Canada’s Energy Outlook

CURRENT REALITIES AND IMPLICATIONS FOR A CARBON-CONSTRAINED FUTURE

EXECUTIVE SUMMARY
Full report available at energyoutlook.ca

By J. David Hughes

MAY 2018

CCPA
CANADIAN CENTRE for POLICY ALTERNATIVES
BC Office

PARKLAND INSTITUTE

CORPORATE MAPPING PROJECT

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The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the funders of this report.

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Introduction

This report analyses Canada's energy system and assesses future options to maintain energy security and meet climate commitments as a foundation for planning a viable long-term energy strategy.

CANADIANS ENJOY A HIGH STANDARD OF LIVING underpinned by a reliable and secure supply of energy. Like many other countries, however, Canada is currently faced with some difficult decisions given the realities of climate change and the need to reduce emissions, as well as the finite nature of its fossil fuel supply. Even considering Canada's position as the second-largest hydropower producer in the world, 63% of its primary energy comes from fossil fuels. On an end-use, delivered energy basis, 76% is provided by fossil fuels, with only 17% provided by electricity.

Canada is also a signatory to the Paris Agreement, and aspires to reduce emissions 30% from 2005 levels by 2030 and 80% by 2050. Given the current status of Canada's energy supply, these are very aggressive targets.

This report analyses Canada's energy system and assesses future options to maintain energy security and meet climate commitments as a foundation for planning a viable long-term energy strategy. The report is divided into four parts:

SECTION 1 examines the evolution of Canada's energy system in the global context in order to develop an understanding of where our energy comes from, trends in production and consumption, and the scale of the problem in maintaining future energy supply while minimizing environmental impacts. It looks at oil, gas, coal, hydro, nuclear and non-hydro renewables. It also looks at emissions and the correlation between economic activity and energy consumption, as well as trends in energy- and emissions-intensity.

SECTION 2 examines Canada's remaining non-renewable energy resources. Existing oil and gas resources are assessed in terms of play type, future viability, resource estimates and National Energy Board (NEB) projections of future production. It also examines jobs and government revenues from non-renewable resource extraction and the decline in royalty and corporate tax payments despite increasing production.

SECTION 3 examines electricity capacity and generation by fuel as well as NEB projections of future generation through 2040. Given that electricity is the principal output provided by renewable sources, particular attention is devoted to generation from solar, wind, biomass and tidal energy. The implications of Canada's mid-century scenarios for emissions reduction in terms of new capacity required and cost are also reviewed for each carbon-free generation source. This section also looks at renewable heating and liquid fuel sources including biomass, geothermal energy and biofuels.

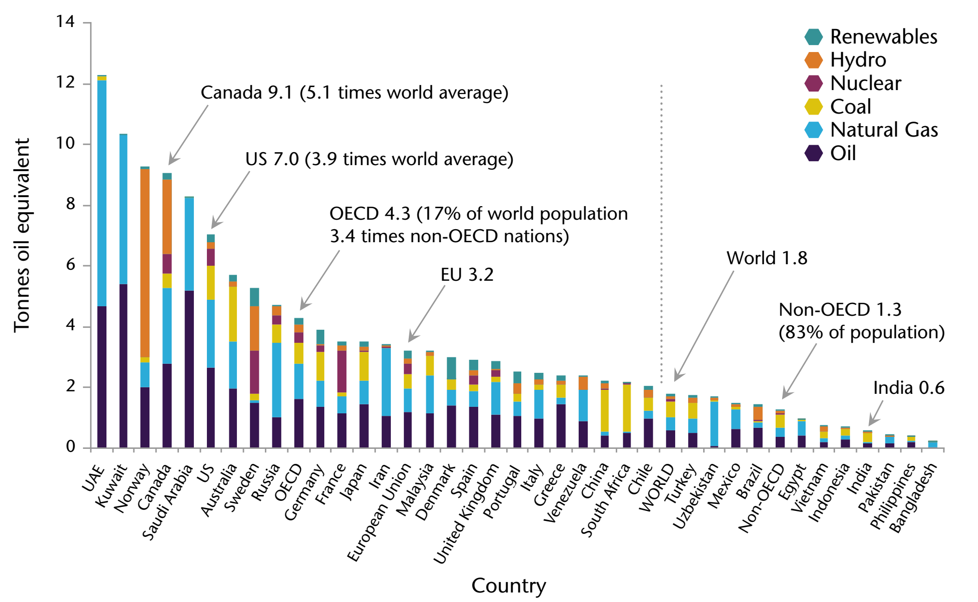
SECTION 4 summarizes key considerations for an energy strategy and the projections provided in Canada's pan-Canadian framework and mid-century strategy scenarios to reduce emissions by 30% and 80% from 2005 levels, respectively. It also reviews the implications of NEB projections of future energy production on Canada's emissions-reduction targets. The low likelihood of success given the implications of the scenarios and projections is highlighted, along with key focus areas that will increase the chances of success in both emissions reduction and future energy security.

Canadian energy consumption in the global context

Canadians are large consumers of energy, with per capita consumption of five times the world average, 29% higher than the US, and nearly triple that of the European Union.

WORLD ENERGY CONSUMPTION HAS MORE THAN TRIPLED since 1965 and continues to grow. Although rates of growth have slowed in developed nations, where per capita consumption rates are already very high, countries like China and India are growing at 3% to 5% per year. Canadians are large consumers of energy, with per capita consumption of five times the world average, 29% higher than the US, and nearly triple that of the European Union (see Figure ES1).

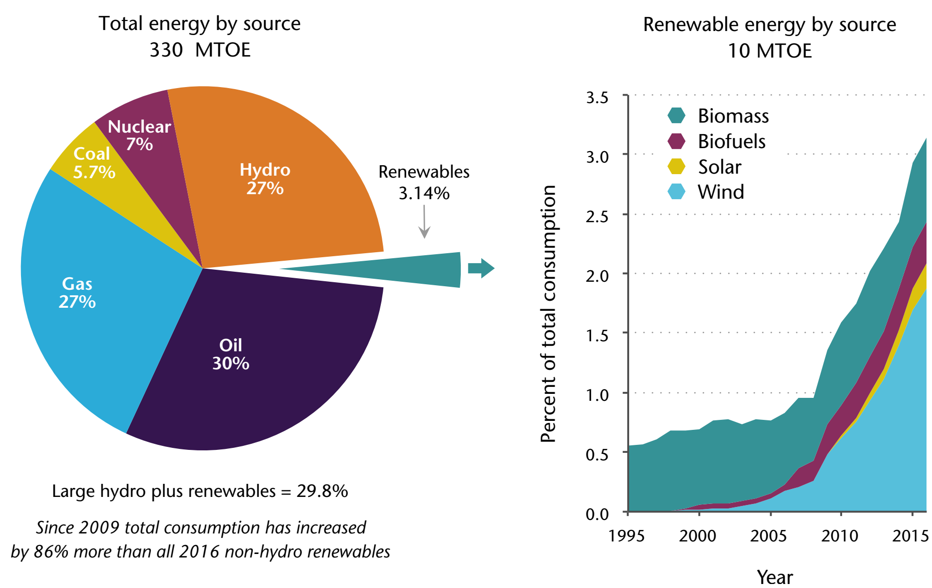
Figure ES1: Per capita consumption of primary energy by fuel and country in 2016



Source: BP Statistical Review 2017 and World Bank population statistics for 2016.

