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Roadmap to Resilient Ultra-Low Energy Buildings with Deep Integration of Renewables

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Executive Summary

This Roadmap provides strategic recommendations to maximize the affordability of the energy transition for buildings toward net-zero operating emissions by optimizing energy efficiency and maximizing resilience. More specifically, it proposes:

- a compelling and achievable vision for a resilient and decarbonized building stock in Canada from 2030 to 2050,
- indicators of success and measurable outcomes of benefit to society and building owners,
- illustrative case studies of buildings that align with the vision and the indicators,
- principles to inform public policy and key influencer organizations, and
- a call to action for the engineering profession to lead the transformation and establish an innovation ecosystem for the design and renewal of buildings.

The scope of the guidance applies to the construction of new buildings and the renewal of existing buildings, along with distributed energy infrastructure and demand-side measures implemented by energy utilities. The focus is on buildings and therefore aligns with provincial/territorial building and safety policy and demand-side management programs to influence the design and renewal of buildings and equipment within them.

In the introductory chapter, the scope of the Roadmap is defined, focused on buildings but extending well beyond the historic responsibilities of building design engineers. The tangible outcomes identified include a building stock that will be resilient through disasters and climate change, utilize new efficient ways of heating/cooling and powering infrastructure, achieve net zero emissions, minimize costs, maximize public safety, optimize occupant health and comfort, incorporate circularity of materials use and integrate with electrified transportation. The role of engineers is to bring technical insight into policy development processes, collaboratively, from multiple fields of expertise, and engaging with experts from multiple non-engineering fields who may be trained to work from significantly different paradigms.

In the 2030 vision chapter, the possibilities for Canada's future as a resilient decarbonized nation are presented, the present situation being contrasted against geographically similar regions at higher levels of decarbonization, while noting large differences between different provinces. Clean electricity, biogenic carbon and carbon-free fuels were noted, along with energy efficiency, district heating and cooling and electrical generation at building and community scale, as technological tools that engineers can apply to help Canada speed up its decarbonization process in the short term until 2030.

In the goals and measurable outcomes chapter, the current and potential future states were presented in a number of sub-categories such as advanced buildings integrated with renewable energy and electrified transportation, evaluability of design process and building performance, buildings' resilience in simulated and in real events, grid decarbonization, and clarification and rationalization of codes governing the built environment, including transition to performance-based codes. Building Codes and electrical codes need to work together to enable technologies such as on-site generation and storage, backup power and integration with electric vehicles. An urgent item is introduction of thermal storage (including thermal mass) in the building codes as it relates to resilience parameters such as building time constants. The introduction of electric vehicles, with their energy storage, energy flexibility services for smart grids and potential role in emergency power generation in extreme weather events need to be addressed in building and electrical codes.

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The case studies chapter summarizes examples of three novel and high-performing community-scale or building projects in Alberta, Ontario and Quebec. Drake Landing Solar Community in Alberta delivers energy and decarbonization performance similar or better to that of Sweden's overall building stock based largely on solar thermal seasonal storage, achieving nearly 100% solar fraction for heating. The West 5 sustainable community in London Ontario, with energy efficient buildings and extensive use of photovoltaic solar panels and integrated electric vehicles, demonstrated that innovations in microgrid business models and adaptations to code limitations are necessary to efficiently integrate renewable energy into communities. The Varennes library in Quebec, by exporting solar electricity from a building-integrated photovoltaic system to the grid, displaced more primary energy through photovoltaic generation than electricity imported from the grid in an average year, thereby achieving net zero energy performance. Each of these three case study projects accessed funding, directly from federal sources and/or through federally funded academic collaborations or federal agency research programs. Existing buildings case studies are under development for the final Roadmap.

In the market uptake chapter, decarbonization certification programs are overviewed and recent progress is summarized. ASHRAE has recently released a major position paper on decarbonization, which is also reviewed with key positions and recommendations highlighted.

In the principles chapter, a detailed description is given of five principles that can guide policy development to achieve the vision of decarbonized Canada. These principles include integration of demand and supply side resource planning; performance outcomes that foster competition and enable innovation; allocation of jurisdictional and institutional responsibility; leveraging building lifecycle investment triggers; and facilitation of data-driven, outcomes-based policy-making.

The Canadian Academy of Engineering invites professional engineers across Canada to review these five principles and identify connections with their own work. The work of decarbonizing Canada will require change in every area of engineering and will prompt exploration of connections between many areas of engineering that had formerly been treated as disconnected. Whereas in the past, code compliance represented adequate diligence as a design practice, engineers now need to understand the changing climate and projected future climate data and its impact on the construction sector, its changing risk assessment and risk management requirements, the pace at which resilient decarbonization needs to occur and how this rapid change necessitates dynamic policy development processes and anticipation of code evolution.

The integrated resource planning contemplated in Principle #1 will require engineers to bring a thorough knowledge of both demand-side and supply-side measures to increase buildings' performance, enabled by holistic public policy. Engineers can review their own area of expertise and identify what broad-brush and detailed numbers they would need to know, to feed into a collaborative process of planning that considers not only decarbonization but also policy goals such as energy system reliability, safety, housing supply, public health (indoor air quality), economic renewal, flexibility/adaptability and resilience.

