and 6 metres deep by 150 metres long. Usually, the lock is located between the spillway and the rock fill dam to be used as the resting wall for the fill. These locks will enable access by ships and barges along the entire length of the Mackenzie River, from Great Slave Lake to the Beaufort Sea.

The Mackenzie Hydroelectric Complex

Technical Description

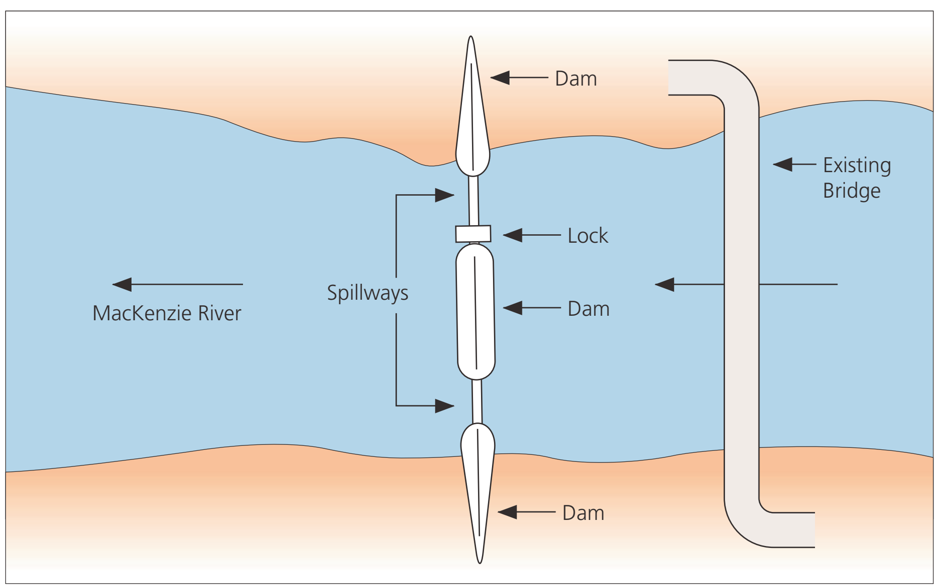
The complex is composed of seven individual projects, the most upstream being a hydraulic control structure for Great Slave Lake. The following provides a summary description of each project, from upstream to downstream (i.e., Figures 1 and 3).

Mackenzie – 7, Fort Providence

From Great Slave Lake (el. 156 m) to Mills Lake (el. 141 m), the 16 metre head is almost evenly spread over an 80 km distance, mostly composed of swamp lands. The only practical objective of this project is to build a control structure which manages Great Slave Lake's marling, plus or minus one metre, to regulate the flow of the Mackenzie River. The height of the dam presently appears insufficient for building an economically attractive electric power generating station.

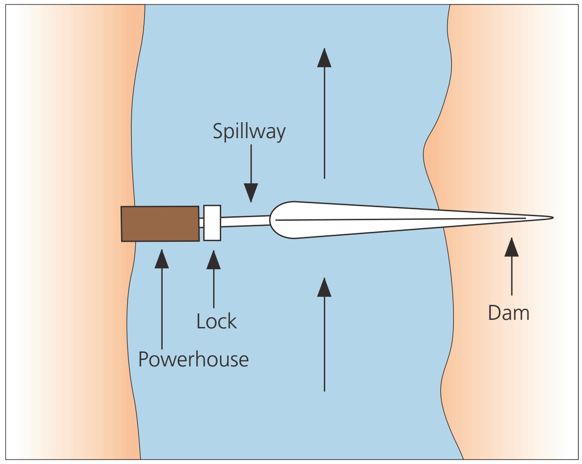
Approximately one kilometre downstream of a recently built bridge, the shorelines are steep enough to build a seven metre high dam. This height is sufficient to have effective control of the spillway, and the project is articulated around two spillways of seven and eight passes respectively, located on each side of the river, having a combined spillway capacity of 29,000 CMS (Figure 4). Individual gates will have a width of 14 metres and a height of 12 metres to ensure that ice can be sent downstream. A navigation lock is located on the left side of the right spillway (i.e., the right spillway being to the right of an observer looking downstream), in the river center. The site is closed by three rock fill dams, one on each shoreline, and in the centre of the river.

Figure 4
General Arrangement:
Mackenzie – 7 at Fort Providence



Mackenzie – 6, Fort Simpson

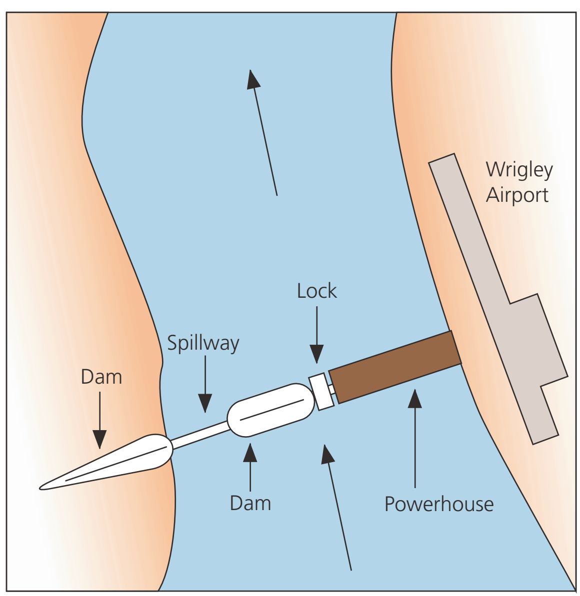
Figure 5
General Arrangement:
Mackenzie – 6 at Fort Simpson



Two kilometres downstream of Fort Simpson, below the confluence of the Mackenzie and the Liard rivers, is proposed a 20 metre high dam (Figure 5). Needed to modulate the flow of the combined Mackenzie and Liard rivers, this dam unfortunately submerges the village of Fort Simpson, slated for displacement on higher ground on the west (left) bank. The maximum upstream water control level is defined by Mills Lake, at elevation 141 m, in order to protect the large wetlands at its periphery. The downstream level is defined by the river's elevation at the village of Wrigley, elevation 121 m, resulting in a 20 m head. At this location, the river is large enough to build both the powerhouse and spillway in a single construction phase. The 1,622 MW powerhouse is equipped with 18 turbine-generator units while the 44,000 CMS spillway has 22 gates of width 12 metres by height 20 metres. A dam of 2 kilometres is needed on the east end of the structures to complete the closure of the river.

Mackenzie – 5, Wrigley

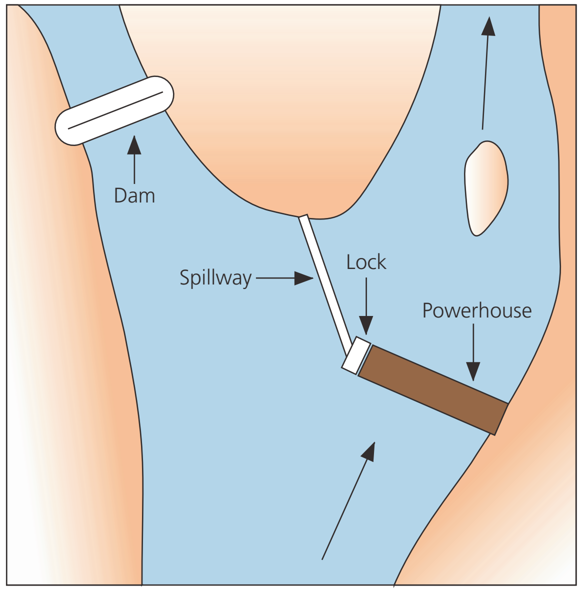
Figure 6
General Arrangement:
Mackenzie – 5 at Wrigley



Immediately facing Wrigley airport, even though river width is insufficient to build both powerhouse and spillway in a single construction phase, this site is recommended to avoid local flooding (Figure 6). The spillway, capacity 46,000 CMS, is located on the west side of the river and is built in the initial construction phase. The next phase consists of the construction of the powerhouse on the east (i.e., right) side of the river, consisting of 19 generators and 1,798 MW harnessing a head of 21 m, located near the future transmission system and village. A short rock fill dam is found at the center, to be closed at the end of the project, in order to maintain the lowest possible upstream water levels throughout construction.

Mackenzie – 4, Birch Island

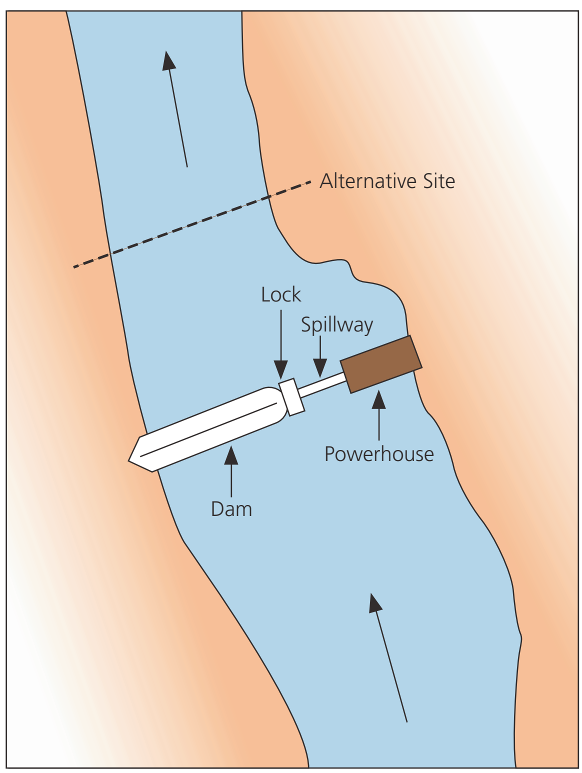
Figure 7
General Arrangement: Mackenzie – 4 at Birch Island



At the present time, there is no village or road access at this site. Even so, the site is recommended in order to minimize flooding. Steep shorelines and the presence of an island make this an ideal site (Figure 7). Diverting the river initially on its west branch enables the project site (i.e., for both powerhouse and spillway) to be enclosed by cofferdams, and built in a single phase upstream of the island. Following this, the spillway is used to divert the river while a 500 metre dam is built on this west branch. The spillway, capacity 48,000 CMS, is equipped with 24 standard 12 by 20 metre high gates. Harnessing a head of 25 metres, the 2,140 MW powerhouse is equipped with 19 turbine-generator units.

Mackenzie – 3, Norman Wells

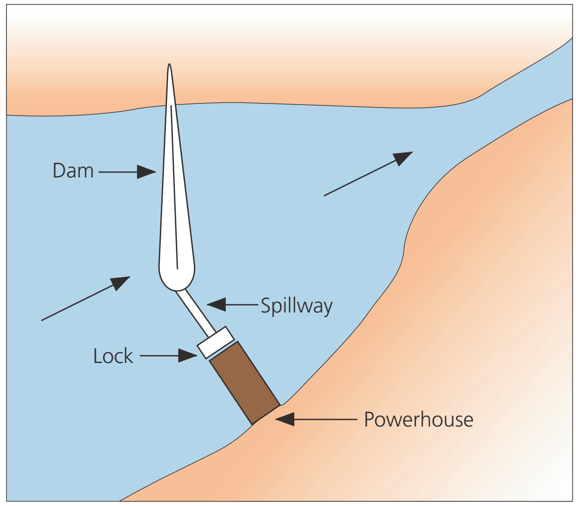
Figure 8
General Arrangement: Mackenzie – 3 near Norman Wells



This site is located 30 kilometres upstream of Norman Wells, near the mouth of Prohibition Creek (Figure 8). Unfortunately, the village of Fort Norman needs to be relocated or abandoned. A 23 m head is harnessed to build a powerhouse consisting of 23 turbine-generator units, for a total of 2,383 MW. The spillway, capacity 54,000 CMS, equipped with 27 gates, is built with the powerhouse in a single phase. The dam is 2.5 kilometres long. A narrower site, three kilometres downstream, may also be worthy of consideration.

Mackenzie – 2, Fort Good Hope

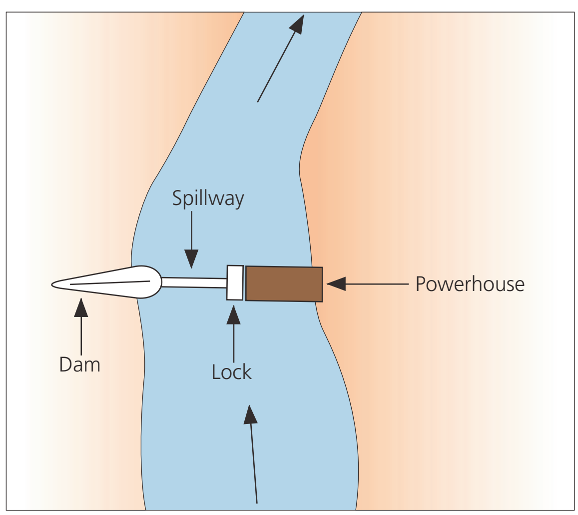
Figure 9
General Arrangement:
Mackenzie – 3 near Fort Hope



The highest dam of the Mackenzie River Hydroelectric Complex is located at the downstream end of what is called the "Bassin des Murailles" because of the very high cliffs which surround this river basin (Figure 9). The site is approximately 15 kilometres upstream of Fort Good Hope. Between these two locations, the river is either too swift or too narrow to embed the structures, or is encumbered with shallow water needing expansive dredging. On the left side of the river, rocky features and islands indicate a high probability of establishing favourable foundations. The site allows the construction of both powerhouse and spillway in a single phase. The powerhouse, with 23 turbine-generator units and a capacity of 2,798 MW, would be one of the largest in Canada. Spillway capacity is 58,000 CMS, with 28 gates. The dam, located on the northern side of the river, is 1,700 metres long.

Mackenzie – 1, Artic Red River

Figure 10
General Arrangement:
Mackenzie – 1 near Arctic Red River



Here again, due to swift currents, a narrow riverbed and high shorelines, the complex' final downstream dam is located approximately 15 kilometres upstream of the village of Artic Red River (Figure 10). Site construction requires two phases, the first focusing on spillway construction, so that the river can subsequently be diverted to build the powerhouse. The 22 metre head is harnessed by means of 24 turbine-generator units for a total capacity of 2,379 MW. The spillway is equipped with 29 gates to accommodate a flow of 58,000 CMS.

Transmission System

To connect the Mackenzie Hydroelectric Complex to the Alberta power grid near Edmonton, some 10,000 kilometres of transmission lines will be needed, based on a 735 kV transmission technology scenario, a technology pioneered in Canada and used successfully in both Quebec and the United States for nearly 50 years (i.e., the 765 kV class transmission technology). At a present cost of 1.5 million dollars per kilometre, a single line has a transmission capacity of approximately 2,000 MVA; 10,000 kilometres of 735 kV lines would therefore cost approximately 15 billion dollars. Incorporating appropriate static var compensation, line capacity can be increased to approximately 2,800 MVA / line. For cost estimation purposes, compensation and associated switching stations are assumed to equal the cost of the transmission lines, resulting in a total transmission system cost of approximately 30 billion dollars. Accounting for inflation and financing until construction end in 2034, this amount rises to approximately 60 billion dollars. This project could be built from 2025 to 2034 at the rate of approximately 1,000 kilometres/year.

