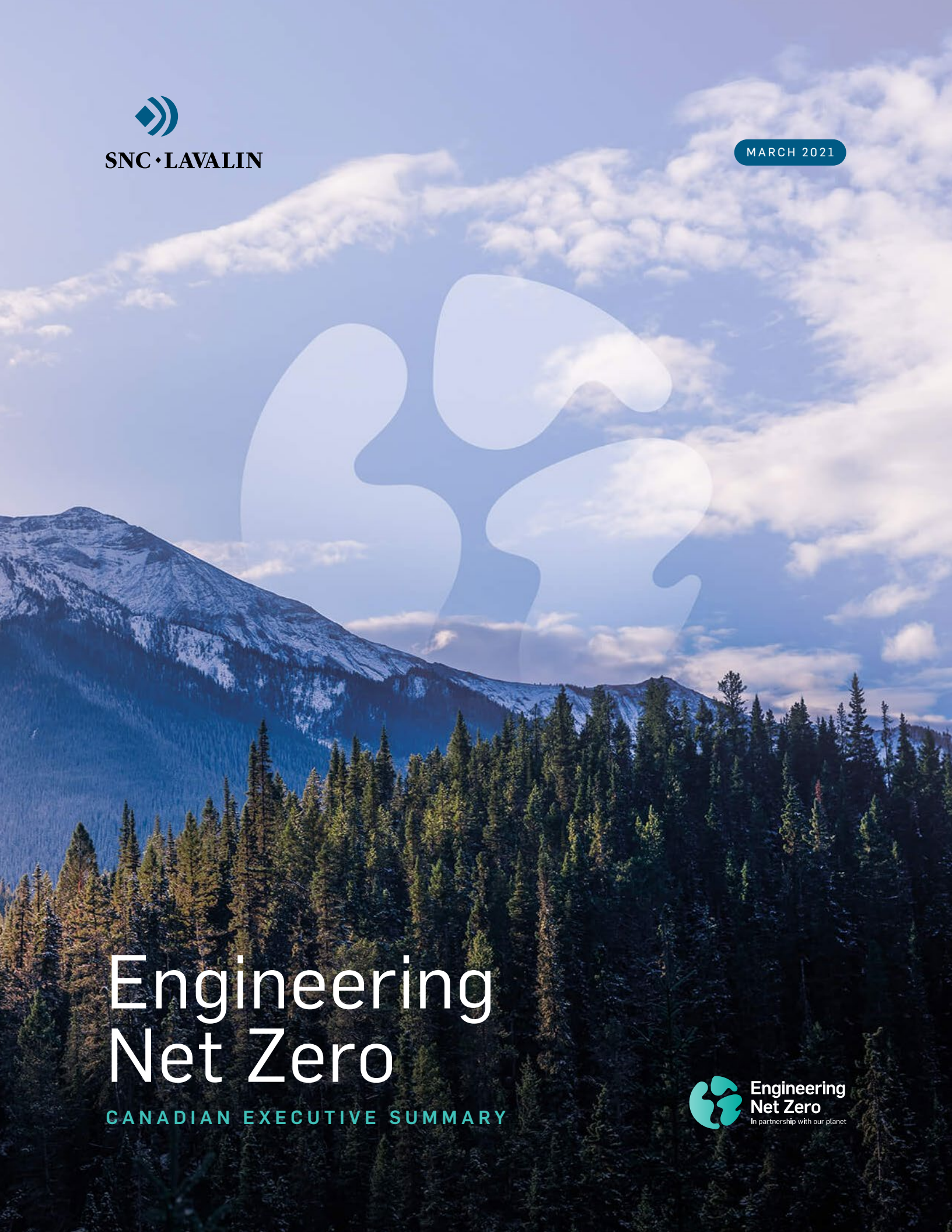


SNC·LAVALIN

MARCH 2021

Engineering Net Zero

CANADIAN EXECUTIVE SUMMARY

Engineering Net Zero
In partnership with our planet

STRATEGIES AND SOLUTIONS FOR A NET ZERO CARBON FUTURE

Key Drivers

The Canadian Government recently announced plans to transition the Canadian economy toward a net zero Greenhouse Gas (GHG) Emissions target by 2050[1].