Principle #2 further focuses attention on multiple performance outcomes that can be used for evaluating trade-offs when considering conflicting priorities. Engineers can advance better solutions with more co-benefits when they use their knowledge of performance metrics in multiple aspects of building design to design for performance rather than following prescriptive requirements. Engineers can also choose to address the fragmented responsibility for buildings by being involved with management of buildings, rather than limiting

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their scope to design and construction at the new build and major renovation stages. Involvement in the operation of buildings will enable engineers to get access to building performance information that can inform improvements in the design process. For example, some design strategies accepted under prescriptive codes will become less effective as climate change continues; engineers who are guided by performance-based codes and aware of actual performance numbers can work with academe, equipment vendors and building operators to find more suitable strategies. This innovation ecosystem approach will promote greater efficiency in climate adaptation than with prescriptive codes, and regulatory authorities will have less difficulty harmonizing across jurisdictional boundaries. To support competition, engineers can communicate difficulties to regulatory authorities as performance shortfalls, rather than revealing specific strategies that may be proprietary to the design firm involved.

Principle #3 focuses on an orderly transition to building codes and energy strategies of the future with governments working together to allocate responsibility to jurisdictions and institutions that have the greatest capacity and by avoiding fragmentation. Engineers working in building design, but also engineers working in all areas that are touched by the extended influence of the built environment, have a vested interest in this orderly transition, working to serve clients over the coming years with a minimum of code confusion or unexpected deficiencies. Engineers can offer their help in this transition and can keep their eyes on the prize of a smooth process toward a hoped-for future where codes will be harmonized between levels of government and across jurisdictions, and responsibility is allocated to the highest practical level of governance.

Principle #4 supports an alignment of timing of building improvements across the existing triggers for investment in buildings during their life-cycle, thereby achieving economies of scale. Because of improved labour efficiencies, applying this principle could reduce overall fees to building design engineers. However, it would make updating buildings for decarbonization more financially feasible, and for this reason engineers are asked to act on the principle.

Principle #5 takes up in greater detail the question of the collection, analysis, synthesis and use of building performance data. Building design engineers are invited to take on the opportunities and burden of gathering data that can support an improved orderly transition to a new building stock and energy system. Data can be used to confirm code compliance, to prompt review of building efficiency or health and comfort, or to highlight proven market value of higher-performing buildings, including providing energy flexibility in their demand to smart grids and optimizing integration of buildings and electric vehicles. In turn, data can be used to inform future building and electrical codes.

The figure below summarizes an example of how professional practice can evolve to support one of the goals and measurable outcomes sought by this Roadmap. This can serve as a Roadmap for professional engineers, along with the other professions supporting the buildings sector such as professional planners. The orange boxes on the left depict individual actions that support the goal in the blue box on the right. The middle, white boxes represent opportunities for continuous improvement over time.

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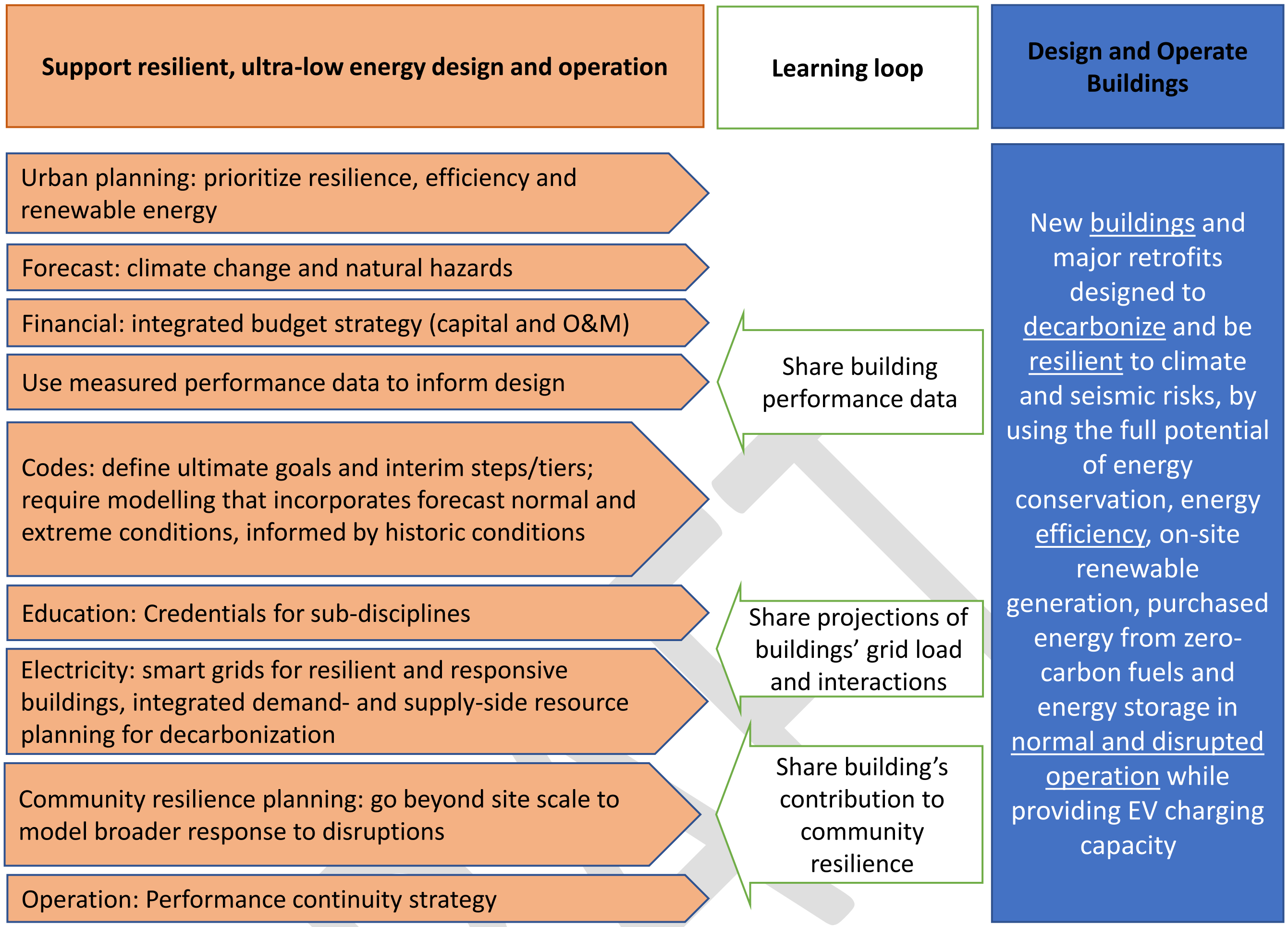