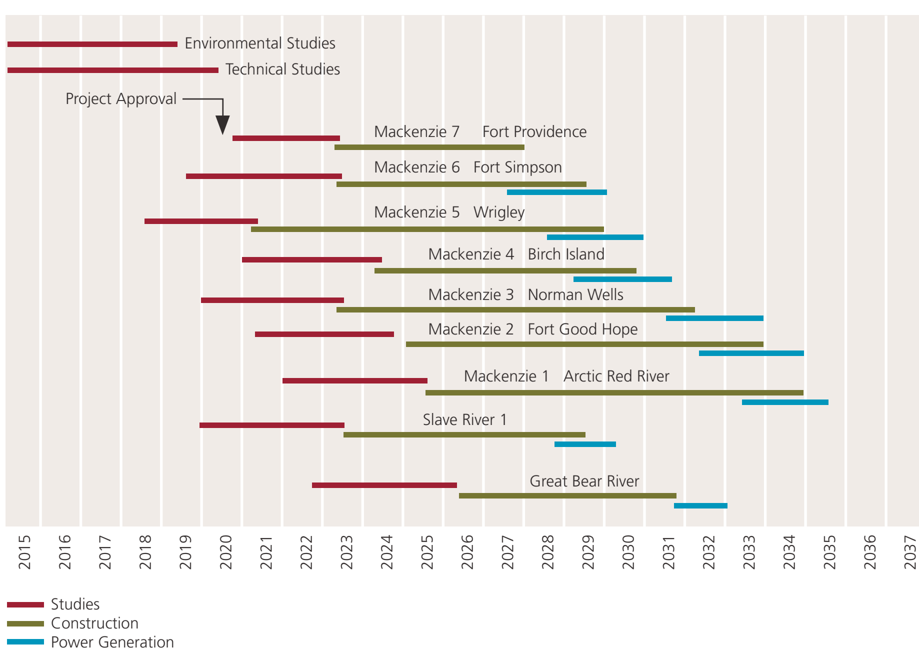
Construction Planning

To manage ice covers and potential winter ice jams, the complex should be built upstream to downstream, as proposed in Figure 11. Top priority goes to Mackenzie 6 and 5, respectively at Fort Simpson and Wrigley, Mackenzie 7 being built faster in the absence of a powerhouse.

The schedule presented here assumes that nothing at all will be done over the next two years, besides publishing the main facts about the project, weighing its advantages and assessing its feasibility and acceptability. From 2015 to 2021, six years are needed to study environmental impacts and identify appropriate corrective measures as needed. In the meantime, geological and hydrological technical surveys should move forward in order to confirm existing knowledge and collect new data establishing the project's feasibility, costs estimates and, more importantly, its profitability.

Even so, the Mackenzie Hydroelectric Complex implementation scenario proposed here incorporates such a pragmatic approach from both an environmental and a design perspective (i.e., in the way each site is similar to the other), that two to three years of design work may well be saved.

Figure 11
Mackenzie River Hydroelectric Complex Construction Schedule



Mackenzie River Hydroelectric Complex Estimates

The cost of the Mackenzie hydroelectric complex is estimated at 114 billion of dollars at the end of construction in 2034, including 60 billion for the transmission system to Edmonton (Table 3). In fact, the investment would likely not need to finance this amount as the project could begin to generate revenue with the first flow of power in 2027; construction could even be suspended for some years after the first power stations are commissioned and producing power in order to finance subsequent power stations.

To this cost of 114 billion dollars, 540 million must be added for the environmental assessment, preliminary design, technical surveys and authorization procedures.

Table 3
Mackenzie River Hydroelectric Complex Estimates
(Millions of Dollars)

Project	Total Cost	Financing	Inflation	Cost ($, 2014)
Mack – 7	1,713	250	433	1,030
Mack – 6	8,349	1,407	1,414	3,630
Mack – 5	6,767	1,579	1,574	3,614
Mack – 4	8,116	1,812	2,077	4,227
MacK – 3	9,697	2,966	2,101	4,629
Mack – 2	10,197	1,929	3,023	5,244
Mack – 1	9,793	2,078	2,911	4,803
	54,632	12,021	13,533	27,177
	100%	22%	24.8%	49.7%
Power Lines	60,000			

Profitability Study

With an installed power output of 13,120 MW, assuming 80% availability over 8,766 hours per year, the yearly energy produced will amount to 92,007,936 MWh.

Table 4
Commissioning Schedule
Yearly added power (MW)

	2027	2028	2029	2030	2031	2032	2033	2034	2035
Power, total (MW)	13,120	270	1,010	1,725	2,075	2,189	2,427	2,380	1,042

Yearly Energy Production Value

The yearly production value is estimated here using three different situations, namely:

Electricity cost in Quebec:
- 8 ¢/KWh or $80/MWh in 2013, with an inflation at a yearly rate of 5% to the year 2034;
- About $202/MWh in 2034:
- Production of 92,000,000 MWh/year;
- Income of 18.58 billion dollars in 2034;
- For a 114 billion dollar project,
- Return of 16.3%/year on the investments

Electricity cost in Ontario:
- $140/MWh in 2013, or $353/MWh in 2034
- Income of 32.46 billion dollars in 2034
- Return of 28.5%/year on the investments

Equivalent energy for oil production

- $100/barrel in the year 2013:
- 5% inflation yearly rate to the year 2034, or 252 $/barrel;
- Energy production equivalent of 191.5 million barrels yearly; or 525,000 barrels/day,
- Income of 55.93 billion dollars in the year 2034;
- Return on this investment of 49%/year.

Conclusion

The Mackenzie River Hydroelectric Complex described in this chapter truly is a "big project," on a scale comparable to the largest hydroelectric complexes ever built. Characterized by flows of up to 9,000 cubic metres per second, steep shorelines avoiding wide-area submersion, and large lakes acting as flow regulation reservoirs, the project harnesses more than 13,000 MW, available 80% of the time, and delivers its high added-value energy through a 10,000 kilometre transmission system to Edmonton. The complex would produce some 92 million MWh yearly, equivalent to producing 525,000 barrels of fuel oil per day. At current Ontario electricity rates, assuming a 5% yearly inflation rate to 2034, this energy output would produce a gross annual revenue of about 32.4 billion dollars, for a total project cost of 114 billion dollars. This clean energy could be used to assist Alberta (10,000 MW) and Saskatchewan (3,000 MW) transition from high-carbon footprint thermal generating stations at the end of their useful life, to low-carbon hydroelectric power, and powerfully contribute to "Canada becoming a sustainable energy powerhouse!"

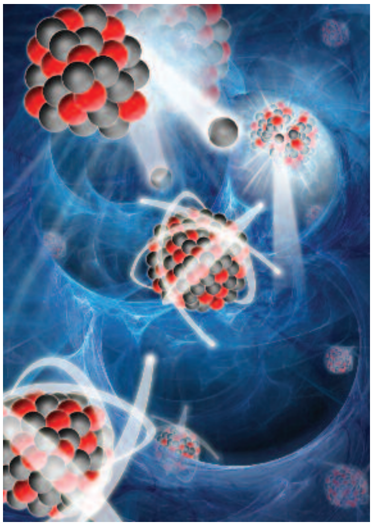
Biography

F. Pierre Gingras has been deeply involved for over 47 years in the execution of major hydroelectric projects, especially as Chief Planning and Cost Engineer for Hydro-Québec's Major Dam Projects like the Manicouagan and James Bay complexes, rebuilding of existing works, and some 200 other hydroelectric projects studies. Retired, he is continuing to study various projects with the Montreal Economic Institute, the Canadian Society of Senior Engineers, the Canadian Academy of Engineering, and some large engineering firms. Among major outcomes of this work is the "Eau du Nord" (Northern Waters) project, intended to direct additional flows into the St. Lawrence River Basin, a technical and economic study for a pan-Canadian high-tension distribution network, and a comprehensive integrated management plan for the entire St. Lawrence River Basin with emphasis on managing the disastrous environmental effects of climate change. In 2013, he completed the first preliminary study about the huge Mackenzie River hydroelectric project.

9

Nuclear Energy – The Path Forward

Daniel A. Meneley



ABSTRACT

Petroleum has been the driving force for building and sustaining societies for more than 100 years. The world now must establish a new primary energy source to relieve the burden on an increasingly scarce and costly petroleum supply. The precise timing is unknown but it is reasonable to assume that, by 2100, a large portion of the world's energy needs must be provided by resources other than petroleum. Uranium is known to be plentiful and, using today's technology, can answer all of humanity's energy needs for at least the next ten thousand years – and likely much longer.

Canada is blessed with several important energy sources and does not suffer from an energy shortage. An indigenous fission energy system named CANDU is fully established, and the required resources of fuel and other materials are available within Canada's borders. Safety, security, and sustainability are demonstrated. It has been shown statistically that uranium energy is cleaner and safer than oil or coal – and best of all, it is available. Canada's uranium resources, both onshore and in adjacent oceans, are truly inexhaustible.

This chapter proposes the concept of large nuclear generating sites producing both bulk electricity and process steam, for use by adjacent industrial parks comprising many high-affinity, energy-intensive industries. A key feature of this concept is that of the "energy cascade" where the inputs and outputs of different industrial activities are both complementary and mutually supportive. Ontario's Bruce Energy Centre is presented as an "example case" of the implementation of a number of these ideas.

Introduction

Commercial nuclear energy systems, now more than 50 years old, utilize a mature technology. These systems are ready to be used more widely in the provision of energy for the benefit of mankind. At the same time, these systems have been applied mostly to one aspect of the needs of society; that is, the production of electricity. A significant opportunity exists to meet many future needs by broadening the market base of nuclear energy to other industrial activities. Scaling up this new primary energy supply is an engineering task of the highest magnitude. It is no longer a subject for scientific research except at the margins; the relevant scientific facts are already well known.

This chapter outlines the major opportunities for diversifying the market for nuclear energy over the next half-century and beyond. The associated challenges form an integrated set ranging from the purely technical to abstract questions of sociology and philosophy, as expected when a major innovative change is introduced to any society. They also touch on broad matters of public policy as well as on future development of the world economy.

Today's challenges to the nuclear industry arise from the world's well-known energy-related challenge; that is, to address climate change by establishing a clean and sustainable alternative to fossil fuels. There may only be two greater challenges: that of managing world over-population, and that of providing sustenance to the billion or more people who still survive with only the most limited access to essential resources. According to the author of the book "The Bottom Billion" (Collier, 2007), these people may be best served in the near term through at least two development phases. In the first phase, restraint in fossil fuel use by the richest societies would result in greater fuel availability for the poorest. If the richest were to fully embrace nuclear energy, the price of fossil fuels would fall, thereby making fossil fuels more affordable to the poorest who then would have a better opportunity to improve themselves. In the second phase, once the basics were established, they could choose their own path. Motivation for the richest to make a change will come from the lower cost and increased cleanliness of nuclear energy when compared with fossil fuels.

Some people believe that petroleum is not, and never will be, in short supply. Better-qualified and more convincing persons and organizations point out the error of this thinking. The world now uses about 1,000 barrels of oil in each second of every year (Tertzakian, 2007). This cannot last. As stated by the Chief Economist of the International Energy Agency (Birol, 2006), "We have to leave oil before it leaves us." The world must soon switch to an available, boundless, alternative fuel – uranium (Lightfoot et al, 2006).

Assuming a plant capacity availability factor of 90 percent, the heating value of oil being consumed in the world today is equivalent to the total fission heat produced by at least 7,000 nuclear units, each with an equivalent electrical production capacity of one billion watts. Building them is no doubt a large job, but it is feasible. There is little time to meet this challenge; using the most optimistic assumptions, the job should be completed before the year 2200. This massive change will require the goodwill and the efforts of many thousands of people, backed by both their governments and by the population at large.

Canada's challenges are simpler than are those in the wider world. As one of the great democracies of the world, Canada has a single social system, and the necessary resources, tools, and skilled manpower. Canada already owns a fully developed nuclear energy technology in the CANDU (CANada Deuterium Uranium) system. With strong will and leadership, Canada can install new nuclear plants as a clean, sustainable alternative to fossil fuels and also provide guidance to other countries that share a similar goal.

The Starting Point: Aiming for the Long Term

At the 2013 winter meeting of the American Nuclear Society, Jim Rogers of Duke Energy spoke of the need for "Cathedral Thinking" in planning the world energy supply system. Rogers identified the concept some years ago (Zakaria, 2007). Energy system development is a long, slow, and difficult process similar to that employed in the building of a large cathedral. It requires careful thought, coupled with a large measure of hope, a willingness to take risks, and above all a vision of a better future. Leaders in Canada must begin to practice "Cathedral Thinking." The likely alternative is chaos and starvation.

Humanity is fast approaching a major shift in its environmental and physical health due to a seemingly accelerating and possibly disastrous change in climatic conditions. It is widely accepted that this trend is driven by the accumulation of greenhouse gases in the atmosphere due primarily to the widespread use of fossil fuels. These same fuels are, today, vitally important to human prosperity. Furthermore, the coming environmental crisis may be exacerbated by a shortage of affordable petroleum — the most valuable of available fossil fuels.

These impending difficulties have prompted a number of people to search for means of alleviating the problems on both the demand and the supply side of energy use. These studies rapidly concentrate on the demand side because of the steadily increasing world population and the near-universal aspiration for a better quality of life. Many of these studies, as evidenced in three of them (Cohen, 1983; Till, 2005; Lightfoot et al, 2006), focus on the positive features of energy from uranium fission because of the vast scale of this resource, its proven feasibility, and economic attractiveness.

What We Have Been Given

The fact that Canada has many cool lakes suggests that ample heat sinks are available for the generation of electricity using conventional Rankine cycle heat engines. Many of Canada's lakes are conveniently located in remote regions, far from population centres, but well within the reach of high voltage transmission lines.

Uranium and thorium are in abundant supply in Canada and the world. Canada also has developed a mature and economical method of producing electricity from uranium, and probably also from thorium. The CANDU reactor is economically competitive with other modern uranium-fuelled plants, and has at least as good a record of safe operation as held by other first-rank reactor designs. Canadians today operate nineteen of these superb machines.

A view of the Bruce Nuclear Generating Station (BNGS) as it appears today is shown in Figure 1. Units 5 to 8 are visible in the foreground while units 1 to 4 are seen in the far background. The small white dome in the left foreground contained a prototype reactor known as Douglas Point that now has been decommissioned. The eight operating Bruce units normally produce some 6,300 megawatts of electricity for Ontarians, about 30 percent of the total provincial demand.

