20 Mill Street | Kitchener

reep
Green Solutions

Energy Consumption Analysis

20 Mill St | Kitchener
Energy Consumption Analysis

Introduction

REEP (Residential Energy Efficiency Project) Green Solutions is an organization that is focused on addressing climate change through residential energy efficiency promotion. They operate two homes in Kitchener, Ontario, that have been renovated to demonstrate sustainable strategies. The “REEP House for Sustainable Living” is located at 20 Mill St. This residence is a super-insulated, water-wise, century brick education centre.

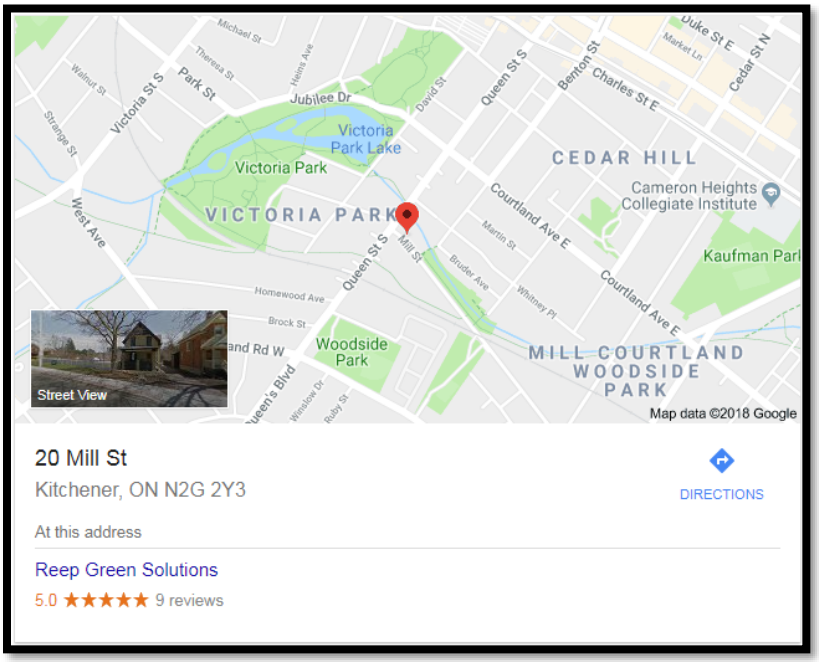

Figure 1: REEP House for Sustainable Living, located at 20 Mill Street, Kitchener

Background Material

Hot2000

The material for this analysis comes from the results of two energy audits completed before and after a major renovation to the century home at 20 Mill Street. These audits were completed with the aid of software developed by Natural Resources Canada (NRCan) called HOT2000. This program was originally developed as a validation tool for low energy buildings designed to meet the requirements of the R-2000 energy use and air quality program [4]. Hot2000 takes inputs such as those shown on the left of Table 1, and provides output shown on the right.

Table 1: Hot2000 Program Inputs and Outputs

INPUTS	OUTPUTS
Weather Data	Canada EnerGuide Rating
Wall/Roof Assembly Details	Estimated Annual Energy Consumption
Window Characteristics	Monthly Energy Profile
Air Leakage and Ventilation	Estimated Annual Fuel Consumption
Space Heating/Cooling Equipment	Estimated Annual Fuel Cost
Domestic Hot Water (DHW) Equipment	Estimated Greenhouse Gas Emissions

Residential Energy

Households around the world use energy to heat, cool (in some cases), and light their space, heat their water, run appliances, and provide power to devices. Common energy sources include electricity, natural gas, oil, propane, and wood. In Canada heating a home uses more energy, on average, then any other activity. As a result, the equipment and associated fuel used for heating homes depends in large part on the location of the home, and the least expensive type of energy in that area. Figure 2 is a pie chat displaying the main heating system in Canadian households. Forced air furnaces heat 57% of households, while electric baseboard heaters are responsible for 27%. Natural gas, which is the fuel for most forced-air furnaces, is the main heating fuel in 50% of Canadian homes, and electricity is the second most common heating fuel source at 39% [5].

