Powering Canada Towards 2050 and Beyond.

Canada has committed to achieving "Net Zero" Greenhouse Gas (GHG) emissions by 2050. In practical terms this means that essentially all energy currently supplied by burning fossil fuels in this country will need to come from low-carbon sources. The carbon credits that many are hoping will be available to offset any remaining emissions, are forecast to be extremely limited and will be required to offset emissions from more challenging sources, such as steel and concrete production. The question that we face today is, *"What Do We Need to Do in Order to Meet our 2050 Goal[1]?"*

According to the 2020 British Petroleum (BP) Statistical Review of World Energy, in 2019[2] Canada consumed 14.2 exajoules (EJ)[3] of energy of which 4.8 EJ came from non-carbon sources, primarily hydro (hydraulic) energy. According to Statistics Canada, in that same year Canada generated and consumed about 660 terawatt hours (TWh) of electricity of which 532 TWh (81%) came from low-carbon[4] sources. The goal therefore is to replace the 128 TWh of fossil fuel generated electricity with generation from low-carbon sources and to replace the 9.4 EJ of fossil fuels used to power transportation, heating loads etc. with low-carbon electricity.

Table 1 - Canada's 2019 Primary Energy Consumption[5]

Source	exajoules
Oil	4.5
Natural Gas	4.33
Coal	0.56
Nuclear	0.9
Hydro	3.41
Other Renewables	0.52
Total	**14.22**

[1] A more in-depth review of this issue can be found in Chapter 5 (Joules in a Decarbonizing World) , of the Bowman Centre for Sustainable Energy book "CANADA- Making the Case for Nation Building Projects", available from www.bowmancentre.ca

[2] 2019 data was used rather than 2020 to avoid any Covid-19 impacts

[3] 1 exajoule = 10^{18} joules = 278 terawatt hours (TWh) = 278 x 10^{12} Watt hours

[4] Includes electricity from renewable sources such as hydraulic, wind, solar, geo-thermal, waves, and some non-renewable sources such as nuclear. The goal is to slow the pace of warming potentially requiring the short term use of some otherwise non-preferred technologies.

[5] Source 2020 BP Statistical Review of World Energy

While the task of determining how much low-carbon energy is required to replace fossil fuels may appear to be relatively straightforward, the devil, as always, is in the details. When burned, fossil fuels produce heat, which can be used to turn a shaft and drive a vehicle, etc., or which can simply be used to heat a building or industrial process. Electricity, on the other hand is a more versatile source of energy, being capable of delivering heat, light and motive force, in addition to driving a host of electronic devices. It isn't a one to one conversion, and the attached spreadsheet (Appendix 1) attempts to simplify the issue in order to reach a reasonable approximation to the future renewable energy needs.

Before getting into the detailed calculations, we need to briefly at Carbon Capture and Storage[6] (CCS) or Carbon Sequestration[7] in the soil or in forests. All of these technologies could potentially help offset emissions, but just how useful they will be, particularly in a hotter and dryer world where the soil may dry up and blow away and forests may burn, remains to be seen We need to use everything we can to reduce atmospheric GHG's, but for the purpose of planning we need to assume the worst. For that reason, while I hope that these technologies will aid us, I have not assumed any significant level of carbon sequestration or storage in this study.

Table 2 - Canada's 2019 Electricity Generation[8]

Source	Generation TWh	Low-Carbon Sources
Oil	4.1	
Natural Gas	69.3	
Coal	54.6	
Nuclear	100.5	100.5
Hydro	382	382
Wind & Solar	49.3	49.3
Other	0.7	0.7
Total	**660.5**	**532.5**

We use oil for a number of purposes, primarily powering road transportation, but also air transportation, shipping, chemicals and plastics production, electricity generation, space heating, etc. With the exception of the oil that goes into chemicals and plastics production where the carbon is locked in (i.e. the oil that goes into the chemicals and plastics does not contribute to our GHG emissions as long as the carbon remains intact. However the energy used in making that

[6] Carbon capture and storage is a process in which CO_2 is captured using a chemical process and subsequently pumped into an underground storage facility (often an old oil or gas well). While the process is simple and well established, it is an energy intensive process and works best on concentrated streams. CCS will only be viable if costs can be reduced and guarantees made that captured CO_2 does not subsequently leak back into the atmosphere.

[7] There are a number of ways in which carbon sequestration into the soil can be improved which hold promise if they can be widely adopted.

[8] Source Statistics Canada

plastic or chemical product does result in emissions), we need to replace all of those uses with some form of low-carbon energy.

Electricity generation from oil (diesel) is usually limited to serving remote communities that are not connected into the provincial or territorial transmission systems and which operate as micro-grids. Unless these communities can be connected into some future expanded national transmission system existing generation will need to be replaced with some form of standalone, low-carbon plus energy storage system. Fortunately, only a small amount of oil is consumed generating electricity. Based on the actual electricity generation from oil and an assumed heat rate of 12 GJ/MWh (spreadsheet cell F6) I have calculated that approximately 0.05 EJ of oil was used to generate electricity leaving 4.45 EJ of oil for transportation, chemical and plastic production purposes.

