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Commercializing Innovation In Residential Energy Retrofits In Toronto: A Case Study Involving Gemeni NTED®

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COMMERCIALIZING INNOVATION IN RESIDENTIAL ENERGY RETROFITS IN TORONTO: A CASE STUDY INVOLVING GEMINI NTED®

by

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Bachelor of Science, Western University, 2006

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ABSTRACT

COMMERCIALIZING INNOVATION IN RESIDENTIAL ENERGY RETROFITS IN TORONTO: A CASE STUDY INVOLVING GEMINI NTED®

Master of Applied Science, 2013

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Retrofitting Canada's existing housing stock to increase energy efficiency of dwellings is an opportunity to reduce energy consumption and greenhouse gas emissions. Gemini Nested Thermal Envelope Design (NTED®) is an innovative building retrofit that drastically reduces energy consumption. However, this innovation's potential can only be realized once it has achieved widespread market acceptance.

Using Gemini NTED® as a case study, an innovation commercialization model was applied to energy retrofits to aid in establishing an appropriate commercialization strategy for Toronto. Market research conducted within this study identified external factors affecting commercialization, barriers to innovation adoption and competitive forces affecting profitability. Economic valuation evaluated discounted monetary savings from reduced energy consumption. Results show that the retrofit market is moderately attractive and conducive to earning profits. Results related to Gemini NTED® show that Gemini may have commercialization potential for retrofitting older electrically heated homes especially in Canadian provinces with high electricity rates. Results arising from a soon to be completed Gemini NTED® pilot will confirm capital costs and economic benefit.

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Most of all I would like to thank my family, who have supported and encouraged me every step of the way.

Dedication

For my grandmother, Mary McInnis, who taught me how to work hard under difficult conditions.

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List of Terms and Abbreviations

AOH	average Ontario home
CC	capital cost
CEAA	Canadian Energy Efficiency Alliance
CMHC	Canadian Mortgage Housing Corporation
d	discount factor
e	energy escalation rate
ECS	energy cost savings
ERS	EnerGuide rating system
ERV	energy recovery ventilator
GCC	Green Communities Canada
GEA	Green energy act
GHG	greenhouse gas
GTA	Greater Toronto area
GWP	global warming potential
i	time period
IPP	intellectual property protection
kWh	kilowatt-hour
MMAH	Ministry of Municipal Affairs and Housing
n	service life
NPV	net present value
NRCan	Natural Resources Canada
NTED	Nested thermal envelope design
OHBA	Ontario Home Builder’s Association
R&D	research and development
REEP	Renewable Energy Education Program
SA	sensitivity analysis
SHEU	survey of household energy use
SP	simple payback
TRCA	Toronto and Region Conservation Authority
WACC	weighted average cost of capital

1.0 INTRODUCTION

The world is currently facing enormous environmental issues as both economic growth and population growth have begun to stress the earth's natural resources. In order to sustain our existence in ways we are accustomed to, burning of fossil fuel for energy production has increased and has negatively impacted our environment, resulting in an increase in pollution and documented changes in climate. As a result of increased energy consumption, dwindling fuel supplies and greenhouse gas emission (GHG) effects have identified a critical need to reduce and eventually eliminate our reliance on non-renewable energy sources (Jaffe et al., 1999).

To help reduce our energy consumption, considerable research has gone in to the development and implementation of sustainable development techniques and practices. Sustainable development became popularized as a result of the publication, *Our Common Future*. Published in 1987, this document provided what is considered a common definition of sustainable development:

> "…*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*," (Brundtland, 1987).

This report drew significant attention to human behaviour and consumption by considering three subsections of sustainable development: environmental, economic, and sociopolitical sustainability. Environmental sustainability requires activities to be designed by society in ways that meet our human needs while forever preserving life support systems of the natural environment. Sustainability is achieved when our consumption of natural resources is less than nature's ability to replenish them; in this case, a state of environmental renewal is reached.

The residential and commercial building sectors are areas that can benefit greatly from incorporating sustainable building techniques into their practices. It is estimated that buildings contribute as much as one third of total global greenhouse gas emissions, primarily through the use of fossil fuels during their operational use (UNEP SCBI, 2009). Designing buildings with sustainability and energy efficiency as top priorities can help decrease our overall environmental impact and dependency on fossil fuels.

In Canada, continuous population growth has resulted in increased construction of new homes. In the past ten years, a total of 6,121,404 homes in Canada were either new starts, under construction, or recently completed (CMHC, 2011). Changes to provincial building codes have increased efficiency of new homes, however, a large proportion of the housing stock needed to accommodate the growing population has already been built and represents a major environmental burden. There is therefore an urgency to understand and develop remedial actions through innovations in renovation in order to transform existing energy inefficient dwellings into more sustainable homes. In recent years, an increasing amount of attention has been focused on Canada's existing built environment. One can gain a better understanding of its significance from a preface from the U.S. Green Building Council (2009), which stated:

> *"The built environment has a profound impact on our natural environment, economy, health, and productivity. Breakthroughs in building science, technology, and operations are now available to designers, builders, operators, and owners who want to build green and maximize both economic and environmental performance. The green building movement offers an unprecedented opportunity to respond to the most important challenges of our time, including global climate change, dependence on non-sustainable and expensive sources of energy, and threats to human health. The work of innovative building professionals is a fundamental driving force in the green building movement."*

Retrofitting Canada's existing housing stock to make dwellings more energy efficient has been identified as an opportunity to help reduce energy consumption and corresponding GHG emissions. Retrofitting the housing stock also prevents complete building demolition and rebuilding. As a result, less waste is generated as the loss of previous buildings materials previously invested can be avoided.

Gemini Nested Thermal Envelope Design (Gemini NTED®) is an innovative form of thermal envelope design, a building technique for retrofitting homes that will maintain our standard of living while drastically reducing energy usage (Chown, 1982). Computer modeling with a Gemini NTED® design has shown that reductions in heating energy of up to 85% are possible (Dixon et al., 2012). This energy efficient innovation can provide several environmental and economic benefits, however, its true potential can only be realized once it has achieved widespread market acceptance.

1.1 Problem Statement

Energy retrofits have been identified as an effective way of reducing residential energy demand and subsequent GHG emissions; however, wide scale market acceptance has not been established. Using Gemini NTED® as a case study, this research applies an innovation commercialization method to energy retrofits to aid in establishing an appropriate commercialization strategy for Toronto and the GTA. Social, economic, environmental, and political viewpoints are taken into consideration when conducting this research to better understand the pros/cons, limitations, and barriers to implementing deep energy home retrofits.

1.2 Goals and Objectives

A significant amount of research has gone into understanding the economic and environmental benefits of energy retrofits. Retrofitting the residential housing stock has been identified as a possible solution for dealing with the inefficiency of the existing housing stock. However, there has been a lack of focus on how these types of innovations can be commercialized and implemented on a wide scale in order to maximize energy savings. This research addresses the following objectives:

(i) Apply an innovation commercialization model to the Gemini NTED® energy retrofit in Toronto and the GTA
(ii) Using Gemini NTED® as a case study, determine the economic value of a whole house retrofit

(iii) Determine the economic value of greenhouse gas emissions reduction from the energy savings of a Gemini NTED® home

(iv) Using the innovation commercialization model, identify implications for commercialization of a Gemini NTED® home

This research adopts a case study methodology to help answer the question, "What is the best commercialization strategy for innovative whole-house energy efficient residential retrofits in Toronto and the GTA?" The research uses Gemini NTED® as the case study and adopts Schilling's (2010) innovation commercialization model to gain insight into this topic.

1.3 Potential Applications

This research will help to identify the current status of the retrofit marketplace in Toronto and the GTA. Market research conducted in this study will identify external factors affecting commercialization, existing barriers to retrofit adoption, and the competitive forces affecting profitability. With a better understanding of the retrofit market, a strategy can be developed to develop a commercialization path for energy retrofits and Gemini NTED®.

This study will also add to the knowledge pool of existing whole house energy retrofits by identifying the options that are currently available to homeowners in Ontario. This will provide a source of information for both contractors and homeowners who may currently not be aware of what options are available to them to make their homes more energy efficient. Additionally, it will provide a more comprehensive understanding of what energy retrofits entail, in terms of what areas of the home are targeted, overall project costs, time to complete the retrofit, and what materials are used in the process.

Currently, low-energy residential retrofits for Canadian homeowners exist; however, they are found to be expensive and not economically feasible. If the results from this research are positive, it will add to the current literature involving energy saving retrofits as well as addressing the issues surrounding financial feasibility. The Gemini design could become a benchmark for comparison when looking at other low-energy retrofit options.

2.0 BACKGROUND

2.1 Energy Consumption and GHG Emissions in Canada

In 2011, the world's population reached 7 billion and Ontario's population climbed to 13.3 million (StatsCan, 2012). As our population rises, it has become necessary to design Ontario communities with long-term sustainability objectives in mind. Rational design and energy consumption control have become important strategies for both energy sustainability and development.

2.1.1 Energy Outlook

Energy use is of two general types: primary and secondary. Primary energy use encompasses the total requirements for all users of energy; the energy required to transform one energy form to another and the energy used to bring energy supplies to the consumer. Secondary energy use is the energy used by final consumers, including residential, commercial and institutional, industrial, transportation and agricultural purposes (Herring, 1999). Since this research is centered on energy retrofits for the residential sector, the focus will be primarily on secondary energy use. In Canada, secondary energy increased by 26 percent during 1990-2008, accounting for 72% of all primary energy use in 2008; a total of 8720.2 PJ (NRCan, 2012). During this time, the Canadian population grew by 20 percent and GDP grew 62 percent. Energy use therefore grew less rapidly than the economy but more rapidly than the population (NRCan, 2012).

The largest consumer of secondary energy use in Canada as of 2008 was the industrial sector, accounting for 37 percent of total secondary energy use (Chart 1). Following the industrial sector were the transportation, residential, and commercial/institutional sectors accounting for 30, 17, and 14 percent respectively (NRCan, 2012). The smallest consumer of secondary energy was the agriculture sector (2 percent).

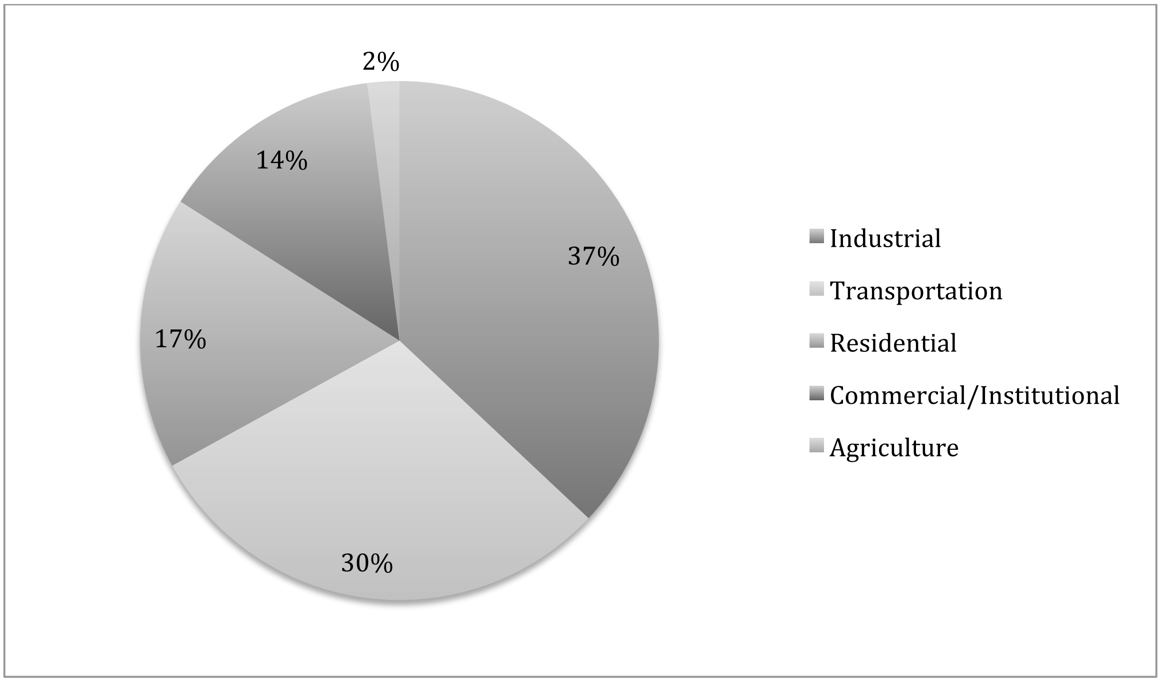

Chart 1 – Breakdown of secondary energy use in Canada in 2009 (NRCan, 2009)

The residential sector, consisting of single detached, single attached, apartments and mobile homes, is a major consumer of energy, the third largest in Canada, and is a major target for energy savings. Between 1990 and 2008, energy use in this sector increased by approximately 15 percent (140.2 PJ). Within this sector, secondary energy use can be further broken down by end-use applications for space heating, water heating, appliances, lighting, and space cooling. Space heating is typically the largest consumer of energy within the home – it accounts for 63 percent of residential energy by end-use (NRCan, 2012). A complete breakdown of residential energy use by end-use in 2009 is provided in Chart 2 below.

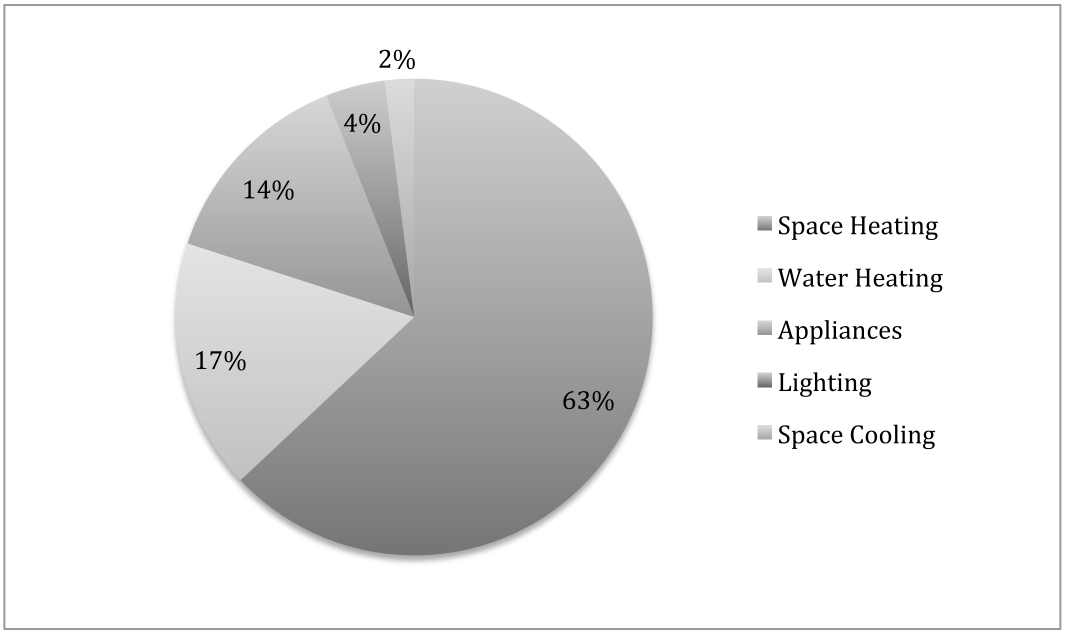

Chart 2 – Residential energy use by end-use in Canada in 2009 (NRCan, 2009)

To save energy in the home, space heating is a logical target for reductions. Making a home more energy efficient through higher efficiency heating equipment and increased insulation can reduce a home's heating load, thereby cutting back heating costs as well as greenhouse gas (GHG) emissions. Figure 1 provides data on the average annual heating consumption for different housing types in Canada.

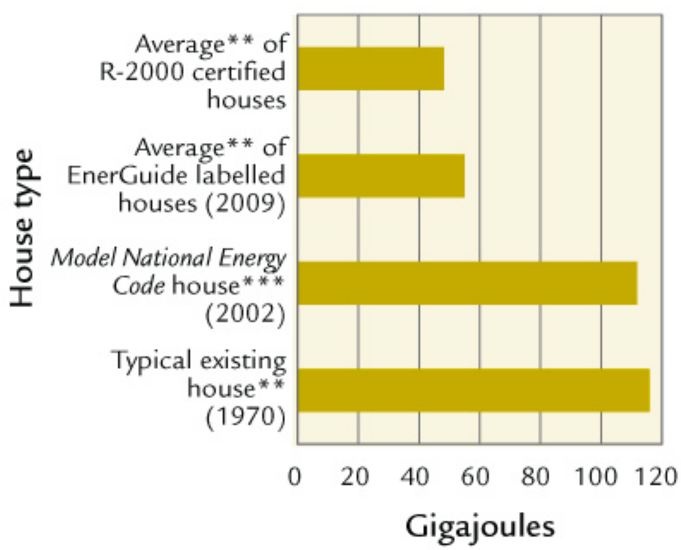

Fig. 1 – Annual heating consumption for different house types (NRCan, 2012)

It is obvious from the figure that homes built with higher energy efficiency standards (R-2000 and EnerGuide labeled homes) consume considerably less energy for heating purposes.

2.1.2 Greenhouse Gas Emissions

Quantifying a country's greenhouse gas (GHG) emissions depends on several factors, which can include: the population size, government involvement, economic activity, and consumer behavior to name a few. In Canada, the major contributors to GHG emissions include the primary energy sectors, producers of oil and gas and electricity generation. Due to the rapidly growing economy and population, Canada's total emissions grew significantly between 1990 and 2005, rising from 589 to 740 Mt. However, since 2005, GHG emissions have declined in almost every sector (EnviroCan NIR, 2013).

In December of 2009, Canada signed the Copenhagen Accord and committed to reducing the country's overall GHG emissions 17 percent below 2005 levels by the year 2020. In 2005, the measured total GHG emissions in Canada were 740 Megatonnes (Mt) therefore setting a target of 607 Megatonnes (Mt) for 2020 (EnviroCan Emissions Trends, 2012). Currently, with the existing government reduction measures/interventions in place, Canada's emissions are expected to total 720 Mt in 2020, over 100 Mt higher than the target. The following table was adapted from Environment Canada's Emissions Trends Study and outlines Canada's expected emissions with no government measures in place versus expected emissions with existing government measures in place between the period of 2005 and 2020.

Table 1 – Predicted Canadian GHG Emissions in Mt CO_2e (EnviroCan, 2012)

Emissions	2005	2010	2015	2020
Assuming No Government Measures	740	718	784	850
With Existing Government Measures	740	692	700	720

Even with government intervention, Canada's predicted emissions in 2020 are well over the Copenhagen Accord target. Additional measures need to be in place in order to get Canada on the right track for meeting its goal.

2.1.2.1 Provincial Emissions

Greenhouse gas emissions vary significantly between provinces due to diversity in population size and demographics, economic activities and resource base. Total GHG emissions by province and emission type are outlined in Tables 2 and 3. Although it is important to have an understanding of Canada's GHG emissions, it is of greater value to this research to identify and evaluate the current trends in Ontario's GHG emissions. Resource base is a major contributing factor to a province's GHG emissions. In Ontario, a large proportion of our energy comes from electricity generation. We are highly reliant on hydropower and nuclear power as generating sources, which contribute less to GHG emissions compared to generation from fossil fuels. As a result, Ontario has per capita emissions below the national average (EnviroCan Emission Trends, 2012).

Table 2 – Provincial GHG emissions in 2010 (EnviroCan NIR, 2013)

Province	**Greenhouse Gases (kt CO_2 equivalent)**		
	1990	**2005**	**2010**
Nfld & Labrador	9,230	10,400	8,860
P.E.I.	1,960	2,240	1,960
Nova Scotia	19,100	23,700	20,400
New Brunswick	15,900	22,500	18,600
Quebec	83,800	86,100	82,000
Ontario	**176,000**	**206,000**	**171,000**
Manitoba	18,300	20,600	19,800
Saskatchewan	43,200	69,900	72,100
Alberta	166,000	228,000	233,000
British Columbia	49,400	63,100	56,100
Yukon	536	414	340
N.W.T	1,200	1,590	1,330
Nunavut	270	340	447
Canada	589,000	740,000	692,000

Table 3 – Provincial GHG emissions by type in 2010 (EnviroCan NIR, 2013)

Province	**Greenhouse Gases**		
	CO_2 (kt)	**CH_4 (kt)**	**N_2O (kt)**
Nfld & Labrador	7,690	41	0.73
P.E.I.	1,390	11	1.0
Nova Scotia	18,800	41	1.7
New Brunswick	16,900	47	1.9
Quebec	63,400	460	20
Ontario	**146,000**	**600**	**33**
Manitoba	11,000	180	16
Saskatchewan	45,000	880	27
Alberta	184,000	1,700	43
British Columbia	43,700	400	7.8
Yukon	312	0.28	0.03
N.W.T	1,250	0.77	0.19
Nunavut	409	0.12	0.02
Canada	545,000	4,300	150

In 2010, GHG emissions in Ontario accounted for approximately 25 percent of Canada's total emissions (Table 2). Emissions in Ontario are expected to decline from 206,000 kt to 167,000 kt of CO_2e (a difference of 39,000 kt) by 2020. This decline in emissions will largely be due to Ontario's commitment to shut down all coal-fired power plants for electricity production by 2014 (EnviroCan: Emission Trends, 2012).

2.1.2.2 Emissions by Sector

Emissions from secondary energy use by sector in Canada totaled 487.8 Mt in 2008 (NRCan, 2012). Emissions were highest in the transportation, industrial, and residential sectors, 37, 32, and 15 percent respectively (Chart 3).

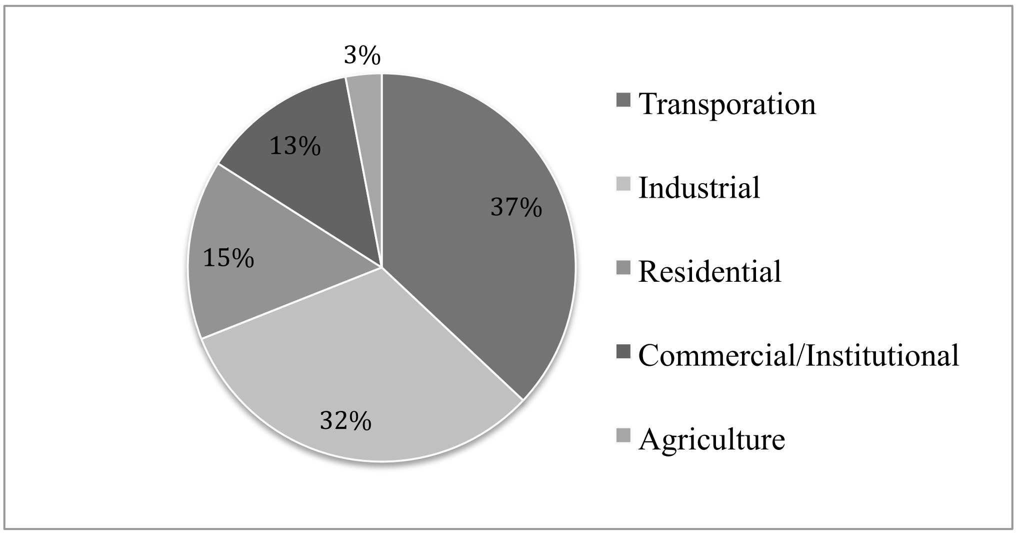

Chart 3 – GHG emissions from secondary energy use by sector in 2008

2.1.2.3 Residential Emissions

The residential sector is the third largest contributor to GHG emissions from secondary energy use (15 percent), contributing approximately 73 Mt of CO_2e in 2008 (NRCan, 2012). Emissions in this sector are expected to remain stable between 2005 and 2020 whereas the number of households is expected to increase by 2.8 million within the same time frame (EnviroCan Emission Trends, 2012). This is assumed to be largely due to federal and provincial measures aimed at increasing the energy efficiency of new residential buildings. Examples of this include the improved regulation to the Ontario Building Code where new builds must meet the performance level that is equal to a rating of 80 or more on the EnerGuide Rating Scale and the now discontinued federal ecoENERGY Home Retrofit grant program which encouraged homeowners to make energy efficient upgrades to their homes (NRCan, 2011).

Emissions from the residential sector also vary greatly between provinces due to population sizes, number of residences, average age of residential buildings, and the source of energy supplied to residences. Table 4 compares residential emissions in each province to their corresponding total provincial emissions (data from EnviroCan National Inventory Report 2013). In Ontario, emissions from the residential sector in 2010 were approximately 18,000 kt of CO_2e. These emissions make up 11 percent of Canada's total emissions (both primary and secondary energy sources).

Table 4 – Provincial GHG emissions from residential sectors in 2010

	Residential Emissions (kt CO2e)	**Total Emissions** (kt CO2e)	**Percent** (%)
Nfld & Labrador	460	8,860	5.20
P.E.I.	400	1,960	20.41
Nova Scotia	1,800	20,400	8.82
New Brunswick	950	18,600	5.12
Quebec	4,000	82,000	4.89
Ontario	**18,000**	**171,000**	**10.53**
Manitoba	1,000	19,800	5.05
Saskatchewan	1,800	72,100	2.50
Alberta	8,200	233,000	3.52
British Columbia	3,800	56,100	6.77
Yukon	33	340	9.71
N.W.T	93	1,330	6.99
Nunavut	No data	447	-
Canada	41,000	692,000	6.01

The residential sector in Ontario has the second highest percentage of emissions, next to P.E.I. and contributes to approximately 44 percent of Canada's total GHG emissions from the residential sector. This presents a major opportunity for savings in terms of reducing emissions. Reducing energy required for space heating in Ontario homes could lead to substantial decreases in GHG emissions.

