SNC·LAVALIN

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Engineering Net Zero

CANADIAN TECHNICAL REPORT

Engineering Net Zero
In partnership with our planet

OUR NET ZERO BLUEPRINT FOR THE FUTURE

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LEADING A LOW CARBON FUTURE

1. What does Canada look like today?

A. Key Drivers

In December 2019, the Canadian Government announced plans to transition the Canadian economy toward a “net zero” Greenhouse Gas (GHG) Emissions target by 2050. This ambitious target has the potential to effectively end Canada’s contribution to global warming and help position Canada as a global leader in low-emission technologies and practices across all economic sectors.

The enormous changes required will impact every aspect of our lives, from the way we travel, heat our homes, and ensure food and health security for our communities, to the ways we generate our power, operate industrial processes, and responsibly tap into our rich natural resources – every aspect of our lives will, in some way, be touched by this revolution.

At the heart of this much needed framework, the following question needs to be answered: “how do we transition toward net zero while maintaining the economic and social progress that is demanded over the next 30 years?”. At a time where the tragic COVID-19 crisis has impacted our economy and our industries, we have an opportunity to rethink the way we do things.

A piecemeal approach will simply not work. Canada must look toward a holistic solution that is well timed across economic sectors. A good strategy should simultaneously focus on demand reduction and decarbonization of the energy supply.

If we are to realistically reach a net zero carbon target for Canada, then we will need to rely on the following areas of interest:

- Emerging and disruptive technologies which will need to be deployed simultaneously – this will not happen without significant government intervention;
- Greater coordination across industries, sectors, provincial governments, and communities;
- Well-defined economics and financial frameworks along with tools such as carbon taxes and other incentives, aimed at driving forward the necessary change;
- Introduction of Canada-wide legislation to reduce demand for energy across all aspects of the built environment, including the introduction of energy efficiency measures and the refurbishment of existing built environment assets.

As a firm supporter of the United Nations Sustainable Development Goals, SNC-Lavalin is committed to actively supporting the Engineering of zero GHG-emitting solutions across the world. In 2019, we published a technical report entitled *Engineering Net Zero* [Ref. 1], aimed at highlighting to the UK government the engineering risks and challenges that must be overcome in order to achieve a net zero carbon target by 2050.

Meeting this ambitious target requires a sense of urgency that cannot be overstated.

Immediate, effective and concerted action is required at all levels of society, industry, and government, and we strongly believe that Canadians will rise to the challenge.

B. Implications of Doing Nothing

Global warming threatens our way of life, from rising sea levels leading to population displacement, to extreme weather events resulting in significant damage to societies and leading to socio-economic instability. If global emissions continue to rise, "the business-as-usual trajectory would lead to an expected 4 - 5°C increase in global average temperature" by 2100, "resulting in severe and widespread climate impacts" [Ref. 2], such as increased risks of flooding, inability to perform outdoor activities in certain regions, biodiversity loss and mass extinctions, and threats to food supply with disproportionate impacts on poor or vulnerable populations. Nearly 70% of the world's population could be exposed to significant river flood risks following a 4°C temperature rise [Ref. 3]. We also face "risks of crossing irreversible tipping points", which "could lead to large and very long-lasting changes in the climate" [Ref. 2].

Today, we have an opportunity to reverse this trend. In that regard, much of today's way of life could be powered by clean electricity; the transition away from GHG-emitting energy sources is slowly underway. We have, however, begun to reach the limits of what existing technology can achieve when aiming for a net zero carbon balance for energy intensive sectors such as oil and gas, heavy industry, and heavy transportation.

Furthermore, as pointed out by the World Economic Forum [Ref. 4], the transition toward a net zero carbon system is not happening nearly fast enough, and the economic impacts of the COVID-19 crisis could further derail the recent momentum in climate change action. Country-specific economic recovery plans are therefore needed to support the energy transition initiatives toward net zero carbon emissions.

C. Approach and Methodology

With environmental issues at the forefront of Canadians' priorities, industries have been tasked with finding ways to reduce emissions and environmental impacts through innovation. The lessons learned in this endeavour will help position Canada's industries as leaders in low and zero carbon technologies. Such ambitious goals will however not easily be reached without sustained efforts and investments in economically viable solutions.

In our Canadian reality, special consideration must be given to the following questions:

- How can we eliminate the use of GHG emitting fuels in remote areas and regions?
- What about the freight transportation industry which is essential for shipment of goods but currently relies heavily on fossil fuels due to its energy intensive requirements?
- Within the buildings sector, will we be able to retrofit all existing assets with energy efficiency measures in time?
- How will the production process for basic raw materials adapt to the new reality?
- What about the limits on carbon capture facilities?
- Are the replacement technologies truly carbon neutral?
- How much can we rely on carbon sinks such as new forests and agricultural lands?
- Will the substitution fuel markets (e.g. hydrogen) be in place in time?

We try to answer some of these questions in the following sections.

Drawing on SNC-Lavalin's expertise in various technological areas, this report recommends key actions necessary to overcome the steep challenges that lie ahead for Canada from a design, engineering, construction, and operations and maintenance perspective alongside a fundamental transformation of societal behaviours and lifestyles to reduce carbon emissions. Our first-hand experience in the planning, design, and execution of large-scale projects across the electricity, agriculture, transportation, oil and gas, buildings, industrial, waste and water treatment sectors, gives us a unique viewpoint on the interdependencies at play between behavioural change, the demand for energy, and the distribution of energy worldwide.

The analysis conducted has been supported through internal consultations with SNC-Lavalin subject matter experts, informed by the Canadian government and industry publications, and considers priority projects that can be deployed in the short term.

D. The Canadian Context

Canada benefits from a large geographical footprint, which contributes to the diversity of its resources, but also comes with the challenge of harsh weather conditions and terrain, factors that must be considered in the selection, design, and deployment of newer technologies. Our population is concentrated in the south, divided among a few large cities, but equally includes remote communities spread out across a vast territory, many of which rely on fossil fuels for heating as well as long-distance transportation. Additionally, populations are rising, and communities are expanding, which further contributes to GHG emissions related to transportation, buildings, agriculture, waste, and water.

Canada is a resource-rich country, and our economy includes important energy-intensive sectors with high GHG emissions such as oil and gas, mining, pulp and paper, iron and steel, cement, smelting and refining, and chemicals processing which employ many Canadians coast to coast.

The oil and gas resources in Canada have historically been expensive to produce and export compared with other global suppliers but have nonetheless constituted a major segment of our diverse economy.

As a result of the above factors, Canada's economy is highly energy intensive with 729 Mt CO_2 eq gross emissions, placing Canada at 19.7 t CO_2 eq emissions per capita, one of the highest contributors to GHG emissions per capita in the world according to 2018 figures, down from 22.6 t CO_2 eq per capita in 2005 [Ref. 5].

Our power grids, which include a significant portion of hydro and nuclear energy generation, are currently managed on a provincial level, and with limited east-to-west interconnections. Canada benefits from an energy surplus, but most power interconnections aim to export power to our southern neighbour, the United States, while inter-provincial system planning and balancing remains very limited, except for a few key interconnections.

Despite its large territory, Canadian power utilities have been able to tackle the challenge of long-distance electricity transmission. Hydro-Quebec provides a perfect example of using very high-voltage 735 kV transmission lines to bring hydro power from northern remote areas to high-demand population centers in the south of the province, and for export to the United States. Large transmission and distribution (T&D) projects have been advantageous for the province from an economic perspective and have allowed economic development in remote communities.

In terms of natural carbon sequestration, net GHG removals related to forest management activities and natural disturbances on managed forest lands were estimated at 146.2 Mt CO_2 eq in 2018. Of that number 129 Mt CO_2 eq originated from emissions associated to harvested wood products, in addition to emissions from Wetlands and Settlements. This resulted in a 13 Mt CO_2 eq absorption capacity in 2018 [Ref. 5].

Canada is one among a very select group of countries that has the option given its abundant zero carbon electricity resources, to move toward the electrification of most of its sectors as a pathway to net zero carbon emissions by 2050. Nevertheless, full electrification is not an option for some energy-intensive industries that will not have easy access to the electrical grid, such as remote mining operations, heavy-haul transport trucking, and certain industrial processes, as well as remote communities. It then becomes a matter of developing cleaner processes and technologies in those sectors that will remain dependent on fossil fuels, such as carbon capture and storage (CCS), as well as the use of alternative fuels such as hydrogen, to maintain their operations while meeting the zero emission targets. This approach would add substantial costs to these operations, which could be a catalyst for innovation, but also risks making these sectors uncompetitive, an unintended outcome that must be avoided.

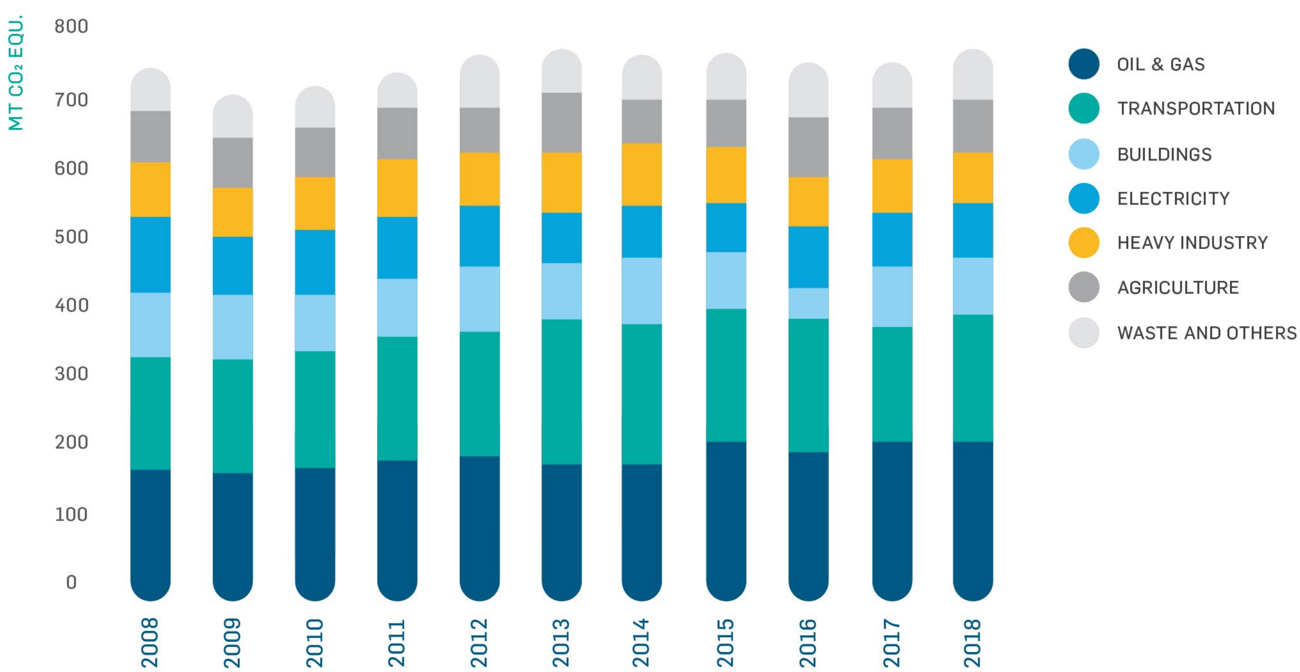


FIGURE 1 TRENDS IN GHG EMISSIONS PER ECONOMIC SECTOR [REF. 5]

These are but a few of the unique challenges that Canada will face in transitioning toward a 100% net zero carbon economy. On the other hand, if this change is properly implemented, it will also provide a great opportunity for economic growth and development for many years to come.

E. Canadian Trends in Greenhouse Gas (GHG) Emissions

Figure 1 shows the historic trends in GHG emissions per economic sector. The total emissions have been mostly steady since 2005, despite the economic and population growth in Canada. While this is encouraging, it also highlights the monumental challenge ahead – we are moving in the right direction, but nowhere near fast enough. Two sectors have seen a considerable increase, namely oil and gas, and transportation, while sectors such as electricity have seen a sharp decline.

F. Canadian Policy Framework

Canada has committed to decarbonization initiatives, with several frameworks already in place aimed at reducing emissions across all sectors.

Among these initiatives are the 2030 Pan-Canadian framework aimed at a 30-40% reduction by 2030 [Ref. 6], and the more ambitious mid-century long-term low-greenhouse gas development strategy [Ref. 7]. The recent net zero carbon commitment aims to eliminate the final balance of CO_2 by 2050, which will prove to be more technically and economically complex.

A change of this magnitude to the long-term targets will have implications on short-term policies and investment priorities of the government in all the economic sectors. A well-designed policy approach is necessary but needs to be focused on key changes across all sectors.

For any policy or initiative to succeed, it must consider cross-sector dependencies. For example, transition toward electrified systems for transportation, resource mining, and industrial processes will not be achieved without a carbon neutral electrical system in place to address the associated power demand. It's also important for the economics to hold for these transformations, so that they can take place without becoming financial burdens that stifle development.

Well-designed policy aimed at reducing emissions will need to prioritize broad electrification, as well as key technologies such as hydrogen and carbon capture. Planning should involve cross-sector and cross-provincial stakeholders, and any advice will need to be based on extensive scientific evidence.

Yet, the concept of net zero carbon emissions does not appear to have been fully defined. Our initial review of publicly available reports has not revealed a detailed strategy on how Canada will achieve net zero by 2050. The Pan-Canadian Framework [Ref. 6] published in 2016 sets out many policy initiatives to reduce CO_2 emissions, but does not provide a step-by-step implementation of these policies, and their respective impact on emissions.

A long-term strategic questioning of the energy sector structure is necessary to move beyond incentivized projects, and toward an economic system where investors and developers are driving deployment of carbon neutral technologies across the country. The net zero carbon emissions objective is likely to challenge historically based assumptions and will need to be at the heart of any development across sectors.

G. COVID-19 Considerations

At the time this report is being written, events related to COVID-19 continue to unfold. The pandemic has certainly impacted much of our lives, from the way we interact with our families, friends and colleagues, to our relationship to the rest of the world. In only a few months, our lives have been drastically altered, as we try to reimagine basic concepts such as the workplace, business and leisure travel, product supply chains, healthcare systems, communications, and so on.

Whether these events will drastically reshape our future way of life is yet to be seen. In all cases, these events have certainly acted as accelerators for revolutions that were already underway, such as the transition to remote work, to online shopping, and to virtual meetings and hangouts, amongst others. The consumers' interest toward locally sourced products has also increased since international supply chains are perceived at risk, but the focus toward local products has also been in solidarity with local business owners who have been affected by closures. Indirectly, these changes will also impact the carbon emissions related to the new social and economic paradigms.

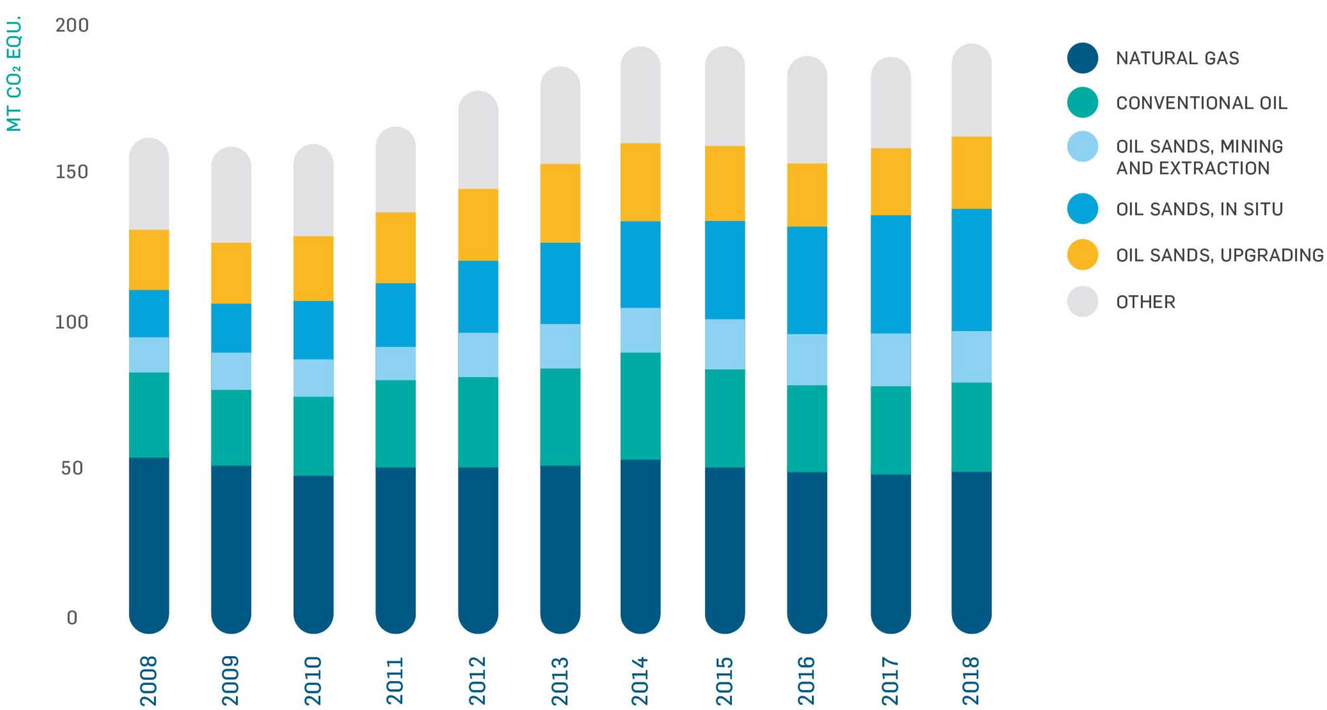


FIGURE 2 OIL AND GAS SECTOR GHG EMISSIONS BREAKDOWN [REF. 9]

For the purpose of this report, the COVID crisis will be treated as an event that has accelerated pre-existing medium-term tendencies. It will be assumed that projections on a 30-year horizon still hold. In fact, 30-year plans are required by design to possess a level of resiliency that enables them to remain relevant even in case of a short-term disruption. The objective should rather be to put forward a robust plan for transition toward a 2050 net zero carbon economy, stable enough to carry through major innovations, investments, and projects that span a decade or more to come to fruition, but agile enough that it can be revised when faced with major disruptions along the way.

The COVID-19 pandemic has demonstrated that forces of nature can overpower us in very short timeframes.

We have a narrow window of opportunity to take action to prevent an even greater calamity due to climate change. This time we know it is coming. The time to act is now. This document outlines the enormity of what needs to be accomplished between now and 2050 to achieve net zero carbon emissions in Canada.

H. What is the current situation in Canada?

This section provides an overview of the Canadian economic sectors along with key issues relating to decarbonization.

The assessment was informed by Canada's Mid-century Long-Term Low-Greenhouse Gas Development Strategy [Ref. 7], the Pan-Canadian Framework [Ref. 6], the Pathways to Deep Decarbonization Report [Ref. 8] and complemented by our observations on issues that we think are critical to decarbonizing each sector. For consistency, this report's analysis will map Canadian GHG emissions to the same sectors as already defined by the Federal Government [Ref. 5].

H1. OIL AND GAS

The oil and gas sector, with the highest rate of carbon emissions of all the sectors in Canada, plays a central role in the transition toward a net zero carbon economy from an economic prosperity, innovation and resource security perspective. First and foremost, we must focus on cutting down the GHG emissions to the atmosphere, resulting in a major part from fossil fuel combustion. This will require a cross-sector approach.

The oil and gas sector saw significant growth in Canada in the last decade, which has also led to increased GHG emissions due to oil sands emitting significantly more GHG emissions compared to conventional oil (Figure 2). Greenhouse gas emissions from conventional oil production increased by 24% between 1990 and 2018, while emissions from oil sands production increased by 456%, of which more than half were the result of in situ production [Ref. 9]. Production of natural gas from unconventional sources, for example, multi-stage fracturing techniques, is also reported to have increased significantly.

Prior to COVID-19, "the global upstream oil and gas industry was slowly emerging from one of the largest downturns in its history", with "strong indications of a continued rebound in global investment activity". However, despite the continuing global demand for oil and gas, Canada is losing its market share due to high production costs, which are further exacerbated by the lack of access to pipeline distribution channels [Ref. 11]. Nevertheless, according to the latest energy forecasts by the Canadian Energy Regulator [Ref. 10], crude oil production is forecasted to peak by 2039, followed by a decline through 2050, with the production levels remaining above today's output throughout. Natural gas production is forecasted to peak in 2040. This suggests that Canada will require a long-term carbon capture strategy.

At the present time, oil and gas sector greenhouse gas emissions have been capped at 100 Mt CO_2 eq as part of government initiatives such as the 2030 Pan-Canadian framework [Ref. 6] for GHG emission reductions. Furthermore, oil and gas facilities are much more efficient than they were ten years ago. This is further complemented by cap and trade mechanisms at the provincial and federal level that aim to incentivize industries to increase their efficiency. Nevertheless, in the context of 2050 net zero carbon target, having 100 MT CO_2 eq of residual emissions from the oil sands industry will not be viable.

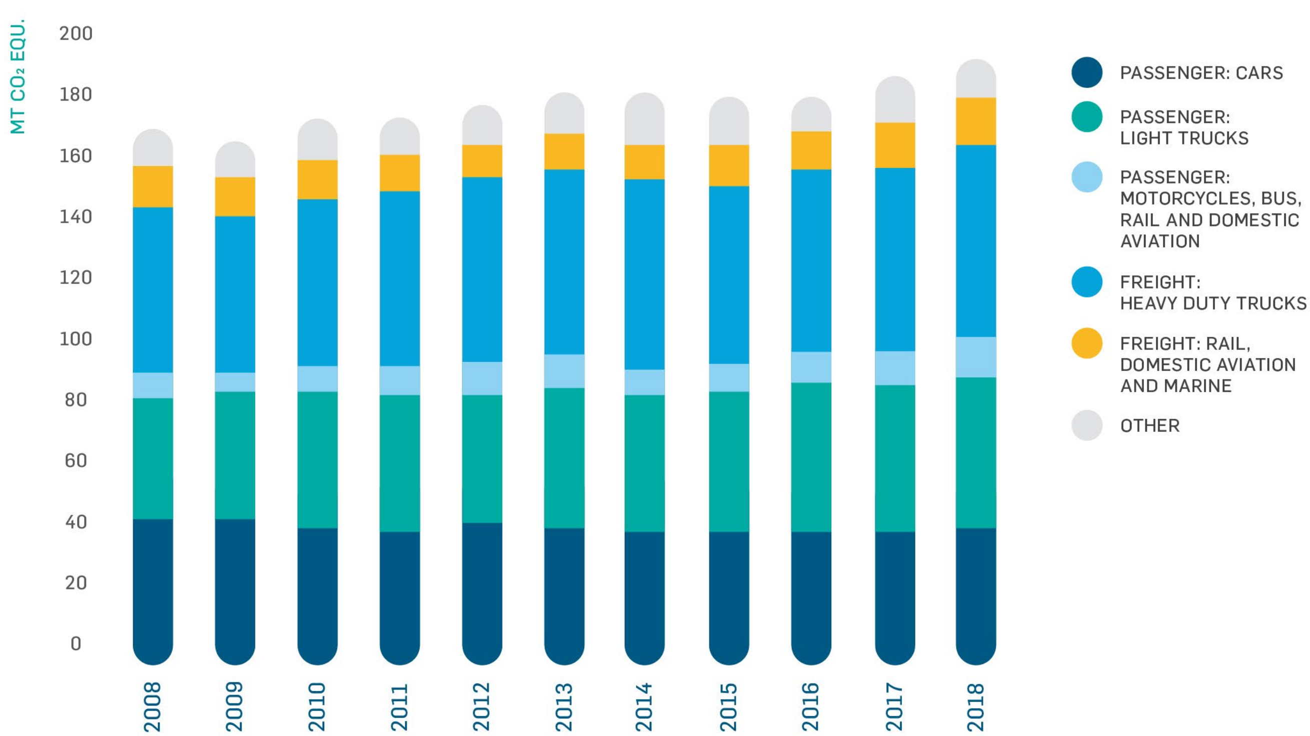


FIGURE 3 TREND OF GHG EMISSION FOR TRANSPORTATION SECTOR - CANADA [REF. 12]

H2. TRANSPORTATION

In 2018, the transportation sector accounted for about 25% (185 Mt CO_2 eq) of Canada's emissions, making this sector the second largest culprit for carbon emissions after the oil and gas sector [Ref. 5]. Although energy efficiency improvements have been put in place over the years, the situation has not improved as GHG emissions attributable to the transportation sector continued to rise. From 2010 to 2018, the Canadian transportation sector saw its emissions rise by 19% [Ref. 12].

Not surprisingly, most transport emissions in Canada are related to road transportation, which includes personal transportation (light-duty vehicles and trucks) and heavy-duty vehicles [Ref. 5]. In fact, "emissions from passenger light trucks and freight trucks have continued to rise due to an increased number of vehicles" [Ref. 12].

As depicted in Figure 3, although Canadians are currently using more efficient transportation means, it has not been enough to offset the growth in vehicles on the road as well as the number of kilometres driven, leading to increased emissions.

In today's reality, we see more and more individuals buying light trucks and SUVs for added convenience [Ref. 12]. The impact is evident through examination of the trend of passengers' light truck recorded emissions, which shows sustainable increase year over year despite efficiencies gained due to the application of fuel standards. This, in turn, has a negative impact on the transportation sector emissions as these types of vehicles tend to be less energy efficient than smaller, more compact vehicles.

As of 2019, the total vehicle registration in Canada exceeded 35 million vehicles. The light motor vehicle segments that include passenger cars, light trucks, and vans account for roughly two thirds of the registered vehicles, while medium and heavy-duty vehicles represent about 5% of the total registration. Medium and heavy-duty vehicles emit approximately the same amount of GHG emissions, as depicted in Figure 3, due to larger engines and longer travel distances [Ref. 13]. As such, from a GHG emission perspective, the medium and heavy-duty vehicles sector requires as much attention as light weight vehicles. Increased emissions associated with heavy trucks, which have seen a steady increase since 1990, are directly linked with increased population and global trade.

H3. BUILDINGS

The buildings sector in Canada has had a long and steady history of development. The early 1990s saw an increase in the construction of both residential and commercial sectors. In recent years, we have seen an increase in mixed-use buildings, as well as growth in the commercial sector [Ref. 14].

Figure 4 illustrates the evolution of building construction requirements related to energy efficiency over the last 20 years [Ref. 14, Ref. 5, Ref. 6].

Canada's buildings sector is a significant contributor to GHG emissions, making up approximately 12% of total GHG emissions. It is composed of residential, commercial, institutional and industrial buildings [Ref. 6] and is the third largest emitter following the oil and gas, and transportation sectors [Ref. 5].

INDUSTRIAL BUILDINGS

Industrial buildings house a very wide variety of activities and processes. The complexity of the various industrial process requirements creates challenges when developing criteria to be widely applied to buildings. New industrial buildings must comply with minimum code requirements but are excluded from more aggressive compliance targets like the optional compliance path within the British Columbia Building Code, referred to as the BC Energy Step Code.

Due to the lack of standards or guidance on industrial buildings, they present both risks and future opportunities in the buildings sector. Integration of the building operations with internal processes can provide positive scenarios of moving toward a net zero carbon economy through the creative utilization of waste energy and localized electricity generation. Some of these measures require significant capital investment and are solely dependent on the industrial processes. The retrofitting of existing industrial buildings will also present the same challenges as other types of building – residential and commercial.

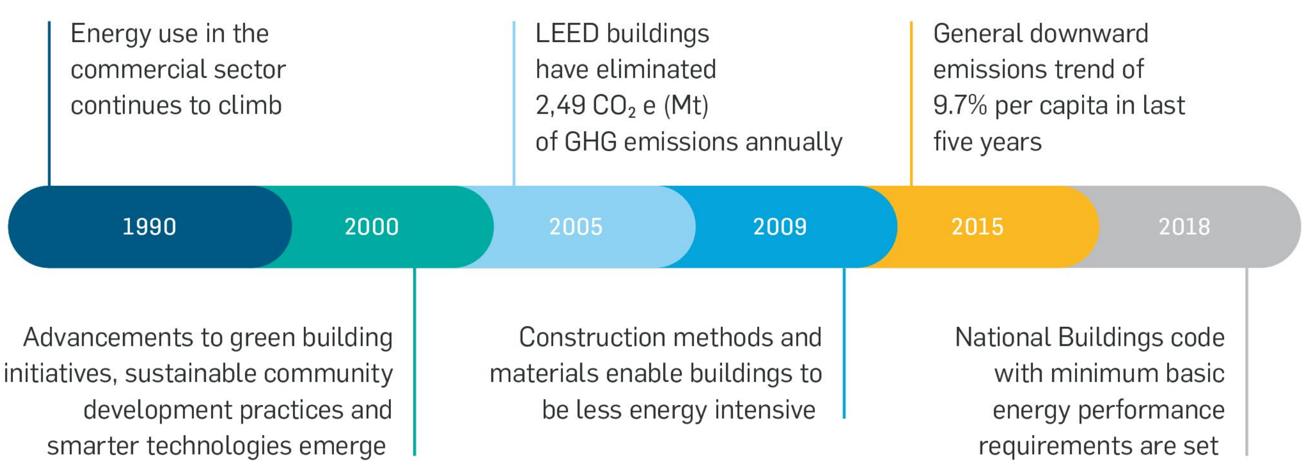


FIGURE 4 BUILDINGS SECTOR TIMELINE

COMMERCIAL BUILDINGS

The commercial sector is composed of offices, retail spaces, warehouses and institutional buildings. Figure 5 provides a breakdown of the commercial sector energy consumption.

