Energy Strategies for the Canadian Province of Ontario

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The current and future energy situations in Canada are put into perspective, and the importance of nuclear energy and controversies surrounding it are investigated. More specifically, to demonstrate the important role nuclear energy has to play in Canada's future, a novel energy modeling tool, Canadian Energy Systems Simulator (CanESS), is employed. CanESS is a modeling platform with a huge database that assists an analyst in defining different energy scenarios by modifying the variables such as population and contributions of different energy sources to the overall production. The CanESS results clearly show that expansion of nuclear energy production is required to meet energy demand and simultaneously reduce greenhouse gas emissions.

To formally study strategic issues connected to the ongoing conflict over nuclear power production in Ontario, the Graph Model for Conflict Resolution (GMCR) is utilized. This flexible systems methodology is used to study the nuclear disputes that existed in Ontario at two key points in time: the fall of 2008 and spring of 2010. The results of the 2008 analysis, especially the sensitivity analyses, show that the only decision makers (DMs) involved in the conflict who hold real power are the Federal and Ontario governments, although at the beginning of the investigation the Atomic Energy of Canada Ltd. (AECL) and the environmental groups had also been considered as participating DMs. The findings and information of the analysis in 2008, as well as an updated background for 2010, are used to perform another analysis in 2010. According to the results of the 2008 analysis, only the two governments are considered as the DMs in 2010. Meanwhile, their options or possible courses of action have also been changed. Again, at this stage the stable states of the game are found, and attitude analysis is carried out to obtain deeper insights about the dispute. The equilibria or potential resolutions of the 2008 analysis are found to be the transition states in the 2010 analysis. Specifically, it is discovered that if the Federal Government does have a negative attitude towards the Ontario Government, it is possible that the final outcome is a state that is among the least preferred states for both DMs.

Acknowledgements

I wish to express my sincere gratitude to my supervisors, Professor Keith W. Hipel and Mitali De, for their support, encouragement, and advice throughout the duration of my graduate studies. In addition to providing guidance for my research, they made arrangements for me to meet with professionals in my field of study. My supervisors believed in me and knew that I would successfully complete my degree.

I would like to extend my appreciation to my readers, Professors Jonathan Histon and Mahesh Pandey, for their constructive comments. I thank them for reading my thesis and providing valuable feedback that improved my thesis.

I would also like to thank many faculty, staff, Conflict Resolution Group members, and students in Systems Design Engineering. I am grateful to Mr. Conrad Hipel, who kindly helped me in proofreading my thesis; his comments and notes greatly improved my thesis. I also wish to express my acknowledgment to Mr. Michael Hoffman, Mr. Bert McInnis, and Ms. Shona Weldon at the "Whatif? Technologies" company for giving me access to their wonderful energy simulator software, CanESS, which was very helpful in my research. I highly appreciate their time and guidance in helping me to become familiar with the software and learn how to work with it.

I am thankful to my family, my precious parents, Dr. Mohsen Armin and Ms. Sholeh Khosravi, and my beloved husband, Mr. Babak Alipanahi, for their supportive role during my study. They were always there for me and taught me to have confidence in my work and abilities.

Dedication

This thesis is dedicated to my precious parents, and my beloved husband.

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Chapter 1

Introduction

Canada is a huge country with vast amounts of energy resources. Oil, gas, water power, and nuclear energy are the largest energy sources. Each Canadian province follows a specific electricity generation policy. For example, hydroelectricity is the most important source in Quebec, while in Ontario, nuclear energy plays a major role in electricity production. In this research, the effort is to provide an overall picture of the energy situation in Canada. Along with literature review, by using the software developed by the "Whatif? Technologies" company, Canadian Energy Systems Simulator (CanESS), the user is able to attain both a quantitative and qualitative understanding of the energy situation in Canada. Nuclear energy is found to be a very important source of energy in Canada. Investing on nuclear industry seems to be vital to have a bright energy future. With regard to nuclear energy, a very important conflict is going on in Ontario. Using the Graph Model for Conflict Resolution (GMCR) (Fang et al., 1993) makes it possible to investigate the Ontario nuclear energy dispute, which is an ongoing conflict between the Federal and Ontario governments.

1.1 Motivation

The goal of this work is to provide an overview on the energy situation in the country, with a special emphasis on nuclear energy in Ontario. Nowadays, energy is playing a significant role in people's lives. Considering the growing population and, consequently, energy demand, one may observe that the issue of energy production is becoming more challenging. The limitations of fossil fuels and their environmental impacts forces nations to be more focused on developing environmentally friendly methods of energy production. This study investigates the situation of energy and electricity generated by renewable sources, such as water, wind, bioenergy, solar, and geothermal, and non-renewable sources, such as coal, natural gas, oil, and nuclear. The aforementioned CanESS software and its associated data time-series are very helpful tools to improve the research.

Since the focus is on the energy situation in Ontario, by using CanESS, some simulations are performed to investigate this province in more detail. The data shows that, in Ontario, natural gas and nuclear energy will be the main sources in future. Nuclear energy is very important for Canada - it is a clean and almost unlimited source. On the other hand, natural gas is a fossil fuel, limited, and causes adverse environmental impacts. In addition, Canada has been one of the world's pioneers in nuclear technology since the technology of the atomic bomb was first developed. Regarding nuclear energy, Ontario is the most important province in the country. The Atomic Energy of Canada Ltd. (AECL) is located in Ontario and is responsible for the country's exclusive CANDU design, and the maintenance of CANDU reactors in the country and those built around the world.

However, there has been a conflict between the Federal and Ontario governments in the past couple of years. The Ontario Government intends to expand the Darlington nuclear site, and plans to procure its reactors from AECL. Meanwhile, the Federal Government announced the decision of restructuring and selling or privatizing AECL. Nuclear technology has been very important to Canada since its genesis. Huge investments have been made in this industry. If AECL is sold and the Ontario Government does not buy its reactors from this company, it is very possible that no other province will make any purchases from AECL in the future. Accordingly, another key purpose of this research is to model this conflict by using the GMCR method. This approach realistically models the conflict between two or more players with multiple alternative options.

This academic work is helpful to researchers who would like to have an understanding of the energy situation in Canada. Moreover, since the analyzed conflict is still an ongoing dispute in the country, this study is instructive to the decision makers and parties involved in the game.

1.2 Organization of the Thesis

This thesis is composed of six chapters as depicted in Figure 1.1. Chapter 2 studies the situation of different sources of energy in the country. This chapter provides very useful information about the contribution of each source in the country's energy production and use. In addition, in some cases, the advantages and disadvantages and related projects are discussed. This chapter puts energy situation into perspective. Furtheremore, since in Chapter 5 the nuclear energy conflict of Ontario is discussed, Ontario's energy perspective is also provided in Section 2.3. In addition, in Section 2.4 (Summary) the view of the Canadian Academy of Engineering (CAE) is explored. CAE had done the most in-depth analysis with regard to the energy issue in the country. In Chapter 3, the CanESS software is introduced, and some examples are provided to explain how it works. Then several simulations are performed. In this chapter, the significance of nuclear energy is well understood. Chapter 4 talks about the history of nuclear energy and the role of Canada in this regard. Since in the following chapter, the concentration is on nuclear energy, Chapter 4 provides a historical background about this source of energy in the country. The insights provided in Chapter 4 is important for the strategic study that is done in Chapter 5. In Chapters 2, 3, and 4, it is explained how nuclear energy is important to Canada. In Chapter 5, the conflict between the Federal and provincial governments is examined. The attempt is to model the dispute with GMCR methodology and its associated software, GMCR II. In this chapter, the methodology is explained, and the components of the model are described. Finally, in the final chapter, Chapter 6, the conclusions and further thoughts and future directions are provided.

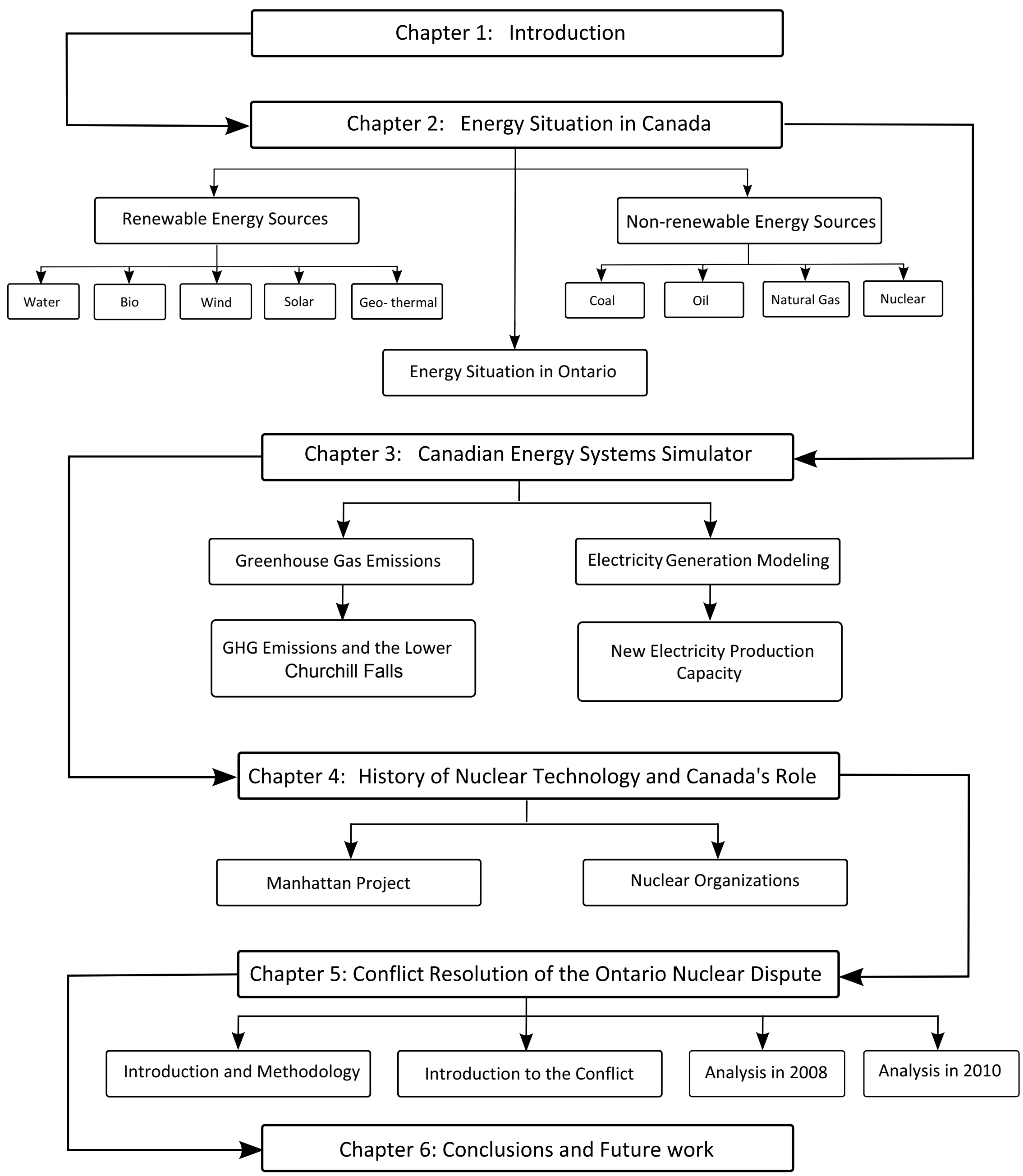


Figure 1.1: Layout of the thesis

Chapter 2

Energy Situation in Canada

The key goal of this chapter is to provide an overall perspective about the energy situation in Canada. The matter of energy is important to Canada which has an enormous potential for the development of different energy sources. In Sections 2.1 and 2.2, the situation of renewable (water, wind, bioenergy, solar, and geothermal) and nonrenewable (coal, natural gas, oil, and nuclear) energy sources in the country are explored, respectively. Their contribution in energy and electricity production, including advantages and limitations are also discussed.

In Section 2.3, Ontario's energy situation is reviewed. Since nuclear energy conflicts in Ontario are analyzed in Chapter 5, knowing about the "big picture" of the energy situation in Ontario provides relevant background material about Chapter 5.

Finally, the view of the Canadian Academy of Engineering (CAE) is explored in Section 2.4 (Summary). CAE has carried out a comprehensive energy study of a rich variety of energy "pathways" for meeting energy demand in Canada, and its work provides a very bright view of the energy situation in the country. CAE has also published a valuable report (Bowman and Griesbach, 2007) exploring short-term and long-term aspects of energy production in the country.

2.1 Renewable Energy Sources

Renewable sources of energy consist of water, wind, bioenergy, solar, and geothermal. These types of energy do not increase carbon dioxide levels in the atmosphere, and, unlike non-renewable sources such as coal, are renewable. Large hydro plants, being considered renewable, account for about 60% of the Canada's electricity production. Electricity represents about 20% of Canada's energy usage, so water provides about 12% of Canadian energy, and is the only considerable renewable energy source since, according to 2008 statistics, the other renewable energy sources account for only 0.5% of electricity production. A major energy goal in Canada is to improve renewable energy production in the country, and huge investments are in place (Environment Canada, 2010).

2.1.1 Water

Statistical Information

Canada has a huge amount of water resources and is the third country in the world in terms of fresh water resources. It is the world's second largest producer of hydroelectricity after China and provides about 13% of the world's supply. Quebec, British Columbia (BC), Newfoundland and Labrador (NL), Ontario, and Manitoba are the largest producers of hydroelectricity in the country (International Energy Agency, 2008a; Government of Canada, 2009). Figure 2.1 shows the electricity production in each province in 2008.

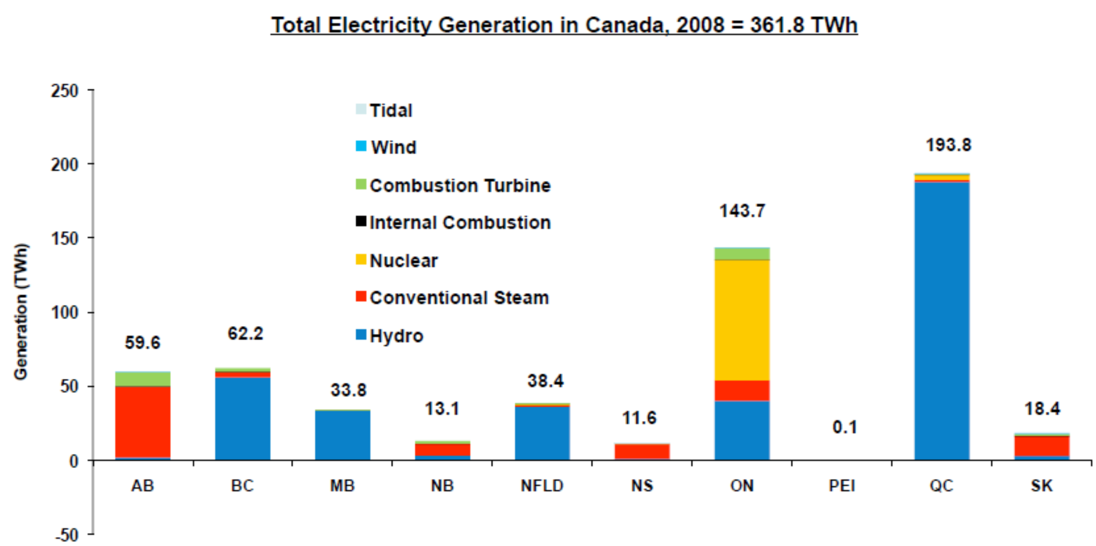


Figure 2.1: Electricity production in each province in 2008 (Canadian Electricity Association, 2008)

Hydroelectricity accounts for about 60% of the electricity produced in Canada. Figure 2.2 is obtained from the 2009 International Energy Agency report, and shows the amount of electricity produced by hydro power in Canada in comparison to other sources.

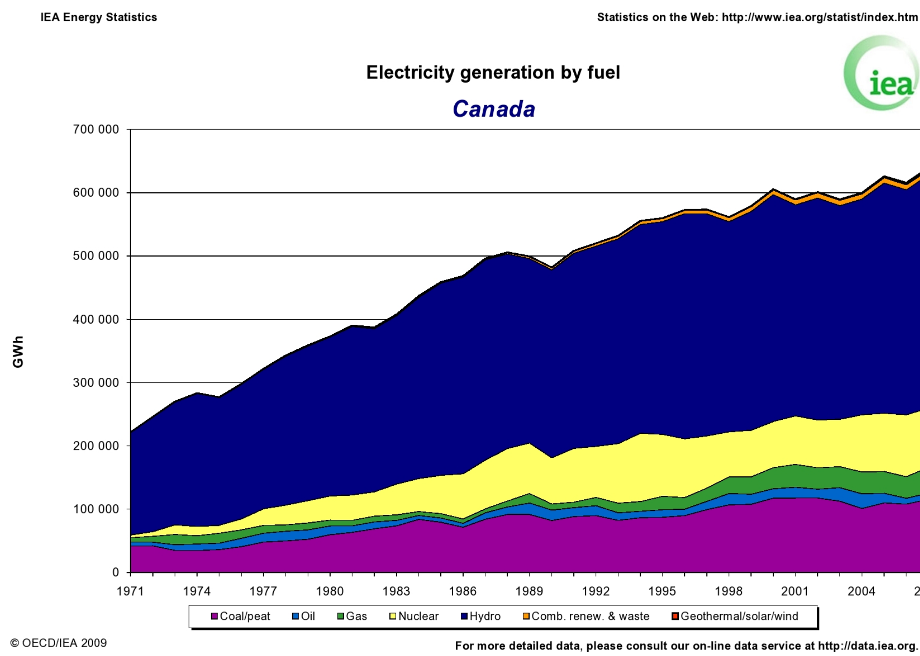


Figure 2.2: Electricity produced by different sources in Canada (International Energy Agency, 2009)

Hydroelectricity Advantages and Disadvantages

Hydroelectric facilities, like any other energy source, have their own advantages and disadvantages. The advantages are as follows:

- Hydroelectricity generation does not produce carbon dioxide. Some GreenHouse Gas (GHG) emissions do occur, but hydro plants release 60 and 30 times less GHG than coal-fired and natural gas power plants, respectively (Lathem, 2010).
- The technology is efficient; modern technologies can convert 95% of the energy in a river's flow to electricity, while the most efficient fossil fuel plants are about 60% efficient (Canadian Hydropower Association, 2008).
- Hydroelectricity production is an ideal backup for high demand periods and intermittent wind electricity generation. During increased electricity demand, a hydro plant can almost instantly respond by increasing the flow of water through its turbines. Nevertheless, the process of starting up a nuclear reactor and a coal-fired plant take about 24 and 12 hours, respectively (Canadian Hydropower Association, 2008).
- Few breakdowns happen in these plants, and they have a long service life; DeCew Falls in Ontario, Pointe de Bois in Manitoba, and Beauharnois in Quebec have been operating for 112, 99, and 75 years, respectively. In addition, the maintenance costs are low (Canadian Hydropower Association, 2008).
- Unlike fossil fuel energy, hydro power is produced through a short energy chain, so this energy can be more reasonably considered "renewable."
- Hydroelectricity is a domestic resource, meaning that its pricing is independent of other fuel price. For example, BC and Quebec have relatively low electricity rates in North America (Natural Resources Canada, 2009a; Canadian Hydropower Association, 2008).

The disadvantages are listed below:

- Methane is emitted due to vegetation decomposition in flooded areas. Studies show that the amount of methane emitted from reservoirs is considerable and contributes to air pollution. Although dams are less polluting than non-renewable resources, dam reservoirs account for over 4% of the total global warming impact of human activities (Lima et al., 2008; International Hydropower Association, 2010).
- Fish habitat is damaged by the bacteria in decaying vegetation which converts mercury in rocks to a soluble form (Centre for Energy, 2010).

- Hydro-power developments across boreal regions, especially if they contain logging, cause major assaults on boreal forests. Boreal forests are sources of carbon storage and water filtration. They are home to migratory songbirds and shorebirds, large populations of bears, wolves, and lynx, and native fish. In addition, Aboriginal communities depend on the region's ecosystems and wildlife for their livelihood and way of life (Schindler et al., 2010).

- To use the flow of rivers for hydroelectricity generation, a significant portion of the river flow must be diverted to that of another river or to a penstock, a pipe that brings water from the river to power turbines located at a lower elevation (Figure 2.3). This diversion leads to negative environmental impacts such as aquatic habitat quality reduction (Watershed Watch Salmon Society Coquitlam, British Columbia, 2007). For example, in the James Bay Project, the flow of Quebec's Eastmain River was reduced by 90% at its mouth and diverted north to the La Grande River (The Global Oneness Commitment, 2010).

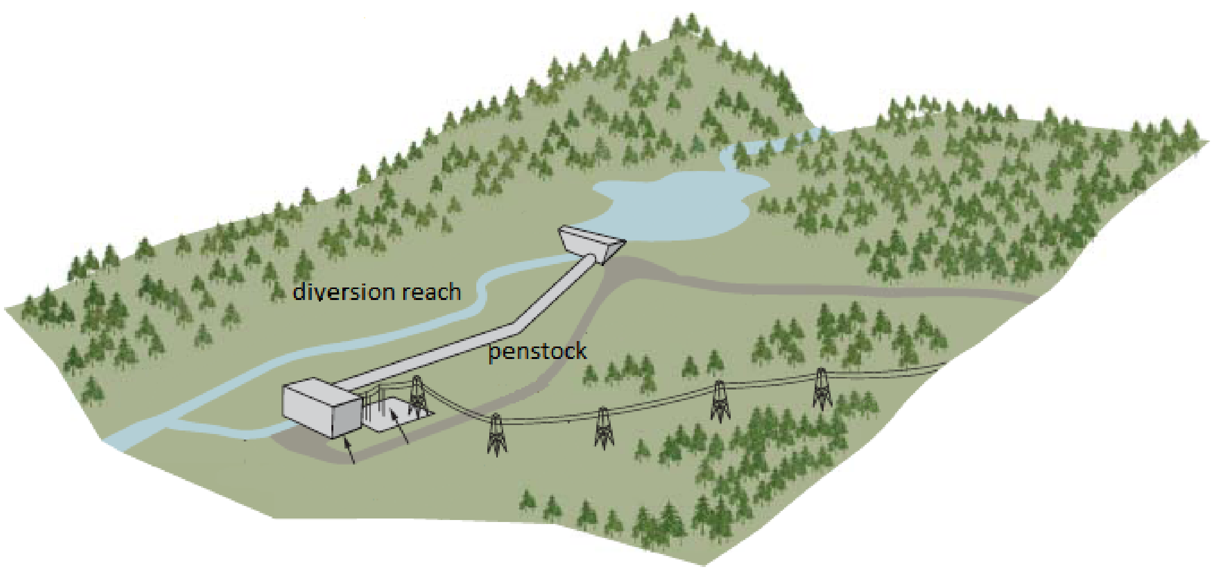


Figure 2.3: A typical hydro project that uses the river's flow (Watershed Watch Salmon Society Coquitlam, British Columbia, 2007)

Regulations

Hydro-power accounts for 97% of Canada's renewable electricity generation; the other 3% is comprised of biomass, wind, geothermal and solar power. Although hydro energy seems to be a renewable resource, not all hydro electricity projects are considered clean and environmentally acceptable. According to the Canadian Environmental Protection Act, 1999 (CEPA 1999), the legislation governing the building of any new project requires the participation of all stakeholders. Environment Canada's website explains this act as "An Act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development." CEPA 1999 became operative on March 31, 2000, and has been updated since then (Government of Canada, 1999).

One of the most challenging parts to building large hydro facilities is dealing with the people who are residents in the area of the potential facility. The construction of hydro plants in the north and west of Canada has already affected the lifestyle of local Native people. Although hydro plants may bring job opportunities to nearby communities, they can restrict farming and hunting, and affect the residents' lifestyles and the natural environment. The advantages and disadvantages of hydro plants (discussed in Section 2.1.1, page 8) are well known, and therefore, communications and meetings with all involved people are necessary when new plants are proposed.

The definition of "renewable energy" can be different according to political jurisdictions. For example, in the US state of California, if the electricity is derived from hydroelectric plants of 30 MW or less, and if the project does not require the construction of a new dam, it is considered renewable. Under the state of Vermont law, only hydro electric projects under 200 MW were previously eligible for renewable status. However, this law has been changed due to a recent energy contract between Hydro-Quebec and Vermont (Lathem, 2010). The current situation of Vermont law is explained in Section 2.1.1, page 11. Hydroelectricity produced through pumped storage technology does not qualify as being renewable in the state of Maryland. However, as mentioned, in Canada, if all the groups involved in a hydro project are satisfied with the conditions, and if the environmental and health assessments are passed, then the hydropower obtained from that project is considered to be renewable.

Small Hydro

In addition to large hydro plants, small hydro facilities play a role in electricity generation. In Canada, the term "small hydro" refers to hydroelectric projects with between 1 and 50 megawatts (MW) in installed capacity. The electricity generated in small hydro projects can be transferred to the grid or used for independent, local, and stand-alone applications in isolated remote areas. Canada's installed small hydro capacity was 3,400 MW in 2009, and the potential capacity is estimated to be 15,000 MW.

Aside from the amount of electricity generation, the major difference between small and large hydro facilities is the environmental impact and GHG emissions. Small hydro uses little or no reservoir storage since most such projects use "run-of-river" technology, thereby mitigating the effects on the environment (Natural Resources Canada, 2009f).

Hydro Projects

To clarify the current and the potential hydroelectricity production in the country, the author has used the data provided in CanESS software to obtain Figure 2.4. CanESS software and the way it works are explained in Chapter 3. Future year data are obtained by executing trend analysis in the software. As shown in Figure 2.4, there is the possibility to double the existing hydro capacity by increasing the load factor of the facilities. However, technology issues are a problem in tis regard. The common hydro plants technologies are explained in Appendix A.

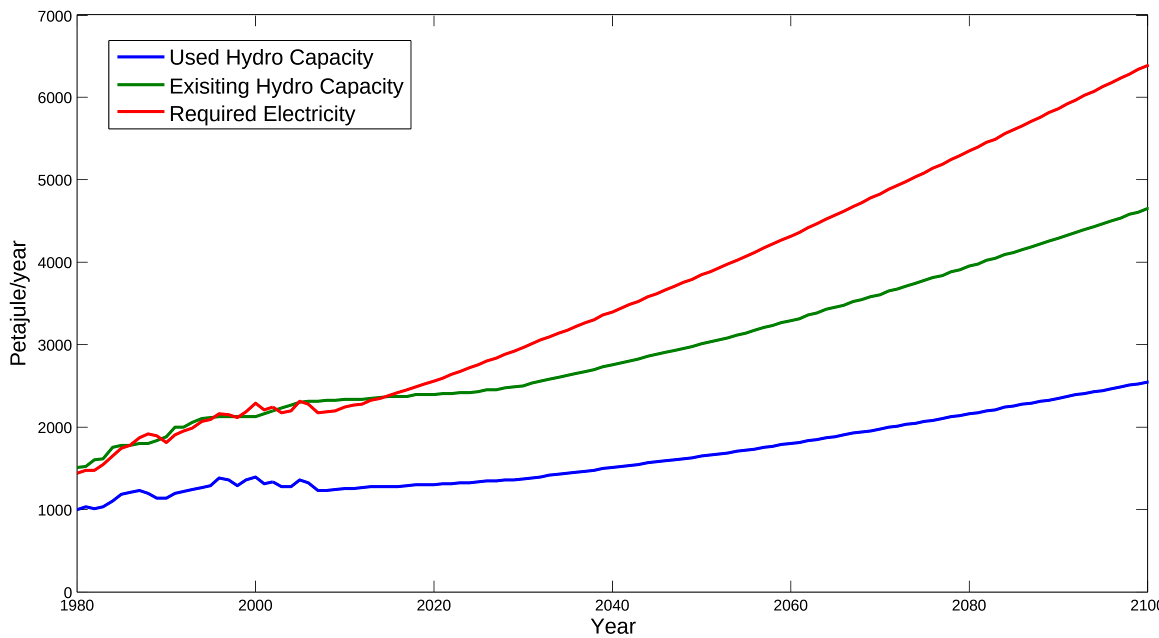


Figure 2.4: Used and potential hydroelectricity capacity, and the required electricity. Obtained using CanESS in Chapter 3

Some of the ongoing hydro projects are listed below:

- **Construction of the Ontario-Quebec Interconnection Line:** This project involves the establishment of a 1250 MW transmission line between the two provinces. It started in 2006, and will be completed in 2010. The first phase, the commissioning of the 230 KV line, switching section, and the first convertor, was finished in 2009, and the second phase will end in 2010 (Hydro-Quebec, 2009).

- **James Bay Project, Construction of Two New Generating Stations:** The James Bay Project is the largest hydroelectricity project in the country and is located in Quebec. The eight operating stations now produce about 16,000 MW of electricity. Another two stations are under construction. The construction is being performed by Hydro-Quebec. The two stations, Eastmain 1-A and Sarcelle, produce 3.4 TWh per year. The construction of the new stations started in 2007 and is scheduled to finish by 2012 (Hydro-Quebec, 2008). The ten generating stations are listed as follows (James Bay Road, 2010):
  - La Grande 1
  - Robert-Bourassa, La Grande 2-A
  - La Grande 3
  - La Grande 4
  - Laforge 1
  - Laforge 2
  - Birsay
  - Eastmain 1
  - Eastmain 1-A (under construction)
  - Sarcelle (under construction)
- **Niagara Tunnel Project:** The tunnel is located under the city of Niagara Falls. The project is designed to divert water from the Niagara River and carry it downstream to the Sir Adam Beck Generating Stations (10.2 km distance and 14.4 m wide). The project was initiated in 2009 and will be completed in 2012 or 2013 (Ontario Power Generation, 2010).
- **Wuskwatim Generation Project:** The project involves the development of a 200 MW generating station at Taskinigup Falls on the Burntwood River by an equity partnership between the Nisichawayasihk Cree Nation (NCN) and Manitoba Hydro, called the Wuskwatim Power Limited Partnership. It is scheduled for completion in 2011 (Manitoba Hydro, 2010).
- **Romaine Complex 1500 MW Project:** The station is located on the lower North Shore of the St. Lawrence River, north of the municipality of Havre-Saint-Pierre in Quebec, and Hydro-Quebec is executing the project. The project was commenced in mid 2009. The first Romaine commissioning is planned for 2014, and it will completed in 2020. Hydro-Quebec Production has obtained the necessary approvals to build it. The complex will consist of four hydropower generating stations with a

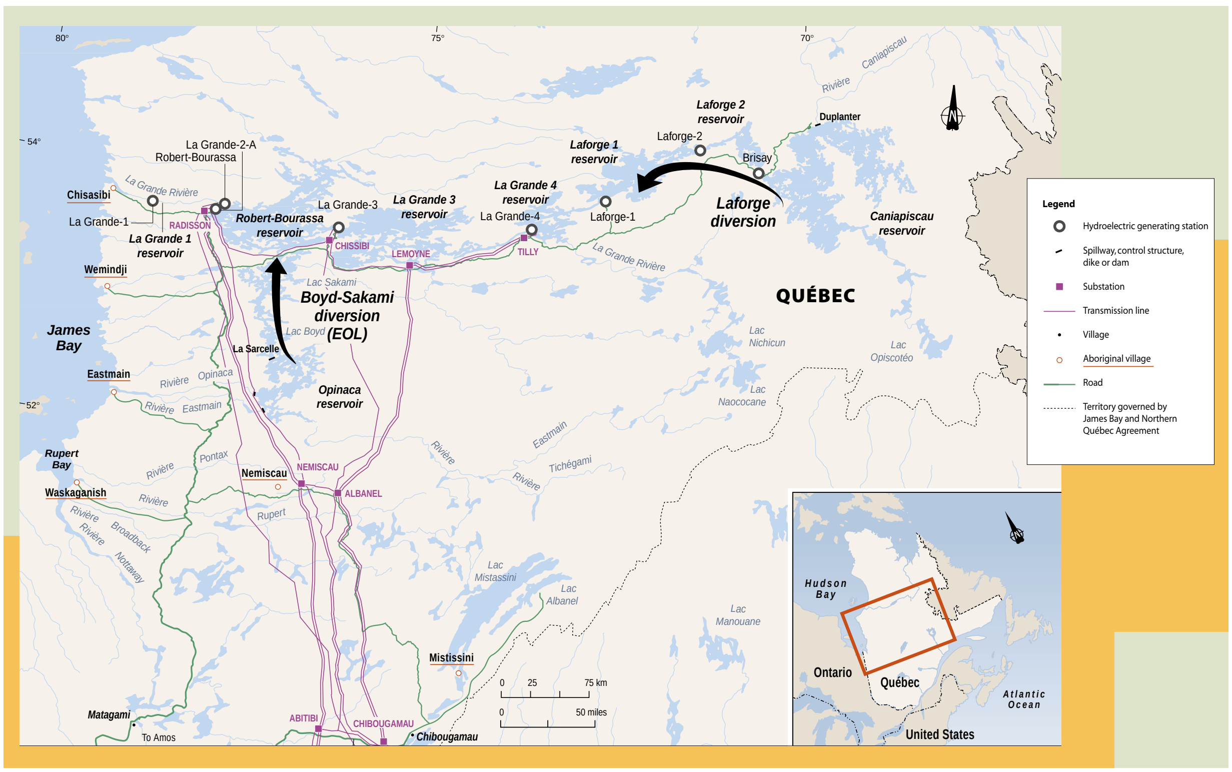


Figure 2.5: James Bay Project map (Hydro-Quebec, 2005)

total annual output of eight terawatt hours (TWh). Hydro-Quebec is following the government's guidelines to minimize environmental damage. The Romaine is one of the last free flowing Atlantic salmon rivers on the north shore of the St. Lawrence. Hydro-Quebec's environmental plans include protecting down river in-stream flows to preserve fish habitats, creating spawning areas, building nesting platforms, developing wetlands and borrow pits, and creating bays to facilitate riparian habitats. It has a plan to spend $20 million on an Atlantic salmon development program over 20 years (Hydro-Quebec, 2004).

In addition to current hydro projects, there are also projects that will possibly be executed in the future. Some of them are listed as follows:

- **New Power Deal Between Hydro-Quebec and Vermont:** With this power supply contract, about 225 MW of Quebec's electricity will be sold to Vermont between 2012 and 2038. Currently, Vermont gets about one-third of its power from Hydro-Quebec. As mentioned above, under previous Vermont law, only hydroelectric projects under 200 Megawatts (MW) were eligible for renewable status, but the Vermont legislature changed the law, so that the electricity from Quebec's massive dams are considered "renewable" (Lathem, 2010). Vermont is the first state in the US that to declare large hydroelectric power as a renewable energy resource (CBC, 2010). The deal was signed in August 2010, but must still be reviewed by the state's Public Service Board (Hydro World, 2010).

- **Site "C" Generating Station in British Columbia:** A significant potential hydro site remains in British Columbia and is located in the northeast on the Peace River. It will provide approximately 900 MW or 4,600 GWh per year. Site C has now advanced to the regulatory review phase, which takes about two years. It is anticipated that this site will be available for supplying domestic electricity needs by 2020 (BC Hydro, 2010).

- **Lower Churchill Falls Generating Station:** Lower Churchill Falls is located in Labrador. There is a potential to construct two hydroelectricity stations on the Lower Churchill River.

  The Project consists of two sub-projects: Generation and Transmission. Nalcor, an energy-development company in New Newfoundland and Labrador (NL), has proposed two locations for the Generation sub-project, Gull Island and Muskrat Falls, shown in Figure 2.6. The two stations will have a combined capacity of 3,074 MW and can provide 16.7 TWh of electricity per year. The start date of the project depends on the Environmental Assessment process (Nalcor, 2010).

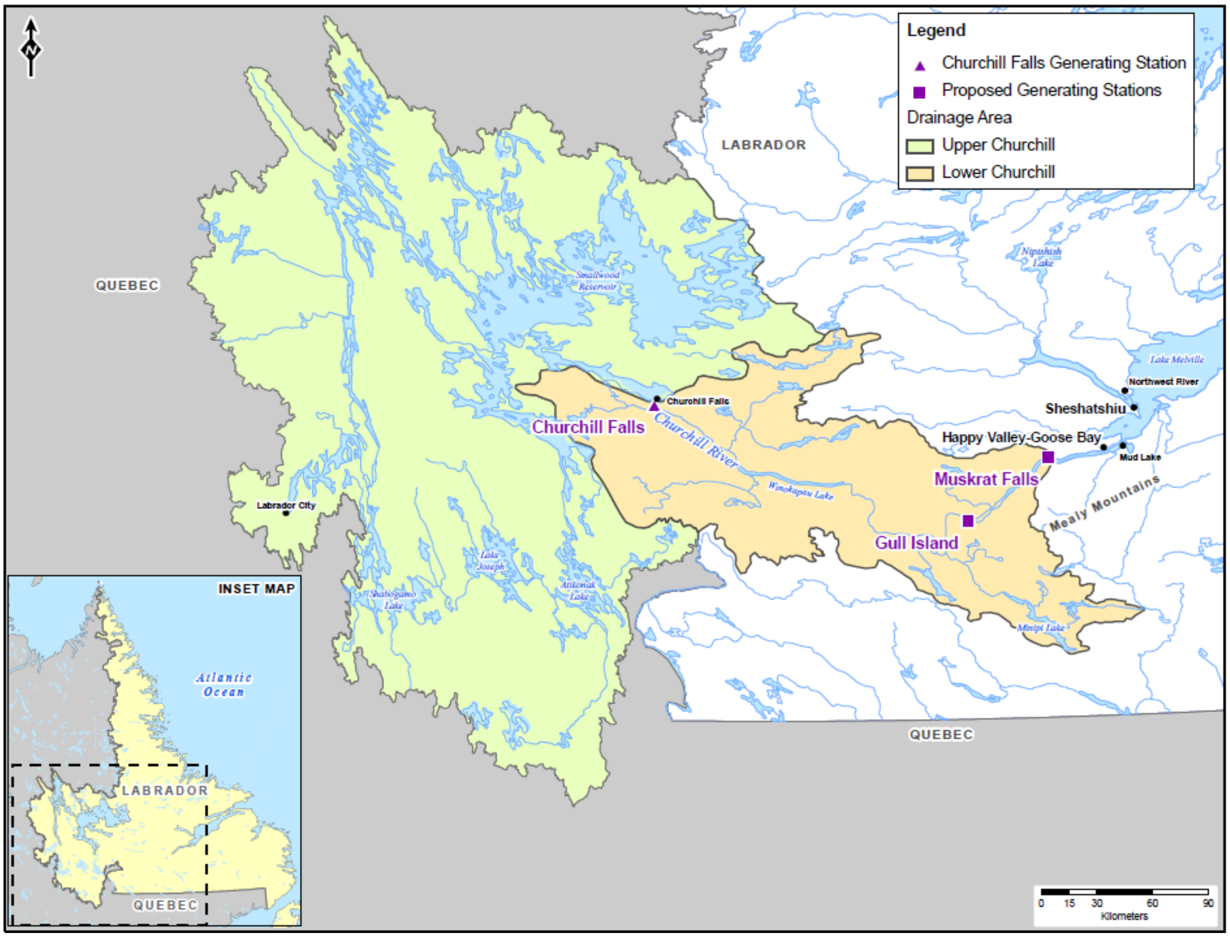


Figure 2.6: Churchill Falls (Newfoundland and Labrador Hydro, 2006)

- **Building the Power Line from Labrador to the New Brunswick Grid:** This project is related to an old controversial hydroelectricity contract in Canada, which will be discussed in the next section. The overall plan is to build a transmission line in order to transmit the electricity produced in Labrador to other provinces in the country.