2.1.2.4 Emissions From Space Heating

As previously stated in Section 2.1.1, the majority of end-use energy in a household is consumed for space heating (63 percent). Space heating is also the main contributor to GHG emissions from a household, depending upon the type of energy generation source. In Canada, the majority of residences use natural gas furnaces for heating (54 percent) followed by electric baseboards (25 percent) (NRCan SHEU, 2010). A breakdown of heating systems used in Canada is provided below in Chart 4.

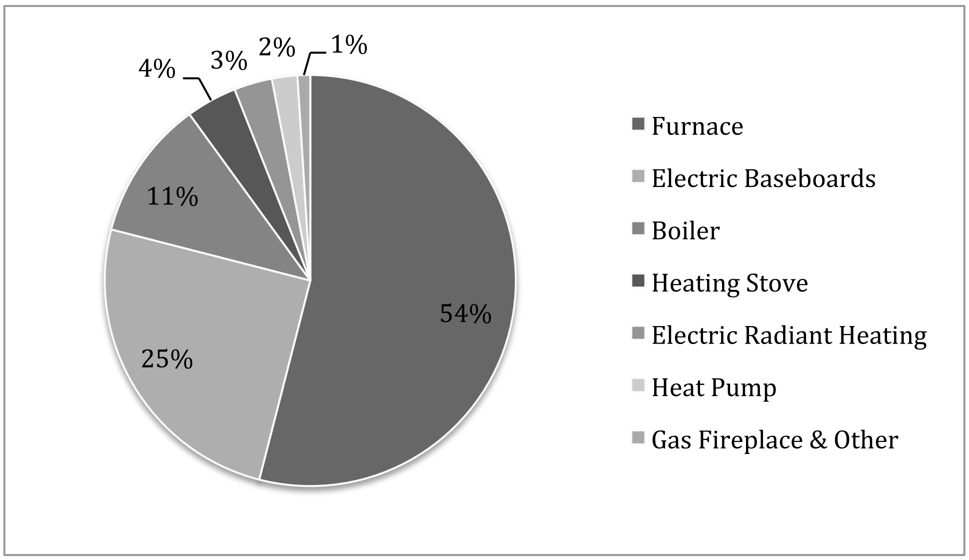

Chart 4 - Heating systems in Canadian households in 2007

Heating systems also vary greatly between provinces, depending on what resources are available. In Ontario, the majority of homes are heated by natural gas, followed by electricity; a summary of heating systems by province is provided in Table 5.

Table 5 – Residential heating systems by province (NRCan SHEU, 2010)

Region	Heating System	Fuel Type	Percent of Households
Atlantic Canada	Electric baseboards	Electricity	30
	Furnace	Heating oil	30
	Boiler	Wood	20
Quebec	Electric Baseboards	Electricity	58
	Furnace	Electricity	17
Ontario	Furnace	Natural gas	73
	Boiler	Natural gas	11
	Electric Baseboards	Electricity	10
Manitoba/ Saskatchewan	Furnace	Natural gas	73
	Electric Baseboards	Electricity	12
Alberta	Furnace	Natural gas	84
	Boiler	Natural gas	11
British Columbia	Furnace	Natural gas	52
	Electric Baseboards	Electricity	21
	Boiler	Electricity	14

In Ontario, the majority of homes use natural gas forced-air furnaces for heating purposes. Less common heating equipment includes boilers and electric baseboards, but they are still in place throughout the province.

Typically, natural gas heated homes emit greater amounts of GHG emissions when compared with electrically heated homes. To heat your home electrically, there is no direct combustion process and therefore essentially no emissions are generated. However, emissions are produced indirectly by the electricity generation source. For example, if your electricity generation source is coal, you are indirectly creating high amounts of GHG emissions. Source emission factors for natural gas and electricity generation in Ontario are presented in Tables 6 and 7. For natural gas, units are expressed as grams or kilograms of CO_2, CH_4, and N_2O emitted per cubic meter of natural gas produced (g CO_2/m^3, g CH_4/m^3, and g N_2O/m^3). For electricity, emissions are expressed in units of grams of CO_2, CH_4, and N_2O produced per kilowatt-hour of electricity generated (g CO_2/kWh, g CH_4/kWh, and g N_2O/kWh).

Table 6 – Emission factors from Ontario natural gas production (EnviroCan NIR, 2013)

Fuel Type	CO_2 Intensity (kg CO_2/m^3)	CH_4 Intensity (kg CH_4/m^3)	N_2O Intensity (kg $N_2O\ /m^3$)
Natural Gas	1.879	0.000037	0.000035

Table 7 – Greenhouse gas intensity from electricity generation (EnviroCan NIR, 2013)

Province	CO_2 Intensity (g CO_2/kWh)	CH_4 Intensity (g CH_4/kWh)	N_2O Intensity (g N_2O/kWh)
Ontario	130	0.01	0.003

Emission factor values for natural gas in Table 6 are representative of Ontario values, however natural gas emissions factor values are similar across the provinces. Greenhouse gas emission factors for electricity vary greatly between provinces, depending upon the source used for generation. Provincial electricity generation details and electricity emissions factors can be found in Tables A-1 and A-2 respectively in Appendix A.

2.1.2.5 Reporting GHG Emissions

Emissions are most commonly expressed in kilograms (kg) or kilotonnes of GHG emissions per unit of consumption activity. Six groups of greenhouse gases are typically considered when reporting emissions, which include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and perfluorocarbons (PFCs) (Ontario Ministry of the Environment, 2012). Although there are several types of gases to report on, carbon dioxide is generally emitted in the highest volume followed by methane and nitrous oxides (resulting gases from fuel combustion for energy), making these gases the most commonly reported types of GHG emissions. Carbon dioxide is also the leading contributor to climate change, both globally and in Canada. It accounts for more than 60 percent of anthropogenic emissions across the globe and nearly 80 percent of emissions in Canada (OECD, 2011).

When reporting GHG emissions, it is also necessary to consider the fact that greenhouse gases are not equal in their effect on the atmosphere; each gas has a unique atmospheric lifetime and heat-trapping potential. To make GHGs more comparable, the concept of global warming potential (GWP) was created. Global warming potentials compare the ability of each gas to trap heat in the atmosphere relative to that of carbon dioxide over a specified time period, common GWPs are listed in Table 8. Typically, GHG emissions are calculated in terms of how much carbon dioxide would be required to produce a similar warming effect over a chosen time period and values are expressed as carbon dioxide equivalents (CO_2e). To do this, you would take the amount of gas (in kg or kt) and multiply the value by the corresponding GWP to give you the resulting CO_2 equivalents. For example, if your emissions were 5 kg of CH_4, you would multiply 5 by 25 for a total of 100 CO_2e.

$$CO_2e \quad = \quad \text{kg of gas} \times \text{GWP of gas}$$

Table 8 – Global warming potentials of CO_2, CH_4, and N_2O

Greenhouse Gas	Formula	GWP
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous Oxide	N_2O	298

The data provided in Table 8 was retrieved from the Intergovernmental Panel on Climate Change (IPCC) (IPCC Report, 2007). The IPCC is responsible for conducting periodic assessments on anthropogenic induced climate change as science evolves over time. The data provided by the IPCC is a requirement for GHG inventory reporting under the United Nations Framework Convention on Climate Change (UNFCCC).

2.2 Carbon Tax Policy

A carbon tax targets GHG emissions by assigning a price to be paid on fossil fuels, which is proportional to the quantity of carbon emitted when each fuel is burned. It is a strategy implemented by governments to help reduce emissions, reduce energy consumption and mitigate the negative effects of climate change. Carbon taxes typically possess two incentive effects, both directly and indirectly. The first is a measureable direct effect through price increases. This generally stimulates conservation measures, investments in energy efficiency, and switching to cleaner fuels. The second is an indirect effect through the recycling of tax revenues back into the economy, which reinforces the previous effects and encourages changes in the economy's consumption patterns (Baranzini, 2000). To reduce the amount a business and individual must pay in carbon tax, several strategies can be considered including reducing fuel consumption, adopting energy efficient technologies, and switching to cleaner fuels.

In Canada, Quebec, Alberta, and British Columbia all have carbon policies. Quebec's carbon tax policy was established in 2007 and was the first North American state or province to place a price on carbon. The policy collects a carbon tax on hydrocarbons (petroleum, natural gas, and coal), however the tax rate is too low to have a meaningful affect on the consumption of any fossil fuels (\$3.20 per ton of CO_2e – less than 1¢ per litre) (Suzuki, 2012: All Over the Map). Making an impact on emissions reduction depends largely on the tax rate and how much you have to pay (Baranzini, 2000). The price on carbon pollution needs to be high enough to provide incentives for industries and individuals to reduce emissions, switch to cleaner fuels and adopt energy efficient behaviours. The goal of the Quebec tax however is not necessarily to discourage fossil fuel combustion, but to raise revenue to pursue environmental projects (Rivers, 2012).

In 2008, British Columbia implemented a carbon tax policy in an effort to combat climate change and help reach their target of reducing GHG pollution 33 percent below 2007 levels by the year 2020 (B.C. Climate Action Plan, 2008). The tax does not apply to all GHG emissions – only to those from fossil fuel combustion. Additionally, the tax does not apply to carbon dioxide emissions from industrial processes including the production of oil, gas, aluminum and cement (Duff, 2008). It is meant for fossil fuel combustion used for transportation, both by individuals and all industries and includes natural gas combustion for the operation of pipelines, road, rail, and marine and air transportation. It also includes fuel used to create heat for dwellings and industrial processes (B.C. Budget 2008). In its first year, the tax was introduced at a rate of $10 per ton of CO_2e emission. Since then, the rate has annually increased by $5 per ton until 2012 when it was capped at $30 per ton. A gradual increase in price was meant to provide businesses and individuals the opportunity to adapt to the tax and make appropriate changes before the prices were increased each year (B.C. Climate Action Plan).

Unlike Quebec's tax, which allocates revenue towards environmental projects, British Columbia's tax is revenue neutral to the government. A revenue neutral carbon tax intends that all revenue generated from the tax is recycled back to the individuals and businesses that pay it in the form of tax cuts. With this reasoning, British Columbia's tax is often considered a *carbon shift* instead of a carbon tax (BCs Climate Action Plan). The idea was to apply taxes to things B.C. wanted to reduce like GHG emissions, and lower taxes on things individuals' value, like income.

From a homeowner's perspective, the carbon tax mainly impacts heating costs. The amount of tax associated with heating a dwelling depends on the type of energy used, the efficiency of equipment, outside temperature, thermostat settings, and energy efficiency of the building (BC Climate Action Plan, 2008). Under this policy, homes that are heated with natural gas or oil are taxed and those heated with electricity are not. Implementing a carbon tax policy similar to this in Ontario would have major implications for commercializing an energy retrofit like Gemini, which is heated electrically. Under the B.C. Carbon Tax, having an electric heating system would result in zero carbon taxes from heating and families would still benefit from personal income tax cuts. However, in Ontario, a large proportion of electricity is generated form natural gas (approximately 30 percent). As a result, a carbon tax would most likely be applied to electric heating in Ontario.

2.3 Energy Efficiency

"Energy efficiency is our most valuable energy resource and must be one of the cornerstones of our national environmental and economic policy for the decade."

-Canadian Energy Efficiency Alliance, 2012

When discussing energy reduction strategies, it is important to differentiate between energy conservation and energy efficiency, as the two terms carry different meanings. Energy conservation refers to efforts made to reduce energy consumption, for example, turning off the lights when leaving a room. Energy efficiency on the other hand refers to using less energy to produce the same amount of service or useful input (Patterson, 1996). For example, insulation added to a home allows residents to use less heating energy to heat the area of their home. Investments in energy efficiency are unique in that they pay for themselves over time through savings.

Gains in energy efficiency can have substantial benefits to society, the economy, and the environment. It can add to the national security of energy supplies by reducing the overall need for energy, save individuals and businesses money by decreasing their energy bills without disruptions to their daily routine, and it can increase access to energy services by reducing their effective cost (NRCan, 2009). Additionally, energy efficiency is considered a strategy for mitigating the effects of climate change by reducing carbon dioxide and other greenhouse gas emissions. Through efforts made to increase energy efficiency, Canadians can reduce their energy bills and contribute to achieving environmental goals. Industry leaders, government agencies, and conservation activists have all targeted the residential sector as an area for great improvement in terms of energy savings, which can be accomplished by the integration of new energy efficient technologies.

2.3.1 Energy Efficiency in Canada

Improvements to energy efficiency practices and standards have had a significant impact on the Canadian economy and have reduced energy consumption from the industrial, transportation, residential, and commercial sectors. Table 9 shows the changes in secondary energy use from each sector due to a variety of effects between the years 1990 and 2009. Changes due to energy efficiency are highlighted in the table and it is clear from the data that energy efficiency has been a substantial contributor to energy reduction.

Table 9 – Changes in Secondary Energy Use from 1990 to 2009 in PJ (NRCan, 2011)

	Residential	**Commercial/ Institutional**	**Industrial**	**Transportation**	**Total**
1990 energy use (PJ)	1286.2	867.0	2721.8	1877.9	6752.9
2009 energy use (PJ)	1426.4	1186.0	3180.3	2104.8	7897.5
Change in energy use (PJ)	+140.2	+319.0	+458.5	+226.9	+1144.6
Change due to (in PJ):					
Activity	492.3	341.2	1181.5	457.5	2472.5
Weather	33.0	8.8	n/a	n/a	41.8
Structure	10.0	-0.9	-706.8	32.4	-665.3
Service Level	75.5	117.9	n/a	n/a	193.4
Capacity Utilization	n/a	n/a	576.5	n/a	576.5
Total	610.8	467.0	1051.2	489.9	2618.9
Energy Efficiency	**-470.6**	**-146.9**	**-592.7**	**-263**	**-1474.3**

From the above table, changes in the amount of energy consumed were categorized into six effects and include: activity, weather, structure, service level, capacity utilization and energy efficiency. Changes in activity, weather, service level and capacity utilization all led to increases in secondary energy use between 1990 and 2009. Changes due to structure resulted in an increase in energy use within the residential and transportation sectors and decreases in energy use within the commercial/institutional and industrial sectors. Descriptions of activity, structure, weather, service level, capacity utilization effects, and energy efficiency are provided in Table 10. With the known total changes in energy from the five effects and total energy use from each sector, fluctuations in energy use due to energy efficiency are determined. Changes in energy use due to energy efficiency are the net result after accounting for increases in energy due to the other five effects (NRCan, 2011).

Table 10 – Various effects causing change in energy use (NRCan, 2011)

Effect	**Description**
Activity	• Different for each sector • eg. In the residential sector, it is the number of households and the floor space of residences
Structure	• Changes in the makeup of each sector • eg. In the industrial sector, increase in activity in one industry over another is considered a structural change
Weather	• Fluctuations in weather can lead to changes in heating and cooling requirements • Measured in terms of heating and cooling degree-days • Considered in the residential, commercial and institutional sectors
Service Level	• Refers to the penetration rate of devices and equipment • eg. Use of appliances in homes – they're becoming more efficient but the addition of more devices results in an increase in service levels
Capacity Utilization	• Refers to the proportion of the installed production capacity that is in use • eg. Industrial processes cut back load due to decreased demand but still operate at same energy levels
Energy Efficiency	• Refers to how effectively energy is being used • Using less energy to provide the same level of energy service

Energy use in the four sectors listed in Table 9 total 7,897.5 PJ in 2009. Increases in energy efficiency across the four sectors saved 1,474.3 PJ in energy between 1990 and 2009. Without improvements in energy efficiency made within the four sectors, it is estimated that energy use would have increased to 9,371 PJ in 2009.

2.3.2 Efficiency in the Residential Sector

Energy efficiency has played a large role in reducing energy consumption within the residential sector in Canada. Between 1990 and 2009, gains in energy efficiency saved approximately 471 PJ of energy and 22.4 Mt of GHG emissions, resulting in energy savings of $8.9 billion in 2009 (NRCan, 2011).

In Ontario, energy efficiency in the residential sector came into focus with the introduction of the Energy Efficiency Act in 1999 and when the Green Energy Act (GEA) took effect in May 2009. The GEA increased the efficiency standards of several home appliances, one of the most significant being the increase in gas furnace efficiency standards from 78 to 90 percent (GEA, 2009). Additionally, the GEA published changes to the Ontario Building Code (OBC). The OBC sets mandatory provisions that must be met by all new buildings and changes made to the code made energy efficiency a key element. As of January 1st 2012, all new homes built in Ontario must be more energy efficient by either meeting or surpassing the energy performance levels equivalent to a rating of 80 on the EnerGuide rating scale (OBC Supplementary Standard, 2013).

In Ontario, the average energy consumption per household has fallen 21 percent between 1990 and 2009 (NRCan, 2011). A growing population and larger dwelling sizes however have resulted in total energy use within the residential sector to rise during the same time frame. Changes made to Ontario's building code to make energy efficiency a top priority is a positive initiative by the Ontario government and should contribute greatly to the reduction of energy consumption and GHG emissions from this sector. However, reducing energy consumption in new builds is not the only concern. An additional factor affecting energy use in the residential sector is the age of Ontario's housing stock. Currently, more than half of Ontario's existing housing stock was built prior to 1983 (Table 11), which means that the majority of homes were built before meaningful energy efficiency improvements were made to the building code.

Table 11 – Ontario housing stock by year (NRCan Historical Database, 2012)

Year Built	Number of Homes (thousands)	Percent of Housing Stock (%)
Before 1946	731.3	14.2
1946-1990	482.4	9.4
1961-1977	1,049.0	20.3
1978-1983	510.6	9.9
1984-1995	1,190.2	23.1
1996-2000	330.9	6.4
2001-2005	463.5	9.0
2005-2010	397.5	7.7

The Ontario building code is applied only to new construction and because of this, improvements that have been made to building standards do not affect existing homes. Additionally, newer, more efficient homes are not entirely replacing the older, inefficient housing stock. In Ontario, for every five new homes that are currently built, only one pre-1983 home is removed (CHBA, 2011). Unless efforts are made to improve the energy performance of existing homes, a large portion of the housing stock will remain inefficient into the future and continue to consume more energy than new builds and produce more GHG emissions. There is therefore a sense of urgency to develop remedial actions through renovation in order to transform existing inefficient residential buildings into more sustainable homes.

2.4 Energy Efficient Gemini NTED® Retrofit

Innovations in residential energy retrofits have been identified as an effective way of reducing energy demand and greenhouse gas emissions of the existing housing stock. Several retrofit options exist for homeowners, one being nested thermal envelope design (NTED). Nested thermal envelope design is an innovative low-energy house design that incorporates two thermal envelopes; one nested within the other (Stahlbrand et al., 2012) and involves a complete gutting of a home's inner core. The design consists of an insulated interior envelope 'core' surrounded by an insulated exterior envelope 'perimeter' area. The interior core contains the primary living spaces, which can include bedrooms, bathrooms, living rooms and kitchens. The outer perimeter would typically include secondary living spaces, such as dining rooms, offices, and spare bedrooms. A sketch outlining the concept of the inner core and outer perimeter design is shown below in Figure 2. It is important to note that the layout of inner core and outer perimeter areas are flexible and can differ from house to house, depending on the house type and size.

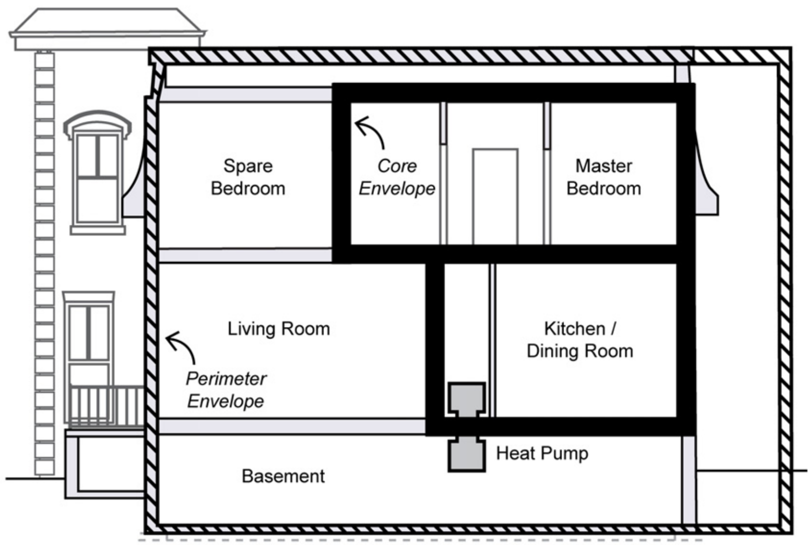

Fig. 2 – Schematic of a possible NTED® home showcasing the inner core and outer perimeter areas (Dixon et al., 2012)

From Figure 2, the inner core encapsulates the master bedroom, kitchen and dining room while the perimeter includes a spare bedroom, living room and basement. This is an example of one way the inner core and outer perimeter could be designed. A significant advantage of the Gemini NTED® design is its adaptability. Depending on the geometry of the house being retrofitted, the perimeter can contract or expand to accommodate special constraints. This is especially significant in terms of retrofitting where homes have already been constructed. Homeowners and contractors can essentially choose which areas of the home should be included within the core and the perimeter areas.

3.0 LITERATURE REVIEW

3.1 Commercializing Innovation

Schilling (2010) has identified a commercialization path for innovations (Figure 3). Outlined as a strategic process, the author progresses from assessing competitive dynamics of a situation, to strategy formation, and finally strategy implementation.

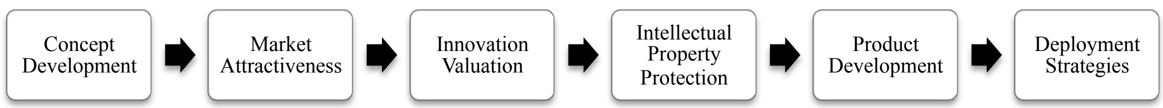

Fig. 3 – Commercialization path for innovations (Schilling, 2010)

Commercializing innovation begins with concept development; a single idea can lead to a new product, system, or process. In order to discuss the commercialization path of an innovation, it is necessary to first define the concepts *idea, invention, and innovation*.

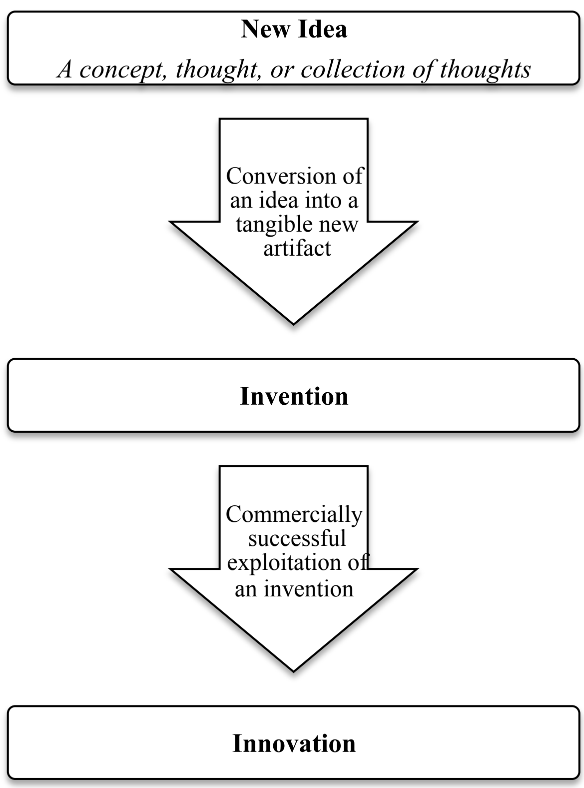

Fig. 4 - Outlining the path from idea to innovation (Trott, 2002)

The generation of new ideas is the starting point for innovations. If the idea is perceived as being "novel" then it is considered to be an innovative idea, the degree to which it is novel is a function of how different it is from previous work and how different it is to an audience's prior experiences (Schilling, 2010). An idea transforms into an invention once it is converted into a tangible artifact (Trott, 2002) (Figure 4). Innovations are generally not regarded as synonymous with invention.

The term innovation is regarded as a broad concept and a number of definitions for it exist. A comprehensive definition of innovation was provided by Myers and Marquis (1969):

> *"Innovation is not a single action but a total process of interrelated sub processes. It is not just the conception of a new idea, nor the invention of a new device, not the development of a new market; the process is all these things acting in an integrated fashion."*

Innovation is often distinguished from invention by suggesting that innovation is concerned with the commercial and practical application of ideas whereas an invention is merely a concept or a collection of thoughts (Trott, 2005). Inventions have also been considered as economically irrelevant, whereas innovations imply economic leadership or commercial success (Schumpeter, 1927). More recently, Rogers (1983) made a differentiation between the two based on process. Rogers considered invention to be a process of discovering and creating new ideas whereas innovation referred to a product's adoption or use.

Sources of Innovation

Innovation can arise from a number of sources, originating from one individual or come from the research efforts of various institutions, including firms, universities, government-funded labs or private nonprofits. However, an important source of innovation exists in the linkages and interaction between several sources. Innovators working together are able to leverage knowledge and resources off one another, creating a complex system where new designs may inherit components from a number of innovation sources. A collaborative system of innovation sources is detailed below in Figure 5 (adapted from Schilling, 2010).