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.

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.

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*, aimed at highlighting to the UK government the engineering risks and challenges that must be overcome for a net zero carbon target.

This report examines the blueprint for Canada to achieve net zero carbon target by 2050 and brings into perspective the size of the monumental task ahead, including challenges and potential solutions across economic sectors. 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.

1 HTTPS://WWW.CANADA.CA/EN/ENVIRONMENT-CLIMATE-CHANGE/NEWS/2020/11/GOVERNMENT-OF-CANADA-CHARTS-COURSE-FOR-CLEAN-GROWTH-BY-INTRODUCING-BILL-TO-LEGISLATE-NET-ZERO-EMISSIONS-BY-2050.HTML

The Need for Broad Collaboration

With environmental issues at the forefront of Canadians' priorities, industries have been tasked with finding ways to reduce emissions and environmental impacts through innovation.

LEADING A LOW CARBON FUTURE

The lessons learned in this endeavour will help position Canada's industries as leaders in low and zero carbon technologies.

Canada must look toward a holistic solution that is well timed across economic sectors and addresses demand reduction and decarbonization of energy supply simultaneously.

A piecemeal approach will simply not work.

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:

Synchronized deployment of emerging and disruptive technologies across sectors - this will not happen without significant government intervention;

Greater coordination across industries, sectors, provincial governments, and communities;

Well-defined economic and financial frameworks along with tools such as carbon taxes and other incentives, aimed at driving forward the necessary change;

Introduction of Canadian-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.


NET ZERO
CARBON.
NET ZERO
EXCUSES.

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.

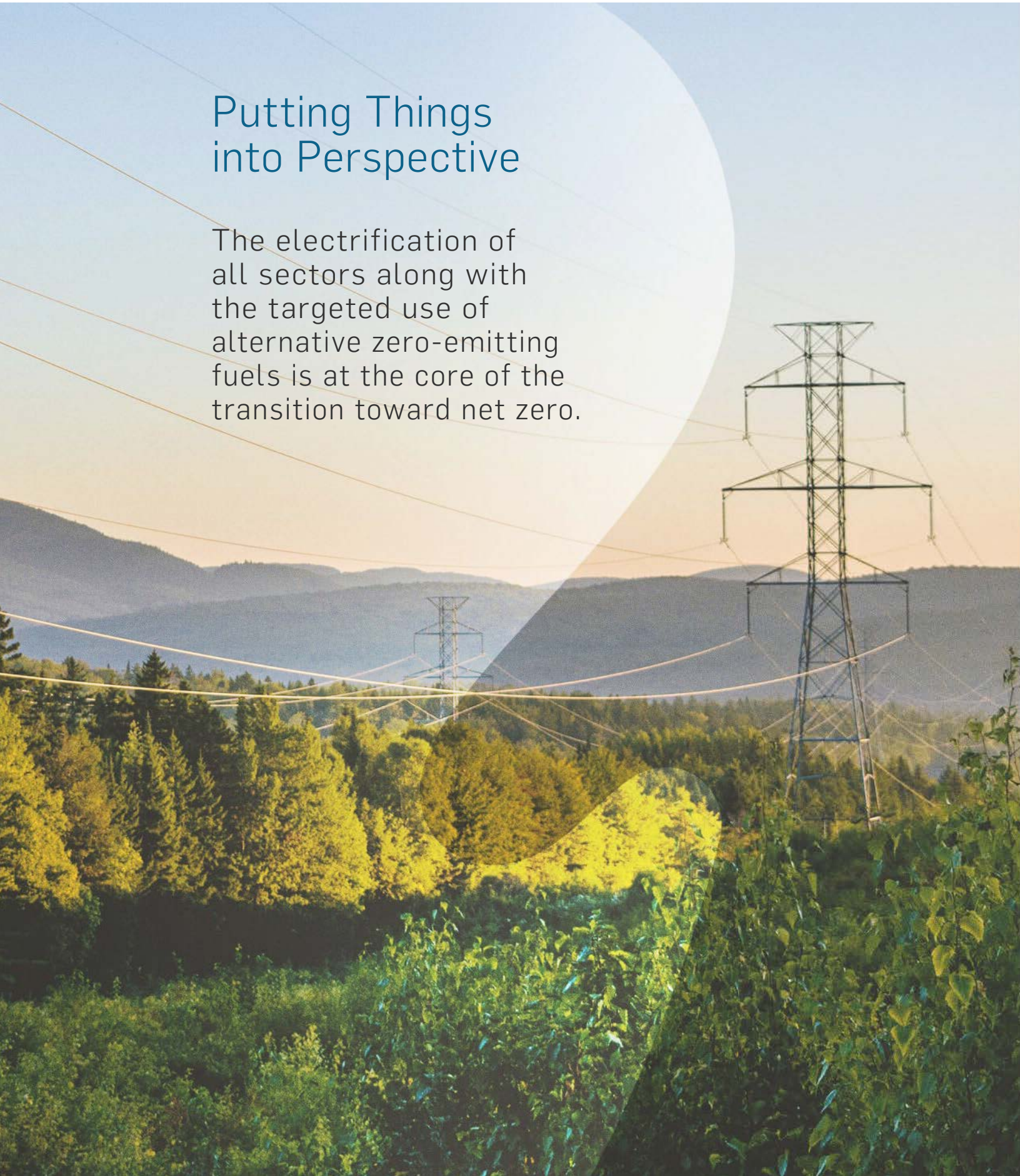
Today, we have an opportunity to reverse this trend. In that regard, much of today's way of life could be powered by clean electricity; the transition away from GHG-emitting energy sources is slowly underway.

