MASTER OF PUBLIC POLICY
CAPSTONE PROJECT

A Study of the Potential Application of Small Modular Reactors (SMRs) for Electricity Generation in the Northwest Territories

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THE SCHOOL OF PUBLIC POLICY

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Capstone Executive Summary

Canada's Northern territories face numerous challenges in the development and generation of energy. The harsh Northern climate, geographically dispersed population, and lack of electrical grids have contributed to a unique pattern of energy use in the North which is notably different than the rest of Canada. This unique environment has resulted in electricity costs that are approximately ten times higher than that of the Canadian average. The North is highly dependent on imported oil for the majority of its electricity generation. This in turn has led to a staggering level of greenhouse gas emissions or GHG which has had a serious impact on the Northern climate, with Northern temperatures becoming warmer at a rate five times that of the global average. The staggering level of GHG emissions, the high cost of electricity as well as the accelerating warming trends in the Northern climate serve as evidence for a dire need of change in policy.

A key to the long term development of reliable and sustainable supply of energy in the North is the re-evaluation of old and less efficient current methods of power generation, while investigating the advantages of newer and more efficient technologies. This leads to the consideration of the public policy question of alternative methods of electricity generation such as the utilization of Small Modular Reactors (SMRs). The characteristics of the modular design of SMRs demonstrate the feasibility of utilization of SMRs to meet electricity needs in the North given the hindering geography and climate of the region. The modular concept of SMRs allow for greater simplicity in design, shorter construction periods, and a smaller plant footprint while

emitting zero GHG emissions. The modular design of SMRs also incorporates operational flexibility which permits local grids to be built in a capacity which matches local electricity demand. While, there are significant benefits to the utilization of SMRs for electricity generation, potential challenges must also be recognized. These challenges include public fear of nuclear energy, licensability of SMRs, and the lack of skilled human resources in the North, among others.

This capstone investigates the potential for utilization of SMRs in the North, focusing on the Northwest Territories in particular as a case study. It then investigates two alternative plans for potential use of SMRs in the NWT. Plan One assumes the continuation of the same mix source in power generation as 2010 to meet projected electricity demand between 2010 and 2030. Plan Two assumes the utilization of SMRs for additional projected future electricity needs, while keeping the existing power generation plants. Greenhouse gas emission levels and estimated investment costs are calculated for both plans. If the government of the NWT pursues Plan Two as opposed to Plan One, it would be able to reduce GHG emissions levels by 1093.3 kT in the year 2030, an equivalent of taking 227,146 cars off the road. Although the estimated investment cost of Plan Two is 62.5 percent greater than that of Plan One, due to the numerous advantages of utilization of SMRs in the NWT, a gradual shift in public policy to include the SMRs in the mix source is highly recommended.

Section 1: Electricity in Canada

1.1 Electricity Generation and Consumption in Canada

Energy use in the Canadian North, which includes the Northwest Territories, significantly differs in comparison to the rest of the country. Fossil fuels provide the majority of energy consumption in the NWT, where over 67 percent of electricity generation for both industries and communities is diesel based. Characteristics such as the harsh Northern environment, lack of an interconnected grid, geography, and a dispersed population serve as barriers for power generation in the NWT and have contributed in high energy and electricity costs. Perhaps of more importance, however, is the staggering level of greenhouse gas emissions as a result of the current use of fossil fuels. The continuation of the current source mix to meet projected growth in electricity demand due to population growth will not only face cost and feasibility challenges given the characteristic barriers of the NWT, but also result in adverse environmental impact. The aim of this study is to consider a potential policy shift towards the use of Small Modular Reactors (SMRs) for electricity generation in remote rural areas within the Northwest Territories.

Energy consumption, electricity generation, source mix for electricity generation, and projected electricity demand for Canada and the Northwest Territories are reviewed in sections 1 and 2 respectively. A brief overview of SMRs is presented in section 3. Section 4 investigates the potential utilization of SMRs in the NWTs by providing a legal/regulatory, logistic, and commercial viability framework. Policy implications conclude this capstone.

1.1.1 Background

The prosperity of a nation, among other things, is reliant on access to affordable and reliable energy which can contribute to greater social and economic development. In particular, electricity, a basic necessity, is a major contributor to greater quality of life. There are numerous applications in which electricity is used by humans as a source of energy. Electricity can be vastly used in residential, commercial and industrial sectors for activities such as heating, lighting, and power for industrial machinery. Electricity is often generated by electromechanical generators: kinetic energy from flowing water and wind, energy from natural gas turbines, movement of steam produced through water boiled by nuclear fission or fuel combustion, as well as energy produced by solar photovoltaic cells are among the various sources which propel electromechanical generators. The generated electricity is then transported to points of consumption through a copper wire where its conversion into usable energy takes place (NRCan a 2012, 1).

Electricity production can be classified as primary energy and secondary energy based upon the sources used in its generation. Renewable and nuclear sources are considered primary energy due to the fact that they are derived directly from natural resources. Renewable resources can be subdivided into hydro and non-hydro renewable resources (National Energy Board 2012, 2). The latter consists of wind, biomass, solar, wave and tidal power. Fossil fuels based electricity is considered to be secondary energy because it is produced from primary energy sources such as coal, natural gas and oil (NRCan a 2012, 2). In 2010, world electricity generation, consisting of both primary and secondary energy, was 21,431.5 TWh (1 TWh is equal to 1 billion kilowatt hours (KWh). 1 KWh is equivalent to having a 100-watts light bulb on for 10 hours). China ranked first in electricity generation in the world. It was then followed by the United States, Japan, with Canada ranking 6th (OECD 2013, 4).

1.1.2 Electricity Generation in the World

World electricity generation has almost quadrupled between 1971 and 2010 from 5,245 TWh to 21,431.5 TWh. While the growth in total primary energy supply between 1971 and 2010 was an annual rate of 2.2 percent, world electricity generation has risen at an average annual rate of 3.7 percent. This increase can be largely explained by the growing use of electrical appliances, electrification of rural areas in developing countries, as well as the expansion of electrical heating in developed countries among other factors. Figure 1.1 shows the trend of world electricity production between the years 1971 and 2009 (OECD 2012, 3).

Fossil fuel based electricity production has gradually decreased from 75 percent in 1971 to 67 percent in 2009. The use of oil for example, has fallen from 20.9 percent to 5.1 percent during those years. Nuclear electricity generation, on the other hand, has increased from 2.1 percent to 17.7 percent between 1971 and 1996. However, this figure has fallen to 13.4 percent by 2010. Natural gas increased from 13.3 percent to 21.4 percent between 1971 and 2009, while the share of hydro-electricity has decreased from 22.9 percent to 16.2 percent. The share of coal has remained stable at approximately 41 percent. New and renewable energies such as geothermal, wind, and solar have seen an increase in OECD (Organization for Economic Cooperation and Development) countries, while accounting for 3.3 percent of total electricity production in the world (OECD 2013, 4).

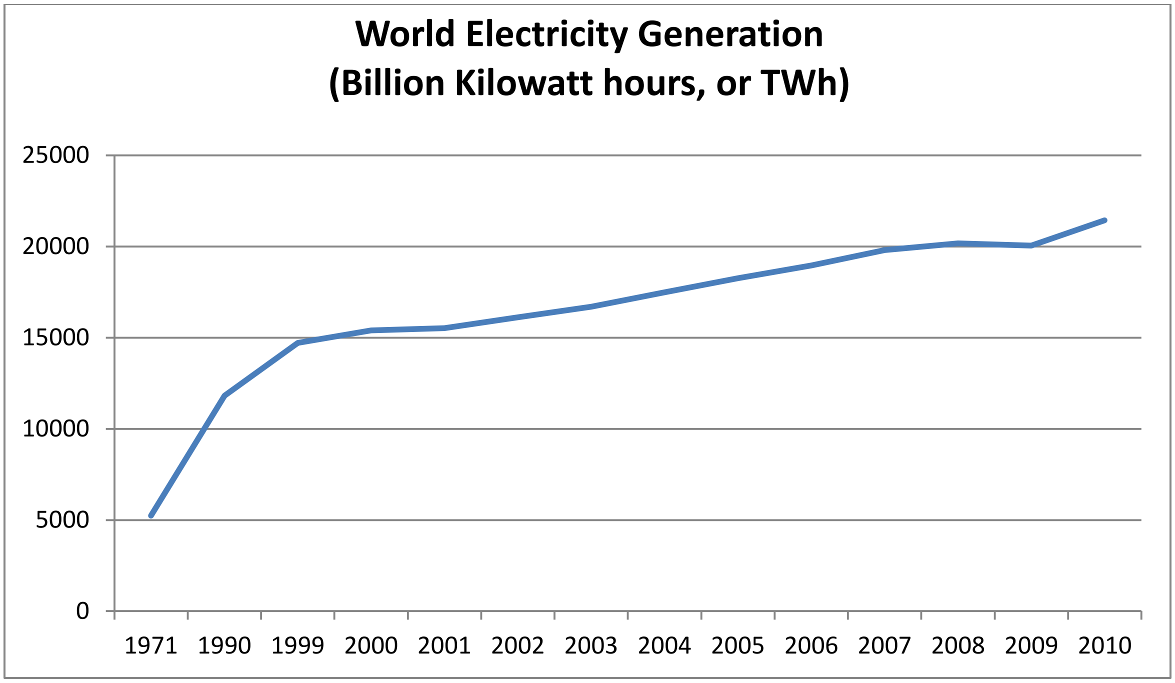

Figure 1.1: World electricity generation
Data Source: OECD Factbook 2011: Economic, Environmental and Social Statistics - ISBN 978-92-64-11150-9

1.1.3 Electricity Generation in Canada

In order to meet the increasing demand as a result of population growth and change in lifestyle, electricity generation in Canada has increased over the past decades. In 1990, with a population of 27.69 million, electricity generation totaled 467 billion kilowatt hours (Statistics Canada 2012 b). In 2010, electricity generation increased to 589 billion kilowatt hours, while the population reached over 34 million (Statistics Canada 2012 b). This shows an increase of 26.12 percent in electricity generation and a growth rate of 22.78 percent in the Canadian population in the past two decades.

Figure 1.2 is a simple bar graph showing the levels of electricity generation in Canada from the year 2003 to 2012 (NRCan a 2012, 2).