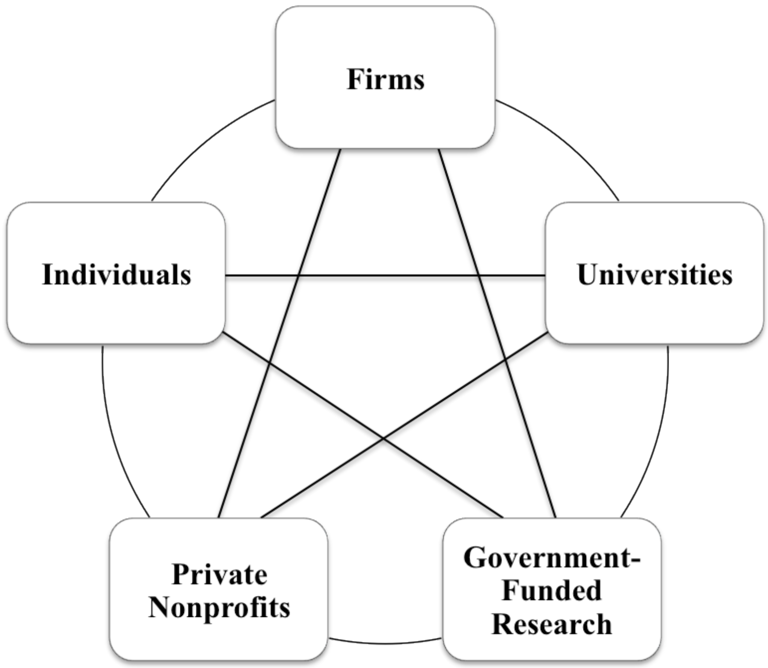

Fig. 5 – The sources of innovation as a system (Schilling, 2010)

Research and development (R&D) efforts of a firm are generally considered to be primary engines of innovation (Schilling, 2010; von Hippel, 1995) with greater access to resources than individuals and a larger management system to utilize the resources and work towards a collective purpose. Additionally, firms are typically faced with the task of developing new products and services to differentiate themselves from competitors, which creates a strong incentive for innovation. Nevertheless, public research institutions including government-funded labs and universities greatly contribute to the innovation process.

Governments invest in research and development (R&D) through their own laboratories and provide grants for both public and private research groups. Globally, R&D expenditures totaled approximately $1.28 trillion in 2009 (most recent year for which data is available) (NSF, 2012). In Canada, the federal government's estimated R&D

funding expenditures were $5.8 billion, making them the second largest contributor to R&D funding, following the business enterprise sector (StatsCan, 2013).

Another important source of innovation comes from universities. In Canada, R&D funding from the higher education sector was estimated at $5.4 billion in 2012. Typically, universities produce both patentable and non-patentable innovations and the institutions hold sole discretion over the rights to commercialize any innovation (Schilling, 2010). In order to facilitate the commercialization process, a number of universities have established technology transfer offices, which play an active role in transferring new knowledge, new skills and new ideas to firms and institutions. As a result, universities have become an increasingly high-profile stakeholder in the generation and dissemination of knowledge, having a direct impact on economic activities (Sergarra-Blasco et al., 2008).

3.1.1 Market Attractiveness, Innovation Valuation & IPP

Following concept development, assessments of market attractiveness and innovation valuation are conducted and aid in defining an innovation's strategic direction. Analysis of both concepts helps provide a better understanding of an innovation's competitive position in a market as well as determine if it is economically feasible for buyers. Analysis of both concepts aids in defining an innovation's strategic direction. Market attractiveness and innovation valuation for commercializing an innovation utilizing the Gemini NTED® case study is the focus of this research (Figure 6) and a more thorough discussion of the role each plays in the commercialization process is discussed in the following sections

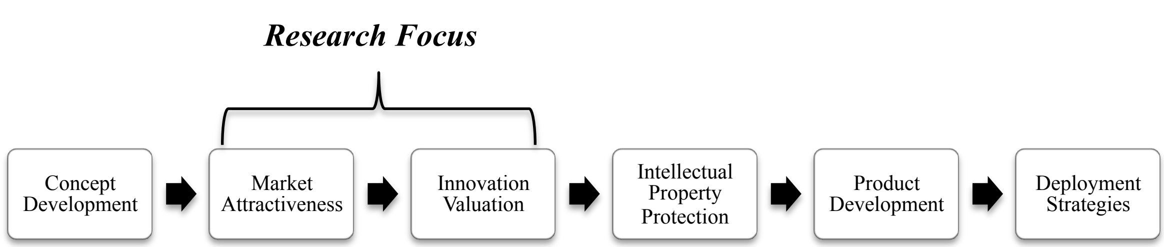

Fig. 6 – Research focus of the innovation commercialization model

Upon completion of a market assessment and innovation valuation, the following steps in commercializing innovation involve protecting an innovation's intellectual property (IPP), developing the product and deciding upon an appropriate deployment strategy. Determining whether and how to protect an innovation is a crucial element of formulating a firm's innovation strategy (Schilling, 2010) and can be accomplished via patents, trademarks, or copyrights. A patent protects an invention; a trademark is used to protect words or symbols intended to distinguish the source or a good and a copyright protects artistic and literary work (Schilling, 2010). A firm must decide whether or not protection is necessary, which often depends on how easy it is for competitors to imitate innovations.

3.1.2 Product development & Deployment Strategies

Following intellectual property protection, a firm must undergo product development and design a product development process. In order for new product development to be successful, it must achieve three goals: (1) maximize the product's fit with customer requirements, (2) minimize development cycle time, and (3) control development costs (Schilling, 2010). Maximizing a product's fit with consumers involves offering more attractive prices than competitors, better features, and better quality. Research completed during the second step of the commercialization model (market attractiveness) provides information to assist firms in successfully achieving the first goal listed. How a market assessment can aid in a firm's product development process is discussed in greater detail in Section 3.2. Minimizing the development cycle time is necessary to prevent failure from a product taking too long to bring to market.

The last stage of Schilling's commercialization method is the development of an effective deployment strategy using information gathered throughout the previous stages. Effective deployment strategies have the ability to reduce uncertainty about a product, lower the ease of switching to competing or substitute goods, and accelerate adoption within the general public. Schilling (2010) identifies five key elements of the deployment strategy process, including (1) launch timing, (2) licensing and compatibility,

(3) pricing, (4) distribution, and (5) marketing. Selecting a strategic product launch timing allows firms to take advantage of business cycles and seasonal effects, to position the new product with respect to previous generations of related technologies, and to ensure complementary goods and services are in place.

Pricing is a crucial element of a firm's deployment strategy. It influences a product's position in the marketplace; it's adoption rate, and a firm's cash flow. Maximizing current profits is a common pricing objective for many firms. Using this strategy, a firm must first estimate expected costs and demand and then set a price to maximize cash flow or rate of return on investments. In terms of distribution, firms must decide whether to sell their products directly to consumers (through direct sales force, online or mail-order catalogue) or through intermediaries including wholesalers or retailers. Selling products directly to consumers gives a firm more control over pricing and services and can capture more information about customers, however; intermediaries can make distribution more efficient and can often sell items in larger quantity. Finally, a firm must also address marketing to complete the deployment strategy process. Common marketing strategies include advertising to build public awareness, promotions to stimulate purchases, or free publicity through newspapers and magazines to generate word of mouth. Well thought out and well delivered marketing can greatly affect public perception of a product and influence sales.

3.2 Research Focus: Market Assessment

Examining a company or product's internal and external environments is necessary to gain insight into market attractiveness and to design a successful commercialization strategy. As shown below in Figure 7, assessing market attractiveness should begin with a look into external drivers including, political, economic, social and technological drivers followed by a in depth look at internal drivers affecting successful entry into a market. It is necessary for the external and internal forces that impact a market's integrity to be understood before key decisions on new product development are considered (Smith, 2001).

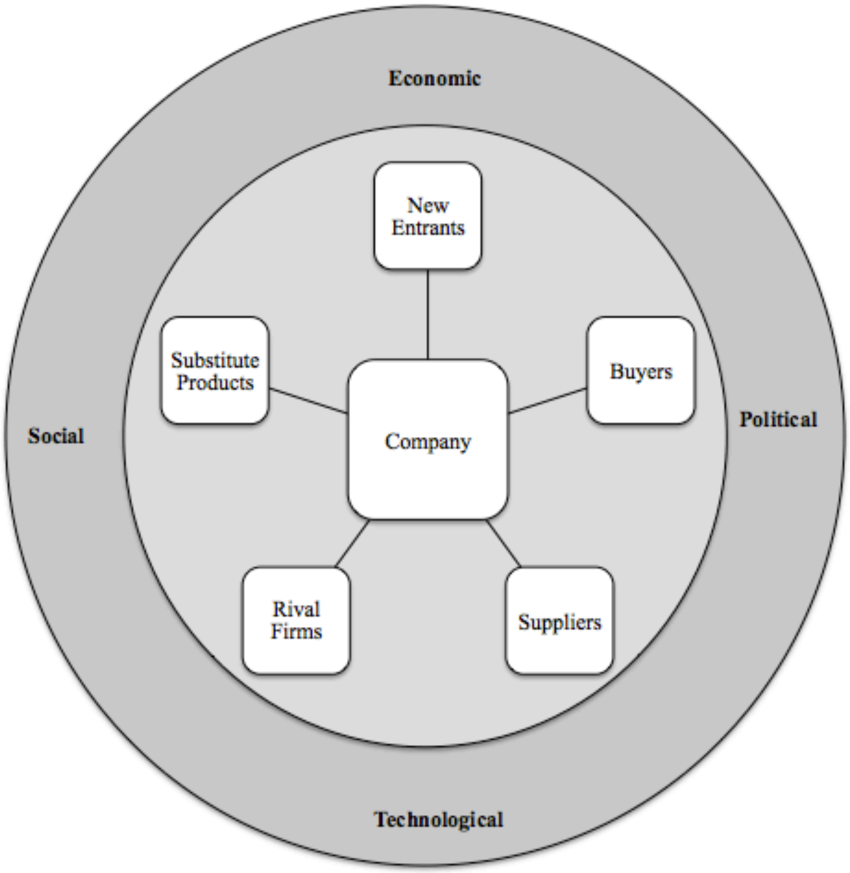

Fig. 7 – A company's internal and external environment (from Thompson, 2010)

Every company operates in a larger environment that goes well beyond the industry in which it operates (Thompson, 2010). Each component (political, economic, social, and technological) has the potential to affect a firm's immediate surroundings and competitive environment, either positively or negatively. Social factors can include societal values, attitudes, and lifestyles and often vary depending on location and change over time. Political factors include any existing policies or regulations and laws that companies must abide by. Political factors have the ability to create an environment where product adoption or commercialization is successful, however they may also hinder adoption by creating significant entry barriers – a concept that is discussed in greater detail in the coming sections. Technological factors effecting market attractiveness can include the pace of technological change and development and are often a result of research and development (R&D) laboratories. Lastly, economic factors also play a large role in a product's successful/unsuccessful adoption. Economic factors can include things such as economic growth, the unemployment rate, and bank interest rates.

The factors and forces that have the biggest strategy-shaping impact are concerned with a company's immediate industry and competitive environment – the competitive pressures, actions of rival firms, buyer behavior, and supplier-related considerations (inner circle of Figure 7). To assess the strength and character of each factor within the internal environment, Porter's Five Forces Model is used.

The Porter's model is the most powerful and widely used tool for diagnosing competitive pressures in a market (Porter et al., 2006). The model states that the competitive forces affecting industry profitability stem from five coexisting sources, which include (1) competition from rival sellers, (2) competition from potential new entrants to the industry, (3) competition from producers of substitute products, (4) supplier bargaining power, and (5) customer bargaining power. A diagram of the Porter model is shown below in Figure 8.

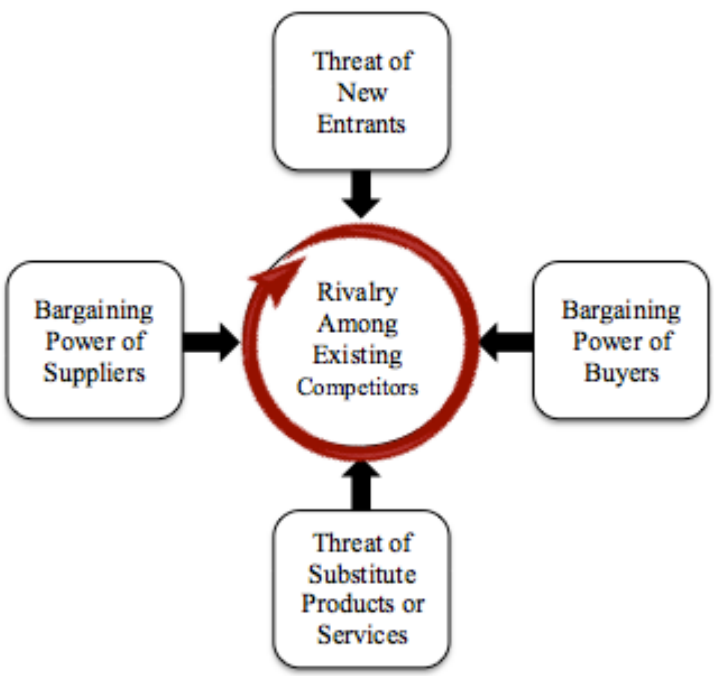

Fig. 8 – The 5 competitive forces affecting an industry's profitability (Porter, 1985)

Threat of Entry

New entrants to an industry bring new capacity and a desire to gain market share that place pressure on process, costs, and the rate of investment necessary to compete (Porter et al., 2006). If there is a high amount of threat, incumbents must hold down their prices in order to deter new competitors. The threat of entry potential therefore places a cap on the possible profit of an industry. To evaluate the threat of entry, entry barriers present to new competitors in the retrofit market were identified. Seven major barriers to entry, previously identified by Thompson et al. (2010), were evaluated. A list of the entry barriers along with a brief description of each is provided in Table 12 below. If there are low or no entry barriers, then the resulting threat of entry will be high and profitability will be moderated. It is important to note that it is the threat of entry – not whether the entry actually occurs – that controls profitability.

Table 12 – Possible entry barriers to the retrofit market (Thompson et al., 2010)

Barriers to Entry	Brief Description of Barrier
Supply-side economics of scale	• When companies produce in large volumes and can charge lower costs per unit • Can force new entrants to come into the industry on a large scale • Requires dislodging entrenched competitors, or to accept a cost disadvantage
Demand-side benefits of scale	• aka. Network effects; a buyer's willingness to pay for a company's product increases when the company has a large customer base • Discourages entry by limiting willingness of customers to buy from a newcomer • Reduces the price the newcomer can command until it builds a large customer base
Customer switching costs	• Fixed costs encountered when customers switch suppliers • Higher switching costs discourages entry • Harder for entrant to accumulate customers
Capital Requirements	• Investment of large financial resources in order to compete can deter entrants
Incumbency advantages independent of size	• Incumbents may have cost or quality advantages not available to new entrants • Can include established brand identities, cumulative experience, strong partnerships
Unequal access to distribution channels	• New entrants must secure distribution of products/services • Limited wholesale/retail channels makes entry more difficult
Restrictive government policy	• Government policies can either hinder or aid entry • May hinder entry through licensing requirements • May aid entry through available funding

The Power of Suppliers

Powerful suppliers have the ability to drain profitability out of the retrofit industry if the industry is unable to pass cost increases off in its own prices. Suppliers are powerful if they are able to capture more value for themselves by charging higher prices or limiting the quality of their services (Thompson et al., 2010). To evaluate the supplier groups in the retrofit industry and rate their strength in the Porter's model, the following points were considered:

1. *A supplier is powerful if it is more concentrated than the industry it sells to*
2. *A supplier is powerful if they do not heavily depend on the industry for revenue*
3. *A supplier is powerful if high switching costs are incurred with changing suppliers*
4. *A supplier is powerful if they offer products that are differentiated*
5. *A supplier is powerful if there is no substitute for what they provide*

The Power of Buyers

Buyers are powerful if they have the ability to capture more value by driving down prices, demanding better quality of products or more service (which drives up cost), and playing industry participants against one another (Thompson et al., 2010). In order to evaluate if buyers are powerful, their negotiating leverage is assessed. Buyers have more power if they have negotiating leverage to industry participants. For this research, buyers (homeowners) negotiating leverage was evaluated by considering the following four points:

1. *Buyers are powerful if there are few of them or they make purchases in large volumes*
2. *Buyers are powerful if the products available within the industry are standardized or undifferentiated*
3. *Buyers are powerful if switching costs are low or non-existent*
4. *Buyers are powerful if they have the ability to integrate backward and produce the industry's product themselves*

The Threat of Substitutes

A substitute is defined as an item or process that performs the same function as an industry's product via a different means. If the threat of substitutes is high, the profitability of the industry can suffer as substitutes can limit the profit potential by placing a ceiling on prices (Thompson et al., 2010). To identify the substitutes to the Gemini NTED® whole-house retrofit, possible substitutes were identified through a review of the literature. The threat of substitutes (whether it be weak, moderate or strong) was then evaluated by considering the following two points:

1. *The threat of substitutes is high if good substitutes are readily available or new ones are emerging*
2. *The threat of a substitute is high if they are attractively priced*

Rivalry Among Existing Competitors

The final force of the Porter model that was considered for the retrofit industry was the potential for rivalry among existing competitors. Rivalry can include such things as price discounting, introducing new products, advertising, and service improvements. If there is a high amount of rivalry within an industry, the profitability of that industry can be limited. Profitability depends on the intensity with which companies compete and the basis on which they compete (Thompson et al., 2010). To evaluate the *intensity* of rivalries within the retrofit industry, five points were considered:

1. *Rivalry is high if there are numerous competitors who are roughly equal in size and power*
2. *Rivalry is high if growth within the industry is slow*
3. *Rivalry is high if there are numerous exit barriers*
4. *Rivalry is high if rivals are committed and have goals that go beyond economic performance*
5. *Rivalry is high if companies are unfamiliar with one another and are unable to read each other's signals*

As mentioned above, the amount of rivalry within an industry also depends on the basis of competition. The dimensions on which competition occurs and whether or not rivals compete on the same dimension can greatly influence profitability. Dimensions can include such things like product costs, product features, customer support services, brand image, delivery time, etc. Rivalry can be destructive to the profitability of an industry if rivals compete solely on product costs as the rivalry can drive product prices down, which transfers profits directly from an industry, to the consumer (homeowner). Competition in areas other than cost is less likely to drive down profitability. To evaluate the basis in which rivals compete, identified competitors of the Gemini NTED® retrofit were evaluated in terms of their overall objectives, product features, image, costs, and marketing tactics.

3.3 Research Focus: Innovation Valuation

Developing innovative new products is a time consuming, costly and often risky process. Firms are tasked with the decision of what projects are worth investing in and then must pursue said projects with a well thought out development strategy (Schilling, 2010). The methods used to evaluate projects range from entirely qualitative to entirely quantitative or a combination of the two. Decision of which valuation technique to pursue depends upon the project and what specific factors firms are looking to evaluate. This research explores the application of a quantitative valuation technique for evaluation of the economic status of innovative residential energy retrofits, using Gemini NTED® as a case study.

The most commonly applied quantitative method involves discounted cash flow analysis, which estimates future cash returns from a project. Quantitative discounted cash flow methods assess whether the anticipated future benefits of an innovation are large enough to justify initial expenditures (Schilling, 2010). In most cases, the costs and benefits of environmental or energy projects occur over an extended period of time, rather than at the moment of purchase and as a result, financial analysis and cost-benefits studies must accommodate future effects of current decisions (Mussatti, D. et al., 2002). Since a dollar today is worth more than a dollar tomorrow, once cannot place the same value on a future dollar as they place on a present dollar; this concept is known as the time value of money. Discounted cash flow analysis takes into account the time value of money for evaluating projects using net present value (NPV) calculations. NPV asks the question, "*Given a particular capital expenditure, a particular level and rate of cash inflows, and a discount rate, what is the project worth today?*" (Schilling, 2010, pg. 139).

NPV is computed from the stream of cash flows resulting from an investment. When using the NPV model, firms must make educated estimates of project costs as well as the size and timing of cash inflows. To justify initial expenditures, the present value of all cash inflows must be compared to the present value of cash outflows:

NPV = Present value of cash inflow – Present value of cash outflows

If the resulting number is zero or greater (a positive value), the project under consideration generates wealth and is eligible for further consideration (Gray et al., 2006). If the resulting number is less than zero, the project is not profitable and should either be disregarded or improved upon until the NPV is positive. Net present value of an energy efficiency project can be calculated using the following formula:

$$NPV = \sum \frac{s}{(1+d)^t}$$

In this formula, *s* represents the value of energy savings in any time period, *d* is the selected discount rate and *t* is the number of years involved. To account for the time value of money, expected future costs and cash flows are discounted back to the present time using a discount rate. The technique alters future values by a specified percentage every year and this percentage is known as the discount rate (or discount factor). For example, using a discount rate of 5 percent would theoretically reduce the value of future costs and benefits by 5 percent every year when calculating the present value. Higher discount rates causes future values to decrease more rapidly, which results in attributing lower present values to future costs and benefits (Guth, 2009).

For many projects, the outcome depends heavily on the discount rate applied. High discount rates may encourage investments in projects that have high benefits and low costs in the short term. On the contrary, low discount rates may encourage investments with high net benefits in the more distant future (Field et al., 2011). At any single time, there are a number of discount rate indices that can be applied to a particular project including interest rates on savings accounts, government bonds or bank loans. Which rate should be applied is often a reflection of the way people think about time. In most cases, a person will prefer a dollar today to a dollar 5 years from now, which means they have a positive rate of time preference (Field et al., 2011). In this scenario, people will make savings decisions by setting up a savings account or purchase government savings bonds that will accrue interest over time. The interest rate provided by the bank is representative of the amount that must be offered to get people to abstain from current consumption. Here, the interest rate provided by the bank would be appropriate to use as the discount rate. However, to avoid error in selecting a discount rate, a range of discount rates can be applied to compare its effect on results. If conclusions drawn from the analysis do not change, then it is not necessary to be concerned about selecting the "right discounting rate" (Kolb et al., 1990).

4.0 METHODOLOGY

4.1 Case Study

Case study research was undertaken involving a combination of both qualitative and quantitative methods. As a research method, case studies are applied to a variety of situations and can contribute to knowledge concerning individual, group, social, political and organizational phenomena. Case studies are often the preferred method in three instances, when (1) "why" or "how" questions are being proposed, (2) the investigator has little control over events and (3) the focus is on a contemporary phenomenon within real life context (Yin, 2009). Additionally, case studies facilitate exploration of a phenomenon within its context using a variety of data sources. The process ensures that the issue under investigation is not explored through a single lens, but rather a variety of lenses, allowing for investigators to obtain holistic and meaningful characteristics of the phenomenon (Baxter et al., 2008).

Once the case study approach has been chosen as the methodology, two items must be identified: (a) the actual *case* being studied and (b) the *type* of case study to be conducted. A *case* under investigation can be defined as, "a phenomenon of some sort, which occurs in a bounded context and is, in effect, your unit of analysis" (Miles et al., 1994). When selecting and defining the case under investigation, boundaries must be set. Boundaries prevent researchers from answering questions that are too broad as well as prevent researchers from selecting a single study with too many objectives.

The *types* of case studies to be investigated have been identified in the literature as being explanatory, exploratory or descriptive (Yin, 2009) and intrinsic or instrumental (Stake, 1995). Table 13 below summarizes these case types identified by both authors.

Table 13 – "Types" of case studies in qualitative research

Author	Type of Case Study	Description
Yin, 2009	Explanatory	Applied when a researcher is seeking to explain causal links in real-life phenomena that are too complex for survey or experimental methods.
	Exploratory	Applied when researchers explore situations where the phenomena have no clear, single set of outcomes.
	Descriptive	Applied when researchers attempt to describe a phenomena and the real-life context in which it occurred.
Stake, 1995	Intrinsic	Applied when the intent is to better understand the case – the purpose is not to build theory
	Instrumental	Applied to provide insight into an issue or help to refine a theory. In this option, the case is of secondary interest, only playing a supportive role to facilitate understanding of something else.

Applied to this research, the *case* being studied is the process of commercializing innovation in energy efficient residential retrofits in the GTA using Gemini NTED® to provide insight. Boundaries were established by time and geographic location and include commercialization opportunities within the GTA by looking at the current status of the retrofit market. Additionally, the type of case study being investigated in this research can be described as both exploratory and instrumental. Designing a commercialization strategy for energy efficient residential retrofits has no clear, single set of outcomes, several items must first be considered, making it exploratory in type. Additionally, this methodology aims to provide insight into a possible commercialization strategy, placing Gemini NTED® in a supportive role to facilitate understanding of appropriate strategies, making it also instrumental in type.

In addition to identifying the case to be studied and type of case in which the study pertains to, investigators must also decide upon conducting either a single case study or a multiple case study method. For this research a single case study approach is applied. Single case study methodology is a valuable method for researchers and has been applied widely in research, including information technology (Tellis, 1997; Peta et al., 1998), psychology (Hilliard, 1993; Crawford et al., 2005), operations management (Voss et al., 2002), and healthcare (Riddoch et al., 1991; Lotzkar et al., 2001; Hellstrom et al., 2005).