However, as pointed out by the World Economic Forum[1], 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, unless country-specific economic recovery plans support the energy transition initiatives toward net zero carbon emissions.

1 WORLD ECONOMIC FORUM. (2020), FOSTERING EFFECTIVE ENERGY TRANSITION, INSIGHT REPORT, 2020 EDITION

Putting Things into Perspective

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.



An infrastructure backbone 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.

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, with most scenarios estimating a total electricity demand of around 1500 TWh.

As such, significant new clean electrical capacity 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.

To put things into perspective: using today's specific capacity factors, and without accounting for the replacement of existing ageing generation, if one were to meet this challenge using only one power generation type, additional capacities required to add 1000 TWh[1] 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 3 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.

1 THE REQUIRED GENERATION CAPACITY (MW) TO ADDRESS THE ENERGY DEMAND (TWH) WILL DIFFER BY GENERATION TECHNOLOGY, DUE TO THE ASSOCIATED CAPACITY FACTORS.

A possible Scenario for a 2050 Generation Mix

In Figure 1, the authors propose one possible order of magnitude scenario for the 2050 generation mix, partly based on data from reviewed literature[1234]. 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.

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. 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.

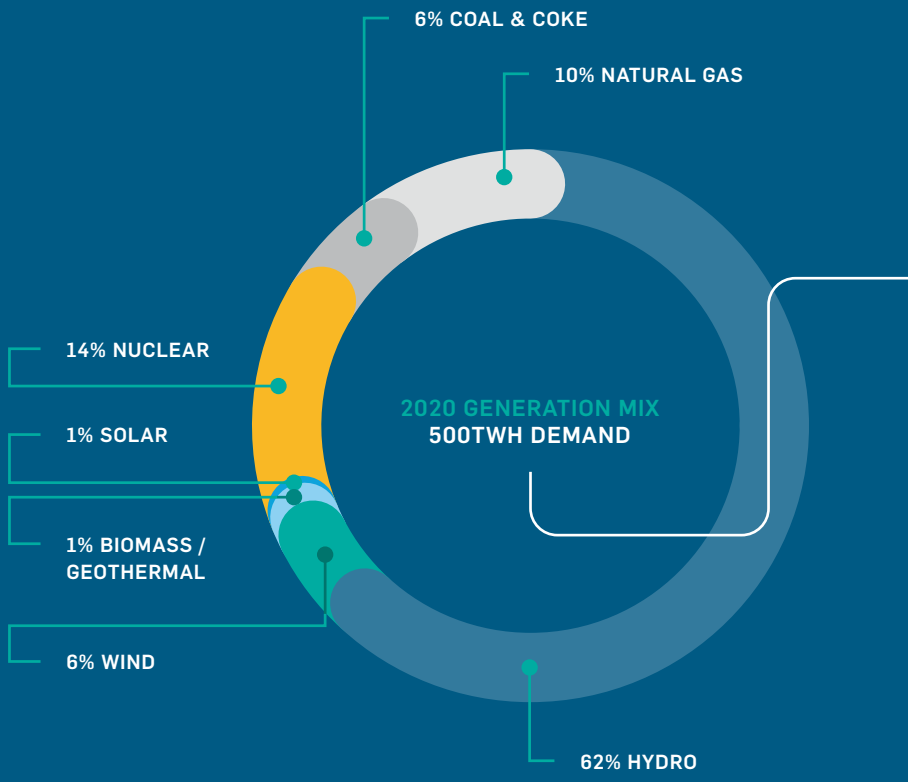


FIGURE 1 INDICATIVE 2050 VS. 2020 GENERATION BY SOURCE

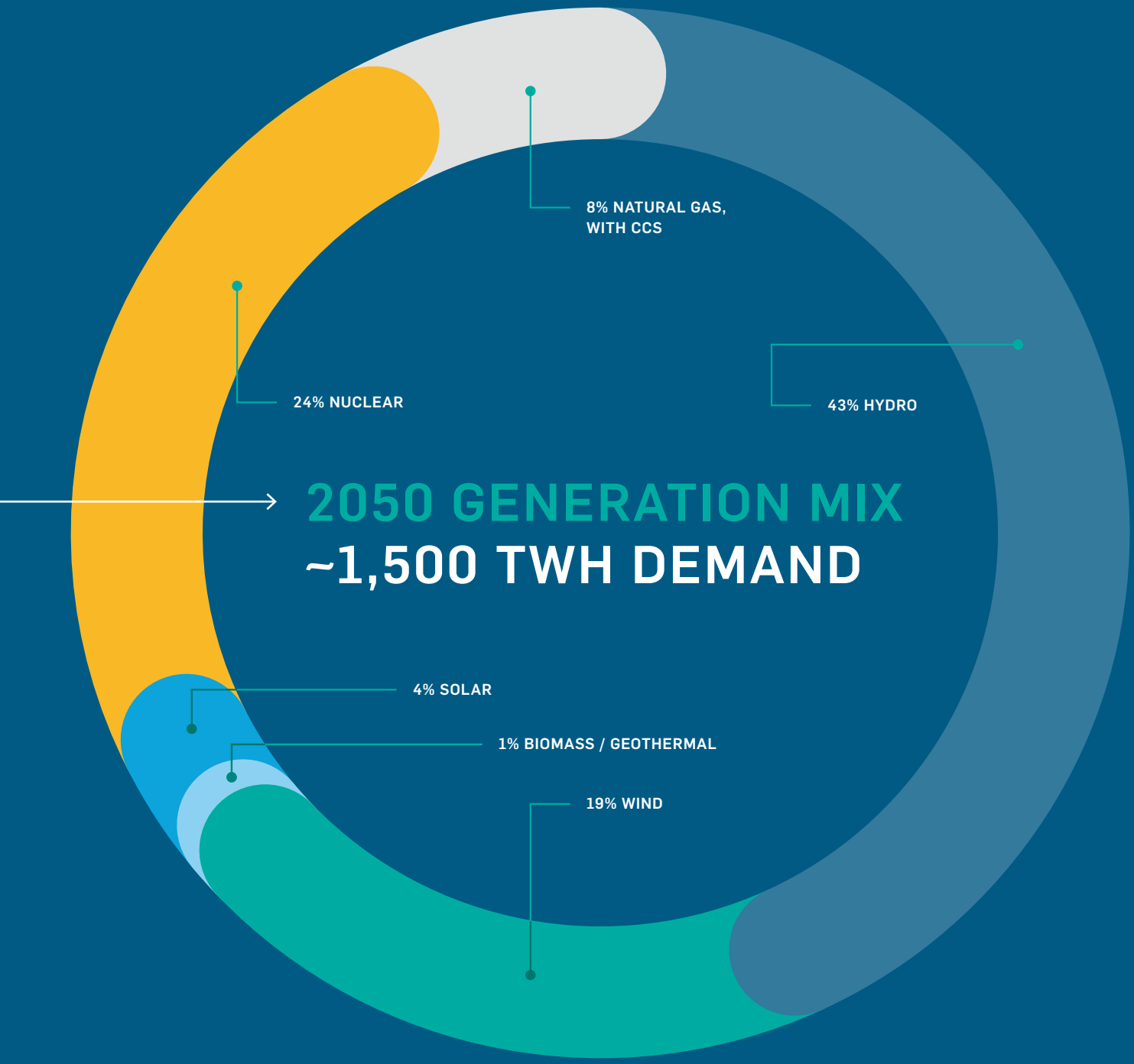
Canada will need to triple its power production levels over the next 30 years.