Churchill Falls Contract

The controversy over the Churchill Falls contract is due to the geographical location of the province of Newfoundland and Labrador (NL). The only province with which NL has land borders is Quebec. Churchill Falls station has an installed capacity of 5,428 MW and generates 35 TWh per year. The majority of the electricity produced is being sold to Hydro-Quebec through a long-term power purchase contract, which was signed in 1969 and is set to expire in 2041.

According to the contract, Quebec is purchasing the electricity at a low price. In 1976, it paid 3 mills, or 3 tenths of a cent, per kilowatt hour. In 1996, it paid 2.7 mills, or just over one quarter of a cent. By 2016, the price will drop to 2 mills, or one fifth of a cent. Quebec sells this electricity at a much higher price to the USA and domestic consumers. "[In 2009], Hydro-Quebec earned about $1.7 billion from the contract..., compared with about $63 million collected by [NL]," said NL Premier Danny Williams (CBC News, 2009b). "[NL] was under huge pressure when it was signing the Churchill Falls contract with Quebec in 1969," stated Brian Tobin, Premier of NL in 1996. By 1969, the Churchill Falls Company had spent $150 million on the construction, but had not signed a power contract. The Vice President of the Churchill Falls (Labrador) Corporation (CF(L) Co), Eric Lambert, said in 1967 that if the deal with Hydro Quebec fell through, it would "bankrupt Churchill Falls and imperil Brinco" (CF(L)Co's parent company). "Hydro-Quebec knew this and exploited it," said Brian Tobin (Newfoundland and Labrador Government Website, 1996).

Quebec has not been allowing NL to transfer electricity through Quebec's electricity grid or to build its own power line across Quebec. Therefore, NL can only sell its electricity to Quebec. NL has requested revision of the contract several times. It has also repeatedly complained that Hydro-Quebec is not allowing fair and open access to its transmission lines. However, NL has not obtained any changes. The last time Quebec denied NL's request was in May 2010 (CBC News, 2010b).

The challenge between Quebec and NL might not be unrelated to the history of the political dispute between the two provinces. The timelines of the conflict are as follows (The Writers' Alliance of Newfoundland and Labrador and Cabot College Literacy Office, 1996):

- In 1774, the Quebec Act gives control of Labrador to Canada, making it part of Quebec.

- In 1809, Labrador is re-annexed from Quebec and restored to Newfoundland.
- In 1902, Quebec and Newfoundland begin to dispute the boundary of Labrador again.
- In March 1927, the present-day boundary of Labrador is established by a British committee.

The conflict was not resolved by the 1927 decision: in 2001, the Quebec Natural Resources Minister and Quebec Intergovernmental Affairs Minister reasserted that Quebec has never recognized the 1927 border: "The ministers reiterate that no Quebec government has ever formally recognized the drawing of the border between Quebec and Newfoundland in the Labrador peninsula according to the opinion rendered by the privy council in 1927. For Quebec, this border has thus never been definitively defined" (The Secrétariat aux affaires intergouvernementales canadiennes, 2001).

NL does not want to allow the same thing to happen with the Lower Churchill Falls project. Officials are searching different options and technologies to transmit the electricity to Nova Scotia and New Brunswick's power grid. However, the price of building undersea power lines is very high, and such challenges have made the progress of the project very slow. The plan was for the first power from Lower Churchill Falls to be drawn as early as 2015. Constructing such a power line between NL and New Brunswick and Nova Scotia needs the cooperation of all three provinces (CBC News, 2010a). To recognize the importance of the electricity produced in this station, the reduction in GHG emissions by a third station entering the grid is examined in Section 3.2.1.

2.1.2 Wind

Canada has considerable wind energy capacity and is the 11th country in the world in wind energy production (World Wind Energy Association, 2009). Currently, wind farms in Canada produce 3,472 MW electricity, which accounts for 1.1% of the country's electricity demand. The most wind energy is generated by Ontario, Quebec, and Alberta. In 2009, a record year for wind energy, 950 MW capacity was installed (Canadian Wind Energy Association, 2009b). Figure 2.7 shows the development of wind energy capacity in the country. A huge potential STILL exists; according to the Canadian Wind Energy Association's "Wind Vision 2025" report, by 2025, Canada can get 20 percent of its electricity–55,000 MW–from wind, by constructing 22,000 wind turbines spread over about 450 locations across Canada (Canadian Wind Energy Association, 2009a).

Wind energy is a clean and renewable source; it causes reductions in greenhouse gas emissions and air contaminants. For example, an installation of six 65 KW wind turbines in Newfoundland is expected to produce approximately 1 million KWh of electricity a

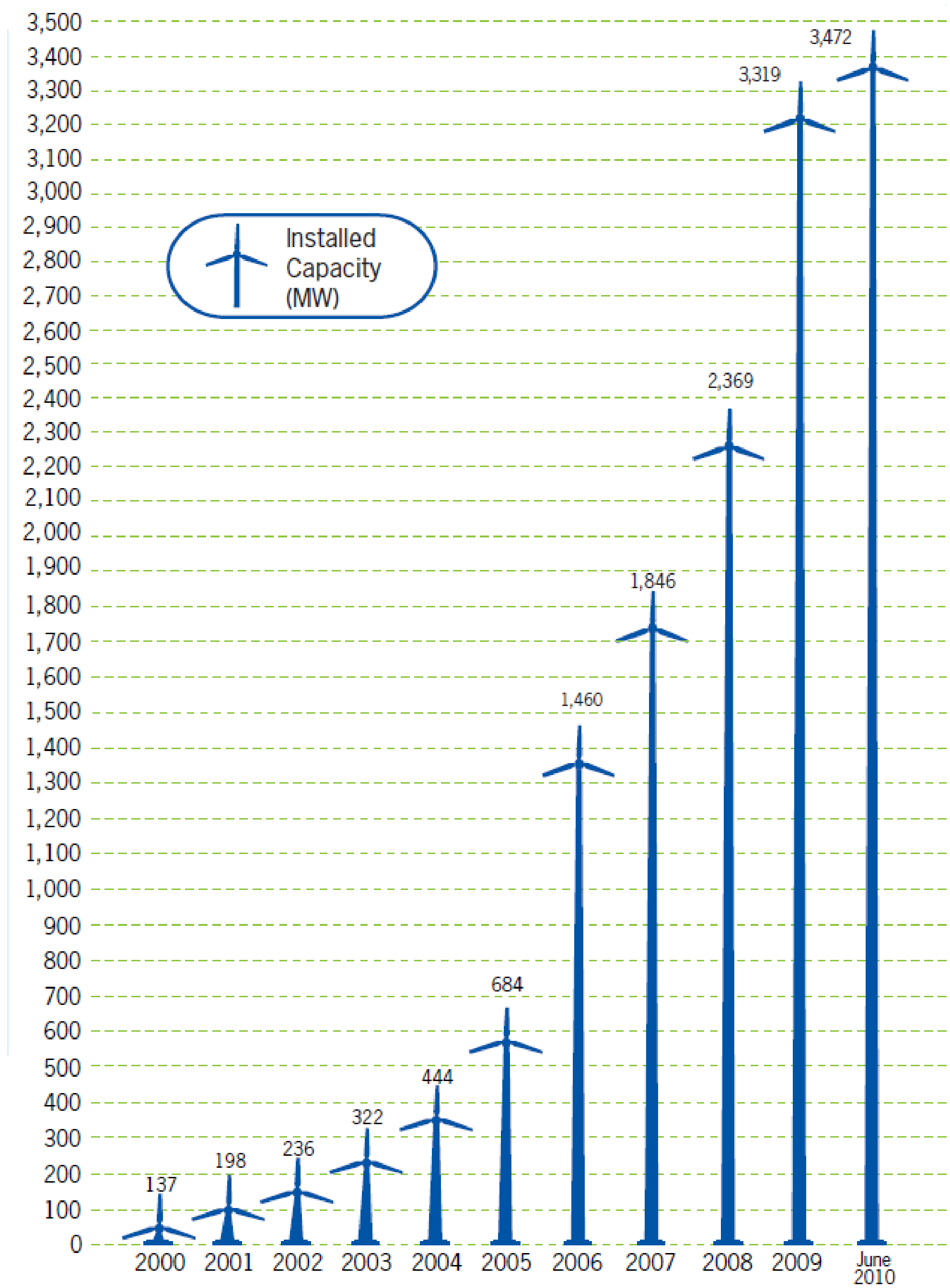


Figure 2.7: The development of wind energy capacity installation (Canadian Wind Energy Association, 2009a)

year and reduce CO_2 emissions by approximately 750 tonnes (Natural Resources Canada, 2009g). The main disadvantage of this source of energy is that wind is intermittent, but offshore wind is a more reliable source of renewable energy. Unlike onshore wind, which can be intermittent and inefficient, offshore wind is consistent and significantly more powerful. However, Canada has as of yet no installed offshore wind facilities.

Strategies in Wind Development

Countries use economic incentives and political legislation to support the idea of wind facility development. For example, in 2006, Ontario Premier, Dalton McGuinty, introduced the Renewable Energy Standard Offer Program. This act supports the renewable projects in Ontario that produce no more than 10 MW (Ontario Power Authority, 2006). In September 2009, the Ontario Government said it would spend $2.3 billion over the next three years to expand and upgrade its power transmission network. As wind farms are far from residential areas, this investment would reinforce wind energy development. “Enhancing our transmission grid is critical to taking advantage of green energy,” said George Smitherman, Ontario’s Minister of Energy and Infrastructure (Calgary Herald, 2009).

The incentive policies were effective; although Canada is still not among the top ten wind energy providers in the world, in it was the eighth participating country in wind capacity development in the world and produced 2.3% of total new wind electricity production in the world (Figure 2.8).

Another important legislation was the Green Energy and Green Economy Act that was passed by Ontario legislators in May 2009. The act has two main goals: to make it easier to bring renewable energy online, and to support the culture of conservation (Green Energy Act Alliance, 2009).

Wind Energy Projects and Organizations

In order to develop more wind farms, many wind projects have been proposed in the country. Some of them are listed below:

- **Knob Hill Wind Farm:** This 150 MW project is located on the Knob Hill Plateau on the northern tip of Vancouver Island. The project consists of 66 wind turbines. The input of First Nations and stakeholders was obtained by Sea Breeze, the company in charge of the project. Its staff helped identify the potential impact of the project on local environments. However, the project must first be approved by the Environmental Assessment Office of British Columbia. The construction schedule is dependent on power purchase contracts (Sea Breeze Power Co., 2009).

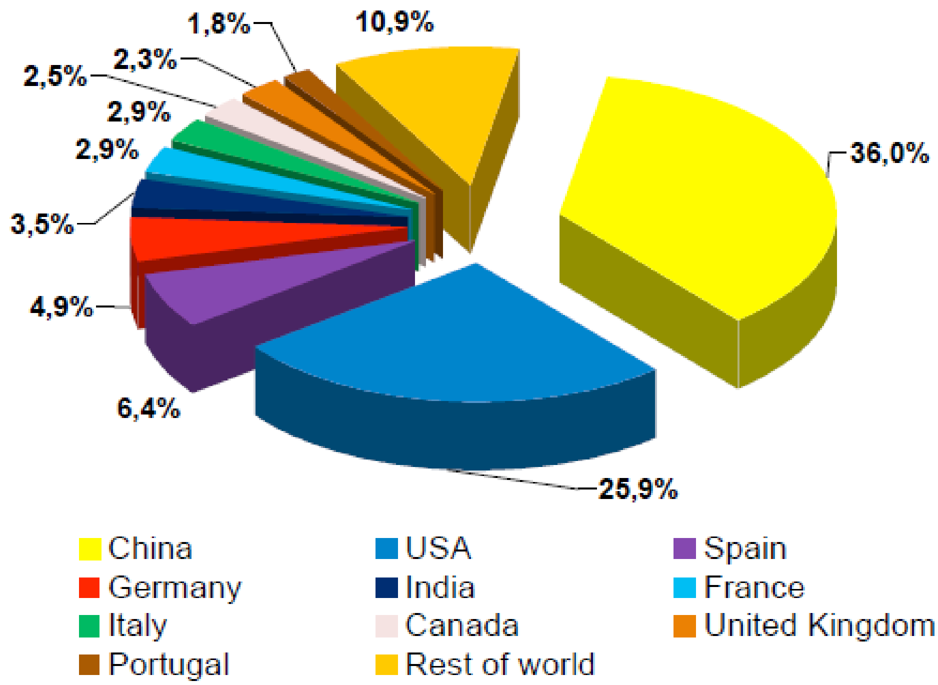


Figure 2.8: Countries' share of new wind energy capacity in 2009 (World Wind Energy Association, 2009)

- **Greenwich Wind Farm:** The site is located in northeast Thunder Bay, Ontario and will generate approximately 100 MW of electricity. Construction is now underway, and the project will be built over 18 months and should be finished by the beginning of 2012. Renewable Energy Systems Canada Inc. (RES Canada) is in charge of the project. In order to promote a better relationship with First Nations, the local community, and the environment, RES Canada sponsored 2010's Dorion Country Canyon Birding Festival for the second consecutive year (Renewable Energy Systems Canada Inc., 2009).

- **Small-Scale Wind Projects in Quebec:** In April 2009, Hydro-Quebec called for small-scale wind proposals, and on the July 6 bid deadline, Hydro-Quebec had received 31 community wind proposals totaling 732 MW and 13 First Nations bids totaling 319 MW. The utility will evaluate the proposals and expects to announce the winners near the end of 2010 (Balley, 2010).

- **Trillium Power Wind1:** This facility will be located 17 to 28 km off the shores of northeastern Lake Ontario and will deliver approximately 420 MW. Trillium Power Wind Corporation is working on this project, which is under environmental assessment. The first commissioning is planned for August 2013, and the turbines should operate for 20 years. The time line is subject to change if the notice to proceed from the Ontario Power Authority is not acquired by June 2011 (Trillium Power Wind, 2010).

Challenges

Although Canada made a great improvement in installing new wind capacity in 2009, some organizations such as Blue Green Canada believe that the country is far behind where should be. Blue Green Canada, an alliance between the United Steelworkers and Environmental Defence, published a report in May 2010, discussing clean energy investments made by Canada's federal Government and by US President Obama. The Canadian government emphasized that it is matching its energy and climate policies with those of the United States. The report looks at support for renewable energy, greener transportation and energy efficiency (Environmental Defense, 2010). Key findings include:

- If Canada matched the US, Cdn $11.5 billion would have been invested in clean energy.
- Compared to the US, Mexico, Australia, China and South Korea, Canada dedicated less of its stimulus budget to clean energy.
- If Canada's investment matched US investment in renewable energy, approximately, an additional 66,000 jobs would have been created.

2.1.3 Bioenergy

Bioenergy is the energy derived by the conversion of biomass, recently living organisms, animals or plants, or their metabolic byproducts. Wood, corn, sugar cane, and cow manure are examples of biomass. Biofuels are fuels such as bio-diesel and ethanol that are derived from biomass. Bioenergy is the second largest source of renewable energy after hydroelectricity. British Columbia, Ontario, Quebec, Alberta and New Brunswick are the pioneer provinces in bioenergy production (Bradley, 2006).

Technologies available to convert biomass are (Natural Resources Canada, 2008b):

- Gasification: converts forestry, agricultural and municipal residues into gas.

- Combustion: converts forestry, agricultural and municipal residues into heat and power.
- Thermal and catalytic processing: convert vegetable oils, waste greases and animal fats into renewable diesel fuels.
- Pyrolysis: converts forestry, agricultural and municipal residues into bio-oils.
- Fermentation: converts the starch and cellulose components of biomass to bio-ethanol.
- Anaerobic digestion: converts manures, food processing and municipal wastes into methane-rich biogas.

Unlike other natural resources such as petroleum, coal and nuclear fuels, bioenergy is a renewable energy source. The combustion of biomass, like other fuels, generates pollution as a by-product. However, the carbon in biofuels is extracted from atmospheric carbon dioxide by growing plants, so the combustion of a biofuel does not result in a net increase of carbon dioxide in the Earth's atmosphere. The main advantage of using bioenergy in electricity and heat production is the amount of GHG emissions. In general, the GHG emissions of bioenergy systems are lower compared to fossil fuel systems (Jungmeier and Spitzer, 2004).

Opportunities and Challenges

Canada is a heavily forested nation, accounting for 10 percent of the world's forests. The BIOCAP Canada Foundation published a report in 2004, estimating that there might be enough unused biomass from Canada's forestry and farming to provide almost 27 percent of the country's energy needs (BIOCAP Canada and Pollution Probe, 2004). However, the gathering and processing of this widely distributed resource is not currently feasible. Some challenges have to be overcome in order to take full advantage of this source.

Some barriers and challenges are discussed in the published reports by the Canadian Bioenergy Association, Canadian Renewable Fuels Association, and Natural Resources Canada- Canadian Wood Fibre Center. They are listed below:

- Canada has huge fossil fuel resources. Significant investments are assigned to their development, so that the price of fossil fuels will be very low. The low price of coal, gas, and oil inhibits investor enthusiasm for bioenergy technology development and trade. With regards to the pricing issue, another problem is high plant construction expenses. For example, the capital cost of building a bioenergy plant ranges between $1,500 to $2,500 per KW, while that of a coal plant ranges from $1,500 to $2,000 per KW (Institute for Energy Research, 2009).

- The logistical situation is another barrier to bioenergy development. Although Canada has vast resources of biomass, many of them are located in hard-to-access areas, far from residential locations, and too spread out to be economical to collect and use (Bradley, 2009).

- Undeveloped supply chains is another issue. Canada does not have low-cost supply chains established for forest harvest biomass projects. It will take a major effort by Nordic and Canadian Associations, companies and governments to transfer technology and learning to Canadian forests. Arrangements for technology transfer and trade missions are in process (Bradley, 2009).

- The pressure to keep biomass as a domestic resource is preventing the growth of bioenergy. The challenge is to develop resources fast enough to produce sufficient amounts for both export and domestic use (Bradley, 2009).

- Many pyrolysis applications are being tested, but not on a scale that allows for the testing of a particular one over a long period. In addition, the volumes have not been large enough to prove the reliability and competitiveness of long-distance supply chains (Bradley, 2009).

- The lack of harmony among incentive tax legislations in different Canadian provinces is another problem. Table 2.1 shows the tax exemptions in some provinces. This inconsistency hinders intra-provincial biofuel trade (Bradley, 2009).

Incentive Policies

Some of the federal and provincial incentive programs are listed below:

- In 2007, Sustainable Development Technology Canada (SDTC) announced a $500 million NextGen Biofuels Fund to partially support the establishment of a first-of-its-kind large demonstration scale facility (Government of Canada, 2007).

- In June 2010, Denis Lebel, Minister of State for Canada Economic Development, announced three financial contributions totalling $1,090,358 to support the development of the forest biomass sector in La Matapédia RCM.

- Some provinces have enacted incentive policies, some of which are shown in Table 2.1.

Table 2.1: Provincial renewable fuel incentives (Bradley, 2009)

Province	Mandate	Incentive
BC	5% ethanol, 5% biodiesel-Jan 2010	14.5¢/ℓ tax exemption, BC fuel only
Alberta	5% ethanol, 2% biodiesel-July 2010	9¢/ℓ tax exemption, Alta fuel only
Saskatchewan	7% ethanol(Gas)	15¢/ℓ tax exemption, Sask fuel only
Manitoba	8.5% ethanol(Gas)	20¢/ℓ producer incentive 2008-09, Man only 15¢/ℓ producer credit 2010-12, Man only 10¢/ℓ 2013-15, Man only
Ontario	5% ethanol(Gas) 2007 10% ethanol(Gas) 2010	20¢/ℓ producer incentive

2.1.4 Solar

The origin of solar energy is the burnt hydrogen in the core of the sun. The sun's energy has been bombarding our planet since the formation of our solar system, but solar technologies have only been under development for about 40 to 60 years. Solar energy is used to produce heat for water heaters and air conditioners (solar thermal) and electricity (solar photovoltaic (PV) energy). In a solar thermal application, a solar panel gathers solar radiation to heat air or water for domestic, commercial or industrial use. Solar PV directly converts sunlight to electricity to be stored in batteries, to be used directly or to be sent to the general grid. The efficiency of solar PV is only 24% in the most modern equipment, while solar thermal systems are 70% to 90% efficient (Energy World, 2010; Lozanova, 2008). However, solar energy is a favored form of energy, because it helps reduce GHG emissions. Canada has abundant solar energy resources. Figure 2.9 shows the solar energy situation in the country.

The capital cost of producing electricity through PV cells is $10,000 to $14,000 per KW, which is more expensive than that of other renewable sources. However, one of the main benefits of solar resources is its ability to provide energy for people living in stand-alone units in inaccessible areas. These areas are not connected to the grid. PV cells are used as off-grid electricity generators to supply electricity for

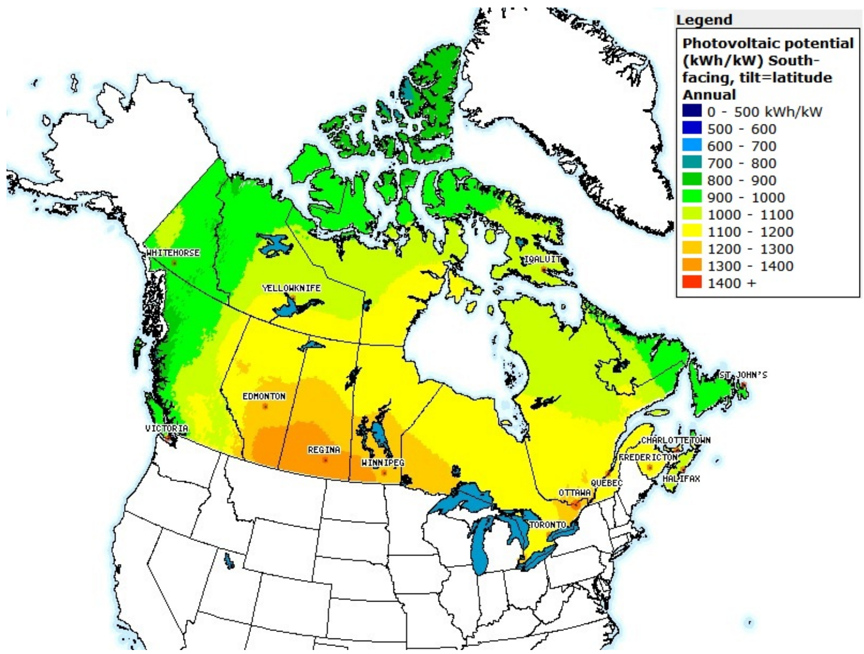


Figure 2.9: Yearly PV potential map for latitude tilt in Canada (Natural Resources Canada, 2010)

- telecommunication repeater stations,
- water pumps,
- navigational aids,
- laptop computers,
- cottages and remote residences,
- parks in remote regions, and
- supplying occasional power.

Incentive Programs

Federal and provincial incentive plans are designed to encourage residential and commercial sectors to use solar systems to produce heat and electricity. Some of the plans are listed below (The Heating, Refrigeration and Air Conditioning Institute of Canada, 2010):

- The ecoENERGY for Renewable Heat Program: This program is administrated by Natural Resources Canada and runs from April 1, 2007 to March 31, 2011. Incentives are offered to the industrial/commercial/institutional sector to install energy-efficient solar air and/or water heating systems. Solar thermal, solar air and solar photovoltaic equipment are eligible under this plan.
- Ontario Solar Thermal Heating Incentive (OSTHI): The Ontario Government has budgeted $14.4 million, which is available until March 31, 2011, to encourage different sectors to install solar thermal heating equipment. This program is administered by the Ministry of Energy and Infrastructure (Ontario).
- Ontario Power Authority (OPA) Electricity Retrofit Incentive Program: Commercial building owners/tenants will receive a rebate from OPA if they retrofit their building with solar hot water heaters and other electricity saving equipment.
- Solar Energy Systems Rebate, in Ontario: When homeowners or builders install energy systems into residential premises, or expand or upgrade an existing solar energy system, Harmonized Sales Tax (HST) paid on solar energy systems will be returned to them. This plan applies to the systems that were purchased and installed in residential premises before January 1, 2010.

2.1.5 Geothermal

Geothermal energy is obtained from the stored energy of the sun in the ground soil and water under the surface soil. The free thermal energy can be moved from the ground by drilling wells or building pumping systems, in which the heat transfer fluid is circulating in pipes and transferring the heat to homes to provide warm water or air. Heat exchangers use the heat from the earth to heat water to create steam, which turns turbines for electricity generation purposes (Canadian Geothermal Association, 2010).

The average temperature a few meters below the earth's surface is similar to the average annual air temperature; for example, the average ground temperature a few meters under the earth's surface is about 10.1 °C in Toronto. This is not a high temperature, so the heat should be concentrated or upgraded, but what is favorable about the temperature is that it remains constant throughout the year (Canadian GeoExchange Coalition, 2010).

Most of the promising Canadian sites to develop enhanced geothermal systems (EGS) are located in British Columbia, Alberta and Saskatchewan (depths ranging from 3.5 to 6.5 km). Deeper wells also exist across the country, for example in Ontario. In commercial levels, these projects must overcome special conditions; subsurface rock must be hydraulically fractured to create cracks that water can penetrate through. In addition, an outside source of water is required, and the drilling process is expensive. Although Canada is located on the Pacific Ring of Fire, where huge geothermal potential exists, and also home to some of the continent's geothermal power developers in different places such as Nevada and California, formal EGS development does not yet exist. The Canadian Geothermal Association believes that Canada could develop 5,000 megawatts of conventional geothermal power by 2015, with wells less than 3 km deep (Tyler Hamilton, 2010).

2.2 Non-Renewable Energy Sources

Renewable energy accounts for 16.1% of the total energy production in Canada, so the rest is provided by non-renewable resources, such as oil, gas, coal, and nuclear energy. Figure 2.10 illustrates the position of each source in the energy supply in Canada. The first three energy suppliers are fossil fuels, which play a considerable role in GHG emissions. Greenhouse gases consists of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro-fluorocarbons (HFCs), per-fluorocarbons (PFCs), and sulphur hexa-fluoride (SF_6). Nuclear energy is a clean source of energy if the existence of nuclear waste is ignored. This section provides an overview of the situation of non-renewable energy sources in Canada.

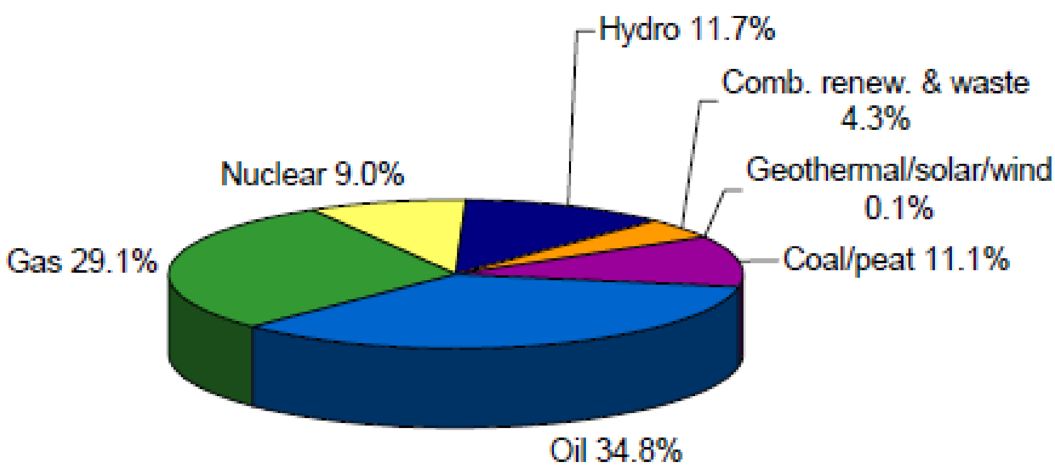


Figure 2.10: Share of total primary energy supply in Canada in 2008 (International Energy Agency, 2008b)

2.2.1 Coal

Coal supplies about 11% of Canada's energy and 19.1% of its electricity (Figures 2.10,2.17). British Columbia, Alberta and Saskatchewan have the largest coal reserves and resources in Canada that are actively mined. Canada produces both thermal and coking coals. About 70 percent of domestic coal production is thermal coal, which is consumed by electricity-generation plants. Coking coal is also referred to as metallurgical coal and is a high-carbon type of coal used in blast furnaces to smelt iron ore for iron and steel production (Natural Resources Canada, 2008a).

Canada is a mid-size producer of coal, and over half of its production is domestically used to generate electricity. The rest is exported. Canada is a large exporter of metallurgical coal, which accounts for 90% of its coal exports. Although the country is a net exporter of coal, it also imports coal mostly from the US to the central and eastern parts of the country. Because of Canada's geographical expanse, importing coal from the eastern and central US is cheaper than purchasing it from western coal-rich provinces (Natural Resources Canada, 2008a).

Coal Consumption Policy

The Canadian energy policy is to reduce its coal consumption, because coal, while cheap, is the dirtiest energy producer in terms of GHG emissions. For example, in 2007, 100.5 megatonnes (MT) out of 126.6 MT of CO_2 emissions in the electricity production sector was due to coal (Office of Energy Efficiency, 2009).

On June 23, 2010, Environment Minister Jim Prentice announced that Environment Canada aims to regulate GHG emissions from coal-fired power plants. According to this regulation, which is expected to be firmed up by early 2011, all new coal-fired plants and those that have reached their economic end of life are required to meet the new standard, matching the lower GHG emissions of more efficient natural-gas fired plants. The federal target is a 17% reduction in GHG emissions from 2005 levels by 2020. The previous target was a 20% reduction from 2006 emission level by 2020 (Government of Canada, 2010).

Ontario's energy policy facilitates GHG reduction to a considerable extent. Ontario Power Generation (OPG) shut down four units of two coal-fired generation plants, accounting for a generating capacity of 2000 MW, in October 2010. These units will be converted to gas and biomass. This action is a part of the four coal-fired plant phase-outs anticipated in the province by 2014 (Ontario Government, 2009b).

However, it is not possible to phase-out all the coal facilities in the country, because other energy resources would not be able to take the place of coal in meeting Canada's energy needs. Therefore, Canada's plan is to advance clean coal technologies (CCT) by testing the use of biomass in coal-fueled generating stations and carbon capturing mechanisms. Natural Resources Canada (NRCan) has developed a Clean Coal Technology Roadmap. It has also made financial contributions to the Canadian Clean Power Coalition projects to develop the technologies that can be used to extract coal's energy with GHG emissions at the same level as natural-gas-fired plants (Coal Association of Canada, 2009).

2.2.2 Natural Gas

Canada is the third largest producer of natural gas after the US and Russia. More than half of Canadian natural gas production is exported to the United States. Natural gas accounts for about 5% of the electricity production and about 30% of the primary energy supply in Canada. Among fossil fuels, natural gas is the cleanest in terms of GHG emissions and emits less than half of carbon dioxide emitted by coal (Energy Information Administration, 2008).

Natural gas is usually produced from conventional sources and in gaseous deposits. However, it also has unconventional sources, such as coalbed methane (methane trapped in coal deposits) and tight gas (methane found in low permeability rock formations) (Natural Resources Canada, 2009b).

The industrial and power generation sectors account for 58% of natural gas consumption, and the rest is consumed by residential and commercial sectors. Ontario and Alberta are major consumers. Ontario's demand is mostly in residential and commercial sectors, while Alberta's consumption is for its large industrial and energy sector, in particular the oil sands operations (Natural Resources Canada, 2009b).

Decrease in Production

Production of natural gas in Canada increased between the 1990s and early 2000s. However, since 2002, production has dropped, such that the amount of natural gas produced in 2006 was close to the amount in 2002. Figure 2.11 shows the production trend of natural gas in Canada.

The production reduction is due to the decrease in Western Canada's supply, which accounts for 98% of the Canada's natural gas supply, virtually all the natural gas production in the country. The main consumers of natural gas are home and business heating uses and the oil-sand industry, which use the gas to extract oil from the bitumen. Currently, unconventional gas, offshore and northern resources, and imports of liquefied natural gas (LNG) contribute to meet the demand (Natural Resources Canada, 2009b).

Canada's National Energy Board has developed an analysis to investigate gas production in various scenarios. Figure 2.12 shows the supply for different cases. In all scenarios,

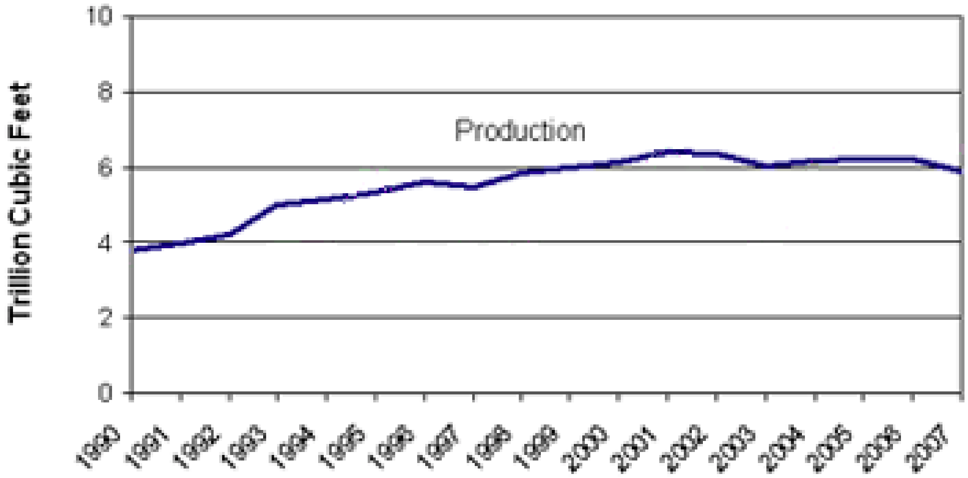


Figure 2.11: Natural gas production in Canada (Natural Resources Canada, 2009b)

the increase in demand is considered, and in order to meet the demand, efficiency improvement projects and using alternative fuels are the primary assumptions. The scenarios are explained below (National Energy Board, 2010a):

- In the Reference Case scenario, gas demand rises 45% between 2005 and 2030 in the oil-sands and electricity generation industries.
- In the Continuing Trends scenario also, gas demand rises 45 per cent between 2005 and 2030. The simultaneous decline in availability is partially compensated for by unconventional gas development. In addition to unconventional gas, more gas production from the North is expected by 2014. Furthermore, imports gradually exceed exports and make Canada a net gas importer before the end of the projection period.
- In the Triple E scenario, gas production in Western Canada levels off by 80% by 2030 from current production levels. This decline occurs because of low gas prices, which prevent producers investing in other gas resources such as unconventional gas or developments in the North. In addition, it is presumed that LNG imports produce half of the gas available by 2030, and these imports are cheaper than developing northern and unconventional gas. In this scenario, imports gradually exceed exports and Canada will be a net gas importer before 2030.
- In this scenario, representing the most aggressive expansion, the decline is partially balanced by unconventional gas production. More gas supply from the North by 2014

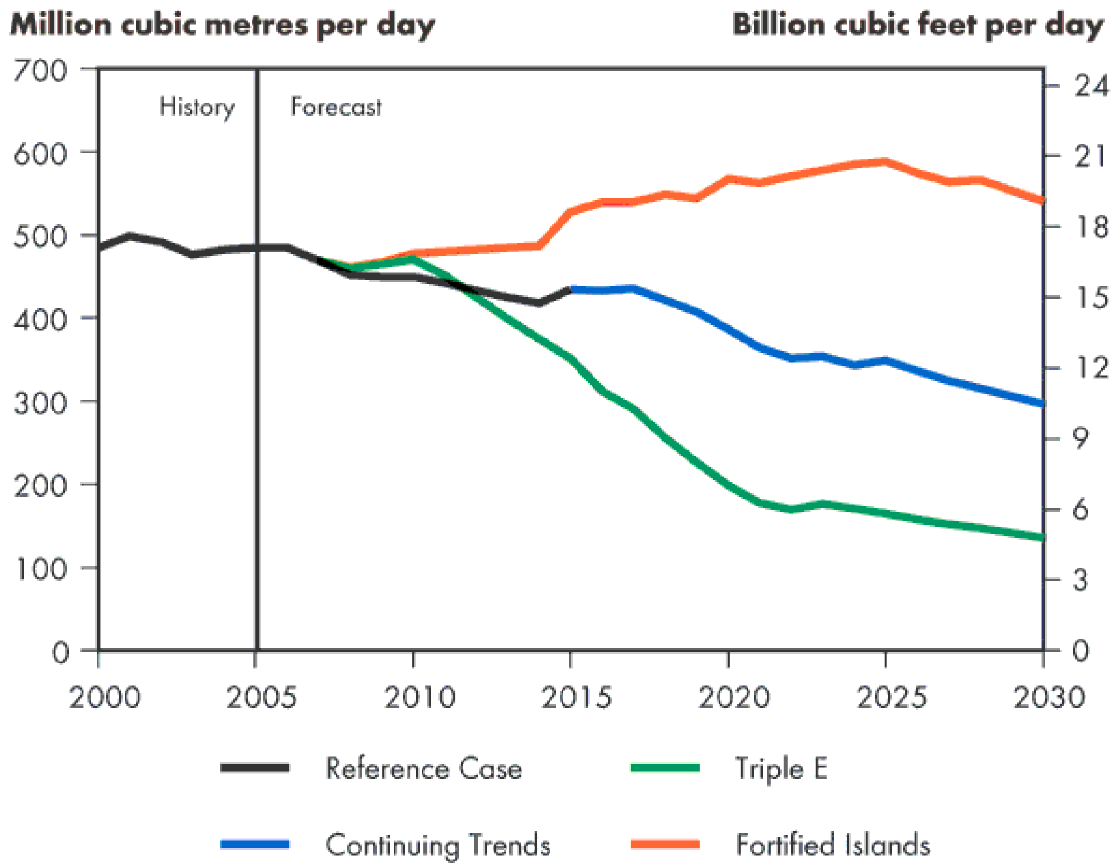


Figure 2.12: Canadian natural gas production scenarios (National Energy Board, 2010a)

is another expectation. In the Fortified Islands scenario, security concerns restrict worldwide LNG supply, and consequently the import. Development of unconventional and northern gas causes Canada's gas exports to rise.