This research adopts a case study methodology to help answer the question, "What is the best commercialization strategy for innovative whole-house energy efficient residential retrofits in Toronto and the GTA?" The research uses Gemini NTED® as the case study and adopts Schilling's (2010) innovation commercialization model to gain insight into this topic.

4.2 Application of Commercialization Model

Following the innovation commercialization model discussed in Section 3.1, the methodology employed involves an analysis of the case of the Gemini NTED® residential architectural design innovation. Using secondary and primary data, an analysis of the factors leading to the development of the Gemini NTED® concept was undertaken. A market assessment was conducted to determine the level of market attractiveness using secondary data to appraise the external factors impacting market acceptance and the overall competitiveness of the market. This latter step employed the use of Porter's 5 Forces model. In the near term, the anticipated market for Gemini NTED® retrofits is Toronto and the GTA as the GTA is currently the most active residential area in Canada (CMHC, 2011). Additionally, the majority of residential buildings in Toronto were built prior to 1980 and represent a major environmental burden, making Toronto a prime candidate for whole-house energy retrofits. In the mid-term, the market will include the remaining urban markets in Ontario and Canada. After assessing the market, a financial valuation of Gemini NTED® is performed including the potential value of emission reductions through greenhouse gas calculations from space heating associated with Gemini NTED® retrofits.

The financial valuation includes the determination of simple payback and the net present value of energy savings and CO_2 reduction. Simple payback is a valuable tool in marketing energy projects; often easily understood by individuals with minimal financial expertise. Additionally, it is typically the first thing homeowners want to know when making decisions about home renovations or efficiency upgrades to appliances and equipment (Ashuri, 2011). Simple payback is outlined below in Formula (1). Payback provides a very rough initial estimate of the time needed to recover initial investment (Banks, 2000).

$$SP = \frac{CC}{AS} \qquad (1)$$

From the above formula:

SP = Simple payback (years)

CC = capital cost of project ($)

AS = Annual energy savings ($/year)

Although payback is a simple and valuable tool for homeowners, it should rarely, if ever, be used as the final basis upon which to select an investment option. This equation does not take into account the time value of money (the idea that a dollar today is worth more than a dollar tomorrow) nor does it reflect savings that will continue to accrue to a project after the payback has been reached. To account for these deficiencies, simple payback is accompanied with a more thorough net present value calculation, which accounts for both the time value of money and savings after payback is reached. In the literature, several adaptations of the NPV model exist. For this research, because it is a retrofit project and economic value is determined from energy savings accrued over a long period of time, the current cost of energy sources and energy escalation rates must be accounted for. The NPV model chosen for this research is shown below in Formula (2). It was adapted from a study conducted by Lui (2010) and chosen because it incorporates the time value of money (discount rate; *d*), current cost of energy (CEC_j), and the average annual escalation rate of energy prices (*e*). Similar formulas have been applied successfully in the literature for calculating the NPV of renewable energy projects and home improvement projects (Galvin et al., 2012; Kumbaroglu et al., 2012 & Verbeeck et al., 2007).

$$NPV = -CC + \sum_{i=n}^{n} \left[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times \left(CEC_j \times E_j \right) \right] \tag{2}$$

From the above formula:

CC = capital cost of the project

e = annual escalation rate of energy prices

d = discount rate

n = service life of the retrofit

CEC_j = current energy cost per unit of energy type *j*

E_j = annual savings of energy type *j*

The original equation from Lui (2010) was modified for this research to eliminate the problem of comparing two different energy types (kilowatt hours and cubic metres of natural gas). To do this, annual heating energy costs (CEC_j x E_j) were first calculated for a number of housing scenarios:

1. *Gemini NTED® home*
2. *R-2000 home with electric heating equipment*

3. *Average Ontario home (AOH) with electric heating equipment*
4. *Average Ontario home (AOH) with natural gas heating equipment*

Once annual costs were determined, annual heating energy cost savings (ECS) were calculated for a Gemini NTED® home by comparing each the annual heating cost from each scenario (2-4 above) to the heating cost of a Gemini NTED® home. Formula (2) was then simplified by replacing current energy cost and annual savings terms with the single annual energy cost savings term (ECS); Formula (3).

$$NPV = -CC + \sum_{i=n}^{n}\left[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times ECS\right] \tag{3}$$

From the above formula:

CC = capital cost of the retrofit

e = annual escalation rate of energy prices

d = discount rate

n = service life of the retrofit

ECS = annual energy cost savings ($)

In order to compute the NPV model, each component of the formula first had to be defined. The following section addresses how each item in Formula (3) was determined and any assumptions that had to be made.

Annual Energy Cost Savings (ECS)

Annual energy savings for a Gemini NTED® home were calculated based on heating energy intensity values; the total amount of energy consumed per unit of heated area. Energy intensity values are most often expressed in gigajoules per square metre (GJ/m^2) or kilowatt-hours per square metre (kWh/m^2). Comparisons were made between a Gemini NTED® home and a traditional R-2000 home, an average Ontario home (AOH) heated electrically and an average Ontario home heated with natural gas. Energy intensity values for Gemini NTED® and R-2000 were previously determined in the work done by Dixon et al. (2012), where energy modeling of a Gemini NTED® and R-2000 home was completed using EnergyPlus 4.0 software. The model used in EnergyPlus 4.0 evaluated heating energy savings of a Gemini NTED® retrofit and a traditional R-2000 house, both being single-detached, 144-m^2 in size and located in Toronto, Ontario.

For this research, annual heating energy cost savings were calculated using a four-step process adapted from Natural Resources Canada (NRCan, 2003).

Step 1: The price of energy sources in Ontario were determined
Step 2: The type of heating appliance was selected
Step 3: The house type and heating load was selected
Step 4: Annual heating energy cost savings calculated

Annual Energy Escalation Rate (e)

The annual energy escalation rate was retrieved from the Ontario Ministry of Energy. The Ministry of Energy has predicted that over the next 20 years, including taxes and other charges, residential electricity bills will rise approximately 3.5 percent per year on average (Ministry of Energy Electricity Prices, 2012). For the NPV model, 3.5 percent was used (0.035 in the formula) for the 20-year service life of the retrofit.

Discount Rate (d)

The discount rate or discount factor is a crucial part of the NPV calculation. It is a mathematical technique for determining the 'present value' of costs and benefits that occur at a future time (Guth, J., 2009). This is achieved by altering future values by a specified percentage every year – the discount rate. High discount rates result in future values decreasing more rapidly, which causes lower present values for future costs and benefits. Selecting an appropriate discount rate can prove problematic, as making predictions into the future is a difficult task. Additionally, renewable energy, energy conservation, and retrofit projects typically all have high capital costs and low future fuel costs and as a result; discount rates, which value the present and "discount" the future, can work against these types of projects.

Discount rates can be determined by calculating the weighted average cost of capital (WACC); the formula for WACC is provided in Formula (4). The weighted average cost of capital is the 'weighted average' of the required return on invested capital (both debt and equity) and represents the opportunity cost of making a specific investment. For mixed financing cases, WACC is a suitable method for determining the discount rate (Amstalden, R. et al., 2007). Applied to this research, the opportunity cost is the return a homeowner could have earned by putting the money intended for a retrofit into a different investment, such as Canada savings bonds or guaranteed investment certificates (GICs) and collecting the accrued interest.

$$WACC = \left[\left(\frac{D}{v}\right) \times r_d\right] + \left[\left(\frac{E}{V}\right) \times r_e\right] \tag{4}$$

From the above formula:

D/V = proportion of funding through debt capital

E/V = proportion of funding through equity capital

r_d = required return on debt capital

r_e = required return on equity

For the case of home retrofits, WACC is calculated from the financing options available to homeowners in order to make home improvements. For whole house retrofits, the typical finance mechanisms are mortgage refinancing or a home equity loan.

Service Life of the Retrofit (n)

The life of a project is chosen based on the length of time it is expected to be in service. Several factors can influence service life including, new product development, evolving technologies, and changing consumer attitudes and preferences.

Project Capital Cost (CC)

Project capital costs are typically derived from input costing data. In the case of retrofits, capital costs can vary from one project to the next depending on current house conditions, house size and homeowner requests. Instead of providing an estimate of the capital cost to input in the NPV formula, a project's capital cost can be solved for. The capital cost necessary to give a resulting NPV of zero can be calculated by setting NPV equal to zero and rearranging Formula (3). The resulting formula is:

$$CC = \sum_{i=n}^{n} \left[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times ECS \right] \tag{5}$$

The resulting capital cost would be the highest possible amount the project could cost in order for homeowners to make back their financial investments.

4.2.1 Sensitivity Analysis

The values and assumptions made in any model are subject to change and error. Sensitivity analysis (SA) is performed in this research to gain insight into which assumptions were critical and understand their impact on conclusions drawn. Net present value is recalculated using upper and lower bounds for the utility cost (price of electricity) and discount factor parameters in order to evaluate their impact on discounted savings. Upper and lower bounds of 20 percent were chosen for each parameter. Sensitivity calculations are performed for the energy cost savings from a Gemini NTED® home when compared to the average electrically heated Ontario home.

4.3 Carbon Emissions Reduction Valuation (CO_2ev)

In addition to evaluating the financial feasibility of the Gemini NTED® retrofit, an environmental case was built, which calculated GHG emissions of a Gemini retrofitted home and compared those emissions with expected emissions from a traditional R-2000 home and the average Ontario home scenarios that were used in the previous studies. A monetary value of GHG emissions reductions associated with Gemini NTED® retrofits (CO_2ev) were determined and incorporated into the NPV formula.

All calculations for GHG emissions are based on a one-year time period and represent the amount of annual GHGs emitted from a Gemini NTED® home, a traditional R-2000 home and an average Ontario home heated (a) with natural gas and (b) with electricity. The same parameters were used from the financial analysis in terms of area and heating energy intensity.

The following formula (Formula 6) was used to calculate emissions for homes that are electrically heated:

$$e_jE = EC \times eF_j \tag{6}$$

From the above formula:

e_jE	=	emissions of type j from electricity
j	=	CO_2, CH_4, or N_2O
EC	=	annual heating electricity consumed
eF_j	=	emission factor for emission type j

For example, if emissions of carbon dioxide were to be calculated for emissions from electricity generation, the following formula would be used:

$$eCO_2E = EC \times 130\ \frac{gCO_2}{kWh}$$

For the scenario involving average Ontario homes that are heated with natural gas, Formula (7) was used to calculate GHG emissions:

$$e_jNG = NGC \times eF_j \tag{7}$$

In the above formula:

e_jNG = emissions of type j from natural gas

j = CO_2, CH_4, or N_2O

NGC = natural gas consumed

eF_j = emission factor for emission type j

Carbon dioxide equivalents were also calculated for the different emission types in order to total the emissions and make comparisons between each scenario. Formulas (8) and (9) below, which incorporate GWPs (previously given in Table 8, pg. 29), were used to calculate carbon dioxide equivalents.

$$CO_2e_j = e_jNG \times GWP_j \tag{8}$$

$$CO_2e_j = e_jE \times GWP_j \tag{9}$$

From the above formulas:

CO_2e_j = Carbon dioxide equivalents for emission type j

j = CO_2, CH_4, or N_2O

e_jNG = emissions of type j from natural gas

e_jE = emissions of type j from electricity

GWP_j = global warming potential for emission type j

Once the carbon dioxide equivalents are calculated, total emissions from each house scenario can be calculated using Formula (10) below, where TCO_2e represents total carbon dioxide equivalents.

$$TCO_2e = CO_2e(CO_2) + CO_2e(CH_4) + CO_2e(N_2O) \tag{10}$$

The final stage of the environmental study was to quantify savings of GHGs by retrofitting to a Gemini NTED® home. In order to evaluate the savings, the total emissions from a Gemini NTED® home are subtracted from the emissions from an average Ontario (electric or natural gas) home using the following formula:

$$CO_2e\ Savings = TCO_2e(AOH_x) - TCO_2e(GEM) \qquad (11)$$

Additionally, emissions savings of a Gemini NTED® home compared to an R-2000 home are calculated using the following formula:

$$CO_2e\ Savings = TCO_2e(R2000) - TCO_2e(GEM) \qquad (12)$$

From the above formulas (10, 11 & 12):

TCO_2e	=	Total emissions in carbon dioxide equivalents
AOH	=	Average Ontario home
x	=	Natural gas or electric
GEM	=	Gemini NTED® retrofitted home
R2000	=	Typical R-2000 home

Finally, the value of the carbon emissions reduction (CO_2ev) was calculated by applying British Columbia's Carbon Tax Policy to the current scenario. To determine the value of carbon, current B.C. tax rates for natural gas usage were used.

Table 14 – Updated tax rates from B.C.'s Ministry of Finance

Fuel Type	Tax Rate as of July 2012	Units
Natural Gas	5.70	¢/m^3

In B.C., the carbon tax is applied only to natural gas heating; electrical heating is exempt from the tax. It is understood that in Ontario, a carbon tax would likely be applied to electric heating, which would result in higher tax values. However, for the purpose of this study, a tax rate of 5.7 ¢/m^3 was used to evaluate its effect on overall cost savings. The value of carbon emission reduction is calculated using the natural gas heating energy consumed in an AOH and the value of carbon (Formula 13). The value of carbon emissions reduction is therefore equal to the tax on annual heating energy.

$$CO_2ev = \ Heating\ Energy \times Cv \tag{13}$$

From the above formula:

CO_2ev = value of carbon emissions reduction ($)

Heating energy = natural gas used in an AOH

Cv = the value of carbon ($0.057/m^3)

Since emissions from electricity are not subjected to the B.C. carbon tax, the carbon reduction valuation can only be incorporated into the NPV analysis comparing annual heating energy cost savings of a Gemini NTED® home to a natural gas heated average Ontario home. The value of emissions reduction is incorporated into NPV in Formula (14) below.

$$CC = \sum_{i=n}^{n} \left[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times (ECS + CO_e ev) \right] \tag{14}$$

5.0 CASE STUDY ANALYSIS

5.1 Market Assessment

Gemini NTED®'s internal and external environments were examined to gain insight into the current status of the retrofit market in Toronto and the GTA and help design a successful commercialization strategy. Evaluation of external factors that can affect commercialization is the first step of market attractiveness from Schilling's commercialization model (2010). Technological and economics drivers are evaluated by researching the retrofit options and financial support options that currently exist for homeowners. Additionally, barriers are evaluated to identify the major issues that are preventing the successful adoption of innovation in whole-house energy retrofits.

5.1.1 Evaluating External Factors

Retrofitting existing residential heating and cooling systems and thermal envelopes presents major opportunities for efficiency improvements. Approximately half of all efficiency and/or carbon reduction potential in North American buildings is associated with retrofit improvements to existing homes (Neme et al., 2011). However, in order to achieve significant savings, a comprehensive "whole-house" retrofit approach where efficiency upgrades are made to multiple components of the home is necessary. By placing a greater emphasis on the early design processes, a whole-house retrofit approach can maximize the available benefits of a project and provide a comprehensive understanding of how and where the most energy can be saved within the home (Olgay et al., 2010).

Whole-house energy retrofits have the overall goal of reducing overall impact to the environment by lowering energy consumption and subsequent GHG emissions. Homeowners must therefore be committed to making these improvements with energy efficiency being a top priority. In a report published by the Canadian Mortgage Housing Corporation (CMHC) in 2011, reasons for renovating were reported for ten major metropolitan areas in Canada including St. John's. Halifax, Quebec, Montreal, Ottawa, Toronto, Winnipeg, Calgary, Edmonton, and Vancouver. In Canada as well as in Toronto, the majority of improvements were made to either add value to the home or extend the useful life of the property followed by needed repairs and maintenance as the second and third most common reasons for renovating. The top three reasons for renovations were the same in 2011 as they were in previous years. The most significant observed change in reasons for renovating was to make the home more energy efficient. In 2010, only 7 percent of respondents to the study were making changes to their home to make them more energy efficient. However in 2011, that number increased to 29 percent of homeowners (CMHC, 2012). This study may imply that the public is becoming more educated in the role energy efficiency can play to reduce energy consumption within the home as well as reduce subsequent GHG emissions.

The following section provides an overview of whole-house residential retrofit projects that have taken place throughout Canada. Major changes made in each scenario are discussed as well as the results of each project.

5.1.1.1 Innovative Energy Efficient Residential Retrofit Projects

Brookside Farmhouse: an R-2000 Retrofit

The Brookside Farmhouse was originally built in 1857 and is located in Nova Scotia. In its original state, the farmhouse measured a 15 on the EnergGuide Rating Scale – making it a very energy inefficient home. Homeowners were looking to complete a whole-house retrofit while preserving as much as possible of the original home. To build to the R-2000 standard, a certified builder focused mainly on the building envelope and heating equipment in the home. The major changes made included a new building envelope, new high efficiency windows and doors, rooftop solar panels, and the addition of a ground-source heat pump for space and water heating. After inspection, the home received R-2000 certification in 2012 and obtained a rating of 87 on the EnerGuide Rating Scale (Moyes, R., 2013). The Energuide Rating System is discussed in further detail in Section 5.1.1.2.

The R-2000 construction program is a voluntary national standard developed by the Office of Energy Efficiency at Natural Resources Canada. Since R-2000 was established in 1986, over 13,000 homes have been built or retrofitted to the standard across Canada (NRCan, 2010). R-2000 goes beyond the energy efficiency requirements in the Ontario Building Code. It promotes the use of cost-effective, energy efficient building practices, typically requires 40 percent less energy to operate than conventional new homes built prior to the new 2012 Ontario Building Code standards, and falls around 85 on the EnergGuide Rating Scale (NRCan, 2010).

Exact specifications are not provided for homes built to the standard, rather a checklist is provided to builders with a list of requirements relating to energy efficiency, indoor air quality, and the use of environmentally responsible products and materials. This provides designers and builders the flexibility to pick and choose amongst a variety of construction options in order to meet the standard. Although there is freedom for builders to choose how they would like to meet the standard, R-2000's main focus is the building envelope with requirements for additional insulation and increased airtightness for windows and doors. The R-2000 standards "pick-lists" are provided in Appendix B.

R-2000 is typically applied to new builds but has also been used for retrofitting existing homes looking to improve their energy performance. Application of the R-2000 standard to the existing housing stock was recognized over a decade ago for its ability to assist Canada in addressing the challenge of reducing GHG emissions (McLellan, 1996). Currently, homeowners wishing to retrofit their home to the R-2000 standard must hire an R-2000 certified builder, who can design the retrofit following the same requirements for new builds.

Now House®

Now House® is a retrofit project of the Canada Mortgage and Housing Corporation's EQuilibrium™ Sustainable Housing Demonstration Initiative that took place in Toronto, Ontario. The project converted a 60-year old singe-detached WWII home into a near zero energy home. The goal was to drastically improve the energy efficiency of the existing house with a focus on healthy indoor environments, energy and resource efficiency, and low environmental impact. Improved energy efficiency of the home was done through major envelope upgrades, plug-load reduction, new CFL lighting, grey water heat recovery, kill switches, and low-e windows (Now House, 2013). On site solar photovoltaic (PV) and solar thermal systems were incorporated into the retrofit for energy production. A full summary of upgrades made to the home can be seen in a diagram of the home in Figure 9.

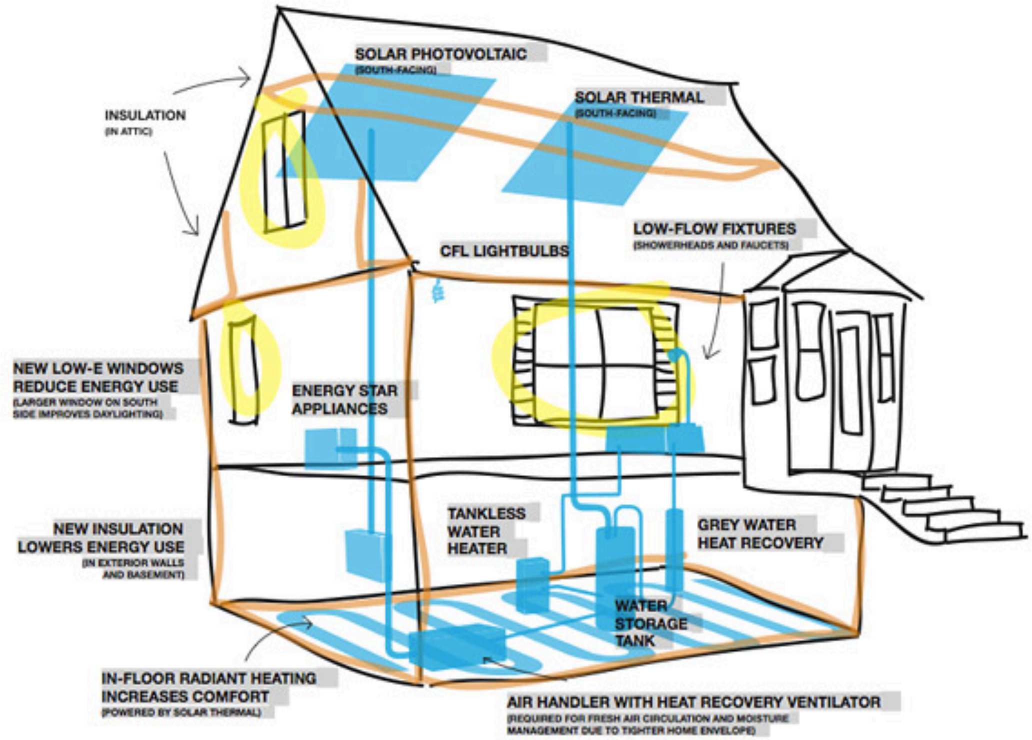

Fig. 9 – Design and technology elements of Toronto Now House (Now House, 2013)

The project is now completed and is currently undergoing a year-long monitoring process to measure changes to energy use, indoor air quality, waste production, and heat loss. From a modeling study of the completed changes, it is expected that the Now House will achieve an annual energy cost of zero, reduce electricity use by 59.8 percent, reduce heat loss and produce enough energy on site to earn an EnerGuide rating of 94, produce minimal waste, reduce GHG emissions by 5.4 tonnes annually, and improve indoor air quality. Table 15 provides a "before and after" perspective on the results achieved from the modeling study.

Table 15 – Savings from Toronto's Now House® (Now House, 2013)

	Before	**After**
Annual GHG emissions	9.7 tonnes	3.72 tonnes
Annual energy cost	\$1,266.58 (2541 m^3)	\$276.71 (555.3 m^3)
Electricity Use	Plug load: 5,110 kWh Lighting: 1,095 kWh	Plug load: 2,500 kWh Lighting: 365 kWh
Heat loss	ACH of 4.61	ACH of 1.5
Produced energy on-site	None - energy user only	Solar thermal system: 7669 MJ/year Solar PV system: 8676 MJ/year
EnerGuide Rating	68	95

While energy efficiency, healthy indoor environments, and low environmental impact were among the major elements of the retrofit, affordability and repeatability were also important aspects of the project. Originally, these homes were designed to provide affordable housing to veterans returning from WWII, however today with rising energy costs, the homes are becoming less affordable to operate. The cost of the retrofit was approximately \$85,000 to complete, which is a significant investment for homeowners to make. The project coordinators hope however that as the efficiency of new technologies continues to increase and sales go up, the costs of purchasing will go down and the cost of retrofitting will decline as a result. In terms of repeatability, because wartime homes were often built in clusters, the Now House model could easily be scaled up to hundreds of thousands homes across the country (CMHC Now House, 2013). Currently, the Now House Windsor 5 Project is underway to perform the energy retrofit on five wartime homes in Windsor and is hoped to serve as a demonstration project for a potential retrofit of 125 similar homes in the city.

The REEP House for Sustainable Living

The REEP house is a single-detached home located in Kitchener, Ontario (Figure 10). Originally built in 1920, it is one of the 43,000 pre-1960 homes in the Waterloo Region (Bin, G., 2010). The ultimate goal of the REEP retrofit project was to increase the energy efficiency of the home; raising the EnergGuide score from 44 to 89 as well as reduce energy use by 90 percent, CO_2 emissions by 63 percent, and the cost of utilities by 80 percent, all while keeping the integrity of the heritage home (REEP Green Solutions, 2013).

Fig. 10 – The REEP House in Kitchener, Ontario (Bin et al., 2012)

As of a result of the renovations, energy used for space and water heating was reduced by 86 percent (153,062 MJ/year), carbon emissions were lowered by 54 percent (7.6 tonnes per year), and energy costs were reduced by 85 percent (saving $1,894/year) (REEP Green Solutions, 2013). This was accomplished by sealing and insulating the entire building envelope, upgrading the heating and cooling systems as well as the hot water production system, replacing windows and doors, and upgrading to energy efficient appliances.

31 Sussex: Gemini Nested Thermal Envelope Design (NTED®)

Construction is currently underway at 31 Sussex Avenue in Toronto, Ontario to retrofit the existing historic home with the Gemini Nested Thermal Envelope Design (NTED®) with the intent to educate and inspire by demonstrating that this design approach is a cost-effective method of achieving superior energy performance in buildings (Touchie et al., 2011). The two-story solid masonry home was built in 1879 and was a prime candidate for an energy retrofit. Figure 11 shows both the home prior to construction (left) and under construction (right).