Canada has many manufacturing industries that can utilize electricity and hydrogen. These are the best available energy currencies to produce the wide range of finished products useful to modern society around the world (Scott, 2008). Canada also has access to markets through which these products can be sold.

Figure 1
The Bruce Nuclear Power Development Site on Lake Huron

The Next Big Project

It is well established that fission chain reactors can be built to provide reliable electricity. What is now proposed is to broaden the product diversity of future reactors to include other commodities needed by a prosperous society. An excellent beginning in this direction was made more than twenty years ago with the development of the Bruce Energy Centre (BEC) on Lake Huron (Gurbin & Talbot, 1994). Figure 2 provides a broad outline of the concept, consisting of an energy cascade powered by uranium energy. To drive this cascade, in addition to producing electricity, the first four units of BNGS were fitted with steam transformer units. Steam excess to electricity generation needs was sent through the transformers to produce lower-pressure steam in their secondary circuits. This steam was directed to the site-wide bulk steam system, including the BEC steam line.

Delegates to the Engineering Institute of Canada's third climate change conference (Engineering Institute of Canada, 2013) recognized that energy, water, and food form the nexus of human material needs – those which engineers are fully equipped to provide. Energy lies at the very centre of these basic needs; without plentiful energy, it is not possible to "engineer" any of the other solutions.

Canada, and indeed the whole world, needs to look beyond those energy-rich resources that are already in service and toward every plentiful and economical new resource that is available for use in the future. As is true in most parts of the world, uranium is plentiful, if only at low concentrations. Even tiny concentrations of uranium, however, can become important reserves if Fast Neutron Reactor (FNR) technology is introduced. This is due to the fact that each gram of uranium yields a very large amount of energy if irradiated by high-velocity neutrons in this special type of fission reactor. Of course, this fact also means that uranium can be imported or exported without any concern about disturbing the balance of trade, because so little uranium is required to support a large fleet of fast reactors – only two tons per year for each one thousand megawatt electric power plant.

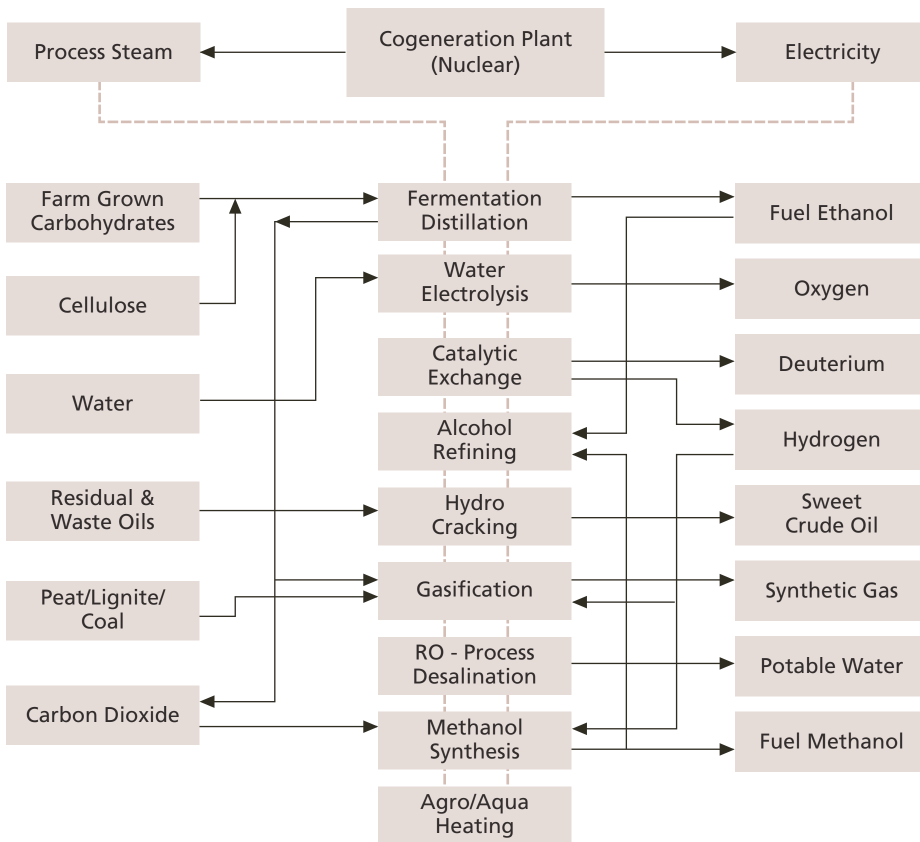
Canadians are familiar with the CANDU reactor that has operated successfully around the world for more than 50 years. CANDU is a thermal reactor, in which most fission is initiated by so-called "slow" – also referred to as "thermal" – neutrons (these "slow" neutrons actually move quite fast – about 8,000 km/hr.). It is recommended by many technical experts that Canada should embark on a venture toward adding the fast neutron reactor (FNR) that offers excellent support advantages for a reactor fleet containing CANDU power plants. FNR reactors have been operated for several decades in a few countries; Russia, China, and India are building this reactor type today. All fission takes place at high neutron velocities in this reactor. At high neutron velocity, the physics of the process is even more advantageous than in the low-velocity CANDU reactor (Till & Chang, 2011). By leveraging their complementary strengths, these two reactor types together offer significant advantages compared to either of them working as independent, stand-alone units.

Drawing on the analogy of the oil fields in the Middle East, Canada - using technologies available today - can establish a local energy supply larger than that offered by all of the Middle East petroleum producing countries taken together. Furthermore, this "Saudi in Canada" concept can be cheaper, cleaner, and more sustainable than those Middle East oil and gas fields. A recent paper (Meneley, 2010) outlines some of the characteristics of a typical industrial complex centered on nuclear power plants, using the Bruce site on Lake Huron as an example.

A Beginning – The Bruce Energy Centre

This bold idea (Gurbin & Talbot, 1994) was founded on the recognition that the Bruce nuclear plant could supply steam in excess of the capacity of its four turbine-generators. A 24-inch steam main and a 10-inch water return line were built to supply steam generated in steam transformers. The steam, along with electricity as required, was to be delivered to a large tract adjacent to the BNGS site, and was to service an energy cascade similar to that shown in Figure 2.

Figure 2
Example of an Energy Cascade Powered by Nuclear Electricity and Steam



Steam from Bruce nuclear plant could be diverted to the BNGS bulk steam supply system to provide energy for the production of heavy water, to heat buildings within the development, and to provide energy for industries at the Bruce Energy Centre at the boundary of the site. One of the largest bulk steam systems in the world, this system was capable of producing 5,350 MW of medium-pressure process steam from the reactors' high-pressure process steam (CNWC, 2014).

Views of the existing Bruce Energy Centre (BEC) are shown in Figure 3. The original concept relied on a supply of low-cost steam from the Bruce reactors. That supply was terminated when Bruce units 1 to 4 were shut down following decisions made by Ontario Hydro senior management in 1997. While the Bruce units 1 to 4 have since been refurbished and are now fully operational, the steam transformer system has not been reactivated.

Figure 3
Views of the Bruce Steam Line and the Bruce Energy Centre

In 1996, a new oil-fired steam plant was constructed to replace the then-inoperable units of Bruce 1 to 4. This plant can deliver up to 250,000 pounds per hour of steam at a pressure of 300 pounds per square inch. This temporary arrangement is unsuitable for the longer term.

Bruce Energy Centre was a great beginning. It is an outstanding example of what can be done with goodwill and determination to expand the future prospects for Canadians through the utilization of home-grown technology – technology that can make many other things grow to the benefit of all Canadians.

Potential Energy Centre Systems

Adjacent to a large nuclear generating site such as Bruce, one might establish a large industrial park similar to the Bruce Energy Centre. As mentioned previously, such a site would benefit from the proximity of bulk electricity and steam, and be home to a number of enterprises, each benefiting from their unique location.

Basic Processes

The left-hand column of Figure 2 shows the raw materials that could conceivably be input to the Bruce Energy Centre. The original concept was that these materials would be transformed through the judicious application of nuclear process steam and electricity into useful products as shown in the right-hand column. The production processes were aligned as a cascade in which the steam enthalpy requirement for the next step of the cascade matched the discharge enthalpy of the previous step to take advantage of the steadily decreasing enthalpy of the process steam. The promise of the Bruce Energy Centre, however, was crippled by events beyond control of its founders. The temporary closing of the Bruce units 1 to 4 in 1997 drastically raised the price of process steam. Future economic viability of energy centers such as this will depend on the availability of cheap process steam from nuclear units.

The mixture of intermediate and final products shown on the right-hand side of Figure 2 is by no means exhaustive, and virtually any process that requires a unique input material and that needs some combination of electricity and steam could benefit from association with the Bruce Energy Centre.

High temperature process steam produced by electrical heating of high-pressure water is an additional input that can be added to the list in Figure 2 and can be supplied by CANDU reactors. While the economics of this supply of high-temperature process fluid are unknown at this time, there is no question that such an operation is technically feasible. The process steam temperature associated with a fast neutron reactor system will be about 550 Celsius, which is high enough to support the Copper-Chloride process of water splitting (Naterer et al., 2013).

A number of industrial processes such as steel-making, depend on the availability of high-temperature process gas which, in turn, appears to work against the CANDU reactor because of its relatively low operating temperature. These reactors, however, are fuelled with cheap natural uranium and have very economical fuel manufacturing processes. One convenient source of high temperature process gas is the plasma torch (Plasma Torch, 2012) that requires direct-current electricity, normally provided by a DC converter connected to a conventional AC power supply. In principle, an electrical plasma torch could be used to raise the temperature of the process fluid to the level required by the Copper-Chloride water splitting process mentioned above.

Synthetic Petroleum Production

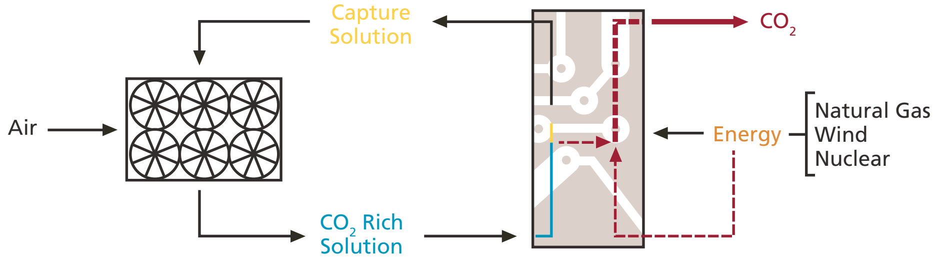
As detailed by David Sanborn Scott (Scott, 2008), hydrogen and electricity together can provide the essential energy currencies on which to base a strong industrial society. Electricity can be produced with relative ease from uranium (or thorium) in fission chain reactors. The reverse process, that is converting energy to mass (stored energy) in the form of hydrogen or hydrocarbons, is more difficult. The most promising method for hydrogen production is a combined chemical-electrical process now under development (Naterer et al., 2013). This process splits water into hydrogen and oxygen; hydrogen then can be combined with carbon to produce synthetic petroleum or natural gas. Some of the valuable mass is lost (and converted back into energy) in this chemical reaction, but the resultant hydrocarbon molecules are much easier to manage than hydrogen. The massive infrastructure currently used to store and transport natural petroleum products can be utilized directly for this purpose.

To provide an idea of the scale of electrical systems required, the direct energy equivalent of 300,000 barrels of gasoline, an amount comparable to that consumed in Ontario each day, equals the total electrical energy output of eighteen large (1.0 GWe) nuclear units. In other words, Ontario's daily gasoline demand corresponds to the total electrical output of about twenty nuclear units. Manufacturing synthetic gasoline is an energy-intensive industry due to the process of converting energy to mass, according to Einstein's famous equation ($E=mc^2$). Aside from inevitable efficiency losses inherent in this conversion process, energy - after being converted to mass - remains stored in the gasoline product to be released later on as needed.

But where does one find carbon to combine with the nuclear-produced hydrogen? Commercially, the correct answer is "from the cheapest source." One's first thought might be that any artificial petroleum process proposed here must add to the atmospheric carbon inventory. Research by Carbon Engineering in Calgary (Holmes et al., 2013), however, is aimed at extraction of carbon directly from ambient air. If successful, this would mean that the same amount of carbon dioxide could be continuously cycled from the liquid hydrocarbon phase to the atmospheric phase, and then back to hydrocarbon.

Figure 4 illustrates the direct capture process in a simple form. Energy is required for circulation of the capture fluid, for operation of the air-flow fans, and for extraction of carbon dioxide from solution.

Figure 4
Carbon Engineering Direct Air Capture Process



Capturing CO_2 directly from the air allows emissions originating from any source to be managed with standardized, scalable industrial facilities. Carbon Engineering's full-scale design, for example, could absorb the emissions created by 300,000 typical cars.

In research conducted at the University of Calgary, David Keith and a team of researchers showed it is possible to reduce carbon dioxide (CO_2) – the main greenhouse gas that contributes to global warming – using a relatively simple machine that can capture the trace amount of CO_2 present in the air at any place on the planet (Keith, 2008). Figure 5 shows the Carbon Engineering prototype system (Holmes et al., 2013).

"At first thought, capturing CO_2 from the air where it's at a concentration of 0.04 per cent seems absurd, when we are just starting to do cost-effective capture at power plants where CO_2 produced is at a concentration of more than 10 per cent," says Keith), "but the

Figure 5
Carbon Engineering Outdoor Air Capture Prototype

(Holmes et al., 2013)

Carbon Engineering's air capture prototype uses an oxy-fuel natural gas kiln to drive the CO_2 out of the solid calcite.

thermodynamics suggest that air capture might only be a bit harder than capturing CO_2 from power plants. We are trying to turn that theory into engineering reality."

This research is significant because air capture technology is the only way to capture CO_2 emissions from transportation sources such as vehicles and airplanes. These so-called diffuse sources represent more than half of the greenhouse gases emitted on Earth.

"The climate problem is too big to solve easily with the tools we have," notes Keith. "While it's important to get started doing things we know how to do, like wind power, nuclear power and 'regular' carbon capture and storage, it's also vital to start thinking about radical new ideas and approaches to solving this problem."

Short and Medium Term Electricity Storage

Many people think that large nuclear power plants cannot be operated to adjust to short-term electricity demand fluctuations. In fact, existing CANDU units, and many others (World Nuclear Association & EDF, 2010), are designed to maneuver daily. CANDU units can do so down to about 60% of full power and return. Smaller power reductions are, of course, easier to accommodate. It is true, however, that power maneuvering is an expensive procedure for a large generator with relatively high specific capital cost and low fuel cost. Experience has shown that frequent reactor power changes may cause increased failure rates of plant components. Subsequent aging of units, resulting in the tightening of operating limits, makes daily maneuvering even more difficult.