Fossil fuels currently provide 85% of global primary energy, with most of the balance provided by hydropower and nuclear energy. Only 3.8% of the world's energy was provided by non-hydro renewables such as solar, wind, biomass and geothermal energy in 2016. In Canada, as noted earlier, 63% of primary energy was provided by fossil fuels in 2016, even though Canada is the second-largest producer of hydropower in the world. Non-hydro renewable energy provided just 3.1% of Canada's primary energy in 2016, despite high rates of growth in wind and solar (see Figure ES2).

Figure ES2: Primary energy consumption by source in Canada in 2016 and trends in consumption of non-hydro renewable energy from 1995 to 2016



Source: BP Statistical Review of World Energy, 2017. (MTOE stands for "million tonnes oil equivalent").

Fossil fuels currently provide 85% of global primary energy, with most of the balance provided by hydropower and nuclear energy.

On a per capita basis, Canadians consume:

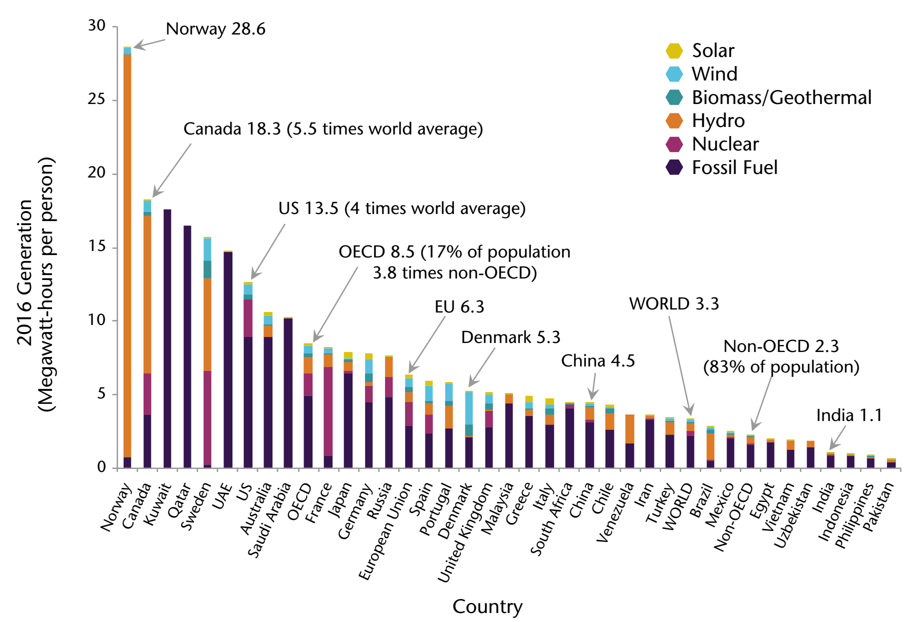
- Five times the world average of oil, although consumption is falling at 1.4% per year. Total consumption is falling at only 0.4% per year due to population growth and is growing at 1.5% per year globally.
- 5.8 times the world average of natural gas, although consumption is falling at 1.3% per year. Total consumption is falling at only 0.3% per year due to population growth and is growing at 1.8% per year globally.
- Equal to the world average of coal, although consumption is falling at 3.8% per year. Total consumption is falling at only 2.8% per year due to population growth and is falling at 0.4% per year globally.
- Eight times the world average of nuclear energy. Total consumption is growing at 2.1% per year due to the recent refurbishment of some reactors, although globally nuclear is falling at 0.3% per year. Without additional refurbishments of the Bruce and Darlington reactors, or the construction of new reactors, Canada will have no nuclear energy by 2037 due to retirements.

- 4.5 times the world average of non-hydro renewables. Total consumption is growing at 18.4% per year and globally at 21.2% per year, but from a small base. As a percentage of total energy consumption, Canada falls below the world average with 3.1% of primary energy provided by non-hydro renewables versus 3.8% globally.

Canadians are also large consumers of electricity, with a per capita generation of 5.5 times the world average (see Figure ES3; note that some of this is exported to the US). Most strategies for a low-carbon future call for large increases in electrification provided by renewable energy sources. In Canada's case, 76% of end-use energy is currently provided by fossil fuels with just 17% provided by electricity. Electrification of the transportation, industrial, residential and commercial sectors to the maximum extent possible will be crucial in meeting Canada's emissions-reduction targets.

Electrification of the transportation, industrial, residential and commercial sectors to the maximum extent possible will be crucial in meeting Canada's emissions-reduction targets.

Figure ES3: Per capita generation of electricity by country and fuel in 2016



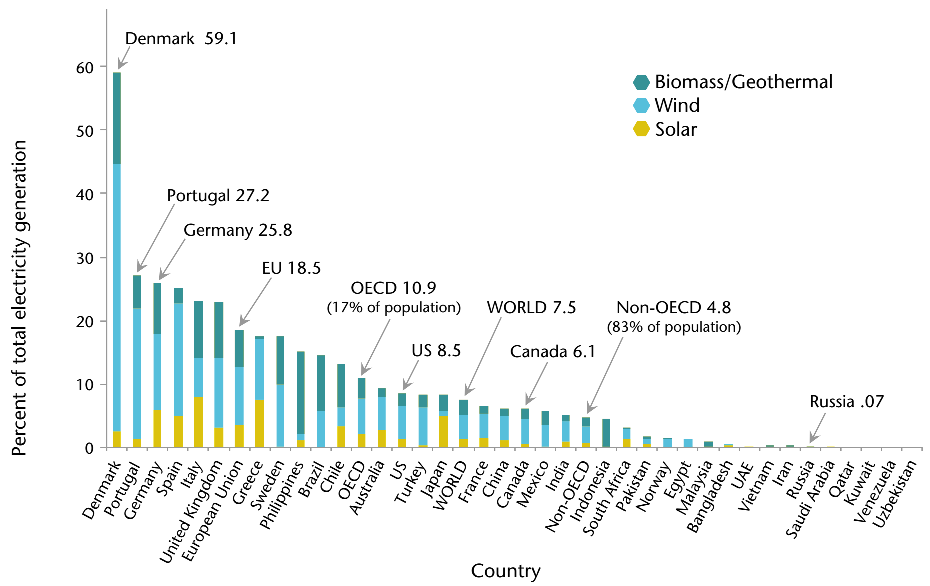
Source: BP Statistical Review 2017 and World Bank population data.