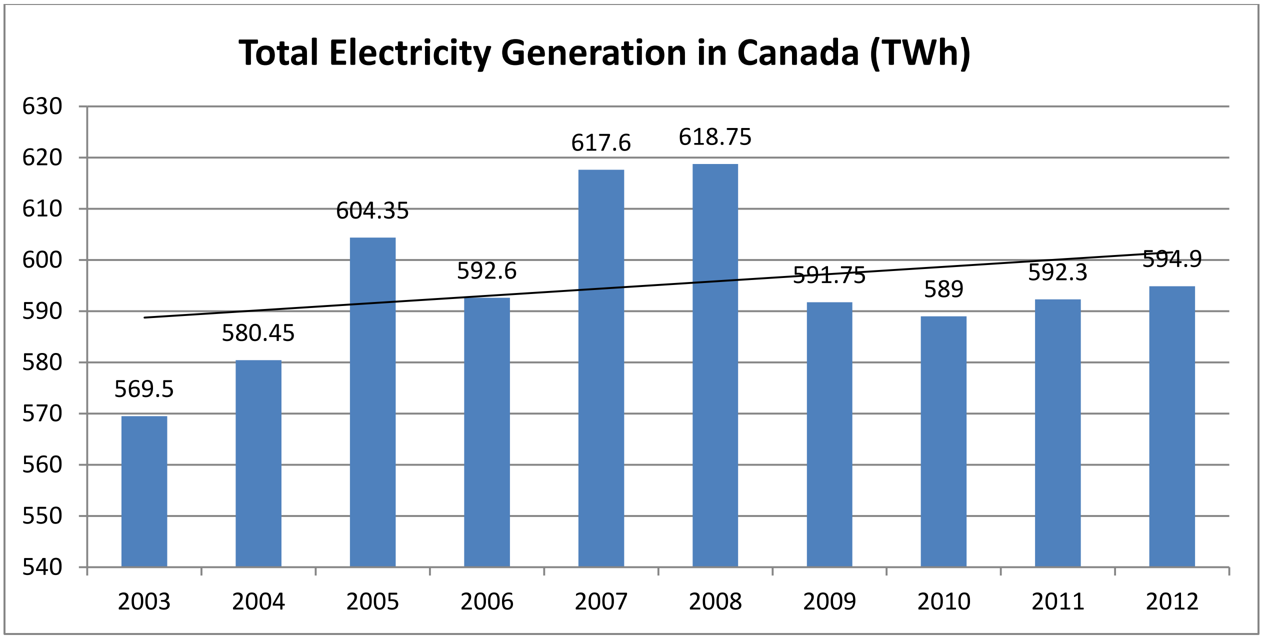

Figure 1.2: Electricity generation in Canada in terawatt hours.
Data Source: Statistics Canada 2012 a, 123.

As seen in Figure 1.2, the difference in the bar heights between 2003 and 2008 indicates a steady growth from 569.5 TWh to 618.75 TWh respectively. There was a significant decline in total electricity generation in Canada between 2008 and 2009, demonstrating the impact of the global recession on the Canadian economy. The Figure also shows a slight increase to 592.3 TWh and 594.9 TWh in 2011 and 2012 respectively (Canadian Electricity Association 2012, 15) which represents the slow post-recession recovery.

1.1.4 Electricity Source Mix in Canada

Canada possesses one of the cleanest electricity generating systems in the world, with three-quarters of Canada's electricity supply emitting no greenhouse gases or GHGs (Environment Canada 2012, 1). Electricity in Canada is generated through a diversified portfolio of sources. The largest share in the portfolio belongs to moving water which generates 59 percent of electricity supply. Hydro power is very flexible as the power generation can be adjusted quickly in accordance with demand and is also not impacted by the fluctuation of fuel costs. In fact, Canada is the third largest producer of hydroelectricity in the world with over 348 TWh in 2010. Quebec serves as the primary location for hydroelectricity power plants followed by British Columbia, Labrador, and Manitoba (NRCan a 2012, 2).

The second significant source of electricity in Canada is fossil fuels. Coal accounts for 12 percent of electricity generation, natural gas for 8 percent, and petroleum generates 1 percent. Fossil fuel based electricity generation is of particular importance in Alberta and Saskatchewan given the vast abundance of coal and oil resources. The Atlantic Provinces, as well as the Northwest Territories and Nunavut are among the other provinces which are heavily reliant on coal fired generation (NRCan a 2012, 2).

The third significant source of electricity production in Canada is nuclear power, which represents approximately 15 percent of electricity supply. All 22 existing nuclear reactors are Canadian designed and built CANDU reactors. These reactors are mainly located in Ontario which has 20 reactors, while New Brunswick and Quebec each have one reactor (NRCan a 2012, 3).

Solar power has become an emerging source of electricity generation over the past several years. Non-hydro renewable sources currently account for a small percentage of electricity supply, generating 3 percent. Wind and biomass account for the remaining 2 percent (NRCan a 2012, p.3). Figure 1.3 is graphic representation of these statistics.

In general, the Canadian electricity sector is responsible for approximately 17 percent of the total greenhouse gas emissions in Canada, 76 percent of which is generated from coal fired units. There has been an attempt to gradually eliminate the use of traditional coal units in order to reduce emission from coal based electricity generation (Environment Canada 2012, 2).

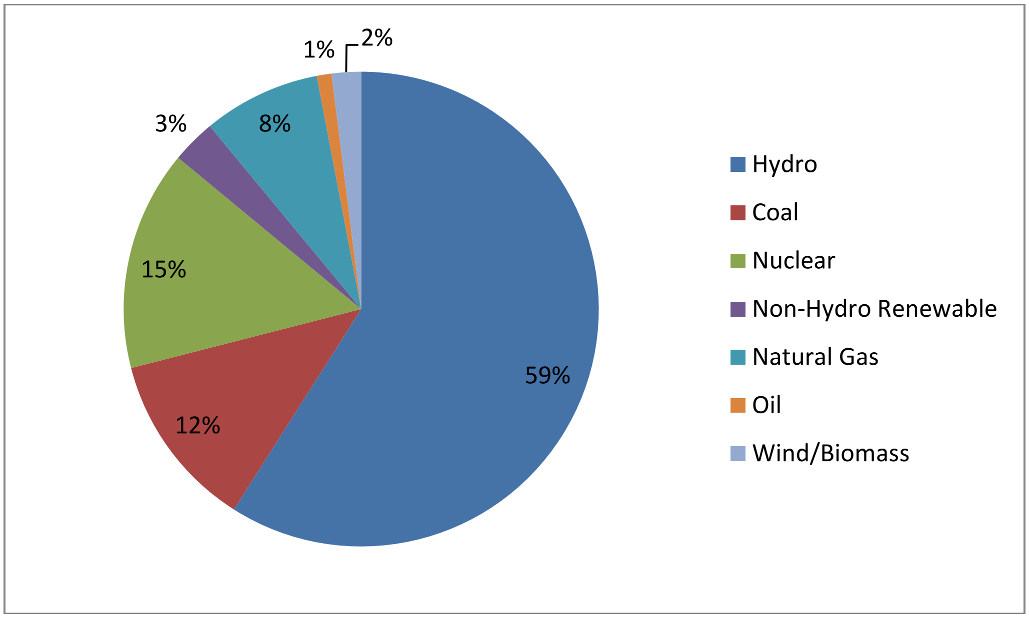

Figure 1.3: Electricity supply mix for total electricity generation in 2010
Data source: NRCan 2013, 3

A study carried out by the National Energy Board of Canada projects the electricity supply mix for 2035 as shown in Figure 1.4. The projected changes in the generation mix show the attempt of the government and industry to reduce energy related green-house gas emission (GHG), and includes provincial energy strategies, utility expansion plans, as well as economics of generation options. It is also projected that the share of non-greenhouse gas emitting generating sources will increase to 79 percent in 2035. A brief comparison of the electricity supply mix in 2010 and the projection for 2035 is presented in Table 1.1. It is important to note that the share of renewable based electricity generation which includes hydro, biomass and wind, is projected to increase from 62 percent in 2010 to 68 percent in 2035. There is also a significant reduction of coal based generation of electricity from 14 percent in 2010 to a mere 6 percent in the projection for 2035 (National Energy Board 2012, 1). It is noticeable that the statistics reported in 2010 in the National Energy Board (2012) used Table 1.1 shows minor discrepancies with the 2010 statistics reported by Natural Resources Canada (NRCan) as used in Figure 1.3.

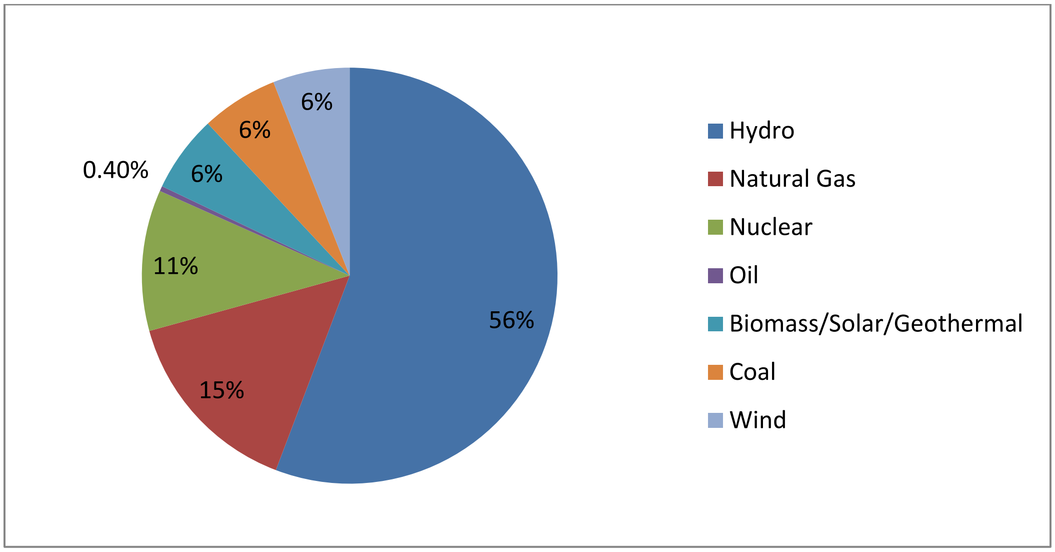

Figure 1.4: Projection for the electricity supply mix for total electricity generation in 2035
Data Source: National Energy Board 2012, 2.

Table 1.1: Electricity supply mix for electricity generation in Canada for 2010, and a projection for 2035

	2010	**2035 (projection)**
Hydro	59%	56%
Coal	14%	~6%
Nuclear	14%	11%
Gas	9%	15%
Wind & Biomass	3%	12%
Oil	1%	0.4%

Figure 1.5 illustrates electricity generation in Canadian Provinces and Territories in 2010. As shown in Figure 1.5, total electricity generation in 2010 was significantly greater in the four most populated Canadian provinces in comparison to the rest of Canada. As discussed below, the same trend is observed in total electricity demand in Canada as well.