Alternatively, it is possible to divert excess generating power to secondary generators (Forsberg, 2011). Night-time storage of hydrogen and oxygen, followed by daytime burning of these gases in specialized gas turbines, provides an efficient electrical system with peaking capacity. Modern electronic DC conversion technology could instantaneously divert electric power to hydrogen electrolysis loads, thereby maintaining fission energy production at maximum levels while producing a second, valuable energy currency. This capability would be most practical for CANDU reactors because of the low cost of natural uranium fuel.

Storage of electricity involves the same basic processes as the production of synthetic petroleum. Energy is used to produce mass, which can then be stored.

Hydrogen production provides the opportunity for extraction of two other valuable products. The first is oxygen and the second is deuterium. Deuterium is a rare isotope, present in natural hydrogen, in concentrations of approximately 1 in 7,000 molecules. It is a vital component in the CANDU reactor. Deuterium can be extracted from hydrogen gas using the combined electrolysis catalytic exchange process developed by AECL some years ago (Hammerli et al., 1978).

Industrial Steam Supply

The Bruce Energy Centre (BEC) utilized medium-pressure steam produced on the secondary side of steam transformers. The maximum energy delivery was approximately 300 megawatts thermal. This steam was used by a variety of facilities on the BEC site.

Other Suitable Energy Centre Industrial Processes

As illustrated in Figure 2, many other processes could benefit from the ready availability of economical heat and electricity, not to mention processes based on a variety of agricultural or biomass feedstocks. These include fermentation, distillation, ethanol and methanol production, and purification of water via reverse osmosis. It may also be worth examining the feasibility of connecting a DC generator to the main AC generator shaft, so that bulk DC power would be available on-site (Scott, 2009) or, alternatively, the addition of electronic converters to provide bulk DC power supply to the site.

Collaborative Operation of CANDU and Fast Neutron Reactors

A fleet of CANDU power plants can benefit from the exchange of nuclear fuel components within fast neutron reactors (Meneley, 2010). The fast neutron reactor (FNR) creates an excess of fissile isotopes, while a normal CANDU plant is always a little bit short of those same isotopes. At the same time, used fuel discharged from CANDU reactors contains exactly the mixture of heavy elements (actinides) that are necessary for the first fuel charge of any fast reactor. There is significant merit in considering fuel cycles integrated between these two nuclear reactor types within the same industrial park.

Fuel Production, Reprocessing, and Waste Management

These separate support functions could be established either at the energy park or might be separated by some distance, depending on site and other conditions. Fuel production for the reactors located at the main site, or even fuels for use as export commodities, might be associated with the energy park to some degree.

A large energy park might include the capability of supporting much smaller remotely located power reactor facilities such as the Secure Transportable Autonomous Reactor (STAR) concept (Wade, 2010). The idea is to deliver a "package" system to a remote site, in a style similar to a conventional battery. This nuclear battery would, however, be capable of delivering megawatt-scale energy supply for several years, after which the "package" would be returned to the energy park for reprocessing. A fresh "package" would be shipped to the remote site. A simple system might consist of a large nuclear plant, local electrical grid, and boilers positioned at or near each major wellhead. Cheap nuclear fuel could make such a network feasible.

Establishment of Functionally Separate Energy Centres

A large nuclear energy park might be developed as separate components; that is, large-scale electricity generation might separate naturally from the growing industrial facilities. The main reason for such separation is the special security and radiation protection requirements at a so-called "nuclear" site. Other industries also may have unique hazard characteristics that might best be isolated from nuclear site safety and security requirements – such as deuterium production using hydrogen fluoride gas. It might also prove advantageous to separate the facilities supported by fast neutron reactors – which, as pointed out in the next section, will likely NOT be primarily bulk electricity producers– from the purely electrical utility functions. Once again, security and unique hazards may be sufficient cause for separation of the various industrial components.

Challenges

The Nuclear Fission Enterprise

Transition from a successful stand-alone thermal reactor fleet to a combined thermal and fast reactor fleet will be difficult for several reasons. The first, and perhaps most difficult task, will be to convince operating organizations of the need for change. They have been operating Generation II or III reactors for decades and the price of fuel has always been a small fraction of the total operating cost. The price of fuel will rise in the future, however, and (perhaps the most convincing reason) the volume of stored used fuel on the site will someday reach difficult proportions.

The above suggests the establishment of a purpose-built fast neutron reactor (FNR) site that serves three primary functions. The first is for processing used thermal reactor fuel into minor actinides, fission products, and Uranium 238. The second is for producing energy (both electrical and thermal) from recovered minor actinides plus a small part of the U238 recovered in the separation process. The third is for storing excess recovered U238 in an adjacent underground storage facility that is sufficient also to retain fast reactor waste products (fission products), and to separate useful fission products from true waste. The U238 would be utilized as needed to sustain long-term FNR operations. Given the expected quantities of actinides and uranium on the site, the fast reactors will never need an off-site source of fuel, after their first startup.

The FNR is, by its nature, a potential net producer of fissionable material. This material could be fabricated into new fuel assemblies to be used either to fuel new fast neutron reactors or to provide thorium fuel containing fissile topping for thorium-fuelled CANDU reactors.

The primary purpose of this distinct type of nuclear site may be to produce products other than electricity. It will not likely be owned solely by a single entity, but rather by a consortium led by a provincial or national government, with the operation of particular industries "farmed out" to specialist organizations. In short, it is an industrial complex whose goal is development of energy-related enterprises for the benefit of the whole nation, and possibly of the wider world.

Synthetic Oil Production

The primary technical challenge in this case is to determine whether or not it is feasible to produce sufficient synthetic petroleum economically to replace all or at least a significant part of our natural petroleum supply.

The best known case of such production was in South Africa some years ago, when the petroleum embargo forced the company known as SASOL (Sasol, 2014) to produce oil from coal by means of an improved version of the Fischer-Tropsch (National Energy Technology Lab, 2014) process developed in Germany before World War II.

Recently, a number of large oil companies have investigated oil and gas production options utilizing coal, oil, and other basic hydrocarbon sources. None of these, however, has looked at the possibility of using cheap uranium as the basic energy source for synthetic fuel production. The most advanced analysis of this type was published in the MIT white paper by Bersak & Kadak, 2007. The specific application was for extraction and upgrading of product from Alberta's oil sands. As such, this application is not "portable." At the same time, the essential added ingredient, once hydrogen has been produced, is a cheap source of carbon. Hydrocarbon is, after all, the energy storage medium "chosen" by nature and one from which humanity has derived great benefit.

Strong support for the feasibility of synthetic oil production can be found in a recent US Navy report (Williams et al, 2010). The authors propose using shipboard nuclear power to produce hydrogen, along with carbon dioxide extracted from seawater, to produce jet fuel. Cost analysis of this system is shown to be highly favorable. The system using commercial-scale nuclear plants and air-derived carbon dioxide (Keith, 2008) should be even more feasible. Obviously, work must be done before such a system could enter commercial service – and proving out a land-based system will take time. But, the system looks promising for the longer term.

Nuclear Waste Management

While this issue is not a major technical concern within the technical community, it has become a "signature" issue among those dedicated to the opposition of the use of nuclear energy. It is important to address this issue in some depth.

The materials we now identify as nuclear waste have been present in our environment since the earth was born. Ionizing radiation strikes our bodies every second of every day. We have evolved into our human form in the presence of ionizing radiation. We inhale radioactive materials, we eat them, and we carry them in our bodies from birth to death. Because ionizing radiation is so pervasive, our bodies have adapted to constant irradiation. It is true that irradiation causes damage to our cells. It is also true that there are many other damage mechanisms, some much more damaging than radiation. Fortunately, powerful defenses exist. Our cells have adapted by producing the means for repairing damage and rejecting badly damaged cells, so that we live normal lives, unaware of all those events going on inside each of us.

When the centre of an atom changes by releasing a particle, energy is released. The fact that energy is stored inside atoms makes them interesting. Heat is released from the breaking up of atoms, in exactly the same way as happens during the burning of fossil fuels, except for a unique advantage granted by the virtually limitless supply of energy available from fission of uranium or atoms. We know that the supply of electricity from uranium can continue for at least as long as humanity exists on this planet. The broken fragments of atoms have done their work. Energy has been released and used to make electricity. Some of these fragments or "fission products" emit intense ionizing radiation, most intensely in the first seconds after fission. The intensity of this radiation decreases steadily but continues at a low level for many years. Used fuel material eventually will become almost identical to the uranium ore first taken out of the ground.

Used CANDU fuel is not waste. It still contains more than 99 percent of the potential energy of the original uranium. Only a very small portion, less than 1 percent of the mass, is strongly radioactive in the short term after being in the reactor. Used fuel bundles are handled, at first, by computer-operated machines that take them out of the reactor for wet storage and place them in racks in deep water-filled pools at each power station. At this point in time they are dangerous, giving off both heat and intense ionizing radiation.

After a few years, both the radiation and heat production levels are sufficiently low that the bundles can be moved for dry storage in concrete and metal-lined canisters; the small amount of heat still being produced by the used fuel bundles is taken away by conduction and air convection. The canisters usually are stacked in a regular array on the reactor site or at a central storage location. Fuel could, in principle, remain safely stored in these canisters as long as the concrete and steel last – at least several hundred years.

Used fuel three hundred years old (or even much younger) could be processed very easily and safely should our descendants want to recover the remaining 99 percent of the potential energy still resident inside the old used fuel (this is good fuel for fast reactors). Alternatively, the canisters could be moved to an underground repository or new canisters could be built, the fuel could be moved to them, and the cycle repeated. It would be truly presumptuous of us to try to foretell what these people will do with the fuel – each of the above three options can be chosen with a very high assurance of safety.

Assuming that our descendants choose to simply place the used fuel bundles underground, it will be feasible for them to copy, or to improve upon, the characteristics of geological formations that exist today – and will exist then, three hundred years from now. Such formations are known to have trapped massive quantities of uranium and other radioactive materials for billions of years.

Canadian plans for long-term waste management of used nuclear fuel are in good hands. The Nuclear Fuel Waste Management Organization (NWMO) was mandated to do the job by the Canadian Federal Government (Government of Canada, 2002); they are now considering options to select one informed and willing community to host this important facility. Their work is funded by nuclear plant operating organizations. There is plenty of time – used CANDU fuel is and will continue to be safely managed – NWMO expects that selection of a location may require several years of work.

Nuclear waste management entails no significant danger either for today's generation or for future generations of society. The small volume and simple containment of these materials entails no significant risk to the human environment.

The Issue of Economics

While nuclear generating stations are expensive, they are in the same class as expressways, hydroelectric works, production oilfields, standing armies, and other elements of national infrastructure. These enterprises all share the characteristic that they are national enterprises intended to serve the community as a whole. Large portions of these systems might be built by private enterprise but, in the end, their natural owner is the provincial or national government. "Ownership" might be expressed in a number of different ways, such as direct management, indirect regulatory control, "permitting" of business activities, collection of royalties, or via taxation. The common factor is that the enterprise cannot and does not proceed without government permission of some sort.

Given the fact of government control of the nuclear energy enterprise, it follows that this activity must be deemed of value to the nation before the enterprise actually begins. Given the fact that the enterprise is intended to benefit the whole community, it follows that both expenditure and revenue should be shared with that community.

Ontario has a strong industrial base, as is evidenced by the knowledge that more than nine-tenths of the total cost of the Darlington Generating Station was expended in Canada, with the majority of the cost incurred in Ontario. It is fair to say then, that the main expenditure was represented by the energies of the people who designed, manufactured, and constructed the plant along with those who now operate it. It can be expected that future nuclear capacity expansion will have a similar ownership distribution, and will bring strong benefits to Canada's economy.

Public Acceptance

The most powerful factor that delays utilization of uranium and thorium to produce plentiful energy is the fear of ionizing radiation – a primordial fear that need not have a basis in reality. Spencer Weart presents a careful analysis of this phenomenon (Weart, 2007). Many people fear ionizing radiation without understanding that it is actually a very weak carcinogen – in other words this fear is based, wrongly, on fear of cancer (Cuttler, 2013). This climate of dread has been stimulated and sustained by a variety of opponents dedicated against the utilization of nuclear energy. The underlying motives of these opponents range from sincere dislike of everything nuclear to obvious self-interest, mostly driven by the possibility of losing market share. Political opposition tends to support uninformed public opinion and is likely driven by an overwhelming desire for re-election.

A large amount of scientific research has been conducted to elucidate the effects of ionizing radiation on live cells and their reproduction. The findings are complex but nonetheless strongly support the case that the earlier assumption that damage is proportional to dose, all the way down to zero, is incorrect. In fact, low doses of radiation may be beneficial to health; at least, there is no net negative effect. Recognition of this established fact by the public and by health regulatory agencies would lead to a profound improvement in the public perception of the whole nuclear enterprise. Wade Allison (Allison, 2013) has given simple and useful advice in consideration of this issue:

"There are 3.5 things to be said in a public forum:

1. Radiation is almost harmless (Fukushima, Chernobyl, Goiania, etc.)
2. Fear of low doses of radiation is very dangerous and has killed many and caused great economic damage, in Japan and around the world for no benefit. This fear, perpetuated by ALARA, was inspired by WWII and the Cold War (but not linked to UV in sunshine).
3. Medium and high doses of radiation as used in medical scans and radiotherapy are highly beneficial and widely appreciated

3.5. Finally, radiobiologists have shown that low chronic exposure to radiation actually reduces cancer risks (which is not surprising if you think about it)."

The essence of Dr. Allison's argument is that fear of radiation is a problem of leadership. The lack of leadership is shown in both government and professional organizations. One suspects that the governmental problem arises from the fact that much "scientific" opinion falls within the jurisdiction of government-controlled bureaucratic organizations that confuse policy imperatives with the very real need for truth about ionizing radiation.

A closely-related and greatly exaggerated fear is of "radioactive waste," or more precisely that of used reactor fuel, that must be isolated and stored for a long time. Ted Rockwell (Rossin, 2013), a pioneer of radiation study and effects, maintained that there is no problem with used fuel as long as it is treated with reasonable care and attention – as we must also treat many other articles we use in our ordinary lives. Rockwell's statement succinctly captures the essence of a complex issue. As evidenced above, effective nuclear waste management strikes a balance between seizing the vast opportunities for additional energy in used reactor fuel, and storing it safely in the meantime. Further, safe storage of used thermal reactor fuel is not expected to be difficult over the next few hundred years. In the very long term, the advent of FNR reactors promises a definitive solution to the waste disposal question.

In recent years, a number of environmentalists have come to the realization that nuclear energy, though it must be treated with care and due caution, is the best hope for sustaining our energy supply and thereby our social stability (Stone, 2013).

The broader world outside the so-called developed economies already has made the decision to install large capacity nuclear generating stations. It is to be expected that the demonstrated success of these foreign ventures, combined with steadily increasing costs and prices associated with fossil fuels at home, will finally result in a change of opinion in Europe and North America, so that a sustained "nuclear renaissance" can arise.