To sum up, the decrease in the resources in Western Canada will lead the country to invest in the development of additional northern, offshore and unconventional gas sources and to import LNG. All these approaches can help Canada to keep its current supply, but not increase it. Therefore, the country may not be a significant gas exporter for the next two decades.

Natural Gas's Energy to Electricity

The most basic mechanism to produce electricity is steam generating units. To do so, natural gas is burnt in a boiler to heat water and produce steam. The steam, then, turns a turbine to generate electricity. These steam generation units have a low efficiency of about 33 to 35 percent.

The other mechanism uses gas turbines and combustion engines. The gas is heated and then pressurized in pipes and then used to drive turbines. These types of turbines are used in peak-load demand periods, as it is possible to quickly and easily turn them on.

Combined-cycle units are used in many new natural gas fired power plants. In this mechanism, both gas turbines and steam units work together. The hot gas is pressurized to drive the turbines, and the waste heat from the gas-turbine process is used in steam units to boil the water in boilers. Combined-cycle plants can achieve thermal efficiencies of up to 50 to 60 percent.

2.2.3 Oil

Oil is a largest supplier of primary energy in Canada, providing 34% of the supply in 2007 (Figure 2.10). Canada is the seventh largest oil producer in the world, and the oil production has had an increasing trend in the last two decades. Oil sands operations have been contributing to about half of the oil production in the country. Figure 2.13 shows crude oil production until 2006. Canada's oil reserves are enough to meet demand for the next 200 years at current rates of production. The Western Canadian Sedimentary Basin, which underlies Alberta, Saskatchewan and part of the Northwest Territories, is the area where most of Canada's oil is found.

Most of Canada's crude oil comes from the western provinces: Alberta (68.8%), BC (1.5%), Saskatchewan (16.1%) and Manitoba (0.7%). In 2006, Eastern Canada's production accounted for 11.9% of Canada's overall production, with NL being the most contributing province in the east with 11.4% of oil production. The factors that affect the conventional oil and oil sands developments in the country, according to Natural Resources Canada, are skilled labor shortages, water availability, environmental regulations, rising costs of labor, refining/upgrading, pipeline capacity constraints, and natural gas shortages. Social challenges, such as the challenge of building new community infrastructures and surrounding communities where the involved workers live, are also factors arising from oil sands developments (Natural Resources Canada, 2009c).

The consumption of oil products differs from province to province. For example, furnace consumption in Western Canada, where natural gas resources are abundant, accounts for about 6% of total furnace oil consumption in Canada. On the other hand, Atlantic Canada, where there is less of an abundance of natural gas and with 7% of the Canadian population, accounts for over 30% of Canada's furnace oil consumption. In addition, Ontario and Quebec account for 63% of Canadian consumption. With regards to gasoline consumption, Ontario and Quebec account for 60% of the total consumption. Western Canada and the

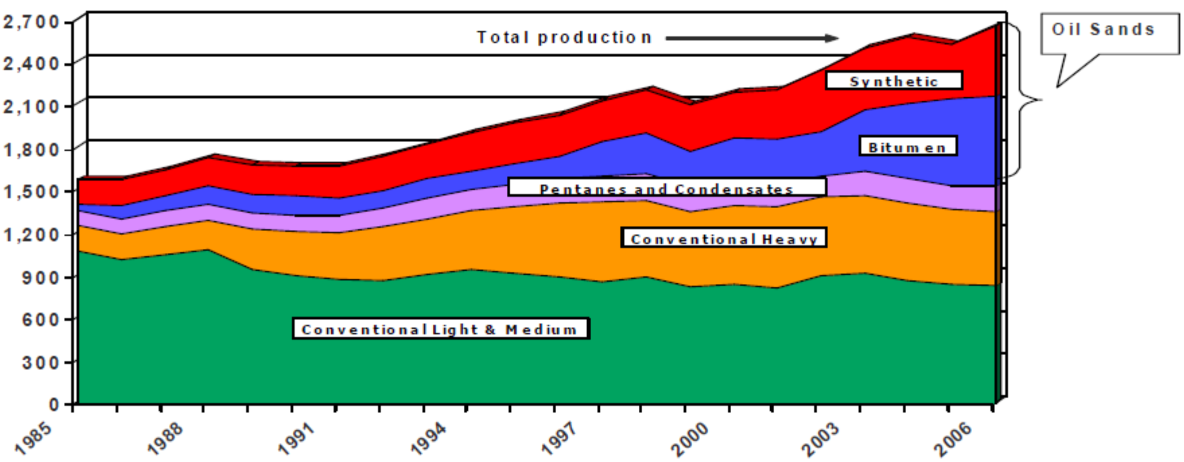


Figure 2.13: Canadian crude oil production (thousand barrels per day) (Natural Resources Canada, 2009c)

Atlantic provinces account for 32% and 8% of Canada's gasoline consumption, respectively. On average, 43% of the consumed diesel fuel occurs in Ontario and Quebec, while the western provinces account for 46% of the total consumption. The greater dependence on this oil product in western provinces is due to having a different fleet composition and a greater need to truck in this region's manufacturing market (Natural Resources Canada, 2009c).

Canada has 19 refineries, and the three main refining centers in Canada are Edmonton (Alberta), Sarnia (Ontario), and Montreal (Quebec). Most provinces have at least one refinery, but Manitoba, Prince Edward Island or the Territories do not have any. On average, half of the crude oil of the refineries comes from domestic reserves. The rest is imported from OPEC countries and the North Sea. Canada is a growing exporter of oil, and oil accounts for 30% of the net exports of the country. Oil is exported from the west and the Atlantic region, and imported in eastern and central provinces. In 2006, virtually all the crude oil exports from Canada were to the USA (Natural Resources Canada, 2009d).

Crude Oil Outlook

Conventional oil production in Canada will decrease as the remaining reserves decline, but Alberta's oil sands production is expected to dominate the supply. By 2020, oil sands will account for about 80% of the crude oil production in the country. Figure 2.14 shows the projected crude oil production until 2020. However, the oil sands industry is reliant upon natural gas to produce heat and hydrogen, so any increase in natural gas prices or reduction in natural gas supply would directly affect the oil sands industry. Projected crude oil and petroleum product imports will remain steady for the next 15 years, whereas crude oil exports will increase by 2010 and remain stable to 2020.

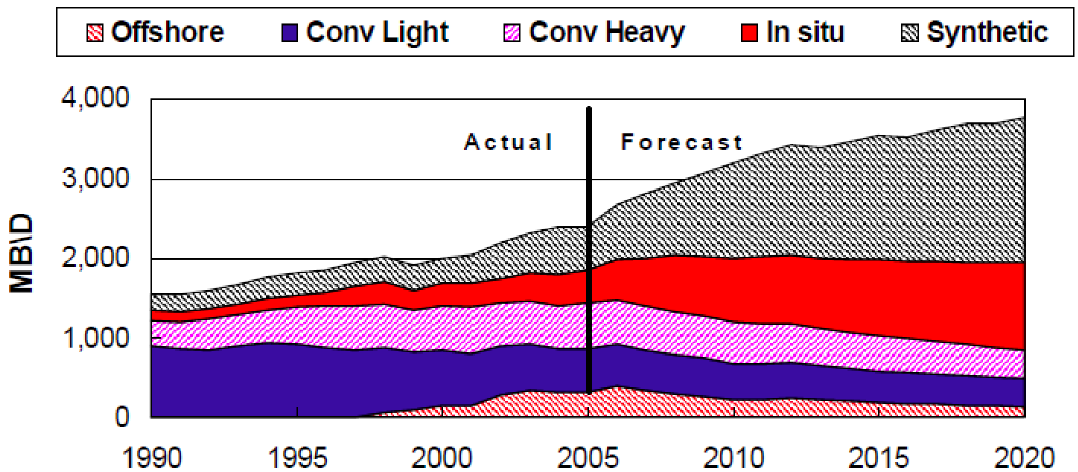


Figure 2.14: Canada crude oil supply forecast (Natural Resources Canada, 2009c)

Total refining capacity in Canada is 332,000 m^3/D, and the estimated crude oil production in 2009 was 429,028 m3/D, from which about 40% was oil sands production. Canadian refining capacity has grown in recent years, but the trend should continue. The consumption has been increasing, but globally, industry investment in refining has not kept pace. This situation plays an important role in the prices of petroleum products (National Energy Board, 2010b).

2.2.4 Nuclear

Nuclear energy is a non-renewable source of energy. Every form of electricity generation produces GHG emissions in mining, building the plants, transportation sections, and building the infrastructures. Although using nuclear energy for electricity generation will produce radioactive wastes, the amount of GHG emissions is less than that of other non-renewable sources. Figure 2.15 shows the amount of CO2 emission per TWh electricity generation in Ontario.

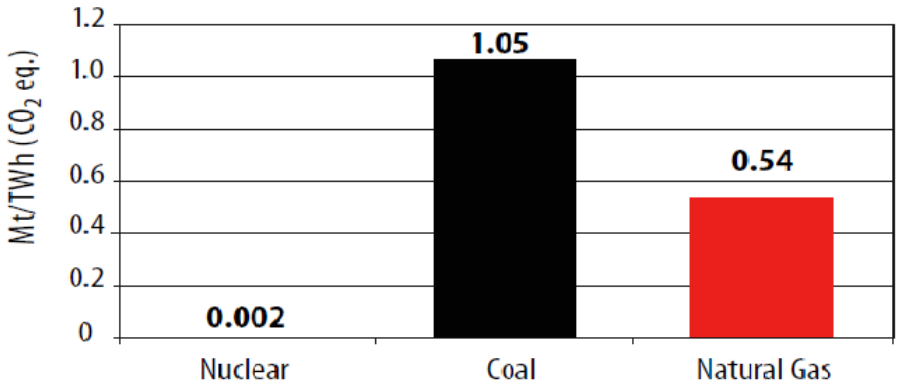


Figure 2.15: Comparative life-cycle GHG emissions for Ontario electricity generation sector (Canadian Nuclear Association, 2009)

Canada has 22 CANDU reactors, 18 of which are in service. Figure 2.16 shows the locations of the 22 reactors in the country. Table 2.2 indicates the Canadian nuclear sites. Units 1 and 2 of Bruce A, Point-Lepreau nuclear generating station, and unit 3 of Pickering A are currently under refurbishment (Canadian Nuclear Safety Commission, 2010a). Canada has been using nuclear energy for 47 years. The oldest operating units, which produce electricity, belong to the Pickering site and became operational in 1971.

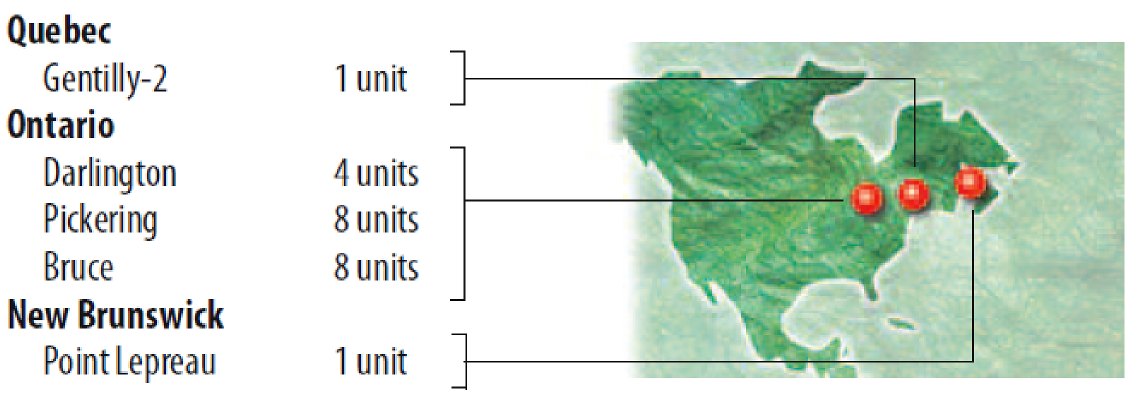


Figure 2.16: CANDU reactors in Canada (Canadian Nuclear Association, 2009)

Canada is the world's largest producer of natural uranium; Saskatchewan's deposits provide about 21% of global uranium production. Nuclear energy is used for peaceful purposes such as electricity generation, medicine, agriculture, research, and manufacturing in Canada. Over 50% of the global supply of medical isotopes for medical purposes is

Table 2.2: List of Nuclear reactors in Canada (Canadian Nuclear Safety Commission, 2010a)

Site and Location	Number of Existing Units	Gross Generation Capacity
Pickering A (ON)	4	4×542 MW
Pickering B (ON)	4	4×540 MW
Darlington (ON)	4	4×934 MW
Bruce A (ON)	4	4×805 MW
Bruce B (ON)	4	1×845 MW+ 3×872 MW
Gentilly-2 (QC)	1	1×675 MW
Point Lepreau (NB)	1	1×680 MW

provided by Canadian reactors. In 2008, 14.8% of the country's electricity generation was produced by a nuclear source(Figure 2.17), with the proportions in Ontario, Quebec, and New Brunswick (NB) being 53% , 3%, and 6.1%, respectively. It should be noted that the Point-Lepreau generation unit in NB is currently under refurbishment, but it normally produces 50% of the province's electricity.

Radioactive Waste

According to the Canadian Nuclear Safety Commission's (CNSC) Regulatory Policy Managing Radioactive Waste, radioactive waste is "any material (liquid, gaseous or solid) that contains a radioactive nuclear substance for which the owner has no foreseen use and is determined to be a waste product." CNSC has classified radioactive waste into four groups (Canadian Nuclear Safety Commission, 2009). The explanation of each class and its related disposal methods is explained below:

- **Low-level radioactive waste (LLRW):** LLRW contains material with a considerable amount of radionuclide content, but has limited long-lived activity. This type of waste does not require significant shielding while it is held in interim storages or handled by nuclear workers.
- **Intermediate-level radioactive waste (ILRW):** ILRW waste needs shielding during handling and interim storage. The organizations that produce LLRW and ILRW are responsible for the waste management. There is as of yet no long-term management facility for these two types of waste. The waste management usually takes

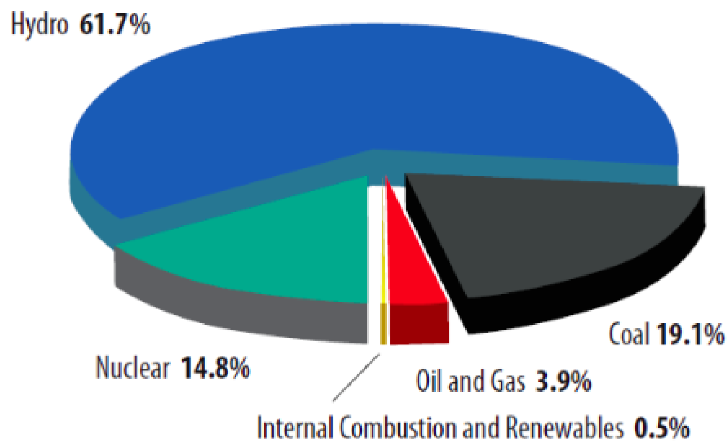


Figure 2.17: Electricity generation in Canada for 2008 (Canadian Nuclear Association, 2009)

place on the site of the waste owner. Some of these wastes contain a small amount of radioactive materials, so the radioactivity decays in hours or days, and then the waste can be disposed by conventional methods.

- **High-level radioactive waste (HLRW):** HLRW is used nuclear fuel that generates heat. Currently, no long-term management facilities for high-level nuclear fuel waste exists anywhere in the world, and used nuclear fuel in Canada is currently held on site in interim storage facilities. Used fuel bundles are used to hold HLRW on site. Interim storage of HLRW consists of two phases known as wet storage and dry storage. At first, used nuclear fuel bundles are removed from the reactors and stored under water in bays or pools. The fuel cools off in a shielded leak-proof and secure facility. After 6 to 10 years, the used nuclear fuel is transferred to dry storage in concrete containers.

- **Uranium mine and mill waste:** This type of waste is generated during the mining and milling of uranium ore and the production of uranium concrete. Uranium mining and milling waste contains long-lived radioactive elements and will not significantly decrease over a long period of time. Since a large volume of waste is generated during mining and milling, the only suitable option for waste management is to develop long-term waste management facilities close to the mining sites. Cameco Corporation and Areva Resources Inc., located in Saskatchewan, are the only facilities operating uranium mines and mills in Canada.

The history of developing nuclear energy in Canada is provided in Chapter 4 in order to have a good understanding about the background of this energy source in the country.

2.3 Energy Situation in Ontario

In this section Ontario's energy situation is explored based on Ontario's Long-term Energy Plan report, which was published by the government (Ontario Government, 2010). Ontario is going forward to improving its reliable and renewable energy system. Ontario is the most successful Canadian province in solar and wind power and seeks a diverse supply mix of energy. Ontario's Landmark Green Energy and Green Economy Act, Ontario's 2010 Economic Outlook and Fiscal Review, and Ontario Clean Energy Benefit are the representatives of the province's attempt to reach its energy related goals. Energy sector employs more than 95,000 of Ontarians. Regarding the environmental issues, Ontario has been made a great progress in energy sector. In 2009, more than 80 percent of the electricity generation came from emission-free sources, and the amount of GHG emission in that year was the lowest amount in the past 45 years.

The province is a net exporter of electricity and is able to meet the current energy demand. However, it needs to supply 15,000 MW electricity over the next 20 years to supply the future demand. The increase in demand is due to Ontario's economic recovery, growing population, industrial growth, and increased usage of electrical appliances, such as electric cars. For example, Ontario's plan is that by 2020, five percent of the vehicles on the roads are electric. The conservation culture is also growing and helps the province to observe a moderate increase in electricity demand over the next 20 years. This means the province has to upgrade and update the energy grid system and create new or rebuild some of the existing electricity capacities. The government needs to increase energy prices in order to finance the required progress. Energy prices are expected to increase 3.5 and 2.5 percent per year for the residential and industrial sectors, respectively. To help the families, farms and businesses with the increased energy prices, Ontario has offered Ontario Clean Energy Benefit, which if passed, can give Ontario families, farms, and small businesses a 10 per cent benefit on their monthly bills for 5 years.

The predicted long-term demand growth is illustrated in Figure 2.18. Three scenarios are considered to analyze the rate of the growth in the province. In the low growth (yellow curve), it is assumed that the demand grows modestly due to several reasons such as economic recession. It is also assumed that only 13 percent of people use electricity for heating, and also electric appliances account for a small portion of electricity consumption. In the medium growth (brown), a consistent move towards high-tech and service industries along with the higher provincial population growth is assumed. In this scenario, the demand will increase moderately by 15 percent by 2030. High growth scenario (orange)

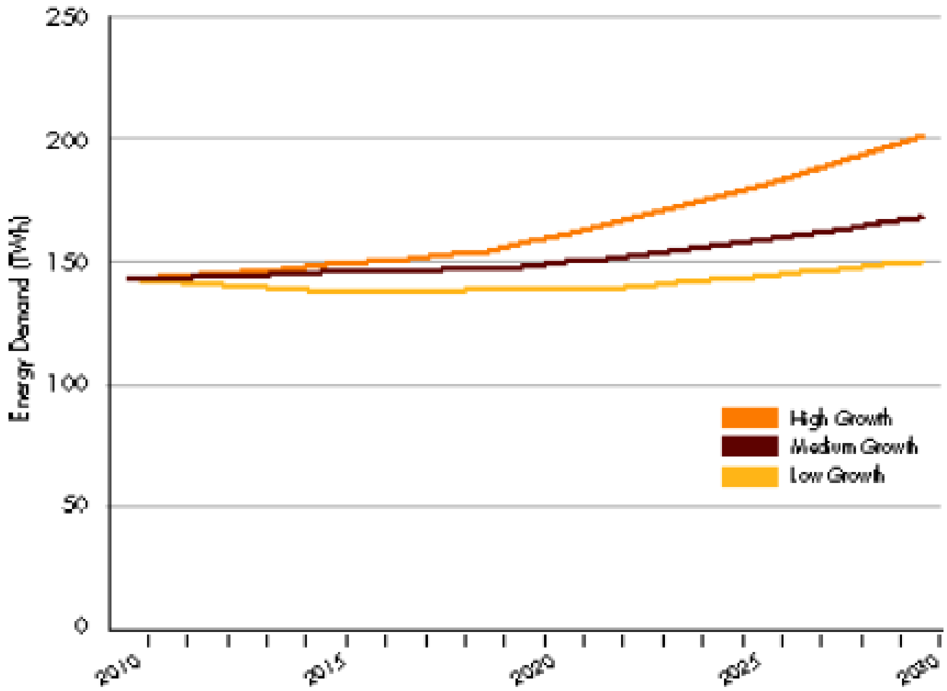


Figure 2.18: Range of energy demand forecast (Ontario Government, 2010)

represents an aggressive electrification situation in the province. Faster population growth and significant industrial change are among the factors assumed in this scenario. Ontario plans to be prepared to provide sufficient capacity for the future demand. It should be noted that in addition to conservation and electricity supply, electricity storage technologies can considerably help the government to meet the demand with a supply mix generation system.

The key features of the plan are as follows (Ontario Government, 2010):

- Ontario's population increases by 15 percent until 2030, and subsequently, the remand will moderately increase.

- Ontario will phase out all the coal units by 2014.

- Clean nuclear energy will maintain the source of 50 percent of electricity supply. Therefore, Ontario has to rebuild or replace its old nuclear fleet.

- Ontario will add 9,000 MW of hydroelectric capacity to the grid. Niagara Tunnel and Lower Mattagami projects are the most important projects contributing to this goal.

- The province will improve its renewable energy capacity (excluding hydroelectric) by 10,700 MW by 2018.
- Natural gas will support the grid in peak demand times, the increase in renewable sources, and modernization refurbishment of nuclear electricity generators.
- The energy efficient plan of Combined Heat and Power will be chased by the province.
- Five transmission projects are under development in the province.
- Ontario will also proceed in conservation plans, and its target is to reduce the overall demand by 28 TWh by 2030.
- Investment of $87 billion in the energy sector is planned and will help the government to pursue the clean energy supply.
- The long-term energy plan will create job opportunities and contribute to clean energy economy.
- Electricity prices will increase in residential and industrial sectors.
- Government's proposed Ontario Clean Energy Benefit, will give Ontarians a 10 per cent benefit on their electricity bills for five years.
- To help families, Ontario will add another 10 hours to the lowest cost period weekly.
- The province will provide Seniors and low and middle-income Ontarians with extra tax credits.

2.3.1 Water

Hydropower has been generated in Ontario since 100 years ago. Currently, it makes up 90% of Ontario's renewable energy supply. Ontario's hydroelectricity potential is not that much – about one fourth of Quebec's. However, Ontario seeks its goal to develop 9,000 MW of hydroelectric capacity by 2018. Niagara Tunnel and Mattagami projects are the most important ongoing hydro projects in the province, and some other potential projects are under consideration. However, building large-scale hydro plants is not economically feasible since they have to be built in remote areas. Their environmental impacts, which were discussed earlier, is another barrier.

2.3.2 Wind, Solar, and Bioenergy

With regards to Wind and solar energy, Ontario is Canada's leading province, and four largest wind and solar farms, such as the world's largest photovoltaic solar farm and Canada's largest wind farm, are located in this province. Ontario has made a huge progress in renewable energy supply since 2003. In 2003, Ontario had 10 wind turbines, while currently, it has 700 turbines. More than 16,000 renewable energy contracts has been signed since 2003. It is worth noting that Feed-in Tariff Program, which supports small and large renewable projects, has played an important role in this progress.

The future of renewable energy is very promising in Ontario. National and international investors have already announced their plans to participate in Ontario's clean energy economy. For example, Samsung and Siemens have proposed plans to build Ontario's first wind turbine blade manufacturing plant, which will create about 900 jobs. Ontario's plan is to generate 10,700 MW of renewable capacity by 2018. This planned development is based on the medium growth of electricity demand.

2.3.3 Coal

In 2003,coal was the supplier of 25 percent of generation capacity in Ontario. Its contribution decreased by the governments plans of gradually closure of coal plants. Coal is amongst the most polluting fuels. As mentioned earlier, the closure of coal-fired plants played an important role in the decrease of GHG emissions (Figure 2.19), and the final purpose of the plan is to phase out coal resources by 2014. Since 2005, eight coal units have been closed, four units in 2005 and four in October 2010. After the closure of these units, coal accounts for 13 percent of electricity capacity in Ontario. The closed coal units are as follows:

- Lakeview (Mississauga): four units closed April, 2005
- Nanticoke: two units closed October, 2010
- Lambton: two units closed October, 2010

Other units in Nanticoke and Lambton and coal-fired plants in Thunder Bay and Atikokan will also be closed. Atikokan generating station will be converted to a biomass generating station, and Thunder Bay generating station will partially converted to natural gas station by 2013.

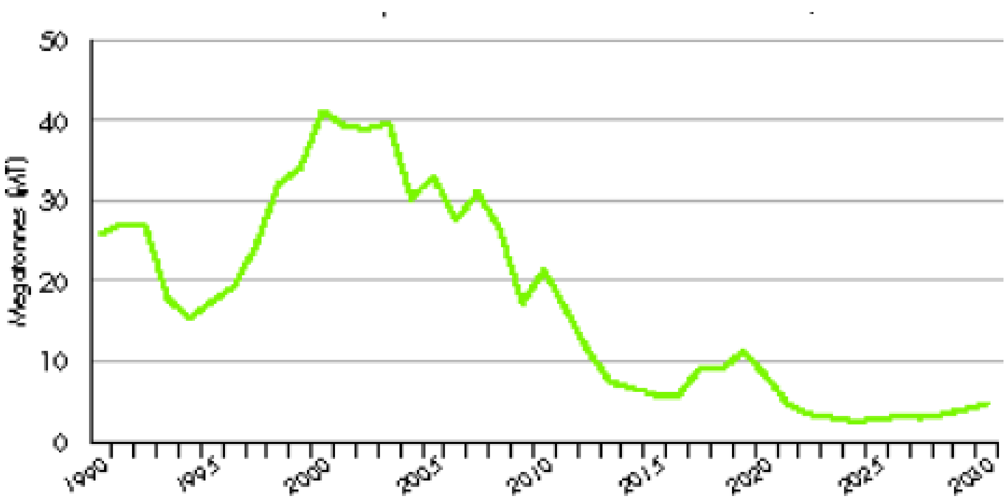


Figure 2.19: Actual and projected GHG emissions 1990-2030 forecast (Ontario Government, 2010)

2.3.4 Natural Gas

Currently, Ontario's natural gas electricity capacity is 9,500 MW. In 2009, natural gas accounted for 10% of Ontario's electricity generation, and the plan is to maintain natural gas as the supplier of 10% of the electricity in future. It is much cleaner than coal. Natural gas plants' most outstanding advantage is that they are flexible and can respond quickly to the demand's fluctuations. This feature is very important for Ontario considering the phase out of coal-fired plants and refurbishment of old nuclear facilities. From 2015 to 2020, when the major parts of the nuclear fleet refurbishment procedures will be done, and in the absence of coal-fired plants, natural gas will be a back up for electricity grid in the province.

2.3.5 Nuclear

Nuclear power produces about 50 per cent of the electricity generated in Ontario. It does not produce GHG emissions and air contaminants. Nuclear power plants can provide consistent supply of energy, and the production costs are very stable. The reason for that is that the fuel costs are much lower than the construction costs, so the fluctuations in the fuel costs do not affect the total nuclear electricity price.

Nuclear energy has a history of 40 years in Ontario, and the industry contains 70,000 direct and indirect employees. The history of developing nuclear energy in Canada is provided in Chapter 4 in order to have a good understanding about the background of this energy source in the country. Bruce B and Darlington nuclear sites are becoming close to the end of their lives, and have to be closed for three years to be upgraded. The economy recession and the considerable contribution of renewable energy resources removes the intence pressure on the province to build or rebuild nuclear fleet, but Ontario requires new nuclear capacity to meet its long-term energy need. Ontario's plan and the challenges that it is facing are discussed in Section 5.1.

2.4 Summary

In this chapter, the author provides an overview of the energy situation in Canada. Canada possesses great potential for developing renewable energy sources, especially wind technology. Currently, hydro power supplys 60% of the electricity in the country. The demand, however, is increasing. Although renewable sources can be improved, they are not sufficient to meet the growing demand in the near future. Fossil fuels, on the other hand, are polluting. Nuclear energy accounts for about 15% of the country's electricity and 50% of Ontario's electricity. Since nuclear energy is abundant and is not a polluting source with respect to greenhouse gases and other pollutants, it does not have the limitations of the renewable and fossil fuel resources. Therefore, the development of nuclear technology will change the energy future of the country.

A number of comprehensive energy studies have been carried out or are underway in Canada. In particular, the Canadian Academy of Engineering (CAE) is an organization working on strategic planning in the energy field. CAE is composed of experts and distinguished engineers who provide strategic advice with regard to important issues affecting Canada. Currently, the academy has about 400 members. In recent years, CAE has been working on energy strategies and has published several reports. The academy is developing an energy pathway for the country and is investigating different energy patterns. In a recent report, CAE experts studied all of the different sources of energy, grid infrastructure and GHG emissions (Bowman and Albion, 2009). In fact, the CAE work constitutes the most comprehensive and in-dept analyses about Canada's energy future. Therefore, the CAE's views and ideas are highly respected and could be very influential.

CAE uses the ProGrid methodology (Bowman, 2005) in its energy studies. ProGrid is a systems methodology and a decision making tool falling under the umbrella of multiple criteria decision analysis. Applying this methodology requires the participation of experts to assess the energy options according to different criteria. Therefore, the expertise of the evaluators plays an important role in achieving proper results. In one of the published reports, the academy proposed energy pathways to meet the energy demands of the country in the near and long-term future. Figure 2.20 is provided by CAE (Bowman and Griesbach, 2007) and illustrates Canada's energy situation. The academy believes that Canada has the potential to reduce the consumption of fossil fuels and to place more of an emphasis on renewable and nuclear technologies in the future.

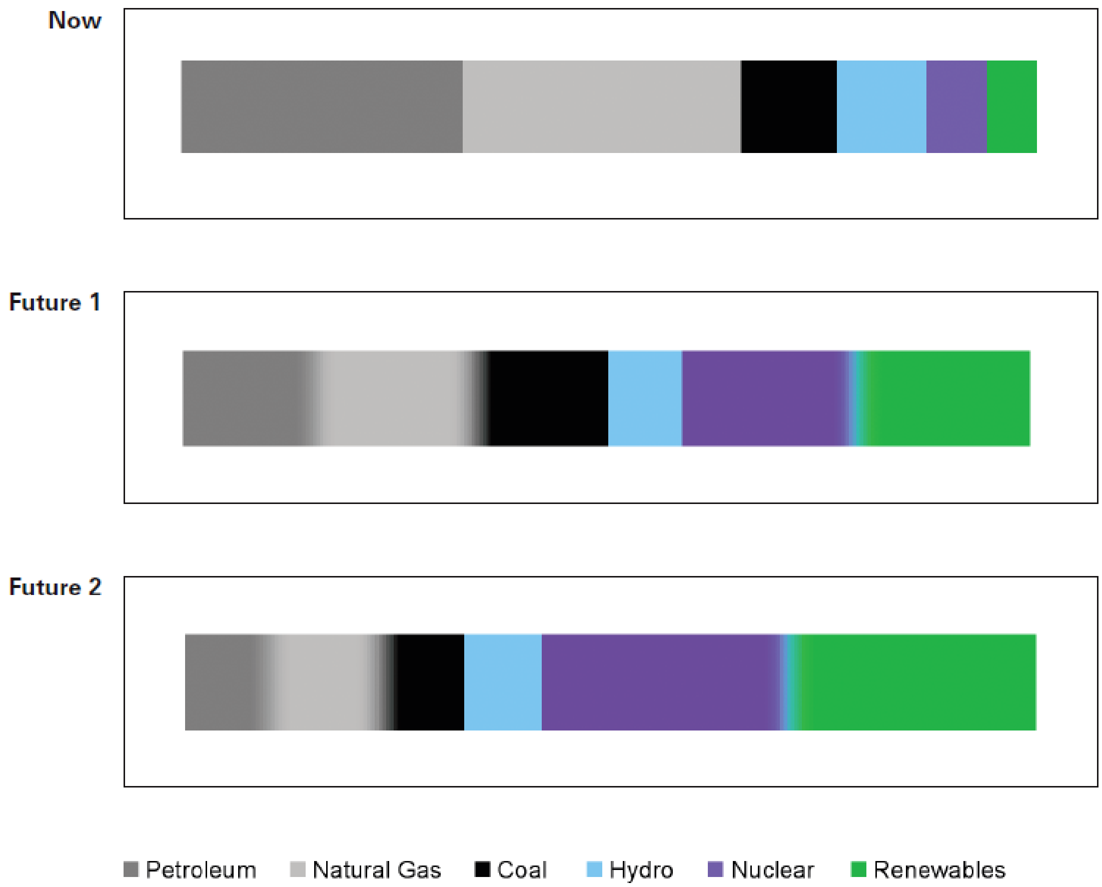


Figure 2.20: Electricity generation in Canada in 2007 (Bowman and Griesbach, 2007)

Chapter 3

Canadian Energy Systems Simulator

In this chapter, the goal is to develop some energy simulations in order to obtain a better understanding about the energy issue in the country. In this regard, the Canadian Energy Systems Simulator (CanESS) is introduced. The information that was obtained in the previous chapter helps the author in defining energy scenarios by using CanESS modeling platform. The simulation results will also indicate how important the nuclear energy is to the country.

3.1 Introducing CanESS

The Canadian Energy Systems Simulator (CanESS) is a tool which was developed by "Whatif? Technologies" company, located in Ottawa, Ontario. The company was founded in 1989 by Robert Hoffman and Bert McInnis. Using a dynamic systems modeling approach, CanESS provides support for strategic and policy analysis in the energy field. In this platform, a wide range of energy systems scenarios over the long term can be simulated and explored rapidly. Energy scenarios can be compared in terms of parameters in Canadian provinces. Parameters such as GHG emissions and the amount of electricity production can be analyzed by defining different scenarios. This way, CanESS examines the impacts of changes in parameters within the scenarios and provides insights to the decision makers in related fields. Using CanESS's simulations, an analyst may reveal the challenges and define problems that may be resolved and analyzed by policy alternatives or changes in the behavior of decision makers and consumers.

CanESS is calibrated from 1978 to 2006 in one year steps. The data base is provided by a wide variety of data sources including Statistics Canada censuses and surveys, the energy end-use data bases compiled by the Demand Policy Analysis Division, Natural Resources

Canada, and technical data from engineering studies and the GHGenius life cycle model for Canada.

The structure of CanESS is shown in Figure 3.1. First, the context for the energy system is set in terms of population, households and gross domestic product to the time horizon of the simulation – the user can set values for migration flows, fertility and mortality parameters, and per capita GDP. Then the transportation, residential, commercial buildings and industrial models calculate the energy currencies – hydrocarbon fuels, electricity, and hydrogen required to deliver services at a level commensurate with the economic context. Essentially, these models keep track of the stocks – vehicles, houses, buildings, etc. – and associate conversion efficiencies with the vintages of the stocks. The model user can set the efficiencies of future vintages and the rates at which new or alternative technologies penetrate into the stocks. Then these requirements for energy currencies along with those required to produce energy sources are fed to process models that calculate energy feedstocks required to produce the energy currencies. The feedstock production models represent the resources – conventional, oil sands, natural gas, coal, uranium, and biomass – and the rate at which the resources can be produced. Differences between feedstocks required and feedstocks produced are made up by international trade (CanESS, 2009).

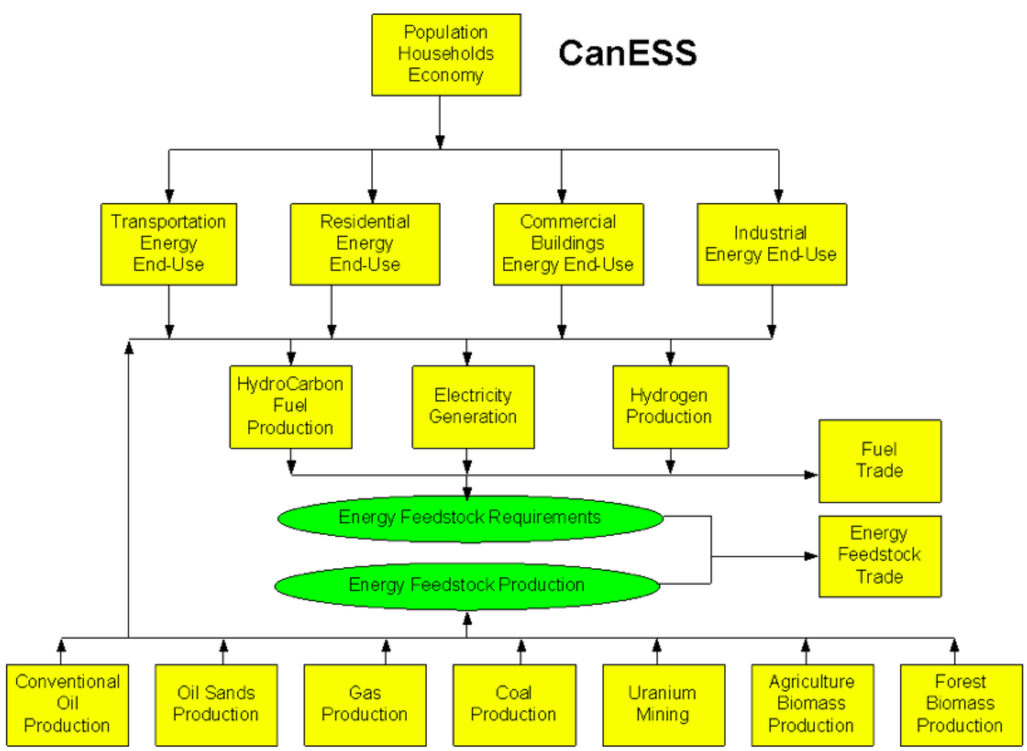


Figure 3.1: CanESS structure (CanESS, 2009)

3.2 CanESS Models and Applications

In this chapter, we discuss the two following models provided by CanESS, which are related to our study:

- Electricity generation modeling
- GHG emission modeling

In the following sections we try to describe how these models work, and how they are related. In addition, the aim is to change some parameters such as population to see how they affect GHG emissions.