Support resilient, ultra-low energy design and operation

- Urban planning: prioritize resilience, efficiency and renewable energy
- Forecast: climate change and natural hazards
- Financial: integrated budget strategy (capital and O&M)
- Use measured performance data to inform design
- Codes: define ultimate goals and interim steps/tiers; require modelling that incorporates forecast normal and extreme conditions, informed by historic conditions
- Education: Credentials for sub-disciplines
- Electricity: smart grids for resilient and responsive buildings, integrated demand- and supply-side resource planning for decarbonization
- Community resilience planning: go beyond site scale to model broader response to disruptions
- Operation: Performance continuity strategy

Learning loop

- Share building performance data
- Share projections of buildings’ grid load and interactions
- Share building’s contribution to community resilience

Design and Operate Buildings

New buildings and major retrofits designed to decarbonize and be resilient to climate and seismic risks, by using the full potential of energy conservation, energy efficiency, on-site renewable generation, purchased energy from zero-carbon fuels and energy storage in normal and disrupted operation while providing EV charging capacity

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Acknowledgments

The authors gratefully acknowledge Advisory Committee members Marianne Armstrong from National Research Council, Harhsan Radhakrishnan from Engineers and Geoscientists BC and Waleed Giratalla from the Federation of Canadian Municipalities for providing substantial and extensive input to the Roadmap. The authors would like to acknowledge the support of the major partners - the Canadian Academy of Engineering (CAE), Concordia University's Centre for Zero Energy Building Studies (CZEBS), the Pacific Northwest Economic Region (PNWER) and the University of Victoria's Civil Engineering Department.

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1. Introduction

This Roadmap provides strategic recommendations to maximize the affordability of the energy transition for buildings toward net-zero operating emissions by optimizing energy efficiency and maximizing resilience. More specifically, it proposes:

- a compelling and achievable vision for a resilient and decarbonized building stock in Canada from 2030 to 2050,
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- a call to action for the engineering profession to lead the transformation and establish an innovation ecosystem for the design and renewal of buildings.

The scope of the guidance applies to the construction of new buildings and the renewal of existing buildings, along with distributed energy infrastructure and demand-side measures implemented by energy utilities. By extension, the scope is on operational carbon emissions from buildings. The authors also note the emerging area of embodied carbon in building materials and equipment which is outside of the scope but necessary for consideration. The focus is on buildings and therefore aligns with provincial/territorial building and safety policy and demand-side management programs to influence the design and renewal of buildings and equipment within them.

The co-authors' perspectives include those of practicing engineers in the buildings and energy utilities (demand-side management) sectors, academic researchers, a government policy practitioner, and the Canadian Academy of Engineering (CAE), a non-profit professional association and the primary sponsor of this work.

The CAE aims to inform a timely, standardized, reliable and affordable transition for the buildings sector for net-zero greenhouse gas emissions, while increasing resilience against the consequences of climate change and other natural disasters, including acute impacts from severe weather events and earthquakes, and recurring effects of climate change such as flooding, wildfires and extreme weather events. The challenge is to accelerate and optimize the complex, multi-stakeholder transition to net zero carbon, resilient communities, while maintaining public safety and reliability of energy supplies, along with emphasizing innovation, affordability, and high quality of life. Another challenge is to coordinate across multiple levels of government and to harmonize the work of dozens of institutions to support a common direction that maximizes the interests of Canadians.