Although Canada has considerable additional capacity for new hydropower dams, a major build-out would be difficult given the ecological impacts and public opposition. Non-hydro renewables such as solar, wind, biomass, biofuels and geothermal energy are viewed by many environmental groups as feasible replacements for fossil fuels, however they currently provide just 6.1% of electricity generation and 3.1% of primary energy consumption.

Over the past five years, solar generation in Canada has grown at 105% per year but in 2016 provided just 0.5% of generation. Wind has grown 30% per year over the same period and provided 4.1% of generation in 2016. Biomass burning provided the remaining 1.5% (biomass is considered carbon neutral even though initial emissions are equal to or greater than coal). Although solar and wind are projected by the NEB to grow considerably in the future, most of the gap left by retired nuclear reactors and coal plants is projected by the NEB to be filled with natural gas.

Scaling non-hydro renewables to replace a major portion of current non-electric delivered energy presents a very significant challenge. Canada is well below the world average in terms of the percentage of electricity generated from non-hydro renewables, as Figure ES4 illustrates. Aggressive policy initiatives such as Germany's *Energiewende* have increased non-hydro renewables there to 26%, but parallel policies to eliminate nuclear energy have also increased coal consumption and limited actual carbon emissions reductions.

Figure ES4: Percentage of electricity generated by non-hydro renewable energy by country in 2016



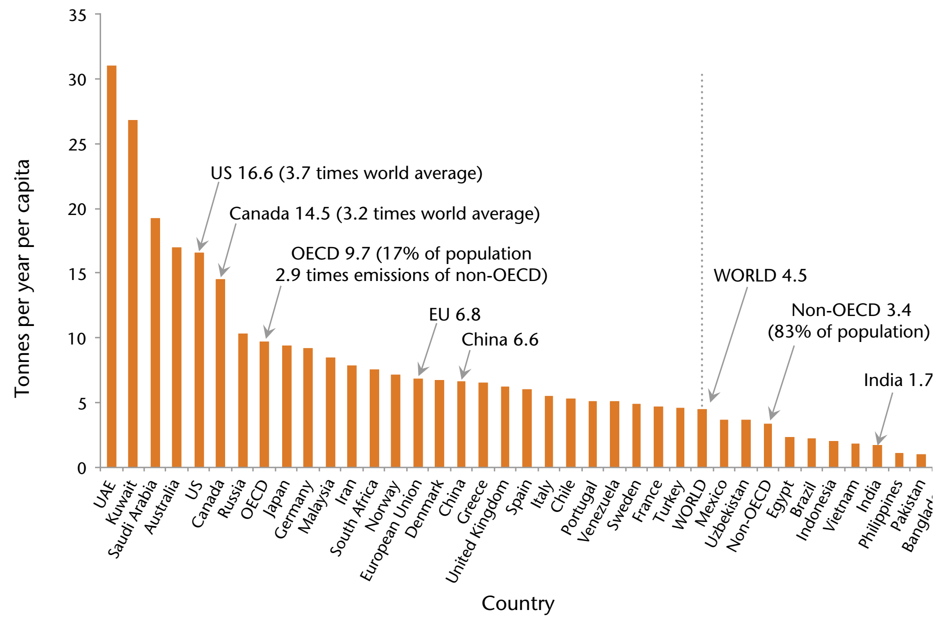
Source: BP Statistical Review 2017.

Given their much higher per capita emissions, Canada and the rest of the developed world will need to have more to offer in meeting emissions-reduction targets than developing nations, whose per capita emissions are already relatively low.

In terms of carbon dioxide emissions, Canada ranks very high, despite its large component of carbon-free hydropower and nuclear. On a per capita basis Canada emits 3.2 times the world average—this is more than double that of China, the largest consumer of coal in the world, and eight times the per capita emissions of India (see Figure ES5). The good news is that Canadian emissions have been falling, along with emissions in most of the developed world. Over the past five years, Canadian emissions fell at 1.9% per year on a per capita basis and 0.9% per year on an overall basis. By contrast, emissions have been rising on an overall basis 0.6% per year globally, 0.7% in China and 6.1% in India. Given their much higher per capita emissions, Canada and the rest of the developed world will need to have more to offer in meeting emissions-reduction targets than developing nations, whose per capita emissions are already relatively low.

Consumption of energy and resultant emissions are highly correlated with economic activity.

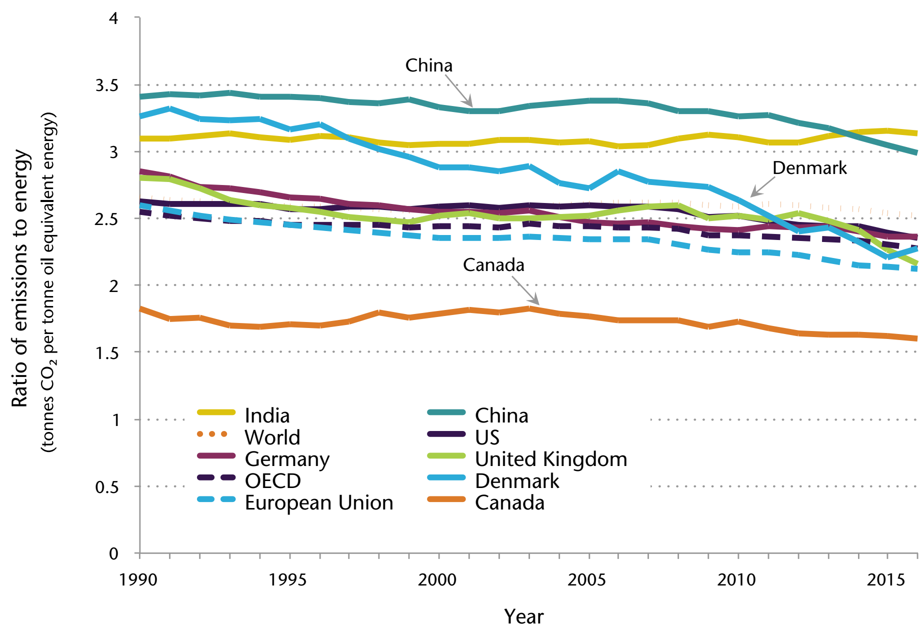
Figure ES5: Per capita carbon dioxide emissions from combustion of fossil fuels by country in 2016*



Source: BP Statistical Review 2017. CO2 emissions from fossil fuels only.
*This does not include emissions from land use change and other sources.