A shift in lower energy consumption for commercial buildings can be attributed to the introduction of advancements in building standards and certifications, such as the Leadership in Energy and Environmental Design (LEED) certification process. Buildings constructed after 2009 are, on average, 15% less energy intensive than buildings constructed between 2000 and 2009 [Ref. 15]. Although there has been an initial shift toward energy efficiency advancements, additional goals need to be developed in the commercial sector to provide owners the balance between energy efficiency and a return on investment (ROI).

A purely voluntary approach, such as LEED, which is left to market forces, will not be as effective as performance regulations for changing how buildings are designed, due in part to long return on investment payback periods for owners looking to upgrade. In contrast, energy efficiency has been embedded across European built infrastructure through mandatory energy performance legislation.

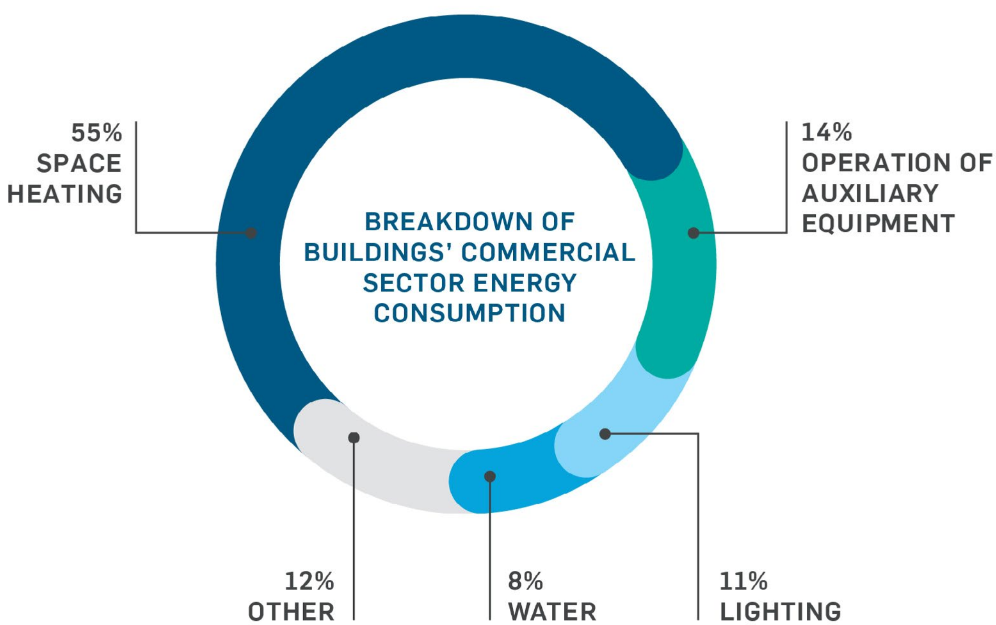


FIGURE 5 BREAKDOWN OF BUILDINGS COMMERCIAL SECTOR ENERGY CONSUMPTION [REF. 15]

RESIDENTIAL SECTOR

Residential buildings in Canada make up 14% of our population's energy usage, higher than the commercial sector at 12% [Ref. 15]. Previously, Canadian households turned to more traditional methods of heating systems such as fossil fuels, but with the construction of newer homes built with energy efficient systems, we are slowly moving toward heating our homes using clean alternatives (electricity from renewable energy generation, geothermal and district heating, solar thermal etc.).

The average Canadian household's breakdown of energy consumption is as follows [Ref. 16]:

- Space Heating (62.4% of total end-use demand);
- Water Heating (18.7% of total end-use demand);
- Energy use for appliances, lighting, and space cooling (18.9% of total end-use demand).

Across Canada, many residential homes use electricity for heating, with higher usage rates in the colder Eastern provinces. To reduce greenhouse gas emissions, investments in space and water heating will be essential to achieving changes in the buildings sector.

The residential sector includes many aging assets across Canada that need to be retrofitted with efficiency measures. Considerable investments in materials with low embodied carbon emissions will need to be made, in addition to ensuring all new developments are designed to meet higher energy efficiency standards.

H4. HEAVY INDUSTRY

According to the Canadian Government, the heavy industry sector currently accounts for 10.8% of Canada's GHG emissions, or 79MT of CO_2 eq per year [Ref. 5]. Since the Paris Agreement, there have been discussions in Canada about potential reduction pathways for the oil and gas and transportation sectors, but fewer about heavy industry. This is related to the fact that steel plants, refineries, mines, paper mills, cement plants, and various chemical plants all use different industrial processes and display a different GHG generation profile. Individual pathways to carbon reduction have been discussed in various industries but there is no "one size fits all" solution to reach net zero carbon emissions in the heavy industry sector as a whole.

GHG emissions in the heavy industry sector have seen a steady decrease over the last 30 years, mainly related to a lower reliance on fossil fuels, greater energy efficiency, and process improvements in the various industries. According to the International Energy Agency [Ref. 17], if every industrial plant on the planet were to be upgraded to use the best currently available technologies, then the global energy consumption (and GHG emissions) would be reduced by only approximately 20%. This reflects the fact that competition and market trends have already pushed a significant part of this sector to use the most up-to-date production processes. Reaching net zero carbon emissions implies that novel processes, technologies and solutions will be needed to deal with the remaining 80% GHG emissions.

H5. AGRICULTURE AND FORESTRY

On the agriculture front, Canada, like other nations, faces the challenge of securing nutritious, affordable and reliable food to meet the demands of its population in a sustainable way in the decades to come. Canada is particularly dependent on food imports, in addition to being an exporter of a few key products, a fact that needs to be carefully weighted-in when determining the policies driving the agriculture sector toward net zero carbon emissions.

At a global scale, the UN estimates that food demand "will require a substantial increase of global food production of 70 percent by 2050" [Ref. 18] [Ref. 19]. Canada is privileged in having the second largest landmass and ample fresh water resources, contrasted with a relatively small population. This, however, can be deceiving since only a small portion of the available land is suitable for food production. It is estimated that Canada has a high biocapacity reserve, meaning our ecological footprint related to food production can be properly compensated by a well-managed agriculture sector [Ref. 20].

In addition to agriculture, the forestry sector in Canada represents an important source of employment and income and has the potential, if managed properly, to serve as a CO_2 sink. With 42% of its territory already covered by forests, Canada is naturally a lead international producer of forestry products, and is second in the world in terms of forestry goods export.

Agriculture and forestry-related GHG emissions can be broken down into several processes producing or absorbing GHGs illustrated in Table 1 [Ref. 22].

PROCESS	PRODUCTS RELEASED
Enteric fermentation from livestock production	**Methane**
Manure management	**Methane and Nitrous Oxide**
Oxidation of fertalized soils	**Nitrous Oxide**
Combustions of agricultural and forestry products for non-energy use	**Carbon Dioxide**
Land restoration and reclamation (sink)	**Carbon Dioxide**

TABLE 1 AGRICULTURAL SECTOR / EMISSION SOURCES AND SINK BY ACTIVITY [REF. 22]

According to the federal government of Canada, "croplands have been a net sink for CO_2 starting in about 1990. However, until recently the removals on croplands were offset by carbon losses from forests and grasslands recently converted to cropland. It is only since about 2000 that agricultural lands have been a net sink for CO_2 when land use change is taken into account" [Ref. 22].

It is estimated that the direct agriculture and forestry emissions will remain relatively constant at between 76 Mt and 79 Mt of equivalent CO_2 per year, between 2020 and 2030. The major contributors can be divided by activity as shown in Table 2 [Ref. 20].

PROCESS	PERCENTAGE CONTRIBUTION
Combustion and non-energy related emissions in agriculture and forestry	**23%**
Livestock production	**49%**
Crop production	**28%**

TABLE 2 EMISSION CONTRIBUTION BY PROCESS IN CANADA – AGRICULTURE SECTOR [REF. 20]

H6. WASTE

With GHG emissions of 18 Mt CO_2 eq in 2018, the waste sector is the lowest emitter of all the sectors, at 2.4%. The GHG emissions in the waste sector can be divided as shown in Table 3, with the primary source resulting from municipal solid waste disposal in landfills and industrial wood waste landfills [Ref. 5].

PROCESS	PERCENTAGE CONTRIBUTION
Solid waste disposal	**69.2%**
Biological treatment of solid waste	**2.6%**
Wastewater treatment and discharge	**6.3%**
Incineration and open burning of waste	**2.3%**
Industrial wood waste landfills	**19.6%**

TABLE 3 EMISSION CONTRIBUTION BY PROCESS IN CANADA – WASTE SECTOR [REF. 5]

Although not apparent in the GHG emission numbers associated to the waste sector, the topic of waste management requires us to examine our societal behaviour with regards to consumption patterns. According to [Ref. 7] “in Canada, avoidable food waste is valued at $31 billion per year”, with organics diversion remaining very low as compared to other countries such as Germany or the US. From a global perspective, food waste and general overconsumption are undoubtedly major contributors to the GHG emissions, and need to be addressed through education, sensitization, as well as economic incentives in order to achieve social change that is necessary for net zero carbon emissions targets to be reached and maintained.

Additionally, we must remain aware of our dependence on products resulting from petrochemicals such as single-use plastic products, which we must reduce or eliminate in our day-to-day lives, as we move toward a net zero carbon emissions system. The Canadian Government announcement to ban the use of single-use plastics by 2030 is an important step toward that end [Ref. 23].

H7. ELECTRICITY

The GHG emissions from the electricity sector (Figure 6) have seen significant reductions due to the retirement of coal power generation in Ontario in 2014. Currently, while coal power generation represents about 7% of the electricity generation in Canada, it contributes about two thirds of the total emissions from the electricity sector. As such, a significant reduction is anticipated in electricity sector GHG emissions following the retirement of coal power generation in Alberta, Saskatchewan, Nova Scotia and New Brunswick.

Canada's electricity production is getting greener every day with 60% coming from hydro, 15% from nuclear, and with other renewables representing about 7% of the total generation. Renewable generation has seen a steady increase of 16% between 2010 and 2018 and is poised to significantly increase in the coming decade fueled by economics, as renewables become very competitive against traditional generation resources and in the context of GHG emission reductions.

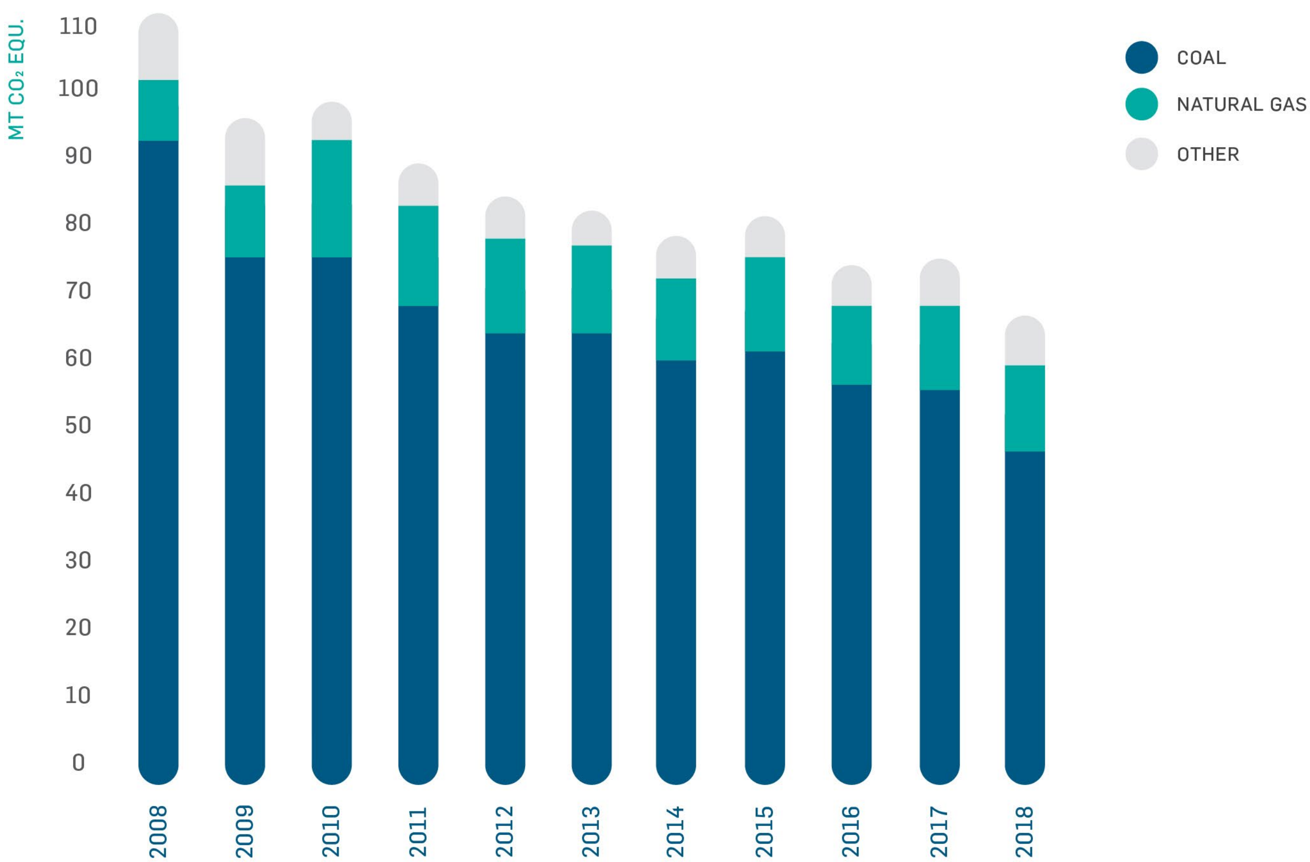


FIGURE 6 ELECTRICITY SECTOR GHG EMISSIONS BREAKDOWN [REF. 12]

ACTION TODAY FOR A NET ZERO TOMORROW

2. Cutting Down Emissions Across Economic Sectors

A. Oil and Gas

A1. GHG REDUCTION APPROACH

Initiatives deployed by the government in recent years have maintained GHG emissions at a slower pace of growth proportional to the growth in production. These approaches have included reduction in methane and hydrofluorocarbon (HFC) emissions and improvement of industrial process efficiencies, as well as investment in future technologies as outlined in the Canadian Framework for 2030 [Ref. 6]. At a provincial level there have been several initiatives, for example the climate technology taskforce [Ref. 24], the Alberta emissions offset system [Ref. 25], and the technology innovation and emissions reduction regulation [Ref. 26].

The path to decarbonizing the oil and gas sector lies in cutting GHG emissions of the full production cycle, which begins by breaking down the process and focusing on a few critical steps. Oil extraction, for example, involves several energy intensive steps such as using trucks for transportation as well as crushing the rocks into fluids. Several GHG-reduction options already exist, including retrofitting facilities with energy efficient technologies using cleaner fuels, as well as carbon taxing mechanisms imposed by the government. However the associated economics have not always made sense for investors and run the risk of driving the projects beyond reasonable operating costs.

The costs of these measures have the potential to continually push oil and gas production prices upwards, rendering Canada's oil and gas products non-competitive on the global market. The net zero plan will need to strike a difficult balance that ensures the gradual economic transformation of regions and communities that heavily depend on the oil and gas market for their economic prosperity.

Renewable technologies which could provide clean power to the oil and gas extraction processes have also not always proven economically feasible and the costs and footprints associated with these technologies have slowed their implementation in the oil and gas sector, given the relatively high break-even price of Canadian oil.

> Many European oil companies have taken a corporate responsibility to decarbonize and are diversifying away from the oil and gas business activities.

This raises the question of whether the complete elimination of GHG emissions in the extraction of fossil fuels will ever become economically viable, or whether it has been deemed out of reach by those major European players, leading to divestment from the sector by 2050.

A2. WHAT'S IN STORE FOR THE LONG TERM?

Oil sand production is likely to remain steady with many improvements on the operation of existing mines, however new mines are unlikely to be developed given the environmental regulations and general trends in the industry. On the other hand, we are likely to see an increased uptake in offshore oil production as access to offshore resources is becoming more economically feasible. Offshore production can result in smaller carbon emissions as compared to oil sands if the sites are principally powered from shore using zero emission power generation available to the coastal provinces.

Emerging technologies such as carbon capture and sequestration as well as hydrogen fuel could prove to be viable solutions to decarbonize the inland oil and gas extraction process, however steady innovation has proven to be a challenge in the oil sector particularly due to the unstable global markets. Oil price fluctuations bring in an additional layer of risk that jeopardizes innovation projects which can operate on a 10 to 15-year horizon before substantiating results. Government and industry support are needed for new technology development during oil and gas price dips in order to sustain the innovation and avoid losing momentum.

Oil and gas extraction will likely continue globally so long as the demand is there from various critical industries such as food and agriculture, healthcare, communications, transportation, etc. Whether Canadian oil and gas production will play a role in this future market is yet to be seen. The high costs associated with Canadian oil and gas production, particularly oil sand extraction, point to the contrary, and this situation is likely to be exacerbated through increased regulations and carbon taxing.

Nevertheless, we must not lose sight of a shared social responsibility to find ways to address societal needs in an environmentally sound way as we transition toward net zero carbon emission economies.

Overall, many of the key initiatives for the reduction of carbon emissions related to oil and gas extraction are already underway in Canada. These include a focus on increasing industrial process efficiency, reducing industrial process emissions using new technology, capping oil and sand production as has already been done, and further relying on carbon capture and sequestration. However, given the trend in GHG emissions in recent years, it is evident that the investment in these newer technologies and processes must be drastically accelerated if we are to meet a 2050 net zero carbon emissions target.

Any realistic plan to reach net zero emissions by 2050 in the oil and gas sector will require clearer intermediate targets and a detailed breakdown of the solutions. Within that context, it is important to note that new technologies often face heavy permitting and take longer to implement, an issue that needs to be urgently addressed. Furthermore, technology investments that have been seen so far are largely insufficient against such an ambitious target. Unwavering support will be needed, in terms of streamlining the regulation process, increasing funding for technology development, and maintaining clearly defined intermediate targets and key performance indicators.

Finally, the creation of hydrogen markets that incentivize oil and gas operators toward relying on this new technology is an essential piece of the puzzle. Hydrogen research must be accelerated, and if deemed viable, the solution must be put to market along with a resilient and accessible supply chain, with predictable pricing.

LEVERAGING CROSS-SECTOR SOLUTIONS

Reductions in carbon emissions in the oil & gas sector will undoubtedly depend on advancements and investments in other sectors, namely the electricity sector and the transportation sector. On the electricity side, non-emitting reliable and affordable power is required to power the sites. On the transportation side, vehicles must transition toward a mix of non-emitting fuels and electric vehicles.

On the other hand, massive changes are needed in consumer behaviour to reduce the dependence on fossil fuels. Most Canadians still drive gas-powered vehicles, and a substantial number of residential and commercial buildings remain dependent on natural gas heating across Canada. Wasteful behaviour results in inefficient use of plastics and other oil-based products. More initiatives aimed at reducing indirect domestic demand for oil and gas related products are urgently required.

B. Transportation

B.1 GHG REDUCTION APPROACH

The transportation sector offers tremendous opportunities for reductions in GHG emissions through electrification and the use of alternative fuels such as hydrogen. Eliminating dependence on fossil fuels in this sector not only reduces direct tail pipe emissions, but also emissions from the production process of these fossil fuels.

The technology to achieve full electrification for light and medium-duty vehicles, urban rail and buses exists today. While there remains significant challenges associated with infrastructure for charging stations, battery life, range and durability, these factors are already improving, and auto manufacturers and utilities are making heavy investments to move rapidly toward full electrification of this sector.

ROAD TRANSPORTATION

Passenger and light cargo vehicles account for 89.3 Mt CO_2 eq, or 48 % of all GHG emissions generated by the sector in 2018. These vehicles are prime candidates for electrification using existing technologies which will significantly reduce GHG emissions.

The ground freight industry is another major greenhouse gas emitter, accounting for 39 Mt CO_2 eq (21%) of GHG emissions in the transportation sector [Ref. 27]. The long distances covered, and tonnage carried by these vehicles presents challenges for their electrification. Transport trucks, which account for most ground transport freight emissions, could be ideal candidates for hydrogen fuel cell conversion using existing technologies. Converting freight trains to alternative fuel sources is more challenging and requires further data and research.

In the meantime, reducing emissions in road transportation can be achieved by improving fuel efficiency through the application of emission standards for light duty vehicles and heavy-trucking segments. A 30% reduction in emissions by 2030 from the 2005 level can be achieved in road transportation if car manufacturers meet the fuel efficiency standards for Internal Combustion Engines (ICE) vehicles. However, achieving this ambitious goal will require more innovative technical solutions especially for the heavy-trucking segment [Ref. 28].

AVIATION

The civil aviation industry accounted for around 20 Mt CO_2 eq (11%) of total GHG emissions in 2017 produced by use of jet fuel [Ref. 27]. Electrification of this sector is not reasonable given current battery technology due to range limitations and the added weight to the aircraft. Some studies have been performed and prototypes have been built to test the feasibility of hydrogen-powered aircrafts. While these have some appeal, a shift of this magnitude would require the wholesale replacement of existing aircraft fleets, overhaul of existing global airport infrastructure, and require all departure and destination locations to be equipped to handle hydrogen planes.

An alternative solution that can more easily be phased-in and capitalized on existing equipment and infrastructure is net zero synthetic jet fuel [Ref. 29]. Combustion of synthetic fuels generate the same amount of GHG emissions as traditional jet fuel. However, improvements would result from the fact that the production process absorbs CO_2, leading to an overall reduction in CO_2 emissions.

MARINE TRANSPORTATION

The marine sector accounted for about 6 Mt CO_2 eq (3%) of the emissions from the transportation sector in 2017 [Ref. 27]. The distances covered, tonnage carried, and remote and severe operating conditions of these vehicles present significant technological and operational challenges in the use of batteries and hydrogen fuel cells. One possible solution is the use of small nuclear reactors similar to those currently utilized in some military navy ships and in limited commercial applications internationally. The challenge here is not technology availability but rather the hurdles associated with commercial nuclear deployment. Generally, nuclear plants address safety concerns, licensing, physical security, and accident controls that are specific to a given location and geography. Overcoming these hurdles for a mobile civilian application would require significant changes to regulations, and licensing. As such, it is unlikely that we will see nuclear-propelled marine shipping any time soon.

Renewable fuel mandates for gasoline and diesel have been introduced by several provinces and on federal level. The current federal regulation mandates fuel suppliers and importers to have minimum renewable fuel content levels of 5% for gasoline and 2% for diesel [Ref. 28].

To achieve a better outcome than the current prognostic, the Canadian federal government has put into place four different policies to enable a shift in emissions for the future.

These four pillars include [Ref. 6]:

- Setting and updating vehicle emissions standards and improving the efficiency of vehicles and transportation systems;
- Expanding the number of zero-emission vehicles on Canadian roads;
- Supporting the shift from higher to lower-emitting types of transportation through investing in infrastructure; and,
- Investing in research and development for cleaner fuels.

B2. WHAT'S IN STORE FOR THE LONG TERM?

Alternative vehicle technologies including electric, hydrogen, automated and connected vehicles have the potential to neutralize emissions from road transportation. This transformation is not without challenges which include cost, availability of infrastructure, and manufacturing capacities, in addition to technical limitations including range limitations, battery life and durability.

Given the high emissions of Canada's transportation sector, this area offers the most immediate and achievable opportunities to reduce overall GHG emissions using existing proven technologies. Electrification of light passenger and transit vehicles, and introduction of hydrogen to the transport trucking industry have the potential to reduce about 150 Mt CO_2 eq, or 82% of all emissions produced by the Canadian transportation sector. Further reduction in GHG emissions will also stem from eliminating the production of fossil fuels that are currently used to operate these vehicles.

Major pillars that would support the transformation of the transportation sector by mid-century are as follows:

ELECTRIFICATION

The transportation sector is increasingly connected with the electricity sector, in addition to its traditional interdependencies with the oil and gas sector. As the Canadian vehicle fleet becomes more electrified, it will be imperative to leverage the electrical grid. The electrification of vehicles will however bring a set of challenges to the current electrical grid infrastructure.

Setting up charging stations across the grid will require strategic upgrades to meet these new loads. In addition, to make the electric grid as efficient as possible, the use of new technologies enabling a smart grid is required. These solutions would allow vehicles to act as energy storage and to support load management. Finally, having vehicles as potential batteries provides an opportunity to add more intermittent resources to the grid such as solar and wind power, which will in turn make electricity generation less reliant on fossil fuel generation.

BLUE AND GREEN HYDROGEN

A full electrification to meet the net zero energy system may require up to 700 TWh/yr. of new renewable electricity in addition to the 400 TWh/yr. that currently contribute to the existing grid, which would require building a new electricity infrastructure which is twice as much as what we have today in terms of generation, transmission, and distribution. Building such an electric infrastructure would face numerous practical challenges, and so, other clean energy resources are needed to reach a net zero emissions targets in transportation [Ref. 30].

It is therefore expected that blue and green hydrogen will provide a new source of clean fuel for the transportation sector. Massive new infrastructure would also be required to enable this transition.

The electrification of the transportation sector then clearly requires a synchronized deployment of blue and green hydrogen generation and distribution, so as to capitalize on economies of scale. This multi-disciplinary planning is critical and will have a significant impact on other economic sectors such as transportation, electricity, and oil and gas.

BIOFUELS BLEND

Another part of the solution would be the replacement of diesel consumption by biofuel blends for heavy trucking and marine transportation. Biofuel blends include ethanol and biodiesel. As per the Canadian Deep Carbonization studies, the percentage blend of biofuel will need to increase steadily from the few percent [2-5%] that are now required by federal and provincial regulations to around 90% by 2050 [Ref. 8].

As of 2016, Canada was ranked fifth in the world for liquid biofuel production with 1,700 million litres of ethanol and 430 million litres of biodiesel. Biofuel represents about 4.5% of the total primary energy supply (TPES) of Canada. The percentage contribution of biofuel to the TPES of Canada is expected to rise gradually as a result of the expected change in clean fuel regulations and considering Canada's vast biomass resources [Ref. 31].

It should however be noted that the source of biofuels is critical. Biofuel production around the world has resulted in questionable practices that endanger ecosystems through the cutting down of forests to grow biofuel crops, which goes against the environmental initiatives and efforts under way to reach the net zero vision. Canada should be able to produce biofuels domestically as well as ensure the procurement of ethically-sourced biofuels on the international market.

MODAL SHIFTING FOR FREIGHT INDUSTRY

Modal shifting consists of shifting away as much as possible from heavy trucking toward rail transportation that uses high efficiency electric engines. This can significantly reduce the GHG emissions associated with heavy trucking in the long run but would require significant investment in rail infrastructure. [Ref. 28]

The Railway Association of Canada estimates that the yearly GHG emissions can be reduced by 5.6 Mt CO_2 eq if just 15% of truck traffic shifted toward rail transportation. Additional savings associated with reduced road congestion and wear and tear of the highway systems add to the benefits of modal shifting.

AUTOMATED AND CONNECTED VEHICLES

Environmental benefits from automated and connected vehicles would be substantial, as artificial intelligence evolves over time to help address congestion problems in major cities and to improve fuel efficiency and vehicle utilization. The merge between self-driving vehicles and ride-sharing services which is currently underway, coupled with societal change, would lead to considerable reductions in the number of light vehicles on the road. [Ref. 28]

Automated and connected vehicles would require major investments in infrastructure that enables the wide adoption of the technology and should be planned and coordinated with other infrastructure in the context of future smart cities and communities.

C. Buildings

C1. GHG REDUCTION APPROACH

There are several ready-to-deploy solutions that have been considered by the Government of Canada in the 2018 report, "Paving the Road to 2030 and Beyond: Market Transformation Blueprint for Energy Efficient Equipment in the Building Sector, Supporting the Transition to a low-carbon economy" [Ref. 32]. Canada's Buildings Strategy [Ref. 33] is a component of the Pan-Canadian Framework that commits federal, provincial, and territorial governments to develop and adopt building codes with increasing levels of energy efficiency. Canada's Building Strategy also includes pathways for improving the efficiency of new buildings, such as designing net zero energy-ready homes with new technologies based on software models. Other approaches include retrofitting existing buildings, collecting and sharing energy-use data, and improving the energy efficiency of appliances, equipment, and windows [Ref. 32].

Improving buildings' efficiency will address GHG emissions both directly through the reduction of consumption of natural gas and other GHG-emitting fuels, and indirectly by reducing the electrical load on the power grid related to electrical heating.

The following are a few examples of these energy efficiency technologies which also merit further exploration through research and development.

SPACE HEATING

Space heating accounts for more than half of the energy consumption in households across the country in both residential and commercial buildings. Technologies such as condensing heaters, ground-source heat pumps (GSHPs), cold climate air-source heat pumps (CCHPs), gas heat pumps, and other advanced technologies (e.g., solar thermal, micro combined heat and power) can help reduce carbon emissions related to space heating [Ref. 32].

WATER HEATING

For buildings across Canada, water heating makes up the second largest source of energy consumption in homes according to the national energy end-user data collected by Natural Resources Canada in 2014. Current solutions in water heating include condensing storage water heaters, electric heat pump water heaters (HPWHs), and gas HPWHs, and other advanced technologies, which can help with reducing carbon emissions related to water heating. For instance, deploying electric HPWHs would significantly increase efficiency relative to electric resistance technology, but presently do not have much adoption in the marketplace. As a result, further promotion, research and development are necessary for water heating solutions [Ref. 32].