With a few exceptions for niche applications like aircraft, shipping, long distance road and rail shipping and heavy construction equipment etc. it looks as though battery electric vehicles (bEV's) will replace internal combustion (ICE) vehicles over the next decade or two. If battery technology continues to improve it may also provide the solution for some of the more difficult applications like long haul road or rail shipping, or even ocean shipping. Here is where technology aids us, because despite over 100 years of research the internal combustion engine is still inefficient (less than 30%). However, electric motors are typically 90+% efficient and even after adding in the battery losses associated with charging etc., a bEV requires about 3.7 times less energy than an ICE vehicle.[9] In the spreadsheet I used a more conservative 3.4 efficiency ratio to calculate that we would need to generate an additional 363 TWh (spreadsheet cell M6) of electricity in order to replace all oil used to drive transportation.

Calculating the amount of electricity required to replace natural gas follows a similar path. In this case the amount of gas used to generate electricity is significantly higher. Using the Stats Can generation data and assuming an average 8.0 GJ/MWh heat rate (to reflect occasional minimum load operation of gas turbines, duct firing, etc.) we can assign about 0.55 EJ of natural gas to electricity generation leaving 3.78 EJ to other uses. Although there are a few natural gas powered vehicles they consume an insignificant volume of gas. The remaining natural gas, is almost exclusively used to generate heat for buildings or for industrial heating and process needs.

As we transition away from fossil fuels, we will see a reduction in the energy used to extract, refine and transport oil. This is particularly true of the oil-sands where large volumes of natural gas are used to heat the oil deposits in order to extract the oil. Further reductions will be made in natural gas consumption when it is no longer required to make hydrogen used in the oil refining process.

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[9] Electric VW Golf rated 17.9 kWh/100 km, Golf gasoline rated 7.4 litres/100km. 1 litre of gasoline contains 8.9kWh of energy. 7.4 litres = 65.9 kWh 3.7 times more energy than the electric vehicle.

Natural Gas is extremely inexpensive, and as a result, currently, it does not make economic sense to properly insulate our buildings (a robust price on carbon would help redress this). However, even the most optimistic forecasts of future renewable electricity costs will result in significantly higher building heating costs unless something is done to reduce thermal losses. Not only will better national building standards and renovation programs be required, but more use of technology solutions such as heat pumps[10] will be required. This makes it more difficult to forecast the extent to which we can reduce the energy input required to maintain comfort, but for this purpose I assumed conservatively that we can use a factor of 2, i.e. half as much energy as we currently use (spreadsheet cell K7). Conservation and engaging new technologies could play a major role in reducing future demand for low-carbon electricity, and this should be an area of focus for all future decision makers and governing bodies.

Coal has few uses outside of electricity generation as is reflected in the spreadsheet. The only significant use outside of electricity generation is for steel refining where it can be replaced by hydrogen, although this requires significant capital investment. For the purpose of this exercise I have assumed that no additional generation is required to replace the insignificant amount of coal used in steel making etc.

The net result is that in order to eliminate all current fossil fuel consumption in Canada whilst maintaining our standard of living will require us to almost triple the generation of low-carbon electricity (spreadsheet cells F&G 22). All else staying equal we would need to increase generation by about 4% a year between today and 2050, but few things in life stay equal. The population of Canada is currently increasing by about 1% a year and there is nothing to suggest that this rate will decline. In fact it is more likely to increase as the number of global climate refugees grows. This could add another 500TWh of annual consumption to our 2050 generation target, requiring an annual 5% increase in low-carbon generation. Under normal circumstances, the growth in population is offset by a roughly 1% a year improvement in energy efficiency, as older appliances and industrial equipment are replaced. But these are not normal circumstances and we will require a much increased rate of energy conservation in order to fully decouple economic growth from energy consumption and emissions.

How we will supply so much new generation from intermittent or seasonal renewable sources like hydro, wind and solar remains to be seen. The cost of both electricity generation and energy storage are declining rapidly, and it is far too early to predict where these costs will plateau and who will be the winners. However, much can be done today to prepare for the future. We can strengthen interprovincial and north-south transmission interties so provinces and states can better support each other. We can also expand the transmission system to the north so it is ready

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[10] Heat pumps can provide over 3 kWh of heat for very kWh input, but they lose efficiency as the outside temperature gets lower. If geology and land use support use of geothermal heat pumps the ratio then can rise to > 4 (COP).

to bring in new renewable generation from remote locations and supply remote communities. We can start retiring our fossil generation by building additional low-carbon generation now. Additionally, we can dramatically improve building, vehicle, appliance and product efficiency standards to reduce demand. What is clear, however, is that we have squandered far too much time already with little or nothing to show for our efforts. We no longer have that luxury, the time for talking is over and the time for action is now.

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