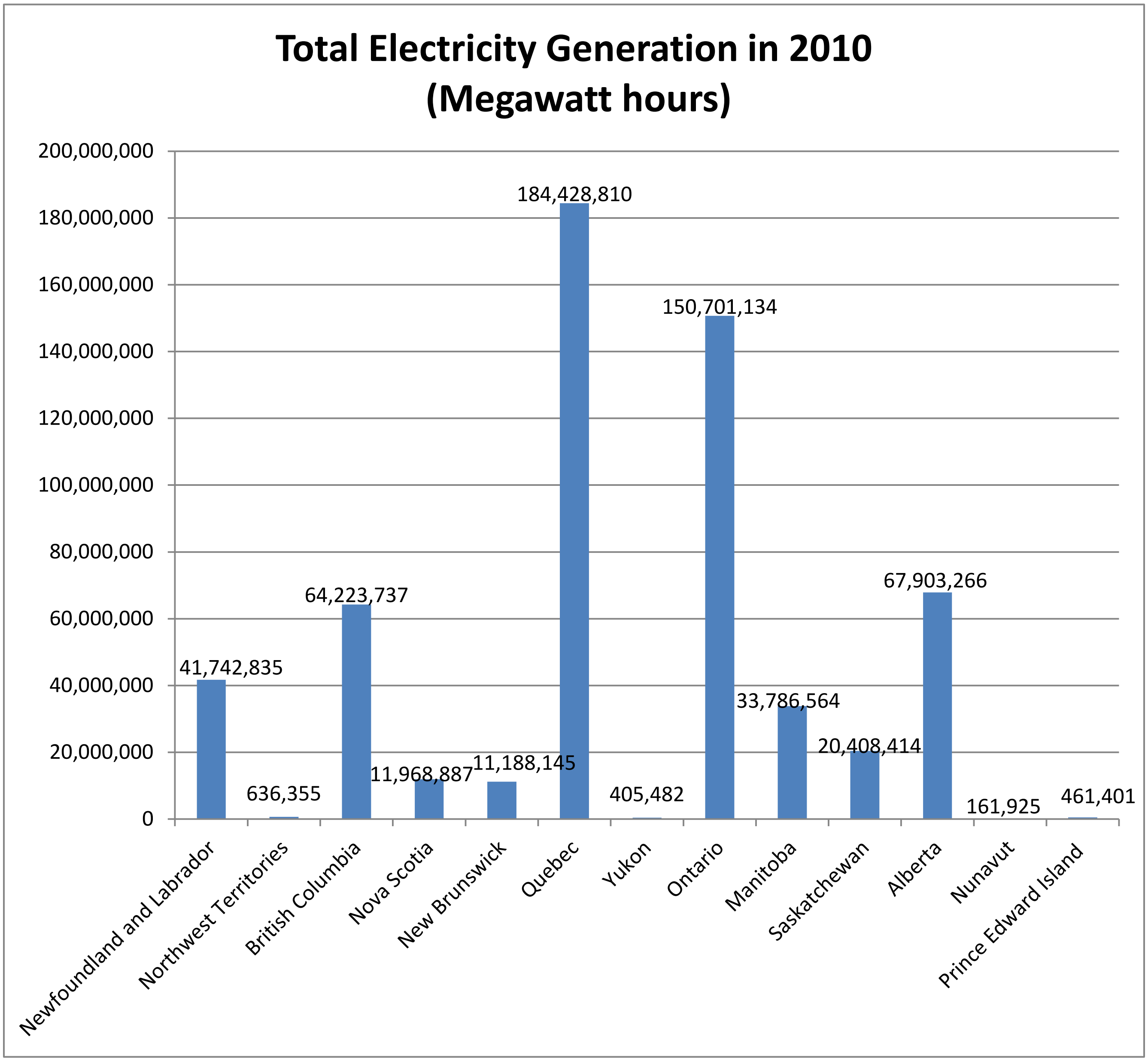

Figure 1.5: Total Electricity Generation in Provinces and Territories in Canada in 2010
Data Source: Statistics Canada. *Table127-0007 - Electric power generation, by class of electricity producer, annual (megawatt hour),* CANSIM (database).

1.1.5 Electricity Consumption in Canada

In parallel to the study of power generation in Canada, the trend of variation in domestic demand of electricity in Canada is to be considered. Electricity demand has increased at an annual rate of 1.2 percent since 1990. The growth in electricity demand can be attributed to a number of factors such as population growth, economic prosperity, increase in the use of electrical appliance, as well as technological advancements (NRCan a 2012, 4). Weather also has a volatile impact on electricity demand, with harsher winters and warmer summers resulting in an increase in demand, while milder winters and cooler summers reduce demand.

Electricity demand in 2010 amounted to approximately 497.5 billion kilowatt hours (TWh). The residential and commercial sectors consume a significant quantity of about 60 percent of the final electricity demand. On the other hand, the industrial sector is responsible for the largest share of electricity demand, an estimated 39 percent. Energy intensive industries such as the mining and manufacturing sectors are the source of the excessive energy demand in the industrial sector (NRCan a 2012, 4). Total electricity demand in Canada in 2011 was 518.9 TWh (Canadian Electricity Association 2012, 12).

The four largest populated provinces in Canada namely Ontario, Quebec, British Columbia and Alberta, also happen to be the largest power consumers. It is expected that Canadian electricity demand will grow at an annual rate of 1 percent between 2010 and 2035. A large portion of this projection for growth in demand would belong to the industrial sector, where demand is expected to grow at a rate of 1.3 percent (NRCan a 2012, 6).

Section 1.1 considered Canadian power generation, consumption, and source mix for electricity generation in order to provide a general overview of existing policies in Canada as a nation. As the main focus of this capstone is the NWT, in the next section, electricity generation, source mix, demand, and the corresponding forecasts for the NWT are presented.

Section 2: Electricity in the Northwest Territories (NWT)

2.1 Introduction

This section focuses on the current and projected electricity generation and demand in the Northwest Territories. A brief review of the geographic, history, population and its distribution among the communities are reviewed in order to establish necessary information for the analysis presented in the next section to evaluate potential utilization of Small Modular Reactors (SMRs) for power generation in the NWT.

Inuit and First Nations peoples inhabited the Northwest Territories for thousands of years. The first European explorers sailed to the Eastern Arctic in 1000 AD. By the 1700s, two fur-trading companies: the Hudson's Bay company, as well as the North West Company, dominated the Northwest Territories (Canadian Heritage 2013). In 1870, the control of the North-Western Territories was transferred by the British government to Canada. In addition, the Hudson's Bay Company sold Rupert's Land to the new Dominion. The combined areas was then renamed the Northwest Territories. Interestingly, the Northwest Territories included all of Alberta, Yukon, Saskatchewan, and most of Quebec, Ontario, as well as Manitoba at some point in its history. In 1870, the province of Manitoba was created from the area. Alberta and Saskatchewan were made into separate provinces in 1905. In 1898, Yukon became a separate territory (Canadian Heritage 2013). The provinces of Quebec, Ontario, and Manitoba increased in size by acquiring land from the Territories in 1912. In 1999, the Northwest Territories was divided in two and 60 percent of the land was transferred to the new territory of Nunavut in Canada's Eastern Arctic (Canadian Heritage 2013).

As of April 2013, the population of the Northwest Territories was estimated to be 43,340 dispersed over 1.2 million square kilometers. The map below, Figure 2.1, illustrates the communities within the Northwest Territories (NWT BoS 2013). One important factor to consider in any infrastructure plan for the Northwest Territories is the disperse distribution of population over a very large area. Table 2.1 records the population of all communities within the Northwest Territories.

Figure 2.1: Map of communities in the Northwest Territories
Source: NWT BoS 2013

Table 2.1: Population in the NWT communities

Community	Population
Aklavik	628
Behchoko	2,174
Colville Lake	157
Deline	559
Dettah	260
Enterprise	118
Ford Liard	568
Fort Good Hope	559
Fort McPherson	808
Fort Providence	788
Fort Resolution	497
Fort Simpson	1,251
Fort Smith	2,450
Gameti	320
Hay River	3,601
Hay River Reserve	341
Inuvik	3,321
Jean Marie River	71
Kakisa	54
Lutselke	292
Nahanni Butte	104
Norman Wells	838
Paulatuk	329
Sachs Harbour	127
Trout Lake	100
Tsiigehtchic	128
Tuktoyaktuk	954
Tulita	567
Ulukhaktok	479
Wekweeti	141
Whati	519
Wrigley	123
Yellowknife	19,752
Total	**43,340**

Data source: GNWT 2011 a, 7

2.2 Energy Consumption in the NWT

The use of energy in the Canadian North, which includes the Northwest Territories (NWT), is notably different in comparison to the rest of the country. Residents of the NWT face increased limitations due to varying factors. Climate, dispersed population, and geography are amongst the factors which create a unique energy use pattern. Energy costs such as electricity and home heating costs are significantly higher in Northern Canada in comparison to the southern provinces, and contribute to the high cost of living in the North. Indeed, the cost of electricity, measured on a per kilowatt-hour basis, in some Northern communities can be ten times higher or more, than that of the Canadian average (National Energy Board 2011, 2).

Government/institutions in the NWT are responsible for a very high share of fuel use in the commercial sector, while the industrial sector accounts for a low share. Industrial operations such as the opening and closure of large facilities which are often very scattered across the North, impact highly on the industrial demand and pattern of energy use. Transportation of fuel is among one of the unique characteristics of the NWT energy use. Almost all fuel used in the NWT is imported from southern provinces (National Energy Board 2011, 2). A large portion of the imported fuel is propane or fuel oil which is used for heating, as well as diesel fuel which is used for electricity generation and transportation. Many of the Northern communities are only accessible by small planes, while many have limited highways and roads. The harsh Northern environment and the geography of the NWT such as long distances, also serve as determining factors in energy use as they place limitation on the timeline for the transportation of fuel (National Energy Boar 2011, 2). These characteristic barriers are to be considered in the evaluation of any proposal for power generation in the NWT as presented in section four.

Average energy consumption in the NWT is nearly double that of the Canadian average on a per capita basis. The total amount of energy consumed in the NWT in 2009-10 was approximately 18.7 million Gigajoules. Figure 2.2 shows the distribution of energy use among different sectors in the NWT (GNWT 2011 a, 5). Energy use outside of communities by mines, oil and gas development as well as exploration camps are included in the industrial sector. Electrical generation and space heating consumption are measured within communities. Transportation consists of on-road and off-road transportation as well as aviation fuel (GNWT 2012 a, 3). As seen in Figure 2.2, a large portion of energy use is contributed to industry (37 percent), while electrical generation only accounts for 10 percent of total energy use. These numbers are reflective of the energy intensive nature of the resource based NWT economy.