Consumption of energy and resultant emissions are highly correlated with economic activity. Although carbon dioxide emissions per dollar of gross domestic product (GDP) have been falling (emissions intensity has declined at 2.1% per year globally and 2.5% in Canada from 2011 to 2015), along with energy consumption per dollar of GDP (energy intensity has been declining at 1.8% per year globally and 1.3% in Canada from 2011 to 2015), GDP has been rising, such that energy consumption and emissions are still rising globally when combined with population growth. Emissions improvements per unit of energy consumed are far more muted (see Figure ES6). The ratio of emissions to energy provided has fallen 0.3% per year globally from 2011 to 2015 and 1.3% in Canada. The greatest improvement has been in Denmark, at 3.3% per year over this period, due to aggressive implementation of wind and solar. Yet in 2015 Denmark remained 38% higher than Canada in emissions per unit of energy provided to the economy thanks to Canada's large component of hydropower.

Figure ES6: Ratio of emissions to energy consumption by country from 1990 to 2016



Source: BP Statistical Review 2017. CO_2 emissions from fossil fuels only.

Non-renewable energy supply, resources and revenue

The oil sands are a low-quality unconventional resource that requires large energy inputs to extract, with resultant large emissions compared to conventional oil.

CANADA IS A MATURE EXPLORATION and production petroleum province. More than 800,000 wells have been drilled, of which 222,000 are still producing. The four western provinces and southern territories comprising the Western Canada Sedimentary Basin (WCSB) have produced most of the oil and gas along with some offshore production in Newfoundland and Nova Scotia. Key considerations for oil production include the following:

- Conventional oil production in Canada peaked in 1973. Some 88% of the NEB's estimate of conventional light- and heavy-oil reserves in the WCSB have been consumed. Including the East Coast, 85% of Canada's conventional oil reserves have been consumed. Yet the NEB's reference case forecast would see the production of nearly three times Canada's known conventional oil reserves by 2040.

- If as yet undiscovered resources in Canada's northern and offshore frontiers are included, 49% of Canada's ultimate potential conventional oil has been consumed. The NEB's reference case forecast assumes that 55% of remaining discovered and undiscovered conventional oil as of year-end 2016 will be produced by 2040. Undiscovered resources are uncertain estimates at best, and recovering oil in northern and offshore frontiers is subject to additional environmental risks.

- Maintaining conventional oil production requires continual drilling as individual well production declines from 32% to 90% over the first three years. Modern hydraulically fractured horizontal wells decline at 78% to 90% over this period, accelerating the need for continuous drilling. The average production of oil wells has declined from a high of 130 barrels per day in Alberta in 1973 to less than 20 barrels per day in 2015.

- With 97% of Canada's remaining oil reserves, the oil sands offer the only hope for substantially increasing Canadian oil production. But this is a low-quality unconventional resource that requires large energy inputs to extract, with resultant large emissions compared to conventional oil (well-to-tank emissions for diesel fuel are 89% higher for oil sands than Canadian conventional oil).

- Raw bitumen extracted from in situ oil sands has a mean energy return on energy investment (EROI) of about 4:1 versus about 8:1 for surface mineable resources. This compares to an EROI of greater than 10:1 for most conventional oil. Although only 20% of oil sands reserves are shallow enough to be surface mineable, they constitute 89% of the oil sands reserves currently under active development. As production from in situ extraction grows relative to surface mining, net energy will decline and average emissions per barrel will increase.

- Oil sands projects target the highest-quality, most economic resources first. Although the resource is large, the energy return on investment will decline and emissions per barrel will increase as extraction moves into lower-quality portions of the resource. About 90% of the resource is in deposits with a pay thickness of less than 15 metres, whereas resources currently under development have a pay thickness of greater than 25 metres.

- Although oil sands projects under construction will be completed and production will rise, it is unlikely that new greenfield projects will be developed unless oil prices increase substantially.

- Existing export pipeline and rail capacity is sufficient to move forecast production through 2040 under the NEB's reference production scenario with Alberta's oil sands 100-megatonne per year emissions cap. Although transporting diluted bitumen (dilbit) by rail is more costly than pipelines, diluent is not needed if bitumen is transported in heated rail cars. Transporting undiluted bitumen allows 42% more product to be shipped per unit volume, making rail more competitive with pipelines while at the same time reducing risk in the event of an accident (given that undiluted bitumen does not flow like dilbit or crude oil and is not volatile).

Transporting undiluted bitumen by rail allows 42% more product to be shipped per unit volume, making rail more competitive with pipelines while at the same time reducing risk in the event of an accident.

- Canadian oil sold in the US is not being unfairly discounted. The US Gulf Coast has the world's largest concentration of coking refineries, which can optimally process heavy oil, and Canadian crude is optimally positioned to replace declining production from Venezuela and Mexico, which have been large suppliers to Gulf Coast refineries. (The increase in the price differential observed since November 2017 is a result of the temporary shutdown of the existing Keystone pipeline and a subsequent reduction in its capacity. This will be eliminated with the completion of Line 3 and the likely completion of Keystone XL.)[1]

Key considerations for natural gas production include the following:

- Natural gas production in Canada peaked in 2001 and is now 14% below that level. Two-thirds of Canada's production comes from Alberta and most of the remainder comes from BC. Future growth will increasingly come from unconventional tight gas and shale gas resources made economically viable with horizontal drilling and hydraulic fracturing technology. The NEB's reference scenario projects that unconventional gas will be 76% of Canadian supply by 2040. Gas production in the rest of Canada outside of Alberta and BC is projected to fall in the NEB's reference case from about 4% at present to 2.5% in 2040.

- Proven gas reserves in Canada amount to 70.9 trillion cubic feet (tcf) according to the Canadian Association of Petroleum Producers (CAPP). This is about 12.8 years of supply

1 Acuña, R., February 9, 2018, Let's share actual facts about the Trans Mountain pipeline, http://www.parklandinstitute.ca/lets_share_actual_facts_about_the_trans_mountain_pipeline

at 2016 production rates. The NEB's reference case forecast projects production of 135 tcf, or nearly double current known reserves, by 2040. Some 94% of the NEB's estimate of 1,225 tcf of remaining natural gas resources is unproven in terms of economic and technical viability.

- The NEB has increased its estimate of remaining Canadian gas resources by 116% since 2007, almost entirely as a result of vastly ramped up estimates for tight gas and shale gas, both of which require horizontal drilling and hydraulic fracturing technology to recover (the latter of which has been subject to widespread environmental opposition in the US and elsewhere). Tight gas estimates have been ramped up by 386% and shale gas by 351%, whereas conventional gas estimates have been reduced by 40%. Some of these estimated resources are extrapolated over broad regions, often with minimal amounts of drilling, and must therefore be considered highly uncertain.

- Maintaining gas production requires continual drilling because the hydraulically fractured horizontal wells required to produce most of the remaining resources decline 70% to 83% over their first three years. The average production rate of gas wells has declined from a high of 3,900 mcf/day (thousand cubic feet per day) in BC in 1973 to 570 mcf/day in BC, 100 mcf/day in Alberta and 20 mcf/day in Saskatchewan, in 2015.

The energy sector has declined as a proportion of the Canadian economy over the past 20 years despite growing production.