1 ENVIRONMENT AND CLIMATE CHANGE CANADA. (2016). CANADA S MID CENTURY LONG TERM LOW GREENHOUSE GAS DEVELOPMENT STRATEGY.

2 BATAILLE, C. ET AL. (2015). PATHWAYS TO DEEP DECARBONIZATION IN CANADA. SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK (SDSN) AND INSTITUTE FOR SUSTAINABLE DEVELOPMENT AND INTERNATIONAL RELATIONS (IDDRI).

3 CANADA ENERGY REGULATOR. (2020). CANADA S ENERGY FUTURE 2020 ENERGY SUPPLY AND DEMAND PROJECTIONS TO 2050.

4 TROTTIER ENERGY FUTURES PROJECT. (2016). CANADA S CHALLENGES AND OPPORTUNITY. TRANSFORMATIONS FOR MAJOR REDUCTIONS IN GHG EMISSIONS.


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

HYDRO: literature suggests that new hydro resources will account for about half of the additional energy required, or about 500 TWh of additional generation. With hydro projects taking at least 10 years to develop, the country would require the implementation on average of approximately 3.5 GW per year of hydro power for the 2030-2050 period.

NUCLEAR: in our opinion, in order to meet the additional net zero electricity requirements, initiation of the licensing process for siting 1000 MW class reactors should begin immediately. One such reactor could be brought into service every year from 2030 to 2050. Once the SMR designs are complete, three 300MW SMR units could be added to the grid each year from around 2035 to 2050. While aggressive, this accelerated new build scenario is less than the nuclear new build rates that both China and India are achieving today. 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.