Potential outcomes of this Roadmap and the proposed transition for the buildings sector could include:

- Enhance energy efficiency, load management and interaction with smart energy networks;
- Achieve net-zero emissions from buildings in advance of 2050;
- Minimize the cost to building owners, occupants, taxpayers and ratepayers;
- Enable opportunities to mitigate transportation emissions; and,
- Install on-site clean energy and/or storage to increase buildings' resilience of energy supply.

The intent is to inform related national strategy, policy, legislation/regulation and investment of government, building and energy codes and standards, guidelines for professional engineering oversight (often in concert with other professions) of building design, construction, management and renewal, and energy and load management in buildings, including distributed energy generation and storage and electric vehicle (EV) charging/integration.

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The intended audiences are primarily the following:

- Governments;
- Standards development and verification organizations;
- Agencies delegated to implement legislation for buildings; and,
- Professional regulators and associations.

The guidance is intended for all Canadian jurisdictions, regardless of the economic factors, demographics, condition of buildings, construction activity and specific mandates of individual governments at all five levels – federal, provincial, territorial, Indigenous, regional/municipal.

From a social and economic standpoint, the guidance aims to:

- Address equity considerations broadly (e.g., provide access to solutions across all buildings and alleviate energy poverty risks via energy efficiency);
- Mitigate risks for vulnerable buildings (e.g., failure due to natural hazards or economic obsolescence due to substandard energy efficiency) and their users;
- Avoid unintended consequences that compromise other values (e.g., energy supply reliability);
- Advance reconciliation with Indigenous peoples;
- Maximize regulatory efficiency and minimize unnecessary market interventions by governments;
- Optimize roles for institutions and registered professionals that implement legislation;
- Enhance opportunities for leadership and circular economy benefits that could accrue to resilient construction, real estate and building operations industries; and,
- Maximize the value of engineering practice to support the vision and partner with governments and institutions.

The concept of a Roadmap was established in 2014 at the Pacific Northwest Economic Region (PNWER) Summit [1]. The concept was elaborated at subsequent PNWER Summits in 2017 [2], 2018 [3] and 2022 [4], along with a PNWER sponsorship of research that will inform Phase 2 on embodied energy and emissions of buildings.

The Canadian Academy of Engineering became the primary sponsor of this work in 2019 that broadened it to a national initiative, including a 2019 Thought Leaders Forum [5] and Symposia in 2020 [6] and 2021 [7] organized by Concordia's Centre for Zero Energy Building Studies (over 500 participants in total), and the PNWER Panel Discussion in 2022. A wealth of evidence was documented in the peer-reviewed published proceedings of the 2020 Symposium [8] (Appendix H).

This Roadmap aims to align with and support Canada's 2030 Emission Reductions Plan [9] and comprehensive Provincial policy documents such as BC's CleanBC Roadmap to 2030 [10] and Nova Scotia Environmental Goals and Climate Change Reduction Act [11].

The Roadmap incorporated feedback from an advisory group comprised of representatives from industry, governments, professional and standards development organizations and academia – see Appendix A. It was also informed by input at the Pacific Northwest Economic Region Summit in Calgary in 2022 [12]. The draft Roadmap were shared with Canadian Academy of Engineering Fellows and Indigenous housing and energy sector leadership organizations for comment in mid-2023.

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2. A 2030 Vision for Canada

Chris Kennedy and Andreas Athienitis

The development of low-carbon, climate-resilient built environments in Canada, can be envisioned by framing the essential role of buildings and communities in the context of a broader energy transition. Climate change adaptation and mitigation necessitate a transformation of Canadian energy systems. Greenhouse gas emissions related to energy used in buildings accounted for 87.8 Mt of Canada's GHG emissions in 2020 [13], increasing to about 130 Mt when emissions related to buildings' use of off-site electricity generation are included [9]. There is a need to change the design of buildings, land use, transportation systems and industry with an emphasis on eliminating fossil fuels, increasing energy efficiency and bolstering resilience.[1] For the design of new buildings, and retrofit of old, this means rigorously adding these attributes – resilient, carbon-neutral and ultra low energy – to existing building requirements, such as safety, thermal comfort, health and adequate indoor air-quality.

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Transformation of Canada's energy supply system will entail the elimination of GHG emissions from fossil fuel combustion by increasing the use of clean electricity, biogenic carbon and carbon-free fuels (Figure 1). There are two distinct strategies for decarbonization. Electricity generated from renewable or carbon-free sources will increasingly be used through the electrification of buildings, transportation and industry, especially where power requirements are low to medium intensity. The other strategy entails the use of biogenic carbon, such as biomass or biofuels, or other carbon-free fuels, such as hydrogen derived in a manner that is free of carbon.

emissions.