Fig. 11 – 31 Sussex Ave before construction (left) and during construction (right)

The images below (Figure 12 A-D) depict the inner core and outer perimeter of 31 Sussex during the construction process. Figure 12 (A) shows the entrance stairwell leading to the second floor, which is encapsulated within the inner core. Image (B) shows the entrance hallway, which is also within the inner core and leads directly into the kitchen. The front door entrance also shown in (B) will be closed off with a door, which will lead into the hallway. This small shoe room is part of the perimeter area. Image (C) shows the dining room, which is part of the perimeter and will be closed off from the kitchen. Image (D) depicts a half bathroom located on the first floor, also incorporated in the inner core.

Fig. 12 - Inner core and out perimeter areas of 31 Sussex under construction

For Gemini NTED® retrofits, operational energy savings are attained through the reduction of a home's overall heating load. During the winter months (heating season), homeowners are expected to inhabit the core areas of their home. The perimeter space will have a lower set point temperature. Duel thermal envelopes and reduced heating space results in energy savings. For example, during the heating season, the perimeter temperature can be set to 5°C, while the core temperature can be maintained at 20°C. In summer months, the core can be maintained at 24°C, while the perimeter temperature is allowed to rise between 30-35°C. With this flexibility, homeowners can choose to use and condition different spaces only when required (Pressnail et al., 2008). Additional energy savings are attained through the use of an inter-zone air-source heat pump system for space heating and cooling and an energy recovery ventilator (ERV) for sufficient ventilation. Core heating with an air-source heat pump is shown below in Figure 13.

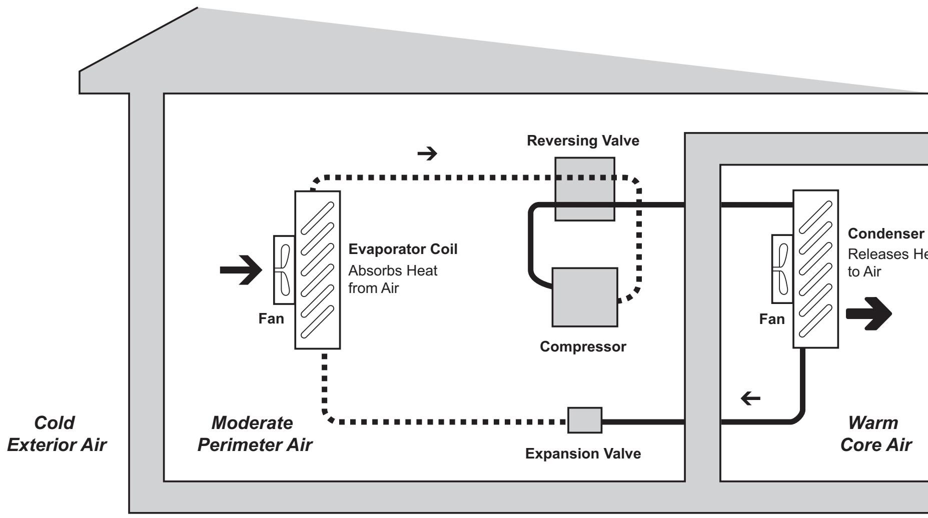

Fig. 13 – NTED® core heating with an air-source heat pump (Dixon et al., 2012)

With the air-source heat pump, heat lost from the core to the perimeter and solar heat gains to the perimeter can be recovered, increasing the efficiency of the system.

Previous energy modeling of Gemini NTED® using EnergyPlus 4.0 software compared heating energy use of a Gemini NTED® home to a traditional R-2000 style home. Results from the study demonstrated 85 percent savings in annual heating energy use with the Gemini NTED® home (1253 kWh) compared to the traditional R-2000 home (8133 kWh) (Dixon et al., 2012).

5.1.1.2 Financial and Educational Support for Homeowners

High upfront costs of residential retrofits are a major barrier to widespread acceptance and application of whole-house energy retrofits. Additionally, homeowners may be uneducated on the existing retrofit options available to them. The availability of financial incentives and educational programs could aid in a larger uptake of energy retrofits and provide homeowners the means to undergo major projects. Financial incentives and grants are typically offered by various levels of government, natural gas and electricity utilities and non-profit organizations. The following section provides a review of existing incentives and grants available to homeowners looking to undergo energy retrofits in Ontario as well as addresses the availability of educational tools to assist homeowners in understanding how to consume less energy and increase the energy efficiency of their home. Financial incentives and grants can assist homeowners in covering the costs of retrofitting their home. In the case of whole-house retrofits, the capital costs of projects are typically high and grants often play a smaller role in assisting homeowners with reducing costs. However, they do have the ability to encourage homeowners to make changes and may get people thinking about their options for making improvements.

Enbridge Home Weatherization Retrofit Program

Under this program, Enbridge is offering insulation and draft proofing at zero charge for homeowners who are also Enbridge Gas customers through two companies: Greenventure and Greensaver. Greenventure services those eligible in the Niagara region whereas Greensaver services customers in Toronto, Peel, York and Durham regions. Both assist in reducing a homeowner's energy consumption through improved attic and wall insulation and draft proofing. This service can be valued up to $5,000 and is expected to save homeowners $350 to $750 per year in energy bills. Qualification for this service requires that homes must have been built prior to 1972, insulation must not have been upgraded for over 20 years and residents are low-income families or seniors (Green Saver, 2013).

Ontario Power Authority saveONenergy^{OM} Program

The Ontario Power Authority (OPA) provides heating and cooling incentives of up to $650 for homeowners who are looking to replace their old central heating and cooling systems (OPA, 2012). Homeowners can apply for furnace replacement incentives and central air conditioning (CAC) system replacement incentives. For the furnace replacement incentive, eligible participants must replace an existing furnace with a high efficiency furnace to receive up to $250 in rebates. To receive a CAC system replacement incentive of $400, homeowners must replace their existing system with an ENERGY STAR® CAC system with a seasonal energy efficiency ratio of 15.

Canada's Energy Efficiency Awards

Canada's Energy Efficiency Awards recognize and honour Canadian innovation and achievement in energy efficiency as part of Canada's response to the global challenge of climate change. The awards are available for new construction of single homes, new construction of multiple homes, and retrofit projects. The annual awards are sponsored by Natural Resources Canada and are adjudicated by NRCan's Office of Energy Efficiency (OEE) and the National Advisory Council on Energy Efficiency (CHBA, 2004). Winners of the award receive a trophy and are assisted by the OEE to help promote their achievements in energy efficiency. For retrofits of single-detached homes, an EnerGuide House (EGH) rating must be obtained before and after the project is completed, the home must be occupied, the project must be cost effective (dollar cost per EGH point achieved) and the project must incorporate a variety of systems, technologies and practices.

ecoENERGY Retrofit Program

The federal ecoENERGY Retrofit Program was developed by Natural Resources Canada as a strategy to advance clean energy solutions and increase the energy efficiency of low-rise residential housing. The program provided homeowners with grants of up to $5,000 to make energy efficient upgrades and reduce the burden of high-energy costs. The program ran for five years until the funding was officially discontinued in March 2012. Throughout the duration of the program, approximately $934 million was paid out in grants to 640,000 people and helped homeowners save on average 20 percent on their home energy use (NRCan Home Improvement, 2012).

In addition to the federal funding, the Ontario government provided financial incentives for homeowners to make their homes more energy efficient through the Ontario Home Energy Savings Program. Grants were made available for homeowners looking to replace inefficient heating and cooling systems, ventilation systems, and domestic hot water systems and improve the building envelope with better insulation (Green Saver Rebate Programs, 2013). Additionally, Ontario established a Home Energy Audit Program, which offered 50 percent off a home energy audit, up to $150. The purpose of this program was to help homeowners identify energy inefficiencies and recommend possible courses of action to make improvements. Both provincial programs were cancelled and ended in March 2012.

CMHC Green Home Incentive

The Canadian Mortgage Housing Corporation (CMHC) has a Green Home financing option that makes energy efficiency projects more affordable through mortgage loan insurance. If homeowners purchase mortgage loan insurance, a 10 percent CMHC mortgage loan insurance premium refund and a premium refund for longer amortization periods are available when making energy-saving renovations (CMHC Green Home, 2013).

Implementation and acceptance of energy efficient retrofits requires understanding, support, and participation of the homeowner – the ultimate consumer of energy. To engage homeowners, making information available regarding various retrofit options, the importance of energy efficiency and reducing energy consumption is necessary. This can be accomplished through door-to-door canvassing, leaflets in the mail, newspapers, magazines, radio and television, demonstrations, workshops, trade shows and online programs (Reddy, 1991). This section provides an overview of programs designed to assist and educate homeowners of the resources available to them for implementing energy retrofits and the resulting benefits.

Live Green Toronto

The Live Green Toronto initiative was launched in 2008 as a component of Toronto's Climate Change, Clean Air and Sustainable Energy Action Plan. Live Green promotes and supports the greening of Toronto by offering grants, expertise, and a one-stop website full of resources, rebates, tips and tools to assist residents and businesses in taking action to reduce emissions, protect our climate and clear our air (Live Green Toronto, 2012). For the homeowner, Live Green provides tips on key areas throughout the home to save energy and water, as well as how to create less waste. Heating and cooling the home are identified as the major energy consumers in the home, as such, the program offers homeowners practical solutions for savings, which include using a programmable thermostat, increasing the insulation of your home, servicing your furnace as well as making upgrades to your furnace, air conditioner and windows. Tips on how to increase the energy efficiency of the home are also given.

Kortright Centre and Archetype Sustainable Houses

The Kortright Centre is located in Vaughan Ontario and is operated by the Toronto and Region Conservation Authority (TRCA). Kortright is a centre of excellence for urban sustainability where technologies and practices that assist in building sustainable cities are showcased to the public. A major focus of the Kortright Centre is education and learning. Several homeowner workshops are held throughout the year, which aid homeowners in learning about and understanding current sustainable building technologies. A significant educational tool for homeowners located at the Kortright Centre is the Archetype Sustainable House, where homeowners can learn about sustainable energy systems and building practices.

The Archetype Sustainable House is a semi-detached model twin house constructed in 2008 at the Living City Campus at Kortright in Vaughan Ontario (Figure 14). The home acts as a prototype for the next generation of "green" production homes (TRCA, 2011). The two homes showcase different technologies; House A in the figure below demonstrates technologies that are practical today while House B showcases sustainable technologies that may be available in the near future.

Fig. 14 – Archetype Sustainable Houses (TRCA, 2011)

The Archetype Sustainable house is open to the public and serves as an education and training centre for builders, students, and homeowners. As energy efficient features and equipment continue to be updated and improved, the homes will update and replace features within the home, which will allow for testing and monitoring of new designs as well as foster a process of continuing education.

Canadian Energy Efficiency Alliance

The Canadian Energy Efficiency Alliance (CEEA) is a not-for-profit organization working with federal and provincial governments and stakeholders to ensure energy efficiency is a priority for all sectors of the economy (CEEA, 2013). The CEEA is also a source of information for businesses and homeowners looking to increase the energy efficiency of their buildings, processes, and homes. For homeowners, the CEEA provides several tips for increasing energy efficiency within the home. It also reports on energy use within the home to educate homeowners about what areas of the home and what equipment typically consumes the greatest amount of energy. This information can assist the public with targeting areas of their homes to make improvements.

Green Communities Canada

Green Communities Canada (GCC) is a national organization comprised of several community organizations providing consumers with ideas of how to go green within their home, work, community, and on the road. Their goal is to help Canadians improve the health of their communities, conserve resources for future generations and reduce pollution (Green Communities Canada, 2013). Green Communities sponsor a number of programs with focus on energy efficiency, waste reduction, green space, sustainable transportation, and water protection. Homeowners looking to make energy efficient changes to their homes can access the Green Communities website, which provides a number of practical and affordable methods of reducing energy consumption in the home and assists homeowners with setting up a home energy audit.

EnergGuide Rating System

The EnergGuide Rating System (ERS) is the most widely adopted rating system in Canada developed by Natural Resources Canada. This rating system measures a home's level of energy efficiency by providing a number on a scale ranging from least efficient (rating of zero) to most efficient (rating of 100). Typical ERS ratings for several housing types are provided in Table 16. In order to obtain an ERS rating, a home energy audit must be conducted by a certified Natural Resources Canada certified home energy auditor.

Table 16– EnergGuide house ratings

Housing Types	**Typical Rating**
Older home not upgraded	0 – 50
Upgraded home	51 – 65
Energy efficient upgraded older home or typical new home	66 – 74
Energy efficient new home	75 – 79
Highly energy efficient new home, OBC new home, R-2000	80 – 90
Home requiring little or no purchased energy	91 - 100

EnerGuide is a well-known rating system and education tool, which allows individuals to make efficiency comparisons between homes.

5.1.1.3 Barriers to Energy Efficient Retrofits

In order to achieve improvements in the energy efficiency of a residential building, actions must be made from a range of levels; from the lowest level – the homeowner, to the highest level – government officials. As a result, barriers to making such changes can arise at any level. Several barriers to the successful adoption of energy efficient whole-house retrofits have been identified in the literature. For the purpose of this research, they have been separated into two categories: demand-side and supply-side barriers.

Demand Side Barriers

Demand side (or market pull) barriers include barriers as a result of the consumer – the homeowner. Transformation of this sector is much more difficult than with new construction. The bottom line is that homeowners must want the change, if demand is non-existent from the homeowner, the energy retrofit will not occur (Vergragt et al., 2012). From a review of the literature, several demand-side barriers were identified and common throughout publications. Common barriers for adoption of energy retrofits included cost, financing, limited understanding of benefits, uncertainty surrounding energy prices, mistrust of contractors, and the overall disruptive nature of the project (Peyman, 2010; Reddy, 1991; Saneinejad, 2011; Vergragt, 2012; Thorne, 2003; Nair, 2010).

In a publication by Reddy et al., the author takes into consideration all of the above mentioned barriers and categorizes them into six different classes of consumers; the ignorant, the poor and/or cost effective, the indifferent, the helpless, the uncertain, and the inheritors of inefficiency (Reddy, A., 1991). This paper refers to consumers as those who may be purchasing energy efficient appliances or making minor energy efficient improvements to their home. For this research, the six categories have been applied to homeowners who are considering undergoing a whole-house retrofit. The six categories of homeowner all present different challenges to the acceptance and adoption of energy retrofits.

Successful adoption of energy efficient improvements requires that homeowners are aware of current technologies, the benefits that go along with making improvements, and the associated costs. Ignorant consumers/homeowners are those that are unaware of these items. They are uneducated in terms of the retrofit options that are available to them and more importantly they are uneducated in terms of the related environmental and financial benefits that go along with making improvements. Poor and/or First-Cost Sensitive homeowners are those that are fully knowledgeable regarding retrofit options and the resulting benefits, however these homeowners are unable to afford the high costs that typically go along with high efficiency items or are unable to afford the high upfront costs. Indifferent homeowners are those that are fully knowledgeable of the options and benefits and area able to afford the associated costs, they however are not motivated to make improvements. This may be because their energy costs are not significant enough relative to their other expenses. Additionally, this group may believe that their improvements will not be significant enough to make an impact and therefore do not feel responsible to make changes. The Helpless are a class of homeowners that are knowledgeable, can afford to make improvements, and are motivated to do so, however they become overwhelmed (or helpless) when the task at hand becomes very large. Whole-house retrofits are a huge undertaking, and as a result homeowners may not know where to begin when undergoing a project of this magnitude. Uncertain homeowners are a group who are wary of the resulting benefits of the retrofit, as they are highly dependent on the future prices of energy. Since the benefits of a whole-house retrofit are spread out over a long lifetime, if there is a lot of uncertainty surrounding future energy prices, homeowners may put off making any major changes. The final class of homeowners is the Inheritors of Inefficiency. These groups of people are those that may be renting a home and have “inherited” inefficient equipment and are unable to make significant changes. In this scenario, building managers or owners would inherit the costs of improvements but would not reap the benefits; also referred to as the split incentive problem.

Additional demand side barriers could include a homeowner’s uncertainty surrounding long payback periods. They may want to sell the house before their investments in increased energy efficiency have been fully paid back via energy cost savings (Persam, S., 2011). Furthermore, homeowner's may not wish to add to their personal debt through financing the project.

Supply Side Barriers

Since the cancellation of the federal ecoENERGY program and Ontario's Home Energy Savings Program, many contractors have had to lay off a significant portion of their workforce (Saneinejad, 2011) and as a result, a declining workforce is identified as a major barrier to the uptake of energy retrofits. The lack of availability of a skilled workforce to successfully upgrade the housing stock can also contribute to a homeowner's mistrust of contractors (Vergragt et al., 2012).

As a result of the declining workforce, remaining contractors may lack the necessary marketing and sales skills to successfully sell efficiency improvements. With the uncertainty of the consumer demand side, contractors are faced with risk involving investing time and resources in learning new, energy efficient retrofit skills (Thorne, 2003). Additionally, they may be reluctant to identify problems that fall outside their area of expertise with concerns of losing business. This poses a barrier to whole-house retrofits, as only certain areas of the home are targeted for improvements, instead of including all possible opportunities.

5.1.2 Porter's 5 Forces Model

The Porter's Five Forces model was used to identify the profitability of the Gemini NTED® design and assist in understanding both the strength of Gemini's current competitive position, and the strength of positions that it may want to move into in the future (Thompson et al., 2010). Collection and interpretation of market research is used to assist in making predictions involving who will use this building system.

The five competitive forces affecting the retrofit industry's profitability were evaluated in three steps:

1. *Parties involved for each of the five forces were identified along with the specific factors that bring about competitive pressures*
2. *The strength of the identified parties and pressures were evaluated and ranked on a scale of 1 – 3; 1 being weak, 2 being moderate to normal, and 3 being strong*
3. *The strength of the five competitive forces were evaluated as a whole*

The following definitions are provided for weak, moderate, and strong:

Weak: competition is nearly non-existent
Moderate: competitive pressures are lively and healthy, acceptable profits are possible
Strong: competitive pressures are vigorous and profit margins are squeezed to bare-bones levels

The Threat of Entry

New entrants into the retrofit market were identified as any possible start-up companies, organizations, or projects that are looking to retrofit existing homes with the end goal of reducing heating energy use and GHG emissions. The threat of entry into the retrofit market in Ontario was evaluated based on existing barriers new entrants may face; barriers were previously described in Section 3.2. Table 17 below lists the seven possible barriers to entry, describes whether or not they exist within the GTA, and identifies the strength of each barrier as being weak, moderate or strong.

Table 17 – Results from an evaluation of entry barriers to the retrofit market

Barriers to Entry	Brief Description of Barrier	Strength of Barrier
Supply-side economics of scale	• No existing retrofit brands that are undergoing work on a mass scale • Therefore, new entrants are not forced to enter the industry on a large scale	Weak (1)
Demand-side benefits of scale	• Homeowners may be less willing to undergo retrofits that are not as well established/accepted (R-2000 brand for example) • However, retrofits are a unique case, costs vary from project to project – consumers do not have much control over costs	Weak (1)
Customer switching costs	• Switching costs involving natural gas to electric heating are high and discourage entry • Switching costs make it difficult to accumulate customers	Strong (3)
Capital requirements	• Capital requirements may stem from introductory advertising and sales promotion campaigns • Commercials, social media, conference presentations, home shows	Moderate (2)
Incumbency advantages independent of size	• R-2000 is an established brand identity and is operated through Natural Resource Canada's Office of Energy Efficiency • Been in operation for over 25 years	Moderate (2)
Unequal access to distribution channels	• Existing brands (like R2000) have strong, well-functioning distributor-dealer networks, resulting in an up-hill battle for newcomers like Gemini to enter the market	Moderate (2)
Restrictive government policy	• No existing policy preventing entry • Cancelation of funding may deter entry	Weak (1)

The strength of each barrier was evaluated by assigning points for each level: weak, moderate, or strong. A label of weak is assigned 1 point; moderate is assigned 2 points, and strong is assigned 3 points. All points are summed and divided by the number of barriers evaluated to determine an overall strength for the threat of entry.

Sum of barrier strengths	=	12
Overall threat of entry strength	=	12 ÷ 7
	=	1.7

The overall strength of the threat of new entrants to the retrofit industry is moderate.

The Power of Suppliers

Suppliers are powerful if they are able to capture more value for themselves by charging higher prices or limiting the quality of their services. Table 18 lists the suppliers for the 31 Sussex retrofit project. General suppliers for the retrofit industry include large retailers like Home Depot, Lowes, Rona, and Home Hardware. Large retailers like Home Depot target professional contractors through extended credit programs. Contractors may go directly to the manufacturer (like Uponor or BASF) for certain materials however it is more common for contractors to use major supplier groups.

Table 18 – 31 Sussex Gemini NTED® supplier list

Supplier	Material
BASF – The Chemical Company	Closed-cell spray polyurethane foam insulation
Advanced Building Products Inc.	Mortairvent
DuPont	Tyvek weatherization systems
Solatube International Inc.	Light tubes
Roxul	Roxul AFB
Zola European Windows	Wood windows
Uponor	Radiant floor systems
Daikin AC Inc.	Heat pump

The following table lists the five points considered for determining the power of suppliers:

Table 19 – Assessing the power of suppliers in the retrofit industry

A supplier is powerful if:	Applied to the retrofit industry	Strength
It is more concentrated than the industry it sells to	• The retrofit/construction industry is dominated by several major suppliers • Suppliers are not concentrated • Contractors can also go to the manufacturer for certain materials	Weak (1)
If they do not heavily depend on the industry for revenue	• The retrofit/construction industry accounts for a large portion of the suppliers profit • Suppliers rely on this industry for revenue • Professional customers are the largest category of customer for major suppliers like Home Depot and Rona	Weak (1)
If high switching costs are incurred with changing suppliers	• Changing suppliers can be costly when you've invested time and money training on one company's equipment – however in this case, standard building practices and equipment are being used • No associated switching costs	Weak (1)
If they offer products that are differentiated	• Materials required for a Gemini NTED® retrofit are a commodity – they are readily available • Items are not differentiated	Weak (1)
If there is no substitute for what they provide	• In terms of building materials, several options exist for purchase • May encounter supplier power with air source heat pumps	Weak (1)

From the table above, each category received a rating of weak; therefore the overall power of suppliers is weak.

The Power of Buyers

Powerful buyers/customers have the ability to force down prices, demand better quality, demand better service and play industry participants against one another – all at the expense of industry profitability. Two categories of buyers were identified within the retrofit industry: homeowners and contractors. However, for the case of whole house retrofits, contractors are assumed to be the main buyers, acting as the source of contact between homeowners and suppliers and working with homeowners to determine what materials to use and the associated costs. For this research, contractors are considered the buyers when assessing power over the retrofit industry. To evaluate the power of buyers (contractors), the four points previously described in Section 3.2 were considered and are discussed below in Table 20.

Table 20 – Assessing the power of buyers in the retrofit industry

A buyer is powerful:	Applied to the retrofit industry	Strength
If there are few of them or they make purchases in large volumes	• There are several contractor/buyer groups in this industry, which decreases their bargaining power • However, for large projects like whole house retrofits, contractors often make purchases in large volumes which can increase their bargaining power	Moderate (2)
If the products available within the industry are standardized or undifferentiated	• Materials are standardized and undifferentiated • Buyers can purchase equivalent products across supplier groups	Strong (3)
If switching costs are low or non-existent	• Buyers in this industry do not face high switching costs making it easier to switch between suppliers and look for lower prices	Strong (3)
If they have the ability to integrate backward and produce the industry's product themselves	• Not applicable in this industry	Weak

Sum of strengths = 8

Overall strength of buyers = $8 \div 4$

= 2

Therefore, the overall strength of buyers is moderate.

The Threat of Substitutes

A substitute is something that performs the same function as an industry's product but through different means. When there is a high threat of substitutes, industry profitability can suffer. To assess the competitive pressures stemming from substitute products, boundaries must first be defined. The main focus of a Gemini NTED® retrofit is to reduce heating energy of a residential unit, which is achieved through a double envelope and heat pump operating between the perimeter and core spaces. Therefore, substitutes to Gemini NTED® were identified as any service with the main goal being reduced heating energy. Table 21 lists identified substitutes for reducing heating energy within the home along with a brief description of each.

Table 21 – Substitutes to Gemini NTED®

Substitute	Description
Service your heating system annually	• Clean the unit and change filters annually
Install a programmable thermostat	• Program lower temperatures while you're at work and at night while sleeping
Add weather stripping around windows and doors	• Door thresholds, window caulking and plastic window film can prevent keep warm air from escaping
Utilize or install ceiling fans in your home	• Hot air rises, by running fans slowly, you can keep warm air circulating
Check the arrangement of your furniture	• Make sure furniture is not blocking vents or baseboard radiators
Be smart about the temperature you set in your home	• By simply turning down your thermostat, you can directly save money on your energy bill
Utilize the sun	• Open windows and drapes during the day to allow the sun to heat your home

To assess the threat of substitutes listed in Table 21 above, the following two points were considered:

1. *The threat of substitutes is high if good substitutes are readily available and perform on the same level of the industry's product*

2. *The threat of substitutes is high if they are attractively priced*

For each of the substitutes listed, costs are relatively low and in some cases non-existent. These options may be attractive to homeowners looking to make quick fixes and minor improvements. Out of all the substitutes listed, none achieve heating energy savings close to that of a Gemini NTED® retrofit and therefore do not make good substitutes for homeowners looking to significantly reduce heating energy within their home. Therefore, the overall threat of substitutes to Gemini NTED® is weak.