WINDOWS

Windows in the residential sector account for up to 35% of a household's heat loss. Today's solutions include different insulation methods in window pane materials to contain heat loss. These solutions include sealed insulating glass units with two or more panes of glass, low emissivity (low-e) coatings, inert gas fills between the glazing cavity (e.g. argon or krypton), non-metal and thermally-broken framing materials and improved weather stripping and locking mechanisms. Additional high efficiency window material technologies are currently under research and development.

Application of efficiency standards in conjunction with the existing home energy rebate system should continue and need to be deployed on a broader scale [Ref. 33], as windows remain one of the main areas of heat loss in buildings.

LIGHTING

Recent developments in lighting provide another notable example of improved energy efficiency. Compact fluorescent lights (CFL) and light-emitting diode (LED) lights consume significantly less energy compared to a traditional incandescent bulb [Ref. 32]. As well, the CFL and LED light bulbs are now a more economical choice and could be a practical technology for adoption.

C2. WHAT'S IN STORE FOR THE LONG TERM?

The Canadian government will need to play a strong leadership role in adopting more stringent building codes, starting with the existing fleet of government assets in order to pave the way for Canadian provinces to act. The research and development in future innovations will need to be piloted by a solid task force in order to quickly create some shifts in the reduction of greenhouse gas emissions.

Furthermore, experience in the UK has shown that the key to a wider change in the market was through mandatory European energy performance legislation, as market forces would often lean toward cheapest upfront capital investment.

CHALLENGES & OPPORTUNITIES

To achieve net zero emissions in the buildings sector by 2050, there will undoubtedly be challenges to overcome. In contrast to the challenges, there is also an overwhelming number of opportunities that the buildings sector will need to quickly act on. These are summarized in Table 4.

CHALLENGES	OPPORTUNITIES
• Standardization and consistency in energy efficiency regulations and acceptance of building codes across Canada. Currently there is no national energy code that applies to existing buildings. • Policy adoption (pricing mechanisms, procurement, partnership models, and regulations). • Capital costs versus operating costs. • Acceptance of upfront costs for both retrofits and new builds. • Continued support for energy rebate and incentivized programs. • Supply chain shift toward energy efficient technology, and low GHG equipment and materials. • Social behaviour shifts in residential, business and institutional communities. • Mechanisms that trigger upgrades of existing buildings. • Remote off-grid communities.	• Improvements to social welfare and economic productivity. • Smart cities and towns that provide sustainable lifestyles. • Hyper-efficient insulated buildings with roof tiles made of solar panels [Ref. 7]. • District heating arrangements for residential and commercial buildings using non-emitting fuel options. • Early engagement, awareness, and leadership in indigenous communities • Further funding in energy-efficient technologies. • Retrofitting older inefficient buildings. • Local utility incentives to encourage fuel switching.

TABLE 4 CHALLENGES & OPPORTUNITIES IN BUILDINGS SECTOR

In the long term, a green generation mix will be combined with a revised National Building Code with mandatory performance regulations. Other factors that will drive the outcome will include sound returns on investments for owners and developers, as well as changes in human behaviour with regards to energy consumption. There will also be an opportunity to connect more communities to the grid with a transition toward district energy, but this needs to start with performance-based regulations across all industries.

LEVERAGING CROSS-SECTOR SOLUTIONS

Electrification of the building sector should be matched with a scale-up of energy efficiency measures, as Canadian households currently continue to consume more energy every year. The electrical demand of cities is likely to increase rapidly as cities continue to become dense environments. Support from the electricity sector will be pivotal to the long-term plan of the buildings sector.

D. Heavy Industry

D1. GHG REDUCTION APPROACH

The principles guiding the GHG reduction pathways in the heavy industry sector have traditionally focused on energy efficiency as well as the reduction on the reliance on fossil fuels. On the energy efficiency front, sensors and SCADA systems that track energy consumption and losses in all parts of the production process are today widely available and cloud computing allows for significantly more complex process analyses and optimization to be performed. On the fossil fuel front, improvements do not only include electrification of industrial processes, but also a drop in fossil fuel consumption. As an example, the forestry and pulp and paper industry has been able to reduce its reliance on fossil fuels by 75% by moving toward the biomass that is produced by their own operations [Ref. 34].

While the world's petrochemical industry and refineries mostly use oil as a feed, Canadian facilities have gradually moved to a natural gas feed. Nickel mining in Canada produces less than half the emissions of international competition [Ref. 35].

It is now widely accepted that although electrification, energy efficiency and fossil fuel reduction measures are required, they will not be sufficient to reach the ambitious net zero carbon target set for 2050. Other new processes, technologies, and combustion innovations will need to be developed and implemented.

The detailed study led by Dr. Bataille [Ref. 35], co-leader of the Canadian Deep Decarbonization Pathways Project (DDPP) and adjunct professor at Simon Fraser University, suggests that pathways to net carbon zero exist in the heavy industry sector and identifies three main approaches:

1. **Replacing the fossil fuel consumption with a carbon neutral alternative:** Among current early developments are biomass and hydrogen combustion. Biomass combustion is limited by the natural resources surrounding the facility, and also tends to impact air quality. Hydrogen on the other hand can be used as a clean fuel but would need to be manufactured in large quantities, either through electrolysis, or through reforming natural gas. The production of such large quantities of hydrogen depends on the availability and reliability of an abundant source of clean renewable power. Canada is exceptionally well positioned in that respect. Other replacements to fossil fuels are also being considered, such as synthetic hydrocarbons, but its application will be limited by the sheer production capacity [Ref. 34].

2. **Apply carbon capture and sequestration to residual GHG emissions from the industrial process:** Carbon capture and sequestration technology could be applied to the carbon produced by the industrial process but would not constitute a competitive solution for middle and lower scale industrial facilities. Furthermore, limitations on storage capacity would have to be resolved, potentially by the implementation of CO_2 pipelines to central storage sites. While carbon capture could help significantly reduce emissions in the heavy industry sector, it should however be considered only as an intermediate step toward a longer term more sustainable solution.

3. **Coming up with brand new industrial processes:** A study on the evolving manufacturing processes for the production of cement, glass, iron and steel, metal processing, mining, refineries, chemicals and pulp and paper has revealed that "there is an R&D gap in heavy industry," and most of the technical options being contemplated "will need extensive R&D and piloting" [Ref. 35]. Another critical factor is the practicality of retrofitting existing industrial plants with the new processes being developed. Options put forward have, at the present time, not yielded any technologies that would allow for an easy and economic retrofit.

   None of the reduction technologies currently on the table offer a readily available long-term solution. The main challenge to be addressed remains the use of fossil fuels. Although progress has been made, the volume of fossil fuels that remains to be offset makes substitutions to synthetic hydrocarbons or to hydrogen impractical in the short term. The only viable long-term pathway appears to involve implementing brand new industrial processes in greenfield facilities to offer a sustainable solution for a carbon free manufacturing process of everyday commodities.

D2. WHAT'S IN STORE FOR THE LONG TERM?

One fact that can be stated with near certainty is that even after pushing the concept of circular economy and assuming lower material intensity, the need for raw materials such as steel and cement will continue to increase in the future. A low-carbon society needs to include a viable low or zero carbon solution for producing these commodities.

Canadian pilot projects have already started, such as Elysis, a joint effort by Rio Tinto, Alcan, Apple, and the governments of Quebec and Canada, described as the world's first carbon-free aluminium smelting process, which claims to produce aluminium and release only pure oxygen into the environment [Ref. 36]. Another example is Carbicrete, a project to develop cement-free, carbon-negative concrete [Ref. 37]. Such initiatives will however take time (and money) to develop into viable solutions which could be widely implemented.

It is clear that on the international scale, viable solutions are expected from countries with (i) large supplies of clean, reliable and cheap electricity, (ii) abundant natural resources, and (iii) the technical talent and know-how to turn these natural resources into usable materials for the industry. Canada is part of a very select group of countries capable of meeting these criteria.

The federal and provincial governments must recognize Canada's unique position in this market and implement a decarbonization investment plan that reflects their confidence in the long-term achievements it will yield for our heavy industry sector. A research and development plan also needs to be put in place to leverage Canada's unique technical talent pool and encourage active links to the industrial community to reduce the time to market for any and all viable technical innovations.

Finally, since the production of low carbon (eventually carbon-free) materials is also highly dependent on the ability of the power grid to deliver clean reliable electricity, it is recommended that both the energy and heavy industry long-term plans be coordinated accordingly [Ref. 35].

E. Agriculture and Forestry

E1. GHG REDUCTION APPROACH

Over the course of the last 15 years, food production in Canada has more than doubled while emissions have remained relatively unchanged. Key advances in technologies and practices have introduced significant reductions in emissions per unit of food output.

At a provincial level, CO_2 emissions and absorption match the predominant agricultural output of each region. An alternative view of food emissions emerges from the inherent CO_2 content of the different animal protein per kilogram shown in Figure 7 [Ref. 38].

Due to improved processes and livestock management, the GHG emissions intensity of Canadian animal protein is one of the most efficient in the world. This places Canadian exports of beef and other animal products on preferable grounds from the emission intensity point of view.

Nevertheless, these proven technologies will need to be applied across-the-board and consistently, namely:

- Improving crop practices that maximize soil carbon sequestration while minimizing nitrous oxide emissions from fertilizers: the net CO_2 emission of fertilized soils can be improved by well-understood practices for tilling, fertilizing and disposal of organic matter that maximize the soil retention of CO_2 and nitrogen fertilizer.

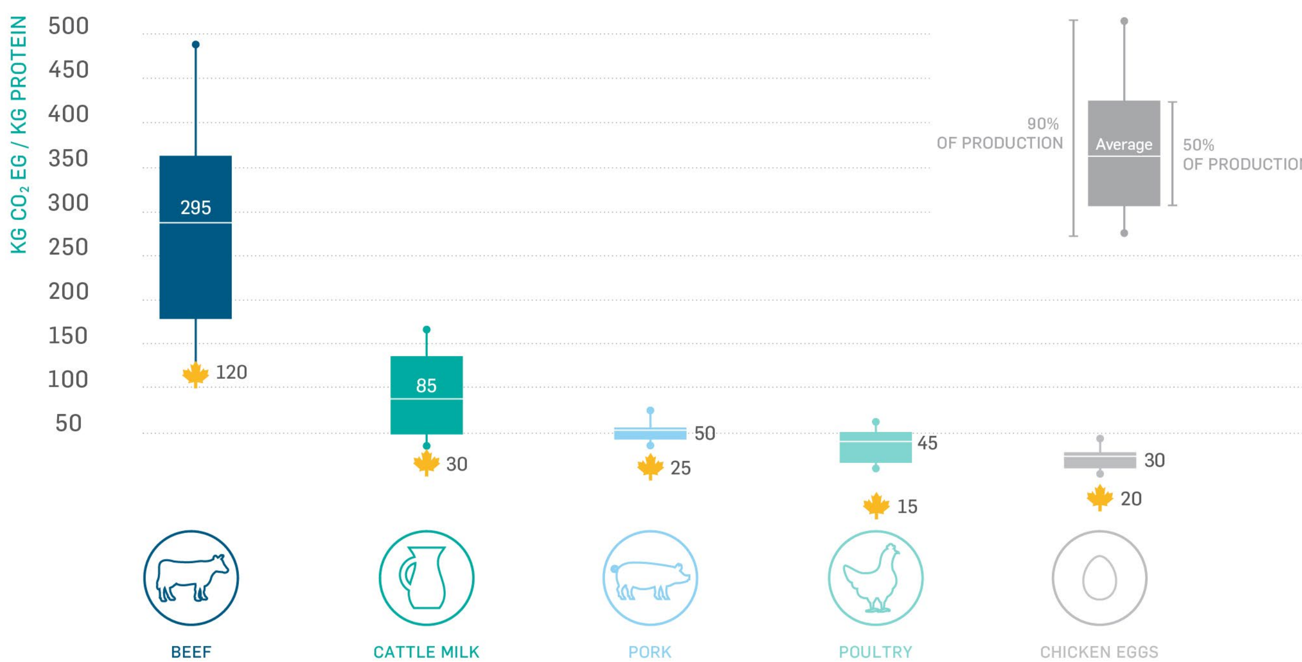


FIGURE 7 GHG EMISSIONS INTENSITY OF CANADIAN LIVESTOCK [REF. 38]

- Improving the efficiency/speed of raising animal protein: technologies that improve the efficiency of raising livestock include balancing of feed in order to lower enteric and manure related emissions. Additionally, optimal breeding and raising help herd efficiency thus reducing the unproductive livestock both in terms of number of animals and time to animal maturity.
- Manure management: the management of manure can improve the recovery of nutrients and its associated emissions.
- Land restoration: the recovery of forests and agricultural land is an obvious mechanism to sequester CO_2 directly from the atmosphere. This however, is dependent on the availability of land that can be converted into a net carbon sink.

E2. WHAT'S IN STORE FOR THE LONG TERM?

Within the next 30 years, additional improvements in the GHG emission intensity of agricultural and forestry products will need to come from cross-sector solutions. The strength of the agriculture and forestry sectors in Canada should be leveraged to improve the carbon emission footprint of the other sectors such as energy. In particular, the following initiatives show the most promise:

- Use of agricultural bio residue for energy uses (space heating and power): one of the main areas of potential is the use of organic residue from agricultural and forestry activities for energy uses. Technologies such as combined heat and power as well as distributed generation can be efficiently used especially for remote sites. In some of the sites, where the major energy consumption is generated from fossil fuels, the use of organic residue has potential positive environmental and economic impacts.
- Natural plant growth and land reclamation from industrial sites such as mines: Canada has a large quantity of sites which were deforested in the past to extract other natural products. These sites, once decommissioned, can be converted into forests acting as carbon sinks.
- Bio carbon sequestration by using wood as construction material: the use of wood as construction material effectively transforms buildings into long-term carbon storage, which avoids or delays GHG emissions that would result from otherwise burning these materials.

F. Waste

F1. GHG REDUCTION APPROACH

From an economic perspective, there is limited incentive for waste diversion or prevention at landfill sites across Canada due to the already low costs [Ref. 7]. This issue would need to be addressed through incentives and a common framework applicable at the municipal levels.

GAS CAPTURE AT LANDFILLS

Carbon capture has proven to be effective in the waste sector. Only 12 out of the 26 Mt CO_2 eq of CH_4 was emitted to the atmosphere in 2018, with the rest of the generated CH_4 captured, flared, or used as an energy source [Ref. 5].

BIOMASS

Biomass offers a pathway toward increasing the efficient use of our resources, through the combustion of discarded resources such as wood waste, resulting in energy generation and biofuels. While the process of biomass results in GHG emissions, it can be argued that those discarded resources would have otherwise been incinerated, and so we are able to extract additional energy from an already ongoing process.

Additionally, due to strong economic sectors such as forestry, Canada has an abundant supply of resources readily available to produce biomass energy and biofuels. With future carbon capture technologies, biomass can play an important role in a net zero carbon system, if this is done within a framework of waste reduction interventions [Ref. 39]. Regulations and monitoring should be put in place to ensure that the biomass industry is not inadvertently incentivized to increase deforestation for the simple purpose of producing biomass fuel, a process that in and of itself is a net emitter of GHGs.

F2. WHAT'S IN STORE FOR THE LONG TERM?

In moving toward a net zero carbon emissions system, the focus in the waste sector will be around the "co-benefits of waste prevention, diversion, and landfill gas capture" [Ref. 7], in conjunction with further developments in landfill carbon capture and flaring, and the necessary economic incentives and cross-provincial regulations to make this a reality.

The concept of a "circular economy" proposed in [Ref. 39], puts the focus on the full lifecycle of products, with the objectives of reducing waste, increasing resource efficiency, maintaining a competitive business environment that drives innovation, and a general drive toward reduction of environmental impacts related to production and consumption. This is a powerful but ambitious concept that will require significant efforts at various levels of industry and government, to gain a deeper understanding of the lifecycle of every consumer product and come up with economically sound ways to improve the process from resource extraction, to production, to consumption.

STRATEGIES AND SOLUTIONS FOR A NET ZERO CARBON FUTURE

3. The Canadian Electricity Landscape

A. Snapshot of the Electricity Sector

A1. POWER GENERATION MIX

Today's Canadian power generation mix (Figure 8) is relatively clean with already more than 80% of power generation coming from non-emitting resources including hydro, nuclear, wind, and solar energy [Ref. 40].

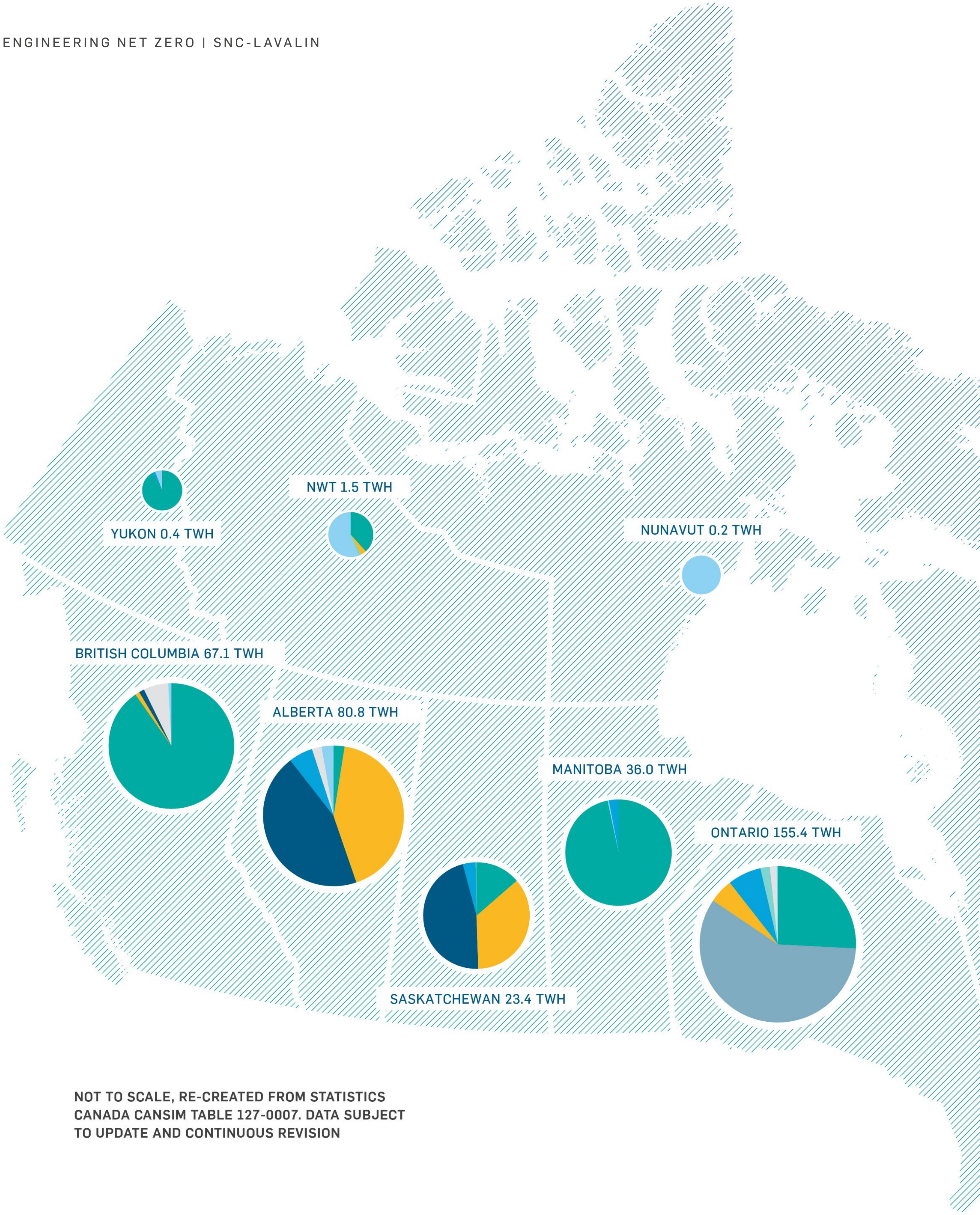
Overall in Canada, total electricity-related GHG emissions decreased by 39% from 2000 to 2016 because of increased generation from non-emitting sources [Ref. 40]. Most of this reduction is attributed to the replacement of all coal facilities in Ontario with nuclear power, thus reducing Canada's GHG emissions by 35 Mt CO_2 eq annually [Ref. 41].

However, a Canadian transition toward a net zero system would entail a major increase in electrical demand, requiring an annual build rate of new electricity generation, transmission and distribution assets well beyond anything we have seen in recent years. Recognizing the massive future demand, intervention is needed to ensure the risks are managed as the electricity demand rapidly grows driven by electrification of the different economic sectors and in particular: transportation, buildings, and the production of green hydrogen.

To put things into perspective, the Deep Decarbonization Study and similar investigations [Ref. 7, Ref. 8, Ref. 42] estimate that Canada will require about 1000 TWh/year on top of the existing demand of 500 TWh by 2050 as a result of the electrification of other sectors. During this transition, parts of Canada will remain highly dependent on fossil fuel generation, namely natural gas, which plays an important role in stabilizing the electrical grid and in responding to short term variation in demand. Furthermore, due to uncertainty associated with the policy developments to support electrification, this massive electricity production is not yet accounted for in the integrated resource plans prepared at the provincial levels.

Canada has committed to phasing out all remaining coal-fired generation by 2030. This is certainly an important step in the right direction and will result in lower GHG emissions even if replaced with natural gas plants.

Provinces that can rely on hydro resources, such as Ontario, Quebec and British Columbia are well-positioned to have a fully clean power supply mix ahead of the 2050 milestone provided that these provinces keep investing in the maintenance of existing assets, as well as tapping into other renewable resources such as wind, solar, wave, and tidal power. Nevertheless, the scale of the challenges to access those additional resources, including financial, environmental, public acceptance, project development time and remote location considerations, should not be underestimated.



NOT TO SCALE, RE-CREATED FROM STATISTICS CANADA CANSIM TABLE 127-0007. DATA SUBJECT TO UPDATE AND CONTINUOUS REVISION

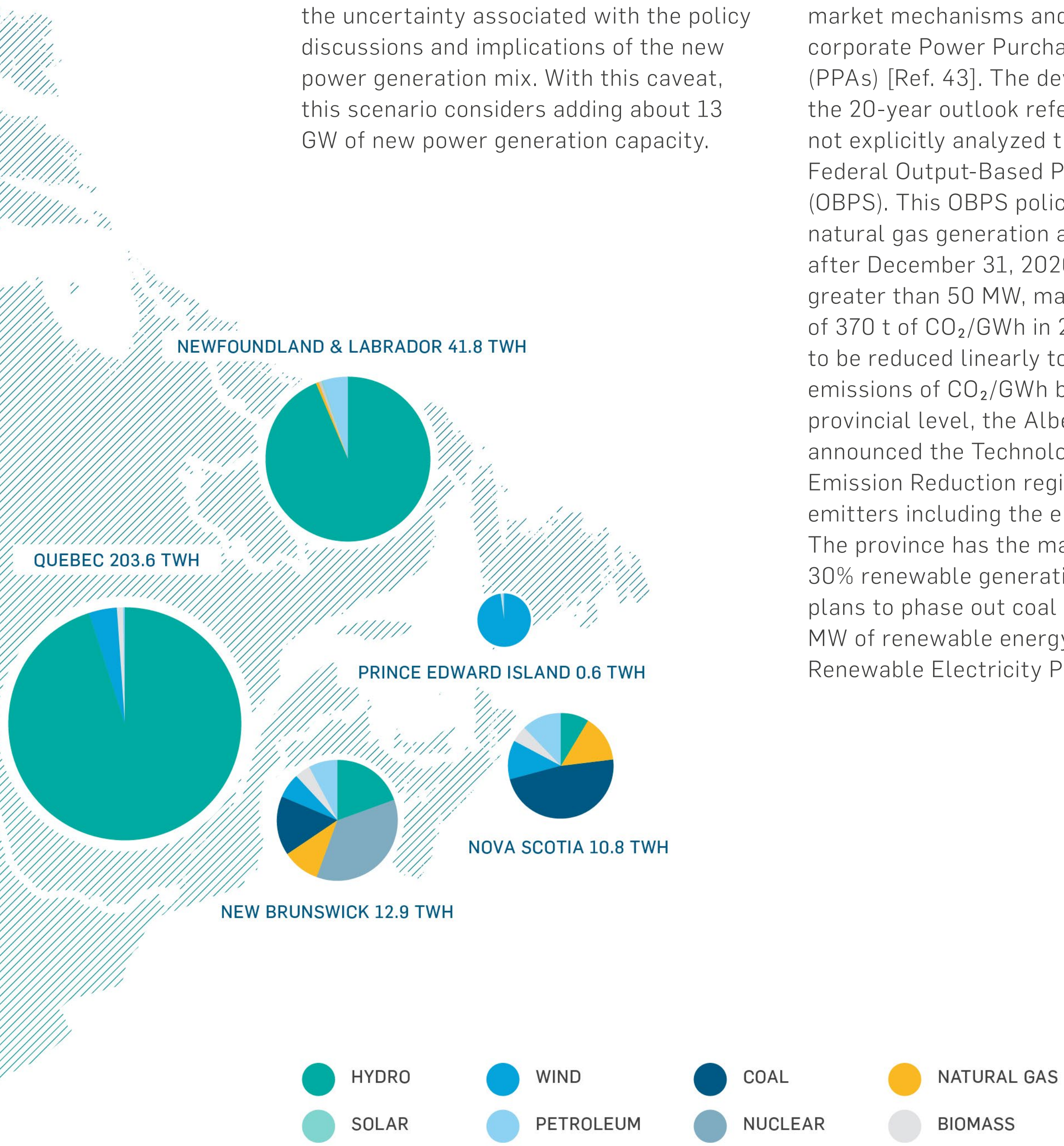
FIGURE 8 CANADIAN ELECTRIC SUPPLY MIX. NRCAN 2017 [REF. 40]

Alberta, Saskatchewan, Nova Scotia, and New Brunswick face an even greater challenge, as the transition toward clean power generation mix by 2050 would require a major shift in their energy supply technologies.

In Alberta, the reference case for generation addition published by the Alberta Electric System Operator noted the uncertainty associated with the policy discussions and implications of the new power generation mix. With this caveat, this scenario considers adding about 13 GW of new power generation capacity.

The reference case indicates that natural gas-fired generation will become the predominant generation source, as 5275 MW of coal-fired capacity is expected to co-fire or be converted to natural gas beginning in 2021.

Additional renewable energy generation (wind and solar) are expected to come online through unsubsidized competitive market mechanisms and support from corporate Power Purchase Agreements (PPAs) [Ref. 43]. The development of the 20-year outlook reference case has not explicitly analyzed the impact of the Federal Output-Based Pricing System (OBPS). This OBPS policy mandates that natural gas generation assets constructed after December 31, 2020, with a capacity greater than 50 MW, may emit a maximum of 370 t of CO_2/GWh in 2021, which needs to be reduced linearly to reach zero emissions of CO_2/GWh by 2030. On the provincial level, the Alberta Government announced the Technology Innovation and Emission Reduction regime for large final emitters including the electricity sector. The province has the mandate to reach 30% renewable generation by 2030, with plans to phase out coal and to add 5000 MW of renewable energy through the Renewable Electricity Program [Ref. 44].



In Saskatchewan, SaskPower committed to reducing emissions related to energy generation by 40% compared to the 2005 level, by 2030. As with Alberta, the reduction will come by deploying gas-fired power generation and a mix of solar and wind generation both at the transmission and distribution levels. R&D activities also include exploring the opportunity to develop a geothermal power plant [Ref. 45].

The Government of Nova Scotia has established the goal of meeting the net zero emissions target by 2050 through the Sustainable Development Goals Act (SDGA) [Ref. 46] which came into effect on Oct 20, 2019. Nova Scotia Power Inc.'s ongoing Integrated Resource Plan (IRP) [Ref. 47] is evaluating the impact of the uncertainty of the GHG targets and environmental policies by considering three scenarios: the comparator scenario (2018 analysis as a reference case), the net zero 2050 scenario, and the accelerated net zero by 2045 scenario. The comparator scenario, which is not compliant with the SDGA, would require the replacement of coal power generation using natural gas and diesel-fired generation. In this scenario, renewable energy addition is limited due to grid operation constraints that would limit the ability to integrate more intermittent resources. The net zero 2050 and 2045 scenarios are examining options that include regional integration to import clean power from Labrador, demand-side management, and clean distributed generation.

Finally, New Brunswick Power is in the process of updating their Integrated Resource Plan (IRP). The objective of the 2020 IRP [Ref. 48] is to ensure having at least 40% of the power generated from renewable energy resources. The 2017 IRP was forecasting the retirement of coal power generation in the province by 2041 or at an earlier date if required by a change in federal regulations.

A2. ELECTRICITY DEMAND

The yearly demand for electricity in Canada is about 500 TWh (Figure 9). The residential and industrial sectors consume more than 75% of the electricity demand. Transportation represents a mere 1% of electricity consumption, and agriculture accounts for 2%. With the push toward electrification across economic sectors agricultural, demand is expected to significantly rise. This demand increase provides a good opportunity for the electric utilities to partially compensate for the upcoming reduction in consumption associated with the implementation of net metering, microgrids and behind-the-meter generation. To meet the net zero carbon challenge, this extra demand must come from renewable non-emitting resources.