It is well established that acceptance of major activities such as this one are founded on trust. In Canada, public acceptance is a rare and precious commodity, difficult to earn and easy to spend. The good news is that public trust is increasing, especially in the domain of nuclear power plant operations. This aspect of acceptance will become more and more important as the number of successful operating stations increases. In contrast, research and development directed toward new plant concepts will gradually become less important as the industry reaches full maturity. Few energy studies recognize this reality but concentrate instead on government, research, export issues and similar subjects (Public Policy Forum, 2014). Meanwhile, the utilities operating nuclear plants work steadily to build their reputation for economy, reliability, and safety.

Public acceptance and trust grows from clear evidence of good performance over a long period of time. The operating organizations are therefore the logical base from which to expand public acceptance. In Canada, it can be seen that government backing and support normally follows public acceptance rather than leading it. The message, then, is to work from the utility operating history toward the goal of general public support for the nuclear enterprise. Development of designs and basic research should now follow what the market (i.e. the utility group) requires. Generally, this leads in the direction of evolutionary rather than revolutionary changes in design, construction, and operation.

The Long-Term Prospect

The central idea suggested in this chapter is that uranium energy can and should be applied much more broadly in society rather than only to the production of electricity, as it is today. Broadening of the market for nuclear energy to the full range of energy-intensive industries can significantly impact Canada's ability to add value to a variety of products while reducing the carbon footprint of energy production and use.

Any energy and industrial facility such as the one proposed here exists to serve the community, and will undoubtedly evolve with the needs and economics of the world. One thing can be assured, however. Given a similar nuclear energy infrastructure, as long as humanity exists there will be a plentiful and reliable energy supply under control of the citizenry.

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Biography

Dr. Daniel A. Meneley is Adjunct Professor, University of Ontario Institute of Technology. Dr. Meneley served as AECL Chief Engineer for 9 years including postings in Korea and China. He established AECL's Shanghai office and lectured extensively on CANDU. During an earlier seven-year Professorship at UNB, he served on the first IAEA-INSAG safety advisory committee. He was employed by Ontario Hydro from 1972 to 1984; first as supervising design engineer, then Manager of Safety Design and Reactor Licensing, and finally as Manager of the 350-person Nuclear Group responsible for design, safety, licensing, and waste management during the building of twelve CANDU stations comprising Pickering B, Bruce B, and Darlington. Before that time he supervised fast reactor physics research, development and design at Argonne National Laboratory. Dr. Meneley graduated from the University of Saskatchewan (1958) with Great Distinction in Civil Engineering. He earned a Doctorate from the Imperial College of the University of London in 1963. He is Fellow of the Canadian Academy of Engineering, Fellow of the Canadian and American Nuclear Societies and Member of the Canadian Society of Senior Engineers. He has published in nineteen refereed journals, more than fifty refereed conference proceedings and has supervised twelve post-graduate theses.

10

The Importance of District Energy in Building Resilient Cities

Terri Chu
Mary Ellen Richardson
Marlena Rogowska

ABSTRACT

Canadian families need energy to heat and cool their homes, offices, commercial, industrial and community recreational spaces. In 2010, the average Canadian home consumed 67% of its total energy for space heating.[1] Approximately one-half (53%)[2] of energy use in the industrial/commercial sectors is spent on space heating and cooling (i.e. thermal energy use). In aggregate, thermal energy use, mainly to cool and heat buildings, accounts for roughly one third of all energy consumed in the country. Becoming more efficient in the way that this energy is applied represents one of the highest impact ways to reduce energy consumption, and improve efficiency in Canada. This energy efficiency opportunity could be exploited through the application of District Energy thermal grid (DE) solutions. DE remains largely unexplored in Canada due to the unregulated market structure to which DE belongs. However, there are many reasons for Canada's current interest in the DE thermal network, most of all, its potential for energy efficiency gains and its ripple social and economic effects. The large potential for community-scale DE solutions to contribute to Canada's aspiration of becoming an energy superpower is largely untapped.

Nearly all the energy for space heating needs is now met by extremely high-grade energy sources (i.e., electricity, natural gas, oil). It is not efficient to be using a high-grade energy resource that burns at several hundred degrees Celsius in order to maintain a room or building between 20-23 degrees Celsius. Better to apply such energy forms for high-grade uses, such as running an elevator or operating a stove.

In most cases, individual home owners and businesses cannot avail themselves of local fuel resources, or waste heat resources. The application of DE solutions can facilitate the matching of lower quality energy sources to the job of meeting the heating and cooling requirements of communities across Canada. This makes the building of DE solutions an essential addition to the existing community energy

[1] The average Canadian household consumed 106 GJ of energy for use in the home in 2007 of which over 60% is used for space heating and cooling. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ca&rn=2&page=4&CFID=31395328&CFTOKEN=87e6577a24457d03-1C383035-9A93-A2DC-CF24BB81198976A6 and http://oee.nrcan.gc.ca/publications/statistics/sheu-summary07/space-heating.cfm

[2] Figure 4.3, "Energy Efficiency Trends in Canada 1990-2009", Natural Resources Canada, December 2011 http://oee.nrcan.gc.ca/publications/statistics/trends11/pdf/trends.pdf

infrastructure arsenal, and one worthy of engineers" and city planners" attention.

To accelerate DE implementation, Canada should take the opportunity to learn from, and catch up to, world-class DE leaders such as Denmark. The people of Denmark have enjoyed tremendous success in achieving energy savings through the construction of thermal grid networks throughout the country. Denmark is a particularly interesting case study because its weather climate conditions are comparable to much of Canada's climate. Many Canadian cities face some of the same energy challenges as experienced in Copenhagen, so understanding how these challenges were successfully overcome is instructive. In this chapter, the Danish approach of using DE solutions to heat and cool buildings is also examined to illustrate what is possible in our largest Canadian metropolis, the City of Toronto, and even more broadly, the Province of Ontario.

In jurisdictions such as Denmark, Sweden and Austria where DE implementation has been successful, this success has been supported and enabled by consistent political vision, legislation, regulation, and fiscal incentives. With the exception of British Columbia, and a few municipalities, Canada has not embraced this approach. Canada needs to change its approach and focus more on local energy planning, by ensuring at all levels of government, that:

1. A long-term thermal energy policy is established.
2. All levels of government adopt, or adhere to, legislation that includes thermal and electrical energy efficiency as key considerations in land use planning.
3. Supportive fiscal legislation and tools are put in place to help municipalities establish a DE network.
4. Supportive local building policies are in place to enable DE within communities.

Political leadership is needed to apply these tools and invest in Canada's vision of becoming a sustainable energy superpower.

Introduction

Every region of Canada has a rich history of constructing massive infrastructure projects to serve the energy needs of a relatively dispersed population over large and challenging geographic areas. There is little doubt that engineers in this country have added immense value to the capture, extraction, conversion and delivery of an abundance of natural energy resources. Indeed, the ability to extract, convert and transport these resources over large distances, efficiently and effectively, has been at the root of Canada's wealth.

Looking forward, many parts of Canada are considering large transformational energy supply projects. Aging energy infrastructure, rising energy prices, increasing urbanization, changing wealth patterns, and continued concerns regarding the building of new large energy infrastructure are driving changes to the country's energy planning environment. Engineers and planners can also work together to consider large, paradigm-shifting energy-use projects at the city and/or local community level. Long-term energy security and resilience requires that local resource stewardship be given much closer attention.

Municipalities are at the front lines of this transformation. There is an opportunity for city builders to endorse and/or invest in efficient municipal energy infrastructure, such as District Energy (DE) systems. These systems would facilitate efficiency and reduce community dependence on any one fuel source.

Local Resource Stewardship: The Case for DE

If Canada is to become a sustainable energy powerhouse, Canadian cities will need to be as focused on resource stewardship[3] and efficient management as they are on resource extraction and transport. Since municipal powers and energy policy are provincial matters, this will require that each province and local authority carefully consider community thermal energy needs, and enable the building of DE systems[4] to efficiently supply energy to meet those needs.

This approach has significant co-benefits. Reducing local consumption means that provinces with capacity to export energy will increase their export capacity and diversify their revenue

Toronto, Ontario

[3] Stewardship is used in this chapter to refer to the responsible planning and management of energy resources.

[4] In this paper, DE systems are also referred to as thermal grids, integrated local energy systems, and can include thermal recovery systems, small scale Combined Heat & Power (CHP) units and thermal storage.

sources. For provinces that are net importers of energy, the benefits will be even larger. These provinces need to be particularly strategic in managing their energy given that their energy deficits make them especially vulnerable to energy supply interruption, including severe weather and man-made supply events. For all Canadians, a renewed focus on energy stewardship ensures that the needs of future generations will be met in a more cost-effective and resource-responsible manner.

DE as an Integral Part of Community Energy Solutions

In 2010, the average Canadian home consumed 67% of its total energy for space heating.[5] If Canadians are serious about conserving energy, space heating is an obvious place to start.

While heating has broad potential across many Canadian towns and cities, District Cooling (DC) is attractive in areas of high density with peaking summer energy needs due to hot weather (e.g., the corridor between Windsor and the Greater Toronto Area). This opportunity is also sizeable. The "sub-region" of Toronto, which makes up about 49 percent of Ontario's population and over 19% of Canada's population, offers wide scope for DE implementation.[6] In addition to space air conditioning, DC is also attractive for process cooling applications such as data centres and for institutional applications such as in hospitals.[7]

In general, DC has economic challenges in that chilled water technology is more capital intensive than heating equipment.[8] Cooling pipes need to be large because of the relatively small temperature differences between supply and return water. It is for this reason that many DE systems begin by laying a thermal grid foundation to supply heating in communities, and provided the density and cooling needs are present, these systems can evolve to offer cooling and electricity supply.

What is District Energy?

District Energy is a foundation for integrated community energy solutions that can optimize local fuel choices. DE is not new, and it is not a single technology. Rather, it is a network that deploys and integrates proven technologies in community-scale infrastructure to produce and distribute thermal energy. As an approach to community energy production and delivery, it is tried and tested, and widely deployed in many parts of Northern Europe.

DE is also being evaluated and implemented widely in select parts of this country. British Columbia (BC) is currently the most active Canadian market, driven largely by environmental legislation which has its foundations in efficient resource management and climate change mitigation. In BC, as in other parts of the country, DE has become an important component of sustainability plans allowing communities to achieve energy goals, environmental objectives and further economic competitiveness. DE implementation has often been facilitated by supportive land-use planning and building approaches.

A District Energy System (DES) is typically comprised of three components – an Energy Centre (EC), a thermal grid referred to as the Distribution Piping System (DPS), and the building Energy Transfer Station (ETS). Thermal energy (heating or cooling) is produced

5 The average Canadian household consumed 106 GJ of energy for use in the home in 2007 of which over 60% is used for space heating and cooling. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ca&rn=2&page=4&CFID=31395328&CFTOKEN=87e6577a24457d03-1C383035-9A93-A2DC-CF24BB81198976A6 and http://oee.nrcan.gc.ca/publications/statistics/sheu-summary07/space-heating.cfm

6 http://www.canadafaq.ca/where+do+most+canadians+live/.

7 Later in this chapter, the City of Toronto's DC system is considered which capitalizes on Lake Ontario's ("free") cool water supply to "fuel" the system. DC is also employed in Ottawa's Parliament Hill which makes use of natural cooling from the Ottawa River.

8 The proportional split in costs between cooling and heating in combined heating and cooling DE systems is roughly 65/35 between cooling and heating costs.

at the central plant, the energy is then carried down through the DPS (usually steam, hot water, or chilled water), and exchanged at the building's ETS interface. DE systems have the capability to deliver heating and cooling to customers and to capture waste heat from buildings (i.e. data centres, treatment plants, etc.) and use that heat to produce needed thermal energy via a closed loop system.

Energy Centres

The EC is the source of thermal energy in a DES. Given that this thermal energy is transmitted to end users using water (or steam in legacy systems) as a medium, multiple fuel feedstock materials can be used to generate the thermal energy. These feedstocks can take many forms, including natural gas, biomass, solar, deep lake water, geothermal energy, thermal storage facilities and waste heat from adjacent industrial or commercial processes.

Having the thermal grid in place provides scale and scope, and allows communities to heat and cool their buildings by any fuel source, on a mass scale. A built-out thermal grid network, such as that which exists in Denmark and throughout many other European countries, has enabled the wide-scale use of renewables, in particular low-temperature district heating (e.g. solar heating, geothermal), which would not be possible with individual heating systems. The EC grid fortifies a community's energy security, and can reduce GHG emissions and fossil fuel consumption when combined with lower emitting feedstocks, and/or by substituting technologies over time as alternative fuels become more abundant, or as technology advances. Due to the design of a DES, rather than retrofitting thousands of homes, only a small number of centralized plants require updates to achieve widespread community benefits.

A DES also reduces communities' dependence on any one fuel, and allows them to respond to energy price and supply fluctuations over time. This is precisely what happened in Northern Europe after the oil shock of the 1970s, when countries such as Denmark, Sweden, Finland and Austria invested heavily in DE infrastructure.

Although the vast majority of thermal heating in Canada still comes from traditional fossil fuel sources, Canadians have experimented with renewable sources of energy in the DE systems that are in place.

The Drake's Landing Solar Community is a master planned community in Okotoks, Alberta that uses solar as its primary source of heating for the DES. Ninety percent of space heating needs at Drake's Landing are met by solar thermal power. Relative to a "conventional approach" to development which relies on individual heating technology, and fossil fuels, Drake's Lading solar thermal community achieves a reduction of 5 tonnes of GHG per home every year.[9]

Other Canadian communities, like Revelstoke and Prince George, British Columbia, have turned sawmills into thermal energy sources. Waste from the mill is burned for electricity, and the thermal energy is recovered as "waste heat" which is used to heat buildings in the communities. In both of these cases, the EC is on the sawmill site and thermal energy is piped to the community. Using a similar line of thinking, Vancouver and Halifax have sewage heat recovery systems that take waste heat (ultimately a "free" fuel resource) from the city sewage system. Ouje-Bougoumou, Quebec uses forest biomass; and Charlottetown, PEI uses municipal solid waste and biomass to fuel their DE systems.