In this chapter, the goal is to investigate the amount of GHG emissions in two case studies. Ontario plans to close two of eight coal units at the Nanticoke station near Simcoe and two of four units at the Lambton plant near Sarnia by 2014, but last year, the government announced that it would close these units by October 2010. Figure 3.2 is provided by CanESS to show the planned decommissioning coal electricity production capacity and the capacity that has been decommissioned since the year 2000.

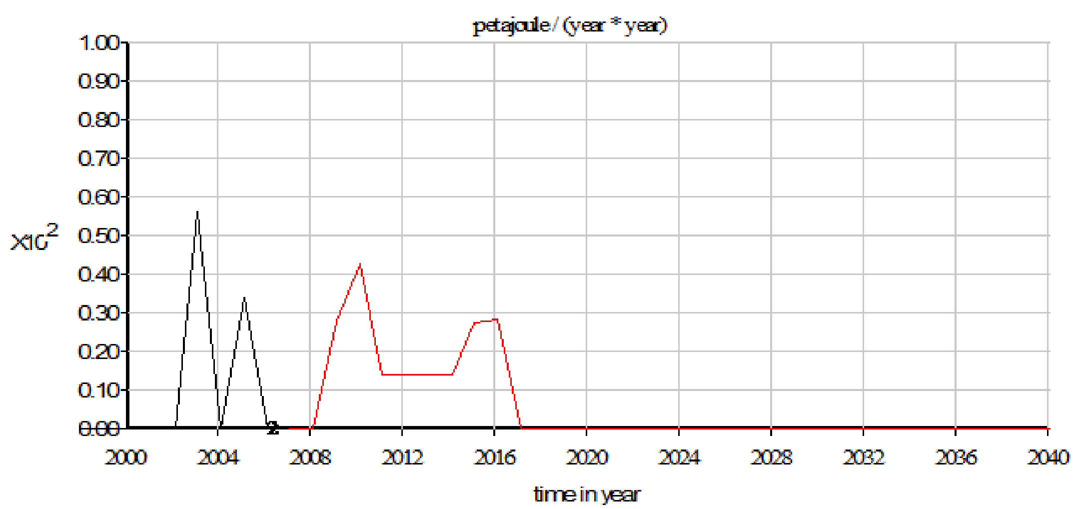


Figure 3.2: Planned decommissioning for coal electricity production capacity (CanESS, 2010a)

CanESS is used to examine electricity production and GHG emissions in the two case studies: (a) when the electricity from the Lower Churchill Falls station comes to the grid,

(b) when the planned new nuclear fleet in Darlington does not come to the grid. These two projects, Darlington and the Lower Churchill Falls, will have a huge impact on the grid capacity in Ontario and Newfoundland and Labrador, respectively. CanESS will provide an overview of the energy situation in these two projects, and the results of this study may be used by energy policy makers in order to provide proper strategic planning. The results also indicate the positive environmental effects of investing in renewable and nuclear resources.

3.2.1 Greenhouse Gas Emissions

The GHG emission model is also a very large one. There are many different variables that contribute to this model. Personal and commercial vehicle emissions, rail and air transport emissions, fertilizer production emissions, animal based emissions, and different energy sources' emissions are among the parameters that affect GHG emissions in the country. To be more familiar with this model, one of the GHG emissions parameters, uranium production emissions, is examined.

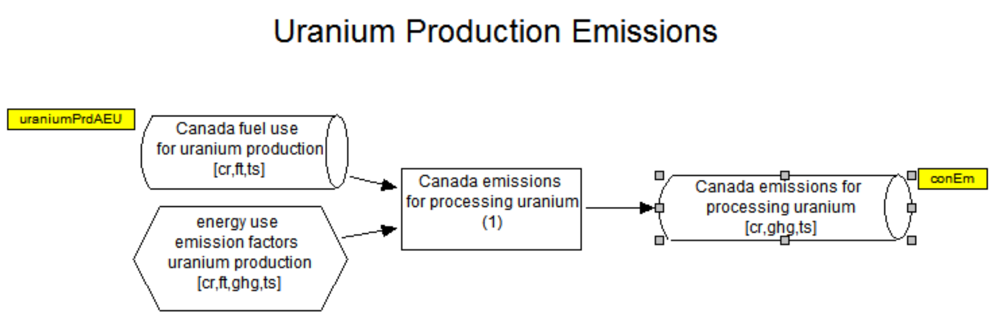


Figure 3.3: Uranium production emissions procedure (CanESS, 2010c)

Figure 3.3 shows the procedure in which uranium production emissions is calculated. The model has one procedure with two inputs, one of which, fuel use for uranium production, is calculated in another procedure. This input data is presented in terms of petajoule per year. The data for the other input, energy use emission factors for uranium production, is obviously obtained from a database, and is in terms of tonnes per petajoule. What needs to be calculated is Canada's emissions for processing uranium. Two variables' graphs are shown in Figures 3.4 and 3.5.

The amounts of these two graphs have to be multiplied year by year to obtain Canada's emissions for uranium production. This output is obtained in this procedure and is shown in Figure 3.6.

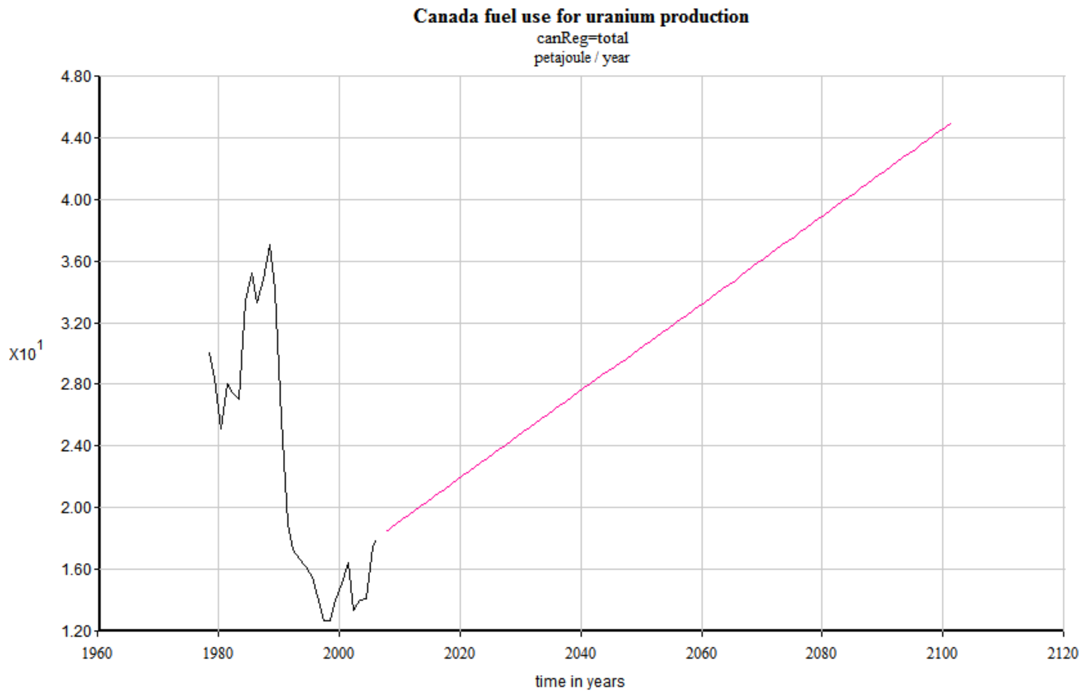


Figure 3.4: Fuel use for uranium production (CanESS, 2010a)

GHG Emissions and the Lower Churchill Falls

In this section, the aim is to define a scenario related to the Lower Churchill Falls contract and implement it by means of CanEss. This way, the impact of constructing this project is investigated in terms of GHG emissions. First, a short overview about the project is provided. The plan is to build two stations in the region and produce a combined capacity of 3,074 MW and 16.7 TWh of electricity per year. Electricity generation is supposed to begin in 2015 (Nalcor, 2010). Since electricity transmission is a challenge in this project, the construction is behind schedule. The purpose is to compare the amount of GHG emissions in the case that these two stations come fully to the grid in 2020 and in the case that they do not. If the project is not finished by 2020, Ontario coal-fired plants cannot be decommissioned as scheduled by the government (Ontario Government, 2009b), since according to the previous chapter, water is considered the most important substitute for coal. Figure 3.7 shows the difference in GHG emissions from 2007 to 2060, if the electricity of the Lower Churchill Falls comes to the grid and is sold to Ontario and becomes a substitute for the electricity from coal-fired plants. The two curves are too close to observe the difference, so Figure 3.8 provides a closer view from the year 2006 to 2040. The estimated decrease in GHG emissions is about 6 megatonnes in 2020.

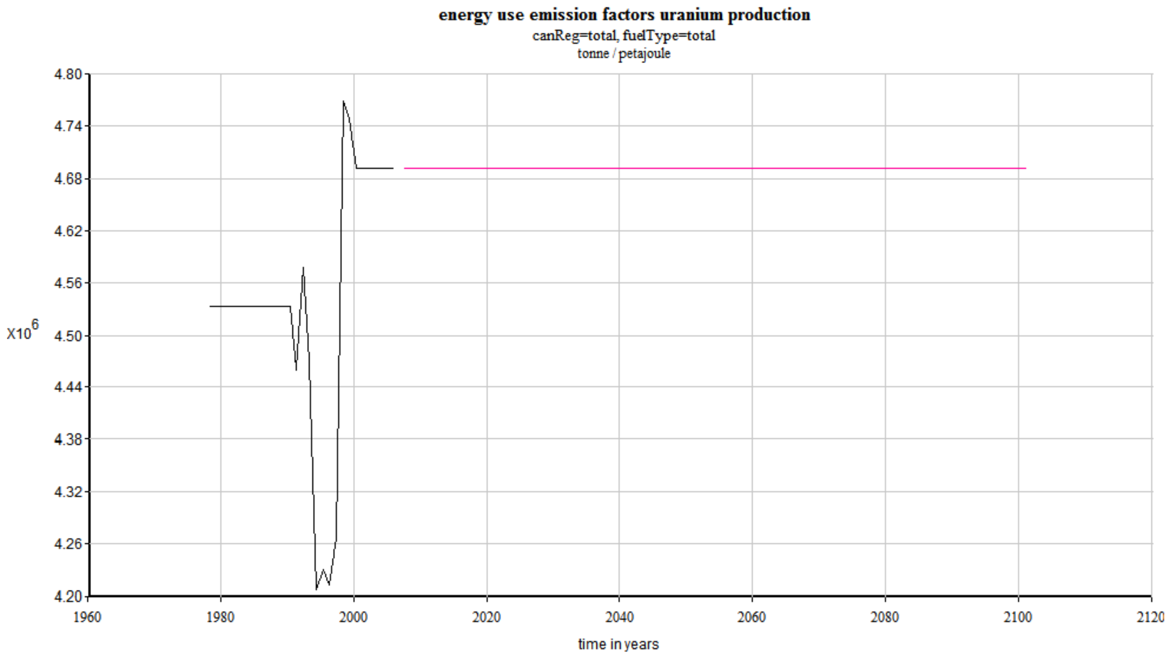


Figure 3.5: Energy use emission factors for uranium production (CanESS, 2010a)

3.2.2 Electricity Generation Modeling

CanESS is a very broad energy platform. In this section the electricity generation model is explained. Each model in CanESS consists of a few procedures, in which the mathematical calculations are performed. In the electricity generation model, there are eleven procedures. Each procedure has some inputs and outputs that may be the outputs or inputs of other procedures. As an example, "Electricity for Enriched Uranium Production", one of the procedures of the electricity generation model, is shown in Figure 3.9. As can be seen in the figure, there are three inputs into this procedure, one of which is coming from another procedure. Enriched uranium production (EUProd), electricity per unit enriched uranium (elecPerEU) and electricity for enriched uranium production history (elecForEUPH) are the inputs that can calculate the electricity for enriched uranium production (elecForEUP) in this procedure. The output is calculated by the following formulations:

Prior to 2007, electricity for EU production, elecForEUP, was equal to elecForEUPH. However the future of elecForEUP is calculated by multiplying EUProd by elecPerEU.

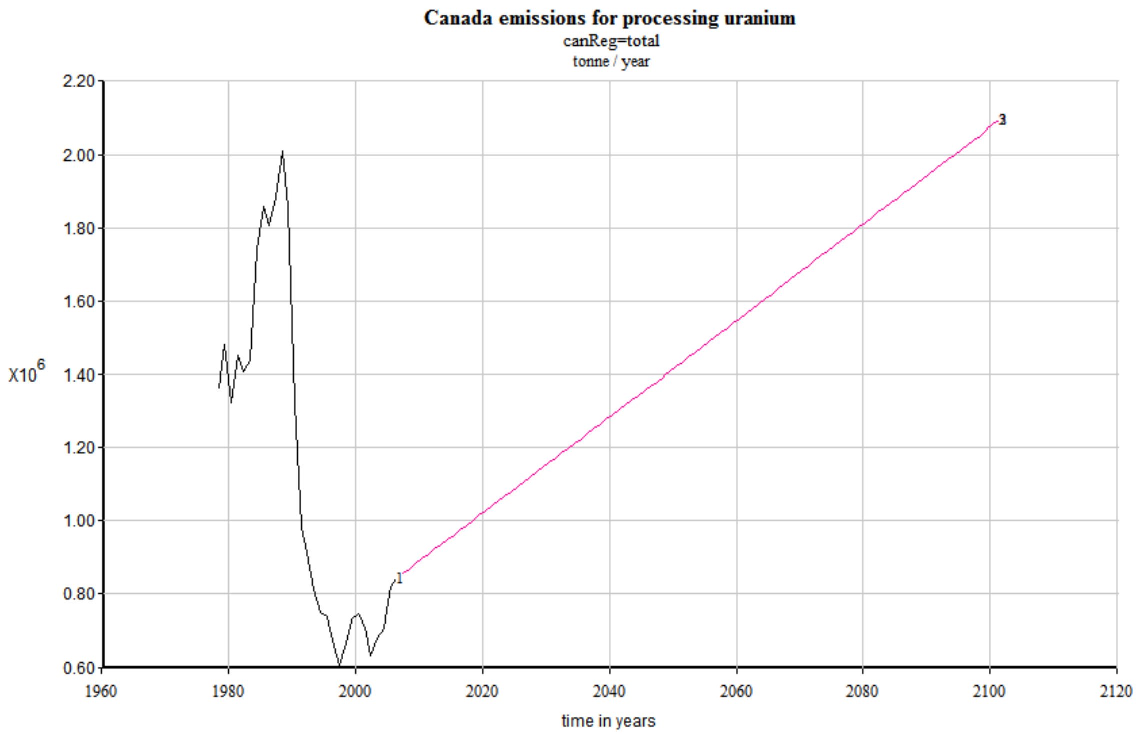


Figure 3.6: Fuel use for uranium production (CanESS, 2010a)

New Electricity Production Capacity

New Electricity Production Capacity is one of the variables in the "Electricity Generation" model in CanESS, and its model-based name is "newElecPrdCap". This variable introduces the history and the future trend of the new installed electricity capacity. This variable helps the analyst to have an understanding of the role of different electricity sources in the future. Figure 3.10 shows the situation of new electricity production capacity in the country. The electricity generation in Ontario is also illustrated in Figure 3.11.

As can be seen in Figure 3.11, in Ontario, nuclear energy, which is shown by a red line, plays an important role in electricity production. In addition to nuclear energy, gas is also an important contributing source. As explained in the first chapter, gas is not a very reliable source, because it is a fossil fuel, and it is possible that its extraction is going to decline in the future. In addition, gas is an important source of the whole energy production, and a small portion of it is used for electricity generation purposes. These facts make the nuclear source more outstanding.

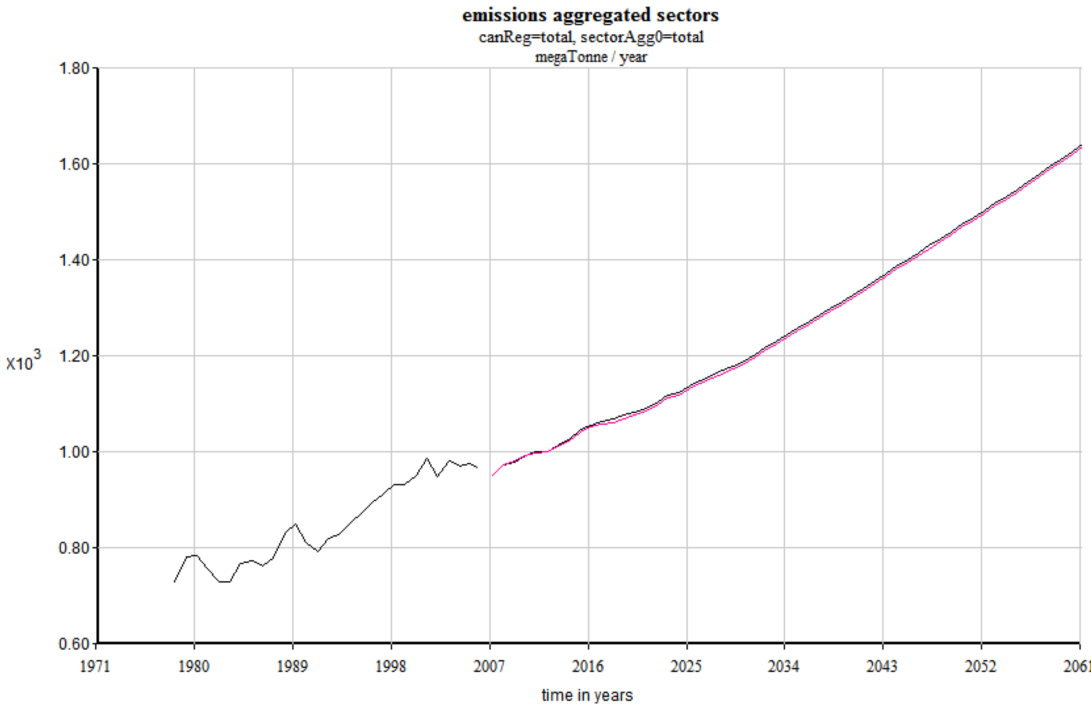


Figure 3.7: The difference between GHG emissions in the two scenarios (CanESS, 2010a)

3.3 Summary

In this chapter, the CanESS platform is introduced. CanESS is a numerical tool for modeling the energy system of Canada. One example is provided to show how this model works. Two important parts of this extremely large model are introduced: Greenhouse Gas Emissions and Electricity Generation Modeling. In Section 3.2.1, the effect of entering the Lower Churchill Falls into the grid on GHG emissions is investigated. In Section 3.2.2, the attempt is to give a better understanding of the situation of the resources used for electricity generation purposes. Subsequently, the significant role of the new capacity of nuclear energy is illustrated.

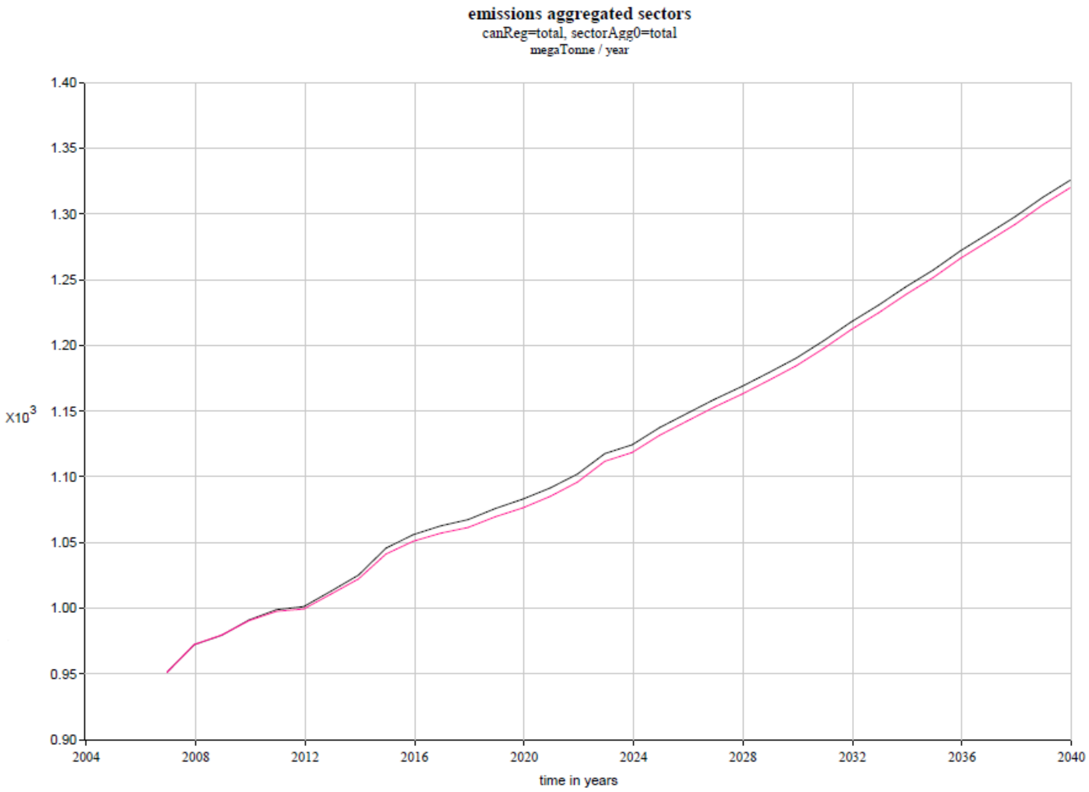


Figure 3.8: The difference between GHG emissions in the two scenarios (CanESS, 2010a)

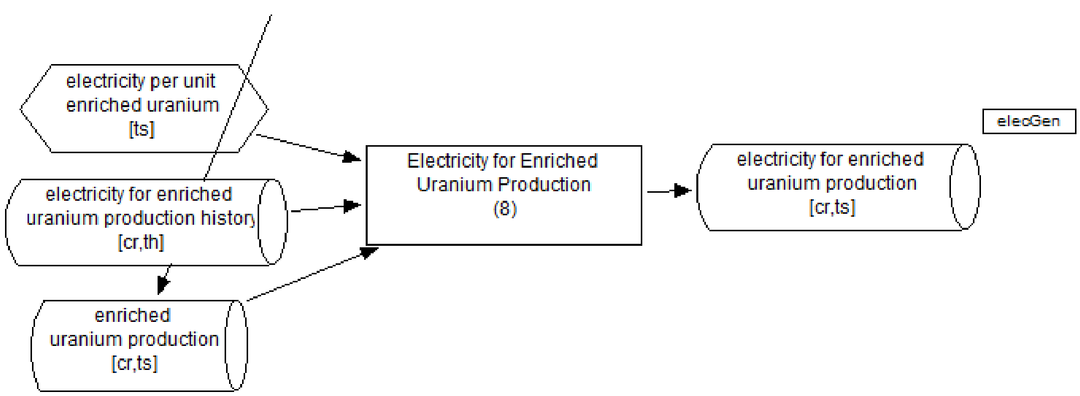


Figure 3.9: Electricity for enriched uranium production procedure (CanESS, 2010b)

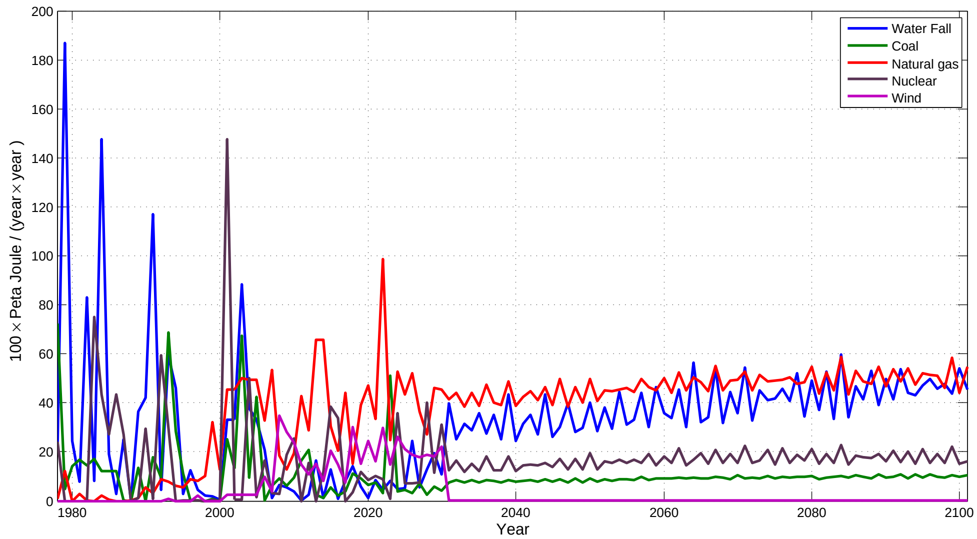


Figure 3.10: New Electricity Production Capacity in Canada (CanESS, 2010a)

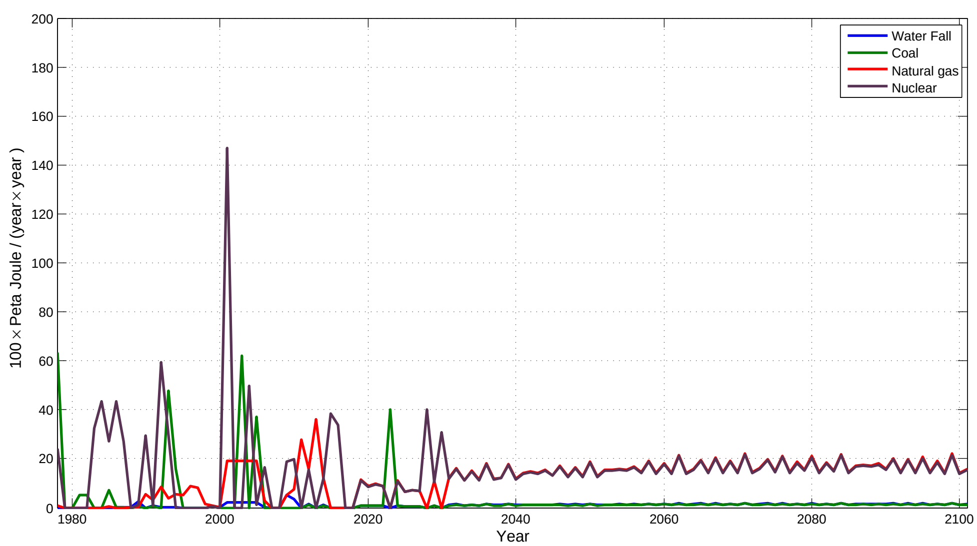


Figure 3.11: New Electricity Production Capacity in Ontario (CanESS, 2010a)

Chapter 4

History of Nuclear Technology and Canada's Role

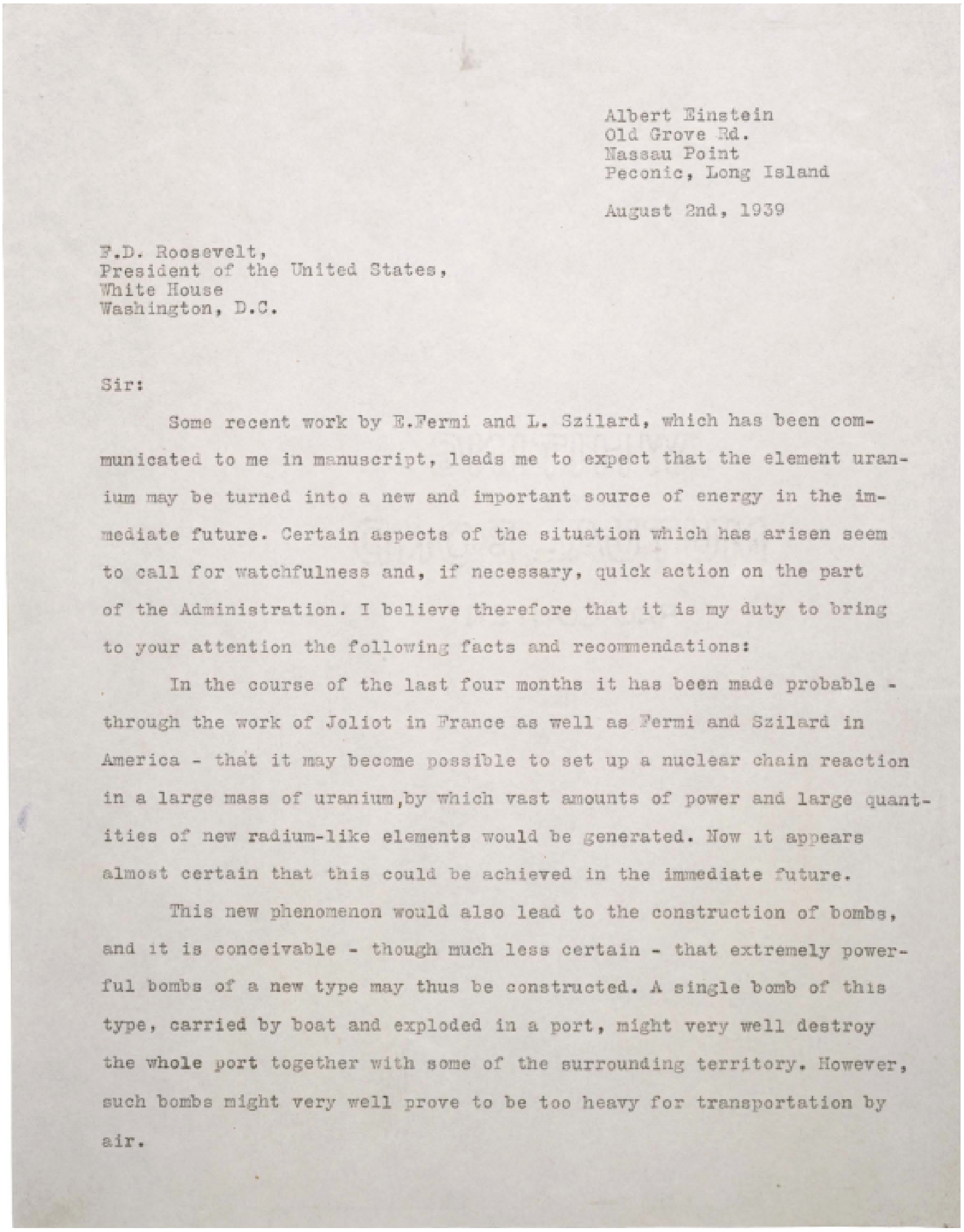
In this chapter, the history of the development of nuclear energy is provided. The history will talk about how the nuclear energy was introduced to Canada, and how the country became involved in this matter. The material provided in this chapter is helpful to have a background about nuclear energy in the country, and is useful to understand the importance of this energy source. The insights provided in Chapter 4 is important for the strategic study that is done in Chapter 5.

4.1 The Manhattan Project

In this section, the history of the development of nuclear energy is provided, and the role of Canada in this matter is studied.

4.1.1 Einstein's Letter

The Manhattan Project was a secret project of the US government during the World War II that succeeded in developing the nuclear bomb during the war. It is believed that the letter from Albert Einstein to US President Franklin Delano Roosevelt triggered the plan to build the nuclear bomb in this country. In the letter (which Einstein would later refer to as the greatest mistake of his life) he talks about the possibility of constructing an extremely powerful bomb and gives some hints that the German government might be working on making this bomb. The letter was written on August 2, 1939, and is shown in Figures 4.1 and 4.2.



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

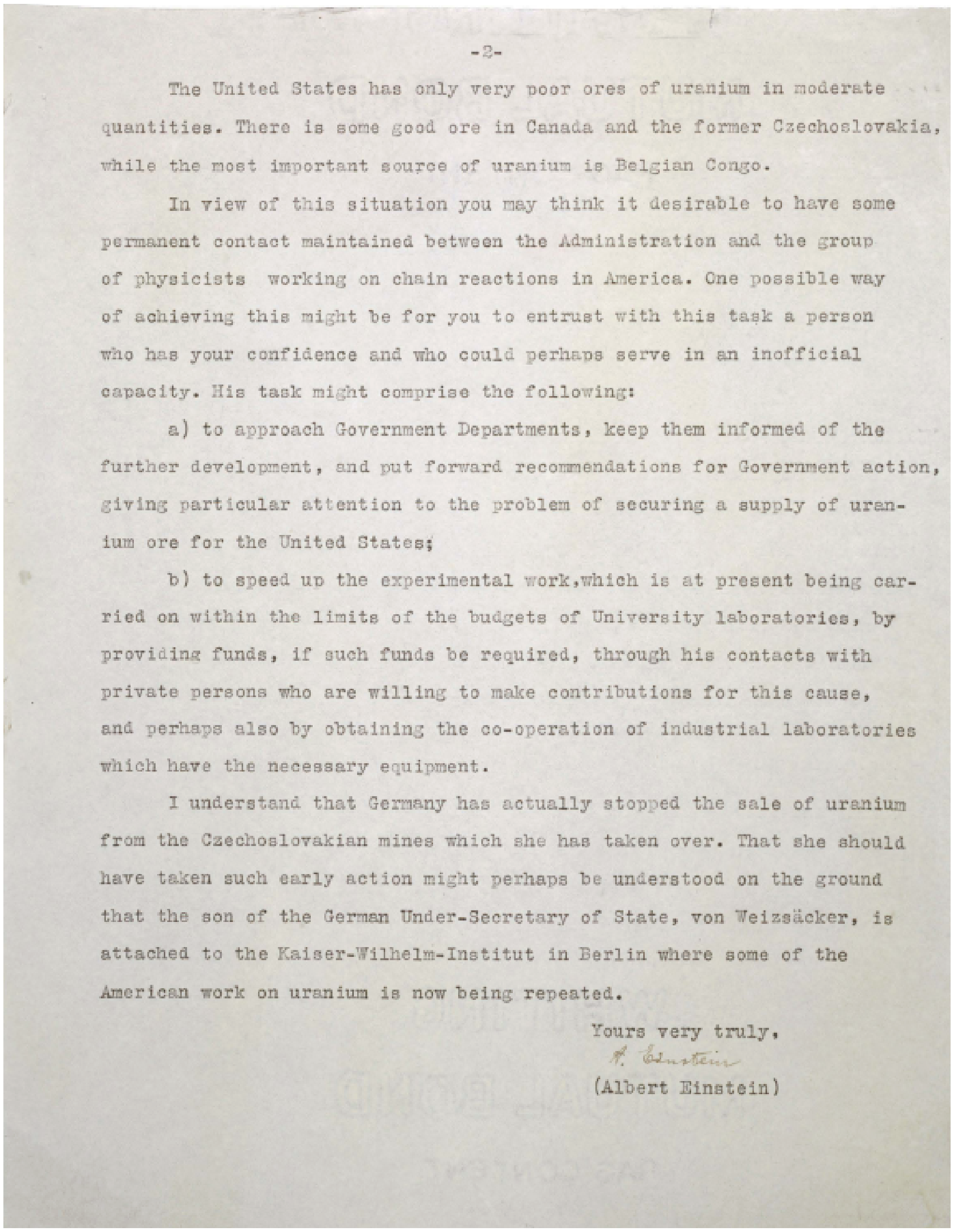
Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

Figure 4.1: Einstein's letter to Franklin Delano Roosevelt, page 1 (Elert, 1997)



-2-

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
A. Einstein
(Albert Einstein)

Figure 4.2: Einstein's letter to Franklin Delano Roosevelt, page 2 (Elert, 1997)

Einstein wrote the letter with the help of the Hungarian physicist Leo Szilard, who had escaped from Nazi Germany to the US, and fellow Hungarian refugee physicists Edward Teller and Eugene Wigner, who felt a responsibility to inform the US government about the possibility that German scientists might build an atomic bomb very soon.

Roosevelt received the letter. Because he was very busy with the events in Europe, it took about two months for him to arrange a meeting with Alexander Sachs, who was an economist and his long-time friend and unofficial advisor, to discuss the letter. They met on October 11, 1939. Sachs read from a cover letter he had prepared and briefed Roosevelt on the main points contained in Einstein's letter.

On October 19, 1939, Roosevelt wrote back to Einstein and informed him that he had set up a committee consisting of Sachs and representatives from the Army and Navy to study the proposal to make a nuclear bomb. He did not want to take the risk that Germans aquire the nuclear bomb before the US (Rossenfeld, 2009).

4.1.2 Atomic Bomb Research in Other Countries

Meanwhile, the British, who made good progress in pursuing the development of the nuclear bomb at the beginning of the war, could not continue their effort, because they were directly involved in the war. Therefore, the British reluctantly agreed that their scientists take part in the Americans' research. The Russians were also working on this matter very seriously, but their first successful test was in 1949, after the war had ended. The Germans were also unsuccessful in completing their project, so the US, which entered the war later than other countries, succeeded in making the first nuclear bomb, and briefly held onto an atomic monopoly (Rossenfeld, 2009).