A3. ENERGY TRADING

Canada is a net exporter of clean energy to the United States. The exports are supported by several power transmission interconnections between Canada and the US. Quebec, Ontario, and Manitoba are net exporters of renewable energy while British Columbia is a net importer. The overall energy exports of electricity (mainly renewable) are increasing over time, a trend which is expected to continue, fueled by the need in the US to increase the renewable energy content in their power generation mix. However, the trend is capped by the existing interconnection capacities. Additionally, new transmission line developments and proposals are facing several permitting and environmental constraints on both sides of the border.

A4. EXISTING TRANSMISSION AND DISTRIBUTION

While there are strong power transmission interconnections between Canadian provinces and the United States – a total of 37 high voltage (HV) interties (500kVDC and 230kVAC), there are limited interconnections between provincial power grids. The weakness of inter-provincial power interconnectors stems from the differences in energy policies at the provincial level.

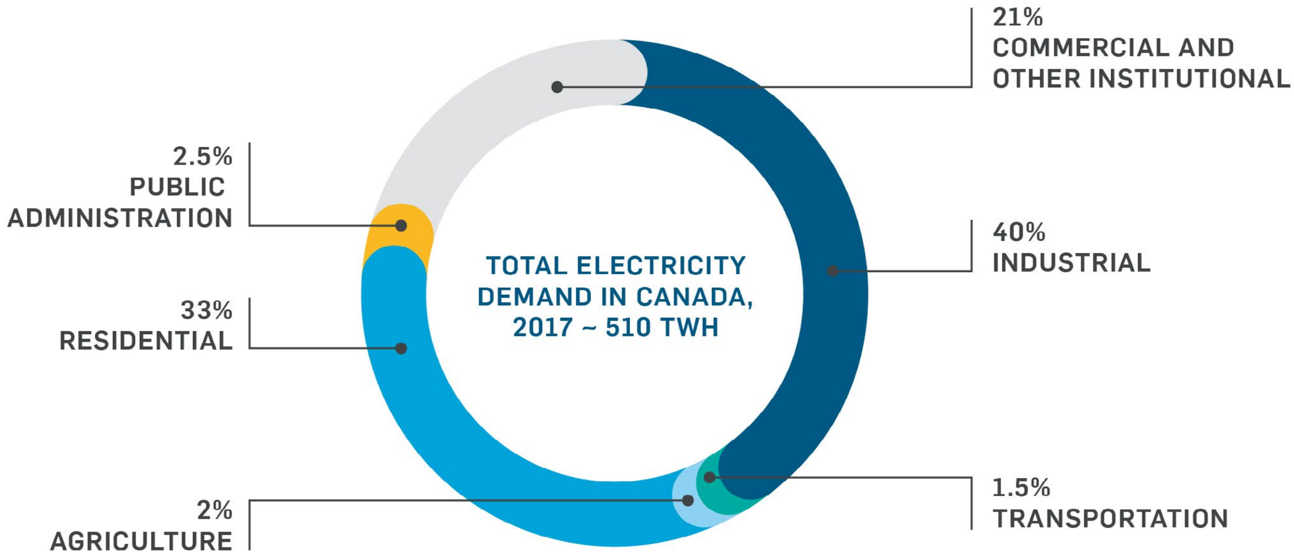


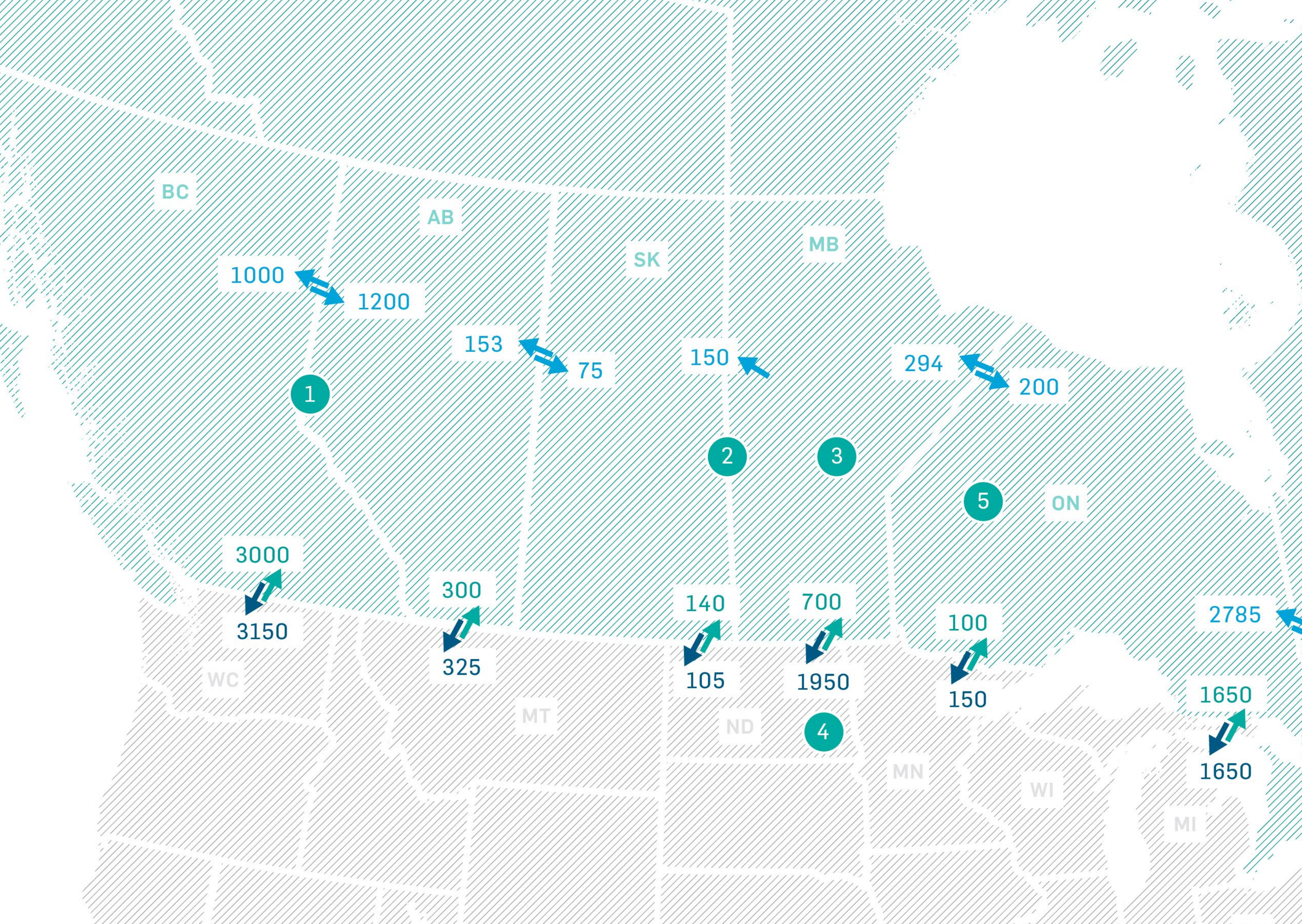
FIGURE 9 TOTAL ELECTRICITY DEMAND IN CANADA 2017 [REF. 49]

Existing provincial grids have technical network limitations that prevent them from integrating the large amounts of renewable generation necessary to meet the net zero carbon emissions target. These limitations include lack of flexible generation that can support the integration of large additional intermittent resources, and congestion of the transmission corridors near sites with the greatest potential for wind, solar, wave and tidal energy development.

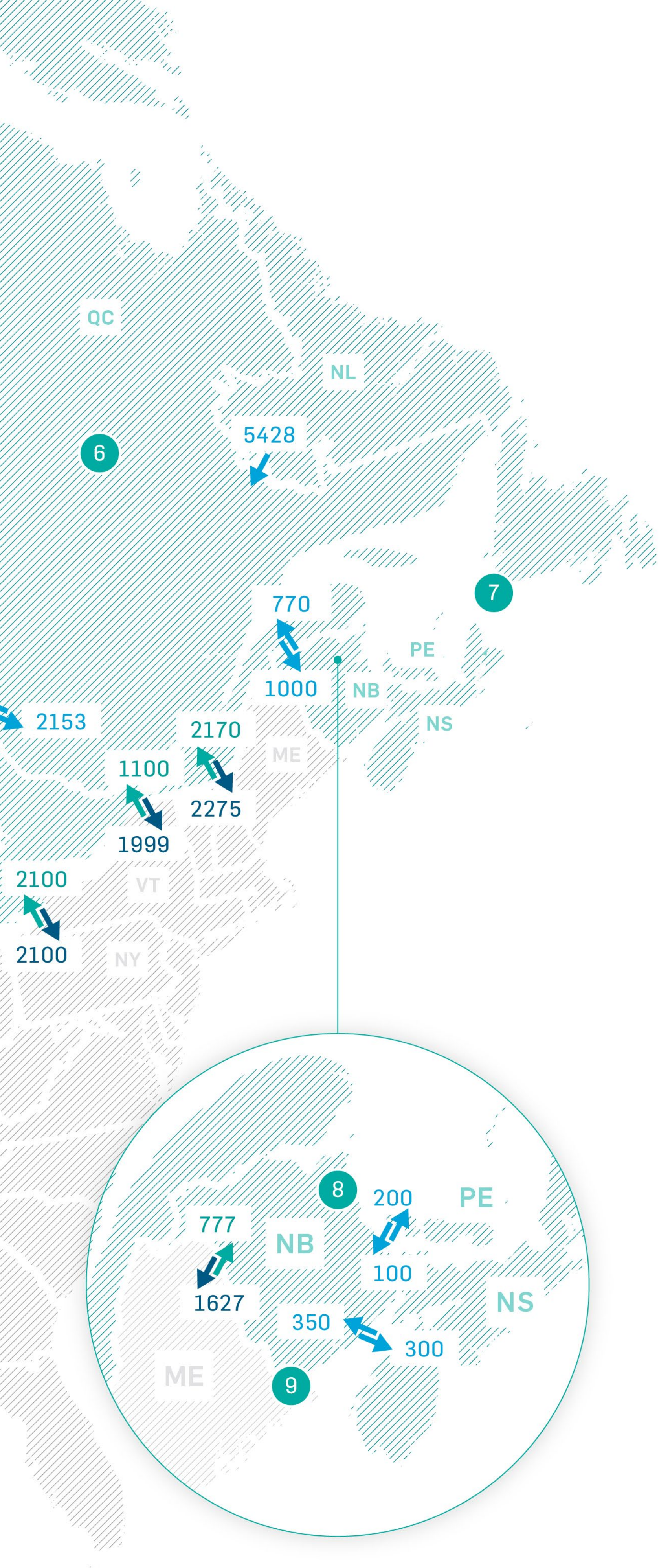
For example, in Alberta, the total integration capacity for new renewable energy in the Southern region is estimated at 470 MW, while the Central-East region cannot integrate any new generation. These values are far below the province's renewable energy capacity requirements. Other Canadian provinces are facing the same challenge and the existing transmission infrastructure will only suffice to integrate a small fraction of the renewable energy generation needed to make the shift toward net zero carbon emissions.

Additionally, transmission and distribution assets are aging, with the bulk of the assets dating back more than fifty years. As such, there is an urgent need to support investment in interconnections at both the cross-provincial level and with the United States and to renew the existing infrastructure. Attaining net zero carbon emissions cannot be guaranteed without such investments. Immediate large-scale investments in the power grids are "no regrets" actions for Canada that could provide benefits under all potential net zero scenarios. Figure 10 shows existing and proposed transfer capability between Canadian and U.S. jurisdictions.

On the distribution side, the use of smart grid technologies, the Internet of things (IoT), and adaptation to challenges associated with distributed renewable energy integration is still lagging. Most of the development in the utility space associated to these new technologies is still exploratory and a regulatory push is needed to enable their integration at a faster pace.



1. In practice, the amount of electricity that can be imported by Alberta from BC and Montana simultaneously is limited to 1100 MW due to internal grid constraints
2. Line under construction between Manitoba and Saskatchewan
3. Proposed line between Manitoba and Minnesota
4. These figures Represent the transfer capability from and to Minnesota and North Dakota combined
5. Proposed line between Ontario and Pennsylvania (1000 MW)
6. Four proposed lines from Quebec to the US:
   - to New York (1000 MW)
   - to Vermont (1000 MW)
   - to New Hampshire (1000 MW)
   - to New Hampshire (1200 MW)
7. Existing Line between Newfoundland and Nova Scotia (500 MW)
8. Two proposed lines between NB and PEI (totalling 360 MW) to replace existing line
9. Proposed line from NB to Massachussetts (1000 MW)



A5. ELECTRICITY MARKET STRUCTURE

The electricity market in Canada consists of provincially planned and regulated grids, with a mixed market and ownership structure. The different provincial generation mixes and market structures add to the difficulties of cross-provincial collaboration. Figure 11 summarizes the current electricity market structure by Canadian provinces.

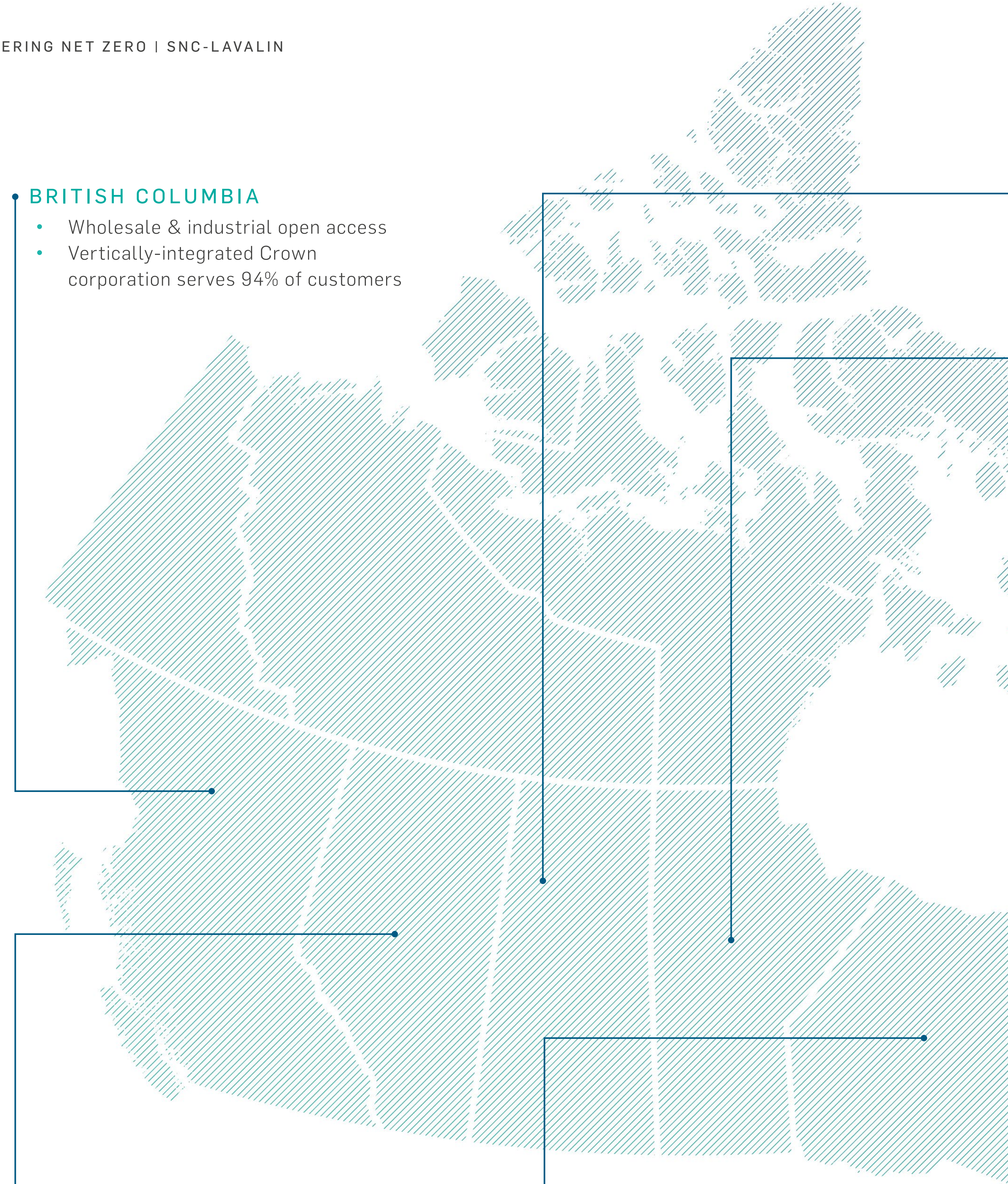
For proper system operation, electric generators provide a host of attributes that include electric energy, capacity, and ancillary services (voltage and frequency support) which help support a power grid in maintaining its healthy operation. The existing market structures in Canada consist mainly of energy markets that provide the generators payment only for the energy attribute and have relied on the classical generation mix to supply other attributes required for resilient grid operation, which are inherent to traditional generators.

Traditional generators, for example, support grid stability through their rotating machines that provide inertia to the grid, as well as controllable power generation to rapidly address fluctuating demand. A stable grid operation then requires a healthy generation mix composed of both traditional generators, as well as intermittent renewable energy generation, such as wind, solar, wave, or tidal. As such, an energy-only market penalizes classical generation in favor of renewable energy generation, in the absence of fair compensation for capacity and ancillary services provided by generators such as nuclear and hydro.

FIGURE 10 EXISTING AND PROPOSED TRANSFER CAPABILITY (MW) BETWEEN CANADIAN AND U.S. JURISDICTIONS [REF. 50]

BRITISH COLUMBIA

- Wholesale & industrial open access
- Vertically-integrated Crown corporation serves 94% of customers



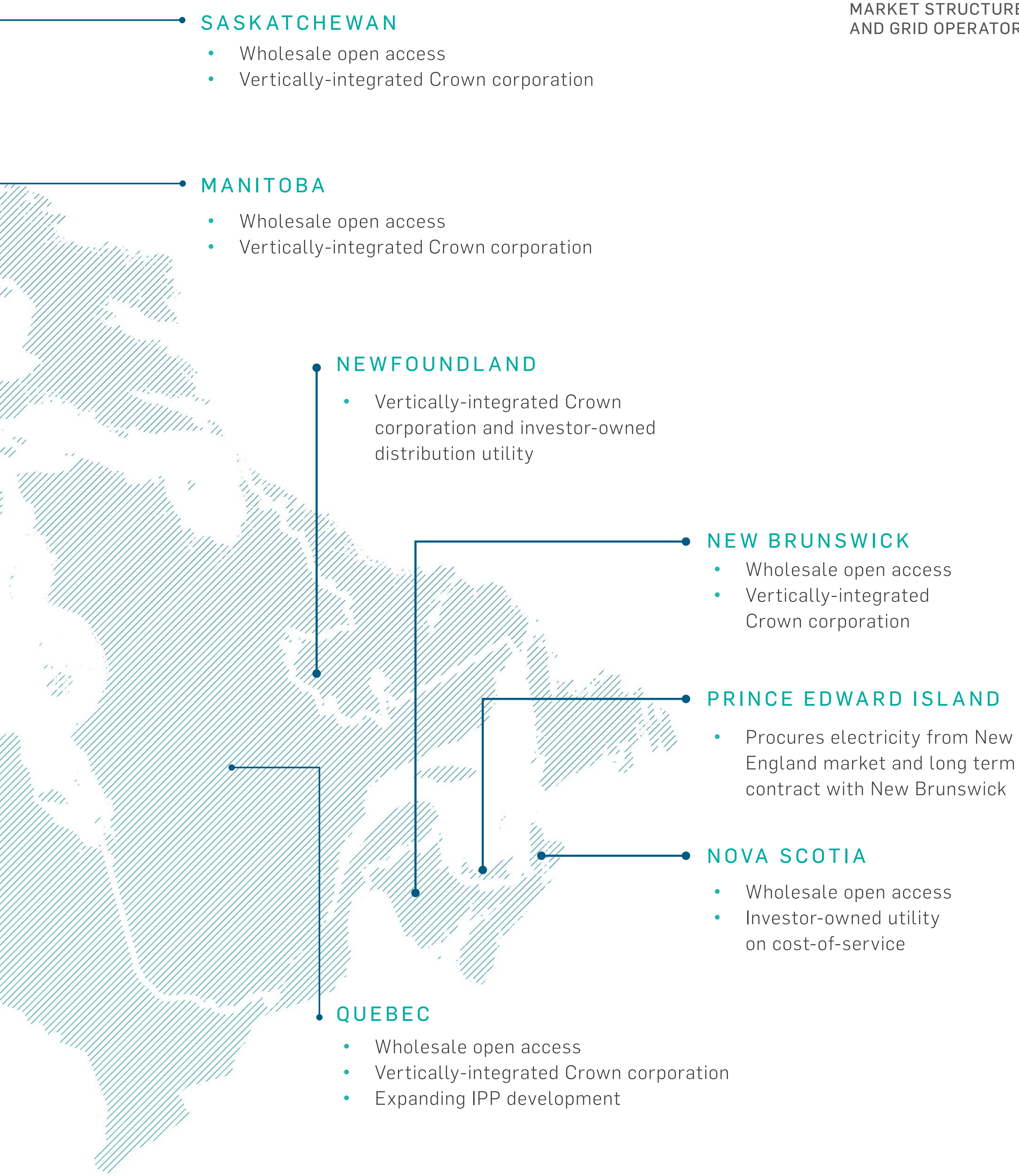
ALBERTA

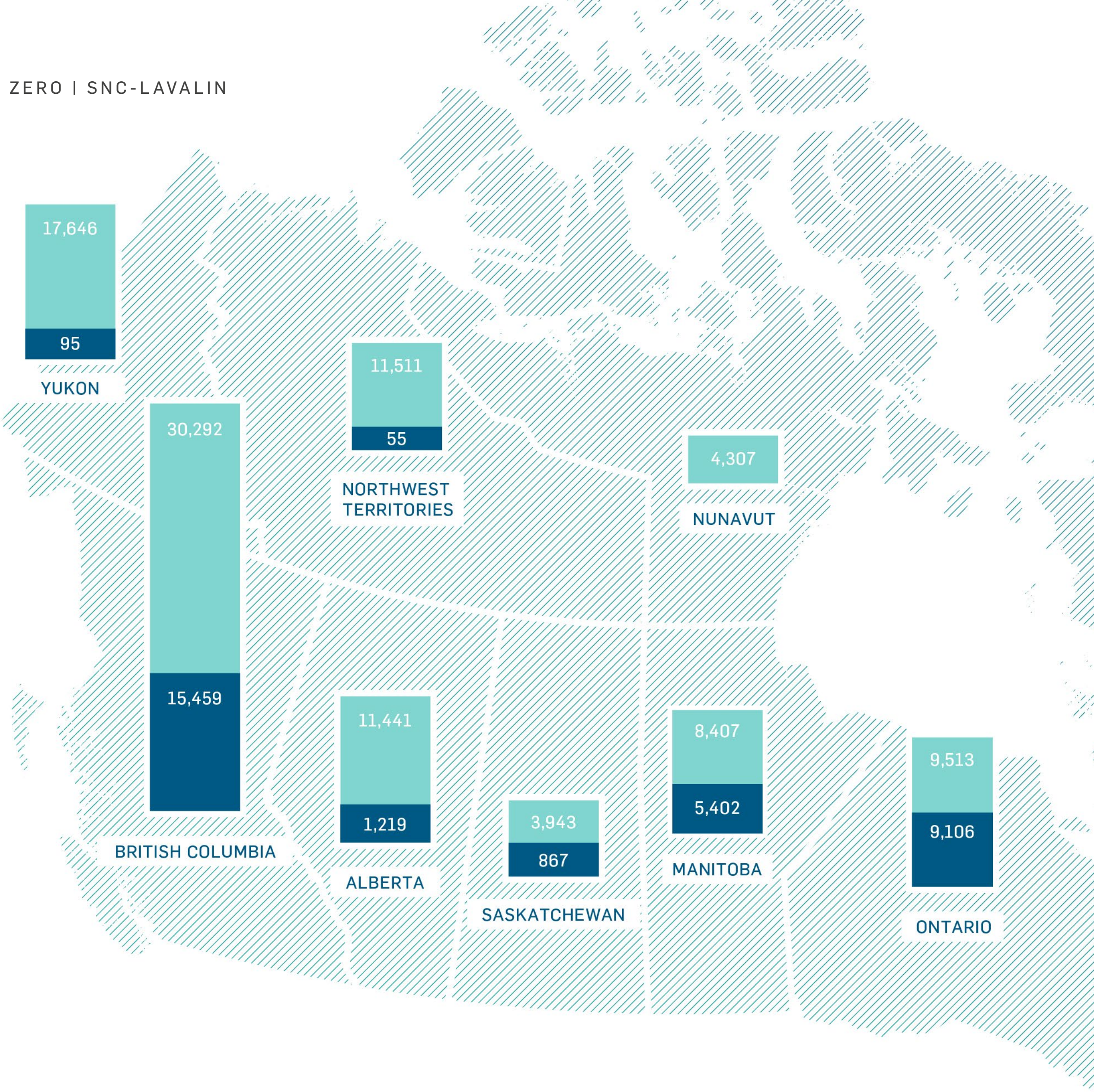
- Mandatory Power Pool
- Wholesale & retail open access since 2001
- Fully competitive wholesale market

ONTARIO

- Industry unbundling in 1998
- Wholesale & retail open access since 2002
- Hybrid regulation and completion model

FIGURE 11 PROVINCIAL MARKET STRUCTURE AND GRID OPERATORS





A market reform that would enable generators to tap into the combined values of energy availability, firm capacity, and ancillary services is needed to encourage market participants in developing resources that support proper system operation including energy storage; which in itself will allow increased renewable energy integration. It is to be noted that both Ontario and Alberta are going through the market renewal process and other Canadian provinces are expected to follow.

B. Existing Generation Mix

B1. HYDRO

More than 60% of electricity generation in Canada comes from hydro energy resources. British Colombia, Manitoba, Quebec, and Newfoundland are rich in hydro energy resources and have responsibly developed these projects over the last several decades. In recent years, though, new hydro projects (except for run-of-river small schemes) have faced significant social, environmental, and economic challenges, as well as stringent regulatory requirements, leading to relatively long development periods.

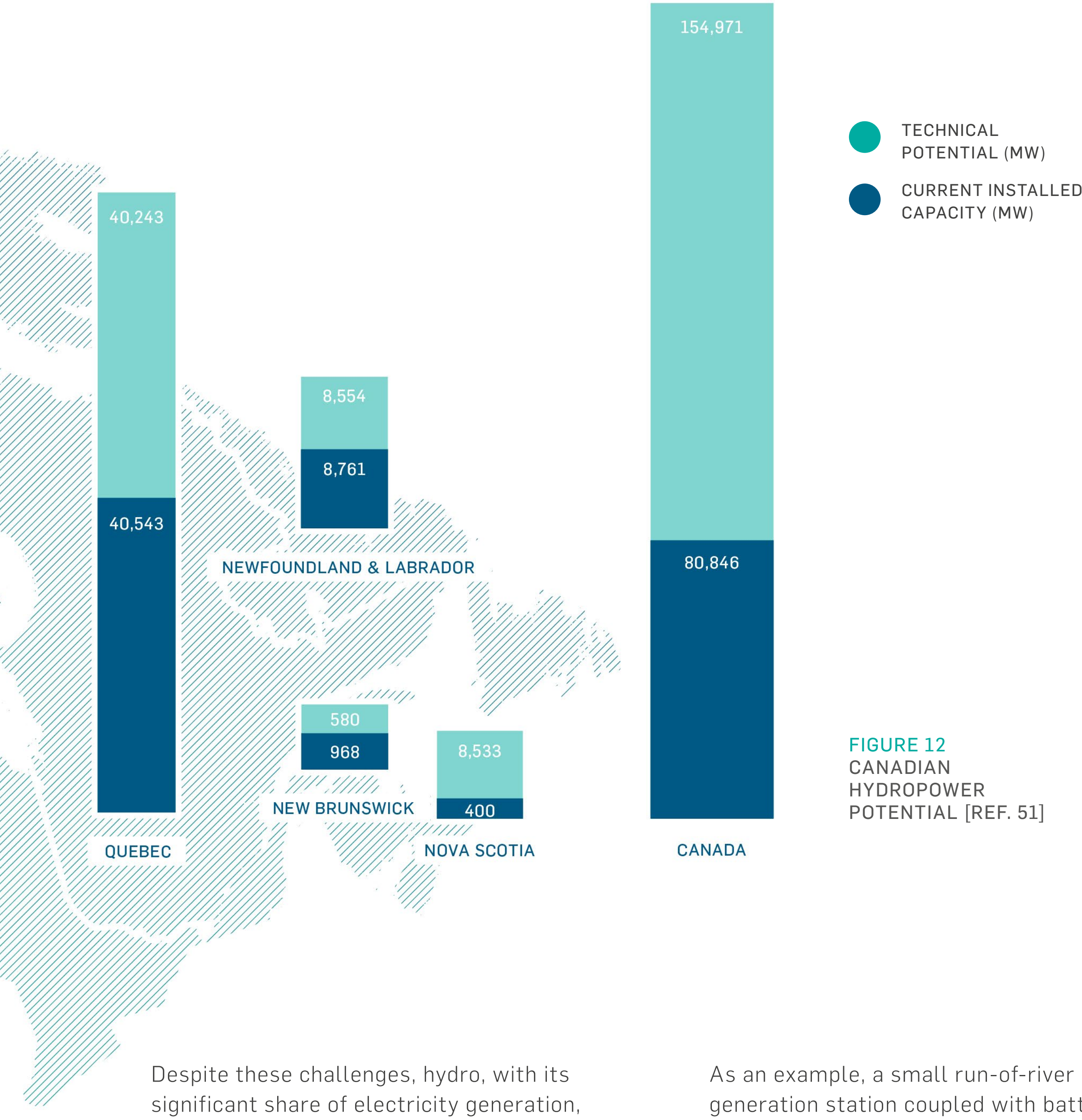


FIGURE 12
CANADIAN HYDROPOWER POTENTIAL [REF. 51]

Despite these challenges, hydro, with its significant share of electricity generation, remains a very attractive source of clean energy for Canada. Hydro energy technology also has a major role to play in bulk energy storage, with pumped storage hydro representing about 99% of the worldwide energy storage market.