Rivalry Among Existing Competitors

Rivalry amongst competitors in an industry can limit profitability and depends on both the intensity in which companies compete and the basis on which they compete. Gemini's largest competitor is the R-2000 standard – a whole house retrofit. To evaluate the intensity of rivalry within the retrofit industry, the five points previously discussed in Section 3.2 were considered and are discussed below in Table 22.

Table 22 – Evaluation of the intensity of rivalries within the retrofit industry

Rivalry is high if:	Applied to the retrofit industry	Strength
There are numerous competitors, equal in size and power	• R-2000 is considered to be the top competitor	Weak (1)
Growth within the industry is slow	• Buyer demand is growing slowly in the retrofit market however there has been an increase in energy efficient improvements made to homes • Contractors must be certified to build to the R-2000 standard	Moderate (2)
There are numerous exit barriers	• Not applicable in this industry	Weak (1)
Rivals are committed and have goals that go beyond economic performance	• Major focus of R-2000 and Gemini NTED® is environmental • Want to reduce residential emissions and decrease energy consumption • Economic performance is not the only focus	Moderate (2)
Companies are unfamiliar with one another	• Information regarding R-2000 is readily available through NRCan and CHBA websites	Weak (1)

Sum of strengths = 7

Overall strength of buyers = 7 ÷ 5

= 1.4

Therefore, the overall strength of the intensity of rivalry among existing competitors is weak.

The basis of competition within an industry relies on the dimensions on which rivals compete. Competition on the same dimension can be destructive and can drive down profitability within an industry. Table 23 lists five dimensions for rivalry and discusses R-2000 and Gemini NTED®'s position for each.

Table 23 – Comparing dimensions for rivalry: the R-2000 standard and Gemini NTED®

Dimension for Rivalry	R-2000	Gemini NTED®
Product costs	- Costs vary from project to project depending on the initial state of the home, what the homeowner wants - No single set price for comparisons	- Costs vary from project to project depending on the initial state of the home, what the homeowner wants - No single set price for comparisons
Overall objectives	- Increase energy efficiency, improve performance of building envelope - Build "healthier" homes with improved ventilation and indoor air quality, reduce GHGs	- Increase energy efficiency - Reduce heating energy with double envelope design - Focus on the house as an integrated "system," reduce GHGs
Product features	- Checklist of requirements for energy efficiency, indoor air quality and environmentally responsible products	- Double envelope design - Inter-zone heat pump - Smaller livable space during heating season
Image	- Voluntary national energy efficiency standard - Operated by NRCan's Office of Energy Efficiency	- Not yet applicable
Marketing tactics	- Range of partners across Canada - Home show exhibits - R-2000 workshops and training for builders	- Not yet applicable

In terms of competition across dimensions, rivalry could exist between Gemini NTED® and R-2000 when considering overall objectives. The objectives between the two retrofit options are similar, both have a strong emphasis on improved energy efficiency, reducing GHG emissions and improving the building envelope. Costs are difficult to compare, as each retrofit project is unique and depends on a number of factors. However, in both cases, whole-house retrofits typically require large capital investments from the homeowner. Product features between Gemini NTED® and R-2000 are very different. R-2000 provides a checklist where homeowners and builders and pick and choose different options for meeting the R-2000 standard. A Gemini NTED® retrofit is more straightforward; the main design is the double envelope to reduce heating energy. Image and marketing tactics for Gemini NTED® have not yet been established, however with an understanding of R-2000's image and marketing tactics, Gemini NTED® can adopt different strategies to avoid rivalry across the same dimensions. Overall, the strength of rivalry across dimensions is considered to be weak.

With both the intensity of rivalry and rivalry across dimensions being weak, the overall threat of rivalry within this industry is also considered to be weak.

Table 24 – Summary of the strength of the five forces affecting industry profitability

Industry Force	Weak	Moderate	Strong
Threat of entrants		✓	
Power of suppliers	✓		
Power of buyers		✓	
Threat of substitutes	✓		
Competitive rivalry	✓		
Overall industry		✓	

From this analysis, the power of suppliers, threat of substitutes, and competitive rivalry were found to be weak. Both the threat of entrants and power of buyers were found to be moderate in strength. Weak is indicative of an attractive industry, moderate represents a moderately attractive industry, and strong represents an unattractive industry. Based on this analysis, the retrofit industry is moderately attractive.

5.2 Financial Analysis of Gemini NTED®

The quantitative impact of the Gemini NTED® retrofit system can be measured by the economic value of the improved energy efficiency. The economic value of improved energy efficiency was evaluated using net present value and simple payback. The following sections provide the formulas used for each calculation along with justification for their use in this research.

5.2.1 Net Present Value and Simple Payback

To evaluate the financial feasibility of completing a Gemini NTED® retrofit, quantitative tools including net present value (NPV) and simple payback (SP) were employed. In order to compute the NPV model, each component of the formula was defined, beginning with annual energy cost savings (ECS_j) of a Gemini NTED® home. The following section describes how each item in the formula was determined and highlights any assumptions that had to be made.

5.2.1.1 Annual Energy Cost Savings (ECS_j)

Energy savings for a Gemini NTED® home were calculated based on heating energy intensity values; the total amount of energy consumed per unit of heated area. Energy intensity values are most often expressed in gigajoules per square metre (GJ/m^2) or kWh per square metre (kWh/m^2). Comparisons were made between an average Gemini NTED® home and a traditional R-2000 home as well as an average Ontario home, heated with electricity or heated with natural gas. Table 25 below provides a summary of the energy intensities used in each scenario.

Table 25 – Expected residential heating energy intensities for different house types

Scenario		Heating Energy Intensity	Source
1	Gemini NTED®	17 kWh/m^2	Dixon et al., 2012
2	R-2000	56 kWh/m^2	Dixon et al., 2012
3	Average Ontario Home	139 kWh/m^2	NRCan, 2009

Energy intensity values for Gemini NTED® and R-2000 were previously determined in the work done by Dixon et al. (2012), where energy modeling of a Gemini NTED® and R-2000 home was completed using EnergyPlus 4.0 software. The model used the study was a single-detached 144 m^2 house located in Toronto, Ontario with an area of 144 square metres.

Heating energy cost savings were calculated using a four-step process adapted from Natural Resources Canada (NRCan, 2003).

Step 1: The price of energy sources in Ontario were determined
Step 2: The type of heating appliance was selected
Step 3: The house type and heating load was selected
Step 4: Annual heating energy cost savings calculated

Step 1: Energy Prices

The price of current energy sources in Ontario were obtained from the Ontario Energy Board website. Energy content values were obtained from Natural Resources Canada (NRCan, 2003).

Table 26 – Current energy prices in Ontario (OEB, 2013)

Energy Source	Local Unit Price
Electricity	8.390 ¢/kWh
Natural Gas	25 ¢/m^3

As of April 5, 2013, new electricity prices for households were released (OEB, 2013); the updated time-of use (TOU) prices are provided below in Table 27.

Table 27 – Time of use prices for Ontario households and small businesses

Category	Time (s)	Price
Off-peak	Weekdays: 7 PM – 7 AM + weekends/holidays	6.7 ¢/kWh
Mid-peak	Weekdays: 7 – 11 AM & 5 – 7 PM	10.4 ¢/kWh
Peak	Weekdays: 11 AM – 5 PM	12.4 ¢/kWh

To calculate the local unit price of electricity in Ontario given in Table 26, the following assumptions were made (taken from OEB, 2013):

Average residential consumption:	800 kWh/month
Off-peak use:	64 percent
Mid-peak use:	18 percent
Peak use:	18 percent

To calculate the average cost of electricity a homeowner in Ontario pays per hour, an average monthly cost for electricity for a household had to be calculated. To find the average monthly cost, first, the percent of electricity consumed during each TOU was multiplied by the average consumption per month (A). The resulting values (in kWh) were the multiplied by the cost of electricity corresponding to each TOU to give you the average amount an Ontario residence is paying per month for electricity during each TOU (B). The costs were then summed to give the total average monthly electricity cost.

	Peak:	800 kWh × 0.18	=	144 kWh
A	Mid-peak:	800 kWh × 0.18	=	144 kWh
	Off-peak	800 kWh × 0.64	=	512 kWh

	Peak:	144 kWh × 12.4 ¢/kWh	=	$ 17.86
B	Mid-peak:	144 kWh × 10.4 ¢/kWh	=	$14.98
	Off-peak:	512 kWh × 6.7 ¢/kWh	=	$ 34.30
		Average Monthly Cost	**=**	**$ 67.14**

To determine the average current cost of electricity a homeowner in Ontario pays per hour (8.390 ¢/kWh), the calculated average monthly electricity cost was divided by the average amount of energy an Ontario household consumes per month (800 kWh).

Step 2: Heating Equipment

Natural Resources Canada provides a list of heating equipment available to homeowners in Canada along with their average seasonal efficiency values (NRCan, 2003).

Table 28 – Heating equipment options for natural gas and electricity (NRCan, 2003)

Energy Source	Technology	Seasonal Efficiency (AFUE) %
Electricity	Electric Baseboards Electric Furnace or Boiler Air-Source Heat Pump	100 100 100
Natural Gas	Conventional Mid-efficiency model High-efficiency condensing furnace	60 78-84 89-97

Gemini NTED® homes utilize an air-source heat pump for heating purposes and have the option of electric baseboards for additional heat if necessary. For this study, to evaluate natural gas heated homes in Ontario, mid-efficiency furnaces with an efficiency of 80 percent were chosen for the study to represent a typical Ontario residence. To evaluate homes that are electrically heated, electric baseboards were chosen as the heating equipment with an efficiency of 100 percent.

Step 3: House Type and Heat Load

As previously stated, the calculations done throughout this section are based on a single-detached home that is 144 m^2 in size.

Natural Resources Canada Survey of Household Energy Use was used to establish the areas for NTED® perimeter and core for modeling. The entire buildings area (core + perimeter) was chosen to be 144 square metres (slightly higher than Ontario average of

139 m²). The individual core and perimeter areas of 72 square metres fall within the second largest category of dwelling area in Canada (Chart 5). For this research, the same square footage was used in the calculations in order to be consistent with the previous research.

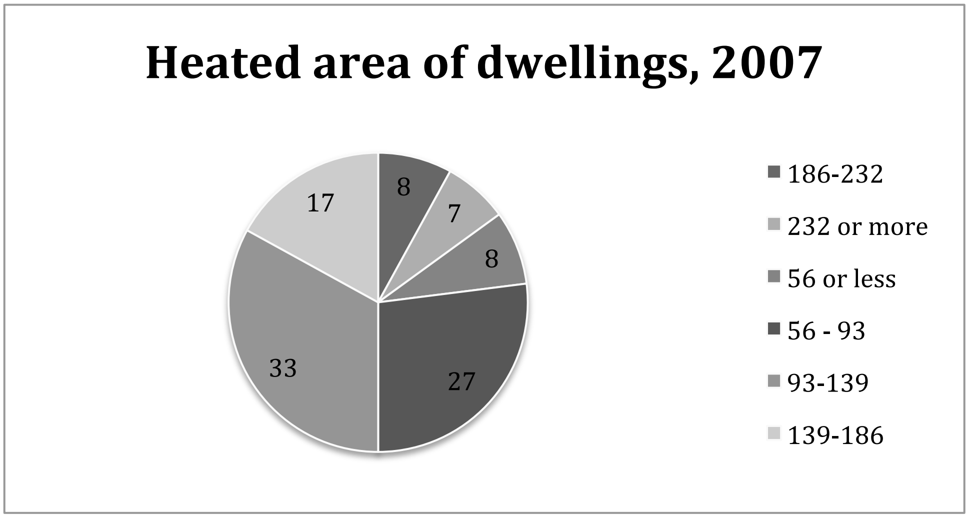

Chart 5 – Heated area of dwellings in Ontario

Heating energy intensities were used to calculate the average heat load for each house scenario (Table 29).

Table 29 – Annual heating energy load for each house scenario

Scenario	Energy Intensity	Heated Area	Heat Load
Gemini NTED®	17 kWh/m²	72 m²	1224 kWh
R-2000	56 kWh/m²	144 m²	8064 kWh
AOH	139 kWh/m²	144 m²	20,000 kWh

Annual heating energy loads of a Gemini NTED® home were compared to both an average Ontario home (AOH) heated electrically and an AOH heated with natural gas. To calculate heating loads for each scenario, energy content and seasonal efficiency of heating equipment is incorporated. Table 30 provides the energy content for both natural gas and electricity as well as the seasonal efficiency of heating equipment used. Formula (14) below was used to calculate consumption:

$$Energy\ used = \frac{Heating\ Load\ (GJ)}{Seasonal\ Efficiency\ x\ Energy\ Content}\ x\ 100 \qquad (14)$$

Table 30 – Energy content and heating equipment efficiencies for an AOH

	Energy Content (kWh or m^3)	**Efficiency**	**Energy Used (kWh or m^3)**
AOH (electrically heated)	0.0036 GJ/kWh	100 %	20,000 kWh
AOH (natural gas heated)	0.0375 GJ/m^3	80 %	2,400 m^3

Step 4: Annual Heating Cost and Savings

The energy consumed for heating that was calculated previously using Formula (14) was used to calculate the annual heating cost for each scenario, shown below in Formula (15):

$$Heating\ Cost\ (\$) = Energy\ cost\ x\ Energy\ used \qquad (15)$$

Results of the calculations are provided below in Table 31:

Table 31 – Annual heating cost of each house scenario

Scenario	**Heating Energy Used**	**Cost of Energy**	**Annual Heating Cost**
Gemini NTED®	1224 kWh	8.390 ¢/kWh	$102.69
R-2000	8064 kWh	8.390 ¢/kWh	$676.57
AOH (electricity)	20,000 kWh	8.390 ¢/kWh	$1,678.00
AOH (natural gas)	2,400 m^3	25 ¢/m^3	$600

Example calculation (AOH natural gas):

Heating cost ($) = Energy cost × Energy used

= (25 ¢/m^3 × 2,400 m^3) ÷ 100

= $600.00

To calculate cost savings from a Gemini NTED® home, the annual heating cost for Gemini NTED® was subtracted from the heating cost of the AOH and R-2000 scenarios using Formulas (16) and (17) below.

$$ECS(\$) = \text{Annual cost of AOH} - \text{Annual cost of Gemini NTED} \quad (16)$$

$$ECS(\$) = \text{Annual cost of R2000} - \text{Annual cost of Gemini NTED} \quad (17)$$

Results of the calculations are provided below in Table 32:

Table 32 – Annual heating energy costs savings

House Scenarios	Annual Heating Energy Cost Savings
Gemini vs. R-2000	\$573.88
Gemini vs. AOH with electricity	\$1,575.31
Gemini vs. AOH with natural gas	\$497.31

Example calculation (Gemini vs. AOH natural gas):

ECS (\$) = Annual cost of AOH – Annual cost of Gemini NTED®

ECS (\$) = \$600 − \$102.69

ECS (\$) = \$497.31

5.2.2 Annual Energy Escalation Rate (e)

The annual energy escalation rate was retrieved from the Ontario Ministry of Energy website. The Ministry of Energy has predicted that over the next 20 years, including taxes and other charges, residential electricity bills will rise approximately 3.5 percent per year on average (Ministry of Energy Electricity Prices, 2012). For the NPV model, 3.5 percent was used (0.035 in the formula) for the 20-year service life of the retrofit.

5.2.3 Discount Factor (*d*)

For the case of home retrofits, the discount factor, or WACC, is calculated from the financing options available to homeowners to make the improvements. For mixed financing cases, WACC is a suitable method for determining the discount rate (Amstalden, R. et al., 2007). For whole house retrofits, a common payment mechanism is mortgage refinancing.

Through the CMHC, a "Green Home" financing option is available to individuals who are either purchasing a home with the intention of renovating to improve energy efficiency or to individuals who are interested in making energy efficiency improvements to their existing home. With the purchase of CMHC Loan Insurance, the homeowner can pay their lender as little as a 5 percent down payment on their loan and finance the remaining 95 percent. In this scenario, the individual must have a home energy audit completed by a certified NRCan energy auditor to obtain an EnerGuide rating prior to and after improvements being made (CMHC Improvement, 2012). The homeowner is then subjected to mortgage interest rates, which are typically lower than personal loan or line of credit interest rates and can pay back the loan over a longer amortization period. The mortgage interest rate is representative of the return on debt capital (r_d) and was determined by averaging current mortgage interest rates in Ontario. Table 33 below provides a list of mortgage rates from major banks and the average used in the net present value formula.

Table 33 – Ontario Mortgage Rates (Rate Hub, 2013)

Ontario Mortgage Rates (%)	
President's Choice Financial	3.49
BMO Bank of Montreal	3.59
TD Canada Trust	3.69
RBC Royal Bank	3.69
National Bank of Canada	3.69
Scotiabank	4.99
Average: 3.86 %	

Equity in the WACC formula is representative of the 5 percent down payment required of homeowners for the cost of improvements and is also lost opportunity cost to the homeowner. Instead of investing this money into home improvements, a homeowner could put this money towards purchasing long-term savings bonds or guaranteed investment certificates (GICs) and collect the accrued interest at a set point in the future. The required return on equity capital (r_e) was determined from current interest rates on 20-year GICs provided by Manulife Financial. To stay consistent with the 20-year service life of the retrofit, it was necessary to select an interest rate that was locked in for the 20-year time period. Manulife Financial offers 20 year GICs with an annual interest rate of 2.80 percent (Manulife Investments, 2013) and a minimum investment of $2,500. Canadian government bonds typically have an investment period of up to 10 years, and are therefore not applicable to this research.

The following calculation was completed using Formula (4) to determine the discount rate (WACC) to use in the NPV formula:

$$WACC = \left[\frac{D}{V} \times r_d\right] + \left[\frac{E}{V} \times r_e\right]$$

$$WACC = (95 \times 0.0386) + (5 \times 0.028)$$

$$WACC = 3.807 \text{ percent}$$

5.2.4 Service Life of the Retrofit (*n*)

A service life of 20 years was chosen for the Gemini NTED® retrofit, the value was based on a review of available literature concerning economic analysis of whole-house retrofits (Ashuri et al., 2011, Galvin et al., 2012 & Liu et al., 2010).

5.2.5 Project Capital Cost (CC)

Since the Gemini NTED® case study at 31 Sussex is a research project funded by the University of Toronto and several other sources, the actual cost of the retrofit a homeowner will encounter is not yet known. This research will provide a cost that is necessary to make economic sense. This is done by rearranging the NPV formula and solving for a project capital cost (CC) that will give a resulting NPV of zero.

$$CC = \sum_{i=n}^{n} \frac{(1+e)^{i-1}}{(1+d)^{i}} \times (ECS)$$

The resulting capital cost value is the highest possible amount that the retrofit can cost in order for homeowners to make back the financial investment in the project.

5.3 Results of the NPV and SP Model

Discounted savings were calculated for each of the four scenarios (circled in the NPV formula below) and are listed in Tables 34, 35, and 36.

$$NPV = -CC + \sum_{i=n}^{n} \left[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times (ECS_i) \right]$$

Table 34 – Discounted savings ($) for Gemini NTED® vs. R-2000 over a 20-year period

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	573.876	1	1.038	0.963	552.830
2	573.876	1.035	1.078	0.960	551.195
3	573.876	1.071	1.119	0.958	549.565
4	573.876	1.109	1.161	0.955	547.939
5	573.876	1.148	1.205	0.952	546.319
6	573.876	1.188	1.251	0.949	544.703
7	573.876	1.229	1.299	0.946	543.092
8	573.876	1.272	1.348	0.944	541.486
9	573.876	1.317	1.400	0.941	539.885
10	573.876	1.363	1.453	0.938	538.288
11	573.876	1.411	1.508	0.935	536.696
12	573.876	1.460	1.566	0.932	535.109
13	573.876	1.511	1.625	0.930	533.526
14	573.876	1.564	1.687	0.927	531.949
15	573.876	1.619	1.751	0.924	530.375
16	573.876	1.675	1.818	0.921	528.807
17	573.876	1.734	1.887	0.919	527.243
18	573.876	1.795	1.959	0.916	525.684
19	573.876	1.857	2.034	0.913	524.129
20	573.876	1.923	2.111	0.911	522.579

Table 35 - Discounted savings ($) for Gemini NTED® vs. AOH (electricity)

Year, *i*	Annual Energy Cost Savings, *ECS* ($)	(1+*e*)^*i*-1	(1+*d*)^*i*	(1+*e*)^*i*-1 ÷ (1+*d*)^*i*	Discounted Savings ($)
1	1575.306	1	1.0381	0.963	1517.534
2	1575.306	1.035	1.0776	0.960	1513.046
3	1575.306	1.071	1.1186	0.958	1508.571
4	1575.306	1.109	1.1612	0.955	1504.110
5	1575.306	1.148	1.2054	0.952	1499.661
6	1575.306	1.188	1.2513	0.949	1495.226
7	1575.306	1.229	1.2989	0.946	1490.804
8	1575.306	1.272	1.3484	0.944	1486.395
9	1575.306	1.317	1.3997	0.941	1482.000
10	1575.306	1.363	1.4530	0.938	1477.617
11	1575.306	1.411	1.5083	0.935	1473.247
12	1575.306	1.460	1.5657	0.932	1468.890
13	1575.306	1.511	1.6253	0.930	1464.546
14	1575.306	1.564	1.6872	0.927	1460.214
15	1575.306	1.619	1.7515	0.924	1455.896
16	1575.306	1.675	1.8181	0.921	1451.590
17	1575.306	1.734	1.8874	0.919	1447.297
18	1575.306	1.795	1.9592	0.916	1443.017
19	1575.306	1.857	2.0338	0.913	1438.749
20	1575.306	1.923	2.1112	0.911	1434.494

Table 36 - Discounted savings ($) for Gemini NTED® vs. AOH (natural gas)

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	497.306	1	1.038	0.963	479.068
2	497.306	1.035	1.078	0.960	477.651
3	497.306	1.071	1.119	0.958	476.239
4	497.306	1.109	1.161	0.955	474.830
5	497.306	1.148	1.205	0.952	473.426
6	497.306	1.188	1.251	0.949	472.026
7	497.306	1.229	1.299	0.946	470.630
8	497.306	1.272	1.348	0.944	469.238
9	497.306	1.317	1.400	0.941	467.850
10	497.306	1.363	1.453	0.938	466.467
11	497.306	1.411	1.508	0.935	465.087
12	497.306	1.460	1.566	0.932	463.712
13	497.306	1.511	1.625	0.930	462.340
14	497.306	1.564	1.687	0.927	460.973
15	497.306	1.619	1.751	0.924	459.610
16	497.306	1.675	1.818	0.921	458.251
17	497.306	1.734	1.887	0.919	456.895
18	497.306	1.795	1.959	0.916	455.544
19	497.306	1.857	2.034	0.913	454.197
20	497.306	1.923	2.111	0.911	452.854

Table 37 – Summary of total discounted savings for each scenario

Scenario	**Sum of Discounted Savings ($)**
Gemini vs. R-2000	$10,751
Gemini vs. AOH with electricity	$29,513
Gemini vs. AOH with natural gas	$9,317

With a discount rate of 3.807 percent, an energy escalation rate of 3.5 percent per year over 20 years, and a service life of 20 years, the discounted savings for a Gemini NTED® home vs. R-2000 is $10,751. Discounted savings for a Gemini NTED® home vs. an AOH home electrically heated is $29,513 and savings for a Gemini NTED® home vs. an AOH home heated with natural gas was calculated to be $9,317.

For a project to make economic sense and be worth pursuing, the calculated net present value must be at least equal to zero. To obtain an NPV of zero, the capital cost of the project must be equal to the discounted savings over the 20-year time period.

$$CC = \sum_{i=n}^{n}[\frac{(1+e)^{i-1}}{(1+d)^{i}} \times ECS]$$

The project capital costs listed below in Table 38 are the maximum costs for each scenario in order to obtain an NPV of zero (break even on costs and savings).

Table 38 – Maximum project capital costs for NPV equal to zero

Scenario	Capital Cost ($)
R-2000 to Gemini NTED®	$10,751
AOH (electricity) to Gemini NTED®	$29,513
AOH (natural gas) to Gemini NTED®	$9,317

The situation with the most potential is an average Ontario home that is currently heated with electricity. In this scenario, homeowners could undergo a Gemini NTED® retrofit with a maximum capital cost of approximately $29,500. However, whole house retrofits tend to be on the scale of $100,000 or greater, and a cost of $29,500 for this type of project is unlikely. If this project were to be completed for $29,500, it would have a simple payback of:

SP = CC ÷ AS

SP = $29,513 ÷ ($1575.31/year)

SP = 18.7 years

Even with a substantially low capital cost, a homeowner would endure a payback of approximately 19 years with the current annual savings being $1575.31 (for an AOH with electric heating). It should be noted that in this scenario, the estimated capital cost is based entirely off of fuel savings. Additional savings from a Gemini NTED® retrofit are expected and would add to the total annual energy savings. The estimated capital cost determined using this method provides a benchmark amount that homeowners could spend in order for their total project costs to equal their total energy cost savings.

5.4 Sensitivity Analysis Results

Discounted savings were recalculated for Gemini NTED® vs. AOH electric heating equipment using upper and lower bounds (+/-20 percent) for the utility cost and discount factor (*d*). The adjusted values are given in Table 39 below.