4.1.3 National Defence Research Committee

Shortly after the beginning of World War II on September 1, 1939, with the German invasion of Poland, the president of the Carnegie Foundation – an educational research organization – tried to convince Roosevelt that the government should more seriously concentrate its scientific efforts on warfare, because sooner or later the US would enter the war. Having in mind that France was in danger of falling, Roosevelt agreed to establish the National Defence Research Committee, with Vannevar Bush as the head. The committee was established in June 1940. Bush reorganized the nuclear research group. He eliminated the military members, and also the foreign scientists. He also banned publications on nuclear research. Then, in 1941, Bush became Director of the newly-created Office of Scientific Research and Development (OSRD). The Uranium Committee became the OSRD Section on Uranium and was codenamed S-1 (Rossenfeld, 2009).

The National Defence Research Committee, now headed by James B. Conant, President of Harvard University, became an advisory body responsible for making research and development recommendations to the OSRD.

The progress of OERD was not very significant. Two reports that were published by the National Academy of Science did not satisfy Bush. However, in July 1941, Bush received a very outstanding report from a group codenamed the MAUD Committee, the National Defence Research Committee liaison office in London. MAUD believed that it could build a bomb in approximately two years. The MAUD group report started a new period in building the nuclear bomb. On December 7, 1941, the Japanese attacked Pearl Harbor, and the US entered the war. Therefore, Americans urged the funding of the project.

4.1.4 Expanding the Research and Canada's Involvement

In August 1942, the program was placed under the direction of the Army Corps of Engineers, and the Manhattan Engineer District (MED) was set up to manage the project. Some scientists were invited to collaborate in the project. A young Canadian scientist, Louis Slotin, was one of the experts who was asked to join the US. In 1942, Canada was invited to the project. Ottawa immediately reopened the Eldorado Mine, which had been closed at the outset of war. The U.S. now had a steady supply of uranium. Canada was the only source of uranium outside of Africa. Canada continued supplying uranium to the US nuclear weapons program until the mid-1960s, when it finally shut down the Eldorado mine at Great Bear Lake (Rose, 2005). In May 1942, Colonel Leslie R. Groves was appointed to head the effort, and he chose J. Robert Oppenheimer to be the head of the atomic bomb research in Los Alamos, New Mexico. By 1944, the researchers at Los Alamos had found a way to build the bomb. Scientists at other laboratories at Oak Ridge and Hanford were trying to get a hold of the required amount of enriched uranium and plutonium. At that time, the war in Europe had almost ended, so the only target was Japan.

By the spring of 1945, the research was finalized, and Americans were ready to test the weapon. At the same time, they found out that Germany was not even close to building the bomb. Americans tested the bomb on July 16, 1945, at a remote corner of the Alamagordo Bombing Range, 210 miles south of Los Alamos, New Mexico, and it was successful. The test was named the Trinity Test. At that time, Harry S. Truman was the President of the US (US Department of Energy, 2009).

4.1.5 The Bomb in Hand

Before they had acquired the bomb, the Americans needed the help of the Soviet Union to attack Japan. The Soviet Union leader, Joseph Stalin, had promised to join the war against

Japan by August 1944. However, upon obtaining the bomb, the Americans no longer felt that they needed the assistant of the Soviet Union. On July 24, 1945, Truman told Stalin that the US has “a new weapon of unusual destructive force.” But the Americans never informed the Soviet Union about their possession of the atomic bomb.

On July 26, Truman, Stalin, and Clement Attlee, the new British Prime Minister, issued a warning statement to Japan: surrender or suffer “prompt and utter destruction.” The Americans never talked to Japan about using the atomic bomb. Although there were anti-war sentiments among the Japanese, they rejected the Potsdam declaration on July 29, 1945 (US Department of Energy, 2009).

Finally, on August 6, 1945, an atomic bomb was dropped on Hiroshima, Japan. By exploding a 9,700 pound uranium bomb, called Little Boy, 70,000 people were killed, and another 70,000 were wounded. Because Japan did not surrender, a 10,000 pound atomic bomb, called Fat Man, was dropped on Nagasaki, Japan, on August 9, 1945. The bomb killed 40,000 people and injured 60,000. Japan promptly surrendered on August 14 .The Manhattan Project cost the United States the equivalent of $2 billion in 1945 spending power and required the combined efforts of a continent-spanning industrial enterprise and a pool of scientists (Schwartz, 1998)

4.2 Montreal Laboratory

About 70 years ago, Canada was not heavily involved in nuclear research and development. Research at the National Research Council of Canada (NRCC) laboratories was usually mission oriented, and there was not much confidence in Canadian scientists to perform creative scientific projects. By 1940, the attention of the laboratories had shifted almost entirely to war problems. It was very difficult to catch up with the new technologies while being isolated from basic research; however, scientific periodicals made Canadian scientific society aware of the discovery of nuclear fission in 1938. Therefore, Canadian scientists started carrying out research on nuclear fission along with United States, Britain and Germany (Laurence, 1980).

After the start of World War II, many of the sources and facilities of Britain were directed to issues pertaining to the war, so it was suggested that the nuclear research in England be moved to the USA. Although in the initial years, Britain was more advanced in the field of nuclear research, the USA was more developed at that time. The American nuclear group, however, was not interested in the suggestion, because there were people in the British group who were refugees from other European countries, and American scientists were worried that their concerns about their relatives in Europe might cause problems.

Britain then suggested a joint British-Canadian laboratory be established in Canada in order to build a pilot plant for the production of plutonium, and the USA agreed to information exchange with the laboratory. Establishing a joint laboratory was a tough decision for Canada to make. Canada had to spend a great deal of money to build the laboratory and recruit the staff. There were also concerns that the project may not be finished before the end of the war. On the other hand, even after the war, Canada could benefit from the nuclear technology at least in terms of economics. Therefore, Canadian Prime Minister William Lyon Mackenzie King agreed to the project, and the work began in Montreal at about the end of the year 1942, as a division of NRCC (Laurence, 1980).

The collaboration between the American nuclear research group and the laboratory did not progress very well. The main reason was that the Director of the Laboratory, H.H Halban, could not establish a good relationship between eitherthe Americans or NRCC. There were misunderstandings and miscommunications among scientists and political leaders. However, after some changes in the management of the laboratory, they reached an agreement, and the project continued. The design of the construction of a heavy water moderated nuclear reactor in Canada was made at a meeting of the Combined Policy Committee in Washington on April 13, 1944. After a score of possible sites was considered, one near Chalk River was chosen and called the Petawawa Works, and the reactor was named: NRX (National Research eXperimental). Before NRX was completed, however, it was desirable to have some experience in operating a comparable reactor. On August 24, 1944, a very simple reactor that could be completed quickly was designed so that its uranium rods and other parts could easily be changed or rearranged. On September 4, 1945, at Chalk River, the construction of ZEEP (Zero Energy Experimental Pile) was completed. While the laboratories were being built at Chalk River, the staff moved there gradually from the Montreal Laboratory, which was closed down in July 1946. In 1945 and 1946, most of the British scientists returned to England and began the research that was to lead the United Kingdom to become the third nuclear military power, and the first to produce electricity in large nuclear power stations economically (Laurence, 1980).

The first phase of nuclear research and development in Canada, involving the collaboration of scientists and engineers from Great Britain, France and other parts of Europe and the United States, was coming to an end. The center of activity in Canada had moved to Chalk River and there was reorganization, new direction and new purpose. Gradually, the CANDU conception of nuclear power stations was to emerge.

4.3 Nuclear Organizations

In this section, Canadian nuclear organizations are introduced, and some related information is provided.

4.3.1 Atomic Energy of Canada Ltd. (AECL)

History

In 1942, a Canadian-British nuclear research laboratory was established in Montreal. The laboratory worked under the National Research Council of Canada to develop a design for a nuclear reactor. According to the history of the Montreal laboratory, in 1946 the Montreal research laboratory was closed and research was consolidated at Chalk River Laboratories. Before the laboratory was closed, the first reactor, named Zero Energy Experimental Pile (ZEEP), had been built in 1945 at the Chalk River laboratories. ZEEP provided valuable information for the research on heavy-water-moderated fuel for building future reactors. In 1947, the 42 MWt NRX (National Research eXperimental) reactor was built at Chalk River, Ontario. It was used for producing radioisotopes, undertaking fuels and materials development work for the next generation of reactors, Canada Deuterium Uranium (CANDU) reactors, and providing neutrons for physics experiments. NRX was the most powerful reactor in the world at the time. In 1952, Atomic Energy of Canada Ltd. (AECL) was formed by the government as a federal Crown corporation, and its mission was to develop peaceful uses of nuclear energy.

On December 12, 1952 one of the world's first major reactor accidents occurred in the NRX reactor at AECL's Chalk River Laboratories, when a combination of human and mechanical error led to a temporary loss of control over the reactor's power level. The reactor building was contaminated, as well as an area of the Chalk River site, and millions of gallons of radioactive water accumulated in the reactor basement. This water was pumped to a waste management area of the laboratories and monitored. Hundreds of military personnel from Canada and the U.S. were employed in the cleanup and disposal of the reactor debris.

On May 24, 1958, the NRU (National Research Universal) reactor (which is described in Section 4.3.3) at Chalk River also suffered a major accident. A damaged uranium fuel rod caught fire and was torn in two as it was being removed from the core due to inadequate cooling. The fire was extinguished, but not before releasing a sizeable quantity of radioactive combustion products that contaminated the interior of the reactor building and, to a lesser degree, an area of the surrounding laboratory site. Over 600 people were employed in the clean-up.

In 1954, AECL partnered with the Hydro-Electric Power Commission of Ontario to build Canada's first nuclear power plant at Rolphton, Ontario. On June 4, 1962, Canada's first nuclear reactor, the Nuclear Power Demonstration (NPD), was put into operation, generating about 20 MWe. This reactor served a prototype of the CANDU system.

In 1971, the first commercial CANDU reactor, Pickering A 1, began commercial operation. By 1973 the other three reactors of the A group at Pickering were online and constituted the most powerful nuclear facility in the world at the time. Each Pickering unit produces about 600 MWe of power.

With a contract signed in 1991, AECL, in partnership with MDS Nordion, began construction of the MAPLE dedicated isotope-production facility. Constructed on-site at AECL's Chalk River Laboratories, this facility will house two reactors and an isotope processing facility. Each reactor is designed to be able to produce 100% of the world's medical isotopes, meaning that the second reactor will be used as a back-up to ensure an uninterruptable supply. Construction and licensing delays have so far prevented the facility from opening.

Medical isotope production using the NRU reactor experienced two forced outages due to safety concerns (December 2007) and a heavy water leak (May 14, 2009). The production from the NRU reactor represents a significant fraction of the worlds medical isotope supply and the disruptions have caused a world-wide shortage. Due to maintenance requirements from the aging NRU reactor and the MAPLE 1 and 2 reactor projects, the long-term production of medical isotopes in Canada has become a controversial topic (Brown, 1965).

Missions and Mandates

The AECL's missions and mandates are listed bellow (AECL, 2009a):

- *To be the best nuclear energy company*
- *To provide safe, reliable, economical and sustainable nuclear energy solutions worldwide*
- *To be Canada's nuclear platform for nuclear science and technological expertise*
- *To operate a commercially viable, self-sustaining business designing, building and servicing CANDU nuclear power reactors*

4.3.2 Canadian Nuclear Safety Commission (CANSC)

The Canadian Nuclear Safety Commission (CNSC) is committed to Canada's international nuclear agreement on the peaceful use of nuclear technology. CNSC protects the health, safety and security of Canadians as well as the environment.

History

The Atomic Energy Control Board (AECB) was established under the Atomic Energy Control Act of 1946. Its role was to assist the Government of Canada in its efforts "to make provision for the control and supervision of the development, application and use of atomic energy and to enable Canada to participate effectively in measures of international control of atomic energy." The AECB had three main functions in the areas of regulation, mining and research. In the 1950s and 1960s, the mandate of AECB came to focus on regulating the nuclear sector, establishing health and safety regulations. In 1957, Canada had a very important role in forming the International Atomic Energy Agency (IAEA) with the support of the United Nations. As part of its mandate, the IAEA establishes and administers international safeguards for the peaceful use of nuclear energy. Over the years, the Atomic Energy Control Board (AECB) saw an increased focus on nuclear compliance and public participation in the licensing process. On May 31, 2000 the Canadian Nuclear Safety Commission (CNSC) replaced the AECB.

Missions and Mandates

Under the Nuclear Safety and Control Act, CNSC's mandate involves four major areas (Canadian Nuclear Safety Commission, 2010b):

- *regulation of the development, production and use of nuclear energy in Canada to protect health, safety and the environment*
- *regulation of the production, possession, use and transport of nuclear substances, and the production, possession and use of prescribed equipment and prescribed information*
- *implementation of measures respecting international control of the development, production, transport and use of nuclear energy and substances, including measures respecting the non-proliferation of nuclear weapons and nuclear explosive devices*
- *dissemination of scientific, technical and regulatory information concerning the activities of CNSC, and the effects on the environment, on the health and safety of persons, of the development, production, possession, transport and use of nuclear substances*

4.3.3 Reactors in Canada

Research Reactors

- **National Research Universal (NRU):** National Research Universal (NRU) is one of the most important reactors that has been operating at Chalk River since 1957. NRU does not produce electricity, but tests the fuels and materials for CANDU reactors. It also produces neutrons for the National Research Council's Neutron Beam Center to investigate industrial and biological materials. NRU produces the majority of the world's medical isotopes used in both the diagnosis and treatment of life-threatening diseases (AECL, 2010c).

- **Zero Energy Deuterium -2 (ZED-2):** ZED-2 is the larger version of ZEEP, and has been operating in Chalk River since 1960. It has been used to study the effects of heavy water and alternative light water and organic coolants (AECL, 2010d).

CANDU Power Reactors

CANDU reactors have been operating in Canada since 1962, and abroad since 1972. CANDU technology is unique for its on-power refueling capability, and heavy-water moderator technology. CANDU units have been built in North America, South America, Europe and Asia, and currently, there are 48 reactors operating around the world whose design is based on CANDU technology. AECL is the designer and the builder of the CANDU reactors, and sells them in Canada and other countries, and it is responsible for managing and maintenance of all its products around the world. Three different CANDU reactors are introduced (AECL, 2010a):

- **CANDU 6 power reactors:** The exclusive feature of the CANDU 6 is that it uses natural uranium as fuel. This feature is very important, because the fuel can be manufactured in the country. CANDU 6 is a 700 MWe nuclear power reactor, and is developed only for electricity generation purposes.

- **Enhanced CANDU 6 (EC6):** EC6 is the evolution of the CANDU 6 design.

- **Advanced CANDU Reactors (ACR-1000):** The Generation III+ is a 1,200 MWe Reactors and is more advanced than existing CANDU reactors, particularly in regard to:

  - Enhanced passive safety
  - Competitive economics

– Designed for operability and maintainability

Table 4.1 shows the locations of CANDUs around the world.

Table 4.1: CANDU Reactors around the world (AECL, 2010b)

Location	Site	Units
Quebec, Canada	Gentilly 2	1
Ontario, Canada	Darlington	4
Ontario, Canada	Peckering	8
Ontario, Canada	Bruce	8
New Brunswick, Canada	Point Lepreau	1
Argentina	Embalse	1
Romania	Cernavoda	2
Republic of Korea	Wolsong	4
People's Republic of China	Qinshan	2
India	RAPS	2
Pakistan	KANUPP	1

Chapter 5

Conflict Resolution of the Ontario Nuclear Dispute

This chapter examines the current nuclear power dispute concerning the expansion of the Darlington nuclear site in Ontario. The Ontario Government plans to install two new nuclear units at the Darlington site, near Toronto. Three companies have bid for the project, one of which is Atomic Energy of Canada Ltd. (AECL). Formed in 1952, AECL is the designer and the builder of almost all CANada Deuterium Uranium (CANDU) reactors in Canada, such as those at the Darlington, Bruce, and Pickering sites. It also has foreign customers, such as Romania and China. AECL is committed to supporting its Canadian and international customers in all aspects of nuclear power technology management. The name AECL has always been a part of the nuclear history of Canada, and it can be considered a national investment (AECL (Atomic Energy of Canada Ltd.), 2008). This chapter analyzes the obstacles that can prevent AECL, as a federal Crown corporation, from winning the bid and discusses the roles of the Federal and the Ontario governments and other Canadian parties and groups regarding this national issue. This conflict is an ongoing dispute, and the situation of the game changes as time progresses. Therefore, an analysis was performed at two points in time, 2008 and 2010, in Sections 5.3 and 5.4, respectively. However, first the conflict resolution methodology is described followed by an overview of the nuclear conflict in Section 5.1.

5.1 Graph Model for Conflict Resolution Methodology

The Graph Model for Conflict Resolution (GMCR) is the approach that is used to analyze this conflict. The GMCR methodology was developed by Fang et al. (1993) based upon earlier work by Fraser and Hipel (1984) and Howard (1971). GMCR can be used to formally investigate a conflict dealing with multiple decision makers with multiple options. It is for this reason that this methodology has been chosen to be used in this research. Other approaches to conflict resolution are described in the books edited by Hipel (2009a; 2009b) and references contained therein. GMCR constitutes a flexible approach to the representation, analysis, and understanding of a strategic conflict. It also facilitates modifications to the way in which the conflict is represented, encouraging sensitivity and what-if analyses. This decision technology can be used to analyze disputes among different parties with different options or decision choices, and different preferences or value systems.

GMCR is able to provide decision makers (DMs) with suggestions for reaching possible resolutions. These suggestions might protect the interests of all parties involved. Figure 5.1 illustrates the way in which a conflict study is carried out in practice. GMCR, along with its associated decision support system GMCR II (Fang et al., 2003a,b; Hipel et al., 1997), is used to model the conflict and analyze the current situation.

The most important part of applying the GMCR model to a real-world conflict is the background investigation. Searching the news, talking to experts, and reading the related published articles help the analyst have a proper understanding about a conflict and develop a realistic model. Therefore, accurate and comprehensive information plays a fundamental role. In fact, the whole "Modeling" section, as shown in Figure 5.1, as well as the "Interpretation and Sensitivity" stage in the "Analysis" part, directly depend on the analyst's findings. In other words, the analyst determines the DMs, their options, infeasible states, and relative preferences. The analyst's decision about executing different sensitivity analyses, and the interpretations and suggestions to actual DMs for an ongoing conflict depend on the available data.

5.1.1 Decision Makers, Options, and States

To use the graph model methodology, one must first model the dispute in terms of the DMs. A DM is a person or a group who plays a role in a conflict and has one or more decisions to make, or alternatives to choose. A DM may also be named a player, actor, or stakeholder. Besides the DMs and options, states should be defined. A state is any combination of chosen options. For example, in a conflict with 2 DMs, and 2 options for each, (Y N, N Y) is an indication of a state in which DM 1 chooses its first option, and DM 2 chooses its second option. Obviously, some states cannot occur in reality. These states are considered "infeasible" and have to be removed from the game. The four different types of infeasible states are introduced as follows (Fraser and Hipel, 1984, p. 34-36):

- ***Type 1*** These states are **logically infeasible** for a single DM. This type of infeasibility can be illustrated in the states in which a DM chooses two or more options

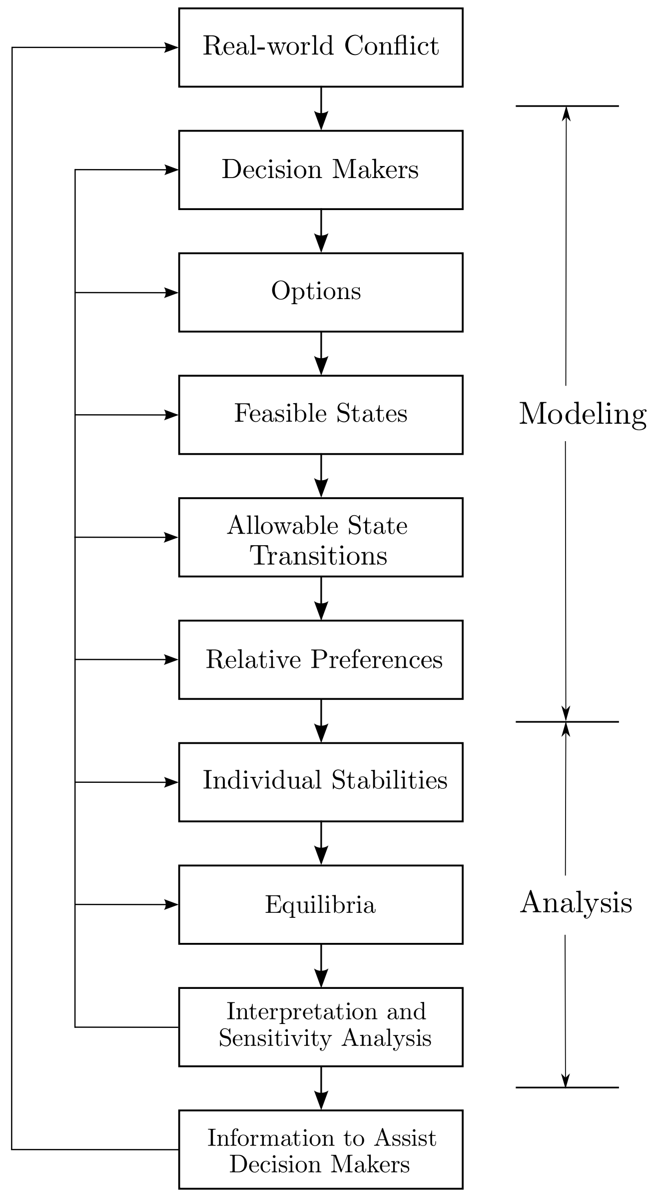


Figure 5.1: Applying the Graph Model for conflict resolution (Fang et al., 1993)

that in reality cannot be chosen together. A DM's mutually exclusive options are an example of a logically infeasible state for a DM. For example, in the conflict that is being discussed in this chapter, the Ontario Government, as a DM, cannot buy its reactors both from AECL and a foreign company. Type 1 infeasible states are the easiest and safest ones to remove.

- ***Type 2*** States that are **preferentially infeasible** for a single player are Type 2 infeasible states. These are the strategies that the DM would not be expected to choose in any circumstances. For example, if a DM must choose between the available options, the state in which the DM does not choose any option is infeasible. Removing this type of infeasible state simplifies the conflict model, but can cause problem in some situations.

- ***Type 3*** There is risk involved in removing this type of state. Type 3 infeasible states are **logically infeasible** among two or more players. For example, assume that DM A has an option to offer a service to DM B, and DM B has the option to accept the service. In this case, it is not possible that DM B accepts the service if DM A does not offer it. The risk of removing this type of state is that the meaning of the options might be restricted. In the aforementioned example, the option to "accept the offer" may have been intended to mean "indicate a willingness to accept." Therefore, if this type of state is removed, there is a risk that the analysis will end up with false results.

- ***Type 4*** The removal of type 4 states presents the greatest amount of risk. These states are **preferentially infeasible** among two or more players. It is possible for a type 4 state to be an eventual resolution to the conflict. These states should be removed in situations where there are still too many states in the conflict after eliminating the other three types of infeasible states. However, eliminating this type of state may cause the analyst to obtain wrong equilibria.

The decision support system GMCR II has a user-friendly approach for obtaining information from an analyst, such as mutually exclusive options, for identifying infeasible states. Subsequently, all of the infeasible states are removed by GMCR II from the game model so that only feasible states are analyzed. If one is not sure whether or not certain states are infeasible, sensitivity analyses can be carried out to ascertain how leaving the states in the conflict model affect the strategic findings.

5.1.2 Relative Preferences and Static Analysis

After generating a complete set of feasible states, the analyst must determine the relative preferences, in which states, for each DM, are ranked from most to least preferred, where

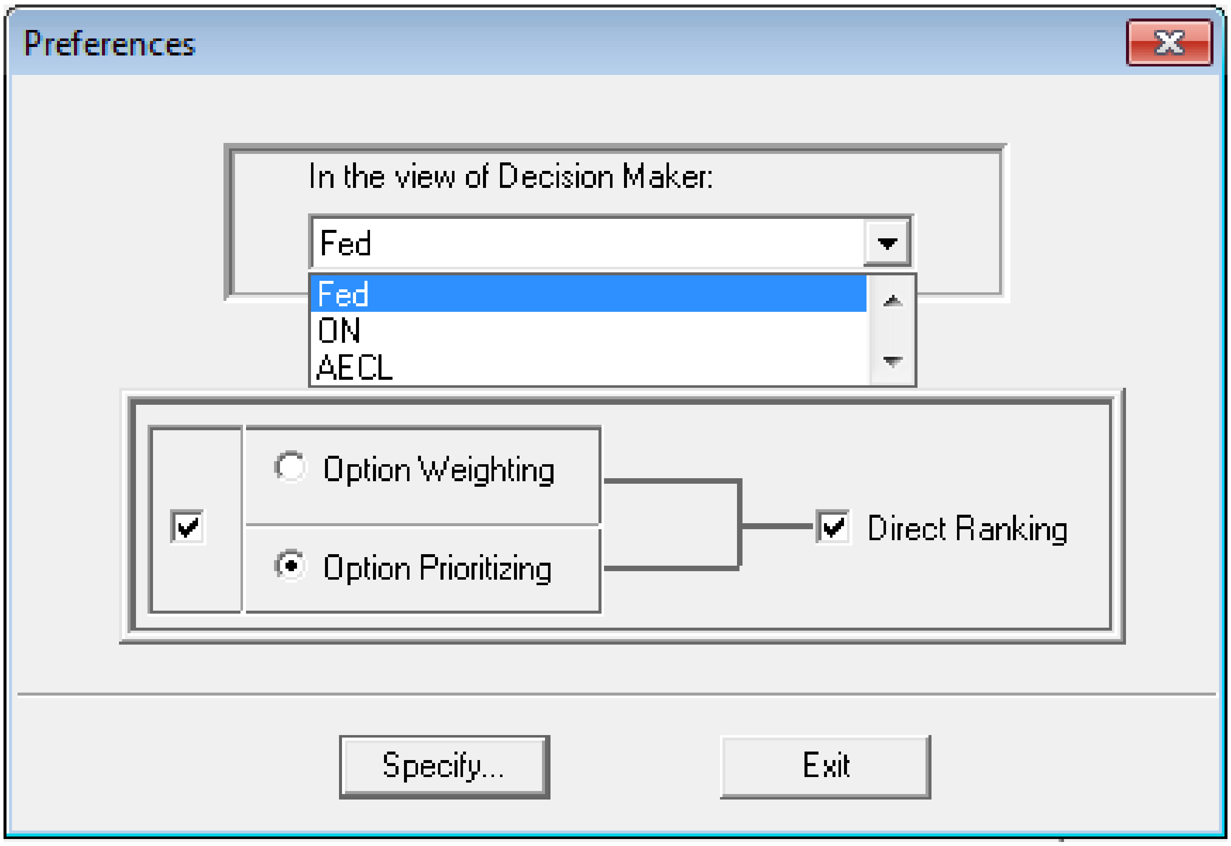


Figure 5.2: The box to choose a method for defining relative preferences (Hipel et al., 1997; Fang et al., 2003a,b)

ties are allowed. There are different methods that could be used in GMCR II in order to define the relative preferences of each DM. Figure 5.2 shows the box which is used in the software to choose the method.

As can be seen in the figure, a DM is selected, and then its relative preferences are determined. Fed, ON, and AECL are the DMs in this example. There are three methods that can be used. The Direct Ranking method may be combined with both the Option Weighting and Option Prioritizing methods.

- In the Option Prioritizing method, the analyst will sort the important criteria and concerns of each DM from most to least important. For example, the analyst can indicate that the most important thing for a DM is that options 1 and 2 are chosen, and after that it is important to the DM that options 3 or 2 are not chosen. The states will then be sorted according to this option prioritization.

Table 5.1: DMs, options, and states in a hypothetical conflict

Decision maker 1												
1. a	N	Y	N	N	N	Y	N	N	N	Y	N	N
2. b	N	N	Y	N	N	N	Y	N	N	N	Y	N
3. c	N	N	N	Y	N	N	N	Y	N	N	N	Y
Decision maker 2												
4. d	N	N	N	N	Y	Y	Y	Y	N	N	N	N
5. e	N	N	N	N	N	N	N	N	Y	Y	Y	Y
State number	1	2	3	4	5	6	7	8	9	10	11	12

- In the Option Weighting method, the analyst has to assign a weights to each option putting him/her self in the position of each DM. This method is not very common since it is possible that the weights do not reflect the reality, yet they may directly influence the output.
- The Direct Ranking is another can be used in combination with two. In this method, the analyst directly sorts the states from most to least preferred. This method is appropriate for small conflicts.

In the first analysis of the conflict under consideration, the Option Prioritizing method is used, because the conflict is rather large (See Section 5.3). In the next analysis, however, since the conflict now has only a few states, the Direct Ranking method is used (Section 5.4). It is worth noting that preferences for a DM depend on not only what options he/she chooses, but also on what options the other DMs select. In other words, relative preferences for each DM are the states, which are the combinations of all the DMs' choices, that are ranked from most to least preferred for that specific DM.

Subsequently, according to a rich range of solution concepts describing how people or organizations may behave under a conflict, a stability analysis of the conflict is carried out to calculate the stable states for each DM. A state that is stable for all of the DMs in the dispute is called an equilibrium, which suggests a possible resolution to the conflict. Before explaining different concepts of stability, the term "reachable states" should be defined. Each DM can move from one state to another one in which other DMs' option choices do not change. In order to explain this matter, an example is provided. In a hypothetical conflict, Table 5.1 shows the DMs and their options and the states of the conflict, where each state is a column of Ys and Ns.

Table 5.2: Reachable states

State	DM 1	DM 2
1	2, 3, 4	5, 9
2	1, 3, 4	6, 10
3	1, 2, 4	7, 11
4	1, 2, 3	8, 12
5	6, 7, 8	1, 9
6	5, 7, 8	2, 10
7	5, 6, 8	3, 11
8	5, 6, 7	4, 12
9	10, 11, 12	1, 5
10	9, 11, 12	2, 6
11	9, 10, 12	3, 7
12	9, 10, 11	4, 8

As can be seen in Table 5.1, DM 1 has 3 options: a, b, and c, and DM 2 has two options: d and e. DM 1 can move from state 1 to 2, 3, and 4, since DM 2's situation is the same in all these states. Therefore, states 2, 3, and 4 are reachable states for DM 1from state 1.

$$R_{DM1}(1) = \{2, 3, 4\}$$

Table 5.2 shows the reachable states for each DM from every state. Another important term is "unilateral move", UM. When a DM moves from one state to another among the corresponding reachable list, this move is called a **unilateral move**. If the state where the DM moves to is more preferred by him/her, the move is called a "unilateral improvement", and the set of the possible UMs from state "k" by DM i is shown as[1]: $R_i^+(k)$

Four different types of stability may be used to analyze a conflict. These definitions hold for GMCR as defined by Fang et al. (1993) while the references for the originator of the stabilities are provided. In Table 5.3, the different types of stability are described and compared. Note that in these definitions, N is the set of DMs in the game.

- **Rational, "r", or "R"** (Nash, 1950, 1951)**:** A state is rationally stable for a DM when that DM does not have any unilateral improvements from that state. This type is also called "Nash" and it could be shown by "n". The mathematical definition is also provided:

[1]Note that the "+" shows that the move is actually an improvement.

A state $k \in U$ is rationally or Nash stable for DM $i \in N$, if and only if: $R_i^+(s) = \emptyset$, where N is the set of DMs, and U is the set of feasible states in the conflict.

- **Sequentially Stable, "SEQ", "s"** (Fraser and Hipel, 1984, 1979)**:** A state is sequentially stable for a DM when all the unilateral improvements from that state are sanctioned by another DM's unilateral improvements in the game. For example, if DM 1 unilaterally improves from state k to k_1, and another DM improves from state k_1 to k_2, and k_2 is less preferred than k by DM 1, then DM 1 stays at k. Therefore, this unilateral improvement is blocked. If all unilateral improvements from k are sanctioned by others, the state is SEQ stable for DM 1, since this DM does not want to move to a less preferred state.

  A state "k" is sequentially stable for DM $i \in N$ if and only if: For every $k_1 \in R_i^+(k)$, there exists at least one $k_2 \in R_{N-i}^+(k_1)$ such that $P_i(k_2) \leq P_i(k)$.

- **General Metarationality, "GMR"** (Howard, 1971)**:** A state is GMR stable for a DM when all the unilateral improvements from that state are sanctioned by another DM's unilateral move in the game. For example, if DM 1 unilaterally improves from state k to k_1, and another DM moves from state k_1 to k_2, and k_2 is less preferred than k by DM 1, then DM 1 stays at k. If all unilateral improvements from state k for DM 1 are bloched in this way, state k is stable for DM 1, since this DM does not want to move to a less preferred state. In this type of stability, the DM is very conservative, as it not only considers the other DMs' improvements, but also all of their moves. Therefore, in this concept, it is assumed that DMs may move to less preferred states to harm others.

  A state "k" is sequentially stable for DM $i \in N$ if and only if: For every $k_1 \in R_i^+(k)$, there exists at least one $k_2 \in R_{N-i}(k_1)$ such that $P_i(k_2) \leq P_i(k)$,

  where $P_i(k_2) \leq P_i(k)$ means state k_2 is less preferred than state k by DM i.

- **Symmetric Metarationality, "SMR"** (Howard, 1971)**:** As in GMR, the DMs are conservative in this concept, as they even consider the particular DM's counter-moves to attempt to escape from possible sanctions.

  A state "k" is sequentially stable for DM $i \in N$ if and only if: For every $k_1 \in R_i^+(k)$, there exists at least one $k_2 \in R_{N-i}(k_1)$ such that $P_i(k_2) \leq P_i(k)$ and for all $k_3 \in R_i(k_2)$, $P_i(k_3) \leq P_i(k)$.

Figure 5.3 shows the mathematical relationships among the stability concepts (Fang et al., 1993). As shown in the diagram, Nash stability is the subset of all the other stabilities. It is also the strongest one, since in the model, the DM can not move unilaterally to a more preferred state. GMR includes SEQ, SMR, and Nash. It is the weakest state, as is the case in reality. In case studies presented in one of the GMCR reference books, "Conflict

Table 5.3: Solution concepts and human behavior (Fang et al., 1993; Hipel et al., 1997)

Solution Concept	**Stability Description**	**Foresight**	**Knowledge of Preference**	**Disimprovement**	**Strategic Risk**
Nash	DM cannot move unilaterally to a more preferred state	Low	Own	Never	Ignores risk
SEQ	All DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others	Medium	All	Never	Takes some risks
GMR	All DM's unilateral improvements are sanctioned by subsequent unilateral moves by others	Medium	Own	By opponent	Avoids risks
SMR	All DM's unilateral improvements are sanctioned, even after response by the DM	Medium	Own	By opponent	Avoids risks

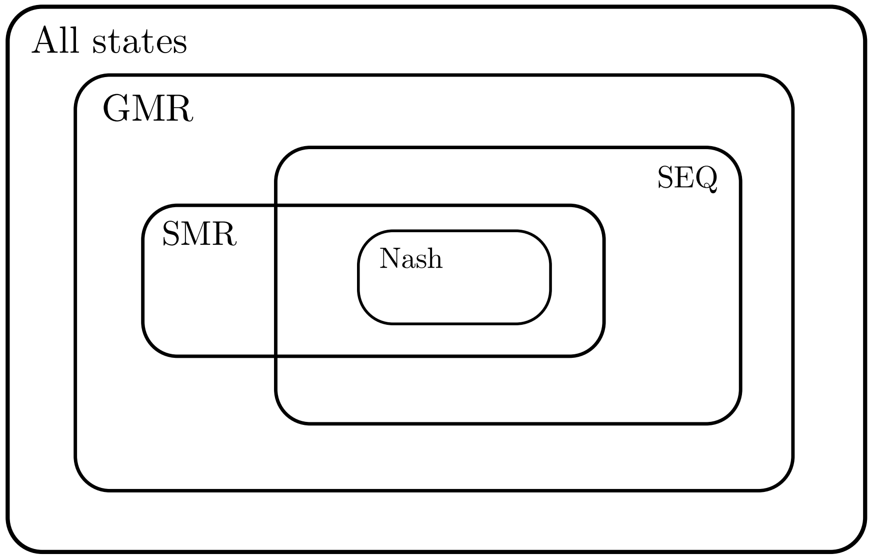


Figure 5.3: Stability concepts in an n-player conflict (Fang et al., 1993)

Analysis, Models and Resolutions" (Fraser and Hipel, 1984), GMR and SMR stable states are not the states that took place in reality and are not the equilibria. As explained above, these concepts occur in special cases in which the players are very conservative and avoid risks.

After carrying out a stability analysis, one may perform some sensitivity analyses. In this case, the DMs, the options, or the relative preferences can be changed to obtain a better understanding of the issue and ascertain how the equilibrium results are affected. There are also other types of analyses that can be carried out within the GMCR framework including attitudes (Inohara et al., 2007; Bernath-Walker et al., 2009), coalitions (Kilgour et al., 2001; Inohara and Hipel, 2008a,b), strength of preference (Hamouda et al., 2004, 2006; Xu et al., 2009a), misperceptions(called hypergames) (Wang et al., 1988), emotions (Obeidi et al., 2005, 2006, 2009b,a), preference uncertainty (Li et al., 2004; Hipel et al., 2011), conflict dynamics (Li et al., 2005), and matrix stability coalitions (Xu et al., 2009b).By applying different analyses, the outcomes can be more deeply interpreted and insights may be achieved.

The first analysis for this dispute was conducted for 2008 in Section 5.3. This issue is an ongoing problem, and the conflict has not been resolved. After the first analysis, some other related announcements and news items have been published. Therefore, a second analysis was performed in 2010 as represented in Section 5.4, taking into consideration the more recent information. Although the two analyses may involve similar DMs and options, they are different in terms of the relative preferences of the DMs.

Next section gives a thorough background of the conflict, providing documents that can be helpful for finding preferences for each DM, followed by the two analyses at two different points of time, 2008 and 2010 in Sections 5.3 and 5.4, respectively. In each analysis, the DMs and their options are introduced. After the feasible and indistinguishable states are determined, the relative preferences for each DM are defined. Then, the static analysis and other dynamic analyses are performed.

5.2 Introduction to the Conflict

Canada has twenty-two CANDU reactors; twenty of them are located in Ontario, the most populous province, one in Quebec, and one in New Brunswick. Nuclear energy provides about 15 percent of Canada's electricity (AECL, 2008). Figure 5.4 illustrates the map of the reactors' locations and Uranium mines in Canada.