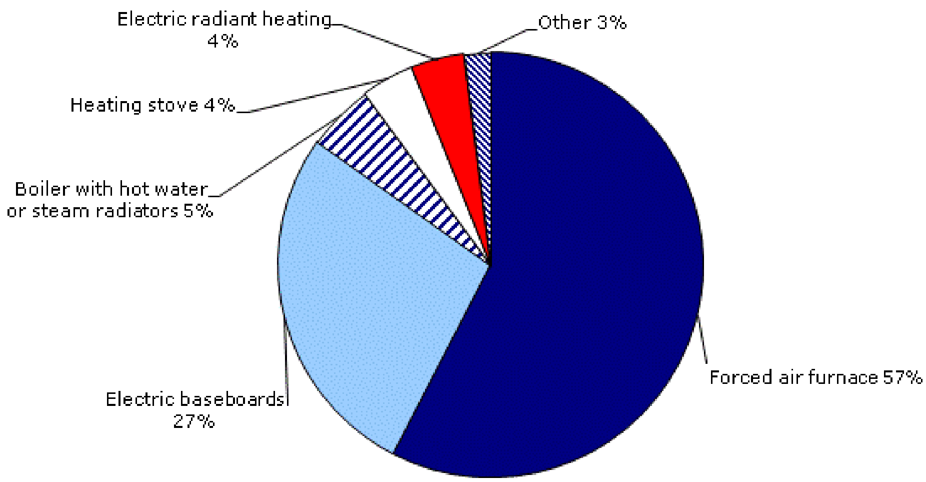

Figure 2: Main heating systems in Canada, 2011 [5]

Even though the national average for electrically sourced heat is 39%, in certain locations where electricity is inexpensive, this number is high higher. For example, in Quebec, where hydro-electric dams make electricity very inexpensive, electric heating is used in 85% of homes [5]! The greenhouse gas emissions from the on-site se of most fuels (such as natural gas, oil, or propane) is a straightforward calculation, but when considering electricity, one must know the source of the electricity. This is discussed in the following section.

Energy may be measured in a variety of units, including gram calories (cal), food calories (Cal), British thermal units (Btu), kilowatt-hours (kWh), therms (thm), and joules (J). Table 2 shows each of these units.

Table 2: Energy Measurement Units

ENERGY UNIT	LOGICAL CONVERSION	COMMON USE
Gram calorie (cal)	Energy needed to raise the temperature of one gram of water one degree Celsius	-
Food calorie (Cal)	1 Cal = 1,000 gram calories	Food
British thermal unit (Btu)	Roughly equal to the thermal energy given off by an ordinary match	Natural Gas
Therm (thm)	1 thm = 100,000 Btu, or ~100 balloons filled with natural gas	Heat
Joule (J)	Defined via work (a force acting over a distance) 1 newton metre or 1 kgm^2/s^2	SI Unit
Kilowatt-hour (kWh)	1 W = 1 J/s therefore 1 kWh = 3,600,000 Joules	Electrical Energy

The average household in Canada used 105 GJ (gigajoules) in 2011 [5]. This is equal to 29,167 kWh.

Energy Sources for Electricity in Canada

Electricity is not a fuel source in itself and must be generated by the burning of fuel (oil, coal, natural gas, garbage), the harvesting of natural energy (water, wind, sunlight, geothermal), or the splitting of atoms (nuclear fission). Figure 3, although outdated, presents a general view of electricity generation in Canada by fuel type. It is shown that BC, Manitoba, Newfoundland, and Quebec rely heavily on hydroelectric power generation, Alberta, Saskatchewan, and Nova Scotia burn more coal, and Ontario leans heavily on nuclear technology. Since this figure was created, Ontario has cut all its electricity production by coal, and significantly increased production by solar and wind (to over 10%). Note that Figure 3 indicates *generation* and not *consumption*. Much of Quebec's generated electricity is not consumed in Quebec, but exported.