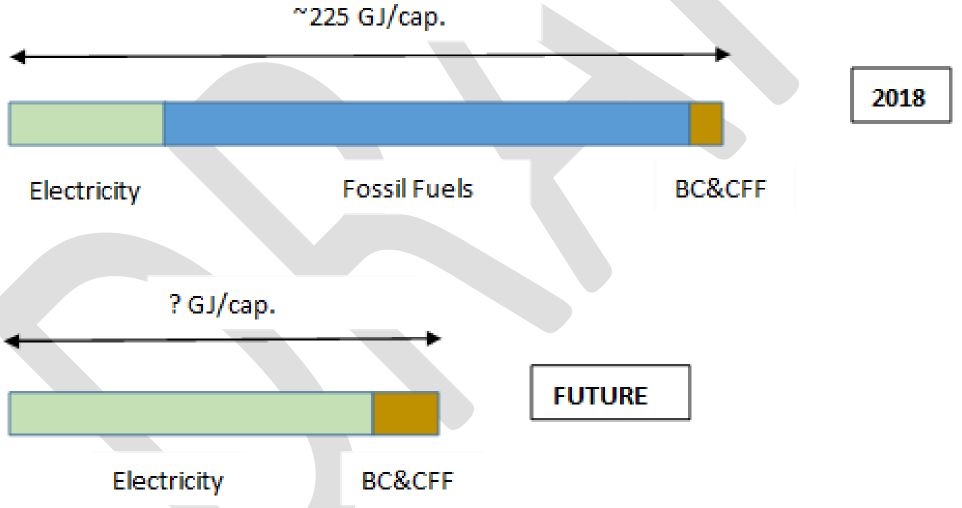

Figure 1: Conceptual transformation of Canada's annual end-use energy under deep decarbonization (BC = biogenic carbon; CFF = carbon-free fuels) in GJ per capita per year.

To meet its climate goals Canada must greatly reduce annual per capita energy consumption while replacing conventional fossil fuels with electricity, and biogenic or carbon-free fuels. Another critical aspect of Canada's energy transformation will be substantial improvements in energy efficiency, leading to a reduction in end-use energy per capita. Gains in energy efficiency will be required due to costs and possible constraints in increasing the supply of carbon-free electricity and carbon-free fuels, and limits to the availability of biogenic carbon. Some energy savings will automatically be achieved through electrification, due to the higher efficiency of

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[1] Resilience is defined as the capacity to withstand or recover quickly from a shock

electric vehicles and heat pumps, for example. Other improvements to energy efficiency will also be achieved through better building design and building retrofits. Canada can expect to reduce its end-use energy consumption from current levels of approximately 225 GJ/cap., by of the order 100 GJ/cap.

Strategies for Canada's energy system transformation and increasing energy efficiency can be seen from a comparison of Canadian energy use to Norway and Sweden. These two Scandinavian nations have climates similar to many Canadian provinces but are on average more advanced in addressing climate change than most of Canada. Sweden employs relatively equal proportions of energy from electricity (44 GJ/cap.), fossil fuels (43 GJ/cap.), and biofuels/waste & heat (46 GJ/cap), while its total per capita end-use energy (132 GJ/cap.) is 58% of Canada's (Figure 2). Whereas Sweden has a notably high use of biofuels, Norway has a greater emphasis on electricity use (78 GJ/cap.), while also having a lower per capita energy use (162 GJ/cap.) than Canada. There is potential for Canada to follow both the electrification and biogenic / carbon-free fuels approaches in its energy system transformation.

Differences between the electrification strategy and the biofuel strategy are particularly apparent in the buildings sector. In both Norway and Sweden, only about 5% of energy use in buildings comes from fossil fuels (Figure 3). Canada currently uses about eleven times more fossil fuels per capita than Norway in buildings – and seventeen times more than Sweden, although there are significant differences among Canadian provinces. In Norway, about 80% of the building energy supply comes from electricity, largely generated by hydropower. Electricity is also the largest source of energy for Swedish buildings (25 GJ/cap.), but biofuels, solid waste and heat supply over 40% of energy requirements, often through district-heating systems. Canada can draw upon the success of these Scandinavian countries in decarbonizing its buildings, while also having several different pathways suited to the different regions suitable to the large size and diversity of Canada. Land use and transport are also major factors in the different pathways.

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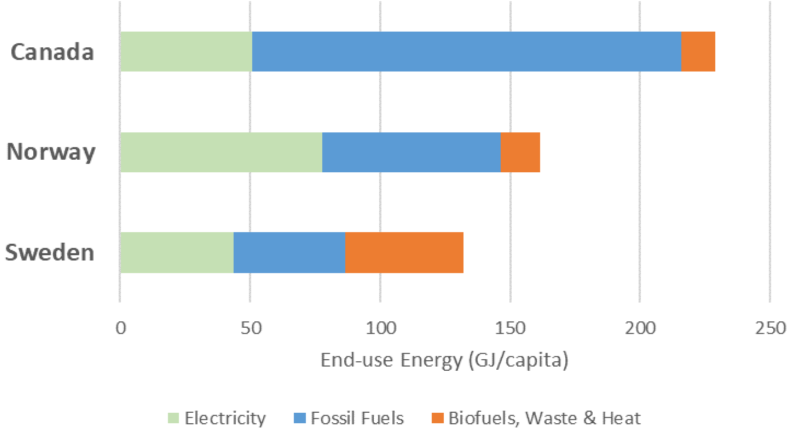

Figure 2: Comparison of per capita total end-use energy by source for Canada, Norway and Sweden in 2019. (Energy data from IEA [14]; population from the World Bank [15]).

The GHG emissions comparison for several countries, including Sweden and Norway is given in Figure 4a, while the comparison between provinces is given in Figure 4b. Floor area per capita is another important parameter that needs to be considered as it relates to density of the urban form and land use.