Thermal coal production is forecast by the NEB to decline 78% from 2016 levels by 2030, due to the phase-out of coal generation in Alberta, whereas the production of metallurgical coal used in steel-making is forecast to increase by 10% over the same period, mainly for export.

The energy sector has declined as a proportion of the Canadian economy over the past 20 years despite growing production:

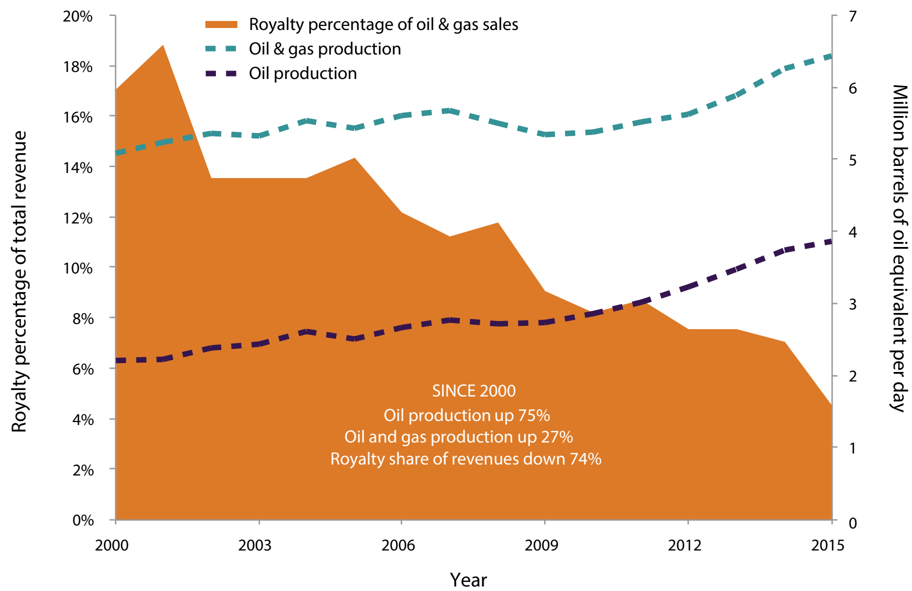
- Production and distribution of oil, gas and coal as a percentage of total Canadian GDP declined from 9.2% in 1997 to 7.4% in 2015. Construction related to oil and gas development added 0.72% and 0.86% in 1997 and 2015, respectively. During this same period oil production increased by 79% and combined oil and natural gas production increased by 33%.

- In Alberta, which contributed 71% of Canadian energy sector GDP in 2015, the proportion of the province's GDP derived from oil, gas and coal production declined from 40% in 1997 to 29% in 2015 (an additional 3% and 3.3% was derived from oil and gas construction in 1997 and 2015, respectively).

Revenues to governments from the sale of non-renewable oil and gas resources have been declining markedly since 2000, despite record prices over parts of this period and growing production. According to CAPP, royalty revenues paid to provinces have declined 63% between 2000 and 2015, from $11.1 billion to $4.1 billion (nominal dollars). Royalties as a percentage of total oil and gas sales revenues have fallen 74% over the same period, from 17.1% to 4.5%, as illustrated in Figure ES7. Meanwhile, oil production grew by 75% between 2000 and 2015, and combined oil and gas production grew by 27%.

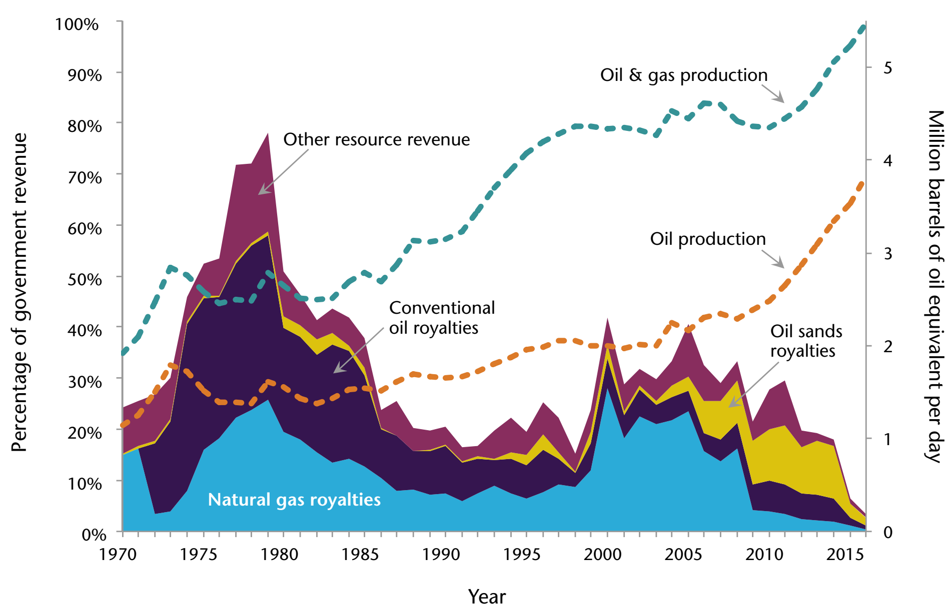
In Alberta, Canada's largest oil and gas producer, revenue from royalties and other resource revenue have declined from 80% of government revenue in 1979 to an estimated 3.3% in 2016 (see Figure ES8). This is in spite of a doubling of oil and gas production since 1980. In 2015 dollars, Alberta government revenue hit $14 billion in 1979 and spiked again to $17 billion in 2005. Estimated 2016 revenue of $1.4 billion is down 90% from 2005 levels, despite considerable production growth since then.

Figure ES7: Royalties as a percentage of total oil and gas sales revenue from 2000 to 2015



Source: CAPP Statistical Handbook tables 04-25B and 04-02B; production data from NEB 2016.

Figure ES8: Alberta government non-renewable resource revenue as a percentage of total government revenue from 1970 to 2016