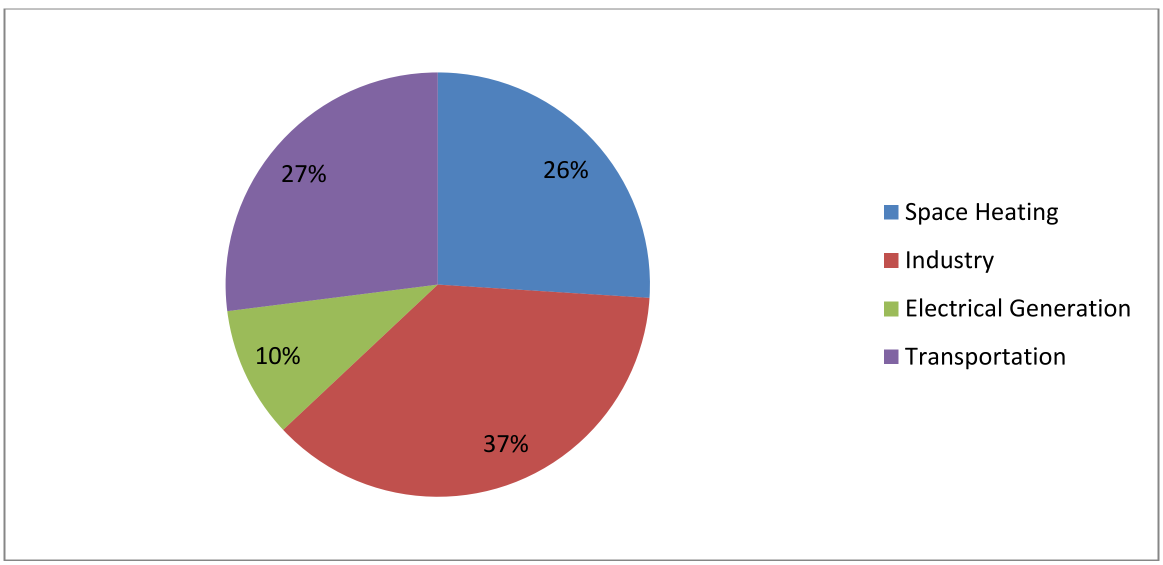

Figure 2.2: Total amount of energy use in 2010
Data Source: GNWT 2012 a, 3

2.3 The Electricity Market in the NWT

The total electricity generation in the NWT was approximately 0.7 billion kilowatt hours in 2010 (CCEI 2013), thereby representing 0.12 percent of Canadian electricity generation. Unlike Southern Canada, there is no transmission grid between most communities in the NWT, nor between the NWT and other jurisdictions. This limits the ability to transfer electricity from one location to another (GNWT 2008, 4). Annual electricity generation in the NWT between 2001 and 2010 amounted to 0.5 billion kilowatt hours (TWh) and 0.7 TWh respectively, which signifies a 24 percent increase (GNWT 2011, 8). Industrial diesel-based generation is responsible for a large share of this percentage.

The NWT is reliant on three main energy sources in order to generate electricity which includes natural gas, hydro resources, as well as diesel fuel. Hydroelectric generation is responsible for electricity generation in eight communities in the Great Slave Lake area. Natural gas-fired power plants, on the other hand, are used in the communities of Inuvik and Norman Wells. Diesel-fired power plants provide electricity for the remaining 23 communities (GNWT 2011 a, 7). Table 2.2 is a record of the location of installations of power plants, their capacities, power sources, as well as corresponding suppliers within the NWT. The provided data is beneficial in the visualization of the distribution of existing power plants in the NWT which in turn assists in the process of evaluation of alternative methods of power generation.

Table 2.2: Electricity Generation in the NWT

Supplier	Source Mix	Installation	Capacity(Megawatt)
Northwest Territories Corporation	Natural Gas	Norman Wells	14.50
	Diesel	Aklavik	1.58
		Colville Lake	0.24
		Deline	1.15
		Fort Good Hope	1.23
		Fort Liard	1.32
		Fort McPherson	1.83
		Fort Simpson	3.21
		Gameti	0.61
		Inuvik	10.90
		Jean Marie River	0.23
		Lutselke	0.82
		Nahanni Butte	0.25
		Paulatuk	0.82
		Sachs Harbour	0.80
		Tssigehtchic	0.50
		Tukoyaktuk	2.21
		Tulita	1.10
		Ulukhaktok	1.16
		Wha Ti	0.98
		Wrigley	0.76
Northland Utilities Ltd.	Diesel	Fort Providence	1.48
		Kakisa	0.30
		Wekweeti	0.38
		Trout Lake	0.33
Mines	Diesel	Diavaik	8.60
		Ekati	11.40
		Gahcho Kue	8.80
		Snap Lake	14.50
Northwest Territories Power Corporation	Hydro	Snare Rapids	8.50
		Snare Falls	7.50
		Snare Cascades	4.30
		Snare Forks	9.00
		Yellowknife River	7.50
		Taltson	18.00

Data source: NWT Energy Facts 2012, 2

There are three suppliers of electricity generation in the NWT which include Imperial Oil (IOL), Northwest Territories Power Corporation (NTPC), and Northland Utilities Limited (NUL) (NWT Energy Facts 2012, 1). These three separate utilities have varying sources for electricity supply mix and distribution operations. NTPC is a government of the Northwest Territories Crown Corporation. Twenty-one isolated diesel plants as well as six hydro plants provide electricity to 27 communities. Imperial Oil, meanwhile, sells natural gas-based electricity to NTPC for distribution in Norman Wells. And finally, the NUL consists of two companies, one of which includes the Northland Utilities (Yellowknife) Ltd which is responsible for the distribution of electricity in the form of hydroelectric power in Yellowknife. Northland Utilities (NWT) Ltd., on the other hand, generates hydroelectric power in four communities in the South Slave and distributes diesel-based electricity in four isolated communities (NWT Energy Facts 2012, 1).

Natural Resources Canada has estimated that over 300 isolated communities across Canada are reliant on diesel-based electricity generation, of which almost half are in the Canadian North. Nunavut, for example, is 100 percent reliant on diesel generated electricity (National Energy Board 2011, 1). Figure 2.3 shows the location of renewable and non-infrastructure across the NWT. Thermal electricity facilities generate power using several different forms of fuels including natural gas, oil/diesel, coal, and biomass. There are 32 diesel-based generating facilities in the Northwest Territories, with a total capacity of 74.3 Megawatts (CCEI 2013). There are also two natural gas-based facilities with a combined capacity of 22.2 Megawatts. The NWT possesses six hydroelectric generating stations with a total capacity of 54.95 Megawatts. While, hydropower is one of the major energy sources in the NWT, less than 0.5 percent from a potential of 12,000 Megawatts has been developed. Three natural gas producing fields exist in the NWT, with a combined production of 15.9 million cubic feet per day. There are also two fields which produce oil in the NWT with a total combined production of 10,493 barrels per day (CCEI 2013).

Supply sources for power generation in the Northwest Territories differ for community and industrial usage generation. As for the community generation in 2010, as shown in Figure 2.4, hydro generation accounts for 74 percent, followed by 17 percent of diesel and 9 percent of natural gas. On the other hand, as seen in Figure 2.5, when the industrial generation is included, then the electricity generation is heavily based on diesel with 50 percent, followed by 32 percent by hydro-power, and 18 percent by natural gas (NWT Energy Facts 2012, 1).

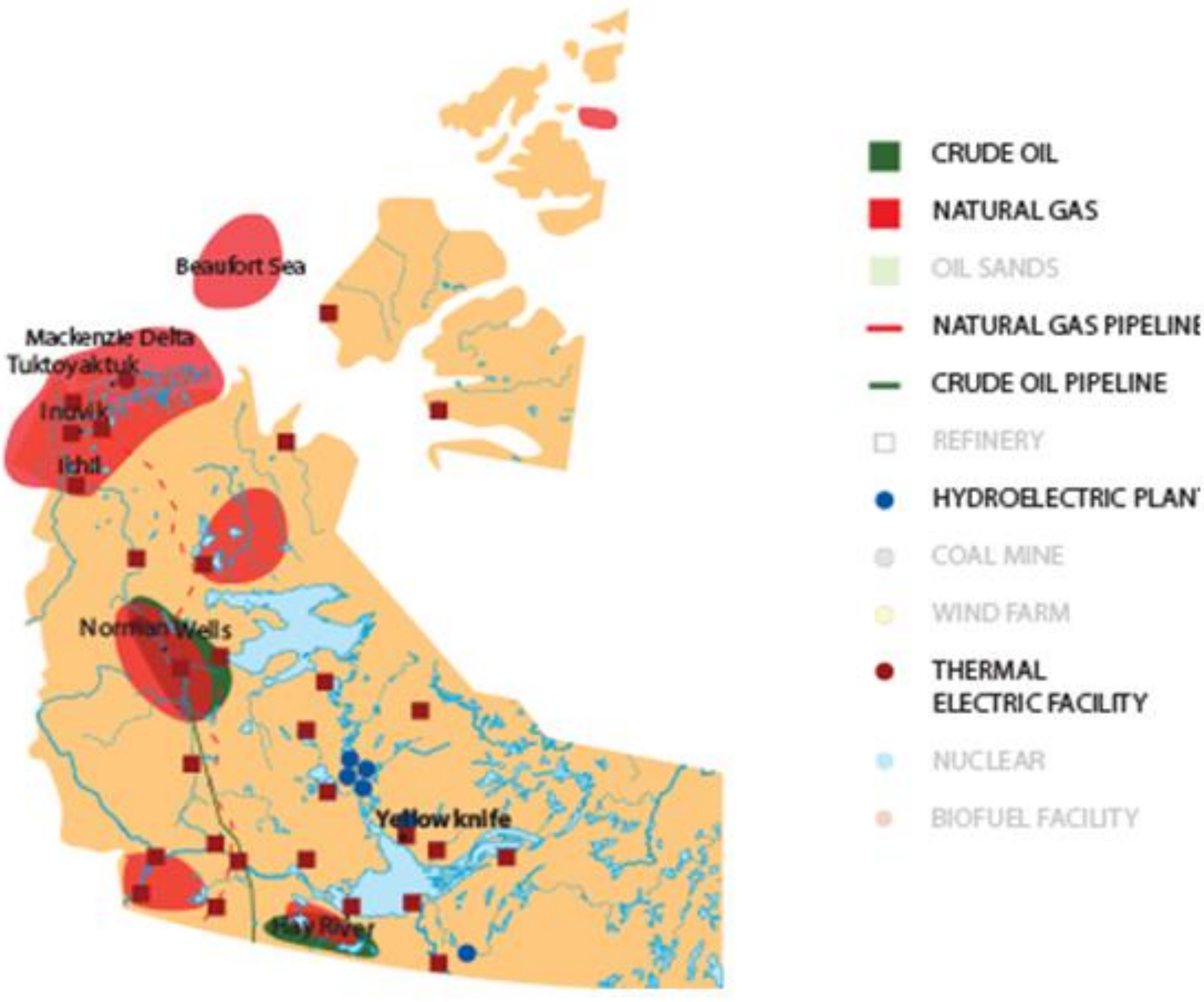

Figure 2.3: Location of Renewable & Non-Renewable Resources and Infrastructure
Source: CCEI 2013