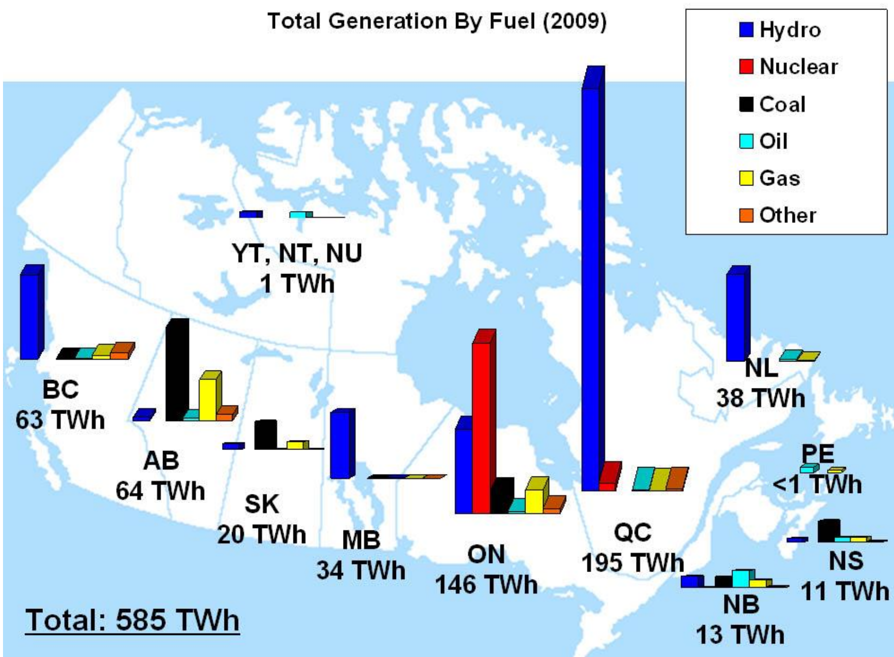

Figure 3: Electricity generation by fuel type in Canada, 2009 [6]

Note that energy sources for electricity in Canada will continue to change as technology, political cycles, power plaint maintenance schedules, and costs of fuel and construction change. However, it is important to estimate, as accurately as possible, the carbon emissions produced on the upstream side of a home's electricity.

It is important to have a well-rounded critique of each power source. Nuclear power generation is very favorable from a greenhouse gas perspective when considering only the operation of a nuclear facility, but one should also consider the full facility life-cycle and try to find a way to encapsulate carbon emissions from construction, maintenance, and decommissioning of the facility into each unit of power generated. Perhaps more importantly, the sustainability of the nuclear facility should not be evaluated purely on the basis of the carbon emissions saved (since nuclear power generates very few emissions compared to other sources). A well-rounded view of nuclear must also include a clear-headed consideration of the risk of nuclear disaster, and the sustainability of the long-term storage of radioactive waste.

Other carbon-friendly energy sources may also have drawbacks, such as the damming of rivers and the associated environmental costs for electricity generation by hydro; this lesson focusses on carbon emissions, however, and it is left to the reader to investigate other issues for a well-rounded view.

CO_2 Equivalencies

Since carbon dioxide, CO_2, is such a common chemical by-product of human activity, and is one of the primary "gases" amongst the "greenhouse gases" responsible for global warming, we generally translate all greenhouse gas emissions into "carbon dioxide equivalent" or CO_2e. As a result, emissions are generally measured in grams or tonnes of CO_2e.