In the coming decades, the Liberal Government of Ontario wants nuclear plants to remain the source of half of Ontario's electricity supply. It plans to install two new nuclear reactors, which will provide up to 3,200 megawatts of electricity, to expand the Darlington nuclear site to address the increasing demand for electricity and also to reduce Greenhouse Gas (GHG) emissions. Although Dalton McGuinty, the Ontario Premier, in his election campaign, had promised to shut down four coal-fired plants, which are highly polluting, by 2007, in 2006, he decided to postpone this plan to 2014, because there was no proper replacement energy producer (CBC News, 2006). At the beginning of March 2008, Energy Minister Gerry Phillips officially announced that the provincial government wants to receive proposals to build a new nuclear plant. He declared that construction should begin in 2012 and electricity should be generated by July 1, 2018 (Benzie and Black, 2008).Organizations that submitted their proposals included AECL, Westinghouse Electric Co. LLC, an American company, and Areva, a French company (Frame, 2008).

As mentioned before, this conflict is analyzed with respect to two different points in time. In the following section, the dispute is explained according to the analyst's information and available publications as of 2008. It is worth noting that the present time in this section refers to the year 2008.

5.2.1 AECL's Reputation

Some incidents have aggravated the position of AECL in this contract and may prevent the Ontario Government from selecting this company as the builder of the new plant reactors.

1. The National Research Universal (NRU) Chalk River reactor is the only nuclear reactor in North America that supplies medical isotopes for molecular imaging, radio therapeutics, and analytical instruments. On November 18, 2007, the Canadian Nuclear Safety Commission (CNSC) ordered the shutdown of the reactor, because it found that AECL had been operating the reactor for 17 months without a back-up emergency power system for cooling pumps, which prevent the reactor core from melting down. In 2006, AECL was ordered by CNSC to upgrade the NRU by installing that system. After two weeks of shutdown, Michael Burns, the chairman of AECL at the time, resigned and Stephen Harper, the Prime Minister of Canada,

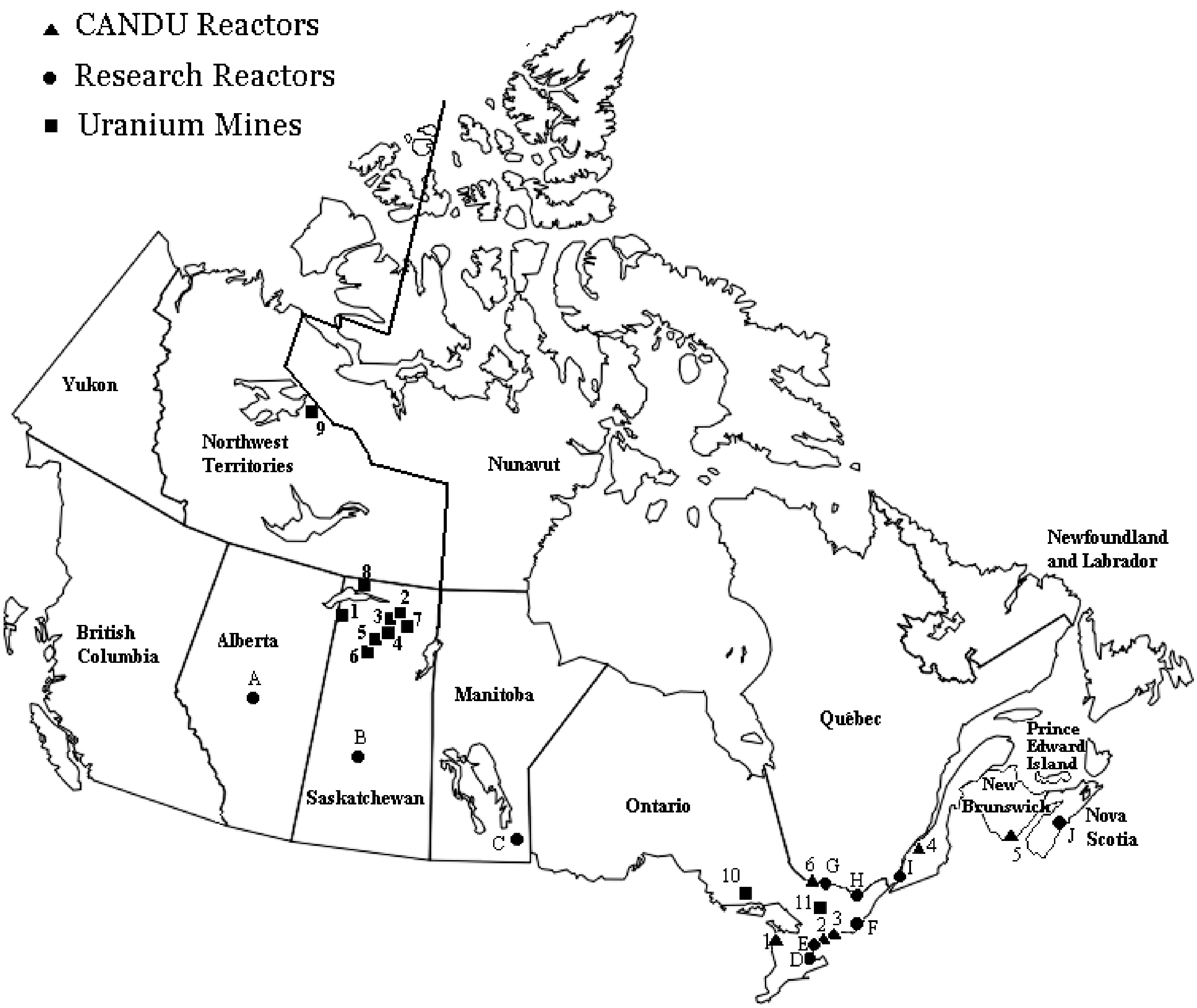


Figure 5.4: Map of Canadian reactors and Uranium mines (Canadian Nuclear Society, 2006)

accepted his resignation and blamed the Liberal appointed Canadian Nuclear Safety Commission for the closure. He pushed an emergency measure through Parliament, on December 12, 2007, but the Liberals opposed the measure. They feared that the NRU is unsafe and requires more upgrades. Eventually, the reactor was restarted in late January 2008, when Harper fired Linda Keen, the CNSC's head, who was a Liberal committee member. The outage created a critical and worldwide shortage of the radioactive diagnostic material and is considered a serious negative point in AECL's history (CBC News, 2008; Spears, 2008; Nathwani, 2009).

2. On May 16, 2008, AECL abandoned its plans to complete Multipurpose Applied Physics Lattice Experiment (MAPLE) reactors, which had started in 1996. These reactors were to serve as a replacement for the NRU at Chalk River. In 2008, the project was millions of dollars over budget and eight years behind schedule. The failure of the MAPLE reactors is a dark point for AECL and has undermined its reputation. As a result of the failure of this project, at the beginning of June 2008, MDS Inc. launched a $1.6 billion lawsuit against AECL (Akin, 2008; Hamilton, 2008b). Moreover, in an expert panel report commissioned by Prime Minister Harper, Goodhand et al. (2009) recommended that a completely new, and more flexible isotpe reactor be constructed.

3. The third incident happened at the Bruce site, in June 2008. AECL was working on the Bruce Power generating station to restart reactor units 1 and 2. This project was originally estimated at $2.75 billion. By 2008, the costs were in the range of $3.1 billion to $3.4 billion, and Ontario electricity consumers had been compelled to pay for $237.5 million of budget overruns. In April 2008, TransCanada Pipelines Ltd., a financial partner in the Bruce restart project, accused AECL of being the main responsible party for the delay and added costs. The main issue was that AECL misplaced a radioactive part while working on the plant and did not notify officials at Bruce Power. After two months, in June, 2008, the missing part was found accidentally by a worker. AECL accepted the responsibility. Spokesperson Dale Coffin acknowledged it took too long for the company to alert officials. "We're disappointed we didn't notify Bruce Power sooner," he said (Hamilton, 2008b).

4. The safety standards are another problem. After September 11, 2001, the International Atomic Energy Agency (IAEA) established guidelines that mandate reactor builders to change the designs so that reactors have the ability to withstand a massive outside shock or explosion. These safety standards must be applied to all new reactor designs. As AECL's reactors do not meet these standards, new regulations could be a major setback for AECL. Jerry Hopwood, vice-president of reactor development at AECL, has accepted the design weaknesses and said: "We would design a CANDU6, the advanced one, or adapt it, the old one, if needed, to meet the

standards[2](Hamilton, 2007)."

5.2.2 The Federal Government's View towards AECL

In light of the problems pertaining to AECL, the Federal Government wants to enhance its nuclear credibility. Gary Lunn, Natural Resources Minister at the time, said that it is "imperative" that Ontario purchase new reactors from AECL (Geddes, 2007). Although Harper's government comprehends the importance of AECL as a federal Crown corporation, it does not completely support AECL's efforts to regain its previous reputation. Harper's government declares that in order to help the electricity production or the improvement of the nuclear technology, the government has to decide about AECL's current status. The Conservatives are looking at different business models for AECL, including the sale of ownership stocks to one of several companies that have expressed interest, such as GE and France's Areva, foreign companies, and Bruce Power Inc., a Canadian company. Natural Resources Minister Lunn said that AECL's status is under review: "All options are on the table," he said, "from the status quo to a partnership with private investors to a sale to a foreign government." Another incentive for the Federal Government to change the status of AECL is the reliance of AECL's development program on federal tax dollars. Regarding its budget overruns, the sale of its stocks to a private company could alleviate taxpayers' criticisms of the Federal Government. On the other hand, industry observers say the lawsuit pertaining to the MAPLEreactors will make it more difficult for Ottawa to find a private suitor for AECL. This increases the probability that the government will opt to sell AECL to a foreign company or government (Hamilton, 2008b; Puxley, 2007).

5.2.3 The Federal Government vs. The Ontario Government

On the other side of the conflict, the Ontario Government is dealing with its own issues. Premier McGuinty stated: "The Ontario Government is unwilling to purchase new reactors from AECL unless it receives assurance that the Federal Government will remain the ultimate backer of AECL". The McGuinty government is concerned about AECL's history and made it clear that while it would prefer to buy home-grown technology, it is open to purchasing from a foreign company if it means getting the best deal for Ontario's taxpayers.

[2]After NRU restarted in January 2008 (Section 5.2.1), another shutdown happened in 2009. On May 14, 2009, NRU was shutdown due to a loss of electrical power in Ontario. On May 15, when the experts were investigating the reactor, they observed a small leak of heavy water within the facility. Therefore, the NRU was kept out of service for repair (AECL, 2009b). On August 17, 2010, the NRU was returned to operation (NRU Canada, 2010). The performance of NRU, as an important supplier of medical isotopes in the world, is critical, and the repeated shutdowns of this reactor diminished the reputation of AECL, the company responsible for it.

If Ottawa does not support AECL, it will be very hard for it to sell the reactors in Ontario, and if it can not do so, it will face a difficult time selling them anywhere else in the world (Hamilton, 2007).

In addition, timing and financial issues affect the Liberal government's decision. McGuinty promised to shut down all the province's coal-powered plants by 2014. New nuclear plants would be completed by 2018 if everything goes according to schedule. Furthermore, construction of a nuclear plant requires huge investments and compels Ontario's taxpayers to bear a heavy tax burden. As mentioned before, taxpayers have already paid for the cost overruns of the Bruce project. Therefore, the Ontario Government wants AECL to be fully financially supported by the Federal Government. The provincial government is in an urgent situation in terms of the need for new power generation. It is unable to wait a very long time for AECL to prove its qualifications, but has to make its decision by March 2009 at the latest (Hamilton, 2008b; McParland, 2008).

5.2.4 Green Groups of Canada

The Green Party of Canada, along with other green organizations and environmental groups, and the New Democratic Party (NDP) of Canada are on the other side of the conflict. They have always opposed the use of nuclear energy and believe that the Federal Government does not invest sufficiently in renewable energies. They think Canada has enough clean energy resources and does not need nuclear plants. These groups do not consider nuclear energy a clean energy, because there is still no proper means of nuclear waste management. They express their disagreement through their websites, articles, and speeches. Green Groups are also concerned about the costs and consider nuclear energy generation to be expensive. In this dispute, Green Groups would agree with privatizing or selling AECL. In this case, there is no need for the Federal Government to spend much money on AECL's funding, and taxpayers will not suffer. Besides, it is easier to oppose AECL as a private nuclear organization when it does not have the government's support (New Democratic Party, 2008; Sierraclub, 2008; Harris, 2008).

5.3 Analysis in 2008

5.3.1 The State of The Conflict in 2008

AECL is in trouble; in ten years (by 2008), it has not sold a single reactor. A new president was appointed in December 2007 to change the situation and return it to its once leading position in the nuclear industry. In the February federal budget, it received an appropriation of $300 million to support research and develop new technology. However, AECL still cannot convince the Ontario Government to buy its advanced reactors. A few key factors can possibly change AECL's situation; in June 2008, AECL announced that it had signed an agreement with the Nuclear Power Institute of China to collaborate on the "design, research, development, and demonstration" of "low uranium consumption CANDU technologies." Moreover, AECL is working with South Korea on a process called "direct use of spent pressurized water reactor fuel in CANDUs" (DUPIC). DUPIC is unique and can give Canada the opportunity to solve many problems in a nuclear energy market increasingly dominated by light-water reactors. DUPIC also gives existing and new CANDU6 reactors a chance to minimize the environmental risks. As nuclear experts point out, the existence of the DUPIC project alone gives the Federal Government a new option to give AECL another chance. It could be a good standing point for the company. If AECL achieves good results with these projects and keeps achieving satisfactory contracts, it might change the Federal and provincial governments' views (Hamilton, 2008a).

Different parties and groups in Canada are concerned about AECL's future. "If they [AECL officials] don't get our order, AECL effectively becomes [just] a CANDU repair shop," said Ontario Energy Minister Duncan, adding that AECL would be worth far less if Ottawa made moves to privatize it. If AECL is to be sold to a foreign country, thousands of skilled workers will lose their jobs at a time that the province is already losing thousands of industrial jobs. However, the political conflicts between the Federal and Ontario Governments make the situation much more difficult. The Federal Government keeps the negotiations and meetings in secret, and does not make clear its intentions regarding AECL. Though it is assessing different options, it seems that the Federal Government mostly prefers to sell AECL. In this case, the Federal Government's financial problems on account of AECL will be resolved, and there will be more opportunity for it to improve technologically. However, AECL does not want to be privatized. Its spokesman, Dale Coffin, disputed suggestions that AECL needs a strategic private-sector partner to compete in the world. Furthermore, Van Adel, the CEO of AECL, expressed strong opposition to any partnership between AECL and Areva, when rumors about a meeting between Areva and Natural Resources Minister Lunn were spread in 2007. If Harper gives his full support and proclaims full confidence in AECL, McGuinty has to recognize the importance of AECL. Currently, no political leaders take into consideration what is the best interests of AECL.

Table 5.4: DMs and options in 2008 analysis

DMs	Options
Federal Government	1. Sell less than 50% of AECL's stocks, and keep the control of it
	2. Sell or privatize AECL
	3. Fully support AECL
Ontario Government	4. Buy reactors from AECL
	5. Buy reactors from a foreign company
AECL	6. Convince both governments that it is capable of fulfilling its mandates
Green Groups	7. Continue their protests against nuclear power

Ontario Energy Minister Gerry Phillips has stated matter-of-factly that "AECL won't be treated differently than any other company." However, AECL *should*, in fact, be treated differently (Frame, 2008; Hamilton, 2007; Puxley, 2007).

5.3.2 Decision Makers

According to the background of the conflict, the decision makers (DMs) of the dispute are listed below:

- The Federal Government
- The Ontario Government
- AECL
- Green Groups

Hereinafter, DM 1, DM 2, DM 3, and DM 4 denote Federal Government of Canada, Ontario Government, AECL, and Green Groups, respectively.

5.3.3 Options

Regarding the background and the current state of the conflict, the four aforementioned decision makers and their options are shown in Table 5.4.

In order to better represent and discriminate states, each state is defined as follows:

$$S_i = (\underbrace{x_1\, x_2\, x_3}_{DM\ 1}, \underbrace{x_4\, x_5}_{DM\ 2}, \underbrace{x_6}_{DM\ 3}, \underbrace{x_7}_{DM\ 4}), \quad x_j \in \{N, Y\}, \ \ j = 1, \ldots, 7 \tag{5.1}$$

where $x_j = Y$ indicates that the j-th option is chosen and $x_j = N$ indicates that it is not. It is a large conflict, so GMCR II software developed by the Conflict Analysis Group in the Department of Systems Design Engineering at the University of Waterloo (Fang et al., 2003a,b; Hipel et al., 1997)was used to perform various types of analyses.

5.3.4 Static Analysis

In this section, states, infeasible states and then coalesce indistinguishable states are determined. Next, the relative preferences for each DM are introduced. Finally, the equilibria of the conflict are found.

Infeasible States and Indistinguishable States

In this section, the infeasible states are determined. Some states are infeasible in reality. These states must be eliminated from the analysis.

Regarding the four types of infeasible states mentioned in Section 5.1.1, Type 1 infeasibility is observed in this conflict, and after removing those states, 48 states remain.

- **Type 1:** The options of the Federal Government (DM 1) and the Ontario Government (DM 2) are mutually exclusive. Therefore, considering the options mentioned in Section 5.3.3, the states listed below should be removed:
  - DM 1: (Y Y -, - -, -, -), (Y - Y, - -, -, -), and (- Y Y, - -, -, -)
  - DM 2: (- - -, Y Y, -, -)

Preferences

In this section, based on the background study of the conflict, the preferences of the three DMs are determined using the option prioritizing method (Section 5.1.2). Some explanations are provided and used to form the relative preferences.

- **The Federal Government** is contemplating the future of AECL: To sell less than 50% of AECL, sell it all or privatize it, or support it. However, its negotiations are

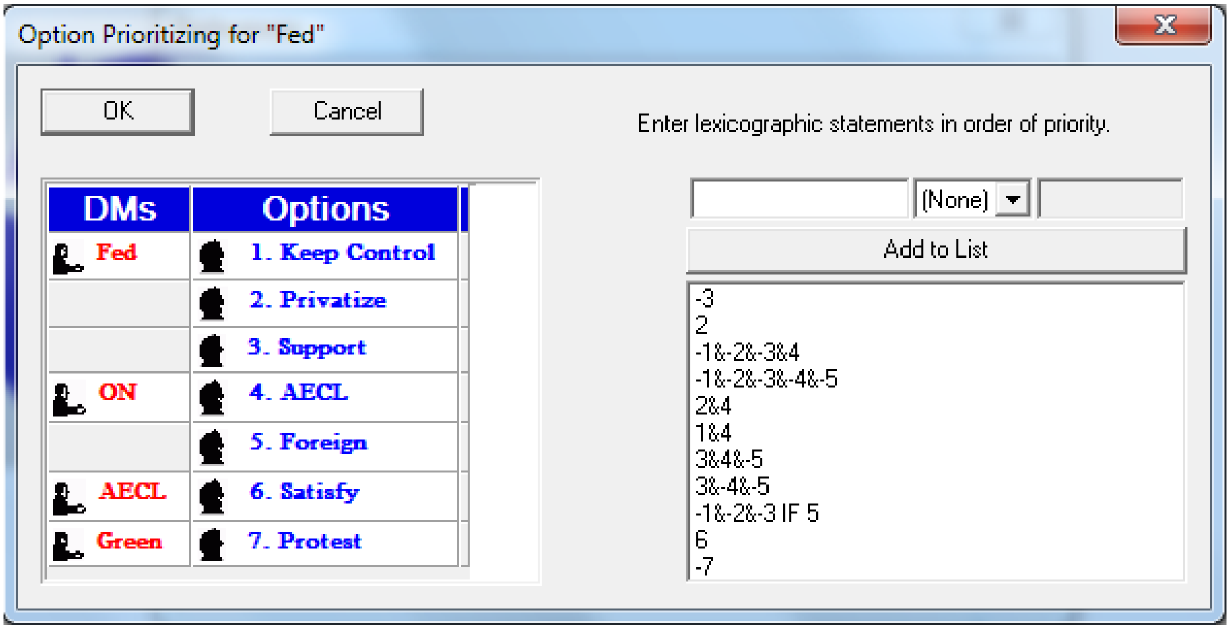


Figure 5.5: Input box to enter relative preferences for DM 1 in GMCR II

not clear to other parties and to the public. The Federal Government prefers AECL reactors be sold to Ontario, so that AECL can gain credit to sell more reactors to other countries. After the states presenting this situation, the Federal Government next prefers the states in which neither the Federal nor the Ontario Government takes any action. The Federal Government would prefer to sell AECL if it is faced with complaints from taxpayers or the Ontario Government. The least favoured states for this DM are the ones that represent the support of AECL by the Federal Government. Table 5.5 demonstrates the specific way that state prioritization is managed in GMCR II for DM 1. In this table, preference statements are listed from most important at the top to least important at the bottom. The numbers in the left column of Table 5.5 refer to the option numbers given in Table 5.4 where a negative sign means that the option is not taken. Notice that the most important preference for the Federal Government is not to fully support AECL by not taking option 3 (denoted by -3). Figure 5.5 shows the related box in GMCR II in which the preference statements for this DM are entered. Assuming transitive or ordinal preferences, an algorithm can take the prioritized preference statements of the Federal Government in Table 5.4 and rank the states from most to least preferred where ties are allowed. Figure 5.5 is the related box in GMCR II, in which the analyst defines the relative preferences. The content in this figure can be compared with the explanations provided in Table 5.4.

Table 5.5: The option prioritizing table for the Federal Government(DM 1)

Preference Statements	Explanation
-3	The most important thing for the Federal Government is not to support AECL, and not to invest more money into it.
2	Next, DM 1 prefers to privatize AECL.
-1 & -2 & -3 & 4	The Federal Government mostly prefers that Ontario buys the reactors from AECL.
-1 & -2 & -3 & -4 & -5	It prefers that both governments take no action.
2 & 4	Next, it prefers to privatize AECL and prefers DM 2 to buy its reactors from AECL.
1 & 4	Next, it would like to sell less than half of AECL's stocks and DM 2 to buy its reactors from AECL.
3 & 4 & -5	After that, it prefers the case that it supports AECL, and DM 2 buys the reactors from AECL.
3 & -4 & -5	It would like the situation that it supports AECL, and DM 2 to wait.
-1 & -2 & -3 if 5	If DM 2 makes a foreign purchase, DM 1 prefers to do nothing.
6	Redesigning the reactors by AECL is the one of its least priorities.
-7	AECL's working on the DUPIC project is also of less importance for DM 1.

Table 5.6: The option prioritizing table for the Ontario Government (DM 2)

Preference Statements	**Explanation**
3 & 4 &6	The Ontario Government mostly prefers to buy the reactors from AECL and AECL redesigns its reactors, and DM 1 supports the company.
3 & 4	Next, it prefers to buy the reactors from AECL, while it is supported by DM 1, even if AECL can not satisfy this DM.
2 & 4 & 6	Next, it prefers the future of AECL to be determined, and by the reactors from this company, when AECL is trusted.
-4 & -5	Next, it would like not to take any action.
5 if 1	If DM 1 sells less than half of the company, DM 2 prefers to buy the reactors from a foreign company.
-7	The Green Groups protest is the least important option to consider.

- **The Ontario Government** most prefers to select home-grown technology if AECL is successful in the redesign process. In addition, it would prefer that the Federal Government supports AECL. AECL being supported by DM 1 is much more important to DM 2 than redesigning CANDU reactors. It expects the Federal Government to support AECL in completing its projects and on schedule. Next, it prefers the future of AECL to be determined, and by the reactors from this company, when AECL is trusted. As the Ontario Government does not want to waste time, it would rather purchase the reactors from a foreign company if the future of AECL is undetermined. Table 5.6 lists the prioritized preference statements for the Ontario Government.

- **AECL** is trying to complete its projects in order not to be sold. The most desirable states for AECL are the ones in which AECL is not sold. Among these states, it is more especially preferable for AECL to be supported, and it is also very important for AECL to sell its reactors to the Ontario Government. Table 5.7 lists the preference statementsfor AECL.

- **Green Groups (GG)** are against nuclear energy. They declare their opposition via speeches and websites. Table 5.8 contains the preference statements for this DM. the specific way that state prioritization is managed in GMCR2 for DM 4.

Table 5.7: The option prioritizing table for AECL (DM 3)

Preference Statements	Explanation
4	The most important factor for AECL is to be chosen by DM 2 in the bid.
3	Next, it wants to be supported by the Federal Government.
-1 & -2 & -3	After that, it prefers just not to be sold.
-2	Next, It prefers not to be sold or privatized.
-1	In the fifth level, it prefers not to be sold partially.
-5	The next important factor for this DM is that DM 2 does not pick a foreighn company to buy the reactors.
6	Helping the two government to trust this company is its last priority.

Table 5.8: The option prioritizing table for Green Groups (DM 4)

Preference Statements	Explanation
7	Their first priority is to continue their protests.
-4 & -5	In the first level, they do not want the Ontario Government to buy any reactors.
-3	Green Groups do not want DM 1 to support AECL and fund its activities.
2	After that, they want the Federal Government to sell or privatize AECL.
1	Selling less than 50% of AECL by DM 1 is their next preferable option.

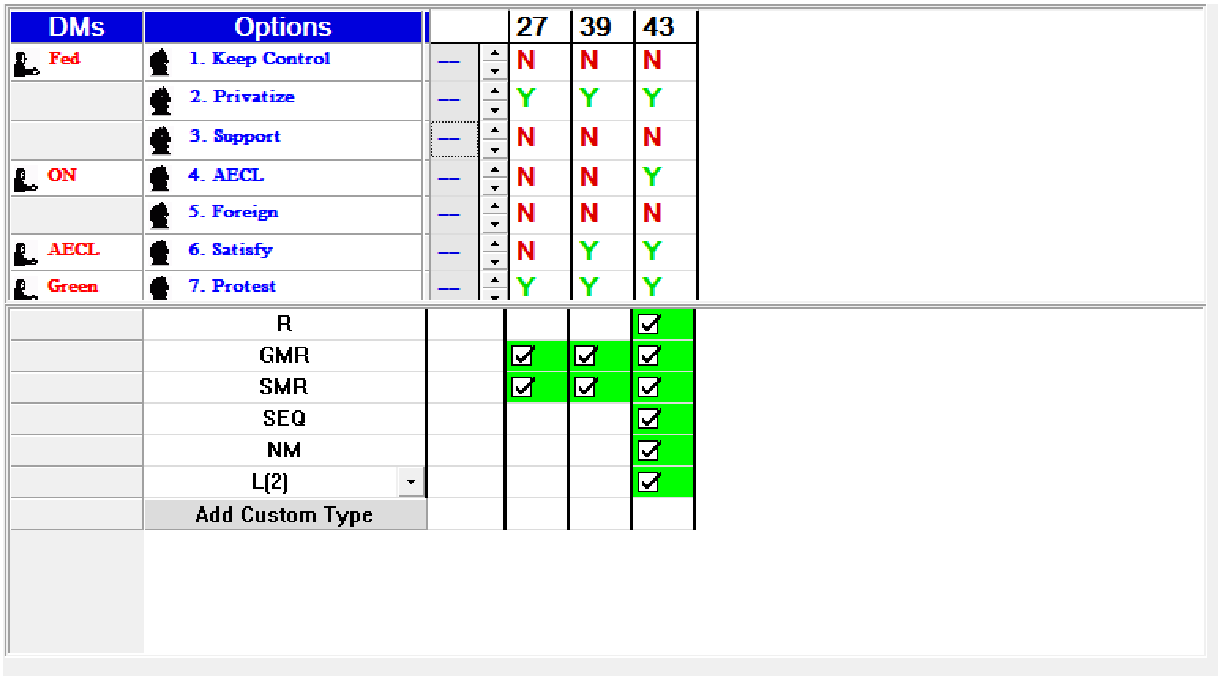


Figure 5.6: Equilibria of the nuclear conflict in 2008

Equilibrium Evaluation

The analytical equilibrium states are derived from running the static analysis in GMCR II, and are shown in Figure 5.6. They are horizontally listed below:

- **(N Y N, N N, N N, Y)**: state 27,
- **(N Y N, N N, N Y, Y)**: state 39, and
- **(N Y N, Y N, N Y, Y)**: states 43.

These states indicate what actually took place in reality. As shown in Figure 5.6, state 43 is the most stable equilibrium state, as its stability type is Nash,R, and the DMs cannot move unilaterally to a more preferred state from state 43. States 27 and 39 are also equilibria in this conflict, GMR and SMR. What has happened in reality (as of 2010) is that the Ontario Government chose AECL as the vendor of the reactors, and then the Federal Government decided to attempt to privatize AECL. After this decision was made, the Ontario Government postponed the purchase of the two reactors, because the future of AECL was very uncertain. Therefore, the state that took place was state 43, but states 27 and 39, which can be presented as (N Y N, Y N, N -, Y), happened after state 43, where a dash means Y or N. Also, since states 27 and 39 are only GMR and SMR equilibria, the stability of these states is not as strong as an SEQ equilibrium in which the sanctions by other DMs against unilateral improvements by a focal DM can only be levied using unilateral improvements.

5.3.5 Status Quo Analysis

To apply status quo analysis, the current state of the conflict has to be determined. Next, the analyst investigates the way the conflict has evolved from its initial state in 2008. In the current state of the conflict, DM 1 and DM 2 are not taking any action; DM 3 is working on the DUPIC project and on the design of ACR reactors, and consequently, trying to satisfy its customer, DM 2, and its owner, DM 1 (option 7), and DM 4 is protesting. This set of options represents the status quo state 25 (N N N, N N, N, Y). In this case, the game develops from state 25 (N N N, N N, N, Y), to states 43, 27, and 39. The evolution of the conflict is shown in Table 5.9. in Each level, one DM can move the conflict from a state to another. The arrows, along with an assigned DM shows that which DM is moving the conflict.

Table 5.9: Evolution of the conflict

DM 1	Sell less than 50% of AECL	N		N		N		N		N
	Privatize AECL	N		N		N	$\xrightarrow{DM1}$	Y		Y
	Support AECL	N		N		N		N		N
DM 2	Buy from AECL	N		N	$\xrightarrow{DM2}$	Y		Y	$\xrightarrow{DM2}$	N
	Buy from a foreign company	N		N		N		N		N
DM 3	Satisfy DM 1 and DM 2	N	$\xrightarrow{DM3}$	Y		Y		Y		-
DM 4	Protest	Y		Y		Y		Y		Y
		25		37		29		43		27&39

Although it is shown that the 2008 conflict will finish in states 27 and 39 (which is what happened in reality), in Section 5.4 the author shows that in fact the conflict will again move to state 43, and states 27 and 39 are the transition states in 2010 conflict. It is worth noting that the number assigned to each state is not the same in the 2008 and 2010 conflicts.

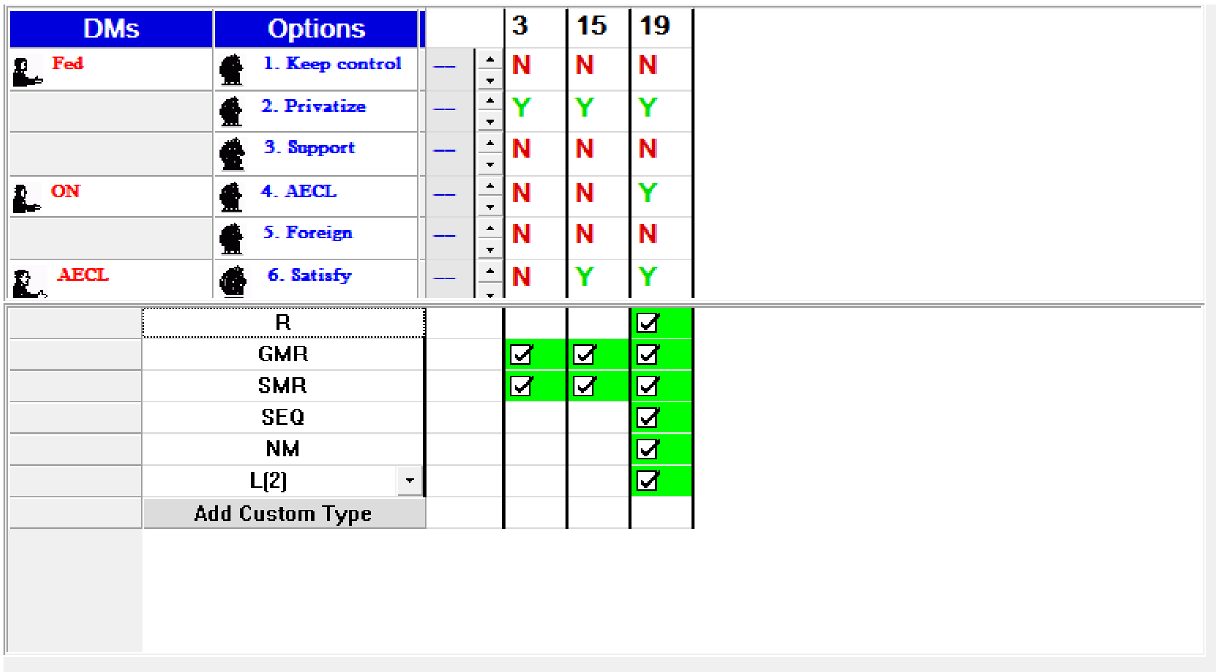


Figure 5.7: The equilibria of the 2008 conflict when DM 4 (Green Groups) is omitted from the game.

5.3.6 Sensitivity Analysis

In order to gain more insights, some sensitivity analyses have been run. Sensitivity analyses can help the analyst to have a better understanding of the conflict and the static analysis. For example, in this conflict, it seems that although the Green Groups, DM 4, have an option to protest against the investment on and the use of nuclear energy, they are not as powerful as the other three DMs. The main reason for this is that all the other DMs, in contrast to DM 4, are in favour of nuclear energy. It seems logical that DM 4, being the only anti-nuclear DM, does not have a considerable effect on the result of the conflict. To see how much this anticipation is correct, DM 4 is omitted from the game, and another static analysis is executed, and the equilibrium states are shown in Figure 5.7.

Figure 5.7 verifies the aforementioned expectation, as the indicated results are essentially the same as the results shown in Figure 5.6. Option prioritization tables show that the decision of DM 4 regarding whether to protest or not is among the least important issues for all DMs except for DM 4. Therefore, the results show that DM 4 is not an important and effective DM in this conflict and does not play an important role. In other words, DM 4 cannot significantly influence the other DMs' decisions regarding the future of AECL.

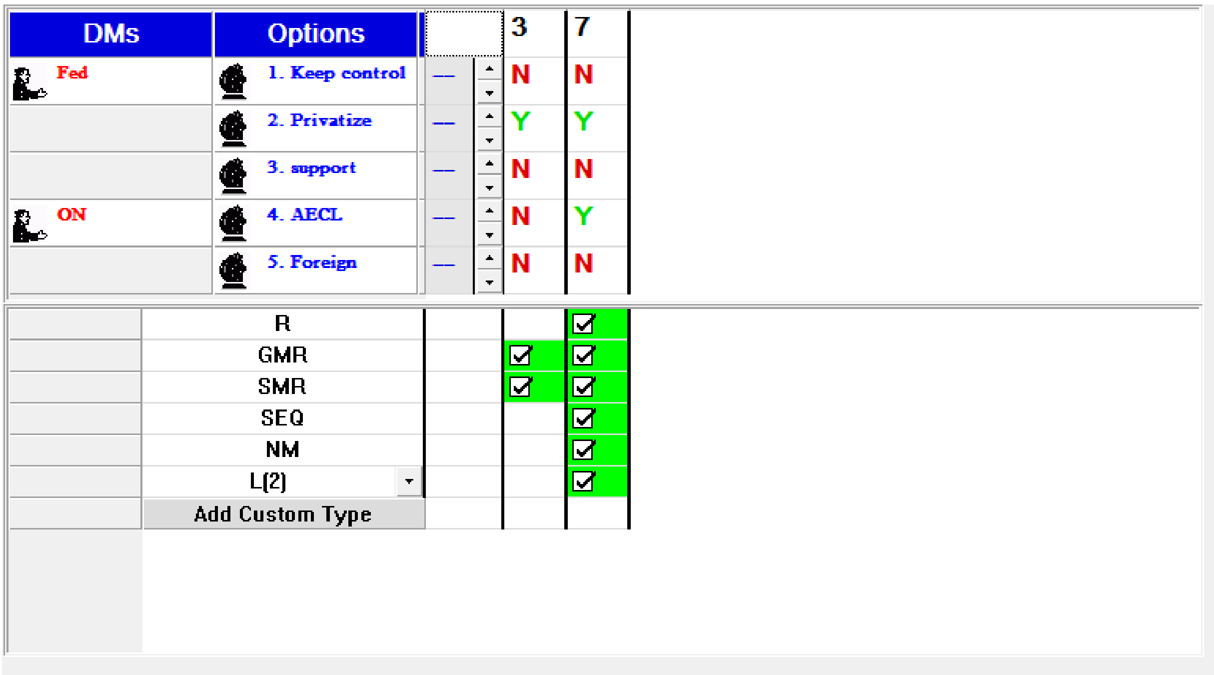


Figure 5.8: The equilibria of the 2008 conflict when AECL and Green Groups are omitted from the game.

Another idea is to eliminate DM 3 as well. Although AECL's attempt to obtain other DMs' trust can change the decision of those two DMs, it is possible that their decisions are independent of AECL's achievements. If this belief is true, AECL is not actually a DM in the conflict, and only the governments are the main DMs. Therefore, the expectation is that the two equilibria are: (N Y N, Y N), which would be equivalent to state 43, and (N Y N, N N), which is the same as states 27 and 39. The related analysis results verify the fact that AECL is not an influential DM. Figure 5.14 shows the results.

In order to more deeply investigate the effect of AECL as a DM on the results of the modeling, the preferences of this DM are changed. If AECL is not significantly affecting the game, changing its preferences should not change the equilibria regarding the future of this company. This change is applied to the game with three DMs, in which DM 4 is omitted. Different arrangements of AECL's relative preferences are made at this level. The results are shown in Figure 5.9. The interpretation is that the equilibria do not change, although their types do. This difference can be observed by comparing Figure 5.9 to Figure 5.7. Therefore, AECL, in fact, does not make a considerable impression on the two other DMs.