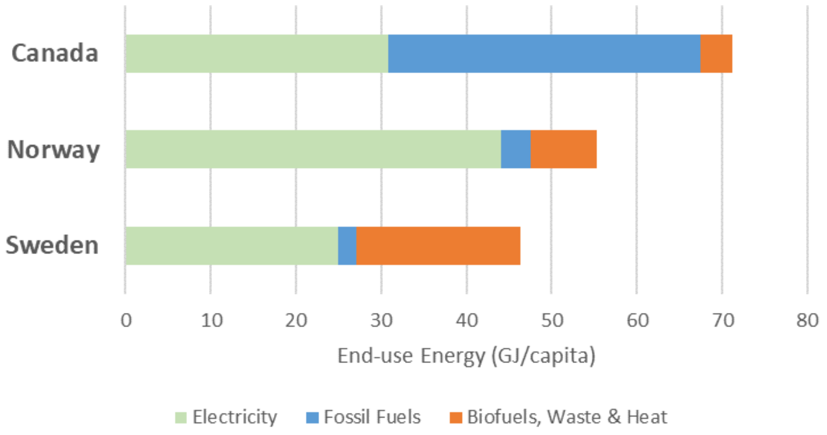

Figure 3: Comparison of per capita building energy use by source for Canada, Norway and Sweden in 2019. (Energy data from IEA [14]; population from the World Bank [15]). Includes energy use by residential, commercial and institutional buildings.

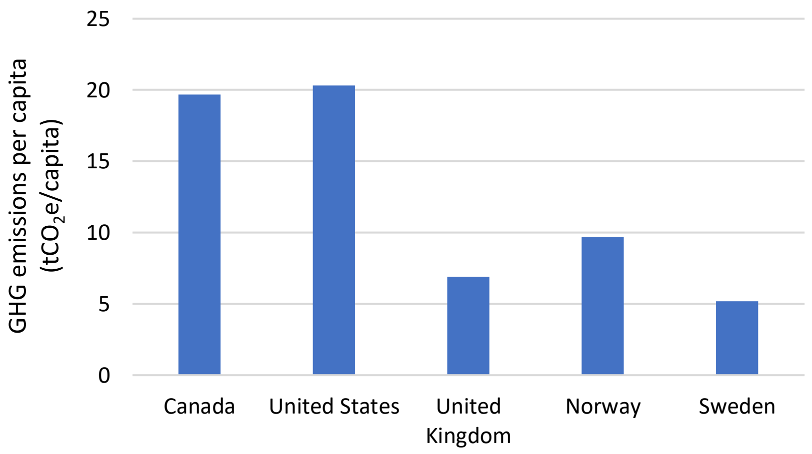

Figure 4a: Total production-based GHG emissions per capita by country in 2018 [16].

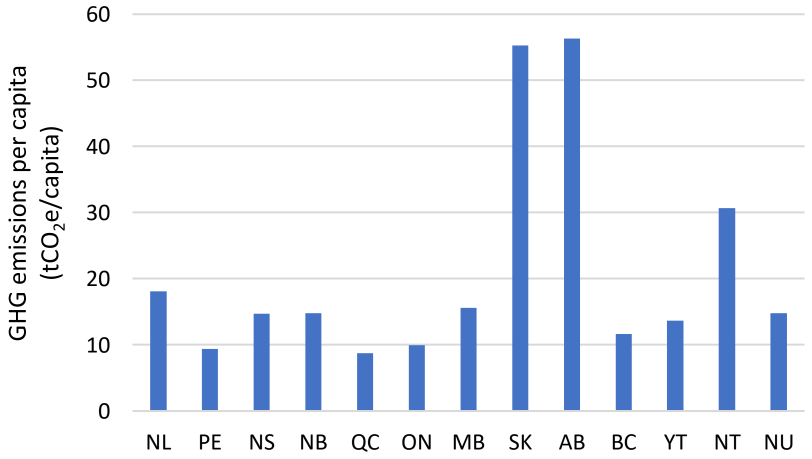

Figure 4b: Total production-based GHG emissions per capita by Province and Territory in Canada in 2020 [17].

GHG emissions vary significantly depending on the province's economic activities, in particular the oil and gas sectors and the type of energy used. Figure 4b shows how Alberta and Saskatchewan produce almost six times more GHG emissions per capita than Quebec and Ontario due to the large oil and gas industries and the widespread use of fossil fuels for power generation and heating. The average carbon intensity of electricity in Canada is just over 100 t CO2e/GWh. Through access to hydropower, nuclear power, and renewables, many of the provinces have low-carbon electricity – including the three most populated provinces. Only in Alberta, Saskatchewan, Nova Scotia and New Brunswick are electricity grids highly dependent on fossil fuels, making decarbonization through electrification more challenging. There are plans for phasing out coal-powered electricity in Alberta, Nova Scotia and New Brunswick, but decarbonizing buildings through electrification in all provinces will necessitate substantial use of building or community-scale renewable energy generation for resilience requirements.