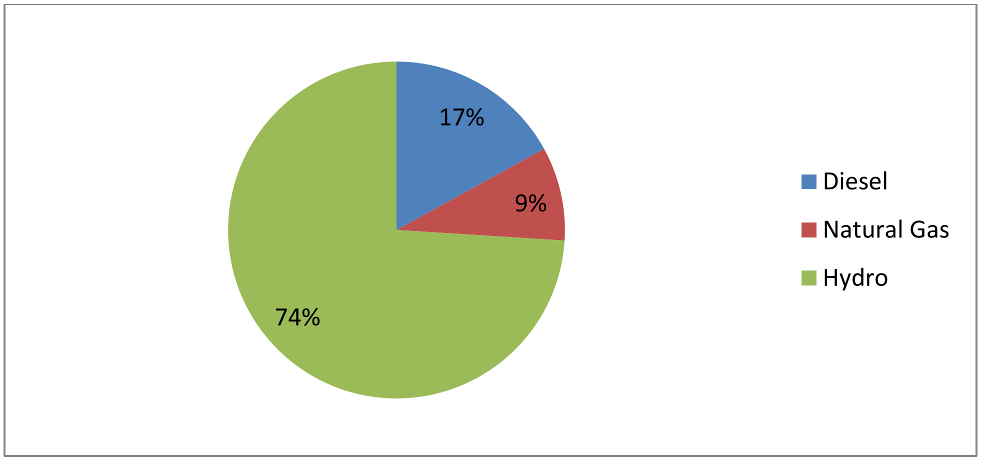

Figure 2.4: Electricity source mix for <u>community</u> electricity generation 2010
Source for Data: NWT Energy Facts 2012, 1

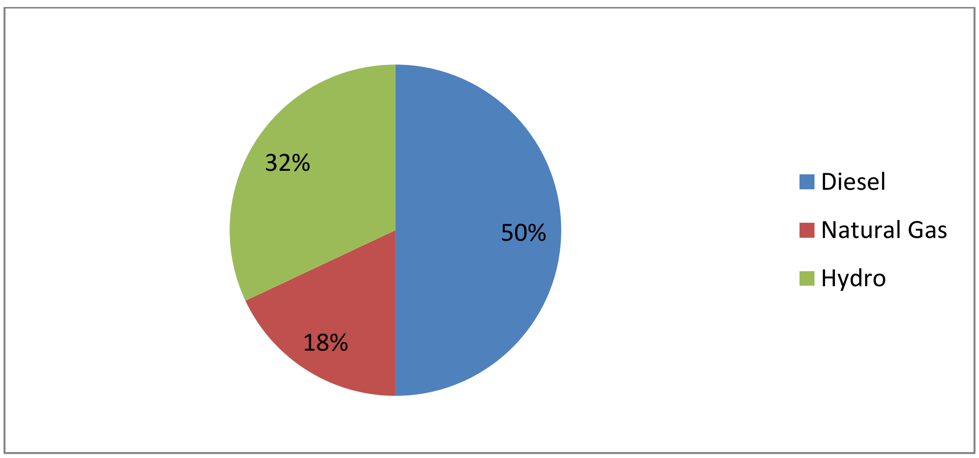

Figure 2.5: Electricity source mix for <u>industry</u> electricity generation 2010
Source for Data: NWT Energy Facts 2012, 1

It is interesting to note that when only the diesel-based electricity generation is considered, 85 percent is allotted to industrial consumption, while the remaining 15 percent belongs to utility for household consumption (GNWT 2011 a, 7). This distribution has been illustrated in Figure 2.6.

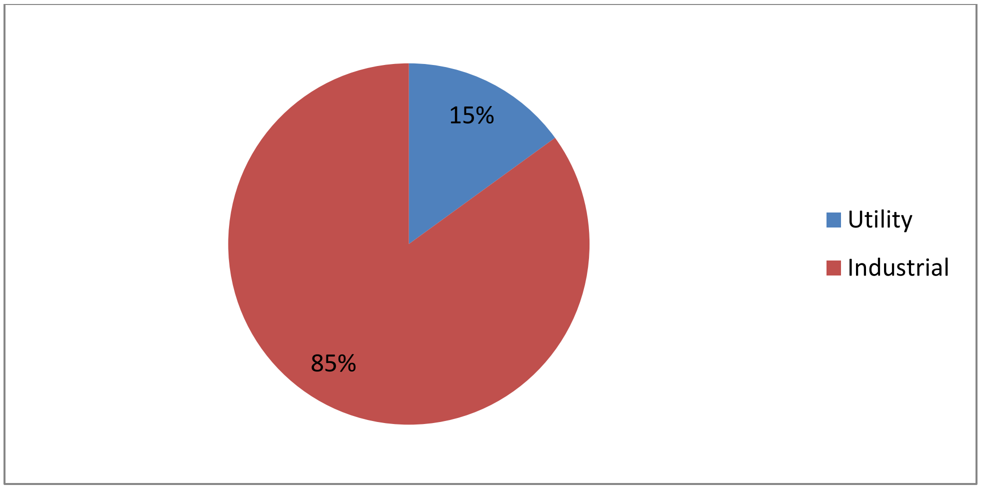

Figure 2.6: Diesel-based electricity generation in 2010
Source for Data: GNWT 2011 a, 7

Considering total electricity generation for both industrial and commercial usage in the NWT in 2010 indicates a mix source of 35 percent of hydro based and 65 percent of thermal (diesel/natural gas/oil) based electricity generation (NWT Energy Facts 2012, 1).

2.4 Greenhouse Gas Emissions in the NWT

Fossil fuel provides the backbone of energy consumption in the Northwest Territories. In 2009/10, 383 million liters of gasoline, propane and diesel were sold in the NWT, of which approximately 121 million liters were utilized for electricity production while 141 million liters were used for transportation (GNWT 2011 a, 5). The high use of fossil fuels due to the geography of the NWT and harsh Northern environment has in turn resulted in higher per capita greenhouse gas emissions. The greenhouse gas emissions in the NWT differ on an annual basis dependent on activities such as off-road diesel for construction projects, and aviation fuel for exploration activities. The government of the NWT has prepared forecasts which point to an increase in emissions as a result of new mines and oil/gas production in lieu of the development of new sources of local renewable energy (GNWT 2011 a, 5). Greenhouse gas emissions in 2010 were estimated to be 1,325 kilo-tonnes (kT). This figure is approximately equal to 27.9 tonnes of emission per person, higher than the national average of 21.7 tonnes per person annually (GNWT 2012 a, 3). Figure 2.7 demonstrates the distribution of emission from various sources in 2010 within the NWT. As seen, electrical generation is responsible for the largest percentage of greenhouse gas emissions, at almost 477 kT of CO_2 equivalents. Space heating and transportation contribute 411 kT and 398 kT of CO_2 equivalents respectively.

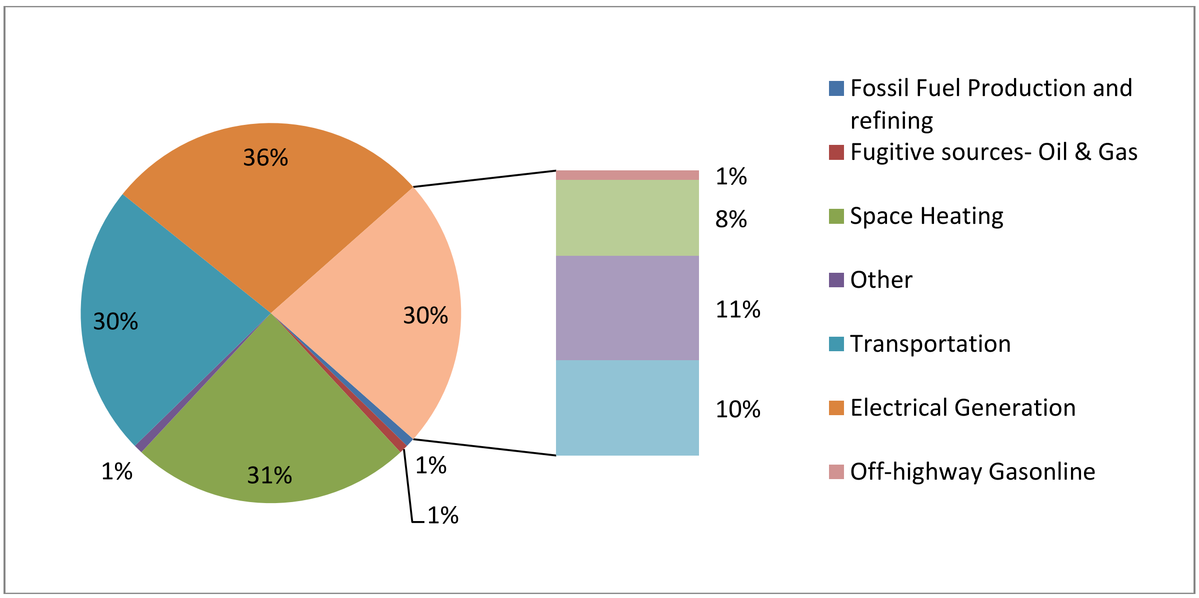

Figure 2.7: Greenhouse gas emissions in the NWT in 2010
Source: GNWT 2012 a, 4

The high level of per capita greenhouse gas emissions is a determinant factor in the process of investigating alternative methods of electricity generation, which is in the interest of this capstone.

2.5 Projection for Future Electricity Generation in the NWT

Proposals for alternative methods of power generation must consider the projection of future population growth as well as corresponding electricity demand. In a study carried out in 2011 by Bataille *et al.* of MK Jaccard and Associates Inc. for the government of the Northwest Territories, projections for the population, gross domestic product (GDP), and number of households leading up to 2030 were estimated. The study notes that the projections between 2010 to 2020 have more concrete and project based assumptions. The projections for 2020 to 2030, on the other hand, are based upon historical reflections and anticipated trends but using a more generalized forecast techniques (Bataille *et al.* 2011, 4). These projections are presented in Table 2.3.

Table 2.3: Projections for Population, GDP, and Number of Households

	2010	**2015**	**2020**	**2025**	**2030**
Population (thousands of people)	43.7	45.3	45.6	47.5	48.2
GDP (basis 2005 prices)	3,692	4,193	5,563	6,253	7,099
Number of Households(thousands)	14.6	15.5	16.2	16.8	17.2

Data Source: Bataillie *et al.* 2011, 4

As seen in Table 2.3, population of the NWT is estimated to grow 10.3 percent between the years 2010 to 2030, while the number of households is anticipated to increase 17.6 percent. Gross domestic product will increase 92.3 percent, with the commercial sector expected to expand in response.

Electricity demand is projected to almost triple between 2010 and 2030, thereby creating a need for the expansion of generation capacity in the NWT. Figure 2.8 shows the forecast of electricity generation by source mix. Electricity generation was 0.7 TWh in 2010, while it is projected to be an estimated 0.95 TWh in 2020 which anticipates a 35 percent growth rate. The study further predicts a substantial increase of a staggering 250 percent in the electricity generation between 2010 and 2030 (Bataillie *et al*. 2011, 9). It is important to point out that a recent study by the Conference Board of Canada has estimated the installation of only a total of 10 MW of hydro-based power plants for the same period of 2010-2030 (Crawford *et al.* 2012, 10). This approximation is very far from the estimated future needs as discussed above. Despite the fact that this huge discrepancy would impact the capital investment to meet the projected future demands in electricity in the NWT, the main focus of this capstone is an investigation of the feasibility and need for a shift in the mix source of power generation.