Finally, since only two DMs found to be influential in this conflict, the status quo table is reproduced to show the evolution of this smaller conflict (Table 5.10.

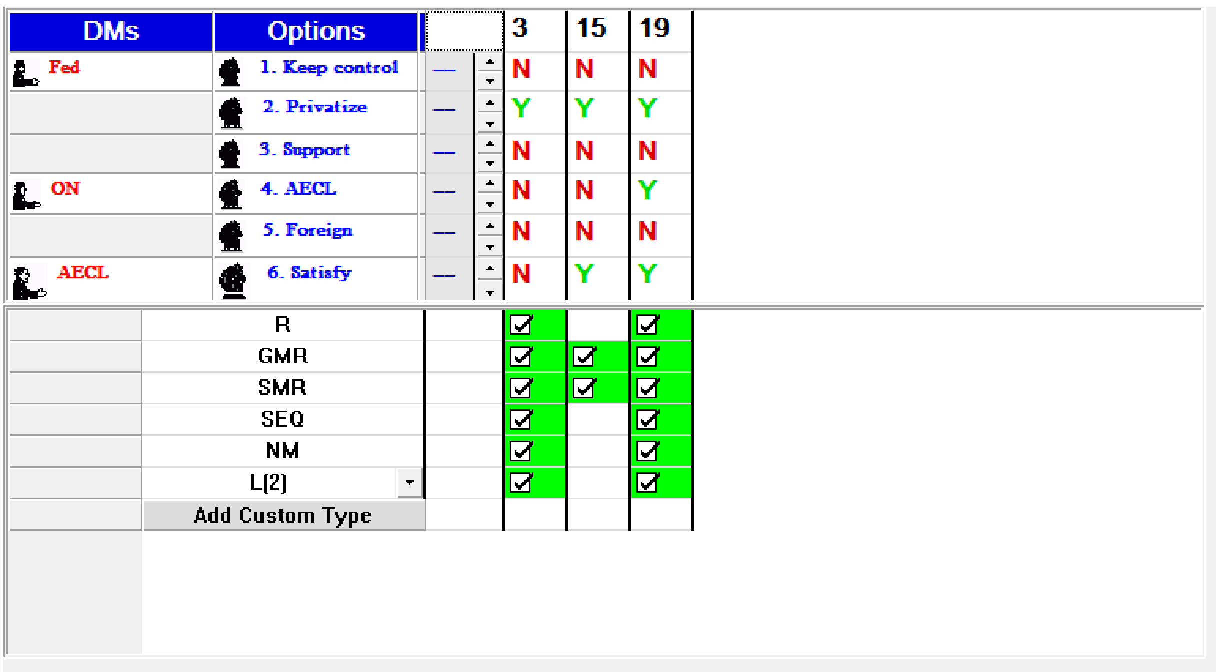


Figure 5.9: The equilibria of the 2008 conflict when all states are equally preferred by AECL.

Table 5.10: Evolution of the 2-DM 2008 conflict

DM 1	Sell less than 50% of AECL	N		N		N		N
	Privatize AECL	N		N	$\xrightarrow{DM1}$	Y		Y
	Support AECL	N		N		N		N
DM 2	Buy from AECL	N	$\xrightarrow{DM2}$	Y		Y	$\xrightarrow{DM2}$	N
	Buy from a foreign company	N		N		N		N
		1		5		7		3

5.4 Analysis in 2010

In Section 5.3, the Ontario nuclear dispute was analyzed for 2008. This dispute, however, is an ongoing conflict in the province. Therefore, in the following sections, an attempt is made to perform a new GMCR analysis of the same conflict, but with an updated background. In addition, regarding energy issues in the province, the Government of Ontario has recently published an updated energy report (Ontario Government, 2010).

5.4.1 Updated Background of the Conflict

To summarize the history of the conflict in 2010, and to update the background of the dispute in 2008, the time line of the nuclear project is described as follows (Ontario Government, 2009a):

- *Phase 1*
  - *On March 7, 2008, the Ontario Government announced a two-phase competitive procurement process to choose a preferred nuclear reactor vendor*
  - *In April 2008, a series of Commercially Confidential Meetings were held with potential vendors*
  - *On May 9, 2008, Infrastructure Ontario announced that three vendors had submitted Phase 1 Proposal Submissions as required by the RFP (request for proposal)*
  - *On June 5, 2008, Infrastructure Ontario announced that all three vendors that had submitted Phase 1 Proposal Submissions received 'satisfactory' ratings and would be invited to proceed to Phase 2 of the RFP*

- Phase 2
  - *On June 16, 2008, Infrastructure Ontario released Phase 2 of the Nuclear Procurement Project RFP*

  At this stage, and in November 2008, the first analysis was performed.

  - *From July to December 2008, a series of bilateral confidential meetings took place on aspects of design readiness and commercial aspects of the project*
  - *On February 27, 2009, Infrastructure Ontario announced that all three respondents submitted Phase 2 Proposal submissions*
  - *On May 28, 2009, the Government of Canada announced that it was proceeding with a restructuring of AECL*
  - *On June 29, 2009, the Minister of Energy and Infrastructure announced that the Nuclear Procurement Project RFP was being suspended due to concerns about pricing and uncertainty regarding AECL's future*

About the Bid

The Center for International Governance Innovation (CIGI) published a decisive report in November 2009. This report studies the nuclear industry in Ontario and briefly investigates the expansion of the Darlington nuclear site, the most important nuclear project in Canada. The report stated that by 2008, Ontario had planned to invest $40 billion to replace and refurbish its nuclear generating capacity, and subsequently, in February 2009, bids to build a new facility at Darlington were accepted by the province (Cadham, 2009).

The CANDU design, proposed by AECL, is proudly Canadian in that Team CANDU represents the provider of the province's existing installed nuclear facilities. The AECL CANDU design met the requirements of Infrastructure Ontario among three vendors, AECL, Areva Group and Westinghouse Electric Co., and the province selected AECL's technology as the winner. The Ontario bid process required the risk of cost overruns to be calculated by potential vendors, and AECL was the only one of the three that met this demand. Toshiba-owned Westinghouse Electric ignored this key aspect of the bid criteria. This company chose to focus only on its reactor technology and relied on others for construction and commissioning. On the other hand, Areva, in its bid, proposed its new Evolutionary Pressurized Reactor (EPR). Areva suggested the idea that it would be more beneficial for Canada to diversify its nuclear technology rather than rely on AECL and CANDU reactors. Areva attempted to convince the province that by announcing their company as the winner, Canada could have a larger stake in the worldwide nuclear revival. Although up to 70 percent of ERP's uranium source could be Canadian, Areva, as well as Westinghouse, failed to satisfy the important criterion of taking cost overruns into consideration. In the final assessment, the Ontario Government was not convinced by either company's proposals (Cadham, 2009).

In July 2009, George Smitherman, the Energy Minister of Ontario, said that the government wanted to negotiate with Ottawa to reduce the bidding price. Smitherman declared that AECL's bid was "billions" above what Ontario anticipated. Ontario Power Generation (OPG) had estimated the cost of the installation of the two Advanced CANDU Reactors (ACRs) at $3,000 per kilowatt, compared to $10,800, the price offered by AECL. One of the major reasons for the offer being this high is that the design of ACR is not yet complete, but Ontario is disinclined to pay for the cost of the research and development (R&D) process. On the other hand, before the offer was submitted by AECL, the Harper government had told the company that its bidding price must cover all the costs of R&D, and that AECL should not count on the future sales to put off the cost overruns. In case the Federal Government decides to keep AECL as a federal Crown corporation and not sell it, the government needs to ensure that the Ontario nuclear project is commercialized in an attempt to preserve AECL's value and to avoid federal taxpayers subsidizing Ontario ratepayers (McCarthy and Howlett, 2009).

The AECL's restructuring is currently under scrutiny. In 2007, the Federal Government hired the National Bank to provide independent financial advice and to help find the best way to carry out the mandates of AECL. The National Bank countered with some solid recommendations. In their recommendations, it was suggested that AECL has two concurrent mandates: *commercial goals* involving the selling and servicing of reactors, and *R&D* with regards to projects and technology. The bank advised that at least 51% of AECL be sold and encouraged the Government of Ottawa to improve AECL's place in the international market. Natural Resources Canada published a report in May 2009 to present the ideas they received from National Bank and other consultants (Natural Resources Canada, 2009e). AECL's failure in handling its projects shows that in the past, the two opposing mandates have not worked well together, and AECL has fallen short on many of its objectives. Some of AECL's unsuccessful projects were mentioned in Section 5.2. The former Minister of Natural Resources, Lisa Raitt, advised: "The best chance to take advantage of this nuclear renaissance is to divide the two of them and seek global participation." Raitt suggested that the designing and building of reactors is very expensive, and Canadian tax payers cannot shoulder this burden on their own, so AECL needs a strategic alliance in order to compete in the world (CTV, 2009). As stated in the project procurement, the Government of Canada announced the restructuring of AECL in May 2009. It also hired N.M. Rothschild & Sons to provide financial advice and available options and received their financial analysis on the restructuring plan of AECL in October 2009, but the report is confidential due to commercial confidentiality considerations.

As stated by Lisa Raitt, the company's research-and-development division, Chalk River laboratories, will continue to be government-owned, but with private-sector management (CBC News, 2009a). The reactor business and its attractive maintenance and refurbishment activities would then be offered for sale on either a majority or minority ownership. Some parties accuse the government of wanting to sell AECL in order to balance its budget deficit. According to the former Minister of Natural Resources, however, "this decision is purely about bolstering the industry and getting it ready for future prosperity." However, this reconstruction is not desired by the Ontario Government as stated by Smitherman: "The government of Canada needs to do the work that they are doing now to clarify the future ownership of AECL, and when they have clarified that, to sharpen their pencils substantially so that the people of the province of Ontario can renew their nuclear fleet with two new units from that company (McCarthy and Howlett, 2009)."

Having discussed the points of view of the two governments, it can be concluded that Ontario will not move until Ottawa clarifies the AECL's ownership status. The other key issue is AECL's bidding price. Therefore, the uncertain future of AECL and the high price were two important factors that led Ontario to postpone the project.

According to the background information, it is clear that Ontario mostly prefers to buy the reactors from AECL. In fact, the province has rejected the foreign companies' proposals. The province, however, does not accept AECL's bidding price. Therefore, it prefers to postpone the contract.

The government of Canada, on the other hand, can decide between several options: privatizing and restructuring AECL, selling it to a Canadian or a foreign corporation, or keeping it public and consequently helping AECL to decrease the price. It has been a long time since the announcement of selling AECL, but it has not yet happened. Therefore, there is still the possibility that the government will not privatize the federal Crown corporation. Industry insiders say that the companies that are interested in partnership with AECL are an international company, US-based Westinghouse Electric Co., Canadian engineering giant SNC-Lavalin Group Inc., and Bruce Power, a Canadian-owned consortium that operates a nuclear station in Ontario. The bidding process closed on June 30, 2010 (The Globe and Mail, 2010). Sources close to negotiations say that only SNC-Lavalin Group Inc. and Bruce Power have submitted their bids to partner AECL (McCarthy, 2010).

Since there is opposition against selling or privatizing AECL, this decision is not an easy one for the government to undertake (The Star, 2009). AECL possesses an internationally competitive reactor design and thousands of Canadian employees, and AECL's supporters argue that it is not beneficial for the governments to let this company be sold. Canadian nuclear analyst David Jackson says that the problem with dividing AECL into two parts, and privatizing one of them is that "no potential purchaser would want to buy an ACR with no assured R&D backup and thus, in effect the restructuring is the end of ACR" (Cadham, 2009). On the other hand, the Federal Government's supporters believe that selling AECL is a sound decision as this company has been a burden on taxpayers for a long time, while not being efficient enough. In addition, they think selling to a foreign company would be a much better decision. A domestic sale will not change the pressure on taxpayers. Furthermore, selling AECL to a domestic buyer will not help the company to regain its reputation and competitive figure in the international market (McCarthy, 2010).

There are also other provinces, such as New Brunswick and Saskatchewan, that have indicated an interest in buying new reactors. In July 2010, however, New Brunswick announced that it would not choose AECL as the provider of its reactors, and instead is turning to Areva Group, which is a company that was interested in buying AECL, but dropped out from the bidding. This decision, along with what happened in the Ontario contract, are considered major setbacks for AECL, and complicate the decision of the Federal Government regarding selling off AECL (The Globe and Mail, 2010). AECL was counting on the Darlington project to galvanize its huge resources to launch its new Advanced CANDU Reactor (ACR). Therefore, in the end, if Ontario, as the largest customer, decides not to buy any reactor at all, it would be unlikely that other provinces would consider AECL's unproven, first-of-its-kind ACR technology as a serious option.

The problem gets more complicated when we consider the massive amount of money that Ontario has spent on its nuclear industry, which totals more than of all other provinces and countries combined. Moreover, AECL has about 5000 employees, and privatizing it will lead to a large number of job losses, which is not desired by any of the DMs or the political parties in the country (McCarthy and Howlett, 2009).

5.4.2 Decision Makers, Options, States and Preferences

In the 2010 analysis, there are only two DMs, the Federal and Ontario Governments. According to the updated background, neither AECL nor the Green Groups are the main DMs. (This matte was investigated in the sensitivity analyses in Section 5.3.6). Consequently, their decisions do not affect the final decision that the Ottawa and Ontario Governments will make. As aptly described in the CIGI report, "This [situation] leaves the Federal and Ontario governments engaged in something of a dance of veil (Cadham, 2009)." In other words, since it is the responsibility of the Federal Government to financially support AECL, if this government does not provide enough budget for the company, the possibility that AECL can compete with its foreign rivals and win the contract becomes very low. Another DM that can seriously affect the outcome of the conflict, and the future of AECL is, obviously, the Ontario Government. Although AECL's suggested bidding price is very high, if the Ontario Government accepts to pay the price to expand its nuclear site, it is possible that AECL could remain as a public company. Regarding the DUPIC project, which AECL is working on, the published news and interviews of the

Table 5.11: DMs and options in 2010 analysis

DMs	Options
Federal Government	1. Sell AECL (to a foreign company)
	2. Sell AECL (to a Canadian company)
	3. Support AECL
Ontario Government	4. Buy from a foreign company
	5. Buy from AECL

Table 5.12: DMs and options in 2008 analysis

DMs	Options
Federal Government	1. Sell less than 50% of AECL's stocks, and keep the control of it
	2. Sell or privatize AECL
	3. Fully support AECL
Ontario Government	4. Buy from AECL
	5. Buy from a foreign company

officials of the two governments do not indicate that they pay much attention to the performance of AECL on this project. They are more concerned about its progress in building and selling reactors. Therefore, in the 2010 analysis, there are only two main DMs, the Federal Government and the Ontario Government.

Regarding the options for the two governments, Table 5.11 shows the options for each DM. As can be seen, the options for each DM change with respect to the previous analysis in 2008, shown in Table 5.12.

In the most recent (2010) analysis, the first two options of the Federal Government change from what they were in 2008, since in 2010, it is determined that if the Federal Government decides to restructure AECL, it will privatize it, and not sell only less than half of its stocks. The options, however, are selling to a local or an international organization. The reason for this is that, in practice, the Federal Government is studying the privatization of one part, R&D, and selling the other part, CANDU. The Ontario Government, likewise, had more options in 2008. However, after examining the vendors' bids, the province recognized that if the final decision is to buy new reactors, the vendor would definitely be AECL, so its second option would be eliminated, and the province will not purchase reactors from a foreign company. Taking into consideration the latest announcements and the updated background, as well as the options, the relative preferences of the

Table 5.13: List of feasible states

DM 1												
1. Sell AECL (to a foreign company)	N	Y	N	N	N	Y	N	N	N	Y	N	N
2. Sell AECL (to a Canadian company)	N	N	Y	N	N	N	Y	N	N	N	Y	N
3. Support AECL	N	N	N	Y	N	N	N	Y	N	N	N	Y
DM 2												
4. Buy reactors from abroad	N	N	N	N	Y	Y	Y	Y	N	N	N	N
5. Buy reactors from AECL	N	N	N	N	N	N	N	N	Y	Y	Y	Y
State number	1	2	3	4	5	6	7	8	9	10	11	12

DMs will also change.

Regarding the feasible states, the options for the two DMs are mutually exclusive. The Federal Government cannot privatize and support AECL at the same time. Similarly, the Ontario Government cannot choose its two options simultaneously. Therefore, the following states, which are the type 1 infeasible states, are removed from the game, and 12 feasible states remain, which are shown in Table 5.13.

- DM 1: (Y Y -, - -), (Y - Y, - -), (- Y Y, - -)
- DM 2: (- - -, Y Y)

Rather than using option prioritization to determine the relative preferences of the second DM, as was done in the previous analysis, direct ranking is employed. As stated in Section 5.3.4, this method is also used in GMCR II to define the preference vector of a DM. In this method, the analyst directly sorts the states from the most to least preferred. Using this method is obviously feasible for small conflicts, so it performs well in this small 12-state conflict. Figure 5.10 and 5.11show the screens that are used to directly define the preference vectors for the Federal and Ontario governments, respectively.

5.4.3 Static Analysis

After defining the DMs, their options and preferences, the static analysis is performed to investigate the final possible outcomes. States 1 and 10 are found to be the equilibria of the conflict. Figure 5.15 shows the related equilibrium box in the GMCR II software.

DMs	Options	10	11	9	2	3	1	6	7	5	12	4	8
Fed	1. Foreign	Y	N	N	Y	N	N	Y	N	N	N	N	N
	2. Domestic	N	Y	N	N	Y	N	N	Y	N	N	N	N
	3. Support	N	N	N	N	N	N	N	N	N	Y	Y	Y
ON	4. Foreign	N	N	N	N	N	N	Y	Y	Y	N	N	Y
	5. From AECL	Y	Y	Y	N	N	N	N	N	N	Y	N	N

Figure 5.10: Direct ranking box in GMCR II for the Federal Government

DMs	Options	12	1	11	10	5	7	6	3	2	4	8	9
Fed	1. Foreign	N	N	N	Y	N	N	Y	N	Y	N	N	N
	2. Domestic	N	N	Y	N	N	Y	N	Y	N	N	N	N
	3. Support	Y	N	N	N	N	N	N	N	N	Y	Y	N
ON	4. Foreign	N	N	N	N	Y	Y	Y	N	N	N	Y	N
	5. From AECL	Y	N	Y	Y	N	N	N	N	N	N	N	Y

Figure 5.11: Direct ranking box in GMCR II for the Ontario Government

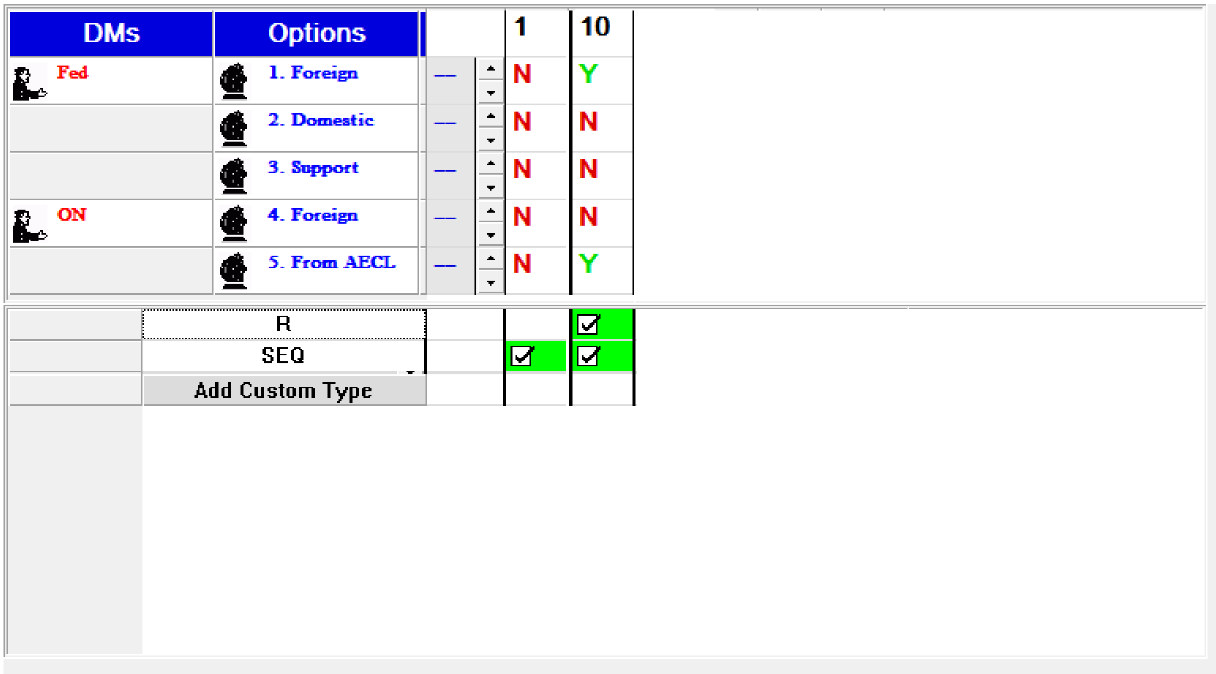
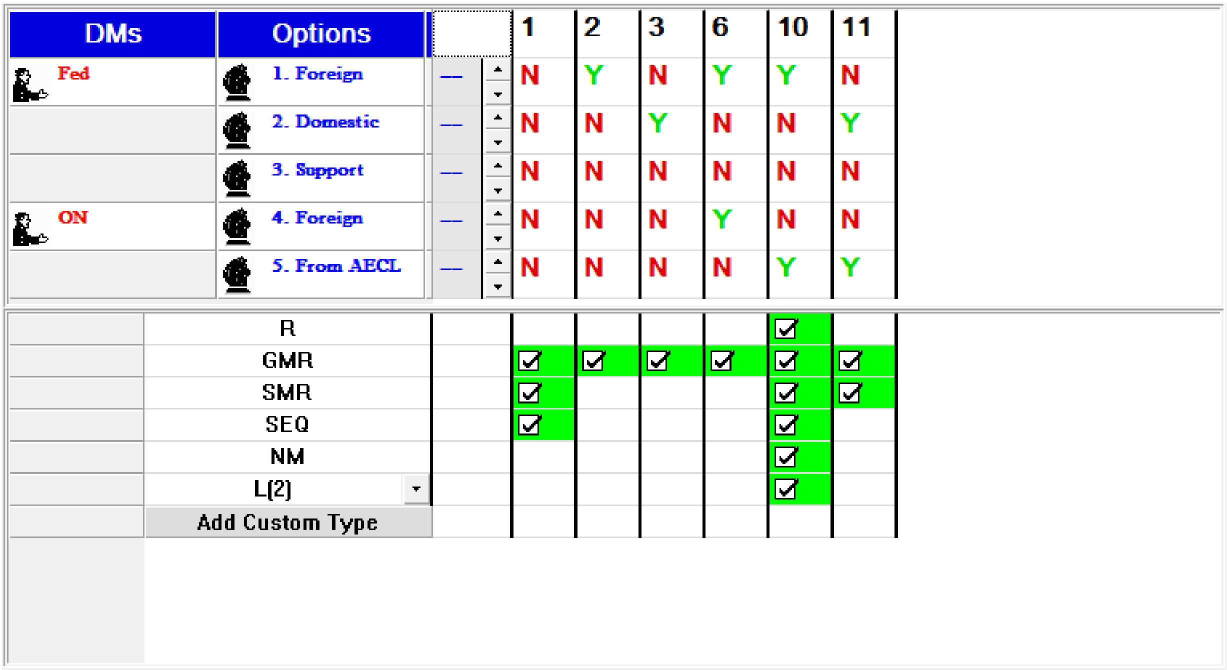


Figure 5.12: The equilibria for SEQ and Nash stability of the static analysis in 2010

It is worth noting that in order to find the equilibria, Sequential and Nash stability are considered. If one wants to analyze the GMR or SMR stabilities, Figure 5.13 should be discussed.

As can be seen in Figure 5.13, aside from states 1 and 10, states 2, 3, 6, and 11 are also the equilibrium states. In other words, if GMR and SMR stability concepts, where the DMs are assumed to be conservative, are involved, 6 out of the 12 states of the conflict are found as the equilibria of the game. This result shows that by DMs being conservative, more states are stable, and the uncertainty of the game rises. The reason for this is that if the DMs refrain from moving to different states on account of the possibility of losing benefits, the conflict will stop in more states states and there will be more equilibria, compared with the situation in which the DMs accept the risks and move from one state to another.

However, in this specific conflict the DMs are not conservative. As an example, more than a year ago, the Federal Government announced the restructuring AECL, but it has not yet sold it. In addition, Ontario Government announced AECL to be the best company, but postponed its decision about buying reactors from it. These examples show that the DMs do accept some risks and do move from state to state. Therefore, GMR and SMR stability concepts are ignored, and SEQ and Nash stability are being considered.



DMs	Options	1	2	3	6	10	11
Fed	1. Foreign	N	Y	N	Y	Y	N
	2. Domestic	N	N	Y	N	N	Y
	3. Support	N	N	N	N	N	N
ON	4. Foreign	N	N	N	Y	N	N
	5. From AECL	N	N	N	N	Y	Y
	R					✓	
	GMR	✓	✓	✓	✓	✓	✓
	SMR	✓				✓	✓
	SEQ	✓				✓	
	NM					✓	
	L(2)					✓	
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Figure 5.13: The equilibria of the static analysis in 2010

Since this conflict is not very big, the static analysis can also be performed by hand without the software. The reachable list is shown in Table 5.14.In Table 5.15, where the term "PV" means preference vector, the unilateral improvements (defined in Section 5.1.2) are indicated under each state for each DM. According to the definitions provided in Section 5.1.2 regarding stability concepts, Nash and SEQ equilibria are found and shown in Table 5.15.

State 1, where no DM takes any action, is one of the equilibria. This is a reasonable solution, as it has been about 16 months since any of the governments have taken any action. Although the Federal Government has announced the restructuring, it has not yet introduced the purchaser. The Ontario Government, on the other hand, has postponed its plan. Therefore, state 1 is an equilibrium, which is currently being played out. State 10 (Y N N, N Y) is another equilibrium.

In order to compare the equilibria of 2008 and 2010 analyses, Figures 5.14 and 5.15 are displayed together. State 10 is a very strong equilibria since it is Nash stable. This state is somehow similar to state 7 in the 2008 analysis. State 7 is also Nash stable and is a stronger equilibria than state 3. Therefore, the relationship between the results of the two conflicts can be listed below:

- State one is the initial state of both conflicts.

Table 5.14: Reachable states

State	DM 1	DM 2
1	2, 3, 4	5, 9
2	1, 3, 4	6, 10
3	1, 2, 4	7, 11
4	1, 2, 3	8, 12
5	6, 7, 8	1, 9
6	5, 7, 8	2, 10
7	5, 6, 8	3, 11
8	5, 6, 7	4, 12
9	10, 11, 12	1, 5
10	9, 11, 12	2, 6
11	9, 10, 12	3, 7
12	9, 10, 11	4, 8

Table 5.15: Stability analysis (e_{11}=e_{22}= +, e_{ij}= 0, i≠j)

Overall Equilibria	E	×	×	×	×	E	×	×	×	×	×	×
Individual Stability	r	u	u	r	s	s	s	r	u	u	u	u
DM 1 **PV**	10	11 10	9 11 10	2	3 2	1 3 2	6	7 6	5 7 6	12 9 11 10	4 1 2 3	8 5 6 7
Individual Stability	r	r	r	r	s	u	u	u	u	u	u	u
DM 2 **PV**	12	1	11	10	5 1	7 11	6 10	3 7 11	2 6 10	4 12	8 4 12	9 1 5

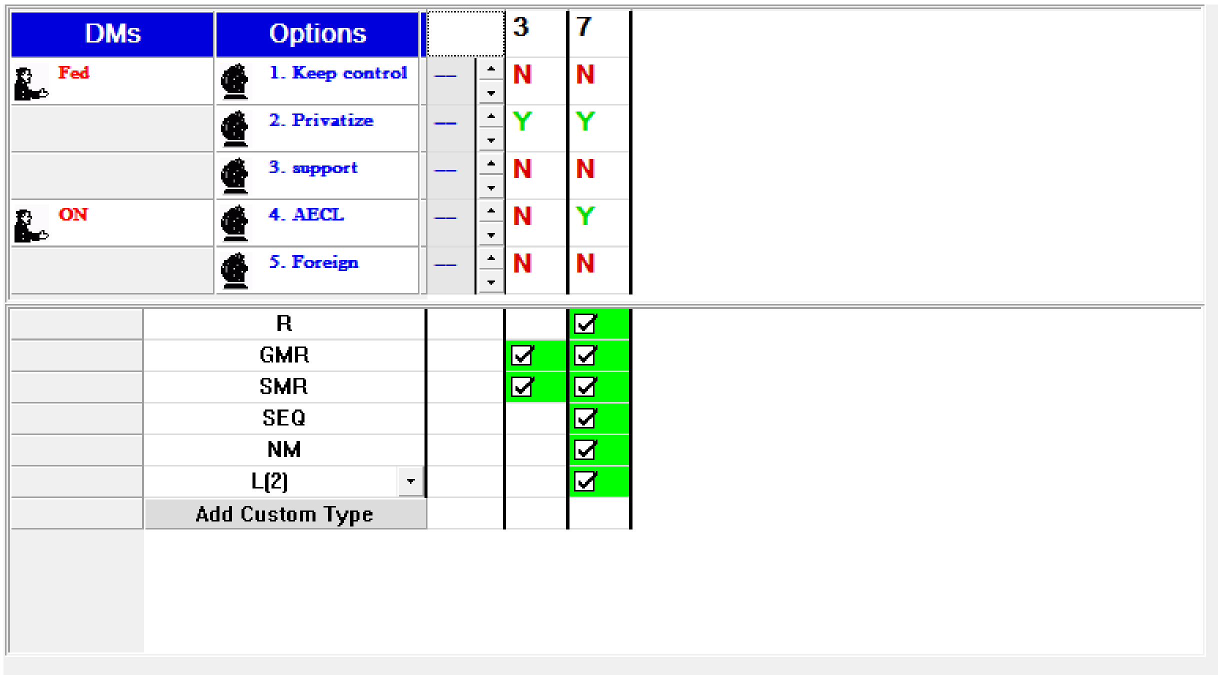

Figure 5.14: The equilibria of the 2008 conflict when AECL and Green Groups are omitted from the game.

- State 2 (which is similat to 3 in the 2-DM 2008 analysis) is a transition equilibria in 2010 conflict and the equilibria of 2008 conflict.
- State 7 or 10 are the strong equilibria in both conflicts.

Now the question is that why is not state 7 the finishing point of the 2008 analysis? The answer is that state 7 (or 10) are actually the equilibria, but state 3 is a very considerable transition state. This nuclear conflict is very complicated since the DMs have changed their decisions for several times. That is why the conflict moved from state 7 to 3 in 2008 conflict.

5.4.4 Status Quo Analysis

To investigate how the conflict evolves and moves from its 2008 state, state 1, to state 10, status quo analysis is performed. The evolution of the conflict is shown in Table 5.16. Normally, the conflicts evolve as presented in Table 5.9; one DM moves the conflict from one state to another, then another DM moves. In addition, it is not common for the conflicts return to a previous state. However, in this specific conflict it is possible for a

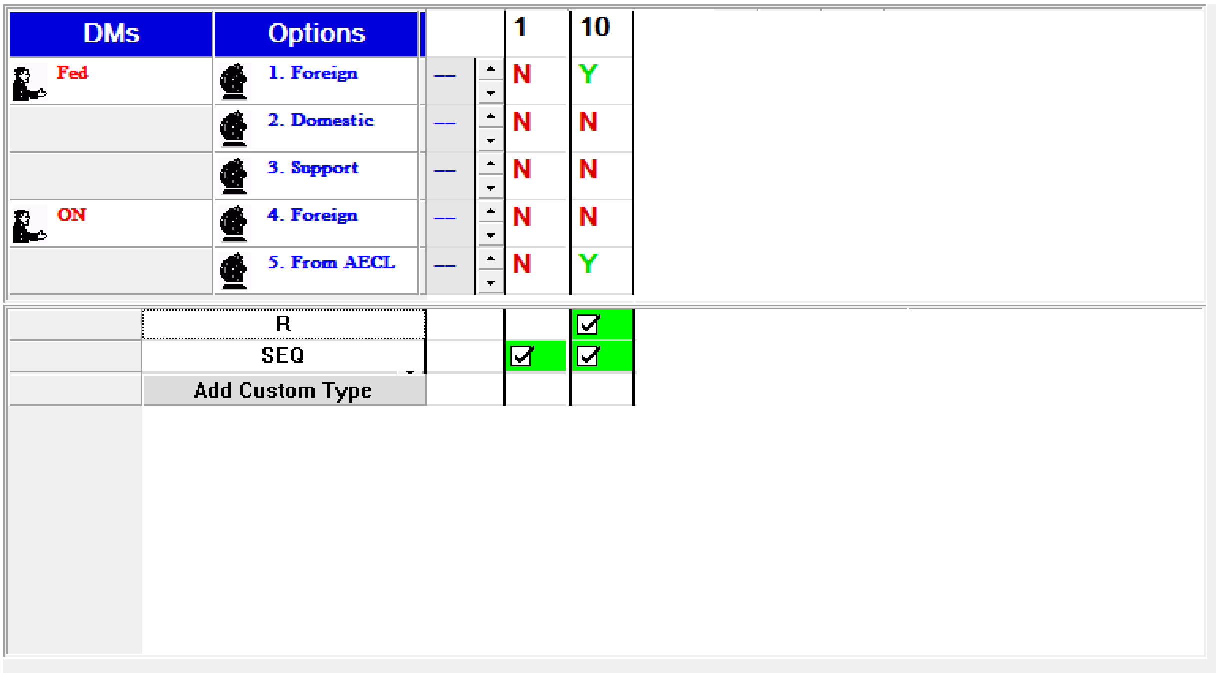

Figure 5.15: The equilibria for SEQ and Nash stability of the static analysis in 2010

DM to move the game in two back-to-back states. For example, both the prediction and the reality are that DM 1 moves the conflict from state 2 to 1. As mentioned before, this game is complicated since the DMs can change their decisions, and this feature makes this game special.

state 2, which is equivalent to state 3 in the 2-DM 2008 conflict, is a transition state. This state is the ending point of the 2008 conflict, but can be considered as a starting point of the 2010 conflict. In order to easily compare the evolutions of 2008 and 2010 conflicts, the status quo table of the 2-DM 2008 conflict is also illustrated here again (5.17). Although the initial state is shown to be state 1 in Table 5.16, this state is actually the very first point of the conflict in 2008. Therefore, state 1 is the initial state if the 2008 conflict, and state 2 is its ending and also the beginning of the 2010 conflict. Finally, state 10 is the equilibria in the 2010 game. The main reason for the difference between the two stages of the conflict is the available information. One may see how the accuracy of information can affect the result of a same conflict in two stages of time.

Table 5.16: Evolution of the 2010 conflict

Federal Gov.	1. Sell AECL to a foreign company	N	N	$\xrightarrow{DM1}$ Y	Y	$\xrightarrow{DM1}$ N	$\xrightarrow{DM1}$ Y	Y
	2. Sell AECL to a Canadian company	N	N	N	N	N	N	N
	3. Support AECL	N	N	N	N	N	N	N
Ontario Gov.	4. Buy from a foreign company	N	N	N	N	N	N	N
	5. Buy from AECL	N	$\xrightarrow{DM2}$ Y	Y	$\xrightarrow{DM2}$ N	N	N	$\xrightarrow{DM2}$ Y
		1	9	10	2	1	2	10

Table 5.17: Evolution of the 2-DM 2008 conflict

DM 1	Sell less than 50% of AECL	N	N	N	N
	Privatize AECL	N	N	$\xrightarrow{DM1}$ Y	Y
	Support AECL	N	N	N	N
DM 2	Buy from AECL	N	$\xrightarrow{DM2}$ Y	Y	$\xrightarrow{DM2}$ N
	Buy from a foreign company	N	N	N	N
		1	5	7	3

5.4.5 Attitude Analysis

Attitude analysis (Inohara et al., 2007; Bernath-Walker et al., 2009) is another analysis that is performed on this conflict. In the original form of static analysis, each DM is considered to have a positive attitude towards him/herself, and to be neutral towards other DMs. This means that each DM does not carry out an action that harms him/herself, but may move to a state that harms or benefits other DMs. The way DMs' attitudes can be shown is indicated in Table 5.18. The symbol $e_{ij} \in \{-, 0, +\}$, $i, j = 1, \ldots, n$ where n is the number of players, denotes the attitude of player i towards player j. $e_{ij} = -$, $e_{ij} = 0$, $e_{ij} = +$ indicate negative, neutral, and positive attitudes towards the opponent, respectively. Table 5.18 demonstrates the method that DMs' attitudes can be presented. Table 5.19 shows the attitudes of players in the original form of static analysis.

Table 5.18: Tabular representation of attitudes in a 2-DM game

	DM 1	DM 2
DM 1	e_{11}	e_{12}
DM 2	e_{21}	e_{22}

Table 5.19: Attitudes in a regular 2-DM game analysis

	DM 1	DM 2
DM 1	+	0
DM 2	0	+

It is worth noting that the analysis that is shown in Table 5.15 is performed by taking into consideration the attitude set indicated in Table 5.19. However, another set of attitudes may be assumed in this game. Two different governments are the DMs in this conflict. The Federal Government is run by the Conservative Party of Canada, and the Ontario Government is run by the Liberal Party. Therefore, aside from the situation of the Ontario contract and the future of AECL, the game involves the political conflicts between these two politically opposed DMs. According to the background of the conflict, after the Ontario Government announced that it favoured AECL's proposal, the government of Canada announced the restructuring of the company. The implementation of a new nuclear station in Ontario is a vital requirement for the province. However, although the Federal Government is keen on being a pioneer in nuclear technology, it seems that it does not have a plan to help Ontario in this matter, and this may be the reason for the political conflicts. Therefore, a new attitude arrangement (Table 5.20) is considered, and a new static analysis is performed (Table 5.21). According to the attitudes in Table 5.20, from each state, DM 1 can move to a state among the reachable states that is less preferred by DM 2 and more preferred by itself. DM 2 can move to the states that are more preferred by itself, ignoring DM 1's preference. The corresponding unilateral moves to each state are indicated under each state in the preference vector (PV) of each DM in Table 5.21.