We can take natural gas, which is a naturally occurring hydrocarbon gas mixture consisting primary of methane, as an example. Methane is a greenhouse gas with a very high "global warming potential", or GWP. GWP is a metric used to allow the comparison of the ability of different greenhouse gases to trap heat in the atmosphere relative to carbon dioxide. The GWP of methane, or CH_4, over a 100 year time horizon, is approximately 25 [2], meaning that it is 25 times more damaging than carbon dioxide. However, when methane is burned, as it is in home's natural gas powered furnace, the combustion reaction turns the methane into carbon dioxide and water (vapor) as shown below:

$$\mathrm{CH_4} + 2\mathrm{O_2} \rightarrow \mathrm{CO_2} + 2\mathrm{H_2O} + \mathit{Energy}$$

Comparing the left and right sides of the reaction, we can see that the right side is much more palatable from a GWP perspective (25 times less damaging, if we ignore the water vapor). However, this carbon dioxide will still contribute as a GHG. Using the chemistry, it is possible to find an emission factor for natural gas, which relates the quantity of the fuel burned to the amount of emissions, in grams CO_2e, produced. For the case of natural gas, which is mostly made up of methane which produces CO_2 when burned, the "e" could almost be removed to simply result in g CO_2. It is best to use an emission factor relating CO_2e to the energy produced, and not to the quantity of the fuel, which may be a different unit across fuel types.

Table 3 does exactly this, for some common fuel types.

Table 3: Emissions Factors for Fuels [2], [7]

FUEL TYPE	EMISSION FACTOR (g CO_2e/MJ)
Natural Gas	50.3
Coal	93
Residential Heating Oil	78
Wood	23

Table 4 shows that 1 m^3 of natural gas converts to 37.3 MJ of energy, when consumed. Other fuel types are also included.

Table 4: Conversion of Fuel Quantity to Energy (MJ) [8]

FUEL (units)	CONVERSION
Natural Gas (m^3)	37.3 MJ/m^3
Electricity (kWh)	3.6 MJ/kWh
Coal (kg)	24.0 MJ/kg
Heating Oil (kg)	46.2 MJ/kg
Wood (kg)	16.2 MJ/kg

Electricity does not have an emission factor in Table 3, because it is highly dependant on the source, as previously discussed. This document will focus on electricity generation in Ontario, since that is where 20 Mill Street is located (in Kitchener). Table 5 presents the generation sources for Ontario's electricity in 2015 and estimated greenhouse gas emissions associated with each [1]. Note that two values are given, one considering only operation, and the other considering the full life cycle emissions, which is much harder to estimate. Life cycle emission factors must be greater than or equal to their operation only counterparts.

Table 5: Summary of Energy Production in Ontario in 2015 [1]

RESOURCE (~GRID %)	OPERATING ONLY (g CO_2e/kWh)	LIFE CYCLE (g CO_2e/kWh)
Hydro (24%)	0.00	18
Nuclear (59%)	0.15	17
Wind (6%)	0.74	14
Solar (1%)	6.15	39
Natural Gas (10%)	525	622

With data from Table 5, which includes the % contribution of each resource to the overall grid for 2015, it is possible to estimate the emission factor for electricity as a whole. If this exercise is done, a value of 21.6 g/MJ would be found for 2015.

Problem Statement

Estimates for energy use and carbon emissions from home operation before and after renovations to 20 Mill St. are required to evaluate the project and provide guidance on future design decisions. Yearly energy costs for the address shall also be computed and compared. Energy data can be used from Hot2000 reports produced before and after the renovation. In the end, a comparison of energy costs and greenhouse gas emissions should be provided (in equivalent tonnes of CO_2), and an explanation should be given as to why the renovation was successful/unsuccessful, and what can be learned for future projects.

Lesson Objectives

After the lesson, students should be able to:

- Convert between units of energy (MJ) and fuel quantity (m^3 natural gas, kWh electricity, etc.),
- Compare costs of natural gas and electricity in Ontario,
- Find greenhouse gas emissions for natural gas and electricity per energy provided,
- Estimate greenhouse gas emissions, in equivalent tonnes of CO_2, produced by a home, and
- Relate tonnes of CO_2 to more easily understood quantities (volume, # of trees, etc.).