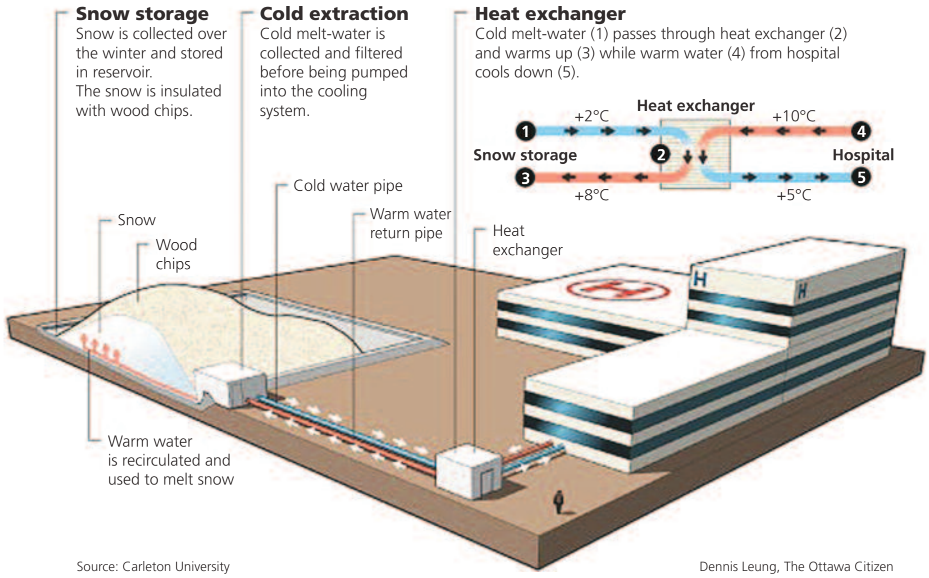
[9] http://www.dlsc.ca/

Figure 1
Schematic of Snow Cooling in Sundsvall

Image courtesy of IEA

Storing Snow for Summer Cooling

The leading cold energy project is in Sweden, where snow dumps are used to cool Sundsvall Hospital.



Other countries, with more pervasive thermal grid infrastructure, have advanced even further in the stewardship and application of local resources to meet the energy needs of large populations in an economic manner. Sundsvall Hospital[10] in Sweden highlights the ingenuity of DE systems operating on locally available resources. The hospital uses the piles of snow shovelled from roads throughout winter as a source of cooling in the summer. The snow piles are thermally insulated by woodchips and the melt water is collected, filtered, and pumped into the cooling system. Environmental concerns continue to serve as important additional drivers in Danish policy, which motivated changes in the fuels used in the generation of thermal energy over time. The Danish thermal grid now relies heavily on both recycled heat sources that otherwise would be wasted (including surplus heat from electricity production (i.e., Combined Heat and Power systems - CHP), waste-to-energy plants, and industrial processes), and renewable heat sources (including forest-based biomass, geo-exchange, solar, wind and biogas). By utilizing surplus heat from industry and various renewable sources, the consumption of primary energy resources is reduced. By 2006, Denmark achieved energy self sufficiency, with CHP units delivering 47% of thermal electricity needs and 82% of District Heating needs.[11] Today, 98% of Copenhagen's population is served by DE systems that are fuelled by waste and renewable sources.

These are just a few examples of how other communities and countries are meeting their energy needs in a manner that reflects principles of stewardship, economic responsibility and innovation.

Distribution Piping System (DPS): The Thermal Grid

A DPS is a network of piping that brings hot water, steam, or chilled water from a centralized plant to a cluster of buildings. Distribution piping used in the Markham District Energy System can be seen in Figure 2. The buildings in turn use this heating/cooling source to meet the needs for space heating, cooling, or domestic hot water. It is analogous to the electricity transmission and distribution wires in an electricity grid. Akin to this grid (as discussed above),

[10] Image Courtesy of IEA: IEA, CHP/DHC Country Scorecard: Denmark, 2008 at http://www.iea.org/g8/chp/profiles/denmark.pdf.

[11] IEA, CHP/DHC Country Scorecard: Denmark, 2008 at http://www.iea.org/g8/chp/profiles/denmark.pdf.

Figure 2
District Energy Pipes in Markham, Ontario

Image courtesy of FVB Energy

multiple feedstocks can be used to create the energy that it transmits. It is typically the costliest part of the DES infrastructure; however, it is a critical component that links the central plant to its customer base. Where dense, more compact communities are planned, there are even more opportunities for efficiencies and cost savings in the building of this "thermal grid".

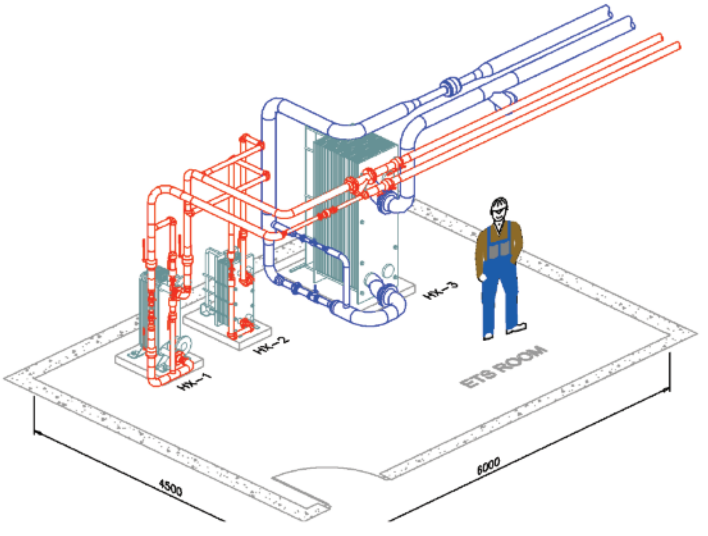
Like other municipal infrastructure, such as water and sewage, the DPS is usually underground (but can be above ground where permafrost is an issue) and will last a very long time. Canada's oldest steam system is in London, Ontario dating back over 100 years.

Energy Transfer Stations (ETS)

The ETS is the interface between the DPS and the building HVAC system.[12] Figure 3 depicts a typical ETS configuration. Buildings are connected to the central plant via underground pipes, and as water enters the system it interfaces with the building's Heat Exchanger (HX) sending ambient water back to the EC.

Figure 3
Typical ETS Configuration

Image courtesy of FVB Energy



[12] Though there is the possibility of a direct connection where the same water in the DPS runs through the building, it increases the chances of fouling the water amid other complications. Most DE system operators prefer that the DPS remain a closed system that simply interfaces with the building's system via the heat exchanger.

Benefits of District Energy: Delivering Value to Canadian Communities

Efficiency

Traditional energy delivery systems operate at much lower efficiencies than modern district energy systems. The efficiency of fossil-fuelled electricity generating plants is typically between 30 - 45%.[13] This means that nearly two-thirds of the energy produced during combustion at large centralized power stations is rejected into the atmosphere as "waste" heat during production.

Once the DE grid is installed, energy efficiencies can be further enhanced through the addition of "ancillary infrastructure", such as small-scale Combined Heat and Power (CHP),[14] which enables electricity to be generated closer to densely populated areas, with the rejected "waste heat" from the CHP system captured to heat buildings through closed-loop heat networks.[15] DES with CHP can achieve system efficiencies of 80% or more by the co-production of thermal and electrical energy. Efficiency gains are increased due to shorter transmission lines than associated with large-scale systems.[16] The reduced fuel consumption also results in commensurate reductions in carbon emissions.

The addition of thermal energy storage units can further optimize operating efficiencies, as can the use of proximate wasted heat from buildings and industry. Manufacturing processes often produce heat as a by-product. This heat is most commonly rejected into the atmosphere. Large-scale commercial applications, such as data centres, similarly produce rejected heat. A thermal grid would allow recovery of that heat which would otherwise be vented into the atmosphere, and the simultaneous delivery of cooler water to the manufacturing facility.

The City of Markham's DE systems have both CHP and thermal storage, achieving a 50% reduction in GHG emissions relative to business-as-usual practices.

There is a growing range of evidence that the wider development of small-scale CHP in association with DE infrastructure is a cost-effective means of accomplishing energy efficiency and GHG reduction goals in the near term. The US Environmental Protection Agency CHP Partnership in 2008 supported the installation of 335 CHP plants stating that this also achieved CO_2 emission reductions equivalent to taking 2 million cars off the road, or planting 2.4 million acres of forest.[18] Furthermore, in a study to assess the cost abatement policies in the Netherlands, CHP was identified as one of the least cost solutions, lower than building insulation, condensing boilers and wind power (Boonekamp et al, 2004).[18] In a 2013 study to compare the cost-effectiveness of alternative strategies to reduce GHG emissions in Ontario, a 5 MW natural gas CHP facility was seen as four times less costly (capital dollars per GHG emission tonnes avoided) than a 250 kw Solar PV facility.[19]

When considering the efficiencies of DE/CHP systems, and the proportion of end-use energy consumption associated with space heating and cooling, the benefits of DE systems becomes apparent.[20]

[13] Gilmour, B., & Warren, J. (2008, January). The New District Energy: Building Block for Sustainable Community Development. Canadian District Energy Association. Toronto: Urban Energy Solutions. p. 20.

[14] Combined Heat and Power (CHP) burns a fuel (often natural gas but could easily be biofuel or solid waste) to produce electricity. This process is very heat intensive and requires the entire system to be cooled. This "rejected heat" can be put into the DE system and sent down the pipes to heat homes and offices rather than be vented to the atmosphere and wasted while having these other buildings burn their own natural gas for heat.

[15] King, M., & Shaw, R. (2010). Community Energy: Planning, Development and Delivery. Retrieved November 2012, from http://www.tcpa.org.uk/data/files/comm_energy_plandevdel.pdf, p. 2

[16] Gilmour, B., & Warren, J. (2008, January). The New District Energy: Building Block for Sustainable Community Development. Canadian District Energy Association. Toronto : Urban Energy Solutions. p. 20.

[17] International Energy Agency, Cogeneration and District Energy, 2009, p. 15

[18] Ibid.

[19] Remarks delivered at October 29, 2013 Combined Heat and Power Workshop by Bruce Ander, CEO, Markham District Energy.

[20] Natural Resources Canada. (2012, May 29). Science and Technology: The ecoENERGY Innovation Initiative. Retrieved April 1, 2013, from http://www.nrcan.gc.ca/energy/science/2003

Assigning the "Right Energy to the Work"

DE systems can play a key role in Canada's reduction of high grade energy use. For example, the energy required to heat a room or a building in winter is of lower quality than the electricity needed to bring a kitchen oven to 250 degrees Celsius. Electricity is the highest quality form of energy, and using it for space heating or cooling means taking energy that can maintain a stove operating at a couple hundred degrees and using it to maintain room temperature around 22 degrees Celsius. This is not an efficient use of high-grade energy. Optimizing energy entails using the right tool for a given job. In order to gain maximum efficiency, energy systems should be designed to address the demand for specific energy uses.

The economics of implementing the building infrastructure necessary to use "free" (or residual) waste heat or cooling would be very challenging. For example, it would be very difficult and expensive to run a pipe from a nearby lake to take advantage of the lake as a massive heat sink if it were only to service one building. With a DES however, only one point of heat exchange needs to be built and the entire community can take advantage of a relatively low cost source of heating or cooling.

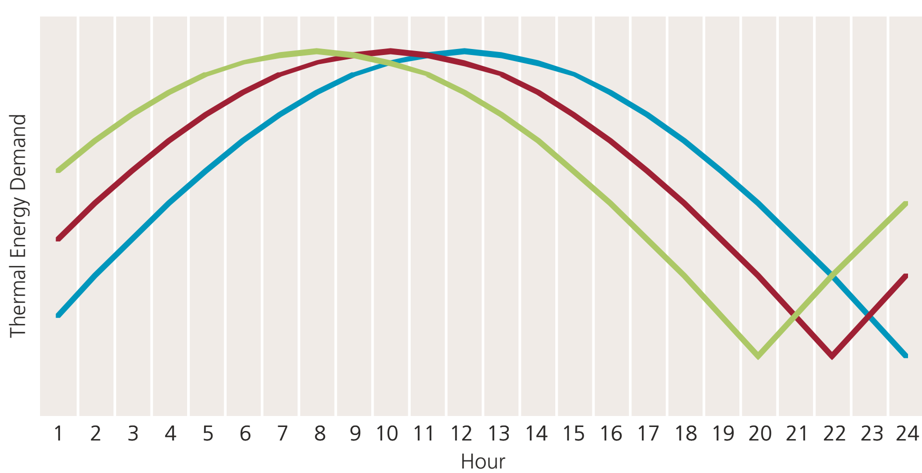
Energy stewardship means allocating electricity, one of the highest forms of energy, to appropriate uses. A DES enables beneficial use of surplus thermal energy from dispersed sources allowing us to tap into lower grade energy to condition a room or a building. Designing cities in a way that optimizes the use of waste heat can foster conditions wherein the overall need for energy is reduced and the "right energy is assigned to do the appropriate work."

Hitting the Sweet Spot

DE systems also take advantage of hitting a boiler and chillers' "sweet spot" or, in other words, operating efficiency.[21] This arises because there is a higher likelihood of equipment in a DES operating in the optimal efficiency range compared to stand-alone buildings. The lines in Figure 4 are meant to be illustrative of thermal energy load profiles of three buildings or institutions over a 24-hour period. Since different buildings will hit their peak loads at slightly different times, an integrated DE system is able to operate at a more consistent level, and closer to optimal efficiency, by tracking and managing the portfolio of building needs.

Peak energy use usually occurs only a few times a year for both heating and cooling – on the coldest and hottest days of the year, or of a multiple-year period. However, buildings are fitted

Figure 4
Conceptual Illustration of Staggered Loads with Three Hypothetical Buildings



[21] The City of Toronto's study of DE potential acknowledged the inherent inefficiency of the "Business As Usual" conventional build-out approach, in their 2010 Genivar study, and that this approach would cause them to miss their GHG targets. "While each type of building has different electrical and thermal load profiles, the heating and chilling equipment is generally sized to the ASHRAE 99% weather data for maximum rating and equipment selection of the facility – which is only needed for 1% of the year. For the balance of the year, the oversized conventional equipment typically operates in less efficient High – Low – Off mode. Hence, for example, boilers with performance datasheets quoting +80% efficiency (at peak load) are frequently only achieving 60 to 65% efficiency over the year. This is analogous to operating a car under stop and go city conditions. This is termed seasonal efficiency and is reflective of significant diversity of energy load through the day and the seasons.... it is agreed that continued development in BAU protocol will miss the 2050 GHG Target Emission Level by 14 Mega tonnes per year." Genivar, Potential District Energy Scan in the City of Toronto, September 2012 (http://bbptoronto.ca/wp-content/uploads/2012/06/FINAL-GENIVAR-Report-City-of-Toronto-District-Energy-September-4-12.pdf) , p. 10

New York: Where the Lights Stayed On

Unprecedented in its size and affecting 21 states, the total estimated cost of the impact of Sandy's wrath was over $70 billion. During Hurricane Sandy, it took days – and sometimes weeks – for utility workers to restore electric services across large swaths of New England and the Mid-Atlantic region, including New York City. Indeed, 8.5 million customers lost power during Sandy. Understanding where the lights stayed on during Sandy might provide valuable lessons to city leaders looking to mitigate the effects of increasingly frequent severe weather events. For example, in Co-op City, a 40 MW CHP/DE system continued to provide lights for more than 60,000 residents during and after Sandy's gale force winds and storm surge. And it wasn't just Co-Op City residents. For four days, the CHP system provided the 290 units in this Manhattan residential complex with all its heating, water, and electrical needs, including elevators, until the grid was back up. Though typically home to about 720 residents, the building nearly doubled its population after Sandy as those without power sought refuge among friends and family who lived there. Contrast that with New York City's public housing facilities, which are often well-suited for CHP, where residents went up to two weeks without electricity and over 15,000 of them were still dealing with no heat or hot water well after that. In the same way, a small number of other facilities – including hospitals, universities, and public service facilities – kept their power, heat, and critical equipment running.