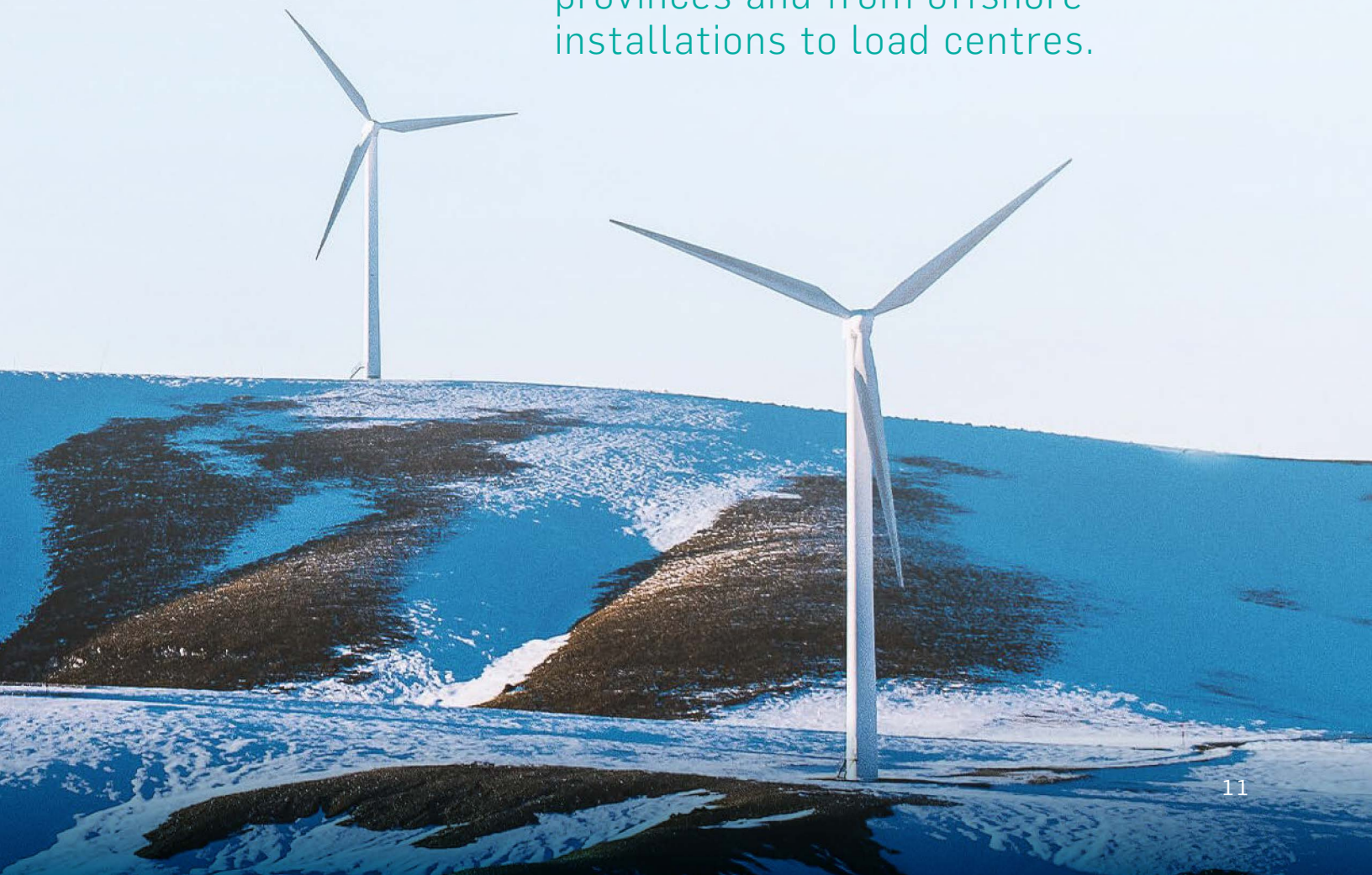
WIND: with decreasing costs and an increased build rate, Canada could install an additional 90 GW of wind (both onshore and offshore) by 2050. Due to wind's capacity factor, this would translate into approximately 300 TWh of electricity.

SOLAR: 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: natural gas plants will continue to play an important role in the Canadian power generation mix given their fast deployment potential as well as their critical role in stabilizing the grid and responding to fast changes in demand. It is anticipated that gas turbines will also replace all remaining coal generation. 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.

All of the above will be accompanied by a stronger pan-Canadian power grid allowing to move clean renewable energy across provinces and from offshore installations to load centres.



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 are 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.