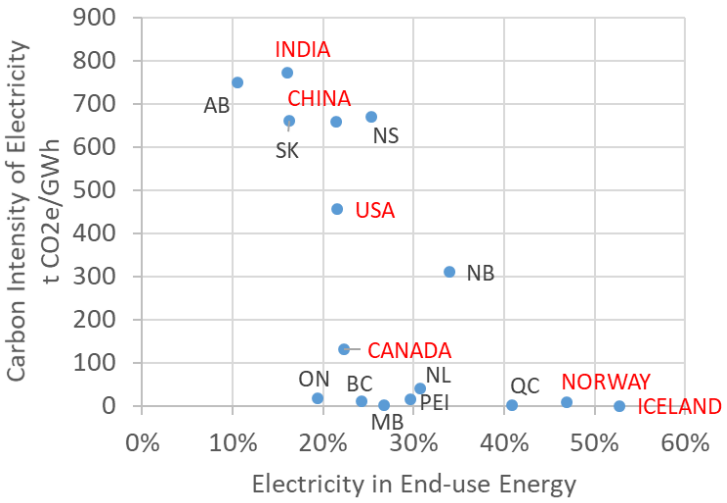

Figure 5: Progress of Canadian provinces towards carbon-free electrification. End-use energy is for all sectors. (adapted from Ref. [18]).

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The solutions needed to achieve decarbonization depend on the energy profile of the load being decarbonized, the characteristics of the current energy supply system, and the local renewable energy resource availability. For instance, provinces with a hydro-dominant power supply can greatly benefit from implementing energy efficiency to free up large amounts of low-carbon electricity that can be used to decarbonize elsewhere. This reduces the need for new low-carbon energy supply infrastructure, which often carries a higher cost and material consumption (embodied emissions) than implementing energy efficiency measures. For example, distributed solar energy generation on buildings is ideal for providing the electricity needed for powering heat pumps or electric vehicles that will be increasingly at home with more teleworking. It is quite feasible for homes and small institutional buildings such as the Varennes net-zero energy Library all-electric building (see case studies section) to power several EVs, thus helping decarbonize the transportation section in addition to the building sector.

The Resilience Imperative

Generation and storage of renewable and zero-carbon energy at the building and community scales will be important in all provinces, due to the imperative to make our communities more resilient under climate change, with an increasing number of extreme weather events. One of the challenges in phasing out fossil fuels, under decarbonization, is that a reduction in the diversity of energy sources or carriers makes communities more vulnerable to extreme events, such as forest fires or ice storms (Figure 6) and flooding, wind storms and wind-driven rain. This challenge may become particularly critical if provinces pursue strong electrification strategies only using grid-scale electricity supply. A community with one hundred percent of its end-use energy coming from provincial electricity grids is highly vulnerable to shocks.

Figure 6: Experiences from forest fires [19] to ice-storms [20] have shown how vulnerable electricity grids can be to extreme weather events. Building and community scale electricity generation and storage will be essential for making communities resilient to the shocks of extreme climate events.

The need for backup generation capacity remains a fundamental requirement for decarbonized energy supply systems. There are three strategies that Canadian communities can employ to remain resilient to climate change shocks and other emergencies such as earthquakes while phasing out the use of fossil fuels:

Building-scale electricity generation & storage, EV integration and grid support. By combining building-integrated photovoltaics and battery storage with advanced energy efficiency, buildings can be designed to generate and store much of their electricity needs. In experiencing major disruptions to provincial power grids, buildings can be designed to maintain basic essential systems using their solar systems and energy storage systems such as batteries (or connected EVs). Energy storage is also important in optimizing energy flows with building needs and smart grids, thus facilitating penetration and integration of intermittent renewable energy resources (wind, solar). Increasingly, buildings will be active prosumers in the power system that can play the role of local energy storage and production, adjusting their behavior to contribute positively to the operation of the grid, and hence contributing simultaneously to the resilience of the smart grid affordably and efficiently. The EVs may function as backup power sources in the future.

Community-scale electricity generation & storage. In higher-density communities or regions with poor solar access, buildings can be connected to community-scale smart grids [21]. Buildings with larger rooftops, such as schools and warehouses can be used as a source of community electricity generation and storage. Other local-scale power sources such as wind, tidal, and biomass can also still be harnessed when provincial power grids are impacted.

Biogenic methane & carbon-free fuels. Other sources of carbon-free energy, other than electricity, can be designed and utilized in ways that provide resilience to acute shocks and chronic stresses. Examples include the

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use of wood stoves and biogenic methane as a backup to heat pumps, and district energy systems powered by biogenic methane and/or providing hydrogen storage.

The new low-carbon energy supply will include a mix of building-integrated renewable energy generation and storage, and community-level centralized generation and storage. The power can be supplied by either intermittent renewable energy resources, such as solar, plus storage or stored dispatchable energy resources such as biomass and waste. Electricity storage is crucial and must be able to provide electricity during periods of low generation, such as a few days/weeks of low wind and solar energy availability, or during emergencies. The supply of backup power can either be from stored energy resources (e.g. biomass, hydrogen, thermal storage) or using renewable natural gas/biogas (biomethane/biogas) and hydrogen from the pipeline network. Such a pipeline can be transformed into a net-zero carbon backup energy source if the fossil natural gas is replaced with synthetic or biologically derived renewable methane, including hydrogen enrichment, provided that the pipeline has sufficient durability.