Table 39 – Upper and lower bounds for sensitivity analysis

Parameter	Original Value	Upper Bound (+20%)	Lower Bound (-20%)
Utility cost	8.39¢	10.02¢	6.71¢
d	3.81%	4.57%	3.05%

To evaluate each parameter's effect on discounted savings, only one parameter was adjusted while the other remained the original value. Recalculated discounted savings are presented below in Table 40 and complete excel spreadsheets are given in Appendix E.

Table 40 – Adjusted discounted savings from sensitivity analysis

Parameter	Upper and Lower Bounds	Discounted Savings	Original Discounted Savings
Utility cost	+ 20%	$35,247	$29,513
	- 20%	$23,603	
d	+ 20%	$27,377	
	- 20 %	$31,890	

Percent difference tests were calculated for each case and a summary of results is provided in Table 41. A sample percent difference calculation is provided using

Equation (18), where *x* represents the utility cost or *d* (discount factor) and DS is the discounted savings for each case.

$$\% \, difference \, (x) = \frac{\left| DS_{\frac{upper}{lower}} - DS_{original} \right|}{DS_{\frac{upper}{lower}} + DS_{original}} \, x100 \qquad (18)$$

Sample Calculation (d, upper bound)

$$\% \, difference \, (d) = \frac{\left| DS_{upper} - DS_{original} \right|}{DS_{upper} + DS_{original}} \, x \, 100$$

$$\% \, difference = \frac{|27{,}377 - 29{,}513|}{27{,}377 + 29{,}513} \, x \, 100$$

$$\% \, difference = \frac{2{,}136}{56{,}890} \, x \, 100$$

$$\% \, difference = 3.75\%$$

Table 41 – Results of percent difference tests

Parameter	Upper and Lower Bounds	Percent Difference
Utility cost	+ 20%	8.85%
	- 20%	11.13%
d	+ 20%	3.75%
	- 20 %	3.87%

5.5 Environmental Study: Calculating GHG Emissions

Emissions of carbon dioxide (g CO_2), methane (g CH_4), and nitrous oxide (g N_2O) were evaluated in this study. To make the GHGs comparable, emissions were also expressed as grams of carbon dioxide equivalent (g of CO_2e) using the appropriate global warming potentials (GWPs):

CO_2 GWP: 1

CH_4 GWP: 25

N_2O GWP: 298

Updated GWPs were published by the IPCC in 2007. Although it has not yet been specified which GWPs should be used for reporting, the updated GWPs are being used in Canada for evaluating GHG emissions (Environment Canada: National Inventory Report, 2013) and were therefore chosen for GHG analysis in this research.

To calculate emissions from heating energy in Ontario homes, emission factors of CO_2, CH_4, and N_2O were used for both natural gas and electrical heating equipment. Tables 42 and 43 provide emission factor data for the major GHG types that were used in this analysis.

Table 42 – Emission factors from NG production in Ontario (EnviroCan NIR, 2013)

Fuel Type	CO_2 (kg/m^3)	CH_4 (kg/m^3)	N_2O (kg/m^3)
Natural Gas	1.879	0.000037	0.000035

Table 43 – Emission factors from Ontario electricity generation (EnviroCan NIR, 2013)

Province	CO_2 Intensity (g CO_2/kWh)	CH_4 Intensity (g CH_4/kWh)	N_2O Intensity (g N_2O/kWh)
Ontario	130	0.01	0.003

Annual heating loads previously calculated in Step 3 of the Annual Energy Savings section were used for this analysis; a summary is provided in Table 44 below. The values represent the amount of energy consumed within the home for heating in one year.

Table 44 – Heating loads for various house types

House Type	Heating Source	Annual Heating Energy
Gemini NTED®	Electricity	1224 kWh
R-2000	Electricity	8064 kWh
Average Ontario Home	Electricity	20,000 kWh
Average Ontario Home	Natural Gas	2,400 m^3

To calculate emissions generated from heating energy in each of the four scenarios, the appropriate emission factors previously given in Tables 42 and 43 were used. Additionally, carbon dioxide equivalents were calculated using the appropriate GWPs. Table 45 below provides a summary of the amount of each GHG (CO_2, CH_4, and N_2O) that would be expected for a Gemini NTED® retrofitted home, a traditional R-2000 home and an average Ontario home (AOH) heated electrically.

Table 45 – GHG emissions from electric heating energy

	Energy (kWh)	**g of CO_2**	**g of CH_4**	**g of N_2O**
Gemini NTED®	1224	159,120	12.24	3.672
R-2000	8064	1,048,320	80.64	42.192
AOH (electric)	20,000	2,600,000	200	60

An example calculation is provided below for a Gemini NTED® home, which is estimated to consume 1224 kWh of heating energy annually.

$$e_{CO2} = 1224 \text{ kWh} \times 130 \text{ g } CO_2/\text{kWh}$$
$$= 159{,}120 \text{ g of } CO_2$$

$$e_{CH4} = 1224 \text{ kWh} \times 0.01 \text{ g } CH_4/\text{kWh}$$
$$= 12.24 \text{ g of } CH_4$$

$$e_{N2O} = 1224 \text{ kWh} \times 0.003 \text{ g } N_2O/\text{kWh}$$
$$= 3.672 \text{ g of } N_2O$$

To compare total emissions of each scenario, carbon dioxide equivalents were calculated using their corresponding global warming potentials (GWP). The following table provides the carbon dioxide equivalents for each house type along with their total emissions (in kg of CO_2e).

Table 46 – GHG emissions from electric heating energy in carbon dioxide equivalents

	CO_2 (g CO_2e)	**CH_4 (g CO_2e)**	**N_2O (g CO_2e)**	**Total (g CO_2e)**	**Total (kg CO_2e)**
Gemini NTED®	159,120	306	1094.26	160,520.26	160.52
R-2000	1,048,320	2016	7,209.22	1,057,545.22	1057.55
AOH (electric)	2,600,000	5000	17,880	2,622,880	2622.88

An example calculation of carbon dioxide equivalents is provided below for a Gemini NTED® home.

$$CO_2e(CO_2) = 159{,}120 \text{ g } CO_2 \times 1$$
$$= 159{,}120 \text{ g } CO_2e$$

$$CO_2e(CH_4) = 12.24 \text{ g } CH_4 \times 25$$
$$= 306 \text{ g } CO_2e$$

$$CO_2e(N_2O) = 3.672 \text{ g } N_2O \times 298$$
$$= 1{,}094.26 \text{ g } CO_2e$$

$$TCO_2e = 159{,}120 \text{ g} + 306 \text{ g} + 1094.26 \text{ g}$$
$$= 160{,}520.26 \text{ g}$$
$$= 160.52 \text{ kg}$$

Emissions calculations from each house type using electric heating along with the corresponding carbon dioxide equivalents are provided in Appendix C.

The above emissions are for homes heated electrically. We also wanted to compare expected emissions from a Gemini NTED® home to the expected emissions from an average Ontario home heated with natural gas. To do so, the total heating energy value that was previously determined in the economic analysis (2400 m^3 natural gas) was used along with the GHG intensities for natural gas in Ontario. Tables 47 and 48 below list the amounts for each GHG along with amounts in carbon dioxide equivalents, again using the appropriate GWPs. For the GHGs calculated, a seasonal efficiency of 80 percent was used in order to remain consistent with calculations made in the economic analysis.

Table 47 – GHG emissions from an Ontario home heated with natural gas

	Energy (m^3)	g of CO_2	g of CH_4	g of N_2O
AOH (natural gas)	2,400	4,509,600	88.8	84

Table 48 – Emissions from natural gas heated Ontario home in CO_2e

	CO_2 (g CO_2e)	CH_4 (g CO_2e)	N_2O (g CO_2e)	Total (g CO_2e)	Total (kg CO_2e)
AOH (natural gas)	4,509,600	2,220	25,032	4,536,852	4536.85

Table 49 – Total GHG emissions from each scenario

Scenario	Total GHGs (kg of CO_2e)
Gemini NTED®	160.52
R-2000	1057.55
Avg. Home (electric heating)	2622.88
Avg. Home (natural gas)	4536.85

Full calculations for emissions from natural gas are provided in Appendix D. To evaluate GHG emissions savings of a Gemini NTED® home, comparisons were made between Gemini NTED® emissions and the emissions from remaining house types using Equations (11) and (12) outlined in Section 4.3 (pg. 62).

Sample Calculation (Gemini NTED® vs. AOH with electric heating)

CO_2e Savings = $TCO_2e(AOH_E)$ - $TCO_2e(GEM)$

CO_2e Savings = 2622.88 kg of CO_2e – 160.52 kg of CO_2e

CO_2e Savings = 2,462.36 kg of CO_2e

Table 50 – GHG emissions savings with a Gemini NTED® home

Scenario	Total GHG Savings (kg of CO_2e)
Gemini NTED® vs. R-2000	897.03
Gemini NTED® vs. AOH (electric)	2,462.36
Gemini NTED® vs. AOH (natural gas)	4,376.33

A Gemini NTED® retrofitted home would save approximately 900 kg of CO_2e compared to an R-2000 home, approximately 2,500 kg of CO_2e compared to an average Ontario home heated with electricity, and approximately 4,400 kg of CO_2e compared to an average Ontario home heated with natural gas.

5.5.1 Carbon Valuation Results

From a homeowner's perspective, a carbon tax would mainly impact heating costs. The amount of tax associated with heating a dwelling depends on the type of energy used, the efficiency of equipment, outside temperature, thermostat settings, and energy efficiency of the building (BC Climate Action Plan, 2008). Under the British Columbia Carbon Tax, homes that are heated with natural gas or oil are taxed and those heated with electricity are not. Implementing a carbon tax policy similar to B.C.'s in Ontario could have major implications for commercializing an energy retrofit like Gemini NTED®, which is heated electrically. Having an electric heating system would result in zero carbon taxes from heating and families would still benefit from personal income tax cuts.

The additional annual costs a homeowner would endure under a carbon tax were calculated with the tax rates currently used in British Columbia (Table 14 in Section 4.3, page 63) using Formula (13). Since the tax applies to natural gas only, values were calculated only for the average Ontario home heated with a forced-air natural gas furnace with seasonal efficiency of 80 percent.

$$CO_2ev = Heating\ energy \times Cv$$

$$CO_2ev = 2400\ m^3 \times \$0.057/m^3$$

$$CO_2ev = \$136.80$$

A carbon tax would add approximately $137 each year to a homeowner's energy bill in Ontario when a home is heated with natural gas and the equipment has a seasonal efficiency of 80 percent. This means that a Gemini NTED® homeowner would save themselves an additional $137 each year because they are not subjected to carbon taxes from heating energy. Over a 20 year time period, savings would accrue to almost $3,000.

Carbon reduction valuation results were incorporated into the NPV formula, comparing Gemini NTED® savings to an AOH home heated with natural gas using the previously modified Formula (14); Table 51 presents the updated NPV results. The sum of discounted savings over 20 years amounted to $11,880. These values are based on the assumption that the carbon tax will remain stable over the next twenty years. If the tax rates were to increase, the annual cost savings would be greater and there would be greater potential for attaining a positive NPV value.

Table 51 - Discounted savings for Gemini NTED® vs. AOH (natural gas) with CO_2*ev*

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	634.306	1	1.038	0.963	611.026
2	634.306	1.035	1.078	0.960	609.202
3	634.306	1.071	1.119	0.958	607.382
4	634.306	1.109	1.161	0.955	605.569
5	634.306	1.148	1.206	0.952	603.760
6	634.306	1.188	1.252	0.949	601.957
7	634.306	1.229	1.299	0.946	600.160
8	634.306	1.272	1.349	0.943	598.368
9	634.306	1.317	1.400	0.941	596.581
10	634.306	1.363	1.453	0.938	594.799
11	634.306	1.411	1.509	0.935	593.023
12	634.306	1.460	1.566	0.932	591.252
13	634.306	1.511	1.626	0.929	589.486
14	634.306	1.564	1.688	0.927	587.726
15	634.306	1.619	1.752	0.924	585.971
16	634.306	1.675	1.819	0.921	584.221
17	634.306	1.734	1.888	0.918	582.477
18	634.306	1.795	1.960	0.916	580.737
19	634.306	1.857	2.035	0.913	579.003
20	634.306	1.923	2.112	0.910	577.274

6.0 DISCUSSION

6.1. Assessment of Market

A review of financial incentives, educational programs, and barriers to retrofits was completed to provide insight into the current retrofit marketplace in Toronto and the GTA. Financial incentives were identified from Enbridge, the OPA and CMHC, however the financial incentives are generally on a small scale, focusing on simple upgrades and replacing inefficient appliances. Additionally, the cancellation of ecoENERGY retrofit program has deterred homeowners from making significant changes to their homes.

In terms of education, several sites exist that provide homeowners with sufficient information regarding energy consumption, GHG emissions, and tips on how to cut back on annual energy usage. The majority of educational programs encountered in this research focused on small, quick, and cheap changes homeowners could undertake to reduce their energy use and cut back on energy bills. However, programs do exist with their main goal being educating the public on energy efficiency, renewable energy, and whole-house retrofitting. The Kortright Centre for example holds a number of homeowner workshops throughout the year to educate and train the public in sustainable building practices. Information regarding retrofits exists, however it typically comes down to the homeowner or contractor to seek it out. This often makes it difficult for homeowners to choose between available options, and determine what changes are going to reduce emissions the most while also being the most cost effective.

A lack of financial incentives and rebates is a major hurdle to overcome in the retrofit industry; projects need to be cost effective in order for homeowners to undertake them. Additionally, without the knowledge of best available options, homeowners are often hesitant to undergo energy retrofits. Without government policies in place, it comes down to the homeowner and their desire to undergo such a project, making energy retrofits a niche market.

6.1.1 Outcomes of Porter's Five Forces Model

Understanding the forces that shape competition within the retrofit industry is the starting point for developing a commercialization strategy for Gemini NTED®. The Porter's Five Forces model was conducted to help answer the following question: *what kinds of competitive forces are industry members facing are how strong are they?* The idea is that by understanding how the five competitive forces influence profitability in the retrofit industry, a strategy can be developed for enhancing the long term profits of a new innovation, using Gemini NTED® as a case study. The nature and strength of the five forces were examined individually and their collective strength was also evaluated. Out of the five forces, the power of suppliers, the threat of substitutes and rivalry among existing competitors were all found to be weak in strength and the threat of new entrants and the power of buyers were found to be moderate in strength.

Evaluation of the strength of the five forces as a whole results in an overall rating of moderate, which means that the forces combined do not negatively affect the retrofit industry's profitability. Instead, as a whole, the five forces are found to be moderately conducive to earning profits. However, the strongest forces are the ultimate determinant of the intensity of the competitive pressures on the industry's profitability. A closer look at the stronger forces can aid in assessing how to insulate Gemini NTED® or other retrofit innovations from the threat of new entrants and the power of buyers.

Powerful buyers (contractors) have the ability to force down prices, demand better quality/service and play industry participants against one another, which can limit profitability within the industry. Gemini NTED® may encounter powerful buyers if the retrofit is marketed similar to the R-2000 brand. It would be required that contractors become certified as "Gemini NTED® builders." Gemini would need to provide training courses for contractors and builders along the same lines of what Natural Resources Canada provides for R-2000 certification. In this case, powerful buyers (contractors and builders) will force Gemini NTED® to develop a strategy to encourage participation in its program, which may include lowering costs. To reduce the strength of the power of buyers, Gemini NTED® will need to clearly distinguish itself from the R-2000 brand, emphasizing its better performance on reducing heating energy and lowering GHG emissions.

New entrants to any market have the potential to bring new production capacity and gain market shares, which places pressure on a company's prices and can escalate the investment necessary to compete. The threat of entry is based on entry barriers. The most widely encountered barriers that entry candidates must hurdle were adapted from Thompson et al. (2010) and evaluated in this research. From the barriers listed, customer switching costs – the fixed costs that buyers face when changing suppliers - was identified as the strongest barrier to entry. In the Gemini NTED® case study, switching costs would be associated with homeowner changing heating equipment from natural gas systems to electric. In Ontario, natural gas is most commonly used for heating purposes and homeowners would incur large upfront costs switching to an electric heating system. Gemini NTED® will need to develop a strategy to overcome this hurdle. One possibility is to consider expanding in a different geographic location, for example in Quebec, the majority of homes are electrically heated and Gemini NTED® could avoid customer switching costs and the threat of entry from placing a cap on potential profit. Targeting different geographic locations is discussed in further detail in the following section regarding GHG emissions and carbon costs.

The above discussion is focused on the competitive forces at a single point in time. It is understood that industry structure is constantly undergoing adjustments and in some instances can undergo abrupt change, which can either boost an industry's profit or reduce it. In the retrofit industry, changes in technology and advancements in product innovation, changes in homeowner interests, or new government policies/regulations could cause shifts in the industry. The research done here provides a framework, once construction and monitoring of 31 Sussex is complete, the various forces within the model will need to be reviewed and updated.

6.2 Financial Analysis Outcomes

Heating energy savings of a Gemini NTED® home are significant compared to an electrically heated R-2000, electrically heated average Ontario home, and a natural gas heated average Ontario home. Annual energy cost savings are $573.88, $1,575.31 and $497.31, respectively. Over a 20-year period, discounted savings amount to $10,751, $29,513, and $9,317, respectively. This means that for each scenario, in order for a homeowner to break even with costs and savings, the capital costs must equal the amount of the discounted savings, which is unrealistic for a whole-house energy retrofit, which can often cost upwards of $100,000. Furthermore, even for the case of the electrically heated AOH with a possible capital cost of $29,513, the simple payback for a homeowner would be nineteen years. With the current estimated energy cost savings, a higher capital cost would extend the payback period to over twenty years, which is longer than the predicted service life of the retrofit.

Results of the sensitivity analysis completed for the case of energy savings of a Gemini NTED® home versus an AOH with electric heating equipment showed that fluctuations in the discount factor do not have a great effect on discounted savings (Table 52 for comparison). Percent difference tests were completed for each case (summary of results were provided in Table 41, pg. 105). Varying the discount factor by 20 percent resulted in percent difference of approximately 3 percent for each case.

Table 52 – Comparison of savings from sensitivity analysis and original calculations

Original Parameter	Parameter Upper and Lower Bounds	Discounted Savings	Original Discounted Savings
Utility cost = 8.390¢/kWh	+ 20% = 10.02¢/kWh	$35,247	$29,513
	- 20% = 6.71¢/kWh	$23,603	
d = 3.81%	+ 20% = 4.57%	$27,377	
	- 20 % = 3.05%	$31,890	

Variations in the electric utility cost had a greater effect on discounted savings. Increasing utility costs by 20 percent raised the discounted savings by $5,734, a difference of 8.8 percent. Lowering the utility cost by 20 percent decreased discounted savings by $5,910, a difference of 11.13%. An increase in the cost of electricity makes the Gemini NTED® retrofit more economically attractive. Electric utility cost increases are a possibility with changes to Ontario's generation sources and may act as a driver for market acceptance of energy retrofits.

The financial valuation of emissions reduction resulted in annual savings of approximately $137 if a carbon tax similar to that of British Columbia's were to be applied in Ontario. This resulted in updated annual heating energy cost savings of $634.31 for the comparison of Gemini NTED® to a natural gas heated AOH. Annual cost savings from the carbon tax are not high enough to greatly influence NPV results in this study. However, since the carbon tax does not apply to emissions generated from electricity, if the Ontario government were to implement a carbon tax, homeowners may begin considering a retrofit option like Gemini NTED®. Additionally, owners of old, inefficient homes would have a greater incentive to switch to a less energy intensive home.

Implications for Commercialization

Financial valuation is undertaken to aid in determining an innovation's strategic direction for commercialization. From the results gathered in this research, the current annual energy cost savings are not great enough to offset the capital cost of retrofitting. Additional energy savings must be attained to make the retrofit more cost effective. Two possible strategic directions have been identified to overcome this hurdle:

1. Incorporate the Gemini NTED® concept into new builds instead of retrofits
2. Target older homes/buildings with high energy intensities

Incorporating the Gemini NTED® design into a new home undergoing initial construction would reduce time and costs required for building. New homes could be built to a Gemini NTED® standard, similar to that of R-2000.

Older homes are generally less energy efficient and produce more GHGs than newly built homes. From the Natural Resources Canada survey on household energy use (NRCan SHEU, 2010), homes built prior to 1946 in Ontario were found to have an average energy intensity of 0.89 GJ/m^2. High energy intensities result in greater heating energy savings when retrofitting to a Gemini NTED® home. A pre-1946 home that is electrically heated would use approximately 35,600 kWh of heating energy and a pre-1946 home with natural gas heating would use approximately 4,272 m^3 of heating energy (Table 53).

Table 53 – Heating energy use in a pre-1946 Ontario home

	Energy Content (kWh or m^3)	Efficiency	Energy Used (kWh or m^3)
AOH (electrically heated)	0.0036 GJ/kWh	100 %	35,600 kWh
AOH (natural gas heated)	0.0375 GJ/m^3	80 %	4,272 m^3

Compared to present day values previously calculated in this research, heating energy in a pre-1946 home is almost doubled. This results in higher annual heating costs and greater energy cost savings (Tables 54 and 55).

Table 54 – Annual heating costs for a pre-1946 Ontario home

Scenario	Heating Energy Used	Cost of Energy	Annual Heating Cost
AOH (electricity)	35,600 kWh	8.390 ¢/kWh	$2,986.84
AOH (natural gas)	4,272 m^3	25 ¢/m^3	$1,070.50

Table 55 – Annual heating energy cost savings for a pre-1946 home

House Scenarios	Annual Heating Energy Cost Savings
Gemini vs. AOH with electricity	$2,884.14
Gemini vs. AOH with natural gas	$967.81

When annual heating energy cost savings are input into the NPV model, discounted savings of $54,033 and $18,132 are found for pre-1946 home with electric heating and natural gas heating respectively (Table 56), complete excel spreadsheets can be found in Appendix F.

Table 56 – Discounted savings of a pre-1946 Ontario home

Scenario	Sum of Discounted Savings ($)
Gemini vs. AOH with electricity	$54,033.521
Gemini vs. AOH with natural gas	$18,131.638

These results show that energy intensity has a major impact on possible energy cost savings. If Gemini NTED® were to target old homes, homeowners could receive a return on investment with higher project capital costs.

A complete summary of each house scenario and their respective discounted savings results is provided below in Table 57.

Table 57 – Summary of discounted savings for each scenario within this research

Scenario	Discounted Savings
Gemini vs. R-2000	$10,751
Gemini vs. AOH with electric heating	$29,513
Gemini vs. AOH with natural gas heating	$9,317
Gemini vs. pre-1946 with electric heating	$54,033
Gemini vs. pre-1946 with natural gas heating	$18,132

6.3 Greenhouse Gas Emissions Results

From an environmental standpoint, in Ontario, it is cleaner to heat your home using electric heating equipment than a natural gas fired furnace. Comparing emissions from an average Ontario home with an area of 144 m^2 and a heating energy intensity of 0.50 GJ/m^2, emissions are nearly cut in half when the home is heated with electricity versus natural gas, 2622 and 5536 kg of CO_2e respectively.

Additionally, a comparison of emissions from a range of furnace efficiencies (Table 58) show that even with 100 percent efficiency, natural gas furnaces still emit more emissions than electric heating equipment.

Table 58 – A range of furnace efficiencies and corresponding GHG emissions

Furnace Efficiency (%)	Heating Energy (m^3)	Emissions from Space Heating (kg CO_2e)
60	3,200	6049.14
70	2,743	5184.97
80	2,400	4536.85
90	2,133	4032.76
100	1,920	3,629.43

Retrofitting a home with the Gemini NTED® design drastically reduces GHG emissions from space heating. A Gemini NTED® home only produces 6 percent of the emissions of an electrically heated AOH and 3 percent of emissions from a natural gas heated AOH.

Implications for Commercialization

An important aspect to consider for commercialization is the location of Gemini NTED® retrofits. In this research, the local price of energy and emissions from electricity generation has been considered. Since Gemini NTED® is an electrically heated home, emissions are highly dependent on the energy generation source. As a result, in terms of GHG emissions, Gemini NTED® would not be suitable for a region that generates the majority of it's electricity from coal, oil or natural gas. Nova Scotia for example generates the majority of its electricity from combustion processes (approximately 88 percent) and would therefore not be a feasible region for a Gemini NTED®. Ideally, Gemini NTED® retrofits would be best in areas that produce electricity via renewable energy sources as emissions from these sources are next to zero.

From an environmental standpoint, provinces including Prince Edward Island, Quebec, and Manitoba would be the most suitable regions, as the majority of their electricity is generated by renewables (wind, tidal, solar, and biomass). Table 59 provides a summary of electricity generation details by province. Complete electricity generation details were provided in Appendix A along with provincial CO_2e emission factors from electricity generation.

Table 59 – Electricity generation details by province in 2010

Province	Generation Details	
	Combustion	**Renewables**
Manitoba	0.20 %	99.80 %
P.E.I.	1 %	99 %
Quebec	1 %	99 %
Nfld & Labrador	2 %	98 %
British Columbia	3 %	97 %
Yukon	5 %	95 %
Ontario	21 %	79 %
NWT & Nunavut	50 %	50 %
New Brunswick	65 %	35 %
Saskatchewan	78 %	22 %
Nova Scotia	88 %	12 %
Alberta	93 %	7 %

Annual emissions for a Gemini home in P.E.I., Quebec and Manitoba were calculated using the appropriate emissions factors (Table 60) and a summary is given in Table 60. Since the majority of electricity in each of these provinces is generated using renewable resources, annual emissions are substantially low (Table 61).