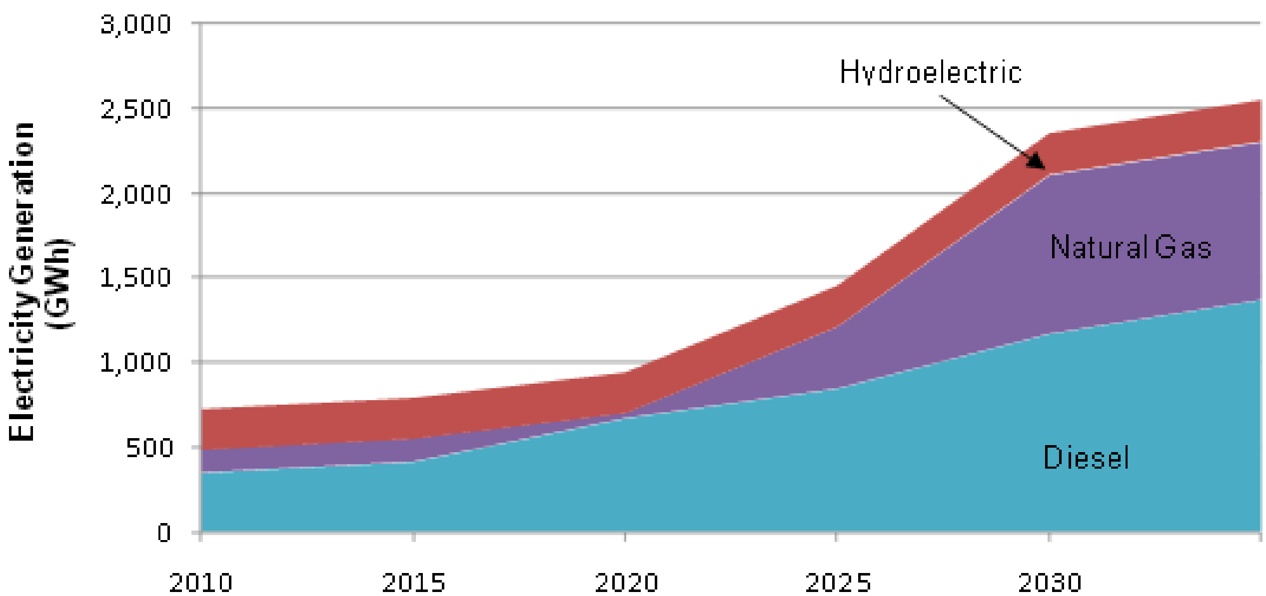

Figure 2.8: Electricity generation by source mix between 2010 and 2030
Source: Bataillie *et al.* 2011, 10

The projected growth of population, GDP, and electricity demand in the NWT leads to the consideration of the source mixes which shall be utilized. As discussed in this section, the current use of fossil fuels in the NWT produces a staggering level of greenhouse gas emissions. Given the climate, dispersed population, and geography of the NWT, the continuation of the current source mixes for electricity generation may face cost and feasibility challenges as well as worsening greenhouse gas emission levels. This may indicate a need to consider the public policy question of alternative methods of electricity generation such as the utilization of SMRs for which a brief overview is presented in the next section.

Section 3: A General Overview of Small Modular Reactors (SMRs)

3.1 Introduction

The world's electricity demand is anticipated to grow at an annual rate of 2.5 percent until 2030, (Vujic *et al.* 2012, 288), while world population is expected to grow an annual average rate of 0.86 percent (UN 2013, 1). Rapid industrial development as well as population growth is likely to double electricity consumption by 2030. As a result of such projections, numerous nations across the world are engaged in developing diverse energy strategies which include non-fossil based energy, including nuclear energy sources (Vujic *et al*. 2012, 288). Nuclear power generation has been established since the 1950s, with the reactor unit size increasing from 60 MWe (electric power) to more than 1,600 MWe. The high capital costs of large scale reactors generating electric power and the need to provide power for small electricity grids has led to a revival of interest in the development of small reactors.

With respect to the unique characteristics and the smaller scale of electricity demand in the NWT as discussed in the previous section, the newly designed Small Modular Reactors (SMRs) appear to be a good potential alternative for the future electricity demands of the NWT. This section provides a basic overview of SMRs and associated advantages and disadvantages of this method of power generation.

3.2 History and Use of SMRs

The first nuclear power plant to be connected to an electrical grid was utilized in the U.S. military's prototype and training facility in Fort Belvoir, VA with the capacity of 2 MW in 1957. Note that 2 MW is equivalent to almost three months of electricity use of an average Calgary household (The City of Calgary 2013). The installation in Fort Belvoir, VA is regarded as the beginning of the so called first nuclear era (Ingersoll 2009, 590). The second nuclear era also known as the nuclear renaissance began in the mid 1980s in an effort to develop smaller scale reactors with a broader scale of applications. The first international program on the potential benefits of SMRs was carried out by the International Atomic Energy Agency (IAEA) in 1985 for small and medium powered reactors. By 1991, the potential benefits of smaller reactors with a broader scope of applications that included both power production and process heat were explored (Ingersoll 2009, 591). The IAEA definition of SMRs is expressed in terms of the power output of the reactors. According to the IAEA, SMRs are reactors with an equivalent power rating of 300 MWe or less. These modules are physically small, and are transportable from factory to site by rail, barge, or truck (IAEA 2013). In order to place these SMRs with a power rating of 300 MWe in perspective with Canadian power generation, consider that the Calgary Energy Centre has a power rating of 320 MWe (ENMAX 2013), while the Balzac Generation Facilities has a power rating of 120 MWe (CBC 2012). Table 4.1 shows the varying IAEA categories of reactors.

Table 4.1: IAEA categories of reactors

Reactor Size	**Power Rating (MWe)**
Very Small	< 150
Small	150-300
Medium	300-700
Large	>700

Source: Humphries 2012, 3

Currently, nuclear power accounts for approximately 16 percent of the world's energy supply, with more than 15 countries utilizing nuclear power to generate approximately 25 percent or more of their electricity needs (Humphries 2012, 4). In particular, SMRs account for

16.7 percent of the world nuclear electricity production (Kuznetsov 2008, 242). There are 131 SMR units in operation for electricity production worldwide in 26 countries. Furthermore, 14 SMRs are under construction in six countries including Slovakia, Pakistan, India, the Russian Federation, Argentina, and China (IAEA 2013).

3.3 Advantages and Disadvantages of SMRs

Small Modular reactors provide substantial benefits in comparison to large scale reactors. They offer greater simplicity in modular designs, while improvements in transportation allow for shorter construction periods. This leads to smaller plant footprint, resulting in greater safety, security, and reliability (Vujic *et al.* 2012, 289). These small reactors are designed with a high level of inherent safety features in the event of malfunctions, with the modular reactors located deeply underground (IAEA 2013). In fact, a report carried out by a special committee assembled by the American Nuclear Society in 2010 states that many safety provisions which are necessary in large scale reactors are not so in the forthcoming small designs (WNA 2013).

The modular concept of SMRs allows for a high fraction of the plant to be constructed in a controlled factory environment, which is then shipped to the site for final assembly. This reduces schedule uncertainties and the amount of on-site work (Ignersoll 2009, 592). It also results in improved safety, quality control as well as lower operation and maintenance costs in comparison to large scale reactors (Vujic *et al.* 2012, 289). The integral primary system configurations in SMRs increase plant safety by eliminating major accident initiators such as large pipe breaks. Moreover, the simplified designs allow for elimination of unneeded safety features, resulting in a compact design which in turn reduces the plant footprint (Vujic *et al.* 2012, 291).

The small designs allow for ease in transportability and can therefore prove to be advantageous in providing electricity to isolated locations with limited distribution infrastructures and transmission resources (IAEA 2013). Small Modular Reactors are ideal for generating electricity in small regions, with limited financial resources due to the reduced level of investment risk, as well as the lower capital costs required for the construction of these small reactors (Vujic *et al.* 2012, 289). The modular concept of SMRs incorporates operational flexibility and permits local grids to be built in a capacity which matches local electricity demand growth. SMRs are therefore ideal for areas with limited or no electricity grid connections such as the Northwest Territories (IAEA 2013). It is important to mention that SMRs also have zero greenhouse gas emissions and therefore can be used to replace aging fossil plants that cannot meet emission limits or in regions which produce significant per capita levels of greenhouse gas emissions such as the NWT (Humphries 2012, 6).

While SMRs can prove to be advantageous in many areas, there are also technical and institutional challenges associated with these small reactors. Foremost, there is an increasing need for further research and development in the testing of the evolving technological innovation and validation of the engineering designs of SMRs (Vujic *et al.* 2012, 295). Licensing and regulatory uncertainties due to first-of-a-kind engineering structure are seen to be the most significant risk factor, hindering potential investors. The need for clear guidelines and concise requirements in obtaining licenses for these small reactors has been recognized (Ignersoll 2009, 600). Another drawback is the need for eventual disposal of used enriched uranium, as well as the cost of reactor decommissioning (Vujic *et al.* 2012, 295). Many investors deem small scale reactors to not be economically competitive. There is a belief that the move from large scale plants to smaller sized plants will result in a loss of economies of scale (Ingersoll 2009, 601).

The existing negative public perception for nuclear energy in general is a potential roadblock in the deployment of SMRs. The unfortunate event of Fukushima has proven to have left a deep psychological impact on the minds of Canadians. A recent poll reports that 6 out of 10 Canadians believe the Fukushima disaster to be a systematic problem of nuclear power (CNA 2012). It is worthwhile to mention that the SMR design organizations are in communication with the IAEA, which has led to the IAEA's project on SMR Technology Development. This project has identified crucial technical lessons learned from the Fukushima accident to be addressed by SMR designers, interested countries, and stakeholders (IAEA 2013). While these technical lessons learned are common to large scale reactors, it is imperative that they are also addressed in the design of SMRs in order to ease public tension surrounding nuclear energy.

Given the advantages of SMRs as discussed in this section on one hand, and characteristics such as the harsh Northern environment, lack of an interconnected grid, geography, and a dispersed population in the NWT on the other hand, the utilization of SMRs could be a good potential alternative to be considered as an electricity generation method to meet projected future demand. This potential is evaluated and presented in the next section.

Section 4: Investigation into the Potential Utilization of SMRs in Electricity Generation in the NWT

4.1 Introduction

As demonstrated in section 2, there will be a need for new power generation plants in response to the growing electricity demand in the NWT within the next 20 years. This demand brings about the potential need for a shift in public policy towards a mix sources to create cost effective, environment friendly, feasible and customized power plants to fit the specific needs of the NWT. As this capstone project aims to investigate the potential utilization of SMRs for electricity generation in the NWT, it is necessary to identify potential barriers and issues which must be considered prior to a further study into the commercialization of SMRs.