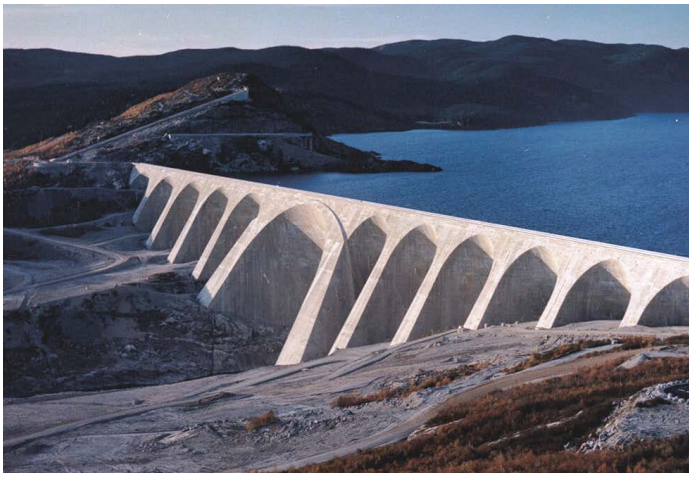
TRANSITION TOWARD 100% NET-ZERO-EMITTING ELECTRICITY GENERATION: Canada benefits from access to a vast amount of low and zero carbon energy generation, and this should be the backbone of our net zero carbon economy. This starts with hydro, nuclear, and hydrogen-fueled thermal power options, which are 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.

A vibrant and economically sustainable hydrogen market is a necessary pillar for these industries to shift toward net zero GHG emissions.



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.

OUR BLUEPRINT FOR A NET ZERO CARBON FUTURE

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.

The challenge ahead will require us to rethink our actions every step of the way.

LEADING INDUSTRY BY EXAMPLE

REACHING THE 2050 NET ZERO TARGET

Canada's Innovation Challenge

Transportation

- Biofuels for heavy transport
- Electrify rail shipment
- Electrification and use of H_2 fuel

Heavy industry

- Carbon capture
- Biofuels
- Much R&D still needed
- Process efficiency

Electricity

- SMRs, Pumped-storage hydro, Offshore wind
- Smart Grid, Micro Grids
- Pan-Canadian grid

Oil and Gas

- Carbon capture
- H_2 for trucks
- SMRs for process
- Develop LNG and H_2 markets

Waste

- Recycling new tech (batteries)
- Landfill carbon capture
- Biofuel generation

Buildings

- District heating / cooling
- Non-emitting fuels
- Advanced building materials
- Stringent building codes
- Smart buildings

Agriculture

- Efficiency (crop, livestock)

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Investing in Emerging Technologies

A transition to net zero carbon by 2050 will be driven by disruptive technologies available today. 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 absent.

A technological solution, far from limited to the technology itself, involves the complete economic ecosystem, from expertise in planning and execution, to supply chains in materials, to operation and maintenance personnel.

When considering the lifecycle of some of these technologies, it is evident that a large 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.

GREATER INVESTMENT IN HYDROGEN PROJECTS

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 carbon capture and sequestration (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.

ENERGY STORAGE, AN ESSENTIAL PART OF SYSTEM PLANNING

High penetration of renewable generation depends on firm power interconnectors, demand-side response and energy storage.

Emerging storage technologies have tremendous potential; however, much work is still needed on the energy efficiency, economics and 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 (EV) are 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 KEY ROLE FOR CARBON CAPTURE AND SEQUESTRATION

CCS is also critical to the proposed net zero carbon scenarios and represents the biggest risk to achieving the global target. 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.

THE INTERNET OF THINGS AND BIG DATA

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 are being gradually implemented in several industrial loads and it is expected they will make their way to the residential sector as well.

Given the complexity of the 2050 net zero 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.

Our data collecting, monitoring and analysis platform will need to be dynamic to global and domestic changes in generation, demand, performance, industry and technology.

ACTION TODAY FOR A NET ZERO TOMORROW

Recommendations for Immediate Action

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 are recommendations for immediate action to enable Canada to quickly start closing the gap toward achieving the 2050 net zero carbon targets:

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 effectively 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.