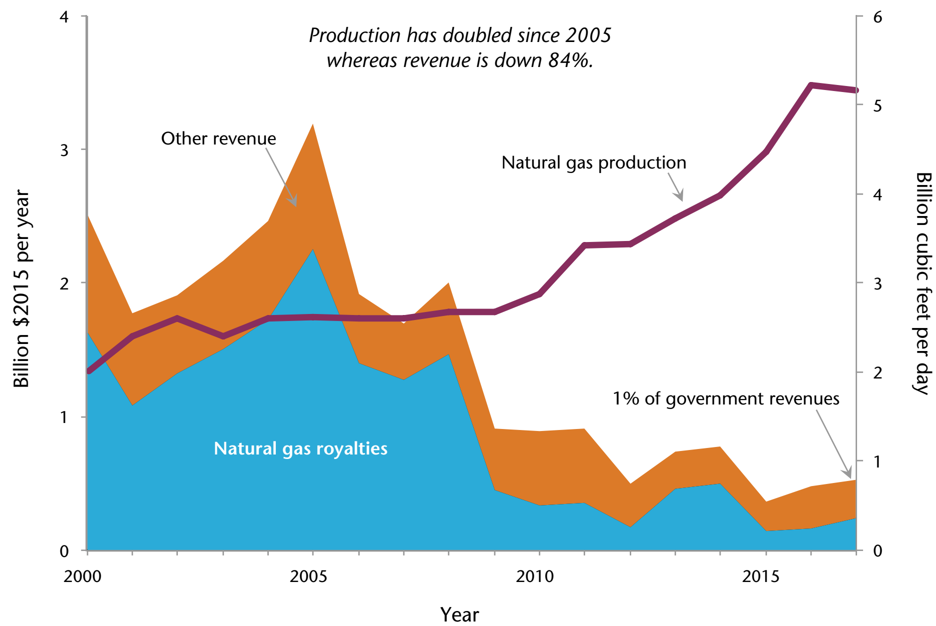


Source: Alberta Energy July 2017 and Alberta 2017 budget estimates; Production from CAPP and NEB; Other resource revenue includes rental fees, lease sales and coal royalties.

A similar decline in resource revenue has occurred in BC, the second-largest producer of natural gas. Despite the fact that gas production has doubled since 2005, royalty and other non-renewable resource revenue has declined by 84%, such that it was only 1% of government revenue in 2017 (see Figure ES9).

Canada's remaining non-renewable energy resources are being sold off in an environment of low prices with minimal and declining returns to governments.

Figure ES9: Non-renewable energy resource revenue in BC from 2000 to 2017



Source: BC Budgets 2000–2017 (note 2016 and 2017 are estimates); production from NEB update, 2016; crown lease revenue excluded as it includes mining and forestry.

Oil and gas jobs are a relatively minor overall component of the Canadian economy: 2.2% of Canada's workforce was employed in oil, gas and coal production, distribution and construction in 2015. Of these jobs, 52% were involved in construction, most of which were of a temporary nature. In Alberta, 6.3% of jobs were involved in fossil fuel production and distribution, and a further 6.6% in related construction. Newfoundland was the second-most important province in terms of jobs, with 1.5% involved in oil production and distribution and 5.1% involved in related construction in 2015.

Despite growing production, jobs in the extraction and distribution portions of the industry have remained relatively flat since 2006, and declined in 2015 with the downturn in oil price. The exception is construction, mainly in the oil sands. Construction jobs are short-term, however, and many will disappear with the completion of projects currently under construction.

If corporate tax revenue is added to royalties and other non-renewable resource revenue paid to governments, total revenue is down 41% since 2000 (as of 2015), while oil production is up 75% and combined oil and gas production is up 27%. Claims of higher revenues through "spin-off" jobs not directly related to the oil and gas industry (through income taxes, etc.) assume that these people would not otherwise be employed, which is unlikely. In short, Canada's remaining non-renewable energy resources are being sold off in an environment of low prices with minimal and declining returns to governments.

Electricity capacity, generation and renewable fuels

ALTHOUGH ELECTRICITY COMPRISED only 17% of delivered energy in Canada in 2016, and the NEB projects that this will be just 19% in 2040, most strategies for widespread replacement of fossil fuels by renewable energy call for much higher levels of electrification. For example, Canada's "Mid-Century Long-Term Low-Greenhouse Gas Development Strategy" (mid-century strategy) contains six scenarios calling for an increase of between 86% and 246% in electricity generation over 2015 levels, which would result in electricity providing between 33% and 65% of delivered energy in 2050. This compares to the NEB's reference case projection, which would see generation increase just 23% over 2015 levels by 2040. Scenarios in the mid-century strategy are targeted at reducing emissions by about 80% from 2005 levels by 2050, and call for reduced levels of overall delivered energy consumption compared to 2015 levels as well as increased electrification.

Sources of electricity have unique characteristics that determine their cost and the related infrastructure needed. Key among these are the capacity factor (the amount of electricity actually generated by a source compared to its theoretical maximum) and whether the source is "dispatchable" or not (the ability of a source to be turned on or off when needed to balance demand). Hydro, nuclear and thermal sources (thermal sources include oil, natural gas, coal and biomass) had capacity factors of 54%, 78% and 47%, respectively, in 2015, whereas wind and solar had capacity factors of 26% and 20%, respectively. Hydro and most thermal sources are dispatchable, whereas nuclear is not, as it cannot be ramped up and down to follow load. Solar and wind are intermittent and therefore non-dispatchable, as they vary on hourly and seasonal timeframes. This means that solar and wind must be backed up by dispatchable energy sources and/or storage to provide a reliable grid. Although wind is typically deployed in large wind farms located in areas with optimal wind speed and connected to points of use by often lengthy transmission lines, solar is amenable to both large commercial installations and to distributed generation at the household- or commercial-building scale.

Although the NEB projects significant growth in wind and solar through 2040, a large part of the decline in coal and nuclear energy, and the increase in electricity demand, is projected to be met with natural gas, such that by 2040, 82% of generation will be met by carbon-free sources, which is roughly the same as today. The scenarios in the mid-century strategy call for much more aggressive growth in carbon-free sources as well as a reduction in overall energy consumption. Carbon-free electricity sources include the following:

- Nuclear, which provided 15% of generation in 2015, has 14 gigawatts of generation capacity. Without refurbishment of the Bruce and Darlington reactors, at a cost of $C26 billion, Canada's nuclear capacity will decline to zero by 2037 due to the retirements of reactors as they reach the end of their planned lifetimes. Assuming the refurbishments go ahead, nuclear generation will still decline substantially. The mid-century strategy's scenarios call for the construction of between three and 108 new one-gigawatt reactors by 2050. At the U.S. Energy Information Administration's average cost of new "advanced nuclear," this would require between $US18 billion and $US642 billion in capital expenditures by 2050, not including transmission lines. Even the declining generation in the NEB's reference case would require four new reactors.

The scenarios in the mid-century strategy call for much more aggressive growth in carbon-free sources as well as a reduction in overall energy consumption.

- Hydro, which provided 59.2% of generation in 2015, had 80 gigawatts of generation capacity in 2016. Canada was second only to China in terms of hydroelectric generation in 2016, which came from 576 facilities rated at more than 0.8 megawatts and 22 rated at more than one gigawatt. Just over 50% of generation came from Quebec, 18% from BC and 11% from Ontario. The mid-century strategy's scenarios call for the construction of new capacity equivalent to between 33 and 118 new 1.1-gigawatt dams by 2050 (which is the size of the highly controversial Site C dam now under construction in BC). Going by the cost of Site C, new dam construction would require between $US205 billion and $US739 billion in capital expenditures by 2050, not including transmission lines.