This section considers two alternative plans, simply labeled Plan One and Plan Two, to meet the future demand for electricity generation in the NWT. In Plan One, it is assumed that all future electricity needs are met through power generation plants which use the same percentage of source mixes for 2010 as described in section 2 (35 percent hydro based, 65 percent thermal based generation). Plan Two assumes that SMRs are utilized for additional future needs of electricity generation while keeping the existing power generation plants. It is worthwhile to note that the intent of this study is not to determine the most efficient combination of mix sources, a subject which is well beyond the scope of this capstone project. Rather, it aims to highlight the applicability and the feasibility of the utilization of SMRs in the NWT given the unique characteristics of the region, namely the harsh Northern weather and lack of an electrical grid among other factors. To this end, this section begins by reviewing the legal and regulatory framework through a discussion of the constitutional jurisdiction to legislate with respect to nuclear energy and electricity. Then, the licensing process for new nuclear plants needed for Plan Two is identified. The section then provides a discussion surrounding the challenges and commercial viability issues associated with the application of SMRs in the NWT. Policy implications conclude this section.

4.2 Considerations in the Application of SMRs in the NWT

4.2.1 Regulatory and Legal Framework

I. **Federal and Provincial Jurisdiction of Nuclear Energy.** Constitutionally, most aspects of nuclear energy in Canada fall within the jurisdiction of the federal government. Sections 91 and 92 of the *Constitution Act 1867* outline the powers of federal and provincial government and identify the specific classes of subjects within the exclusive jurisdiction of each level of government. While nuclear energy is not explicitly included in sections 91 or 92, the federal government has the authority to legislate in matters of "national concern" under the "peace, order, and good government clause" (Watt 2007, 1). This power allows for the federal government to uphold the constitutionality of federal legislation over nuclear generation. Moreover, the federal government has declared that all works and undertakings carried out for the production, use and application of nuclear energy must be done for the general advantage of Canada. This declaration in effect allows for the federal government to have legislative authority over nuclear power plants as if it was specifically listed in section 91 (Watt 2007, 1). The role of the federal government encompasses research and development as well as the regulation of all nuclear activities and materials within Canada (NRCan b 2009, 1). Federal jurisdiction over nuclear energy is exercised through the Canadian Nuclear Safety Commission (CNSC), while the role of the federal government in the development of nuclear energy technology in Canada is mandated by the Atomic Energy of Canada Limited (AECL) which has both a public policy and commercial role (NRCan a 2012, 2).

Canada's current nuclear policy advocates for only Canada Deuterium Uranium (CANDU) based reactors, with no utilization of newly designed technologies. However, the world is in the midst of a revival in nuclear energy which in turn will impact Canadian nuclear policy. There are three factors which are contributing to the global nuclear revival including a substantial increase in global electricity demand, the need to diversify electricity source mix away from fossil fuels, and the growing importance in reducing the adverse environmental impacts of greenhouse gas emissions (Bratt 2012, 3). This revival in Canadian nuclear policy must consider certain aspects of public policy, namely national security, safety, and the environment which are of significance in the development of nuclear energy (Bratt 2010, 63). A survey by Ipsos Reid reports that an overwhelming majority of Canadians support economic nationalism of the nuclear sector, emphasizing the importance of Canadian involvement in the development of nuclear technology as well as the role of government in ensuring the safety and security of nuclear energy (Bratt 2010, 63).

Given the exclusive jurisdiction of the federal government over nuclear energy and its uses, provincial governments such as the government of the NWT cannot directly regulate nuclear energy. However, provincial governments are able to enact laws within their constitutional powers which will in turn have an indirect effect on federal matters (Watt 2007, 1). The provinces, along with the relevant provincial energy organization and power utilities, decide on the development of new nuclear plants (NRCan b 2009, 1).

A comprehensive legislation framework focused on health, safety, security and the environment has been established by the federal government. This framework consists of the

Nuclear Safety and Control Act (NSCA), *Nuclear Energy Act*, *Nuclear Waste Act,* and the *Nuclear Liability Act* (NRCan b 2009, 1). The key legislation which governs the approval and regulation of nuclear facilities is the federal *Nuclear Safety and Control Act (NSCA).* The *NSCA* has established the CNSC which is responsible for providing licenses (CNA 2009, 1). The mandate of the CNSC is to limit the risk to national security, health, safety of persons, and the environment which are generally associated with nuclear energy (Watts 2007, 2).

II. **Federal and Provincial Jurisdictions of Electricity.** The federal government plays a supporting role in the electricity industry in Canada. This is implemented through the investment in research and development as well as the support for commercialization of new technologies (NRCan b 2009, 2).

Provinces are primarily responsible for the generation, transmission and distribution of electricity. Provincial Crown utilities as well as regulatory agencies allow for provincial governments to exercise their jurisdictions. The past decade has witnessed significant change in the structure of the electricity industry. An increasing number of provinces such as the NWT have divided the generation, transmission, and distribution of electric utilities into separate entities (NRCan a 2012, 2). Provinces also make decisions regarding investments in electric generation (NRCan b 2009, 2). Electricity regulation is within provincial jurisdiction. In the NWT, the GNWT has established seven electricity rate zones through the Electricity Review process. This structure recognizes that there are three separate utilities and a mix of electricity generation and distribution operations (GNWT 2011 a, 7).

III. **Licensing Process for Nuclear Plants.** As mentioned previously, the CNSC is responsible for granting license. Nuclear power plants require separate licenses for all stages in the lifecycle of nuclear substances which includes preparation, operation, construction, abandonment and decommissioning of nuclear plants, as well as the possession, use, and transportation or storage of nuclear substances (CNSC 2012, 1). There is a well-established licensing process outlined by the federal government (CNSC 2012, 1) which must be closely adhered to by the NWT government and potential investors if they wish to pursue utilization of SMRs for electricity generation in the NWT.

The inter federal-provincial jurisdiction of nuclear energy and electricity as discussed above must be considered in the potential utilization of SMRs in the NWT if Plan Two is to be pursued. While the NWT would have jurisdiction over electricity as well the development of new nuclear plants, it must adhere to federal regulations of nuclear energy as stated in NSCA, and must follow the licensing procedure as outlined by the CNSC.

4.2.2 Implications of the Modular Nature of SMRs

A significant barrier in electricity generation in the NWT is the lack of an interconnected electrical grid between many communities in the NWT, as well as between the NWT and other jurisdictions as discussed in section 2. This hinders the ability to share electricity costs between more communities in order to reduce customer electricity rates. The lack of an interconnected transmission grid has also resulted in the need for stand-alone generation in many of the NWT communities. This implies that large scale diesel/natural gas based electricity generators cannot be established in a cost effective manner in a single location to provide electricity to be shared between the isolated and relatively small and dispersed population of the NWT communities.

The modular construction design of SMRs permits all plant components to be fabricated in a controlled factory environment, while the small design concept allows for ease in transportability and final site assembly. This, in turn reduces lead times and the amount of work needed on-site, resulting in lower operation and maintenance costs. The refueling cycle for these reactors differs between various models; however it is approximately an average of four years (U.S. DoE 2013). This figure reduces the need for on-site staff required for refueling of the reactors. As previously mentioned, the NWT is a region with a unique geography and climate which hinders the scheduling and timeline available for transportation of fuel for electricity generation. The short construction timeline of SMRs enables an isolated region such as the NWT to have more maneuver room in scheduling, given the limited window of good weather conditions.

Characteristics of SMRs as previously discussed in section 3 demonstrate the feasibility of utilization of SMRs to meet electricity needs in the NWT. Importantly, the modular design of these reactors also allows for a high level of inherent safety features in the event of malfunctions (IAEA 2013). The modular concept of SMRs specifically allows for operational flexibility by permitting incremental capacity increase in order to match local growth in electricity demand in the NWT communities. This allows a region with limited distribution infrastructure such as the NWT to meet local electricity demand.

4.2.3 Reduction in Greenhouse Gas Emissions by SMRs

As previously discussed in section 2, the harsh Northern environment, lack of amenities in isolated and remote communities, and the extremely dispersed population of the NWT has had a profound impact on the development and generation of electricity throughout the region. These challenges have yielded to a unique operating environment in the NWT, creating an energy intensive economy which is heavily reliant on fossil fuels for its energy and electricity generation. The high use of fossil fuels has not only contributed to high cost of living, but of more importance, an astounding level of greenhouse gas emissions on a per capita basis. In 2010, GHG emissions in the NWT were 28 percent higher than the national average on a tonnes per person basis (GNWT, 2012, 3). These higher levels of GHG emissions have contributed to adverse impacts on the Northern climate. The past 50 years has witnessed significant change in the climate of the NWT, with the climate becoming warmer at a rate which is five times more rapid than the global average (GNWT 2011 b, 8).

In order to secure a clean energy future for the Northwest Territories, given the expected increase in the economic and environmental costs of fossil fuels, and the important need of reducing GHG emissions, the NWT must take necessary measures to shift away from its heavily reliance of fossil fuels (GNWT 2013 a). While the NWT faces numerous challenges in the reduction of greenhouse gas emissions due to the geography, climate and economy of the region, the accelerating warming trends in the Northern climate serve as evidence for a dire need of change in policy. An alternative method for electricity generation which could be potentially considered by the government of the NWT is the utilization of SMRs.

To demonstrate the impact of the use of SMRs for electricity generation, namely Plan Two in GHG emission levels, Table 4.1 has been prepared. The Table shows projected greenhouse gas emissions due to electricity generation in the NWT between the years 2010 to 2030, for both Plan One, the continuation of the existing source mix, and Plan Two, the utilization of SMRs. The projected figures have been calculated with 2010 as the baseline year. Total electricity generation in the NWT in 2010 was 0.7 billion kilowatt hours, while greenhouse gas emissions for electricity generation was 477 kT (GNWT 2012 a, 3). The first row in Table 4.1, new power generation for the projected years (Bataillie *et al.* 2011, 4), have been calculated relative to total electricity generation in 2010, and represents the additional accumulated power generation need for each year with respect to 2010 electricity generation capacity. The figures in the second row of Table 4.1 show additional accumulated greenhouse gas emissions assuming the continuation of the existing source (as of 2010) which includes diesel, natural gas, and hydro. The third row in Table 4.1, the total GHG emissions of projected years, have been calculated by adding the GHG level of 2010 (477 kT) to the additional accumulated GHG level for each projected year as shown in the second row. It must be noted that these figures have been calculated assuming that no technological advancements have been developed to reduce GHG emission levels as there is no practical measure to anticipate it. The fourth row in Table 4.1, displays added GHG emissions if the utilization of SMRs for new electricity generation in the NWT is pursued. As discussed in section 3, SMRs have zero greenhouse gas emissions and therefore the figures in the fourth row are all zero. The last row shows total greenhouse gas emissions caused by electricity generation if Plan Two, utilization of SMRs, is chosen. This row has been calculated relative to 2010 GHG levels. Because SMRs emit no GHG emissions, total GHG emissions for the projected years remain at the 2010 level of 477 kT. Figure 4.1 is a graphic representation of the numbers calculated in rows three and five of Table 4.1. As seen, Plan One, represented by the red line, shows increasing trend of GHG levels if the current source mix is continued for future electricity needs in the NWT. Assuming no technological advancements, total GHG emissions for electricity generation would increase from 477 kT in 2010 to 1,567.3 kT in 2030, a staggering increase of 228.5 percent. Plan Two, i.e. the utilization of SMRs for any new electricity generation in the NWT, on the other hand, demonstrates that GHG emissions due to electricity generation would remain constant at the 2010 level of 477 kT as represented by the green line in Figure 4.1.