Looking toward the future, a net zero carbon emissions system will require Canada to maintain and renew existing hydro generation assets, while developing new sites for hydro energy storage that would help provide the steadiness needed for the integration of intermittent renewable energy sources.

As an example, a small run-of-river hydro generation station coupled with battery storage and a solar plant (wherever possible) could help remote communities reach net zero carbon emissions and remove their dependency on diesel fuel.

As shown on Figure 12, the technical potential for developing hydropower is about double the hydro capacities we have developed to date [Ref. 51][1]. Further development is however faced with significant challenges, such as the remote location of the resources, the associated environmental impact and the lack of transmission capacity.

1 NOTE THAT THE NOVA SCOTIA INSTALLED GENERATION COMES FROM REF. 47.

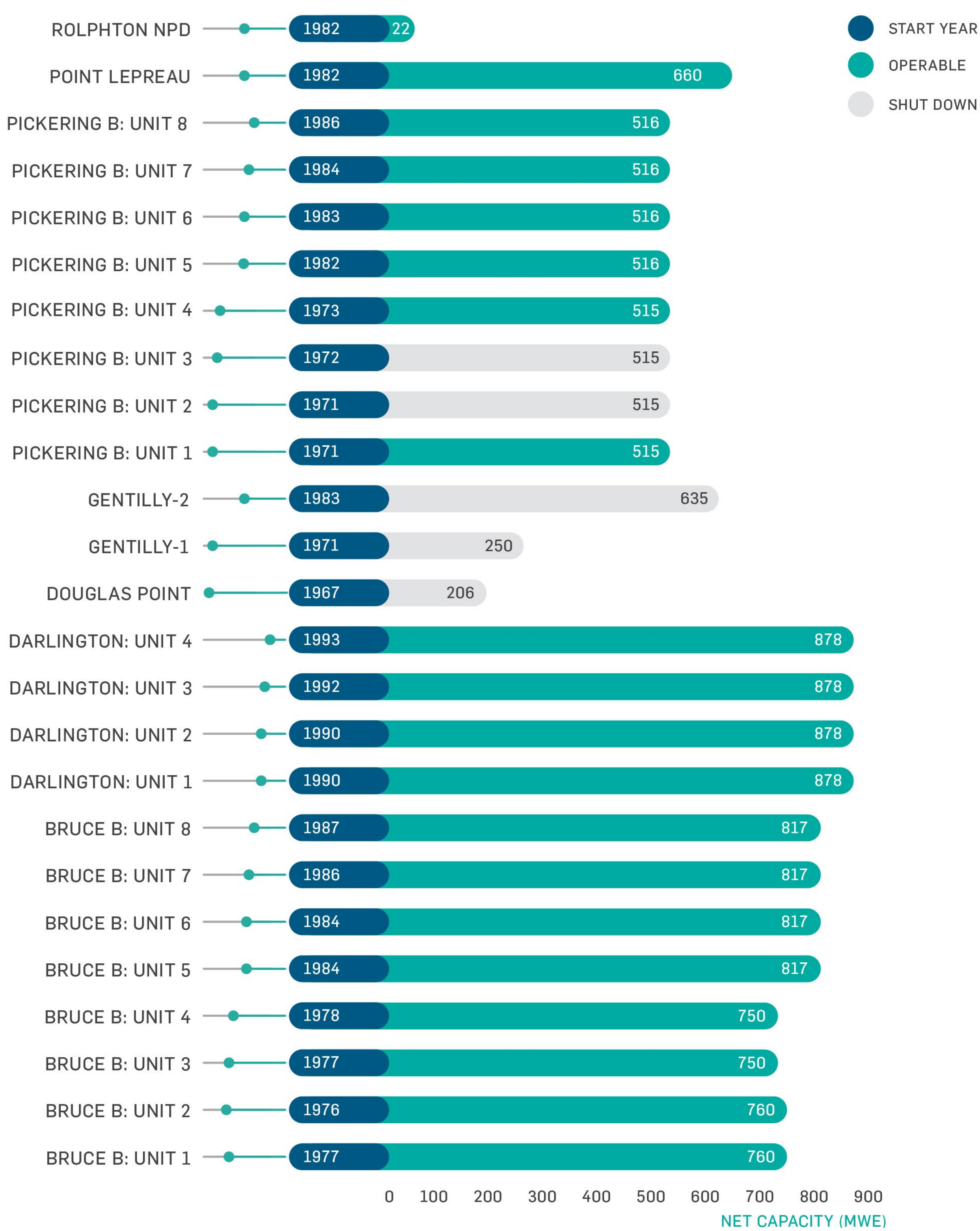


FIGURE 13 CANADA NUCLEAR POWER PRODUCTION ADDED TO THE GRID 1971 TO DATE [REF. 54]

B2. NUCLEAR

Currently, nuclear power accounts for about 15% of overall electricity production in Canada. Existing plants are located in two provinces: Ontario (constituting 60% of Ontario's electric energy production) [Ref. 52] and New Brunswick (constituting 40% of New Brunswick's electric energy production) [Ref. 53].

Nuclear power is not dependent on weather, climate, or sun conditions, has a very small relative footprint per megawatt output, and all designs are emissions-free. Nuclear plants could be sited nearly anywhere in the country. Furthermore, because of the heat output, they can be used for industrial applications that require steam, or a combination of steam and electricity including relatively efficient methods of hydrogen production.

The last new nuclear facility to be built in Canada was completed in 1993. In 2025, six currently operating reactors will reach the end of life and be permanently decommissioned. This will take over 3000 MW of emissions-free electricity off the grid permanently. Nuclear power generation capacity additions over the years are presented in Figure 13.

Nuclear development and construction require significant environmental assessment processes, design licensing by the Canadian Nuclear Safety Commission (CNSC), and long timelines for heavy component manufacturing, construction, and commissioning. Even for a plant design that is relatively well-understood and requires little research and development, the current process takes approximately 8 to 10 years between site identification and power production.

The nuclear industry has more recently introduced small modular reactors (SMRs) which range from 10 MW up to 300 MW. While this technology certainly holds promise, many of the more innovative designs also require licensing and development of new fuel facilities which themselves carry 4 to 5-year design, licensing, and construction timelines, in addition to the 8-10 years cited above. As such, advanced SMRs are not likely to connect to the grid until the mid-2030s or later. Once SMR technology is proven and begins to be widely deployed, it can help play an important role in transforming the Canadian energy mix, especially for remote off-grid areas that currently depend on diesel generation.

Nuclear power is forecasted to supply a significant portion of the electricity needs to support any of the 2050 net zero carbon scenarios [Ref. 7, Ref. 8, Ref. 42]. However, given the timelines involved in new nuclear development, licensing, and environmental permitting, it is vital that no more time is lost between now and 2050.

B3. NATURAL GAS

Natural gas generation will continue to be an important part of the power generation mix as it provides the power grid with the stability to maintain proper system operation and provides truly dispatchable power – where the power plant can rapidly respond to actual demand. By 2030, 10% to 15% of the total generation in Canada is expected to come from natural gas power generation, considering the provincial long-term plans that aim to replace coal power generation with a mix of natural gas-fired generation and renewables.

To meet the anticipated stringent requirements of net zero carbon emissions, major equipment manufacturers are committed to retrofit their gas turbines to run fully on hydrogen (H_2) a decade from now [Ref. 58, Ref. 59, Ref. 60]. Some of the commercially available larger frame gas turbines can already run with a mix of natural gas and up to 50% of hydrogen. For smaller turbines, the percentages are even higher. Eventually, as the technology matures, these turbines are expected to have the ability to run at 100% renewable hydrogen [Ref. 58], thus eliminating GHG emissions that would otherwise be emitted through the combustion of natural gas. Green hydrogen could be produced from electrolysis using renewable power.

Another possibility for eliminating GHG emissions is the use of post-combustion capture and sequestration technology on natural gas-fired power plants. Carbon capture and sequestration (CCS) technology for gas-fired turbines continue to develop with new technologies being introduced. As an example, “bolt-on” fuel cells can capture carbon while increasing plant power output to thermal cycles. Carbon dioxide becomes part of the combustion process by being recycled back into the combustor and partially sequestered.

The potential use of H_2 to fire gas turbines, in addition to the many promising new technologies around CCS, can help Canada meet the 2050 net zero carbon target for the electricity sector.

B4. WIND

Wind generation has been installed in all Canadian provinces. In 2019, the installed wind generation in Canada reached 13,413 MW providing just under 5% of Canada’s electric energy production [Ref. 61]. The development of larger wind turbines helps harness more energy, reduces wind projects’ marginal costs, and improves competitiveness against other generation technologies. Canada still has very large opportunities for wind development. Figure 14 provides the installed wind capacity added in Canada since 2008.

Canada also has a large potential to develop offshore wind projects on the East and West coasts. Offshore wind tends to yield more energy compared to onshore wind due to higher and steadier wind profiles. A single 12 MW offshore turbine can provide power for more than 20,000 homes. However, stronger transmission networks and additional provincial interconnections are required to enable greater integration of wind generators.

B5. SOLAR

Solar contribution to the Canadian generation mix is still low. In 2019, installed solar capacity exceeded 3 GW and contributed less than about 1% of the total electricity production in Canada [Ref. 40]. With the falling cost for solar installations, it is expected that solar will contribute more toward the renewable energy mix. The modular nature and declining prices of solar generation will help increase distributed generation and support microgrid developments for remote and off-grid communities. Figure 15 demonstrates the installed solar capacity added in Canada year over year since 2008.

B6. WAVE, TIDAL AND GEOTHERMAL ENERGY

There is a potential to harness electric energy from the ocean using wave and tidal energy. Canada has a 20 MW tidal station (Annapolis Tidal Station) at the Bay of Fundy, in Nova Scotia. There is also the potential to generate electricity from geothermal energy in Western Canada. However, further research and development are still needed to reach the full potential of those generation resources.

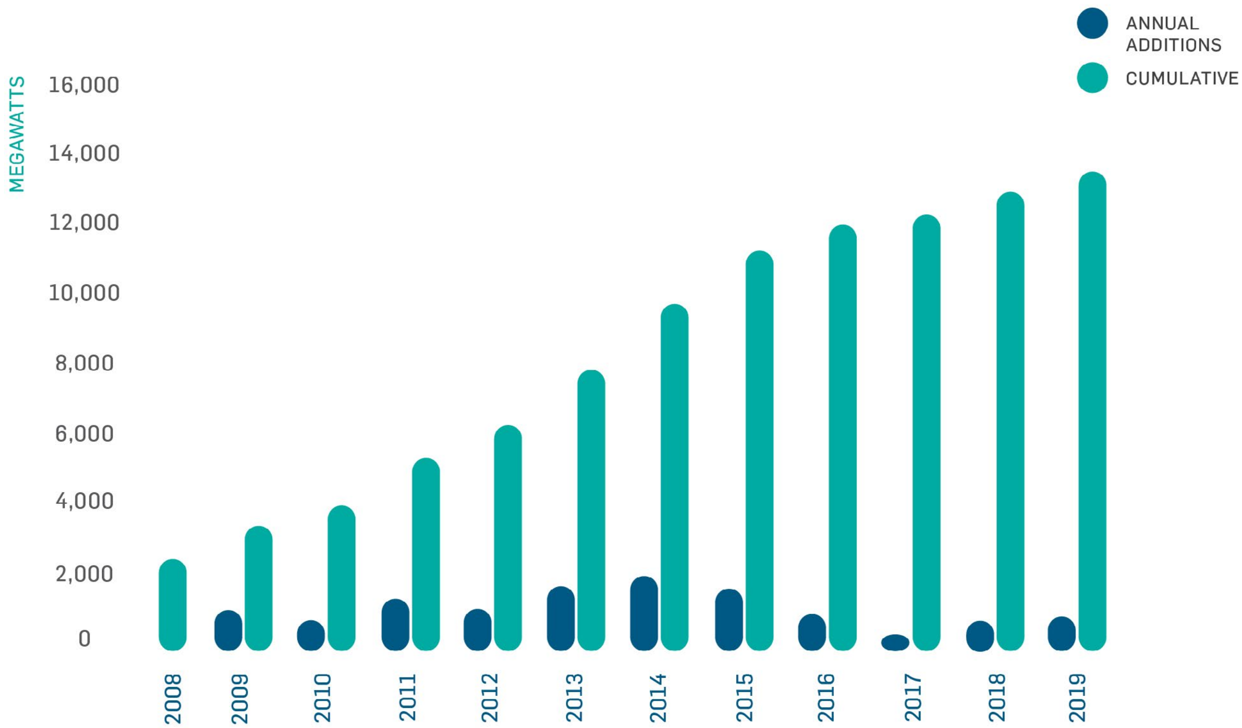


FIGURE 14 WIND CAPACITIES ADDED TO THE GRID 2008-2019 [REF. 40]

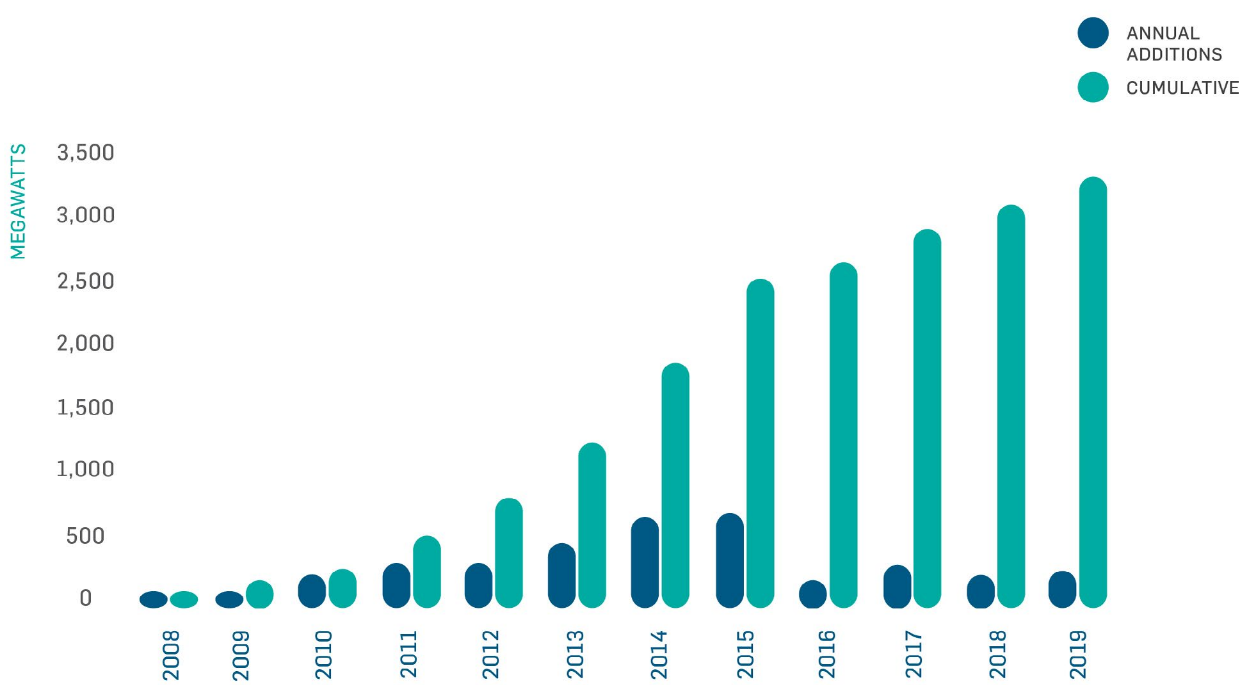
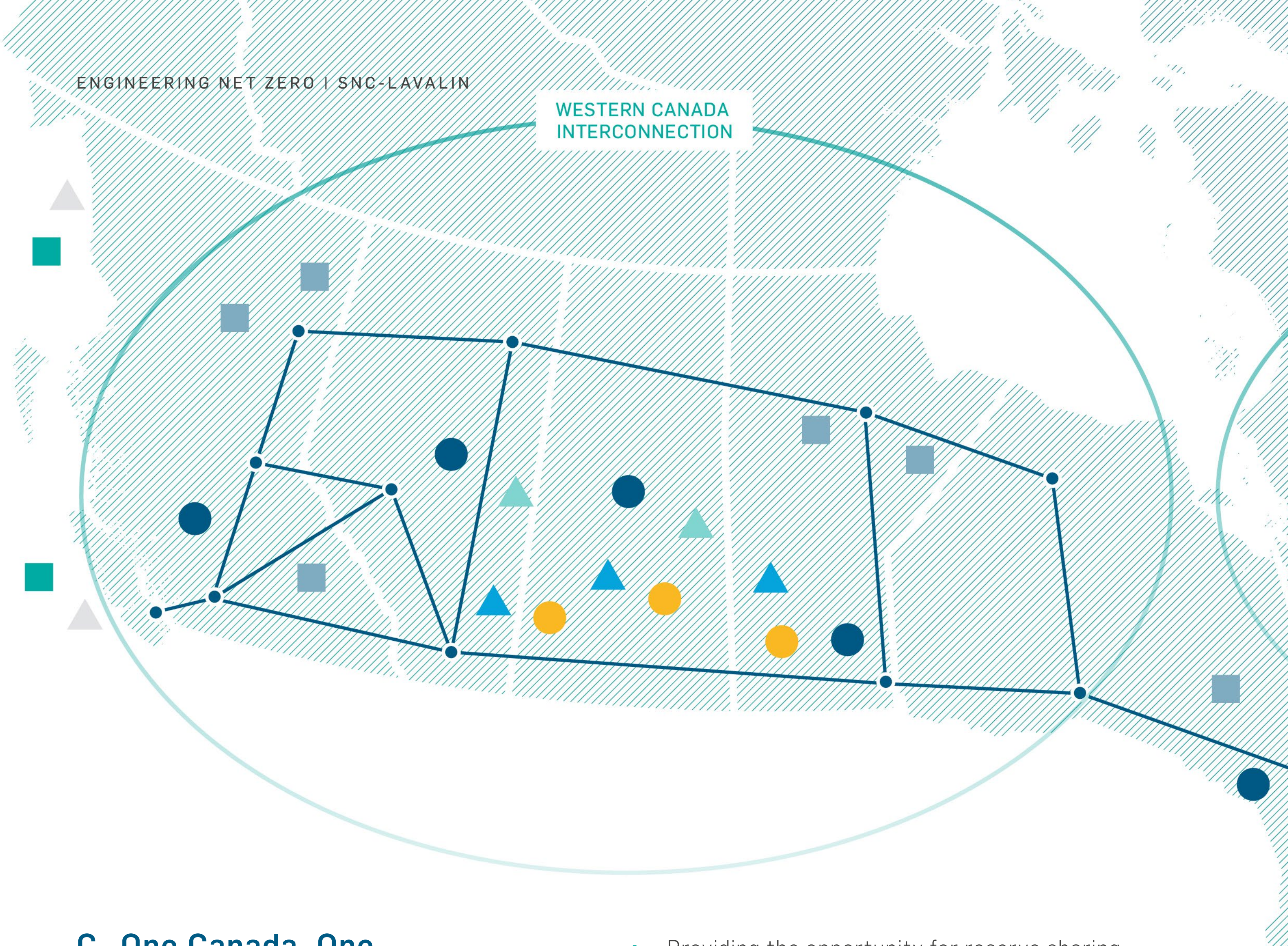


FIGURE 15 SOLAR CAPACITIES ADDED TO THE GRID 2008-2019 [REF. 40]



C. One Canada, One Transmission Network

Renewing and expanding transmission and distribution infrastructure to accommodate more renewable energy generation is essential to meet the net zero carbon target for the electricity sector. Additional effort is needed to implement the East-West nationwide transmission network. Completing this integrated transmission network could yield the following benefits [Ref. 50]:

- Helping provinces achieve net zero carbon emissions by providing access to clean power when otherwise not possible;
- Supporting higher integration of renewable energy resources;
- Exchanging economic benefits between energy-exporting and energy-importing provinces;
- Providing the opportunity for reserve sharing and for importing energy during peak hours, which reduces the need to build additional generation; and,
- Avoiding power spillage and renewable energy curtailment.

The East-West Canadian network (Figure 16) would entail three main components: the Atlantic Loop, the Western Interconnections, and additional interconnections to the US.

THE ATLANTIC LOOP

The Atlantic Loop was presented in this year's (2020) throne speech as an enabler that would support Atlantic Canada to phase-out coal power generation. Upon completion, this loop could provide non-emitting electricity to the Atlantic region generated from the Point Lepreau nuclear power station, and from Quebec's and Labrador's hydropower.

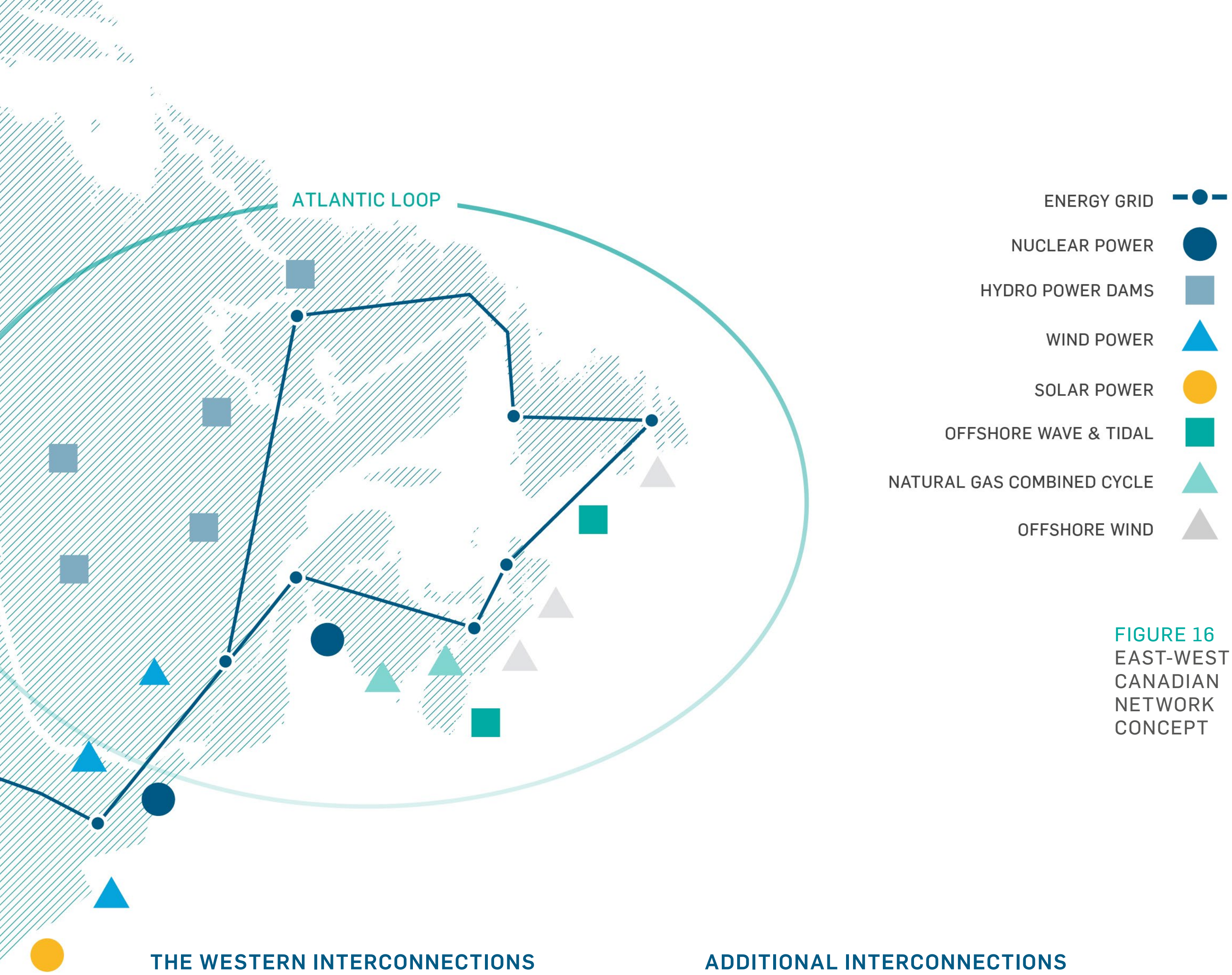


FIGURE 16
EAST-WEST CANADIAN NETWORK CONCEPT

THE WESTERN INTERCONNECTIONS

A similar concept could help Alberta and Saskatchewan substitute coal generation via clean hydropower imports from British Columbia and Manitoba. The following options were evaluated in greater detail in the Western RECSI study [Ref. 62]:

- Two options for a new intertie between B.C. and Alberta: the Northern and Southern interties;
- Three options to interconnect Manitoba and Saskatchewan: one 500kV line and two 230kV lines; and,
- A new HVDC link between Alberta and Saskatchewan.

The study concluded that the interprovincial transmission projects examined could offer GHG emission reductions in the range of 0.5 Mt to 1.2 Mt CO_2 eq per year.

ADDITIONAL INTERCONNECTIONS TO THE US FROM NB, QC, AND ON

Additional interconnections between New Brunswick, Quebec, and Ontario to the US could provide additional support for renewable energy integration and energy trading with the US.

The following interconnectors have been proposed:

- A second 345kV interconnection between New Brunswick and New England [Ref. 63];
- HVDC connectors between Quebec and New England/New York - several projects are being proposed and are presently at different development stages; and,
- An HVDC connector between Ontario and the US - the proposed Lake Erie Connector consists of a 117km 1000 MW submarine link between Ontario and Pennsylvania [Ref. 64].

Figure 16 shows a simplifed map of a conceptual East-West Pan Canadian transmission network.

D. Development Challenges

New large-scale clean generation projects along with their associated transmission infrastructure are facing many planning and development challenges that would require the federal and provincial government collaboration with all stakeholders to facilitate project advancement.

Table 5 presents key planning and development challenges and recommendations in addressing them.

CHALLENGE	DESCRIPTION	RECOMMENDATION
	PLANNING CHALLENGES	
Integrated Resource Planning and demand projection updates taking too long – 3-5 years in most jurisdictions	Current electricity projections do not show a demand for significant additional capacity to be added to Canada's power grid. All projections need to be updated to be consistent with a 2050 net zero carbon system along with the associated electrification requirements to achieve this goal.	A shorter development cycle for integrated resource planning is needed to ensure the electricity sector is catching up with electrification in other economic sectors which can ramp up quickly. Plans to develop clean capacity should be ready and in place.
Each sector approaches planning independently	Net zero planning is highly interdependent and will involve the electrification of many sectors, high use of carbon capture and sequestration (CCS) technology, and consolidated planning for significant additional electricity generation and significant new transmission & distribution assets.	In coordination with provinces, territories, and industry, create a highly detailed Canada net zero carbon blueprint. Establish a federal-provincial committee empowered to strengthen regional and interprovincial electricity cooperation that ensure that proposed projects are in alignment with the overall blueprint and continuously updates the blueprint to incorporate new technologies and breakthroughs.

CHALLENGE	DESCRIPTION	RECOMMENDATION
Market factors cannot drive continued GHG emissions reduction	The combined cost to establish transmission/distribution, build new clean electricity generation, replace fossil-fueled vehicles with electric vehicles, and establish new infrastructure including charging stations, amongst other initiatives, is very high. It is unlikely that natural economic drivers will push the market to adopt these changes at the pace required to achieve net zero carbon emissions by 2050.	Government to set the regulations and provide incentives to move toward high electrification and hydrogen adoption in the transportation and building sectors.
Seams Issues	Seams issues appear due to non-harmonized system operator market rules. This difference creates complexity when interpreting the agreement or engineering designs between importing and exporting provinces.	The federal-provincial planning committee should be tasked to harmonize the market rules between importing and exporting provinces. The committee should support a fair assessment of the power interconnection benefits and regulate how the power interconnections would be built and operated.
DEVELOPMENT CHALLENGES		
Regulatory and Environmental Approvals	The social and environmental challenges have a great impact on project viability. An intertie project can take more than 10 years to build due to the difficulty of obtaining environmental approval. Issues encountered during the environmental process include land ownership issues, siting, and consulting with indigenous people.	Introduce changes in the permitting process that can support streamline the development process. Early engagement with stakeholders and an effective public consultation process can help mitigate opposition to a new transmission.