Source: Drawn from American Council for an Energy Efficient Economy, December 6, 2012 "How CHP Stepped Up When the Power Went Out During Hurricane Sandy," By Anna Chittum, Senior Policy Analyst

http://www.aceee.org/blog/2012/12/how-chp-stepped-when-power-went-out-d; and "Lessons from where the Lights stayed on During Sandy," http://www.forbes.com/sites/williampentland/2012/10/31/where-the-lights-stayed-on-during-hurricane-sandy/

with systems that operate year-round to meet these peak needs. The advantage of the DES is that the boilers and chillers are aggregated in one place. In part-load conditions, the energy centre might only run two out of five boilers, but will run both very efficiently. Moreover, aggregating customer loads across a community can serve to "level out" the demand curve by combining different customers with different peak and off-peak demand periods. This contributes to further optimization of equipment operation.

Resilience and Security

A thermal grid, with small-scale CHP, also increases the reliability of the electricity generating system. Given trends in urban population growth, it is likely that future electricity supply facilities will need to be built to maintain electricity supply reliability (particularly at peak load times), and operate in targeted urban and electricity system-constrained areas.

DE systems can be built so that they can be "isolated" from the main electricity grid — continuing to provide thermal and electrical services to critical loads.

The experience of some New Yorkers during the 2012 Hurricane Sandy illustrates the immediate benefit that a DES brings to provide backup supply security, islanding capacity and such important services as black-start capability. During the hurricane, CHP/DE systems played an important role in providing local resilience in the face of worsening weather and grid outages caused by climate and man-made supply crises. This mitigated communities" vulnerability to the failure of grids that transmit power over long distances.

In late December 2013, the Toronto region experienced a record ice storm. Hundreds of thousands were without power for days and, in some cases, more than a week. Several deaths have been attributed to this ice storm as people desperate for heating brought outdoor devices inside the home, causing carbon monoxide poisoning.[22] The DES with CHP facility operating in Markham, Ontario had the ability to continue to provide power and heat to critical customers throughout this event (15 centres, and approximately 5 million square feet).[23]

Fuel Flexibility

DE systems offer the flexibility of fuel choice and upgrades over time, allowing Canadians to more easily modify the type of heating fuel used for space heating. Although the economics of renewable fuels may be questionable at the moment, given the low price of natural gas, future

[22] http://www.cbc.ca/news/canada/ice-storm-makes-christmas-a-dark-day-for-tens-of-thousands-1.2476164

[23] Conversation with Bruce Ander, President and CEO, Markham District Energy. The Markham DES capability was available, but never used, as the City did not officially declare a state of emergency during the 2013 Ice Storm.

prices are unpredictable. DE systems enable whole communities to switch from their individual natural gas furnaces to whatever heating source is available with minimal retrofits.

GHG Reduction

Energy plays a critical role in the quest to adapt, mitigate and reverse the impacts of climate change at a community level. According to a study released by the United Nations Human Settlements Programme (2010), 75% of commercial energy is consumed in urban and semi-urban areas. In addition, up to 60% of GHG emissions, which cause global climate change, originate from cities.[24] Nandi and Bose estimate that 70% of the global population will live in cities by the year 2050, further amplifying the strain placed on municipalities to provide energy services.[25] Interestingly, the International Energy Agency estimates that the proportion of global energy consumed in cities is greater than the proportion of the world's population living in cities – thus signalling that intervention is needed to reverse this trend.[26]

Considering the extent to which cities consume energy,[27] and the rate at which urbanization is taking place, reducing energy consumption in cities will be of paramount importance to combating climate change The way cities are planned and local energy systems are built has enormous potential to affect the efficiency with which energy is used, the type of local convertible fuels used (from proximate water or snow, to urban biomass and municipal solid waste), and the resulting quantity of GHG emissions.

A DES allows for optimized local fuel choices and increases the efficiency with which those fuels are converted to useful energy. Many DE systems in both Europe and Canada make use of local biomass materials (e.g., forest-based wood, urban-based forest materials, clean construction waste, etc.) to generate heat for their communities. In Europe, the use of municipal solid waste to generate heat is commonplace. Sophisticated systems, with advanced emission-mitigation technologies, are viewed as a sensible "closed system" approach to sustainability.

Economic Benefits

Communities can reap economic benefits from DES implementation, thereby providing the opportunity for local investment, jobs, and creation of local fuel resource supply chain development (e.g., urban forest biomass or clean construction wood waste).

Research undertaken in 2011[28] by Natural Resources Canada into the quantification of socio-economic benefits associated with DE investment in several Canadian communities indicated that there are positive economic multiplier effects for the dollars invested in terms of jobs and commercial activity. Using the District Energy Economic Model (DEEM),[29] the City of Markham was one of four systems studied. The DEEM results for Markham, although preliminary, indicate positive net economic benefits from local energy infrastructure investment, with every dollar invested by Markham in their DES generating economic impacts equal to $1.37 (i.e., GDP, tax base, wages). This does not include any return on equity of the DE investment itself.[30] A recent study of the City of Toronto also documented the potential economic benefits of district energy to that city.[31]

[24] El Sioufi, M. (2010). Climate Change and Sustainable Cities: Major Challenges Facing Cities and Urban Settlements in the Coming Decades, p. 5. UN-HABITAT, United Nations Human Settlements Programme. International Federation of Surveyors, p. 5

[25] Nandi, S. & Bose, R.K (2010). The Imperative of Efficient Energy Use in Cities: Analytical Approaches and Good Practices. In Bose, R.K. (Eds.), Energy Efficient Cities: Assessment Tools and Benchmarking Practices(pp. 1-20). Retrieved from http://www.esmap.org/node/271

[26] International Energy Agency. (2008). World Energy Outlook 2008. Retrieved February 7, 2013, from http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf

[27] In 2006, the global primary energy use in cities was 7,900 Mtoe (million tonnes oil equivalent), or 67% of global demand; however, global city energy use is projected to grow by 1.9% per year, and make up 73% of global demand by 2030 (International Energy Agency, 2008, pp. 182, 184). Therefore, urban areas will continue to increase in importance as strategies for mitigating climate change are developed. Reducing urban energy demand and implementing local embedded energy solutions including district energy and distributed generation technologies must be a component of these strategies if climate change goals are to be realized. This positions our cities at the crux of the climate challenge where solutions to critical energy issues will have most significant impacts. Municipalities generally cannot adequately meet these complex challenges on their own.

[28] This pilot research is not yet publicly available.

[29] Bruce Ander, President and CEO, Markham District Energy, Presentation to QUEST Conference, November 12, 2013

[30] Bruce Ander, President and CEO, Markham District Energy, Presentation to QUEST Conference, November 12, 2013.

[31] Beck, T. et al. (2012). The Power to Grow: The Economic and Fiscal Benefits of Urban Development Facilitated by Local Generation, District Energy, and Conservation in an Electrically Constrained Scenario. University of Toronto Masters paper, prepared for the City of Toronto, Energy Efficiency Office and Department of Economic Development & Culture. Toronto.

Learning from DE Leaders

Denmark & Copenhagen

In just a few decades, Denmark has become a world leader in District Energy solutions. Its success story is based on a package of policies that evolved after the first Heat Supply Law was introduced in 1979, followed by a ban on electrical heating in buildings (1988), and national financial incentives to ensure the ongoing economic viability of CHP/DE.

The strategy was adopted as a result of the oil crisis that Denmark faced during the 1970s, at a time when more than 90% of Danish energy was met by oil imports. The energy crises of 1973 and 1979 resulted in long-term increases in energy prices and a heightened awareness for enhanced fuel flexibility. Emphasis was placed on having more secure energy supply and more efficient generation and use of energy, making CHP/DE a natural, competitive choice.[32]

The 1979 law required municipalities to carry out studies on their future needs for heating, and on the potential for district heating (DH) in their jurisdictions. It also allowed for the zoning of DH networks to replace individual oil boilers. Crucially, the expanded provision of DH was supported by a new power for local authorities to require households to connect to the networks.[33] The law created a clear strategic goal, and relied on strong local and municipal participation. Sharing responsibility and involving local authorities in this national planning process has been an effective way of creating an efficient heating network in Denmark.

A new planning system launched in 1990 mandated local authorities to convert DE providers to CHP providers. DE and CHP played a critical role in reducing Copenhagen's carbon footprint and securing fuel supply, primarily using local energy resources as feedstock. Power plants run as CHP stations where the steam is extracted from a turbine to heat water for large scale DH networks. Fiscal measures related to specific fuels have resulted in 35% of the CHP plant fuelled by surplus heat from waste incineration, and the remaining production of district heating is based on geothermal energy and fuels such as wood pellets, straw, straw pellets, natural gas, oil and coal.

Environmental concerns have been addressed by the ability to switch feedstock to lower emission fuels, and the addition of CHP.

More recently, the Danes have further benefitted by the synergistic opportunity of a holistic energy approach—one that realizes the value integrating their thermal planning more broadly with electricity planning. This has arisen because electricity system changes developed in isolation have resulted in a significant and increasing amount of intermittent electricity produced by wind. Rather than exporting surplus base load generation at a loss, at times when there is surplus (and non-dispatchable) renewable electricity available, the Danes are seeking integrative solutions to utilize the surplus electricity within the country by using the surplus to power heat pumps in DE systems using geo-exchange technology. The Danish investment in a geographically significant thermal grid has become a crucial part of the energy infrastructure, enabling utilization of fluctuating renewable energy sources.[34]

Denmark is a leader in DE/CHP, and it is important to learn from those who lead. The experience of Copenhagen illustrates the benefits to communities from utilizing DE/CHP to

[32] IEA, Cogeneration and District Energy, 2009, pp 18-19

[33] Danish Energy Authority, Heat Supply in Denmark Who What Where and Why, 2005, http://dbdh.dk/images/uploads/pdf-diverse/varmeforsyning%20i%20DK%20p%C3%A5%20engelsk.pdf

[34] Closer to home, this is not dissimilar to the Markham Ontario DE system, which is seen by the municipality as being their most strategic energy asset, facilitating their economic goals as well as meeting their energy and environmental goals. More detail on the Markham experience is contained below.

support local economic development, energy efficiency, energy security and resilience to unforeseen events.

Energy strategy is as much a city planning issue as a technical issue, and communities have been vital players in achieving greater scales of energy sustainability and increased economic value.

A Case Study: Applying the Danish Approach in the Province of Ontario

It is interesting to consider what would happen if Ontario followed the same path as other DE leaders and invested in building DE systems to salvage waste heat.

In Denmark, electricity generation facilities cannot be built unless a recipient for waste thermal energy is first identified for the waste heat. Closer to home, the City of Markham has been a leader in the deployment of DE in two growth nodes. As a result, since 2000, Markham District Energy has invested in four small-scale CHP units totalling 15 MW, and uses rejected heat to supply the thermal energy needs of its customers.

The province of Ontario could insert this requirement into energy policy, particularly with thermal generation stations that are built in proximity to communities. If Ontario were to recover all the "waste" heat generated by gas fired generators and use it for space heating purposes, the province could reduce its natural gas consumption by 4.6 billion cubic metres annually.[35] This is enough natural gas to heat 1.5 million Canadian homes[36] and is equivalent to reducing emissions by 864 Mega tonnes of CO_2 annually.[37]

As illustrated in Figure 5,[38] Toronto is growing at an unprecedented rate and is leading in the construction of the most high-rise buildings in all of North America for 2012. The city is welcoming 178 high-rise construction projects, thereby further increasing the density of the city's built form and introducing a need to heat, cool and power a new stock of buildings.

Energy Challenges in the City of Toronto

Toronto, with a population of 2,615,060 (or 7.8% of Canada's population),[39] is already home to Canada's largest DES. The Enwave system currently keeps 200 downtown buildings air conditioned via a world-famous deep-lake water cooling system. As impressive as this system is, however, there has been remarkably little new investment in DE infrastructure over the last several decades despite Toronto facing growing energy challenges.

For Toronto, most of the energy supply is produced outside of the city, with approximately $4.5 billion spent on energy each year.[40] At the same time, the downtown core of Toronto is experiencing the highest growth rate in condominium development in North America. With industry moving out and condominiums moving in, population and energy intensification are predicted to continue. On average, two condo proposals add the equivalent of three 8,000-person Ontario towns within a six block area.[41]

While demand for all types of energy is expected to increase in the city, the electrical capacity and reliability is of particular concern, especially in the downtown core which is supplied with electricity by just two transmission lines and one small central power plant.

[35] Electricity production data provided by the Ontario Independent Electricity System Operator. 28,750,000 MWH gas fired generation. 60% efficiency for combined cycle.

[36] Assuming that, on average, Canadians use 92 GJ of heating energy per household. http://www.statcan.gc.ca/pub/11-526-s/2010001/part-partie1-eng.htm

[37] Using emissions factor for Ontario http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=AC2B7641-1

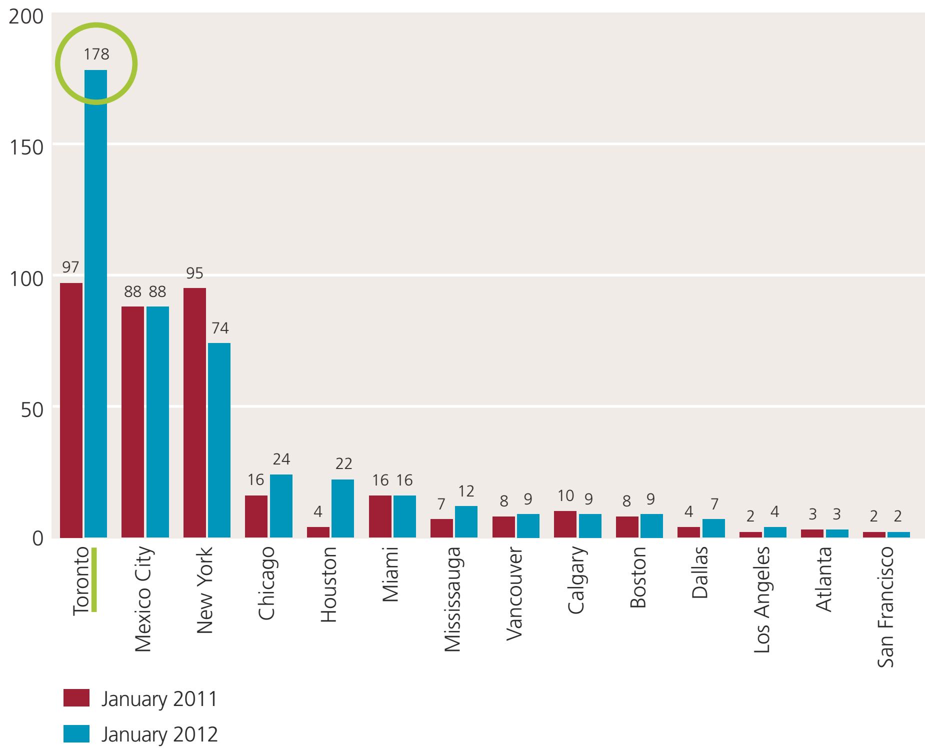
[38] Chart adapted from: Baxter, Jim, Director Environment and Energy Division, City of Toronto. "Energy Crunch in the City." QUEST Conference Presentation. November 13, 2013.