- Wind, which provided 4.4% of generation in 2015 (according to the NEB, while Statistics Canada indicates 2.7%), has nearly 12 gigawatts of generation capacity. The highest generation is in Ontario, followed by Alberta and Quebec. The mid-century strategy's scenarios call for a 12% to 1,792% increase in wind generation by 2050, which would require between 654 and 97,362 new two-megawatt wind turbines. At the U.S. Energy Information Administration's average cost of wind turbines, this would require between $US2.5 billion and $US366 billion in capital expenditures by 2050, not including transmission lines. High-quality wind sites are geographically restricted, with the best sites in the southern prairies, in other more-restricted locations, and offshore.

- Solar, which provided 0.5% of generation in 2015 (according to the NEB, while Statistics Canada indicates 0.05%), has two gigawatts of generation capacity, most of which is in Ontario. The mid-century strategy's scenarios call for a growth in solar generation of up to 3,192% by 2050, which would require adding up to 73 gigawatts of new solar capacity at a cost of up to $US185 billion. In addition to daily (and shorter) fluctuations from cloud cover and day/night cycles, solar generation is subject to large seasonal variations, with capacity factors dropping below 6% in winter months in many parts of Canada.

- Biomass, which provided 1.9% of generation in 2015 (according to the NEB), has 2.8 gigawatts of generation capacity from 136 widely distributed plants, most of which have a capacity of less than 100 megawatts. The mid-century strategy's scenarios call for a growth in biomass generation of up to 873% by 2050, which would require adding up to 21 gigawatts of new biomass capacity at a cost of up to $US105 billion. Biomass is considered a carbon-neutral energy source; although when initially burned biomass emissions are comparable to coal, it is assumed that these emissions will eventually be sequestered through regrowth. Biomass has an advantage over other non-hydro renewable sources in that it is dispatchable and can therefore be used to back up intermittent sources such as wind and solar.

- There is no geothermal electricity generation in Canada at present, and the mid-century strategy does not anticipate significant development by 2050, although there is potential, particularly in BC and the southern territories.

Other renewable forms of energy include biofuels (ethanol, biodiesel and biomass gas), the use of biomass for heating and the use of geothermal energy for space-heating. Canada is not self-sufficient in the production of ethanol for blending with gasoline and imports 36% of its requirements, although it is self-sufficient in biodiesel. The net energy return on ethanol and biodiesel is less than 1.6:1, making biofuels a marginal replacement for fossil fuels at best. Notwithstanding this, "renewable fuels" are assumed to increase two-fold to 10-fold from current levels in the mid-century strategy's scenarios. Biomass heating facilities are widespread in Canada, with 270 large-scale facilities and many more using biomass for residential heat. In addition, Canada is a major exporter of wood pellets, mainly to Europe. The fact that biomass has emissions equivalent to coal when burned, and that biofuels and biogas have emissions equivalent to their fossil fuel counterparts, will exacerbate the greenhouse gas emissions problem in the near term, until regrowth removes emissions from initial combustion.

The mid-century strategy's scenarios call for a growth in solar generation of up to 3,192% by 2050.

The use of geothermal energy for space-heating (also referred to as geo-exchange) offers a significant pathway to reduce the consumption of fossil fuels currently used for this purpose. There are a number of large geothermal heating projects at the commercial building scale and the residential community scale, and a much larger number at the individual residential dwelling scale. Although the initial capital costs are higher than those of some alternatives, they will pay back in the longer term with major emissions reductions.

Emissions-reduction targets and implications for an energy strategy

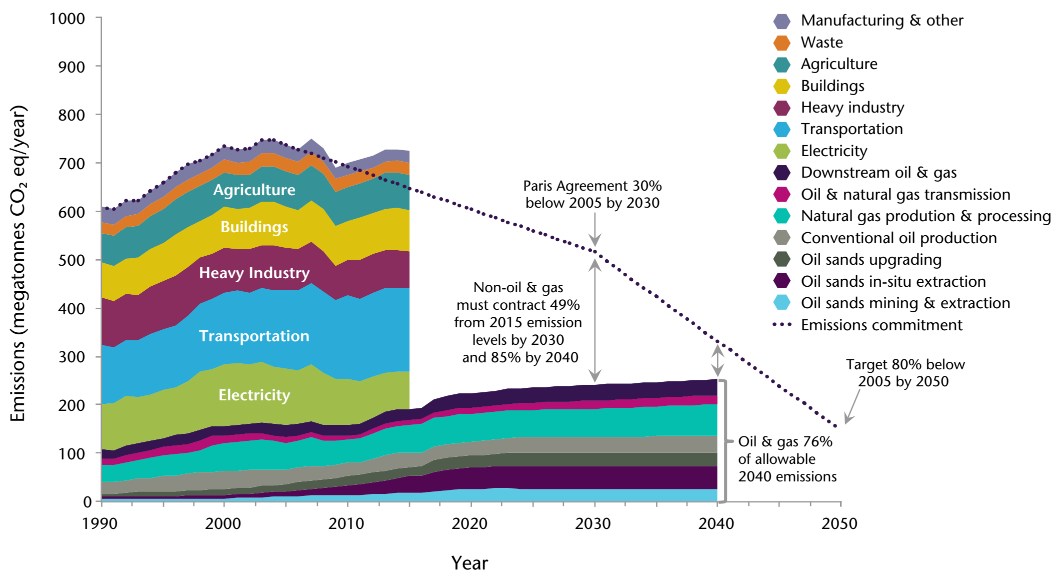
The federal government maintains that growing oil and gas production and meeting emissions-reduction targets are mutually compatible goals.

CANADA HAS COMMITTED TO a 30% reduction in emissions from 2005 levels by 2030 and targets an 80% reduction by 2050. Environment and Climate Change Canada (ECCC) projects, however, that emissions under measures announced by provincial and federal governments as of November 1, 2016, will be just 0.7% below 2005 levels in 2030. Included in this projection are a 71% reduction in emissions from electricity generation, an 8% reduction in transportation emissions and a 5% reduction in emissions from waste. Offsetting these reductions is a 47% growth in emissions from the oil and gas sector, and a 6% to 11% growth in emissions from heavy industry, buildings and agriculture. Figure ES10 illustrates emissions for the NEB's reference oil and gas production scenario, including the Alberta oil sands emissions cap, and the 2030 and 2050 emissions-reduction targets. To meet the 2030 target, non-oil and gas sectors must contract 49% from 2015 levels and then contract a further 71% from 2030 levels by 2040, when the oil and gas sector would constitute 76% of Canadian emissions. Clearly, the constraint imposed by growing oil and gas production, even with the Alberta oil sands emissions cap, will make meeting Canada's emissions-reduction goals extremely difficult and likely impossible.

The federal government maintains that growing oil and gas production and meeting emissions-reduction targets are mutually compatible goals. It offers the "Pan-Canadian Framework on Clean Growth and Climate Change" (pan-Canadian framework) as a plan to meet 2030 targets, and the aforementioned mid-century strategy to meet 2050 targets.