With the new set of attitudes, two states are found as the equilibria of the conflict, states 4 and 10. State 10 represents the situation in which DM 1 sells AECL to a foreign company, and DM 2 buys the reactors from AECL. State 4 is a state in which the Federal Government supports AECL, and the Ontario Government decides not to buy any new

Table 5.20: Attitudes in the new analysis

	DM 1	DM 2
DM 1	+	0
DM 2	-	+

Table 5.21: Stability analysis (e_{11}=e_{22}= +, e_{12}= -, e_{21}= 0)

Overall Equilibria	E	×	×	×	×	×	×	×	×	×	E	×
Individual Stability	r	u	r	r	s	u	r	u	u	u	r	r
DM 1 **PV**	10	11 10	9	2	3 2	1 3 2	6	7 6	5 7 6	12 9 11 10	4	8
Individual Stability	r	r	r	r	s	u	u	u	u	r	u	u
DM 2 **PV**	12	1	11	10	5 1	7 11	6 10	3 7 11	2 6 10	4 12	8 4 12	9 1 5

reactor. The results show that if, in reality, the Federal Government does have a plan to harm the provincial government, and at the same time, benefit itself, it is possible that the final outcome of the game is state 4, which is among the least preferred states for both DMs.

5.5 Summary

The dispute over the expansion of the Darlington nuclear site in Ontario is modeled in this chapter. The history of the conflict goes back to March 2008. The dispute has been analyzed and modeled with respect to two different points of time, fall 2008 and spring 2010. According to the background of the game in 2008, four DMs were considered to be involved in the game, the Federal and Ontario governments, AECL, and Green Groups. However, after several sensitivity analyses, the author arrived at the conclusion that the main DMs only include the Federal and Ontario governments. The status quo analysis is also provided and the evolution of the conflict from March to fall 2008 is explained. It is found that the spirit of the conflict is about the doubt of DMs in making certain decisions. Sometimes, even DMs change their decisions, or at least announce different or opposite points of views. Therefore, some of the equilibria of the 2008 analysis are found to be the transition states in 2010 analysis. The conflict did not terminate at this point and is still ongoing. The results and information of the analysis in 2008, and an updated background in 2010 are used to perform another analysis in 2010. Only the two governments are counted as the players this time. Meanwhile, their options have also been changed. The stable states of the game are found, and attitude analysis is carried out to obtain deeper insights about the dispute. It is discovered that if the Federal Government does have a negative attitude towards the Ontario Government, it is possible that the final outcome is a state that is among the least preferred states for both DMs.

Chapter 6

Conclusions and Future Work

This thesis studies the energy situation and electricity generation in Canada. Each energy source is briefly explained, and its role in energy production is examined. By means of CanESS, the author was able to provide a future perspective about the energy issue. The focus of the study is the province of Ontario. Therefore, some simulations were performed by using CanESS with regards to this province. Since nuclear energy is the most significant source of energy in Ontario, this type of energy was studied in detail. There is a conflict between the Federal and provincial governments with regard to nuclear energy. GMCR II was used to analyze and model this conflict, since this dispute involves multiple decision makers with multiple options.

Since the conflict began in 2007 and has not yet been resolved, two analyses were performed at two different points of time, in 2008 and 2010. In fact, by having the results of the simulations in 2008, the analyst obtains more confidence in the results of the more recent analysis. The outputs of the analysis in 2008 are the transition states in the 2010 analysis and are depicted in the status quo analysis.

In summary, the two GMCR analyses along with the data series provided by CanESS and the simulations that were run by this software were presented to assist analysts in the field of energy strategy and especially the ones who are involved in the current nuclear conflict of Ontario.

6.1 Contributions of Thesis

The major contributions of this thesis are as follows:

- The examination of different energy sources in Canada presents a perspective about energy infrastructure in this country. Because the focus of the research is energy in

Ontario and nuclear energy is more significant than the other energy sources, this type of energy is investigated more deeply in the thesis. A brief history of nuclear energy is provided in Chapter 4 and the role of Canada has been described in this regard.

- CanESS, which is an energy systems simulator tool, is presented and introduced in Chapter 3. CanESS provides a large of Canadian energy. In addition to being a database, CanESS contains a very large energy modeling platform. Thousands of parameters, factors, and mathematical formulations are playing roles in this platform in order to define different energy-related scenarios and analyze the issues of interest with a "what if" method.

- The Ontario nuclear dispute which has been taking place between the two Federal and provincial governments is modeled and investigated in this thesis. Since multiple decision makers are involved in this conflict and each of them has multiple alternatives, the Graph Model for Conflict Resolution is the chosen methodology to study the conflict. The results will assist stakeholders and policy makers involved in this issue.

6.2 Future Work

This thesis has studied the role of different energy sources in Canada. It then focuses on nuclear energy in Ontario. To determine an overall energy policy, every source of energy should be investigated in more detail, and the associated technological issues should also be examined. In addition, several energy related conflicts are taking place in the country. GMCR possesses great potential to model the games involving multiple decision makers and options. Therefore, GMCR is highly recommended to investigate strategic energy disputes.

With regard to the Ontario nuclear conflict, more sensitivity analyses can be performed. Furthermore, other methods of option prioritization may be utilized to define relative preferences. Moreover, since this dispute has not yet been resolved, further analyses should be done with updated information in the future.

Energy regulations are also very important in policy and strategy making processes. To investigate the obstacles that prevent the Federal and provincial governments from cooperating and thereby making progress towards Canada becoming an energy superpower, energy policies and regulations should be suitably analyzed. The regulatory study will be beneficial to assist stakeholders and policy makers in the decision making processes.

Finally, in all national decision making processes, cost and benefit studies are mandatory, and energy conflicts are not an exception. Whatever decision a government makes, it should be economically sound. Therefore, it is suggested that before modeling a conflict by GMCR, cost analyses be performed. In this way, if an alternative is not cost-efficient for a decision maker, a coalition of decision makers, or for all of the decision makers, different approaches can be chosen to model and resolve the conflict. This suggestion may also be followed for the continuing dispute over nuclear energy in Ontario and elsewhere.

References

AECL (2008). CANDU Reactors. http://www.aecl.ca/Reactors/CANDU6.htm. Accessed on September 25, 2008. 78

AECL (2009a). 2009 Annual Financial Report. http://www.aecl.ca/Assets/Publications/Reports/2009_AFR_Eng.pdf. Accessed on March 20, 2010. 63

AECL (2009b). Restarting Safely, Reassuring Canadians. http://www.nrucanada.ca/en/home/projectrestart/NRUOutage.aspx. Accessed on December 8, 2010. 81

AECL (2010a). Canadian Technology. http://www.aecl.ca/Reactors.htm. Accessed on May 9, 2010. 65

AECL (2010b). CANDU Reactors Around the World. http://www.aecl.ca/Reactors/CANDU6.htm. Accessed on May 18, 2010. ix, 66

AECL (2010c). Chalk River Laboratories. http://www.aecl.ca/Science/CRL.htm. Accessed on December 1, 2010. 65

AECL (2010d). History and Evolution. http://www.aecl.ca/Science/RR/History.htm. Accessed on May 20, 2010. 65

AECL (Atomic Energy of Canada Ltd.) (2008). About AECL. http://www.aecl.ca/about.htm. Accessed on September 20, 2008. 67

Akin, D. (2008). Over Budget and Behind Schedule, Reactor Replacement Axed. http://www.canada.com/topics/news/story.html?id=ba8921b1-5d42-4122-983e-3e0a3008ccea. Accessed on October 20, 2008. 80

Balley, D. (2010). Hydro-quebec gets 1gw in small-scale wind project submissions. http://www.windpowermonthly.com/news/1015068/Hydro-Quebec-gets-1GW-small-scale-wind-project-submissions/. Accessed on September 5, 2010. 20

BC Hydro (2010). Site C Clean Energy Project. http://www.powerofbc.ca/Building-Clean/New-Clean-Infrastructure/project-page.aspx?cid=213. Accessed on November 13, 2010. 14

Benzie, R. and Black, D. (2008). Darlington to Get 2 New Reactors. http://www.thestar.com/News/Ontario/article/444474. Accessed on October 10, 2008. 78

Bernath-Walker, S., Hipel, K. W., and Inohara, T. (2009). Strategic Decision Making for Improved Environmental Security: Coalitions and Attitudes in the Graph Model for Conflict Resolution. *Journal of Systems Science and Systems Engineering*, 18(4):461–476. 76, 108

BIOCAP Canada and Pollution Probe (2004). Primer on Bioproducts . http://www.biocap.ca/images/pdfs/BioproductsPrimerE.pdf. Accessed on October 14, 2010. 22

Bowman, C. (2005). *Intangibles: Exploring the Full Depth of Issues*. Grafiks Marketing & Communications. 43

Bowman, C. and Albion, K. (2009). Canada's Energy Progress. Technical report. 43

Bowman, C. and Griesbach, B. (2007). Energy Pathways Task Force. Technical report. xii, 5, 43, 44

Bradley, D. (2006). Canadian Biomass-Bioenergy Report. http://www.bioenergytrade.org/downloads/canadacountryreportmay312006.pdf. Accessed on July 3, 2010. 21

Bradley, D. (2009). Canada Report on Bioenergy 2009. http://www.canbio.ca/documents/publications/canadacountryreport2009.pdf. Accessed on August 14, 2009. ix, 23, 24

Brown, M. (1965). Canada's Nuclear History Chronology. http://media.cns-snc.ca/history/canadian_nuclear_history.html. Accessed on February 21, 2010. 63

Cadham, J. (2009). The Canadian Nuclear Industry: Status and Prospects. 96, 97, 98, 99

Calgary Herald (2009). Ontario to Spend $2.3B on Renewable Power. http://www.calgaryherald.com/business/fp/Ontario+spend+renewable+power/2016882/story.html. Accessed on April 13, 2010. 19

Canadian Electricity Association (2008). Canadian Electricity Generation by Fuel Type. http://www.electricity.ca/media/Industry%20Data%20July%202010/Electricity%20Generation%20in%20Canada%20by%20Province%20and%20Fuel%20Type%20(Chart)%202009.pdf. Accessed on December 16, 2010. xi, 6

Canadian GeoExchange Coalition (2010). How GeoExchange Systems Work? http://www.geo-exchange.ca/en/geoexchange_how_it_works_p49.php. Accessed on May 3, 2010. 26

Canadian Geothermal Association (2010). What Is Geothermal? http://www.cangea.ca/what-is-geothermal/. Accessed on May 3, 2010. 26

Canadian Hydropower Association (2008). Hydropower in Canada,Past, Present, and Future. http://www.canhydropower.org/hydro_e/pdf/hydropower_past_present_future_en.pdf. Accessed on April 6, 2010. 8, 129

Canadian Nuclear Association (2009). Canada's Nuclear Energy: Reliable, affordable and clean energy. http://www.cna.ca/english/pdf/nuclearfacts/2009/CNA_Booklet_09.pdf. Accessed on August 17, 2010. xii, 35, 37

Canadian Nuclear Safety Commission (2009). How is Radioactive Waste Classified? . http://www.nuclearsafety.gc.ca/eng/about/regulated/radioactivewaste/how.cfm. Accessed on April 19, 2010. 36

Canadian Nuclear Safety Commission (2010a). Operating Nuclear Power Plants. http://www.cnsc-ccsn.gc.ca/eng/licenseesapplicants/powerplants/operating/. Accessed on December 7, 2010. ix, 35, 36

Canadian Nuclear Safety Commission (2010b). Our Mission. http://www.cnsc-ccsn.gc.ca/eng/about/mission/index.cfm. Accessed on May 17, 2010. 64

Canadian Nuclear Society (2006). Canada Reactor Map. http://www.cns-snc.ca/nuclear_info/canadareactormap.gif. Accessed on October 22, 2008. xii, 79

Canadian Wind Energy Association (2009a). Powering Canada's Future. http://www.canwea.ca/pdf/CanadaCurrentInstalledCapacity_e.pdf. Accessed on April 10, 2009. xi, 17, 18

Canadian Wind Energy Association (2009b). Windfarms. http://www.canwea.com/farms/index_e.php. Accessed on June 16, 2010. 17

CanESS (2009). CanESS Approach. http://whatiftechnologies.com/index.php?option=com_content&view=article&id=115:approach&catid=48:caness&Itemid=98. Accessed on December 8, 2010. xii, 46

CanESS (2010a). CanESS Software. xii, 47, 49, 50, 51, 52, 53, 54

CanESS (2010b). Electricity Production, CanESS. xii, 53

CanESS (2010c). Greenhouse Gas Emission, CanESS. xii, 48

CBC (2010). Quebec, Vermont sign hydro deal. http://www.cbc.ca/money/story/2010/08/12/qc-vermont-power-deal-hydro.html. Accessed on September 18, 2010. 14

CBC News (2006). McGuinty Takes Blame for Broken Promise on Coal plant Closures. http://www.cbc.ca/canada/toronto/story/2006/11/16/coal-responsibility.html. Accessed on September 15, 2008. 78

CBC News (2008). Nuclear Safety Watchdog Head Fired for "Lack of Leadership": Minister. http://www.cbc.ca/canada/story/2008/01/16/keen-firing.html. Accessed on December 8, 2008. 80

CBC News (2009a). Canada Eyes Sale of Stake in AECL Reactor Business. http://www.cbc.ca/money/story/2009/05/28/aecl-future-sale.html. Accessed on December 8, 2010. 98

CBC News (2009b). No renegotiating Churchill Falls: Quebec. http://www.cbc.ca/canada/montreal/story/2009/12/01/quebec-churchill.html. Accessed on October 4, 2010. 16

CBC News (2010a). New Powerline Route Explored by NB and NS. http://www.cbc.ca/canada/new-brunswick/story/2010/07/20/nb-nbpower-nspower-transmission-138.html. Accessed on October 4, 2010. 17

CBC News (2010b). Quebec regulator rejects N.L. power play. http://www.cbc.ca/canada/newfoundland-labrador/story/2010/05/12/churchill-nalcor-quebec-decision-512.html. Accessed on September 4, 2010. 16

Centre for Energy (2010). Key Potential Environmental Impacts. http://www.centreforenergy.com/AboutEnergy/Hydro/Environment.asp?page=4. Accessed on December 9, 2010. 8

Coal Association of Canada (2009). Clean Coal. http://www.coal.ca/content/index.php?option=com_content&task=category&sectionid=8&id=36&Itemid=41. Accessed on December 7, 2010. 29

CTV (2009). Feds Announce Major Shakeup of Nuclear Agency. http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/20090528/AECL_shakeup_090528/20090528?hub=Canada. Accessed on December 8, 2010. 97

Elert, G. (1997). Einstein's Letter to Roosevelt. http://hypertextbook.com/eworld/einstein.shtml. Accessed on September 25, 2008. xii, 56, 57

Energy Information Administration (2008). International Energy Statistics. http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=3&aid=8&cid=CA,&syid=2004&eyid=2008&unit=MMTCD. Accessed on December 7, 2010. 29

Energy World (2010). SunPower Sets Solar Cell Efficiency Record at 24.2% . http://www.renewableenergyworld.com/rea/news/article/2010/06/sunpower-sets-solar-cell-efficiency-record-at-24-2. Accessed on December 7, 2010. 24

Environment Canada (2010). Renewable Energy. http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=F62D29CC-1. Accessed on September 16, 2010. 6

Environmental Defense (2010). Falling Behind: Canada's Lost Clean Energy Jobs. http://www.environmentaldefence.ca/reports/Falling_Behind.html. Accessed on September 12, 2010. 21

Fang, L., Hipel, K. W., and Kilgour, D. M. (1993). *Interactive Decision Making.* Wiley, New York. ix, xii, 1, 67, 69, 73, 74, 75, 76

Fang, L., Hipel, K. W., Kilgour, D. M., and Peng, X. (2003a). A Decision Support System for Interactive Decision Making, Part 1: Model Formulation. *IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews*, 33(1):42–55. xii, 68, 71, 85

Fang, L., Hipel, K. W., Kilgour, D. M., and Peng, X. (2003b). A Decision Support System for Interactive Decision Making, Part 2: Analysis and Output Interpretation. *IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews*, 33(1):56–66. xii, 68, 71, 85

Frame, A. (2008). A Very Political Power Play. http://www.thestar.com/comment/Columnist/article/349255. Accessed on september 20, 2008. 78, 84

Fraser, N. M. and Hipel, K. W. (1979). Solving Complex Conflicts. *IEEE Transactions on Systems, Man, and Cybernetics*, 9(12):805–816. 74

Fraser, N. M. and Hipel, K. W. (1984). *Conflict Analysis, Models and Resolutions.* Elsevier, New York, second edition. 68, 74, 76

Geddes, J. (2007). Harper Embraces the Nuclear Future. http://www.macleans.ca/canada/features/article.jsp?content=20070507_105095_105095. Accessed on October 25, 2008. 81

Government of Canada (1999). James Bay Project, Environmental Impact. http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=26A03BFA-1. Accessed on March 9, 2009. 10

Government of Canada (2007). $500M Fund Launched to Support Next-Generation Renewable Fuels. http://www.ecoaction.gc.ca/news-nouvelles/20070912-eng.cfm. Accessed on February 3, 2010. 23

Government of Canada (2009). Canada-U.S. Energy Relations. http://www.canadainternational.gc.ca/washington/bilat_can/energy-energie.aspx?lang=eng. Accessed on June 23, 2010. 6

Government of Canada (2010). Canada's Mid-term Quantified Emissions Reduction Commitment. http://www.climatechange.gc.ca/default.asp?lang=En&n=D6B3FF2B-1. Accessed on December 7, 2010. 28

Green Energy Act Alliance (2009). About Green Energy. http://www.greenenergyact.ca/Page.asp?PageID=1224&SiteNodeID=201&BL_ExpandID=43. Accessed on April 25, 2010. 19

Hamilton, T. (2007). Could Reactors Withstand Blast? Report That Regulator Will Impose New Safety Standards May Pose a Big Hurdle for AECL Nuclear Sale in Ontario. http://pqasb.pqarchiver.com/thestar/access/1196866631.html?FMT=ABS&FMTS=ABS:FT&type=current&date=Jan+19,+2007&author=Tyler+Hamilton&pub=Toronto+Star&edition=&startpage=F.1&desc=Could+reactors+withstand+blast. Accessed on October 25, 2008. 81, 82, 84

Hamilton, T. (2008a). A Chance for Nuclear Industry to Clean up Its Act. http://www.thestar.com/article/293658. Accessed on September 23, 2008. 83

Hamilton, T. (2008b). AECL Failed to Disclose Loss of Radioactive Part: Report. http://www.thestar.com/News/Ontario/article/467742. Accessed on October 20, 2008. 80, 81, 82

Hamouda, L., Kilgour, D. M., and Hipel, K. W. (2004). Strength of Preference in the Graph Model for Conflict Resolution. *Group Decision and Negotiation*, 13:449–462. 76

Hamouda, L., Kilgour, D. M., and Hipel, K. W. (2006). Strength of Preference in Graph Models for Multiple Decision-maker Conflicts. *Applied Mathematics and Computation*, 179(1):314–327. 76

Harris, J. (2008). Nuclear power: Expensive, Irresponsible and Unnecessary. http://www.greenparty.ca/en/node/4218. Accessed on September 25, 2008. 82

Hipel, K. W., editor (2009a). *Conflict Resolution*, volume 1. Eolss Publishers, Oxford, United Kingdom. (ISBN-978-1-84826-120-4 (Adobe e-Book), ISBN-978-1-84826-570-7 Library Edition (Hard Cover)). 68

Hipel, K. W., editor (2009b). *Conflict Resolution*, volume 2. Eolss Publishers, Oxford, United Kingdom. (ISBN-978-1-84826-121-1 (Adobe e-Book), ISBN-978-1-84826-571-4 Library Edition (Hard Cover)). 68

Hipel, K. W., Kilgour, D. M., and Bashar, M. A. (2011). Fuzzy Preferences in Multiple Participant Decision Making. *Scientia Iranica special publication in honour of Professor Lotfizadeh*. to appear. 76

Hipel, K. W., Kilgour, D. M., Fang, L., and Peng, X. (1997). The Decision Support System GMCR in Environmental Conflict Management. *Applied Mathematics and Computation*, 83(2 and 3):117–152. ix, xii, 68, 71, 75, 85

Howard, N. (1971). *Paradoxes of Rationality: Theory of Metagame and Political Behaviour*. MIT Press, Cambridge, MA. 68, 74

Hydro-Quebec (2004). The Romaine Complex. `http://www.hydroquebec.com/projects/pdf/romaine.pdf`. Accessed on May 15, 2009. 14

Hydro-Quebec (2005). Environmental Monitoring of the LaGrande Complex. Technical report. Accessed on December 5, 2010. xi, 13

Hydro-Quebec (2008). Eastmain-1-A and Sarcelle Powerhouses and Rupert Diversion. Technical report. Accessed on March 5, 2010. 12

Hydro-Quebec (2009). Interconnection with Ontario. Technical report. Accessed on December 5, 2010. 11

Hydro World (2010). Vermont Utilities, Hydro-Quebec Sign Long-Term Hydropower Deal . `http://www.hydroworld.com/index/display/article-display/9147561326/articles/hrhrw/News-2/2010/07/hydro-quebec_-vermont.html`. Accessed on July 9, 2009. 14

Inohara, T. and Hipel, K. W. (2008a). Coalition Analysis in the Graph Model for Conflict Resolution. *Systems Engineering*, 11(4):343–359. 76

Inohara, T. and Hipel, K. W. (2008b). Interrelationships among Noncooperative and Coalition Stability Concepts. *Journal of Systems Science and Systems Engineering*, 17(1):1–29. 76

Inohara, T., Hiple, K. W., and Walker, S. (2007). Conflict Analysis Approaches or Investigating Attitudes and Misperceptions in the War of 1812. *Journal of Systems Science and Systems Engineering*, 16(2):181–201. 76, 108

Institute for Energy Research (2009). The Facts about Air Pollution from Coal-Fired Power Plants. `http://www.canadafreepress.com/index.php/article/11599`. Accessed on May 20, 2010. 22

International Energy Agency (2008a). Electricity. `http://www.eia.doe.gov/cabs/Canada/Electricity.html`. Accessed on August 23, 2010. 6

International Energy Agency (2008b). Share of total primary energy supply in 2007. `http://www.iea.org/stats/pdf_graphs/CATPESPI.pdf`. Accessed on December 7, 2010. xi, 27

International Energy Agency (2009). Electricity Generation By Fuel. http://www.iea.org/stats/pdf_graphs/CAELEC.pdf. Accessed on August 20, 2009. xi, 7

International Hydropower Association (2010). Hydropower Sustainability Assessment Protocol. Accessed on December 9, 2010. 8

James Bay Road (2010). Hydro-Quebec Project. http://www.jamesbayroad.com/hydro/index.html. Accessed on March 15, 2009. 12

Jungmeier, G. and Spitzer, J. (2004). Greenhouse gas emissions of bioenergy from agriculture compared to fossil energy for heat and electricity supply. *Nutrient Cycling in Agroecosystems*, 60(1-3):267–273. 22

Kilgour, D. M., Hipel, K. W., , Fang, L., and Peng, X. (2001). Coalition Analysis in Group Decision Support. *Group Decision and Negotiation*, 10(2):159–175. 76

Lathem, A. (2010). Vermont Gives Hydro Quebec Renewable Energy Label. http://www.towardfreedom.com/environment/2012-vermont-gives-hydro-quebec-renewable-energy-label. Accessed on August 23, 2010. 8, 10, 14

Laurence, G. C. (1980). Early Years of Nuclear Energy Research in Canada. http://media.cns-snc.ca/history/early_years/earlyyears.html. Accessed on September 25, 2008. 60, 61

Li, K. W., Hipel, K. W., Kilgour, D. M., and Fang, L. (2004). Preference Uncertainty in the Graph Model for Conflict Resolution. *IEEE Transactions on Systems, Man, and Cybernetics, Part A*, 34(4):507–520. 76

Li, K. W., Kilgour, D. M., and Hipel, K. W. (2005). Preference Uncertainty in the Graph Model for Conflict Resolution. *Journal of Operatinal Research Society*, 5:699–707. 76

Lima, I. B. T., Ramos, F. M., Bambace, L. A. W., and Rosa, R. R. (2008). Methane emissions from large dams as renewable energy resources: A developing nation perspective. *Mitigation and Adaptation Strategies for Global Change*, 13(2):193–206. 8

Lozanova, S. (2008). 4 Things to Consider Before Going Solar Thermal. http://www.triplepundit.com/2008/03/4-things-to-consider-before-going-solar-thermal/. Accessed on December 7, 2010. 24

Manitoba Hydro (2010). Wuskwatim Generation Project. http://www.hydro.mb.ca/projects/wuskwatim/overview.shtml. Accessed on May 15, 2009. 12

McCarthy, S. (2010). Ottawas plan to sell aecl threatens future of canadas nuclear industry. http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/ottawas-plan-to-sell-aecl-threatens-future-of-canadas-nuclear-industry/article1792762/. Accessed on December 7, 2010. 98, 99

McCarthy, S. and Howlett, K. (2009). AECL's Future in Doubt as Ontario Suspends Nuclear Power Plans. http://www.theglobeandmail.com/news/national/ontario-suspends-nuclear-power-plans/article1200469/. Accessed on December 8, 2010. 97, 98, 99

McParland, K. (2008). Dalton McGuinty's Opportunity to Slash Verbal Gas Emissions. http://network.nationalpost.com/np/blogs/posted/archive/2008/03/26/dalton-mcguinty-s-opportunity-to-slash-verbal-gas-emissions.aspx. Accessed on September 25, 2008. 82

Nalcor (2010). Lower Churchill Project. http://www.nalcorenergy.com/lower-churchill-project.asp. Accessed on October 4, 2010. 14, 49

Nash, J. F. (1950). Equilibrium Points in N-player Games. *Proceeding s National Academy of Sciences*, 36(1):48–49. 73

Nash, J. F. (1951). Non-cooperative Games. *Annals of Mathematics*, 54(2):286–295. 73

Nathwani, J. (2009). Canada's Medical Isotope Crisis: A Way Forward. *The Journal of Policy Engagement*, 1(4):12–13. Available at www.ocepp.ca. 80

National Energy Board (2010a). Canada's Energy Future: Reference Case and Scenarios to 2030 - Natural Gas Highlights. http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/2007/fctsht0738ntrlgs-eng.html. Accessed on December 7, 2010. xi, 30, 31

National Energy Board (2010b). The Canadian industry. http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/prcng/crdlndptrlmprdcts/cndnndstr-eng.html. Accessed on December 7, 2010. 34

Natural Resources Canada (2008a). About Coal. http://nrcan.gc.ca/eneene/sources/coacha-eng.php. Accessed on December 7, 2010. 28

Natural Resources Canada (2008b). Bioenergy Systems. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/bioenergy/publications/200843.html. Accessed on February 3, 2010. 21

Natural Resources Canada (2009a). About Electricity. http://nrcan.gc.ca/eneene/sources/eleele/abofai-eng.php. Accessed on January 18, 2010. 8

Natural Resources Canada (2009b). About Natural Gas. http://nrcan.gc.ca/eneene/sources/natnat/abofai-eng.php. Accessed on December 7, 2010. xi, 29, 30

Natural Resources Canada (2009c). Canadian Oil Market. http://nrcan.gc.ca/eneene/sources/crubru/outape-eng.php. Accessed on December 7, 2010. xi, 32, 33, 34

Natural Resources Canada (2009d). Refinery Economics. http://www.nrcan.gc.ca/eneene/sources/petpet/refraf-eng.php. Accessed on December 7, 2010. 33

Natural Resources Canada (2009e). Review of Aatomic Energy Canada Limited. http://www.nrcan-rncan.gc.ca/media/newcom/2009/200950-eng.pdf. Presented to the Honourable Lisa Raitt Minister of Natural Resources. Accessed on December 10, 2010. 97

Natural Resources Canada (2009f). Small Hydro Power. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/renewables/small_hydropower.html. Accessed on September 19, 2010. 10

Natural Resources Canada (2009g). Wind Energy. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/renewables/wind_energy.html. Accessed on June 27, 2010. 19

Natural Resources Canada (2010). PV Potential and Insolation. https://glfc.cfsnet.nfis.org/mapserver/pv/pvmapper.phtml?MapSize=800%2C600&ViewRegion=Quick+Zoom&minx=-3440042.000000&miny=5139927.500000&maxx=4012398.000000&maxy=10729257.500000&imagewidth=800&imageheight=600&CMD=ZOOM_IN&CMD=ZOOM_IN&CHKBOXHKBOX%5B2700%5D=2700&CHKBOX%5B92163%5D=92163&units=0&tilt=1&period=13&title=PV+potential+and+insolation&title_e=PV+potential+and+insolation&title_f=Potentiel+photovolta%EFque+et+ensoleillement&NEK=e&LAYERS=2700%2C2701%2C2057%2C4240&SETS=1707%2C1708%2C1709%2C1710%2C1122&RLAYER=92163. Accessed on September 25, 2010. xi, 25

New Democratic Party (2008). NDP Platform. http://www.ndp.ca/platform/environment/newenergyeconomy. Accessed on October 17, 2008. 82

Newfoundland and Labrador Government Website (1996). Speaking notes from an address by Brian Tobin, Premier of Newfoundland and Labrador on Churchill Falls today in Toronto at the Empire Club. http://www.releases.gov.nl.ca/releases/1996/exec/1119n06.htm. Accessed on July 4, 2009. 16

Newfoundland and Labrador Hydro (2006). Lower Churchill Hydroelectric Generation Project. Accessed on December 4, 2009. xi, 15

NRU Canada (2010). Delivering on Our Commitment to Restart. http://www.nrucanada.ca/en/home/default.aspx. Accessed on December 1, 2010. 81

Obeidi, A., Hipel, K. W., and Kilgour, D. M. (2005). The Role of Emotions in Envisioning Outcomes in Conflict Analysis. *Group Decision and Negotiation*, 14(6):481–500. 76

Obeidi, A., Hipel, K. W., and Kilgour, D. M. (2006). Turbulance in Miramichi Bay: The Burnt Church Conflict over Native Fishing Rights. *Journal of the American Water Resources Association*, 42(12):1629–1645. 76

Obeidi, A., Kilgour, D. M., and Hipel, K. W. (2009a). Perceptual Graph Model Systems. *Group Decision and Negotiation*, 18(3):261–277. 76

Obeidi, A., Kilgour, D. M., and Hipel, K. W. (2009b). Perceptual Stability Analysis of a Graph Model System. *IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans*, 39(5):993–1006. 76

Office of Energy Efficiency (2009). Electricity Generation GHG Emissions by Energy Source. `http://oee.nrcan-rncan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/egen_00_2_e_4.cfm?attr=0l`. Accessed on December 7, 2010. 28

Ontario Government (2009a). Nuclear Procurement Project Update. `http://www.news.ontario.ca/mei/en/2009/06/nuclear-procurement-project-update.html`. Accessed on July 19, 2009. 95

Ontario Government (2009b). Ontario Coal Closure Launches Countdown To Green Energy. `http://news.ontario.ca/mei/en/2009/09/ontario-coal-closure-launches-countdown-to-green-energy.html`. Accessed on December 7, 2010. 28, 49

Ontario Government (2010). Ontario's Long-term Energy Plan. `http://www.mei.gov.on.ca/en/energy/`. Accessed on December 7, 2010. xii, 38, 39, 42, 95

Ontario Power Authority (2006). Standard Offer Program - Renewable Energy. `http://powerauthority.on.ca/sop/`. Accessed on June 27, 2010. 19

Ontario Power Generation (2010). Niagara Tunnel Project. `http://www.niagarafrontier.com/chrono.html`. Accessed on March 5, 2010. 12

Peter Goodhand and Richard Drouin and Thom Mason and Eric Turcotte (2009). Report of the Expert Review Panel on Medical Isotope Production. `http://www.marketwire.com/press-release/Natural-Resources-Canada-Expert-Panel-Delivers-Report-on-Isotopes-1085758.htm`. Presented to the Minister of Natural Resources, Ottawa, Canada. Accessed on December 20, 2010. 80

Puxley, C. (2007). Sale of Canada's Nuclear Giant Shouldn't be Negotiated in Private: Liberals. http://energyquest4nanticoke.ca/nukegiant.htm. Accessed on November 28, 2008. 81, 84

Renewable Energy Systems Canada Inc. (2009). Greenwich Wind Farm Project. http://greenwichwindfarm.com/greenwich-wind-farm-project.php. Accessed on November 25, 2009. 20

Rose, T. (2005). Canada and the Atomic Bomb: 60 Years On. http://www.cbc.ca/news/viewpoint/vp_rose/20050805.html. Accessed on February 14, 2010. 59

Rossenfeld, C. (2009). Setting up the First Committee. http://www.atomicarchive.com/History/mp/index.shtml. Accessed on September 25, 2009. 58

Schindler, D., Wells, J., and Carlson, M. (2010). Sign the Boreal Forest Conservation Scientist, Sign-on Letter. http://www.borealbirds.org/petition/. Accessed on March 9, 2010. 9

Schwartz, S. I., editor (1998). *The Costs and Consequences of U.S. Nuclear Weapons Since 1940*. Brookings Institution Pres, Washington, D.C. 60

Sea Breeze Power Co. (2009). Knob Hill Wind Farm. http://www.seabreezepower.com/page176.htm. Accessed on January 25, 2010. 19

Sierraclub (2008). Towards a Nuclear-Free Canada. http://www.sierraclub.ca/national/programs/atmosphere-energy/nuclear-free/index.shtml. Accessed on September 23, 2008. 82

Spears, T. (2008). Reactor Connected to Second Safety Pump. http://www.canada.com/topics/news/national/story.html?id=0e63c2ea-fd59-4a80-b047-b3880f30c729. Accessed on November 5, 2008. 80

The Global Oneness Commitment (2010). James Bay Project, Environmental Impact. http://www.experiencefestival.com/a/James_Bay_Project_-_Environmental_Impact/id/5176481. Accessed on March 13, 2010. 9

The Globe and Mail (2010). New Brunswick throws a wrench into AECL sale plans. http://www.nuclearcounterfeit.com/?p=3445. Accessed on December 7, 2010. 98, 99

The Heating, Refrigeration and Air Conditioning Institute of Canada (2010). Grants and Incentives and Rebates. http://www.hrai.ca/renewablesdatabank.html. Accessed on October 20, 2010. 25

The Secrétariat aux affaires intergouvernementales canadiennes (2001). The Minister of Natural Resources of Quebec and Minister for Canadian Intergovernmental Affairs expressing the position of Quebec on the constitutional change in the designation of Newfoundland. http://www.saic.gouv.qc.ca/centre_de_presse/communiques/2001/saic_com20011031.htm. Accessed on September 4, 2010. 17

The Star (2009). Privatization of AECL Radioactive Issue for Ottawa. http://www.thestar.com/Opinion/article/612823. Accessed on December 20, 2010. 98

The Writers' Alliance of Newfoundland and Labrador and Cabot College Literacy Office (1996). Timelines of Newfoundland and Labrador: A Joint Project of The Writers' Alliance of Newfoundland and Labrador and Cabot College Literacy Office. http://www.nald.ca/CLR/social/book1/book1.pdf. Accessed on September 19, 2010. 16

Trillium Power Wind (2010). Draft Project Discription Report, Trillium Power Wind 1. http://www.trilliumpower.com/energy/project-wind-1/. Accessed on November 12, 2010. 21

Tyler Hamilton (2010). Geothermal Could Meet Canada's Power Needs. http://www.thestar.com/business/cleanbreak/article/809649--hamilton-geothermal-could-meet-canada-s-power-needs. Accessed on December 7, 2010. 27

US Department of Energy (2009). Setting up the First Committee. http://www.cfo.doe.gov/me70/manhattan/index.htm. Accessed on September 25, 2009. 59, 60

Wang, M., Hipel, K. W., and Fraser, N. M. (1988). Modeling Misperceptions in Games. *Behavioral Science*, 33(3):207–223. 76

Watershed Watch Salmon Society Coquitlam, British Columbia (2007). Run-of-River, Hydropower in BC. Technical report, Watershed Watch Salmon Society Coquitlam, British Columbia. Accessed on December 5, 2010. xi, 9

World Wind Energy Association (2009). World Energy Report 2009. Technical report. Accessed on September 19, 2010. xi, 17, 20

Xu, H., Hipel, K. W., and Kilgour, D. M. (2009a). Multiple Levels of Preference in Interactive Strategic Decisions. *Descrete Applied Mathematics*, 157(15):3300–3313. 76

Xu, H., Hipel, K. W., and Kilgour, D. M. (2009b). Multiple Levels of Preference in Interactive Strategic Decisions. *IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans*, 39(1):96–108. 76

APPENDICES

Appendix A

Hydro Plants Technology

Three main types of hydroelectricity producing technologies are available (Canadian Hydropower Association, 2008):

- **Run-of-River:** The plants producing electricity by this technology are located close to rivers. Turbines are placed in the river's flow and produce electricity immediately using a river's water flow. Therefore, the amount of electricity produced varies according to the flow. Canada has several large run-of-river facilities, such as the 1,600 MW Sir Adam Beck 1 on the Niagara River in Ontario. Several small run-of-river facilities have also been developed as part of a bigger generation facility, such as the 1,436-megawatt La Grande-1 on James Bay, and many smaller run-of-river plants, like Waterton in Alberta.

- **Storage:** A storage facility includes a reservoir. This type of facility generally produces more energy than a run-of-river project of the same size, because in this technology, water is saved when it is plentiful, and its power is used in periods when electricity is scarce. Because hydropower maintains the balance between electricity supply and demand, a storage facility can support the development of other renewable but intermittent sources such as wind and solar.

- **Pumped Storage:** In this technology, excess electrical energy (for example, energy generated at night) is used to pump water uphill to a storage reservoir. At other times when energy is needed, the water is released and converted back into electricity in the hydro station. In Canada, there is one pumped storage facility, the 174-megawatt Sir Adam Beck Pump Generating Station at Niagara Falls in Ontario.