Readings

**needed to complete assignment*

- *Background Material
- *Hot2000 Reports
- *Website Showing Live Electricity Generation in Ontario
    - https://cns-snc.ca/media/ontarioelectricity/ontarioelectricity.html
- Other Textbooks/Reports/Articles/Websites

References

[1] Greenhouse Gas Emissions Associated with Various Methods of Power Generation in Ontario. Intrinsik, 2016. Obtained from: https://www.opg.com/darlington-refurbishment/Documents/IntrinsikReport_GHG_OntarioPower.pdf

[2] Global warming potentials. Government of Canada, Intergovernmental Panel on Climate Change. 2012. Obtained from: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/quantification-guidance/global-warming-potentials.html

[3] CO_2 Emission Factors. Natural Resources Canada, 2018. Obtained from: https://www.nrcan.gc.ca/energy/efficiency/industry/technical-info/benchmarking/canadian-steel-industry/5193

[4] Residential Sector Energy and GHG Emissions Model for the Assessment of New Technologies. Lukas G. Swan, 2010. PhD Thesis, Dalhousie University.

[5] Households and the Environment: Energy Use. Statistics Canada, 2011. Obtained from: https://www150.statcan.gc.ca/n1/en/pub/11-526-s/11-526-s2013002-eng.pdf?st=N30ltmRV

[6] Image from online conversation forum obtained from: https://forums.tesla.com/forum/forums/are-these-cars-really-green-electric-power-plants-and-carbon-footprint

[7] reepgreen.ca HOT2000 Reports

[8] Energy Conversion Factors. Obtained from: https://web.archive.org/web/20100825042309/http://www.ior.com.au/ecflist.html

20 Mill Street | Assignment

Notes:	-	Complete the following calculation and discussion questions.
	-	Always show units, and cite sources, where appropriate.
	-	Clearly indicate final answers.
	-	Minimum standards of neatness are expected.

Calculation Questions:

1. How much energy, in gigajoules (GJ), would 3,000 m^3 of natural gas yield? Is this a reasonable amount of natural gas for a home in northern Canada to use in a given year if it uses natural gas as its primary fuel source? *Hint: Compare to the Canadian average from 2011 given on page 3.*

   Solution:

$$3,000\text{m}^3\left[\frac{37.3\text{MJ}}{\text{m}^3}\right]=111.9\text{ GJ}$$

   Yes, this is a reasonable amount of energy for a typical northern Canadian home to use, considering the 2011 average yearly energy use of 105 GJ. Some electricity use would put the total household use higher than 111.9 GJ, but it is still a reasonable value.

2. How much energy, in gigajoules (GJ), would 85 kWh of electricity yield? Is this a reasonable amount of electricity for a home in Canada to use in a given year if it uses electricity as its primary fuel source? If not, over what period of time might a house use this much electricity?

   Solution:

$$85\text{kWh}\left[\frac{3.60\text{MJ}}{\text{kWh}}\right]=0.306\text{ GJ}$$

   No, this is not a reasonable amount of energy for a typical Canadian home to use in a given year, considering the 2011 average yearly energy use of 105 GJ. This would be more representative of a single day. A typical Tesla model S has a batter this large (can travel ~ 500 km).

3. Table 6 displays costs of fuel types in Ontario that were used for the Hot2000 Analyses of 20 Mill Street. These costs will not necessarily remain stable as time goes on but were reflective of the conditions at the time of renovation. Compare the relative cost of energy from Electricity, Natural Gas, Heating Oil, and Wood, normalized per MJ. Take the density of heating oil to be 0.92 g/cm^3, and 1 chord of wood to weigh 3,000 kg. *Hint: Use Table 4.*

Table 6: Hot2000 Fuel Cost Library [7]

FUEL TYPE	COST
Electricity	0.11 \$/kWh
Natural Gas	0.45 \$/m^3
Heating Oil	0.80 \$/L
Propane	0.95 \$/L
Wood	300\$/chord

   Solution:

FUEL TYPE	COST (cents/MJ)
Electricity	3.06
Natural Gas	1.21
Heating Oil	1.88
Wood	0.62

We see that Natural Gas is about 2x more expensive than wood per energy yield. By comparison, heating oil is 3x more expensive, and Electricity is 5x more expensive.