CHALLENGE	DESCRIPTION	RECOMMENDATION
Public Support	All large infrastructure projects face delays and challenges of viability due to public consultation and consideration. For many large projects, these have resulted in significant costs, delays, and in many cases, cancellations.	Launch a series of public engagement campaigns about the urgency of net zero goals and each infrastructure project's contribution to getting to that goal.
Large Projects require large capital investment and high-risk profiles	With the move toward higher levels of privatization, utilities and private enterprises are less likely to undertake infrastructure projects that require large upfront capital, entail higher risks in terms of costs and schedule accuracy, and have long timelines for return on investment. As such, large hydro and nuclear projects similar to the ones that make up the backbone of Canada's baseload power have become rare undertakings over the last 30 years.	A national clean energy fund supported by the Federal Government and administrated by the Canada Infrastructure Bank, as an example, can boost public trust and encourage provinces to participate in creating the unified grid.

TABLE 5 PROJECT DEVELOPMENT CHALLENGES

E. What's in Store for the Long Term?

The following will be required on a pathway to net zero carbon emissions by 2050, on the electricity supply front:

E1. ELECTRIFICATION ACROSS-THE-BOARD

Coordination to enable cross-sector solutions for full electrification of the transportation sector, the buildings sector, agriculture sector, and other economic sectors will help Canada meet the net zero carbon target and balance eroded utility revenues associated with demand-side management, energy conservation, distributed generation, and net metering.

E2. SUPPORT ACCELERATED DEVELOPMENT OF NEW CLEAN POWER PROJECTS

As referenced earlier, achieving net zero carbon emissions by 2050 requires tripling Canada's energy generation capacity over the next 30 years. This is in addition to the replacement capacity required for existing coal and gas plants and nuclear facilities that are at end-of life. The challenge of building this volume of generation capacity at this rate is unprecedented in Canada's history.

E3. PAN-CANADIAN TRANSMISSION NETWORK

Easing the regulatory barriers and building an Integrated Transmission Network, which would include the Atlantic Loop, Western Interconnectors, and more interconnections to the US. Additionally, local provincial grids will need to be strengthened to enable greater renewable energy generation integration.

E4. SMART GRID AND IOT TECHNOLOGIES TO BETTER MANAGE DISTRIBUTION ASSETS

Increasing the use of Smart grid and IoT technology will enable increased integration of the renewable energy resources and energy management and conservation at the distribution level. These technologies will also support the distribution assets by addressing issues such as electrification of transportation, intermittent generation, aging infrastructure while maintaining and improving grid reliability and quality of the supply.

E5. GRID-SCALE ENERGY STORAGE

Incentives are needed to develop grid-scale energy storage solutions that would provide needed flexibility to integrate more intermittent renewable generation, including pumped storage hydro. This could be achieved through a combination of new sites conducive to pumped storage hydro development and identification of existing hydro schemes where an upper, or a lower, storage could be added in a socio-environmental and economically responsible manner.

E6. HYDROGEN-POWERED COMBINED-CYCLE POWER PLANTS

Providing incentives for combined-cycle natural gas power plants to have gas turbines retrofitted for some percentage of hydrogen combustion, with the ability to increase the percentage of hydrogen combustion over time as the equipment manufacturers continue to improve the process. This can maintain the plant infrastructure while shifting to lower GHG emissions.

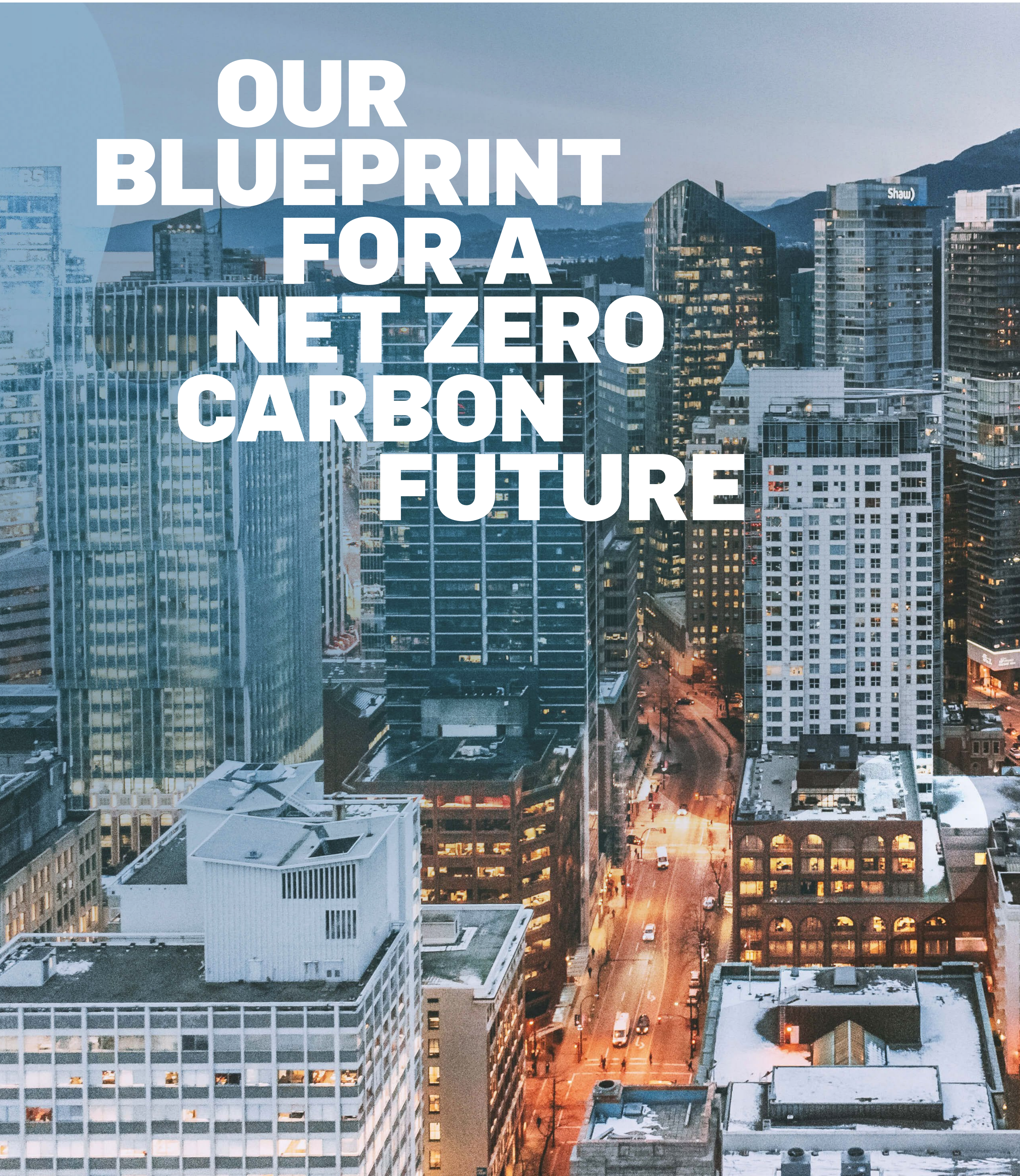
E7. RENEWABLE DISTRIBUTED GENERATION AND MICROGRID DEVELOPMENTS

Cost reduction of the renewable distributed generation and energy storage will support the effort of remote communities and resource extraction sites to phase-out diesel generation and develop microgrids that support attaining sustainable and reliable non-emitting power generation.

E8. RESEARCH AND DEVELOPMENT FOR CLEAN GENERATION

Support the research and development of power generation, transmission and distribution technologies that support achieving the net zero target including green hydrogen, CCS, SMRs, offshore wind, geothermal, wave, and tidal power.

OUR BLUEPRINT FOR A NET ZERO CARBON FUTURE



4. Transition Toward a Net Zero Carbon Economy

A. Moving Toward a 2050 Net Zero System

The 2050 net zero carbon framework is currently under development by the Government of Canada and will need to put forward a portrait of the 2050 net zero carbon economy. In that context, we believe the following catalysts to be critical for the success of this initiative.

Our recommendations are informed through a review of the Government's plans and reports relating to decarbonization, consultation with subject matter experts in technical fields of interest, as well as a thorough consideration of initiatives currently underway globally, adapted to a Canadian context.

TRANSITION TOWARD 100% NET ZERO-EMITTING ELECTRICITY GENERATION: Canada benefits from access to a vast amount of low and zero carbon energy generation, and this should be the backbone of our net zero carbon economy. This starts with hydro, nuclear, and hydrogen-fueled thermal power options, which are necessary to maintain a stable electrical grid. These technologies provide the necessary capacity to enable further integration of renewable energy technologies, such as wind, solar, wave and tidal. Other than hydro electricity, which is location bound, nuclear offers the only zero-GHG emitting base-load power generation with assured security of supply and is an essential component for a stable energy system. If natural gas remains present in the 2050 mix, it will have to be accompanied by carbon capture. Energy storage may also play an important role in specific scenarios to optimize power grid planning.

ELECTRIFICATION OF ALL SECTORS - TIMING IS CRITICAL: with a net zero carbon electric grid in place, significant GHG gains can be achieved through electrification of the various consumer-driven sectors where the technologies have already been proven to work. From electrical vehicles (EV) to low carbon energy efficient buildings, a major shift toward fully electrified sectors is required. The timing of these initiatives is critical, as we must ensure that consumer behaviour aligns with the supply of zero carbon electricity available. Within that context, the availability of "ready to deploy" generation projects, such as SMRs, is crucial for that shift to happen.

COUNTRY-WIDE PLANNING AND INTERPROVINCIAL COLLABORATION: Canadians are committed to a low carbon and sustainable future, and we see these shifts taking place from coast to coast. However, in order to maximize the returns on investments related to new generation, these initiatives must be coordinated. A centralized planning entity for the development of an interconnected Canadian electricity grid needs to provide a platform for consultations, collaboration, and data sharing amongst the provincial entities. Inter-provincial agreements for major electricity interconnections, standardization of electric vehicles and smart building infrastructure, as well as big data sharing, are key enablers of a net zero carbon economy. This entity would also need to consider providing an integrated approach to system planning that looks at optimizing resource and energy use across Canada.

BUSINESS COMMUNITY AND INDUSTRY ENGAGEMENT: the net zero carbon revolution cannot take place without the active participation of the business community. Detailed commercial frameworks need to be put in place to support the market transformation in all sectors, streamline GHG-reduction projects, and accelerate development of viable supply chains. Policy makers are encouraged to sit down with businesses to understand the hurdles encountered in deploying disruptive and innovative technologies. Detailed step-by-step plans providing foresight and commitments in each sector are then necessary for the transition to take place. First movers will be taking very large business risks in venturing into technical territories with limited expertise, inexistent supply chains, and much uncertainty; in that regard, the frameworks must provide the stability needed to sustain investment and ensure a return on investment for all stakeholders, both monetarily and in terms of scientific advancement.

UNWAVERING COMMITMENT TO INNOVATION – AND FAST: a net zero carbon economy means technologies that are in their early stages today are fully deployed, operational and profitable by 2050, without the need for continued subsidies. Some of these would include for instance enhancements in carbon capture technology, fast deployment of energy management systems, smart algorithms for optimization of power routing and usage, etc.

As of today, significant technological breakthroughs are still necessary in order to achieve the 2050 vision laid out in most plans. With most energy and heavy industrial facilities having lifecycles of several decades, there is an urgent need to start deploying pilot and demonstration projects across all sectors. It will be critical to support these new technologies during the transitions, as the business case may not be there today, but will certainly be there in the decades to come. Such innovative enterprises should also be resilient in the face of fluctuating world economies, and a sense of stability and commitment needs to be instilled across Canada, to maximize the long-term benefits of a low carbon society and the continued engagement by the business community.

DEVELOPMENT OF STABLE HYDROGEN (OR OTHER ALTERNATIVE FUEL) MARKETS: an important piece of the puzzle in decarbonizing our economy lies in addressing industrial processes and activities which consume very large amounts of energy, often in remote locations. Alternative fuels have already been deployed to reduce emissions in sectors such as freight transportation, industrial processes, and alternative thermal generation. A vibrant and economically sustainable hydrogen market is a necessary pillar for these industries to shift toward net zero GHG emissions. This initiative also enables Canada to tap into its electrical power surplus to generate hydrogen from electrolysis, a 100% clean process.

INDIGENOUS COMMUNITIES LEADERSHIP AND EQUITABLE TRANSITION: the transition away from fossil fuels and toward a net zero economy starts and ends with the people that make up our diverse communities. Any solution must ensure an equitable and fair outcome. Policymakers and industry leaders will need to work with communities across Canada, and to empower local communities in driving this change through consultations, economic development, as well as workforce training and job creation in new fields of expertise. Local leadership is key to arriving at the best economically sustainable low and zero carbon solutions and achieving a secure future that preserves our environment. The pathway to decarbonize remote communities across Canada's vast landscape, through transition toward zero-emitting fuels and renewable electricity is an important piece of the puzzle that is reflective of Canada's unique challenges toward meeting the net zero emissions targets.

SOCIAL CHANGE: the challenge ahead will require us to rethink our actions every step of the way. Whether in terms of our consumption patterns, the way we build and operate facilities, or the way we measure our successes, everything will be called into question. Consumers will have a major impact on the net zero transition, by reducing wasteful resource consumption patterns of behaviour, as well as through embracing new technologies such as EVs, smart and resource efficient buildings, and low and zero carbon energy technologies. In a time where unchecked information flows freely across all media, it is crucial to empower Canadians to make the right choices, independently. Public education and empowerment are yet another critical pillar required to stay the course.

B. What would a 2050 Net Zero System Look Like?

The 2050 net zero carbon emissions system is envisioned to be powered by clean electricity, a robust hydrogen economy, and supported by carbon capture and sequestration (CCS). Enablers for such an environmentally friendly ecosystem must include a strong power transmission and distribution network and significant energy storage in all forms (electric, hydrogen, thermal, etc.). Demand side management (DSM) and resources conservation would be enabled via the use of the internet of things (IoT) and the optimized use of our resources.

This section provides an overview of what a 2050 net zero carbon system could look like, which provides a sense of the monumental number of projects, investments, policies, and social transformations needed to achieve this vision.

To illustrate the sheer magnitude of the need for additional clean energy, the following figures don't even account for the retirement of existing generation by 2050. On top of the new facilities discussed below, one must add the upkeep and renewal of existing net zero assets as well as the replacement of existing GHG-emitting generation.

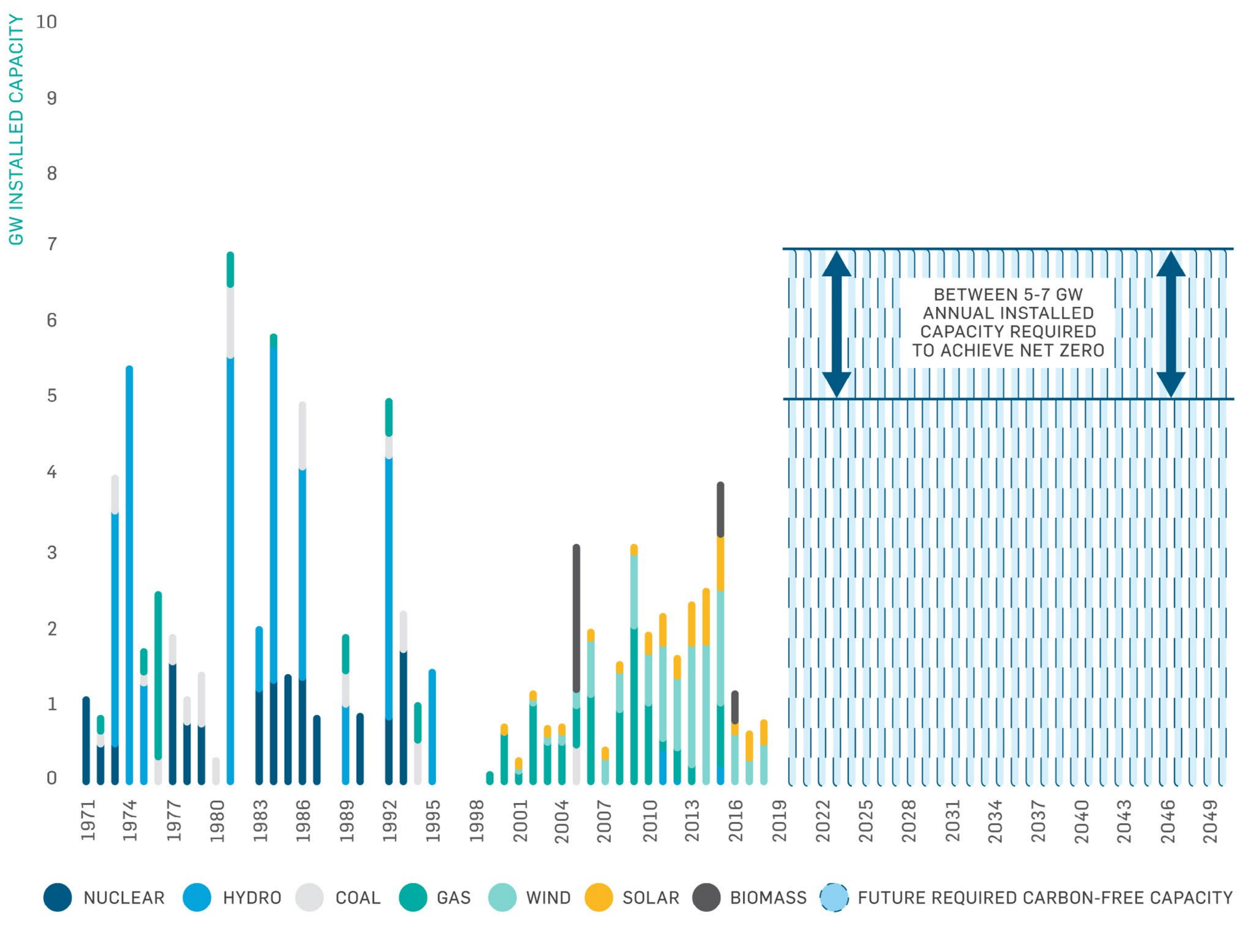


FIGURE 17 GENERATION CAPACITY BUILDING: HISTORIC VS. FUTURE NEEDS

B1. ELECTRIFICATION

As described throughout this document, electrification of transportation, buildings and heavy industrial processes would provide significant reduction of the GHG emissions. Several net zero carbon emissions studies conclude that Canada's electricity annual demand would see significant increase from 500 TWh to somewhere between 1250 and 2000 TWh by 2050 [Ref. 7, Ref. 8, Ref. 42], with most scenarios estimating a total electricity demand of around 1500 TWh. The energy demand of 1500 TWh is the estimate associated with the Deep Decarbonization Pathways Project - High ambition (DDPP) which assumes emission reduction of 88% from 2015 recorded levels by 2050. The DDPP assumes our electricity sector's share of the total Canadian energy demand would jump from 20% to about 43% by 2050.

The energy generation requirements linked to a 2050 net zero carbon system requiring 1500 TWh of electrical energy consumption correspond to a potential installed power generation capacity of around 300-350 GW, a significant increase from roughly 150 GW installed today. All new electricity production would need to be carbon-free or supported by CCS technology.

Even if only the electricity generation component of the future system is considered, the deployment rate of new capacity will be unprecedented in Canadian history. The average capacity of electricity addition over the last 50 years in Canada was approximately 2 GW annually. Moreover, the largest previous annual gigawatt addition to Canada's generation capacity was approximately 7 GW, a project dating back 40 years.

In order to meet the ambitious generation capacity target of 300-350 GW by 2050, Canada would need to add significant new generation capacity over the next 30 years. Depending on the amount of renewable energy included in the scenario, the overall average annual capacity additions need to be between 5 and 7 GW annually for the next 30 years; roughly 3 times the average annual amount added over the last 50 years (Figure 17).

It should be noted that wind and solar energy have lower capacity factors due to intermittent power production, so a larger proportion of renewables requires that total installed capacity be higher to achieve overall output. Nuclear and hydro power have higher capacity factors so a larger proportion of nuclear and hydro allows for total installed capacity to be lower.

The following illustrates the magnitude of the challenges ahead. Using today's typical capacity factors, if one were to meet this challenge using only one power generation type, and without accounting for the replacement of existing generation, additional capacities required to add 1000 TWh would translate into:

- 115 x 1100 MW-sized large hydro reservoirs similar in capacity to BC Hydro's Site C project;
- 114 x 1000 MW-sized large nuclear reactors (i.e. 19 sites the size of Bruce Power in Ontario);
- 380 x 300 MW small modular reactors;
- 20,000 x 10 MW-sized wind turbines;
- 200 wind farms with 100 turbines for an aggregated capacity of 1000 MW per site; or,
- More than 400 GW of aggregate solar capacities.

The above is a monumental task, and one which Canada has not undertaken in a while. Looking back to the 70s, 80s and even the 90s, Canada did come close to this volume of infrastructure building. As such, with innovations in construction techniques, modular designs, and overall efficiencies, Canada could tackle this challenge, assuming sufficient economic and political drivers, enabling factors, cohesive planning at the national system level and most importantly, the will to do so.

B2. POWER GENERATION

Without any doubt, very large capacities of new clean electrical generation will be required to enable the electrification of economic sectors, and to achieve net zero carbon by 2050. In order to do so, Canada will need to triple its power production levels over the next 30 years. This will require the development of all the available zero carbon generation technologies simultaneously including offshore wind in the Atlantic and Pacific oceans, hydro plants in remote locations, and large nuclear facilities across Canada. The below discussion is based on several studies [Ref. 7, Ref. 8, Ref. 10, Ref. 42] that suggest different generation mixes to achieve varying degrees of decarbonization. The purpose is to provide an indication of the order of magnitude of the transformation required in our journey to achieve net zero carbon emissions through increased electrification.

HYDRO

Most of the scenarios studied in literature recommend a large increase in hydro installed capacity to support the forecasted electrification demand and to balance the intermittent nature of other renewable resources such as wind, solar, wave and tidal. The increase in hydro energy production could in-part be attained by increasing the efficiency of the turbines from existing hydro sites. Today, about 60% of electricity production in Canada consists of hydro power with 80 GW of installed capacity. Literature suggests that new hydro resources will account for about half of the additional energy required, or about 500 TWh of additional generation. Acknowledging that the development of hydro projects and the associated transmission would take at least 10 years in development, then the country would require the development on average of approximately 3.5 GW per year of hydro power for the 2030-2050 period.

NUCLEAR

As of 2017, nuclear was the second largest source of clean power generation with 13.5 GW installed capacity supplying about 15% of Canada's electric energy using 19 commercial reactors mostly in Ontario. Canada became a significant player in the global nuclear industry through federal investment that started in the 1950s to develop Canadian commercial nuclear technology. This ultimately resulted in the development and deployment of CANDU® reactors, a unique reactor type that allows for production of electricity by burning natural unenriched uranium, a natural resource abundant in Saskatchewan. However, despite continuing to be a significant global player in the commercial nuclear industry with over 200 Canadian nuclear companies with capability in design, heavy equipment manufacturing and construction, new reactors have not been built in Canada since the early 1990s.

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Contrary to the recent Canadian Energy Regulator Forecast for 2050 [Ref. 10], a number of other official and academic sources [Ref. 7, Ref. 8, Ref. 42] all envision a significantly larger proportion of new nuclear electricity production. Canada has both existing technology that can be deployed in the near term, and innovative next-generation technology that is currently being developed for future use. However, with current licensing, permitting and deployment timelines, it can take 8-10 years before power is being produced, once a site is selected. It will be important to consider these timelines in the net zero system plans, and to ensure that enough concurrent projects are planned in parallel to meet the enormous projected 2050 demand.

In our opinion, in order to meet the additional net zero electricity capacity required for projected demand in 2050, initiation of the licensing process for siting 1000 MW class reactors could begin immediately. Under this timeline, it is reasonable to project that the first 1000 MW class reactor could be in-service and producing power by 2030. Following a moderate new build scenario, it is projected that a 1000 MW class reactor could be brought into service every year until 2050. Then, once the SMR designs are complete, three 300MW SMR units could be added to the grid each year, starting around 2035 and continuing in parallel with the 1000 MW class reactors. This moderate new build scenario would result in an overall additional 35 GW of nuclear electricity in Canada by 2050. Under an accelerated nuclear new build scenario, it is possible that electricity production by 2050 could be as much as 55 GW. While aggressive, this accelerated new build scenario is less than the nuclear new build rates that both China and India are achieving today. To realize these projections, expanded capacity within Canada's nuclear regulatory and supply chain organizations is required in the near term to support all activities associated with nuclear new build programs. Because of nuclear power's high capacity factors, this 35GW - 55GW range translates to between 275 TWh - 440 TWh of new nuclear electricity by 2050.

WIND

Today, wind energy is one of the fastest growing technologies in Canada and worldwide. Canada has installed an average of 1 GW per year of wind over the last decade. These capacities were achieved without yet tapping into the offshore wind energy potential available in the East and West coast. With decreasing costs and an increased build rate (consistent with Ref. 10), Canada could install an additional 90 GW of wind by 2050. Due to wind's capacity factor, this would translate into approximately 300 TWh of electricity. However, the current provincial grids are congested, and there isn't enough capacity on the transmission networks to move offshore wind energy to load centers. The development of a strong pan-Canadian transmission grid along with provincial transmission upgrades would thus play an important role in enabling higher levels of wind development.

SOLAR

Although solar generation currently represents a small portion of installed generation capacity, a rapid increase in solar installation is expected to be fueled by the decarbonization of buildings, heavy industries, and transportation sectors. Compared with other technologies, solar energy is modular and does not require strong transmission or distribution grids as it can be installed safely near the end load. With solar panel prices trending downwards and with efficiency trending upwards, the solar energy share has the potential to grow. On the other hand, solar technology has a low capacity factor. The power produced by solar generation is also typically much smaller than hydro or nuclear, meaning the energy delivered through solar generation will remain small in the 2050 picture. Consistently with literature, we assume that solar will grow to serve about 60 TWh of energy by 2050.

NATURAL GAS

The use of combined-cycle and simple gas turbines will continue to play an important role in the Canadian power generation mix in the short to medium term, given their fast deployment potential compared to other power generation technologies, as well as the critical role of natural gas-fired power plants in stabilizing the grid and responding to fast changes in demand. It is also anticipated that gas turbines will also replace all remaining coal generation. These aspects are reflected in Alberta, Saskatchewan, New Brunswick, and Nova Scotia's integrated resource plans. To reduce and eventually eliminate GHG emissions, the combined-cycle power plants will need to be built or retrofitted with carbon capture and sequestration (CCS) technology, or fueled using clean hydrogen, or a clean fuel mix.

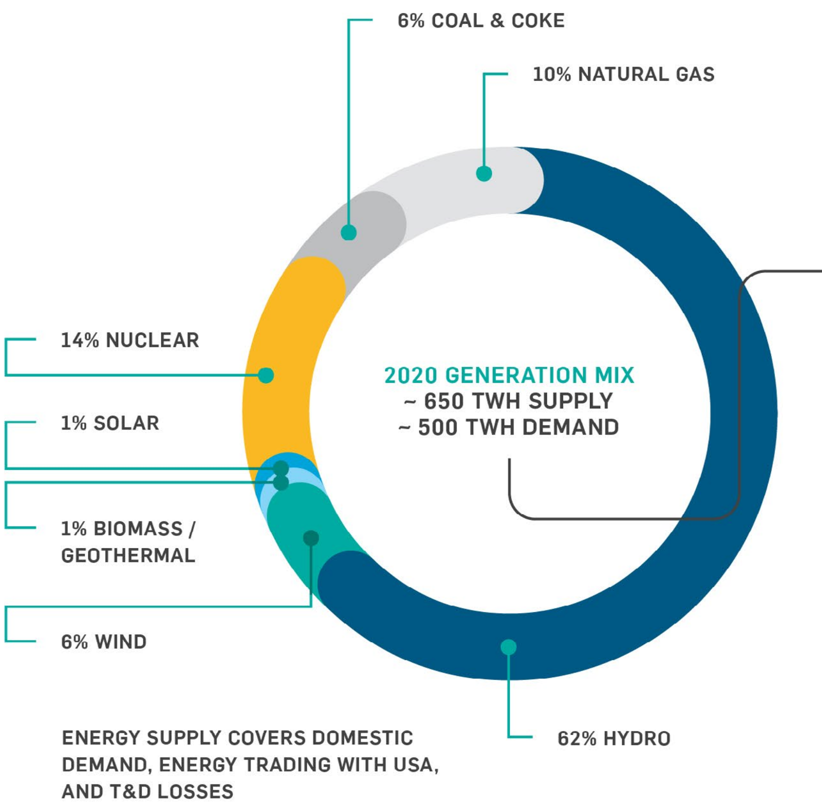
BIO-ENERGY, WAVE, AND TIDAL

Innovative generation technologies including those running on bio-energy, tidal, and wave power are expected to see a rapid development cycle and are expected to contribute to the generation mix when the technologies mature. We do not however expect these technologies to compete with hydro or nuclear for the purposes of the 2050 objective.