BECAUSE
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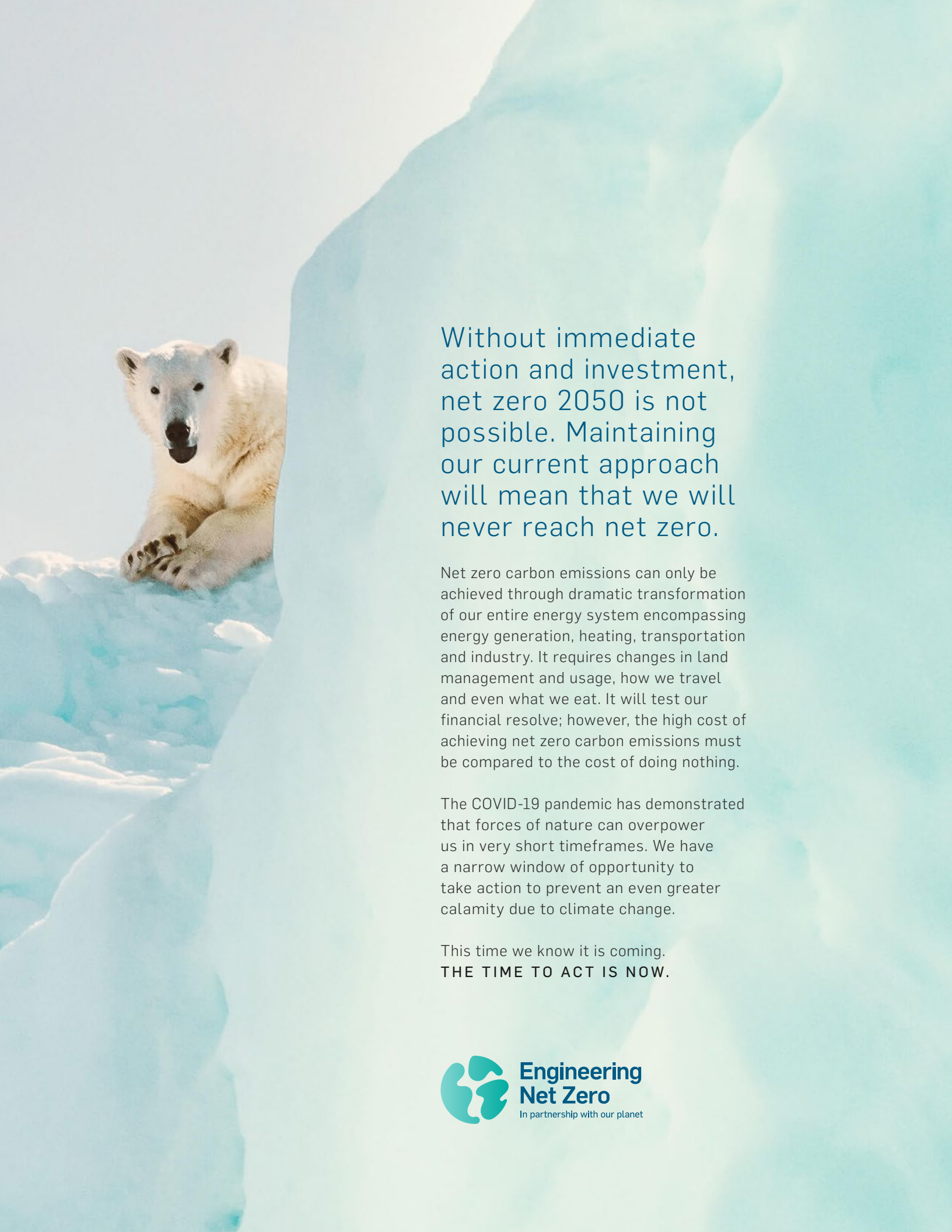

Without immediate action and investment, net zero 2050 is not possible. Maintaining our current approach will mean that we will never reach net zero.

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.

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.

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