Table 60 – Provincial electricity emissions factors

Province	**CO_2 Intensity ($g\ CO_2/kWh$)**	**CH_4 Intensity ($g\ CH_4/kWh$)**	**N_2O Intensity ($g\ N_2O/kWh$)**
Manitoba	3	0.0001	0.0001
P.E.I.	3	0.000	0.000
Quebec	2	0.0002	0.0001
Ontario	**130**	**0.01**	**0.003**

Table 61 – Annual GHG emissions from a Gemini NTED® home in each province

Province	**GHG Emissions from Gemini NTED® Home (kg of CO_2e)**
Manitoba	3.7
P.E.I	3.7
Quebec	2.5
Ontario	160.5

In order for a Gemini NTED® retrofit to be successfully adopted in P.E.I, Quebec or Manitoba, it must also make financial sense as cost is the most significant hurdle to overcome when commercializing this system. Table 61 provides the cost of residential electricity generation along with the estimated annual heating cost for a Gemini NTED® home in each P.E.I., Manitoba and Quebec. A comparison was made to the expected costs of an average home heating with electricity (using 0.50 GJ/m^2 and 144 m^2) for each case

Table 62 –Annual Gemini NTED® cost savings in Ontario, P.E.I, Quebec, and Manitoba

Province	**Cost of Electricity (¢/kWh)**	**Estimated Annual Heating cost of Average Home**	**Estimated Annual heating cost of Gemini NTED®**	**Annual Cost Savings**
Ontario	8.39	$1,678	$103	$1,575
P.E.I	18.40	$3,680	$225	$3,455
Quebec	5.41 (first 30 kWh) 7.78 (remaining kWh)	$1,555	$95	$1,460
Manitoba	6.67	$1,335	$82	$1,253

Typically, the lowest electricity prices in Canada are in provinces that have an abundance of hydroelectric generation, which is the most cost effective way to generate electricity. Other low cost areas use large amounts of coal or nuclear. P.E.I, which generates almost all electricity from wind, typically has the highest electricity prices in Canada (MaritimeElectric, 2013). In Quebec, all electricity is generated in province, the majority being hydroelectric generation, and homeowners are charged 5.41¢/kWh for the first 30 kWh consumed, the remaining consumption is charged at 7.78¢/kWh (HydroQuebec, 2013). In Manitoba, the majority of electricity generation is also hydroelectric and residential customers currently pay 6.67 ¢/kWh for their energy use (Manitoba Hydro, 2013).

For a Gemini NTED® home in P.E.I., homeowners would pay approximately $225 per year in space heating costs, Quebec homeowners would pay approximately $95 annually and homeowners in Manitoba would pay approximately $82 annually. The most important figure is annual cost savings. P.E.I has savings upward of $3,500 annually from a Gemini NTED® retrofit, making this province a potential candidate for innovation commercialization.

7.0 CONCLUSIONS

Schilling's innovation commercialization model was applied to the case study of Gemini NTED® and the retrofit at 31 Sussex Avenue in Toronto, Ontario. Market assessment and innovation valuation were completed to gain insight into the retrofit marketplace in Toronto and the GTA and determine the economic value of savings from Gemini NTED® retrofit. Assessment of external factors affecting commercialization and the Porter's Five Forces model provided an understanding of the forces that are shaping competition within the retrofit industry. Lack of funding and educational programs focusing primarily on whole-house energy retrofits act as a deterrent for homeowners to undergo such projects. However, completion of the Porter's Five Forces model provided an overall rating of "moderately weak" for the combined forces, meaning they are conducive to earning profits within the retrofit industry (a moderately attractive industry). With the strongest forces found to be the threat of new entrants and the power of buyers, an innovation like Gemini NTED® trying to enter the market must develop a strategic direction to avoid or overcome the threats. Targeting different geographic locations was identified as a possible solution for overcoming entry barriers and reducing the threat of new entrants. To reduce of the power of buyers, Gemini NTED® must clearly distinguish itself from the R-2000 brand, focusing primarily on the improved energy savings and reduced GHG emissions.

Innovation valuation was completed using discounted cash flow analysis to determine the economic value of energy savings from a Gemini NTED® retrofitted home. Since the estimated energy cost savings are not great enough to offset the project capital costs, measures must be taken to overcome this hurdle. The incorporation of Gemini NTED®

into new builds instead of retrofits was identified as a possible solution to this problem. Additionally, marketing Gemini NTED® retrofits to old homes with significantly greater energy intensities was identified as a possible solution as the majority of existing homes in Toronto and the GTA were not built to the efficiency standards that exist in the building code today.

A study of GHG emissions from a Gemini NTED® home showed that there is commercialization potential for Gemini in provinces including P.E.I, Quebec and Manitoba, with the most significant emissions reduction and cost savings in P.E.I.

7.1 Study Limitations

Energy savings calculated in this research are based entirely off of reduced heating energy from the Gemini NTED® design during a typical Ontario heating season. It is expected that additional savings will be accrued from other energy saving aspects of the home. Additionally, energy savings are expected to be experienced during the summer cooling months. Previous energy modeling studies were done based entirely on heating energy savings and as a result, monetary savings in this study are limited to those previous findings. Once construction is completed at 31 Sussex, the home will be monitored over a 5-year period. After this time, a complete energy consumption study will need to be completed.

7.2 Future Work

The next stage of this research will be to establish a product development and deployment strategy for Gemini NTED® retrofits (Figure 15) using the information previously collected in the market assessment and financial analysis portion of this research.

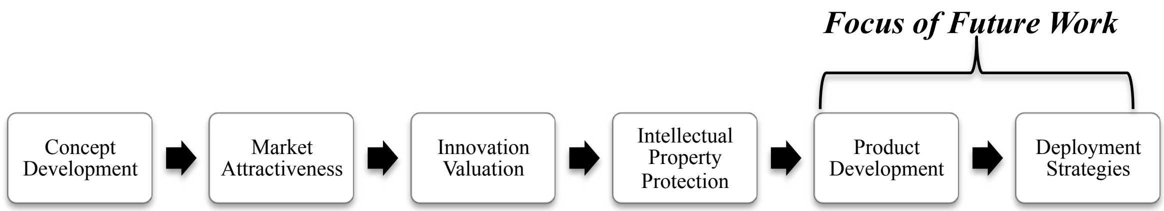

Fig. 15 – Next steps in the innovation commercialization model

Results derived from the ongoing pilot project at 31 Sussex will provide useful data to allow for a more accurate economic evaluation and determination of marketable product attributes and related deployment strategies.

Appendix A - Electricity Generation Details by Province

Information listed in the following table was retrieved from Environment Canada's National Inventory Report published in 2012.

Table A-1 – Provincial electricity generation details in 2010 in GWh

	Newfoundland & Labrador	**P.E.I.**	**Nova Scotia**	**New Brunswick**
Combustion				
Coal	0	0	8,730	3,070
Ref. Pet. Prod.	920	0	50	2,020
Nat. Gas	0	0	0	350
Biomass	0	5	230	0
Other fuels	0	0	1,320	1470
Nuclear	0	0	0	0
Hydro	39,400	0	970	3,330
Other Renewables	150	458	410	390
Other Generation	0	0	0	0
	Ontario	**Yukon**	**Manitoba**	**Saskatchewan**
Combustion				
Coal	13,700	0	60	12,600
Ref. Pet. Prod.	30	20	20	0
Nat. Gas	16,700	0	0	3,170
Biomass	450	0	0	0
Other fuels	0	0	0	0
Nuclear	82,000	0	0	0
Hydro	31,800	380	33,300	3,900
Other Renewables	3,230	0.1	340	510
Other Generation	0	0	0	0
	British Columbia	**Alberta**	**Quebec**	**NWT & Nunavut**
Combustion				
Coal	0	52,600	0	0
Ref. Pet. Prod.	80	20	400	220
Nat. Gas	2,430	10	200	30
Biomass	630	580	760	0
Other fuels	570	0	40	0
Nuclear	0	0	3,600	0
Hydro	44,400	1,830	170,000	250
Other Renewables	120	2,090	1,320	0
Other Generation	2,980	0	0	0

Table A-2: Provincial electricity generation details

Province	**CO_2 Intensity ($g\ CO_2/kWh$)**	**CH_4 Intensity ($g\ CH_4/kWh$)**	**N_2O Intensity ($g\ N_2O/kWh$)**
Nfld & Labrador	20	0.0002	0.0003
P.E.I.	3	0.000	0.000
Nova Scotia	800	0.037	0.01
New Brunswick	505	0.032	0.01
Ontario	**130**	**0.01**	**0.003**
Yukon	44	0.002	0.01
Manitoba	3	0.0001	0.0001
Saskatchewan	760	0.04	0.02
British Columbia	29	0.006	0.0007
Alberta	840	0.03	0.02
Quebec	2	0.0002	0.0001
NWT & Nunavut	367	0.024	0.05
All of Canada	180	0.01	0.004

Appendix B - R-2000 "Pick-List"

All R-2000 building features are provided on the Natural Resources Canada webpage (NRCan, 2010).

Indoor Air Quality Pick List

The R-2000 standard requires builders to incorporate a minimum of three of the following indoor air quality features:

1. Carpeting

Carpeting used in the house shall meet either of the following criteria:

a) The carpet shall be labeled under the Canadian Carpet Institute's Green Label Program; *or*

b) A non-Green Label carpet shall cover no more than 50 percent of the interior floor area. In this case, the interior floor area does not include the basement floor area.

2. Air filtration

One of the following must be installed:

a) A medium-efficiency air filter with a minimum MERV rating of 13 or 10 percent ASHRAE average dust spot efficiency, installed where air-circulating heating, or cooling systems are used; *or*

b) An electronic air cleaner permanently installed in the forced-air system ductwork; *or*

c) An air filtration system (e.g., activated carbon, catalytic air cleaners, etc.) in the forced-air system ductwork that is capable of removing gaseous contaminants from the air.

3. Paints and varnishes

All liquid coatings used indoors, including wood floors, shall have low-VOC content as determined by a third party certification program.

4. Flooring adhesives

All finish flooring adhesives shall be water dispersion, low-VOC formulations or be pre-adhesive types.

5. Kitchen cabinets and bathroom vanities

Cabinets and vanities shall be solid wood or, if made from manufactured wood products, shall be made from formaldehyde-free fibreboard or particleboard or have all exposed surfaces sealed with an Environmental Choice-approved sealer or a low-VOC sealer.

6. Vinyl flooring

All vinyl flooring shall be either linoleum or synthetic vinyl tile - sheet vinyl flooring shall not be used.

7. Particleboard underlayment

All particleboard-flooring underlayment shall have all surfaces sealed with an Environmental Choice-approved sealer or a low-VOC sealer; or be pre-finished.

8. Sub-slab depressurization system

Install an active sub-slab depressurization system to control the entry of radon and soil gases into the house.

9. Indoor moisture control

One of the following options must be selected:

a) Provide control measures to isolate a crawl space or space underneath a basement floor so as to minimize the transmission of moisture and soil gases into the occupied space; *or*
b) Provide insulation with an RSI of 0.9 or greater under the entire floor slab area; *or*
c) Include basement waterproofing, as opposed to damp proofing, or a free-draining layer, as a measure to keep the foundation drier and therefore less prone to mold development.

Environmental Features Pick Lists

The R-2000 standard requires builders to incorporate a minimum of two of the following environmental features:

Insulation	
Glass fibre insulation	Meets or exceeds the requirements of the EcoLogoCM Program for raw material from recycled glass
Cellulose insulation	Meets or exceeds the requirements of the EcoLogoCM Program for raw material from recycled paper
Mineral fibre insulation	Meets or exceeds the requirements of the EcoLogoCM Program for recycled raw material
Insulation made from plastic	Meets or exceeds the requirements of the EcoLogoCM Program for recycled content

Sheathing/Drywall	
Fibreboard	Product is made from recycled newsprint and/or wood fibres.
Siding	Product is manufactured from factory and sawmill waste
Drywall	Product contains recycled gypsum and/or newsprint

Interior framing and trim	
Steel studs	A minimum of 23 percent of the raw material is recycled steel
Studs and trim	Product is manufactured from sawmill cut-offs and waste, and is urea-formaldehyde free
Foundation and/or under-slab drainage	Install a mixture of post-consumer glass and crushed rock or stone around the foundation wall and/or under the slab-on-grade. Product must replace equivalent conventional backfill in its entirety
Energy-efficient appliances	Builders who include major electrical household appliances with the sale of the home shall provide appliances that meet the ENERGY STAR® technical specifications.

Reduction in energy use	
Energy target	The house's predicted energy consumption is at least 15 percent less than its Energy Target
Cooling systems	The cooling system shall be ENERGY STAR® qualified
Energy-efficient motors	The house air distribution system shall be equipped with an energy-efficient motor

Appendix C - Greenhouse Gas Calculations from Electric Heating Energy

Formulas:

$$e_j E = EC \times eF_j$$
$$CO_2 e_j = e_j E \times GWP_j$$
$$TCO_2 e = CO_2 e(CO_2) + CO_2 e(CH_4) + CO_2 e(N_2O)$$

Table C-1 – Emissions of a Gemini NTED® Home

Emissions			Carbon dioxide equivalents		
e_{CO2}	=	1224 kWh × 130 g CO_2/kWh	$CO_2e(CO_2)$	=	159,120 g CO_2 × 1
	=	159,120 g of CO_2		=	159,120 g CO_2e
e_{CH4}	=	1224 kWh × 0.01 g CH_4/kWh	$CO_2e(CH_4)$	=	12.24 g CH_4 × 25
	=	12.24 g of CH_4		=	306 g CO_2e
e_{N2O}	=	1224 kWh × 0.003 g N_2O/kWh	$CO_2e(N_2O)$	=	3.672 g N_2O × 298
	=	3.672 g of N_2O		=	1,094.26 g CO_2e
TCO_2e = 159,120 g + 306 g + 1094.26 g = 160,520.26 g = 160.52 kg					

Table C-2 – Emissions from an R-2000 Home

Emissions	Carbon dioxide equivalents
e_{CO2} = 8064 kWh × 130 g CO_2/kWh = 1,048,320 g of CO_2	$CO_2e(CO_2)$ = 1,048,320 g CO_2 × 1 = 1,048,320 g CO_2e
e_{CH4} = 8064 kWh × 0.01 g CH_4/kWh = 80.64 g of CH_4	$CO_2e(CH_4)$ = 80.64 g CH_4 × 25 = 2,016 g CO_2e
e_{N2O} = 8064 kWh × 0.003 g N_2O/kWh = 24.19 g of N_2O	$CO_2e(N_2O)$ = 24.19 g N_2O × 298 = 7209.22 g CO_2e
TCO_2e = 1,048,320 g + 2,016 g + 7209.22 g = 1,057,545.22 g = 1057.55 kg	

Table C-3 – Emissions from an average Ontario Home (electrically heated)

Emissions	**Carbon dioxide equivalents**
e_{CO2} = 20,000 kWh × 130 g CO_2/kWh = 2,600,000 g of CO_2	$CO_2e(CO_2)$ = 2,600,000 g CO_2 × 1 = 2,600,000 g CO_2e
e_{CH4} = 20,000 kWh × 0.01 g CH_4/kWh = 200 g of CH_4	$CO_2e(CH_4)$ = 200 g CH_4 × 25 = 5,000 g CO_2e
e_{N2O} = 20,000 kWh × 0.003gN_2O/kWh = 60 g of N_2O	$CO_2e(N_2O)$ = 60 g N_2O × 298 = 17,880 g CO_2e
TCO_2e = 2,600,000 g + 5,000 g + 17,880 g = 2,622,880 g = 2,622.88 kg	

Appendix D - GHG Emissions from Natural Gas Heating Energy

<u>Formulas</u>

$$e_j NG = NGC \times eF_j$$
$$CO_2 e_j = e_j NG \times GWP_j$$
$$TCO_2 e = CO_2 e(CO_2) + CO_2 e(CH_4) + CO_2 e(N_2O)$$

Table D-1 – Emissions from an average Ontario Home (natural gas heated)

Emissions	**Carbon dioxide equivalents**
e_{CO2} = 2,400 m^3 × 1879 g CO_2/m^3 = 4,509,600 g of CO_2	$CO_2e(CO_2)$ = 4,509,600 g CO_2 × 1 = 4,509,600 g CO_2e
e_{CH4} = 2,400 m^3 × 0.037 g CH_4/m^3 = 88.80 g of CH_4	$CO_2e(CH_4)$ = 88.80 g CH_4 × 25 = 2,220 g CO_2e
e_{N2O} = 2,400 m^3 × 0.035 g N_2O/m^3 = 84.00 g of N_2O	$CO_2e(N_2O)$ = 84.00 g N_2O × 298 = 25,032 g CO_2e
TCO_2e = 4,509,600 g + 2,220 g + 25,032 g = 4,536,852 g = 4,536.85 kg	

Appendix E - Sensitivity Analysis and Discounted Savings Results

Discounted savings were recalculated for the comparison of a Gemini NTED® home to an average Ontario home heated with electric equipment for a sensitivity study.

Table E-1 – Discounted savings with upper bound (+20%) of electric utility cost

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	1881.355	1.000	1.0381	0.963	1812.359
2	1881.355	1.042	1.0776	0.967	1806.999
3	1881.355	1.086	1.1186	0.971	1801.655
4	1881.355	1.131	1.1612	0.974	1796.327
5	1881.355	1.179	1.2054	0.978	1791.014
6	1881.355	1.228	1.2513	0.982	1785.717
7	1881.355	1.280	1.2989	0.985	1780.436
8	1881.355	1.334	1.3484	0.989	1775.171
9	1881.355	1.390	1.3997	0.993	1769.921
10	1881.355	1.448	1.4530	0.997	1764.686
11	1881.355	1.509	1.5083	1.000	1759.468
12	1881.355	1.572	1.5657	1.004	1754.264
13	1881.355	1.638	1.6253	1.008	1749.076
14	1881.355	1.707	1.6872	1.012	1743.903
15	1881.355	1.779	1.7515	1.016	1738.746
16	1881.355	1.854	1.8181	1.020	1733.604
17	1881.355	1.931	1.8874	1.023	1728.477
18	1881.355	2.013	1.9592	1.027	1723.365
19	1881.355	2.097	2.0338	1.031	1718.268
20	1881.355	2.185	2.1112	1.035	1713.186

Table E-2 – Discounted savings with lower bound (-20%) of energy escalation rate, *e*

Year, *i*	Annual Energy Cost Savings, *ECS* ($)	(1+*e*)^*i*-1	(1+*d*)^*i*	(1+*e*)^*i*-1 ÷ (1+*d*)^*i*	Discounted Savings ($)
1	1259.870	1.028	1.0381	0.963	1213.665
2	1259.870	1.057	1.0776	0.954	1210.076
3	1259.870	1.086	1.1186	0.945	1206.497
4	1259.870	1.117	1.1612	0.936	1202.929
5	1259.870	1.148	1.2054	0.926	1199.372
6	1259.870	1.180	1.2513	0.917	1195.825
7	1259.870	1.213	1.2989	0.909	1192.288
8	1259.870	1.247	1.3484	0.900	1188.762
9	1259.870	1.282	1.3997	0.891	1185.246
10	1259.870	1.318	1.4530	0.882	1181.741
11	1259.870	1.355	1.5083	0.874	1178.246
12	1259.870	1.393	1.5657	0.865	1174.762
13	1259.870	1.432	1.6253	0.857	1171.287
14	1259.870	1.472	1.6872	0.849	1167.823
15	1259.870	1.513	1.7515	0.840	1164.370
16	1259.870	1.556	1.8181	0.832	1160.926
17	1259.870	1.599	1.8874	0.824	1157.493
18	1259.870	1.644	1.9592	0.816	1154.070
19	1259.870	1.690	2.0338	0.808	1150.657
20	1259.870	1.028	2.1112	0.800	1147.254

Table E-3 – Discounted savings with upper bound (+20%) of discount factor, *d*

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	1575.306	1	1.046	0.956	1506.484
2	1575.306	1.035	1.093	0.947	1491.092
3	1575.306	1.071	1.143	0.937	1475.857
4	1575.306	1.109	1.196	0.927	1460.778
5	1575.306	1.148	1.250	0.918	1445.853
6	1575.306	1.188	1.307	0.908	1431.080
7	1575.306	1.229	1.367	0.899	1416.459
8	1575.306	1.272	1.430	0.890	1401.986
9	1575.306	1.317	1.495	0.881	1387.662
10	1575.306	1.363	1.563	0.872	1373.484
11	1575.306	1.411	1.635	0.863	1359.451
12	1575.306	1.460	1.709	0.854	1345.561
13	1575.306	1.511	1.787	0.845	1331.813
14	1575.306	1.564	1.869	0.837	1318.205
15	1575.306	1.619	1.954	0.828	1304.737
16	1575.306	1.675	2.044	0.820	1291.406
17	1575.306	1.734	2.137	0.811	1278.212
18	1575.306	1.795	2.235	0.803	1265.152
19	1575.306	1.857	2.337	0.795	1252.225
20	1575.306	1.923	2.443	0.787	1239.431

Table E-4 – Discounted savings with lower bound (-20%) of discount factor, *d*

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	1575.306	1	1.030	0.970	1528.747
2	1575.306	1.035	1.062	0.975	1535.488
3	1575.306	1.071	1.094	0.979	1542.259
4	1575.306	1.109	1.128	0.983	1549.060
5	1575.306	1.148	1.162	0.988	1555.891
6	1575.306	1.188	1.197	0.992	1562.752
7	1575.306	1.229	1.234	0.996	1569.643
8	1575.306	1.272	1.271	1.001	1576.565
9	1575.306	1.317	1.310	1.005	1583.517
10	1575.306	1.363	1.350	1.010	1590.500
11	1575.306	1.411	1.391	1.014	1597.514
12	1575.306	1.460	1.433	1.019	1604.558
13	1575.306	1.511	1.477	1.023	1611.634
14	1575.306	1.564	1.522	1.028	1618.741
15	1575.306	1.619	1.568	1.032	1625.879
16	1575.306	1.675	1.616	1.037	1633.048
17	1575.306	1.734	1.665	1.041	1640.250
18	1575.306	1.795	1.716	1.046	1647.483
19	1575.306	1.857	1.768	1.050	1654.748
20	1575.306	1.923	1.822	1.055	1662.044

Appendix F - Discounted Savings Excel Spreadsheets for Pre-1946 Home

Discounted savings were calculated for two pre-1946 homes, one with electric heating equipment and the other with natural gas heating equipment.

Table F-1 – Discounted savings for a pre-1946 home with electric heating equipment

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	2,884.140	1	1.038	0.963	2778.368
2	2,884.140	1.035	1.078	0.960	2770.151
3	2,884.140	1.071	1.119	0.958	2761.958
4	2,884.140	1.109	1.161	0.955	2753.790
5	2,884.140	1.148	1.205	0.952	2745.646
6	2,884.140	1.188	1.251	0.949	2737.526
7	2,884.140	1.229	1.299	0.946	2729.430
8	2,884.140	1.272	1.348	0.944	2721.358
9	2,884.140	1.317	1.400	0.941	2713.310
10	2,884.140	1.363	1.453	0.938	2705.285
11	2,884.140	1.411	1.508	0.935	2697.285
12	2,884.140	1.460	1.566	0.932	2689.308
13	2,884.140	1.511	1.625	0.930	2681.354
14	2,884.140	1.564	1.687	0.927	2673.424
15	2,884.140	1.619	1.751	0.924	2665.518
16	2,884.140	1.675	1.818	0.921	2657.635
17	2,884.140	1.734	1.887	0.919	2649.775
18	2,884.140	1.795	1.959	0.916	2641.939
19	2,884.140	1.857	2.034	0.913	2634.126
20	2,884.140	1.923	2.111	0.911	2626.335

Table F-2 – Discounted savings for a pre-1946 home with natural gas heating equipment

Year, *i*	**Annual Energy Cost Savings, *ECS* ($)**	**(1+*e*)^*i*-1**	**(1+*d*)^*i***	**(1+*e*)^*i*-1 ÷ (1+*d*)^*i***	**Discounted Savings ($)**
1	967.810	1	1.038	0.963	932.317
2	967.810	1.035	1.078	0.960	929.559
3	967.810	1.071	1.119	0.958	926.810
4	967.810	1.109	1.161	0.955	924.069
5	967.810	1.148	1.205	0.952	921.337
6	967.810	1.188	1.251	0.949	918.612
7	967.810	1.229	1.299	0.946	915.895
8	967.810	1.272	1.348	0.944	913.186
9	967.810	1.317	1.400	0.941	910.486
10	967.810	1.363	1.453	0.938	907.793
11	967.810	1.411	1.508	0.935	905.108
12	967.810	1.460	1.566	0.932	902.432
13	967.810	1.511	1.625	0.930	899.763
14	967.810	1.564	1.687	0.927	897.102
15	967.810	1.619	1.751	0.924	894.449
16	967.810	1.675	1.818	0.921	891.803
17	967.810	1.734	1.887	0.919	889.166
18	967.810	1.795	1.959	0.916	886.536
19	967.810	1.857	2.034	0.913	883.914
20	967.810	1.923	2.111	0.911	881.300

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