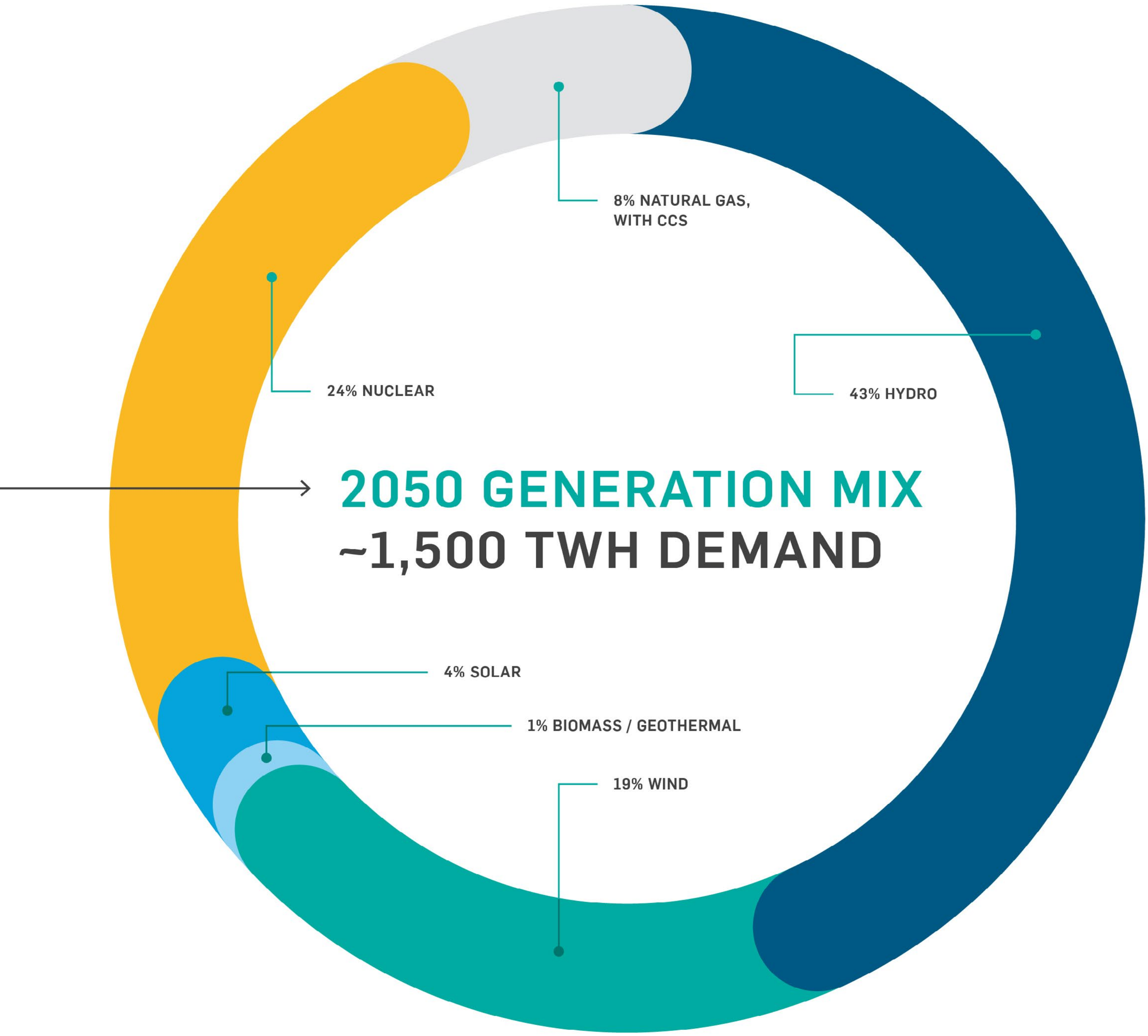
A POSSIBLE SCENARIO FOR A 2050 GENERATION MIX

In Figure 18 below, the authors propose one possible order of magnitude scenario for the 2050 generation mix, partly based on data from Ref. 7, Ref. 8, Ref. 10 and Ref. 42. We have adjusted the data according to the trends described in this section for each generation type, and scaled to meet a predicted 1,500 TWh demand, corresponding to our own "net zero" scenario.

FIGURE 18 INDICATIVE 2050 VS. 2020 GENERATION BY SOURCE



Canada will need to triple its power production levels over the next 30 years.


8% NATURAL GAS,
WITH CCS
24% NUCLEAR
43% HYDRO
2050 GENERATION MIX
~1,500 TWH DEMAND
4% SOLAR
1% BIOMASS / GEOTHERMAL
19% WIND

The generation mix proposed in Figure 18 makes the following assumptions:

- Coal & coke as well as oil-based electricity generation become negligible or disappear by 2050, consistently with available literature[1];
- Natural gas generation grows consistently with the Canadian Regulatory Agency's report (Ref. 10), accompanied by the corresponding carbon capture and sequestration of the GHGs produced. This includes natural gas being used to produce blue hydrogen;
- Canada's nuclear sector grows according to the mid-range described above, to account for approximately 360 TWh of the total, including any retirements that might occur in the meantime.
- Wind and solar grow significantly, in accordance with all available literature, accompanied by corresponding amounts of energy storage and production of green hydrogen. The wind portion may include offshore wind as well.
- Finally, the largest growth comes from the hydroelectric sector, by developing a part of Canada's natural resources.

C. Power Transmission

The current power transmission networks simply do not support this level of generation resource integration. In fact, numerous renewable generation developments in Canada are facing difficulty moving forward due to transmission constraints.

As such, the need for a stronger transmission and distribution power grid that can support mass electrification cannot be overstated. Smart, resilient, and interconnected grids with storage capacity are critical in enabling the higher use of intermittent renewable power, and in closing the gap between average demand levels and surge capacity.

For example, it is possible to tap into significant capacity from offshore wind in the Atlantic, however, the existing power transmission lines out of PEI or NS are limited to 200 MW and 350 MW respectively. On the Pacific side, the intertie capacity between BC and AB is limited to 1,000 MW. Hydro energy developments are facing similar transmission constraints, as most potential sites are located in the Northern part of Canada with no access to a strong transmission grid to transit the power to the load centers.

Cohesive and comprehensive integrated resource planning that tracks the increase in electrification demand and encompasses generation planning with transmission planning across the full Canadian landscape is vital to the 2050 net zero carbon project success. As discussed, transmission projects, especially those that cross jurisdictions, provincial boundaries, and extend into the United States and across multiple states, require significant planning, permitting, environmental assessment, and public consultation, before getting to the engineering and construction phase. These processes can easily add-up to a decade in overall project development.

The development of higher capacity networks will be essential considering the large transmission capacities required to meet the net zero carbon targets and given the limited availability of power transmission corridors. Corridor capacity could be increased with the deployment of 1,000 kV extra high-voltage (EHV) transmission lines, multi-terminal HVDC transmission, or overlaid HVDC networks. These new technological solutions could work in conjunction with the existing AC power grid, all-the-while increasing the capacity of existing corridors to carry thousands of MWs across provinces.

1 OIL-BASED ELECTRICITY GENERATION IS NOT SHOWN IN 2020 AS IT REPRESENTS A SMALL PROPORTION OF THE GENERATION MIX.

C1. HYDROGEN

Canada is one of the lowest cost producers of both blue hydrogen with CSS and green hydrogen in the world. The cost of producing blue hydrogen from natural gas with CCS is estimated at $10/GJ(HHV) H_2, and at about $20/GJ(HHV) H_2 for green hydrogen generated using hydroelectricity. While the cost of generating blue hydrogen in Canada is low compared to green hydrogen, it is expected that green hydrogen will see a steep reduction in production cost due to advancements in technology and improvements of the process efficiency. Hydrogen prices appear to be generally competitive against the cost of wholesale diesel averaging at $20/GJ(HHV) [Ref. 65].

Blue hydrogen can be generated economically at oil and gas hubs in Alberta and Saskatchewan, while green hydrogen can be produced in provinces with access to low-cost hydro electricity such as Manitoba and Quebec.

A recent study [Ref. 30] shows that a pan-Canadian end-use hydrogen market could address about one-third of Canada's projected primary energy use. To reach this level, Canada's production capacity would have to increase eight-fold (8x) from 8 kt H_2/day to about 64 kt H_2/day. With all the foreseen end-use technology advancements by 2050, hydrogen could be used as fuel source for transportation, industrial processes, and heating in buildings. This higher hydrogen production capacity using natural gas and carbon capture utilization and storage (CCUS) technology would require CCS capacity in Canada of about 200 Mt CO_2/yr, equivalent to five-times (5x) the total existing worldwide CCS capacity available today.

C2. 2050 NET ZERO CARBON SYSTEM

Figure 19 provides a vision for Canada's 2050 net zero carbon system. Power generation would consist of zero GHG-emitting sources such as hydro, nuclear, wind, solar, wave and tidal energy. This would be complemented by natural-gas turbines combined with CCS, or using hydrogen, bio-energy and other non-emitting fuel technologies that may emerge. As discussed earlier, Canada would require the addition of 5-7 GW of capacity per year (on average) to meet the projected 1000 TWh/year demand resulting from the electrification of economic sectors, on a 2050 horizon.

On the end-use side, blue and green hydrogen are expected to replace fossil fuel in transportation especially for heavy trucking and industrial processes.

To ensure the balance between the power generation and demand, the 2050 net zero system will need to be supported by a strong pan-Canadian grid enabling the integration of the intermittent renewable generation. To maximize the efficient use of resources, the Canadian power system would rely on energy storage, energy conservation, demand response, and broad deployment of smart grids and Internet of things.

CCS would address the remaining balance of GHG emissions produced, while enabling the production of blue hydrogen at natural-gas power plants. CCS would serve to balance out the GHG emissions in specific areas where it would be very difficult or expensive to shift away from fossil fuels.

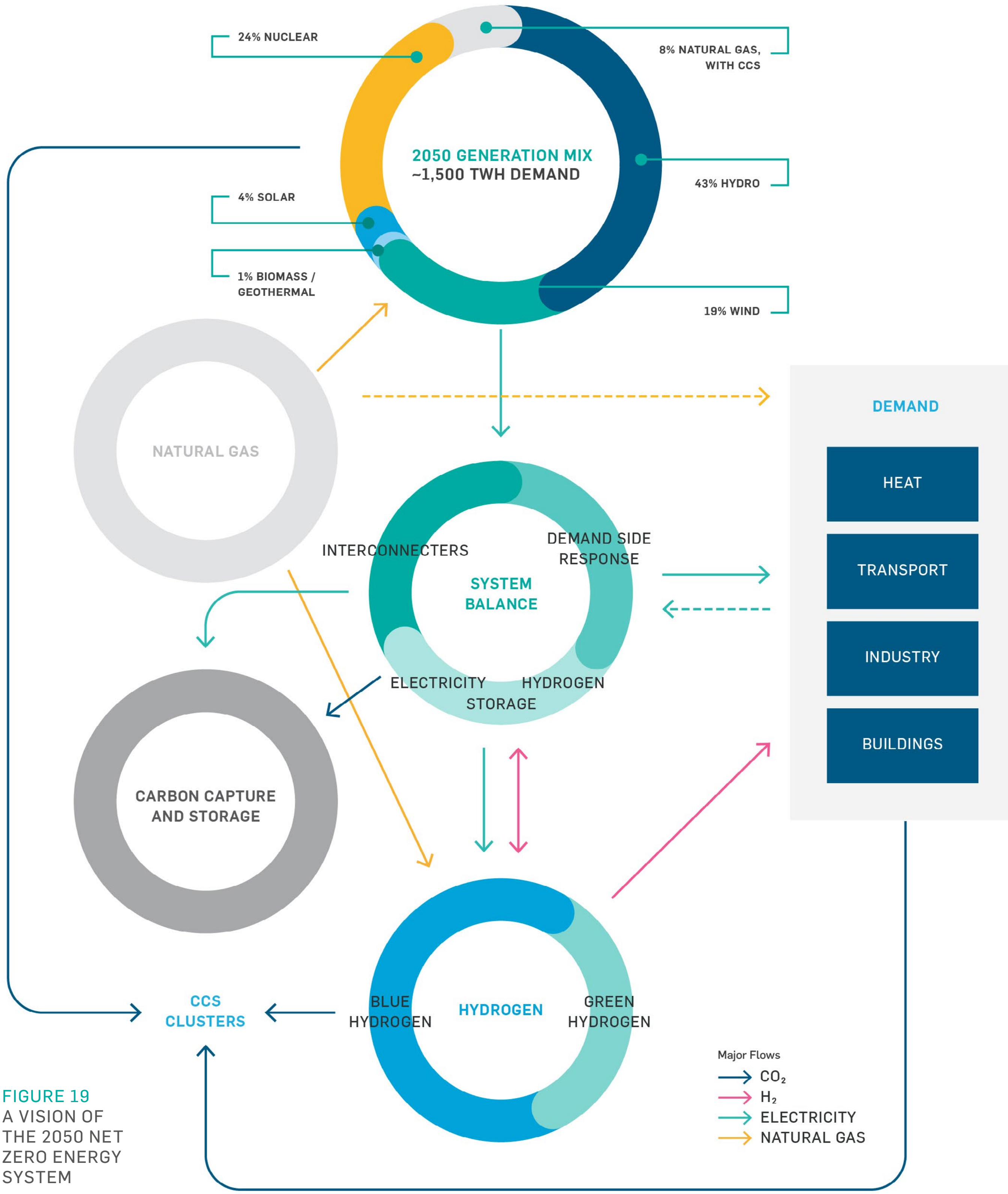


FIGURE 19
A VISION OF THE 2050 NET ZERO ENERGY SYSTEM

D. The Urgent Need for Immediate Infrastructure Projects

Given the very large number of projects needed to achieve the 2050 net zero carbon vision, a thirty-year timeline can be considered somewhat short in the world of infrastructure, where project development can take 5 to 10 years from concept to in-service date, and where facilities have 40+ year lifetimes. Additionally, no plan should be set in stone, and so the net zero carbon initiative will need to be built around no-regret resilient initiatives and investments, that make sense scientifically and economically under various scenarios.

The following list highlights some of the important considerations in streamlining and classifying infrastructure required for a cross-sector net zero carbon emissions system, which could be deployed immediately:

1. Projects will need to be assessed on many criteria, including key issues such as Canadian job creation per dollar spent, location requirements and benefits to local communities, long-term economic return, alignment with long-term energy strategy, minimising risk of stranded assets, and capacity to accelerate change (e.g., EV charging network in cities).
2. In terms of project deployment speed, and with consideration for "out-of-the-box" solutions, the following type of projects are likely to make the top of the list:
    - **a.** extensions or upgrades of existing projects;
    - **b.** projects already holding planning and regulatory approval;
    - **c.** duplications of former projects;
    - **d.** projects wholly financed by government, requiring no additional party to invest;
    - **e.** projects that do not depend on 'long lead' supplies or extended foreign supply chains, which may be disrupted for some time, in a COVID-19 context.
3. Projects focused on job creation and reviving communities will likely lean toward smaller 'lower tech' projects, located in areas of high unemployment, and requiring minimum overseas supply.
4. Projects providing long-term economic return. Assessment of stimulus projects will require an economic impact analysis properly valuing stimulus outcome, which would not be captured by a conventional project level assessment of ROI.
5. Projects that generally add resilience to our systems, whether in the face of cyber-attack, environmental catastrophe, economic uncertainty, or other known and unknown threats. In the electrical sector for example, this could correspond to power transmission and distribution upgrades, distributed generation assets, microgrids, and energy storage. Addressing the quantification and pricing of the benefits related to system resiliency is essential in this regard.
6. Projects that will bring forward accelerated changes in energy use, but which do not easily attract initial private investment, such as infrastructure supporting multiple yet unknown users. This may include EV charging networks, hydrogen production, hydrogen charging facilities and infrastructure, carbon capture transport infrastructure, as well as long distance transmission assets that can be shared amongst developers in a specific region, for example for Northern resource projects.

ACCELERATED SHOVEL READY INFRASTRUCTURE (ASRI)

ASRI [Ref. 66] is SNC-Lavalin's framework for assisting asset owners, government agencies, and government sponsors of infrastructure investment to identify and responsibly accelerate projects that will most significantly drive economic stimulus forward. ASRI offers an expedited process for shovel-ready projects that is scalable, flexible, and more collaborative. It engages multiple stakeholders and manages project life cycle elements in parallel. This allows projects to be more agile, engages the supply chain earlier, and prevents time and value leakage in the end-to-end construction process, while adhering to low carbon drivers and delivering social economic gain.

E. Recommendations for Immediate Action

Government plans are currently under development following the net zero 2050 announcement, which will include a set of medium and long-term milestones. The detailed plans will need to be adaptable to various socio-economic realities, consider many techno-economic scenarios, and remain resilient to changes over the years. Nevertheless, important actions can be undertaken immediately in order to unlock the technologies required for definite reductions in GHG emissions, under any potential scenario.

The electrification of all sectors along with the targeted use of alternative zero-emitting fuels is at the core of the transition toward net zero. A backbone infrastructure needs to be up and running to support the transition toward electric vehicles and railroads, building heating and services, and heavy industrial processes and agricultural processes. Furthermore, zero-emitting fuels will be required for operations requiring heavy energy intakes, such as freight transport, oil and gas mining trucks, and remote industrial processes.

To put things into perspective, total TWh production in Canada in 2017 was 652.3 TWh, out of which 9% was coal and 10% was gas, oil and others [Ref. 67]. An estimated 124 TWh (based on 2017 figures) of coal and gas generated electricity in Canada will need to be replaced with low or zero carbon emitting generation by 2050.

Additionally, significant electrical capacity (roughly estimated at around 1000 TWh), will be required to meet the cross-sector electrification and production of zero-emitting fuels. Using today's specific capacity factors, if one were to meet this challenge using only one power generation type, additional capacities required to add 1000 TWh would translate into:

- 115 x 1100 MW-sized large hydro reservoirs similar in capacity to BC Hydro's Site C project;
- 114 x 1000 MW-sized large nuclear reactors (i.e. 19 sites the size of Bruce Power);
- 380 x 300 MW small modular reactors;
- 20,000 x 10 MW-sized wind turbines;
- 200 wind farms with 100 turbines for an aggregated capacity of 1000 MW per site; or,
- More than 400 GW of aggregate solar capacities.

Under this assumption, the overall average annual capacity additions would need to be between 5 and 7 GW annually for the next 30 years; roughly three times the average annual amount added over the last 50 years. The above is a monumental task, and one which Canada has not undertaken in a while.

Within that context, the following are recommendations for immediate action:

Establish a federal-provincial committee for the Canadian electrical grid, to enable greater reliability, resiliency, and efficiency through inter-provincial ties. This could pave the way for an east-west interconnected grid, that would help balance operations, enable more renewable integration, and effecively support electrification of other economic sectors.

As such, **early build projects should be initiated for energy sources such as hydro and nuclear**, where a single plant easily takes more than 10 years to develop. Other renewable resources, such as wind and solar, should be developed quickly to meet load increases. Emerging renewable technologies have also shown significant promise, including offshore wind, tidal, and wave power generation.

Expedite and fund pilot carbon capture and storage projects as quickly as possible, which are the key to eliminating the balance of GHG emissions from energy intensive processes.

Accelerate current hydrogen (and other alternative fuels) research programs, with a minimum number of demonstration projects.

Consult industry in the development of the net zero 2050 plan, to ensure concrete, measurable and coordinated efforts are put in place, and to maximize the ROI for Canadians, both from a financial and environmental impact perspective.

Without immediate action and investment, net zero 2050 is not possible – maintaining our current approach means we will never reach net zero. Net zero carbon emissions can only be achieved through dramatic transformation of our entire energy system encompassing energy generation, heating, transportation, and industry. It requires changes in land management and usage, how we travel and even what we eat. It will test our financial resolve; however, the high cost of achieving net zero carbon emissions must be compared to the cost of doing nothing.

Global warming threatens our way of life, from rising sea levels leading to population displacement, to extreme weather events resulting in significant losses, to socioeconomic instability. Today, we have an opportunity to reverse this trend and to give future generations a fighting chance against what could already be considered an uneven burden.

WORKING TOGETHER TO PROTECT TOMORROW

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LEADING INDUSTRY BY EXAMPLE

Appendix 1 Overview of Emerging Technologies for Net Zero

We are seeing the emergence of disruptive technologies that hold the key to a net zero carbon economy. While theoretically feasible, these technologies are often misunderstood, and the supply chains and expertise required to deploy them in an effective and economically sound way are not in place. A technological solution is far from limited to the technology itself, but involves the complete economical ecosystem, from the expertise in planning and execution, to the supply chains in materials, to the operation and maintenance personnel. When considering the lifecycle of some of these technologies, it is evident that a massive number of well-defined projects need to be launched now and in coming years, in order to reach the ambitious 2050 net zero carbon targets.

A. Hydrogen

Hydrogen may serve as both an energy vector and an energy store. Hydrogen can contribute to industry decarbonization, domestic heating and transportation. A large portion of hydrogen would have to be produced by methane reformation (MR) which depends on CCS. Hydrogen may also be generated from electrolysis, which is a 100% clean process that would enable Canada to tap into its renewable electrical power surplus.

As an example, hydrogen has been produced using wind energy in Norway for the past 20 years, which could be a viable consideration for Canada. This type of hydrogen production has traditionally been used in remote and rural areas with high wind resources [Ref. 68, Ref. 69].

A1. WHAT ARE GREEN AND BLUE HYDROGEN?

Hydrogen has the potential to serve as a carbon-free energy carrier for industrial, commercial and domestic use, therefore paving the way for major decarbonization of the economy. Hydrogen's remarkable characteristic is the absence of greenhouse gases emissions at point of use in comparison to any other fuel, suggesting that hydrogen is an ideal fuel to alleviate air pollution, to arrest global warming and to protect the environment in an economically sustainable manner.

Green and blue hydrogen differ in their production method yet share a common pivotal role in the battle against climate change. As green hydrogen is a product of electrolysis of water and clean energy, with its abundant renewable energy sources, Canada is set to shift toward green hydrogen as a greenhouse gas-free alternative energy carrier to heat buildings, fuel vehicles and manufacture chemical compounds. Although blue hydrogen is produced from non-renewable sources of energy, carbon capture storage used in the process, prevents CO_2 from escaping into the atmosphere, which makes this method of hydrogen production non-polluting [Ref. 70, Ref. 71].

From storage, to distribution and utilization, to global exportation, the advantages of hydrogen as an energy carrier are numerous and will serve as motivation to the challenges yet to be overcome.

A2. WHAT IS THE ROLE OF HYDROGEN IN DECARBONIZATION?

Canada is currently one of the major global producers of hydrogen, with 3 Mt of hydrogen produced annually [Ref. 72]. Globally, hydrogen is used in three main industries: refineries, ammonia production and metal processing. However, hydrogen offers a variety of possibilities for its application, and may potentially replace existing, polluting technologies:

ENERGY CARRIER

Hydrogen is not an energy source, but rather a carrier, thus it may serve the same purpose as electricity [Ref. 72]. Generated hydrogen can be compressed and distributed over an extensive network of pipelines to residential customers, commercial buildings and industrial plants. This application of hydrogen shares similarities with the existing natural gas network, but has a major advantage in terms of environmental impact.

TRANSPORT

The transport industry is moving forward with the integration of hydrogen fuel cell vehicles which use hydrogen as fuel to power an electric motor, eliminating the need for gasoline and diesel. Such vehicles operate on electricity obtained through the combination of hydrogen and oxygen by the fuel cell within the vehicle. The only by-products of hydrogen fuel cells are water vapor and heat, which are not harmful to the environment [Ref. 73]. In comparison to conventional electric vehicles, hydrogen vehicles do not operate through electric charging, but rather require a tank to be filled with compressed hydrogen, which is faster and centralized, thus comparable to refueling a car running on gasoline [Ref. 74].

With conventional vehicles being out of the picture, and the development of hydrogen production technologies being an interesting investment to many industries, hydrogen vehicles may compete with EVs for their share of the market. Likewise, besides being a suitable option for personal cars, heavy-load trucks and trains, hydrogen fuel may have a future in aviation. The world's first hydrogen fuel cell powered flight of a commercial-grade aircraft took off on September 23rd, 2020 [Ref. 75].

GLOBAL EXPORT

Hydrogen may potentially give rise to international trade deals through global exportation. Hydrogen can be exported in liquid and compressed gaseous forms, as well as it can be converted to a chemical substance such as ammonia (NH_3) for long-distance transport. Liquefied hydrogen is obtained by cooling gaseous hydrogen to very low temperatures (-253 °C) and is transported in large, insulated cryogenic tanker trucks [Ref. 76]. The need to liquefy hydrogen is explained by the fact that a larger mass of hydrogen can be transported in trucks when liquid versus gaseous. Hydrogen gas must be compressed prior to distribution and is delivered either through long-distance pipelines, either by trucks, also called tube trailers [Ref. 77]. Given hydrogen's storage and transport characteristics, Canada may be well positioned with its non-emitting electricity surplus, to meet the global demand for hydrogen and position itself as an important player in that market.

STORAGE

Hydrogen gas can be compressed or liquefied and stored for future-use during off-peak hours of energy production highly dependent of renewable sources (wind, solar, wave and tidal). Stored hydrogen can thus be dispatched based on demand and provides reassurance for emergency situations. Above-ground facilities, the pipeline network, and subsurface storage are viable options for storage of hydrogen [Ref. 1]. Storage of gaseous hydrogen requires high pressure tanks and takes up more space than liquid hydrogen. The latter, however, requires cryogenic temperatures to keep the hydrogen in liquid form [Ref. 78]. Although hydrogen storage is still in an early developmental stage and presents lower efficiencies than batteries, it may be stored in large quantities due to "high energy density" and for longer periods due to a "low rate of self-discharge" [Ref. 79].

INDUSTRIAL APPLICATIONS

As previously mentioned, produced hydrogen is commonly used for ammonia synthesis, which is further converted to fertilizer. Hydrogen equally plays a role in the electronics industry acting as a reducing agent and as a carrier gas and is used in the production of necessary materials for electronic components such as semiconductors. Additionally, hydrogen is currently used in oil refineries to process crude oil into refined fuels, such as gasoline and diesel, and also for removing contaminants. Other applications such as flat glass manufacturing and rocket fuel suggest that hydrogen gas is already widely used in distinct industries. Steel manufacturing is on the list of potential industrial processes that may be revolutionized by hydrogen [Ref. 80].

A3. HYDROGEN PRODUCTION TECHNIQUES

Although hydrogen is the most abundant element on Earth, pure hydrogen (H_2) is rare, and is rather found in chemical compounds, such as water (H_2O) and methane (CH_4). To produce hydrogen gas, the compounds must undergo chemical processes, such as Electrolysis and Advanced Gas Reforming (or Steam-Methane Reforming) with the latter being the most common. As hydrogen fuel is carbon-free, its environmental impact is determined by the method of production.

ELECTROLYSIS

Electrolysis of water is the conversion of water (H_2O) molecules to oxygen (O_2) and hydrogen (H_2). This process requires energy (an electric current) to be fed into the electrolyzer, such as renewable energy, nuclear, or energy recovered from waste heat. Renewable energy is generated from sources such as hydro, wind, solar, biomass and geothermal. This method of hydrogen production is entirely carbon-free, which makes it a leading competitor for the domination of the energy industry [Ref. 81].

Currently, as little as 0.1% of all produced hydrogen uses the electrolysis technique [Ref. 82]. This may be explained by our current ability to only produce small volumes of hydrogen with electrolysis, suggesting that this method is currently economically unappealing at a large scale. However, this is expected to change with extensive research being conducted to perfect the technique by improving efficiency, with many industrial participants involved and resulting cost reduction.

STEAM-METHANE REFORMING

Steam-methane reforming is the process of obtaining hydrogen from methane (CH_4), the latter being a product of coal, natural gas or oil production [Ref. 83, Ref. 84]. The process is comprised of three chemical reactions: steam-methane reforming reaction, water-gas shift reaction and pressure-swing adsorption. In the first step, under high pressure, high temperature steam reacts with methane and a catalyst, to produce carbon monoxide (CO) and hydrogen (H_2). Next, to produce additional hydrogen, the outputted carbon monoxide reacts with steam to produce carbon dioxide (CO_2) and hydrogen (H_2). As a final step, hydrogen is isolated from all impurities [Ref. 83]. As the outputs of the chemical reactions involved in steam-methane reforming suggest, this method is not carbon-free. To produce blue hydrogen, carbon capture and storage must be introduced into the process. Although steam-methane reforming is a well-known technique, it does not meet the ambitious objectives of a carbon-free economy unless combined with CCS.

A4. H_2 DEPLOYMENT CHALLENGES

To adopt hydrogen in our economy as a leading energy carrier, developers must make considerable adjustments, such as introducing electrolysis plants, developing pipeline infrastructure, building storage facilities, improving the transportation technologies and coordinating the supply chain with consumer demands [Ref. 85].

LARGE-SCALE PRODUCTION

The production of green hydrogen requires abundant sources of renewable energy, sources of quality water for electrolysis and electrolyzer plants in proximity with power generation plants. Luckily, 82% of Canada's energy is clean energy as it is generated from renewable and nuclear sources [Ref. 86].

As Canada is rich in fresh water sources, the main challenge for hydrogen production is the incorporation of electrolysis plants in the process. On the other hand, large-scale production of hydrogen using advanced gas reforming is highly dependent on the development of techniques such as CCS, allowing production of blue hydrogen.

TRANSPORTATION AND STORAGE INFRASTRUCTURE

The most economical solution for the transportation of hydrogen gas requires a network of pipelines to be constructed. Instead of developing a brand-new network, the 80,000 km of existing natural gas pipelines and storage facilities across Canada could potentially be reused and modified to ensure that the equipment is consistent [Ref. 87]. However, research and testing must be conducted to ensure that the pipelines meet the constraints brought by hydrogen gas and prevent fractures.

ECONOMICS

Although the production of green hydrogen may increase as the climate change awareness rises, current production costs suggest that significant technological innovation is necessary to reduce the prices of green hydrogen to a competitive level. Besides, production costs are only part of the whole system cost of delivering hydrogen-based energy.