The pan-Canadian framework provides a number of initiatives for reducing emissions, but it does not quantify the impact of each. Furthermore, it assumes an unspecified amount of reductions will be met with purchases of "international cap and trade credits" and appears to have double-counted potential reductions from announced measures as of November 1, 2016. For example, the ECCC reference case projection of near-zero emissions reductions by 2030 includes "measures taken by federal, provincial and territorial governments as of November 1st, 2016," yet the pan-Canadian framework projects 89 megatonnes of reductions from the ECCC projection from "announced measures as of November 1st, 2016" along with buying emissions credits. The

Figure ES10: Canadian emissions by sector from 1990 to 2015 and oil and gas emissions under the NEB's reference scenario production forecast*



Source: ECCC National Inventory Report 2017; NEB Energy Future 2017; Government climate commitments. *Including the Alberta 100-megatonne oil sands emissions cap. Canada's emissions-reduction targets in 2030 and 2050 are also shown.

pan-Canadian framework also appears to have double-counted the impact of the coal phase-out, given that it was already included in the ECCC reference case projection.

In contrast to the pan-Canadian framework, the mid-century strategy provides more detail on the projections of energy consumption by fuel in 2050. The six scenarios offered provide a range of projections, the average of which is illustrated in Table ES1.

Table ES1: Average electricity generation increase by source in the six scenarios in Canada's mid-century strategy*

AVERAGE OF SIX SCENARIOS			
Source	**Increase from 2015**	**New units of generation needed**	**Cost ($C2016 billions)**
Nuclear	368%	59 new 1GW reactors	442.7
Hydro	107%	91 new Site C-sized 1.1GW dams	716.4
Wind	679%	36,886 new 2MW windmills	175.3
Solar	1,128%	258 new 100MW solar farms	82.8
Biomass	224%	540 new 100MW biomass plants	34.1
Total generation	152%	Per cent of total 2050 delivered energy = 53.2%	1,451.2

*Including the number of new generation units required and cost estimated from the U.S. Energy Information Administration's latest projections.

Three of the six scenarios in the mid-century strategy require purchases of carbon credits to make up 15% of the 2050 reduction, and two of them only achieve a 67% reduction by 2050. On average, electricity would provide 53% of delivered energy in 2050, compared to 17% at present, through a 152% ramp-up in total generation—meaning 47% of delivered energy would have to come from other sources. New generation capacity would cost in the order of $1.45 trillion. These scenarios illustrate well the scale of the problem. The prospect of building dozens of new nuclear reactors and dozens of new large-scale hydropower dams seems highly unlikely, for environmental, economic and, in the case of nuclear, fuel-supply and waste-disposal reasons.

Based on the present analysis and commitments to reduce emissions, recommendations for a more sustainable Canadian energy strategy include the following:

- A major focus on reducing consumption. Implement energy conservation and efficiency measures and incentives to the maximum extent possible.

  This includes aggressive infrastructure improvements, building retrofits, enhanced building codes, mass transit and higher efficiency in all end uses. Reducing consumption will maximize the effectiveness of investments in renewable energy, and will minimize overall expenditures on new energy supply and the inevitable economic costs and environmental impacts of developing it.

Recommendations include a phase-out of fossil fuel subsidies to provide incentives for reducing consumption and for ramping up renewables.

- A major focus on renewable energy with incentives, but with an understanding of its limitations in being able to provide a complete switch-out for fossil fuels at the current levels of consumption. This includes the intermittency of solar and wind and backup requirements, and the ecological and economic consequences of new large hydro dams. Geothermal energy for space-heating to displace fossil fuels should also be an important focus.
- A phase-out of fossil fuel subsidies to provide incentives for reducing consumption and for ramping up renewables. Fossil fuel subsidies were reported by the International Monetary Fund to be $US1,283 per person in Canada in 2015 (mainly due to the external costs of climate change, local air pollution and congestion, but also including pre-tax subsidies, foregone consumption tax revenue, accidents and road damage).[2] This amounts to $US88 per tonne of carbon dioxide or $US324 per tonne of carbon emitted (without a phase-out, total subsidies would amount to $US1.151 trillion or $C1.457 trillion from 2016 to 2040). A carbon tax that is considerably higher than the one currently implemented would provide a mechanism to more accurately cost the environmental externalities from fossil fuel combustion.
- Recognition that Canada is a well-explored petroleum province and remaining recoverable oil and gas resources are finite. They consist mainly of energy-intensive oil sands and unconventional gas, the extraction of which is responsible for a major portion of Canada's greenhouse gas emissions and significant additional environmental impacts.
- A realization that ramping up oil and gas production is a non-starter if Canada wants to meet its emissions-reduction targets. Increasing production while attempting to meet emissions-reduction targets are conflicting goals, and the reality of having to limit production growth must be faced.

2 International Monetary Fund, IMF Survey: Counting the Cost of Energy Subsidies, July, 2017, https://www.imf.org/en/News/Articles/2015/09/28/04/53/sonew070215a

- A realization that the nature of oil and gas production is to extract the most economic resources first and leave the lower-quality, higher-emissions and higher-environmental-impact resources for last. Canada's oil and gas resources remain a valuable backstop should renewable sources prove to be insufficient. Selling off the best of Canada's remaining non-renewable resources at low prices, with minimal and declining returns to the public, compromises future energy security.

- A realization that although oil and gas production is important to the Canadian economy, it is a relatively small component. Oil and gas will be required at some level by Canadians for the foreseeable future, so the industry is not going away, but plans to aggressively ramp up production for export are misguided and severely compromise emissions-reduction objectives and long-term energy security. They amount to a sell-off of the highest-quality portion of remaining resources at rock-bottom prices.

Ramping up oil and gas production is a non-starter if Canada wants to meet its emissions-reduction targets.

- A realization that radically increasing hydropower, which would require building dozens more large-scale hydropower dams, as assumed in some of the scenarios in Canada's mid-century strategy, is unlikely to happen, for ecological and economic reasons.

- A realization that ramping up nuclear energy generation by several-fold, as assumed in some of the scenarios in Canada's mid-century strategy, is also unlikely to happen for economic, environmental and fuel-supply reasons.

- A realization that the low net-energy gains of biofuels as a replacement for fossil fuels make them a marginal substitute, and that the initial emissions of biomass burning are equivalent to burning coal.

Canada faces some very difficult choices in maintaining energy security while meeting emissions-reduction targets. Current scenarios, such as those in Environment and Climate Change Canada's mid-century strategy, are highly unlikely to deliver. In developing a viable plan, all energy options must be assessed in terms of availability, scalability, cost, environmental impacts and alternatives. This report provides an objective assessment of Canada's energy options as a foundation for the development of a viable and sustainable long-term energy strategy.

CORPORATE MAPPING PROJECT

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