[39] Census Canada. (2012). 2011 Census: Population and Dwelling Counts. Retrieved from: http://www.toronto.ca/demographics/pdf/2011-census-backgrounder.pdf pp. 1

[40] Genivar, Potential District Energy Scan in the City of Toronto, September 2012 (http://bbptoronto.ca/wp-content/uploads/2012/06/FINAL-GENIVAR-Report-City-of-Toronto-District-Energy-September-4-12.pdf) , p. 3.

[41] Baxter, Jim, Director Environment and Energy Division, City of Toronto. "Energy Crunch in the City." QUEST Conference Presentation. November 13, 2013.

Figure 5
Bar Graph Depicting the Number of High-Rise Construction Projects in Major North American Cities



Electricity demand in downtown Toronto is approaching supply capacity, particularly at summer peaks, and fears of continued extreme weather events are growing. Adding large-scale generation and transmission infrastructure and even refurbishing or replacing aging electricity distribution infrastructure is difficult and expensive in the crowded right-of-way corridors of downtown Toronto. Large-scale refurbishment also often attracts significant community opposition.

Energy Savings Potential of Expanded District Cooling in Toronto

What would happen if Toronto followed the same path as Copenhagen and invested in building energy-saving thermal grids for District Heating and District Cooling in its growth nodes?

The Enwave system[42] in Toronto takes water from Lake Ontario in a deep part of the lakebed where the temperature is a constant 4 degrees Celsius year round. The cold water is used to pre chill Enwave's District Cooling system before being fed to the city's potable water system.[43]

The Enwave system is unusual in that it uses drinking water as the coolant. What would happen if Toronto decided to make a commitment to expand its use of the available cooling sources for all its space cooling needs? The city uses approximately 420 million litres of water daily. If the City expanded its system to use all of its potable water supply to extract thermal cooling energy, similar to Enwave's Deep Lake Water Cooling system, roughly 670,000 kWh of electricity per day could be reduced. This is equivalent to 121 million m3 of natural gas that could be conserved on an annual basis assuming 60% efficiency for combined cycle generation.[44]

[42] Enwave Energy Corporation, a private corporation owned by Brookfield Asset Management and formerly jointly owned by the City of Toronto municipal government and the Ontario Municipal Employees Retirement System, is one of the largest district energy systems in North America. Enwave was formed after the restructuring of the Toronto District Heating Corporation. Currently, 150 buildings in downtown Toronto are connected to the Enwave network.

[43] Cold water from the lake is passed through a heat exchanger to pre-chill the water being sent back from buildings before it re-enters the plant to be cooled and redistributed for space cooling purposes.

[44] Enwave is also evaluating options to expand the cooling capacity of their existing system through the use of underwater storage caverns.

Introduce a Long Term Thermal Energy Policy

Given the benefits of DE systems, it is important for Canadians to consider how DE implementation could be accelerated.

In jurisdictions where DE supplies a significant portion of the total heating and cooling needs, energy policy has explicitly included both thermal and electrical energy considerations and also included specific references to DE, with CHP. Public policy drivers have included: energy security; environmental issues; increased energy efficiency; and local economic development. Further, public policy goals are supported by enabling legislation, regulation and fiscal incentives to accelerate DE implementation. Left to itself, the market does not adequately recognize the broader public policy goals (i.e., energy prices do not adequately reflect long-term goals or externalities related to carbon).

There are many parallels between the public policy goals espoused in these other jurisdictions and those of most Canadian provinces with respect to environmental, economic and energy goals (e.g., Ontario's Green Energy and Economy Act, 2009).[45] Adding thermal policies in Canadian energy, environmental and land use planning legislation will allow provinces to accelerate the accomplishment of these goals.

Including Thermal and Electrical Energy as a Key Elements in Land-Use Planning Requirements

Land-use planning decisions guide the way cities look and grow. Most Canadian provinces lag behind leading jurisdictions in important land-use planning legislation. The political and practical decisions centre on shaping how and where our communities will grow, and have a direct impact on the social, economic and environmental performance of communities. Land-use planning is also considered a tool to curb sprawl as well as to support rational stewardship of resources by directing where residential, commercial, institutional, industrial, recreational and other infrastructure and essential services are located.

Municipalities are required to consider many types of essential infrastructure including water, transit, sewage, and recreational facilities, to ensure adequacy of supply to maximize the welfare of their citizens. Some provincial planning legislation considers certain kinds of electricity generation facilities. By adding thermal energy use and energy production in land-use legislation, land-use planning can also optimize the efficient use of local energy resources, including waste heat, in a way that increases energy efficiency, and reduces the draw on imported energy resources. Considering that thermal energy accounts for a significant portion of community energy needs, the lack of explicit thermal elements in land-use policies emerges as a startling gap that should be redressed through provincial legislation.

Supportive Fiscal Policy Regime

An investment in the Distribution Piping System (DPS) is capital-intensive with up-front expenditures yielding benefits over time as communities" thermal energy demands grow. Investment in thermal infrastructure is particularly challenging given the relative low price of competing alternatives, delivered through existing electricity and natural gas grid infrastructure. Unlike traditional energy delivery systems such as electrical systems with a

[45] In May 2009, the Ontario government passed the Green Energy and Economy Act ("GEA"), which further accelerated the implementation of renewable energy (i.e. electricity) and introduced the Feed-in Tariff program for renewable electricity generation. It was intended to expand renewable energy projects, promote a "green economy," and encourage all Ontarians to use energy efficiently. The GEA is best known for creating a number of feed-in tariff rates for different types of energy sources, and was focused exclusively on matters related to electricity. Prior to the introduction of the GEA, Ontario had enacted a number of different programs focused on electricity, introducing renewable energy or promoting conservation, including the Energy Conservation Leadership Act and the Energy Efficiency Act.

regulated rate base and recovery of incremental expenditures, there is no regulatory construct to support the up-front capital cost to transition communities to DE.

Many of the benefits of building DE grids are difficult to monetize for the municipal host (e.g., energy security, operating efficiency, economic development), and for many private sector investors, these benefits are irrelevant. Community resilience is becoming an increasing focus with every extreme weather event. Despite the benefit of greater local energy resilience, municipalities find it hard to fund capital to achieve the benefit. The private sector will not invest unless compensated for the incremental investment. Absent a carbon pricing regime, there is less financial motivation to migrate to non-conventional fuel sources. Without assured economic returns, DE projects will struggle to attract willing investors capable of bringing new DE projects forward. It will be difficult to attract large-scale investors, such as municipalities, utilities and pension funds capable of bearing the substantive up-front capital expenditures. If financing cannot be coordinated, developments will default to more conventional forms of energy delivery systems where long-term energy contracts and/or regulatory regimes provide revenue certainty, making financing easier.

It is for these reasons that public sector intervention has supported the growth of the DE industry in every jurisdiction in which it has grown. Fiscal incentives have taken the form of low interest loans, tax incentives, grants, and direct public investment.

A supportive fiscal framework will assist investors to overcome the fiscal challenge they face in building new thermal infrastructure. In the same way that Canadian electricity policy has been supported with appropriate fiscal policies, and executed through contracts and programs, DE/CHP systems need fiscal incentives or economic regulation. They are akin to other essential infrastructure.

Supportive Municipal Policies to Enable DE within Communities

Municipalities not only have the jurisdiction to drive a DE project, they also contribute to the longevity and success of a project. They have the authority to introduce progressive policy related to urban form, define growth nodes, determine areas and levels of density, and make developmental decisions with opportunities to blend residential, commercial, institutional, industrial or cultural uses through zoning bylaws.[46] All of these policy elements contribute to creating communities with the critical mass to support DE. Municipalities are responsible for local infrastructure, often own local utility companies, and are in a position to invest in DE projects, either directly or through a public/private partnership. Municipalities can facilitate DE through ensuring rights-of-way connections. They can also define DE areas where connection to an existing DH scheme is obligatory.[47] Municipalities have a key role in community consultation regarding energy options, communicating and positioning DE as a "green energy option" to key stakeholders. Municipalities can also influence developers to connect new builds to district energy or to incorporate community energy solutions through policy tools, moral suasion or by mandating connections.

For these reasons, provinces should support municipal planning tools to accelerate DE development. These planning tools have been used in many jurisdictions to great effect, positioning DE investment as a key part of essential municipal infrastructure, including:

[46] Compass Resource Management. (2010, July). Ontario Power Authority: District Energy Research Report. Retrieved October 2012, from http://www.powerauthority.on.ca/sites/default/files/news/16925_CRM_OPA_District_Energy_Research_Report_15July10.pdf.

[47] Such bylaws are in place in North Vancouver, Vancouver, Surrey and Richmond, British Columbia.

- Mandatory (or rewarded) connection
- DE-ready infrastructure
- Zoning bylaws
- Site plan control
- Use of local improvement charges to support grid investment
- Height and density bonusing and /or
- Expedited development permitting for DE connected buildings.

Conclusion

Like their European counterparts, Canadian communities and municipalities increasingly understand that local sustainable energy development will contribute to their economic, environmental and social objectives.

Conventional land-use planning approaches tackle energy at the end of the planning process, with energy considerations presently appearing secondary to building or community design. This approach misses the opportunity for increased efficiencies, the use of local energy fuels, and the application of other energy stewardship concepts. As such, the typical planning approach also fails to acknowledge the many tertiary benefits of including DE in city planning that are outlined above. This reactive approach promotes business-as-usual practices that result in conventional energy systems that lock communities into long-term, less adaptable energy scenarios.

Unfortunately, in many provincial jurisdictions, energy policies have focused primarily on electricity. Additionally, despite discussions of "smart grids," energy investment has predominately concentrated on large central electricity plants located hundreds of kilometres away from the communities they serve. This is not only an expensive approach, it condemns many provinces to the "status quo" approach for decades, one that is geared towards a "one-size-fits-all" model that is often out-of-sync with the needs of individual communities.

Community energy systems, including DE and small-scale CHP, are more responsive to community needs. These elements clearly affect communities and have the potential of facilitating greater local social acceptance by virtue of what they can contribute to local goals.

In jurisdictions such as Denmark, Sweden and Austria where DE implementation is successful, this success has been supported and enabled by consistent political vision, legislation, regulation, and fiscal incentives. With the exception of British Columbia, and a few municipalities, Canada has not embraced this approach. Canada needs to change its approach and focus more on local energy planning, by ensuring, at all levels of government, that:

1. A long-term thermal energy policy is established.
2. All levels of government adopt, or adhere to, legislation that includes thermal and electrical energy as key considerations in land use planning.
3. Supportive fiscal legislation and tools are put in place to help municipalities establish a DE network.
4. Supportive local building policies are in place to enable DE within communities.

Political leadership is needed to apply these tools and invest in Canada's vision of becoming a sustainable energy superpower.

It is time to focus on the full range of the energy cycle, and consider how energy is produced, delivered and used in order to support Canada's ambition to be a sustainable energy superpower. A tried and tested way to meet this ambition is to start with community-level District Energy Systems.

Biography

Terri Chu: Terri is project analyst at FVB energy. She has a particular interest in how the interaction of municipal infrastructure can be optimized to reduce overall energy consumption. Terri holds a bachelor's degree in aerospace engineering and a master's in civil engineering with a specialization in sustainable urban systems. Terri is the lead author of "How District Energy Systems can be used to reduce Infrastructure Costs and Environmental Burdens."

Mary Ellen Richardson: Mary Ellen's career in the oil, natural gas and electricity industries spans 30 years. Over the last 10 years, Mary Ellen has held executive positions with the Canadian District Energy Association (President), the Ontario Power Authority (Vice President Corporate Affairs) and the Association of Major Power Consumers in Ontario (President). Each of these roles entailed a broad geographic and sector reach, involving frequent interaction with private, public, academic and industry representatives from across Canada and Europe. More recently, Mary Ellen has contributed as a lead author in the Mowat Centre's report on energy planning. Mary Ellen has served on the management board of the Ontario Centre of Excellence in Energy, as a board member for EcoCanada, on Ontario Province's 2003 Electricity Conservation and Supply Task Force, on the Executive of the Stakeholders" Alliance for Competition and Customer Choice, on the Electric Power Engineering Education Consortium, and as a member of Hydro One's Customer Advisory Board. She has also been a member of both the City of Guelph's Mayor Advisory Task Force and the City of Vancouver Community Energy Advisory Committee. Mary Ellen has completed the Institute of Corporate Directors program at the University of Toronto.

Marlena Rogowska: Marlena Rogowska is an urban and regional planner with experience in both the public and non-profit sectors. Her experience in the public sector is focused on land-use planning and policy development, and climate adaptation strategies whereas her experience in the non-profit sector provides her with a unique lens of domestic and international approaches to city building and resource management. She has an interest in research exploring opportunities for energy efficiency gains with a focus on community energy planning and other embedded energy solutions. Marlena holds a Master of Planning degree in Urban Development from Ryerson University, and an Honours Bachelor of Arts in Environmental Studies and Political Science from the University of Toronto.

Chapter Reviewers

Bruce Ander is President & CEO of Markham District Energy (MDE). With over 30 years in Ontario's energy sector, Mr. Ander is currently Vice Chair of the International District Energy Association (IDEA); an industry association with over 2000 members in 26 countries. Other industry affiliations have included his role as Chair of the Canadian Energy Efficiency Alliance and APPrO (Association of Power Producers of Ontario). Mr. Ander is a Professional Engineer with a degree from the University of Western Ontario and holds a Masters in Business Administration from the University of Toronto.

Richard Damecour, P.Eng., MBA, Chief Executive Officer – FVB Energy Inc., is the International District Energy Association (IDEA)'s Chair of the Canadian Forum. He is the Chief Executive Officer of FVB Energy Inc., a consulting company specializing in district energy and CHP business development, engineering and marketing, with offices in Toronto, Edmonton and Vancouver. FVB also has offices in Minneapolis and Seattle in the US and various cities in Sweden. He has over 30 years of experience in the energy industry, including 12 years in oil and gas, and for the past 20 years has helped to develop at least 25 new district energy systems that have been successfully brought into service in North America and the Middle East. Richard is a registered professional engineer in the Province of Ontario and has an MBA from the University of Alberta.

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Tel.: 613-235-9056 • Email: info@cae-acg.ca

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