4. The HOT2000 report for the REEP House provides a comparison of energy consumption before and after the renovations. This includes space heating, domestic heat water, space cooling and appliances. Consult each report and find the sections titles: ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY. Use the total fuel consumption listed to calculate greenhouse gas emissions for both before and after the renovation. For natural gas use the emission factor given in Table 3, and for electricity use 150.6 g CO_2e/MJ.

5. Add up the total energy used by the house in a given year, before and after the renovation (use total fuel consumption and convert to energy in MJ). Comment on how much energy usage was reduced, compared to greenhouse gas emissions calculated in question 4.

Solution to 4 and 5:

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	5.75	
					54,013.54	MJ	6.547	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	5.08	
					202,155.56	MJ	13.554	tonnes CO_2e
Natural Gas to CO^2 eq	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**150.60**	g/MJ	0.000151	tonnes/MJ				

Even though energy was reduced by a factor of 4, the emissions were only halved. This is because the electricity emission factor used was 150.6 g/MJ, three times higher than the natural gas emission factor of 50.32, and the newly renovated home actually used more electricity after the renovation! Emissions would be drastically reduced if the source of the electricity was altered.

6. Derive the 21.6 g/MJ value given for the emission factor for Ontario electricity in 2015. Visit https://cns-snc.ca/media/ontarioelectricity/ontarioelectricity.html and calculate the emission factor for electricity in Ontario for today.

Solution:

OPG Report					
Type	**Distribution**	**LCA g/kWh**			
Nuclear	59.0%	17	10.03		
Hydro	24.0%	18	4.32		
Solar	1.0%	39	0.39		
Wind	6.0%	14	0.84		
Gas	10.0%	622	62.20		
	100.0%		77.78	g/kWh	
			21.61	g/MJ	
LIVE! 10/26/2018					
Type	**Generation MW**	**Distribution**	**LCA g/kWh**		
Nuclear	9,991	57.0%	17	9.70	
Hydro	4,905	28.0%	18	5.04	
Solar	1,287	7.3%	39	2.87	
Wind	1,233	7.0%	14	0.99	
Gas	99	0.6%	622	3.52	
	17,515	100.0%		22.11	g/kWh
				6.14	g/MJ

7. Repeat question 4 using an electricity emission factor of 7.8 g/MJ for British Columbia, and a 225 g/MJ value for Alberta (2013 values). Comment on the results.

Solution:

British Columbia

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	0.30	
					54,013.54	MJ	1.095	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	0.26	
					202,155.56	MJ	8.739	tonnes CO_2e
Natural Gas to CO^2 ec	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**7.80**	g/MJ	0.000008	tonnes/MJ				

Alberta

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	8.59	
					54,013.54	MJ	9.388	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	7.59	
					202,155.56	MJ	16.062	tonnes CO_2e
Natural Gas to CO^2 ec	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**225.00**	g/MJ	0.000225	tonnes/MJ				

Discussion Questions:

1. Rank the fuel sources of Wind, Solar, Hydro, Natural Gas, and Nuclear on their overall sustainability. Why have you chosen the order you have? Consider more than just carbon emissions – what unintended downsides result from the use of each of these fuels?

   Nuclear (risk of disaster, storage of radioactive nuclear waste, heating of mass quantities of water for cooling, large transmission distances)
   Hydro (damming of rivers and associated ecological damage, large transmission distances)
   Wind (upset farmers, micro-vibrations in the soil, low yields at times of power usage)
   Solar (recycling of equipment, large amount of real estate taken up)

2. Using the results from questions 4 and 6, comment on how the electrical grid in Ontario has changed from the year 2009 (when the 20 Mill Street renovation was completed), to the year 2015, to today. Do you anticipate future changes? What strategy would you recommend to a local political for Ontario's future?