ROUND-TRIP EFFICIENCIES

To optimize the system design, potential round-trip efficiencies of hydrogen must be considered (Figure 20). Depending on its area of application, hydrogen may not be the most efficient solution as conversion and system losses add up. For instance, the conversion of hydrogen back to electricity results in 25% efficiency, suggesting that at peak power demands, alternative sources of energy available at a specific location must be explored [Ref. 1].

B. Carbon Capture

Carbon capture and storage is also critical to the proposed net zero carbon scenarios and represents the biggest risk to achieving it, as CCS is still under early development, with no firm plan to develop a CCS industry in Canada or globally, beyond a few pilot projects. CCS can be used to decarbonize multiple sectors, including power generation, heavy industry, heat, transportation and waste, and to remove CO_2 directly from the atmosphere. The technologies required for CCS can be broken down into three segments: CO_2 capture, transportation and storage.

B1. WHAT IS CARBON CAPTURE AND STORAGE (CCS)?

Carbon capture and storage is a technology that has the potential to eliminate the undesirable environmental impact linked to the use of fossil fuels. CCS engages in the capture of emitted carbon dioxide (CO_2) and the transportation of the latter through pipelines to high-capacity storage sites, thus preventing CO_2 from escaping into the atmosphere.

The appealing feature of this solution to halt global warming is that current economic activities operating on fossil fuel combustion may not all need to be suspended; but rather an additional step must be introduced to the existing chain of processes.

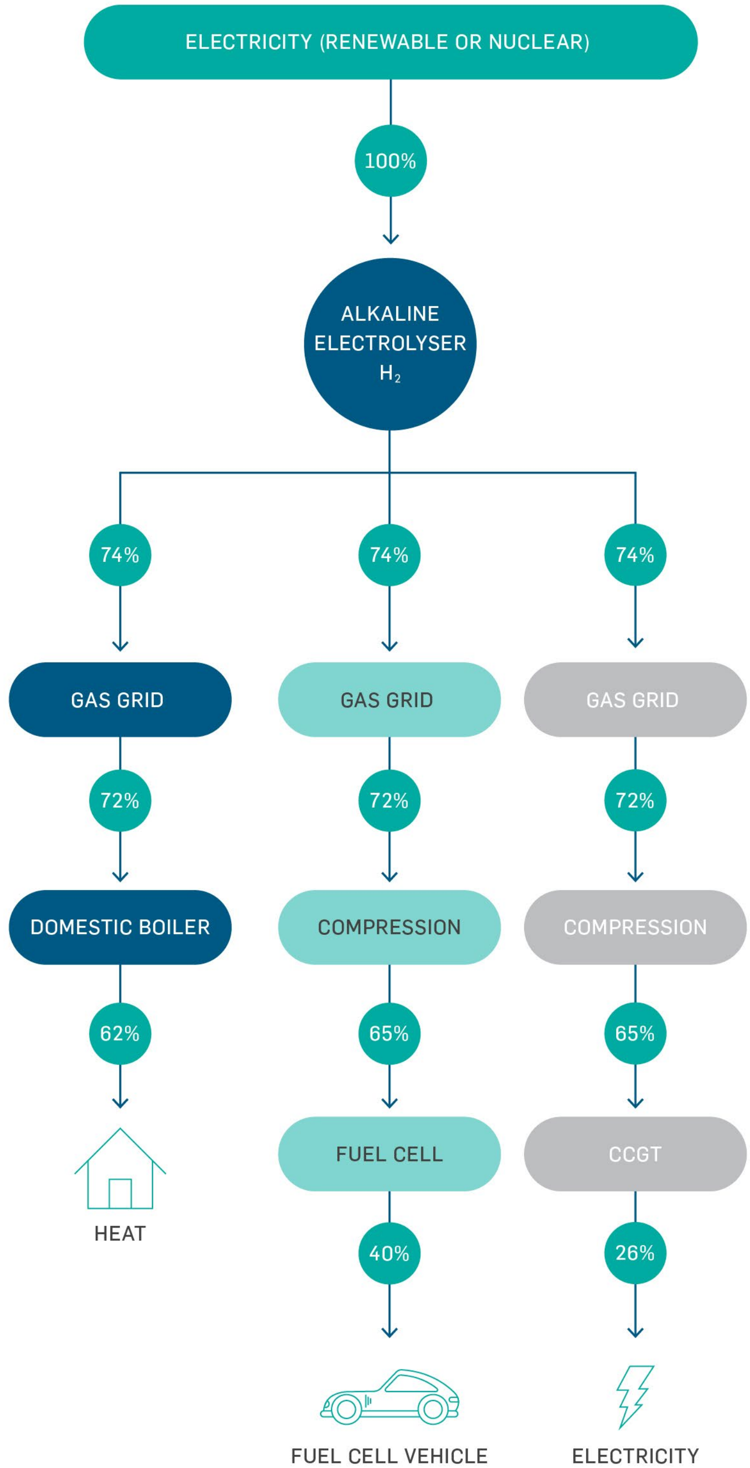

FIGURE 20 HYDROGEN PROCESS EFFICIENCY

CCS can be used to decarbonize multiple sectors, including power generation, heavy industry, heating, transportation and waste, and to remove CO_2 directly from the atmosphere. The adoption of such technology allows for global environmental sustainability suggesting promising environmental conditions for the generations to come. [Ref. 88, Ref. 1]

B2. CCS PROCESS OVERVIEW

The carbon capture and storage process (Table 6 and Figure 21) is composed of three steps: capture, transportation and storage of carbon dioxide. An alternative to storage is the utilization of CO_2 in industrial applications.

CAPTURE

Generated CO_2 gas is captured as an undesirable product of power generation and industrial activities, such as oil refineries, ammonia production, cement manufacture and iron and steel production. This gas often contains impurities from which pure CO_2 must be separated [Ref. 89].

TRANSPORTATION

Captured and purified CO_2 is liquefied, or brought to a "supercritical condition", through compression, and transported to storage facilities or for use through pipelines or by trains, trucks and ships. Pipelines are the most efficient method for onshore transport of high volume of CO_2 over long distances for plants with a longer lifetime. The optimal conditions for pipelines carrying CO_2 are above 32.1°C and 72.9 atm [Ref. 90]. The transport of CO_2 via pipeline is common practice in Canada, with the 240 km long pipeline developed as part of the Alberta Carbon Trunk Line (ACTL) project [Ref. 91].

STORAGE

CO_2 is then stored long-term in underground geological formations such as oil and gas fields, un-mineable coal beds and saline reservoirs. Geological storage is advantageous as it has the potential to store large volumes of CO_2 generated from different sources. Alternative storage options include deep in the ocean or fixated in rock [Ref. 92].

UTILIZATION

Carbon capture and utilization (CCU) is the process of reusing recycled CO_2 from electricity generation or industrial processes in the chemical industry, agriculture, and for fertilizer and energy production. CO_2 can also be used in food beverages, refrigerants and fire extinguishing gases. Enhanced oil recovery projects may further increase CO_2 utilization [Ref. 90].

B3. CCS TECHNOLOGIES AND CHALLENGES

Although existing techniques have been tested reliable over decades with various operational projects in place, introducing carbon sequestration at a large-scale poses a challenge. In 2018, Canada has emitted approximately 720 Mt of CO_2 [Ref. 5]. With numbers rising on a yearly basis, CCS technologies are key to meeting the settled targets.

CO_2 CAPTURE TECHNOLOGIES

Capture technologies are grouped into three types: post-combustion, pre-combustion and oxy-fuel combustion. These techniques differ in the way CO_2 is produced during an industrial process, yet share a purpose to isolate carbon dioxide from the other gaseous compounds emitted simultaneously.

Industrial processes such as steel production release almost pure CO_2 from the process. Currently, common practice is to discharge this CO_2 into the atmosphere, although the new initiative is to compress, transport and store the polluting gas [Ref. 89].

CAPTURE TECHNIQUE	PROCESS	ADVANTAGES	DISADVANTAGES
Post-combustion	Separation of CO_2 from gases released from combustion of fossil fuels	Most mature technique, easy retrofitting, compatible with existing plants	Low efficiency resulting from low CO_2 concentration in captured gas
Pre-combustion	Separation of CO_2 from gases released from "pre-treatment" (e.g., gasification) of fossil fuels	High concentrations of CO_2, high efficiency	Lowest thermal efficiency, energy penalties and efficiency decay
Oxy-fuel combustion	Separation of CO_2 from gases released from burning of fossil fuels in oxygen (O_2) rather than in air	Very high concentrations of CO_2 (80%), high efficiency, require smaller equipment	Production of O_2 is energy intensive and costly; possibility of corrosion

TABLE 6 OVERVIEW OF CCS CAPTURE TECHNIQUES

Capture technologies are expensive, accounting for 70-80% of the total costs of a CCS system [Ref. 90]. This suggests that extensive research must be conducted focusing on reducing the costs of capturing CO_2 from flue gases prior to fully relying on CCS as a practical solution to decarbonize the economy. Fortunately, federal and provincial governments in Canada are investing in CCS technology development with four large-scale projects ongoing.

SEPARATION TECHNIQUES

Prior to injecting the released CO_2 into the network of pipelines, it shall be isolated from any impurities in flue gases. The following technologies are currently available: wet scrubbers, dry regenerable sorbents, membranes, cryogenics, pressure and temperature swing adsorption.

The importance behind separation techniques is explained by the necessity to have pure CO_2 circulating through pipelines to avoid changes in temperature and pressure caused by impurities. Similarly, the presence of water may lead to corrosion of the pipelines [Ref. 90].

STORAGE

Carbon dioxide is ideally stored in underground geological formations which satisfy several storage site characteristics to allow for high capacity, permanent and safe storage of CO_2. The subsurface site must be evaluated based on storage resource, injectivity, integrity and depth [Ref. 94].

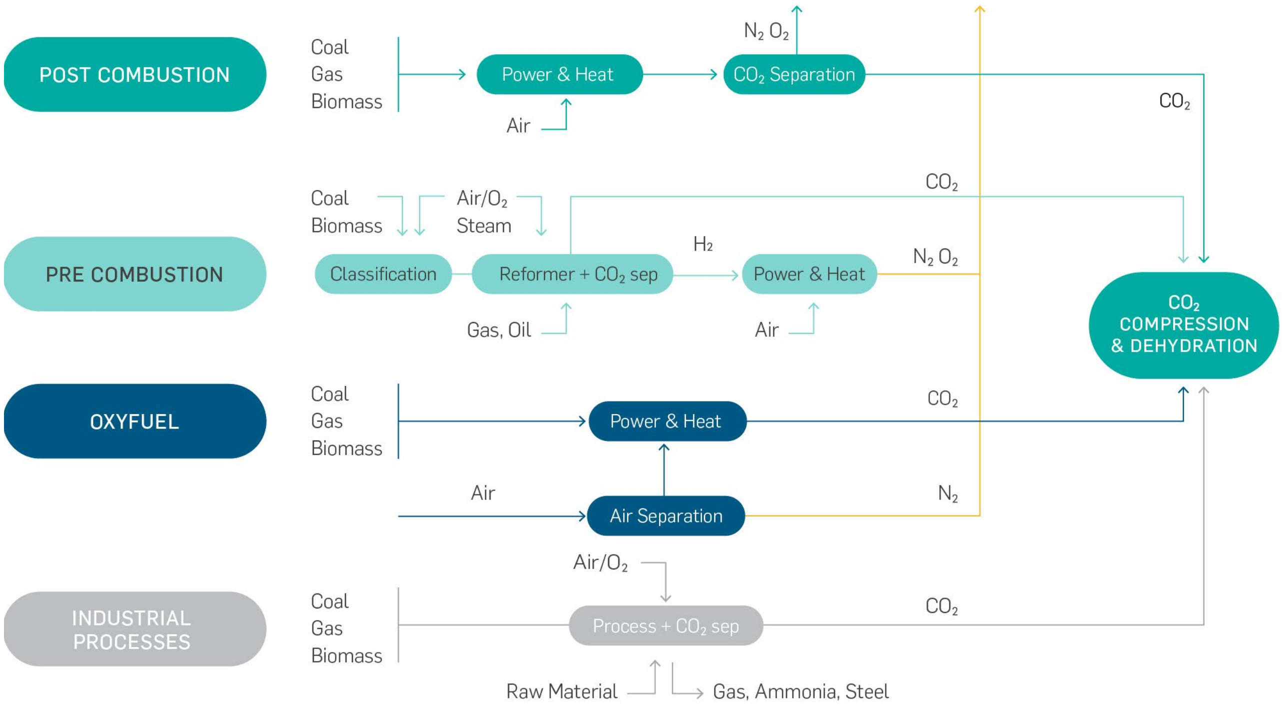

FIGURE 21 CARBON CAPTURE AND STORAGE PROCESS [REF. 101]

Storage resource refers to the site's available capacity to store CO_2. The potential CO_2 storage capacity across Canada is estimated to 132 billion tons [Ref. 95]. If calculated using current CO_2 emission rates, Canada has roughly over 235 years of storage capacity. Injectivity is the rate with which CO_2 can be injected into the site. Integrity of a formation reflects if the storage is safe and preventative of leaks; the latter may be precautioned by a solid layer surrounding the formation. The safety requirement also refers to the isolation of the storage zones from potable water sources using several sealing layers. The depth of the natural storage site must assure the required temperature and pressure for CO_2 to be stored as a "supercritical fluid". At this critical condition, CO_2 may be stored in much larger volumes than at the surface [Ref. 94].

ENHANCED OIL RECOVERY

Enhanced oil recovery (EOR) is a well-established technology which combines CO_2 storage and utilization. Once CO_2 is transported and injected into the oil and gas fields, it dissolves in the residual oil which becomes more susceptible to be extracted using water pressure as a driving force. The injected CO_2 itself remains stored underground in the oil and gas reservoirs. Such projects, where captured CO_2 is used to enhance oil recovery, are currently progressing in Canada, with Alberta's large deposits of oil in oil sands and reservoirs [Ref. 95, Ref. 90].

EFFICIENCY & ECONOMICS

Current CCS technologies have demonstrated to capture up to 90% of net CO_2 emissions. However, studies suggest that we are not limited to such performance of CCS technologies and that higher capture rates, even greater than 95% may be technically achievable. “Negative” carbon emissions technologies are also being explored such as direct air capture, afforestation, cloud treatment with alkali and several others [Ref. 96].

Certainly, with the incorporation of new technologies into the existing processes, come large costs for research, development and realization. However, the Intergovernmental Panel on Climate Change has estimated that limiting global warming to 2°C would be 138% more expensive without carbon capture storage technologies, suggesting that this technology is inevitable in the near future [Ref. 97].

B4. CANADIAN CARBON CAPTURE AND STORAGE PROJECTS

Currently, Canada has four operating or under construction CCS projects capable of capturing up to 6.4 Mt of CO_2 per year as shown in Table 7 [Ref. 98]. Although these projects have proven to be successful and effective, CCS is still at an early stage of being integrated into the economy as the current capture capacity is equivalent to a bit over 1% of total Canadian CO_2 emissions.

C. Digitalization: IoT, Big Data and AI

Data analytics and machine learning will play an important role in the infrastructure world, as more digital devices are interconnected allowing us to collect valuable data. Energy management systems (EMS) are being gradually implemented on the industrial side and it is expected they will make their way to the residential sector as well.

PROJECT	CO_2 CAPTURE CAPACITY (Mt / YEAR)	CO_2 SOURCE	STORAGE TYPE
Boundary Dam (Saskatchewan)	1.0	Coal-fired power plant	EOR at Weyburn oil field
Quest (Alberta)	1.2	Oil sands	Saline aquifers
Alberta Carbon Trunk Line (Alberta)	1.5 to 2.0	Sturgeon Refinery & Agrium Fertilizer Plant	EOR at Clive oil reservoir or storage in aquifers
Fort Nelson (British Columbia)	2.2	Gas processing plant	Aquifers

TABLE 7 CCS PROJECTS IN CANADA

Given the complexity of the 2050 net zero carbon energy system, effective system balancing across sectors is essential, and the optimal system will not be delivered without data analytics, machine learning and AI intervention for resiliency. This should be based on a strategic view of the entire system architecture and evaluation of the whole system cost, which will require federal and cross-provincial government coordination. Since no plan is ever set in stone, the data collecting, monitoring and analysis platform will need to be dynamic to global and domestic changes in generation, demand, performance, industry and technology.

C1. BIG DATA/IOT/AI BENEFITS FOR DECARBONIZATION

The 2050 net zero carbon emissions vision will require a level of cross-sector, interprovincial, and cross-industry collaboration unlike anything we have seen before, and that is anchored in secure and reliable data sharing. To arrive at an efficient and economically viable way to function as a society without relying on fossil fuels, we need to rethink our whole systems. A sound transformation plan needs to recognize that the systems we currently have in place are the result of decades of iterative progress and innovation and have proven to be resilient and predictable over time.

For the necessary transition to take place, a comprehensive understanding of our existing systems and of the new technologies deployed is necessary, and this starts with sensor deployments, data collection and data monitoring. This would form the Internet of Things in the infrastructure world, enabling monitoring and control of physical assets through software platforms.

The collected data could include real-time greenhouse gas emission levels, energy needs, production efficiency, and supply chain monitoring, along with thousands of other data points. The resulting sets of data would form what is referred to as big data, due to the massive amount of information. Big data combined with faster telecommunication networks and computer processing capabilities could allow industries to make real-time decisions in their operations, leading to increased efficiency and reductions in their carbon emissions.

The subsequent data analysis and application of the latest artificial intelligence algorithms could reveal a deeper understanding of what is working and what isn't, and insights on how to adjust processes and policies accordingly. As such, artificial intelligence could potentially play an important role in decarbonization due to its ability to predict future requirements and trends while uncovering useful patterns and insights.

C2. THE EXAMPLE OF DIGITAL ELECTRIC UTILITIES

Power utilities will need to consider the numerous changes facing their industry and the ongoing digital transformation when replacing or upgrading the existing assets. The digitization of power utilities promises to optimize the supply and demand of electricity, to manage the complexity of bidirectional flow of information generated by smart meters, to offer residential customer load management in support of energy efficiency programs, and to provide networks which are more resilient with respect to against natural disasters and extreme weather events [Ref. 99].

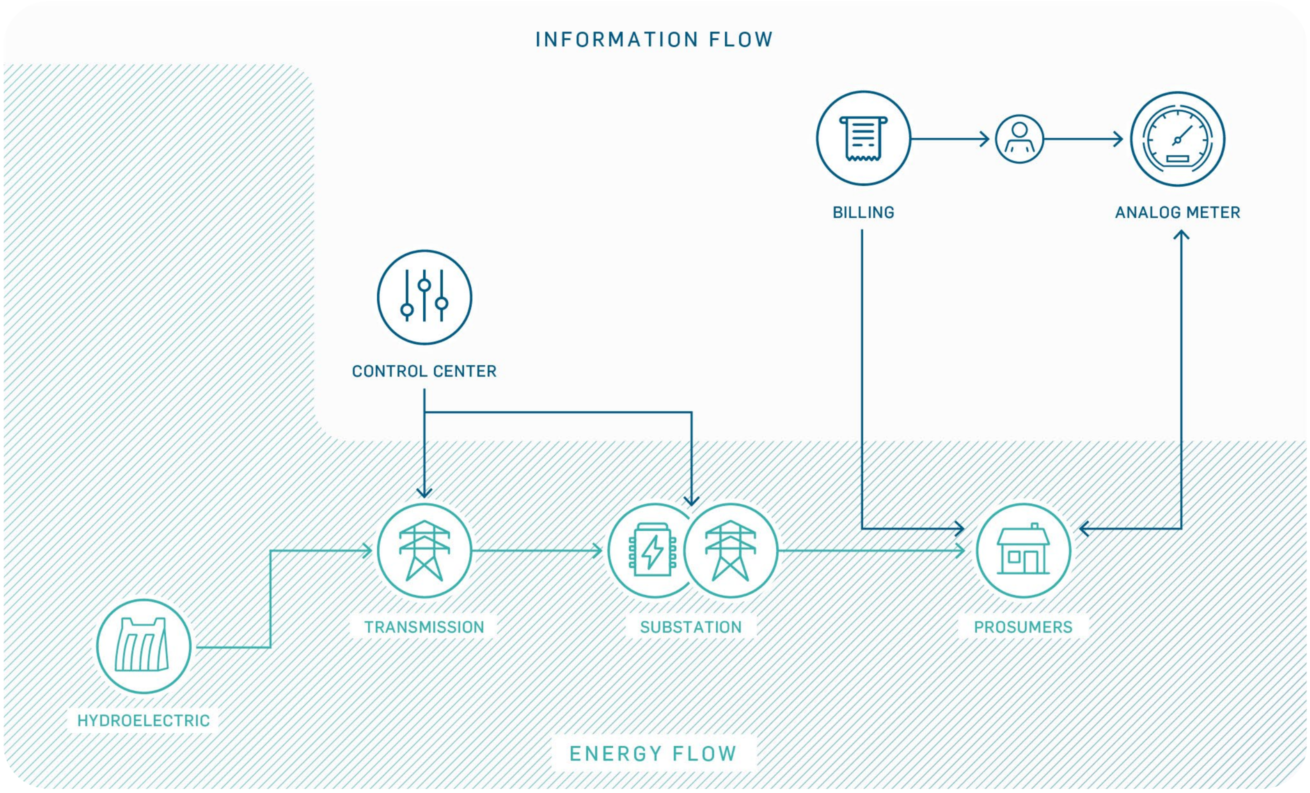

FIGURE 22 CONVENTIONAL POWER GRID

Intelligent substations will allow power utility companies to efficiently manage the intermittent power introduced into the grid by renewable energy sources, optimize the use of energy storage, support bidirectional communications with prosumers (e.g., electricity consumers that also provide energy generation or storage to the grid), and generate useful data that will be used to perform predictive maintenance on substation equipment.

On the cybersecurity front, utilities will need to effectively secure their critical infrastructure against new and evolving threats. The selection and integration of the right technology, combined with rigorous procedures and cultural change, are of prime importance to minimise security risks.

Figure 22 and Figure 23 compare the conventional and modern electrical grids. An example of a hydro powered grid is provided; however, a similar structure applies to other conventional generation such as thermal, coal, etc. In moving toward a modern grid which enables bi-directional power flow, the digitalization of the grid becomes the main bottleneck. The modern grid integrates bulk renewable energy generation, behind-the-meter renewable energy generation, energy storage, microgrids, and electrical vehicles charging stations. This operational shift will require a massive amount of bi-directional data flow, in order to facilitate real-time grid monitoring of millions of access points, and to provide the automated controls needed to maintain resilient and efficient operation.

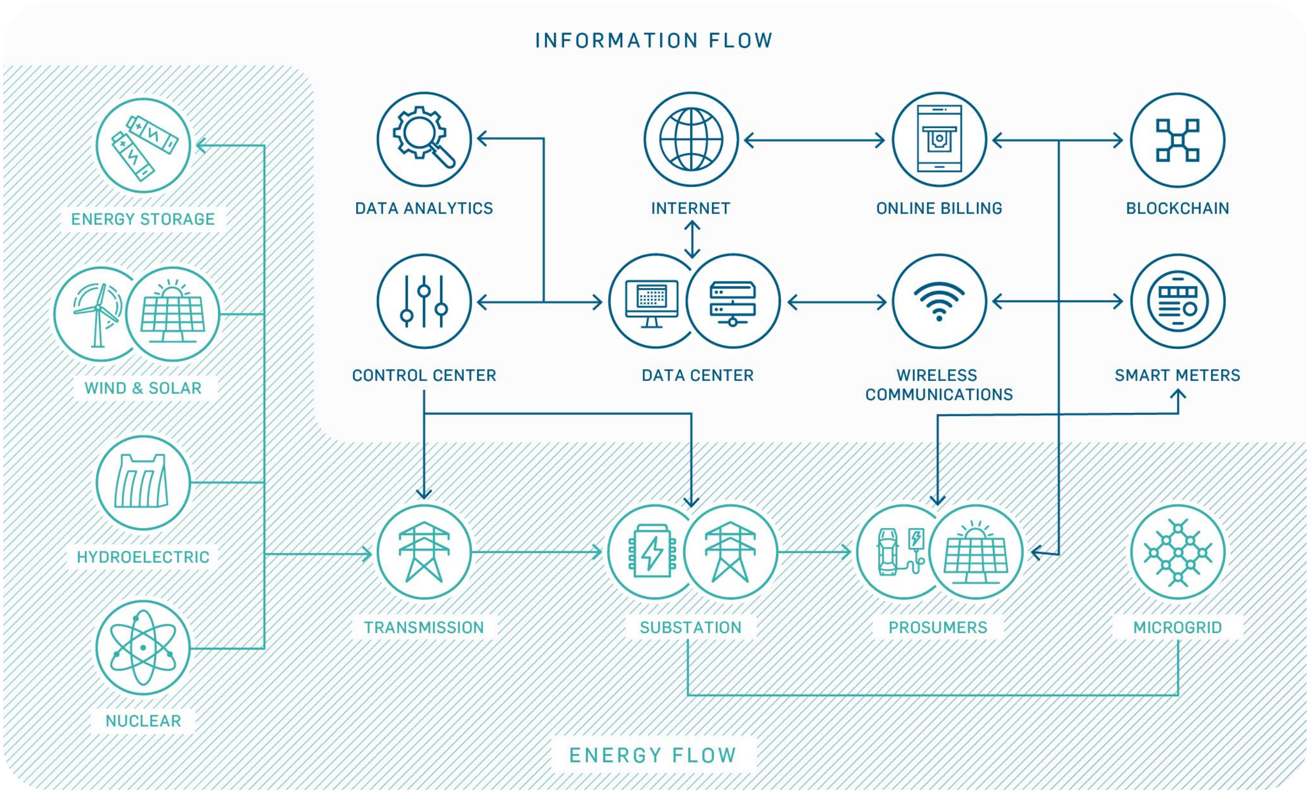

FIGURE 23 MODERN POWER GRID

C3. CHALLENGES IN DIGITALIZING INFRASTRUCTURE

A large part of emissions reduction relies on technologies that will enable to converge the physical infrastructure to the digital world. Enabling such a transformation requires industries to upgrade their current infrastructure. This includes replacing obsolete analog equipment with new digital equipment and upgrading the telecommunication infrastructure to enable the transmission of data.

To protect the infrastructure and the data from being taken over by malicious individuals, it is imperative that industries embarking on such a transformation ensure that they also protect their digital infrastructure from cyber attacks. Once this infrastructure is built, the industries will be able to start reaping the benefits of the digital infrastructure. There is a strong argument for investing in digital assets, as was proven in several industries so far.

Underneath the data sets that could be made available to researchers, lies tremendous potential for more efficient use of time, resources, and energy across the board. Today, there is an opportunity to provide this initial push to fully digitalize Canadian infrastructure industries through targeted funding and forward-looking policies promoting sensor deployments, data sharing, and applied data sciences.

D. Energy Storage

Higher integration of renewable generation depends on firm power interconnectors, demand-side response and energy storage. Emerging storage technologies have shown some potential; however, much work is still needed on the energy efficiency, the economics and the regulation aspects to make grid-scale balancing storage such as batteries, liquid air and compressed air, a viable solution.

Furthermore, Canada benefits from a landscape that is conducive to hydro pumped-storage, which could greatly benefit the Canadian grid as part of a country-wide system planning. Advancements in battery storage technologies related to electric vehicles is another major part of the puzzle, and the combined fleet of vehicles may act as a distributed bulk energy storage system that will interact with the grid to charge and discharge energy, at millions of potential connection points. A live project on the isle of Orkney in Scotland demonstrates the technical potential for this type of smart grid technology [Ref. 100].

D1. ENERGY STORAGE BENEFITS FOR DECARBONIZATION

Energy storage (ES) is a crucial tool for enabling the effective integration of renewable energy and unlocking the benefits of local generation and clean, resilient energy supply.

The ES technology continues to prove its value to grid operators around the world who must manage the intermittent generation of solar, wind, wave and tidal energy. However, the development of advanced energy storage systems (ESS) has been highly concentrated in select markets, primarily in regions with highly developed economies.

Energy storage includes both mature technologies and technologies that appear to have much development potential. To date, 99% of bulk storage energy worldwide is pumped hydro storage. While pumped hydro storage is expected to play a major role in this market in Canada, the utilization of Li-Ion and flow batteries is expected to grow in the coming decade following a similar trajectory as seen in other countries around the world. Battery storage brings multiple services for utilities, system operators, and end customers. Figure 24 depicts the range of services that can be provided by battery energy storage.

D2. CHALLENGES FOR ENERGY STORAGE

Barriers to energy storage development suggest policy intervention is merited to promote competition among projects and technologies and promote market design improvements to better reflect the value of its various ancillary services. Additionally, a standardized integration with utility energy management systems is still lagging and requires development.

UTILITY SERVICES	SYSTEM OPERATOR SERVICES	CUSTOMER SERVICES
TRANSMISSION DEFERRAL	ENERGY ARBITRAGE	BACKUP POWER
DISTRIBUTION DEFERRAL	SPIN/NON-SPIN RESERVE	PV INTEGRATION
TRANSMISSION CONGESTION REFERRAL	FREQUENCY REGULATION	DEMAND CHARGE REDUCTION
	VOLTAGE SUPPORT	TIME OF USE BILL MANAGEMENT
RESOURCE ADEQUACY	BLACK START	OFF GRID OPERATION

FIGURE 24 SERVICES OF THE BATTERY STORAGE TECHNOLOGIES


NET ZERO
CARBON.
NET ZERO
EXCUSES.

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