Table 4.1: Projected greenhouse gas emissions due to electricity generation for the years 2010 to 2030 (Baseline Year 2010)

	2015	2020	2025	2030	Comments
New accumulated power generation relative to 2010 (TWh)	0.08	0.25	0.70	1.60	Measured based on 2010 level capacity
Added GHG emissions in kT of **Plan One** to the 2010 level	54.4	170.3	477	1090.3	The same mix source in power generation as 2010 is assumed
Total GHG emission in kT of **Plan One** (including 2010 level)	531.4	647.3	954	1567.3	Assumes no technological change to reduce GHG
Added GHG emissions in kT of **Plan Two** to the 2010 level	0	0	0	0	No greenhouse gas emissions (GHG) is projected
Total GHG emission in kT of **Plan Two** (including 2010 level)	477	477	477	477	GHG remains at 2010 levels

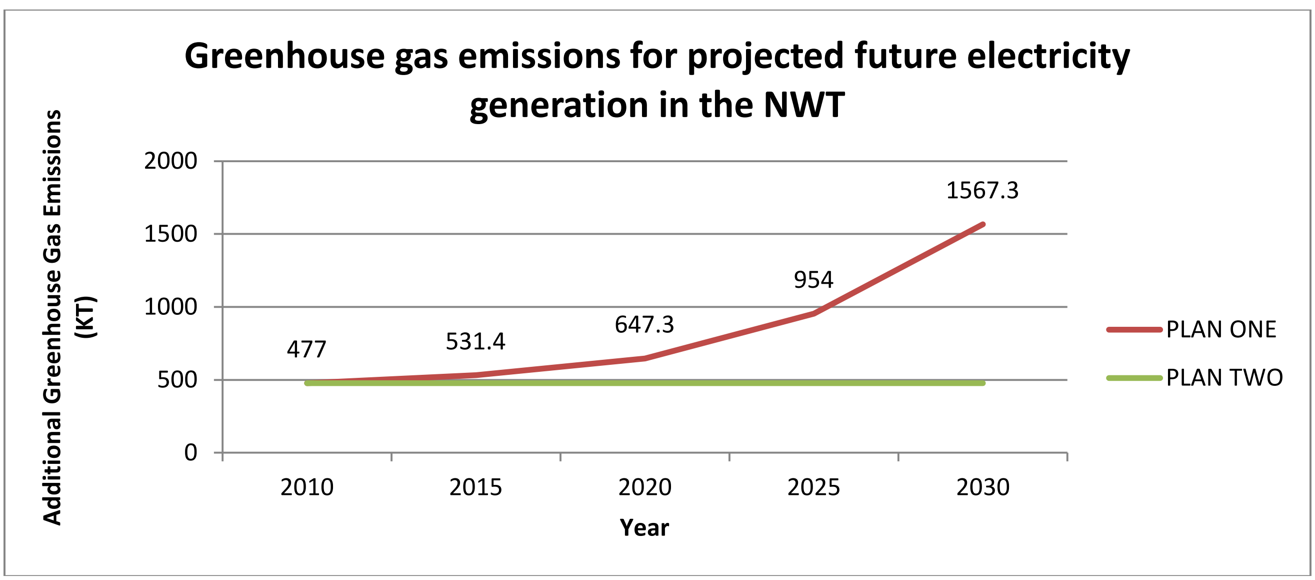

Figure 4.1: Greenhouse gas emissions for projected future electricity generation in the NWT

If the government of the NWT pursues the utilization of SMRs for the generation of projected future electricity demand, as opposed to the continuation of the heavily reliance on fossil fuels, it would be able to reduce GHG emissions levels by 1093.3 kT in the year 2030. This would be an equivalent of taking 227,146 cars off the road (EPA 2013). It is imperative to note that the total numbers of cars in the NWT in 2011 was only 1,414 (GNWT 2012 b, 8). While the economic value of this impact cannot be measured quantitatively, the sheer figure alone highlights the immense positive impact of Plan Two in reducing the carbon footprint caused by electricity generation.

4.2.4 Commercial Viability

In the process of the study of the commercial viability of the potential utilization of SMRs, the following assumptions have been made to create Table 4.2. This table illustrates a comparison of investment costs required for Plan One and Plan Two as proposed previously.

a) For Plan One, a mix source of 35 percent hydro-based and 65 percent thermal-based electricity generation as presented in section 2.3 for 2010 has been assumed throughout the projected years. As for Plan Two, all additional future electricity demand will be met through the utilization of SMRs.

b) Average cost of power generation for Plan One per megawatt hour has been calculated based on the following equation:

   Average investment cost ($)/MW = 0.35× (average investment cost ($)/MW for hydro electricity generation) + 0.65× (average investment cost ($)/MW for thermal electricity generation

   The average investment costs per megawatt hour in the NWT for both hydro and thermal electricity generation have been calculated as $3.5 million and $1.8 million respectively (Crawford *et al.* 2012, 10). The substitution of these two figures into the above equation provides an average investment cost per megawatt of $ 2.4 million for the mix source used in Plan One. This figure is the basis for the calculation of the accumulated cost estimates recorded in Table 4.2.

c) As for Plan Two, the average investment cost per kilowatt hours of power generation is highly dependent on the specific design of SMRs, the rated capacity of the reactor, as well as the number of modular reactors installed in a series production manner. An investment cost per megawatt hours of $6.5 million (for an installation of 600 MWe) has been used as an average between the estimates found in two literatures on SMRs. (Vujic *et al.* 2012, 294; Goldberg & Rosner 2011, 25).

d) The reduction in equipment and fabrication costs of SMRs as a result of the economics of serial production strategy have not be included in the investment cost estimation for Plan Two in Table 4.2. This is due to the inability to select the modular size which in turn defines the number of serial production which determines cost reductions. It is worthwhile to mention that the cost reductions associated with serial production are significant. For instance a second-of-a-kind plant would lead to 15 percent in cost reduction and at least 5 percent for consequent n^{th} of a kind plants. Furthermore, these reductions could be as much as 40 percent before reaching a stabilization range of over 6-8 units (Humphries 2012, 24). The cost reduction factor associated with serial production factor must be taken into account in any final decision making through the consultation with SMRs specialists.

e) The estimated investments costs for both Plan One and Plan Two recorded in Table 4.2 for each year are accumulated figures with the exception of rows three and five.

f) As mentioned in section 2, the projections for the years 2010 to 2020 are more reliable and fact based, while historical reflections and anticipated trends have been used for 2020 to 2030 projections thereby making them no very reliable. Regardless of the discrepancy in estimated needs for future electricity generation, the analysis presented here establishes a basis for the comparison of the capital investments required to generate a unit of electric power (1 MW) through Plan One and Plan Two alternatives.

Table 4.2: Estimated investment costs of Plan One and Plan Two

	2015	**2020**	**2025**	**2030**
New accumulated power generation relative to 2010 (TWh)	0.08	0.25	0.70	1.60
Estimated accumulated investment cost for **Plan One** (100 billion$)	1.92	6	16.8	38.4
Net new investment needed for **Plan One** (100 billion$)	1.92	4.08	10.08	21.6
Estimated accumulated new investment needed for **Plan Two** (100 billion$)	5.2	16.25	45.5	104
Net new investment needed for **Plan Two** (100 billion$)	5.2	11.05	29.26	58.5

Given the strategy of series production in the economic competiveness of SMRs, the new investment needed for Plan Two could be significantly reduced once the numbers of reactors needed are determined. As stated above, a reduction of almost 40 percent is possible through the economics of serial production. Taking this into account, Plan Two, the utilization of SMRs still requires approximately 62.5 percent additional funds. This difference in investment costs could be partially offset by the potential resource revenues of the government of the NWT following the recent enactment of the Devolution Agreement (Devolution Agreement 2013).

4.2.5 Challenges

Despite the various advantages and benefits associated with the utilization of SMRs in the NWT, there are also potential challenges which must be addressed.

First, Small Modular Reactors strongly rely on the economics of serial production. A key to the economic competiveness of SMRs is the need for a large initial order of SMRs in order to launch the serial production process. Therefore it is imperative to identify all initial customers and the number of SMRs designs needed for future deployment (Humphries 2012, 24). This could prove to be a challenge in initiating the utilization of SMRs in a remote region such as the NWT given the lack of private sector incentive and investment due to the limited degree of consumers. An absence of community based financing mechanisms, and lack of coordination amongst various levels of government as well as major government funding programs has created barriers in the entry of new investment projects such as SMRs (GNWT 2013 b, 13). A further challenge in the potential utilization of SMRs in the NWT could be the GNWT debt limits. However, given the recent enactment of the Devolution Agreement (Devolution Agreement 2013), millions of dollars from resource revenues will now stay within the NWT, and will enable the GNWT to perhaps invest in alternative electricity generation methods such as SMRs.

Another challenge in the utilization of SMRs in any region is the licensing process. The innovative engineering structure and the passive design features of SMRs will make licensability difficult within the existing legal/regulatory framework.

A third possible challenge is the widespread fear of nuclear energy since the unfortunate Fukushima disaster. A lack of public acceptance of new nuclear development could be a potential roadblock in the utilization of SMRs in the NWT.

Fourth, the inherent high technology in the design and operation of SMRs will require highly skilled human resources. The harsh Northern environment has led to a lack of a skilled labour force, and limited local knowledge of new technologies which will prove to be difficult in the potential utilization of SMRs in the NWT.

Finally, a further issue which must be considered is the need for the eventual disposal of enriched uranium used as fuel for SMRs. While these SMRs emit zero greenhouse gas emission, the lifecycle of the radiation of the waste material is lengthy and if improperly dumped will have catastrophic consequences. However, given the vast geography and dispersed population of the NWT, it is quite possible to locate a remote location for the safe disposal of waste materials.

4.3 Conclusion and Policy Implications

The attempt of this capstone has been to demonstrate one option for a shift in policy in electricity generation methods in the NWT and to investigate the potential utilization of SMRs in the region. The harsh Northern climate, lack of amenities in remote communities, and the extremely dispersed population of the NWT has had a profound impact on the development and generation of electricity throughout the region. It has created a high level of dependency on imported oil for energy use and electricity generation resulting in high cost of living and GHG emission levels.

The continuation of the current source mixes for electricity generation in the NWT is unsustainable and inefficient given the rising fuels costs and logistic barriers. Moreover, the continuation of existing methods will result in staggering projected GHG emission levels of 1093.3 kT by the year 2030. Given the reported adverse impacts of current GHG emissions on the Northern climate, attempts in reducing GHG emission levels in electricity generation should be of particular importance in the energy policy objectives of the government of the Northwest Territories. The sole use of SMRs for future electricity generation is impractical and unrealistic for a small scale economy such as the NWT. A policy of gradual incorporation of utilization of SMRs in the existing mix source for electricity generation is practical and achievable. This policy is also beneficial in the reduction of GHG emissions and therefore recommended.

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