For biogenic methane the emissions at the point of combustion in a building need to be fully offset by measurable, incremental, and verified reductions in greenhouse gases at the source of the biogenic materials. This raises the question of tracking “scope 3” emissions and retiring Scope 3 emission reductions after the environmental attributes of biogenic methane are sold to building owners, managers and tenants who have no physical control of those Scope 3 emissions. Buildings owners can control Scope 1 emissions, while the energy utility providing purchased energy controls Scope 2 emissions [121].

Seasonal solar thermal energy storage such as at the Drake Landing Solar Community (see Case Studies section) provides the opportunity to store solar energy when it is abundant in the summer for use in the winter (seasonal energy storage) and a strong basis of thermal resilience.

Among the three options to increase the energy resilience of buildings, there is an opportunity for a combination that right sizes capacity of equipment with the cost and resilience of fuels. For example, battery storage operating critical electrical loads and system control with backup fuels providing space heating.

The transport sector is among the largest contributors to GHG emissions in Canada [13]. Within the great challenge of mobility decarbonization, opportunities arise. The energy stored in battery and hydrogen fuel cells vehicles, in addition to energy stored at future refuel stations, provides the opportunity to store large amounts of renewable power that can serve as backup power to support the grid in case of emergencies, but also hold the prospect of assisting the grid in times of need such as periods of peak power demands and/or to store excess power generation. Since the new low-carbon energy supply will require backup energy, early-stage planning to integrate the new mobility infrastructure could lead to higher energy and resource use efficiencies and/or lower overall costs. Ideally, the various solutions needed at different stages should be implemented in a gradual, phased manner and appropriately weighed in the decision-making process based on key performance indices such as life cycle cost, emissions analysis, and supply chain criticality.

The other dimensions of resilience of buildings against climate change and other natural disasters include the ability of the building envelope to withstand extreme weather events and flooding from structural, moisture control and durability standpoints, the capability of the ventilation system to maintain indoor environmental quality to prevent entry of, filter and remove contaminants such as forest fire smoke, ground-level ozone (i.e., smog), toxins, mold, viruses and others, the maintenance of healthy indoor living environments, particularly regarding overheating, and finally the strength of the building to withstand forecast seismic events, prevent

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collapse and preserve life-safety. In some cases building resilience includes enabling post-disaster operations, going beyond life-safety and health.

This Roadmap does not address the resilience aspects covered in the previous paragraph, and focuses only on the resilience of energy supplies for buildings, also a necessary component of disaster response and recovery.

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3. Goals and Measurable Outcomes

Rosamund Hyde

A key Canadian climate-change-related goal is to reduce building-related emissions to net zero by 2050. Many interacting approaches involving energy efficiency, renewable energy and system integration will be required to achieve the ultimate goals of resilient, ultra-low energy, net-zero emissions buildings. Designers working on new buildings and major retrofits will need to develop skills in modelling at site and city scales to understand how each building during changing future conditions will interact with the systems around it and how the whole community will perform in normal operating conditions and in disruptive events, for example, air pollution, wildfires, earthquakes, hurricanes, flooding, heat waves, power outages, water shortages and pandemics, separately or in combination. Designers' increased capacity for simulation is necessary to support and be supported by new strategies for code development and enforcement at all levels and across jurisdictions, as well as utilities' movement to a decarbonized grid. Alignment will need to be improved between the skills of community planning and building design professionals, sub-disciplines including electrical design, and their roles and responsibilities in the process of designing, commissioning, and operating buildings.

The main transitions foreseen in meeting the resilient, ultra-low energy, net-zero emissions goals for buildings are summarized in Table 1. These are presented in terms of preliminary performance "Metrics" that can be determined by and replicated by thousands of professional practitioners across Canada. They represent a means of determining whether the building sector is moving in the right direction toward the vision presented in the earlier chapter. The Metrics are science-based, not political, and should be widely accepted across Canada for different building types and across the building sector stakeholders. As such, they are suitable for measurement by building sector professionals. The authors assert in chapter 5 that the collection of data on these areas of performance is a high priority for the short term, possibly as a requirement of building and/or electrical codes in Canada. Not only will the Canadian building sector be able to verify its transition toward the vision, but the metrics could also inform future government policy.

Building Codes and electrical codes need to work together to enable technologies such as on-site generation and storage, backup power, integration with electric vehicles. An urgent item is introduction of thermal storage (including thermal mass) in the building codes as it relates to resilience parameters such as building time constants. The introduction of electric vehicles, with their energy storage, energy flexibility services for smart grids and potential role in emergency power generation in emergencies need to be addressed in building and electrical codes.

Table 1: Main transitions foreseen in meeting the resilient, ultra-low energy, net-zero emissions goals for buildings.

Transition	**From**	**To**	**Metric**
Net-Zero Emissions			
Toward high-performance, efficient buildings with integrated energy storage,	Buildings designed to use only grid electricity and on-	New buildings and major retrofits designed to decarbonize by using the full potential of energy conservation, energy	Fraction of new buildings and major retrofits using the full potential of energy efficiency, energy storage, renewable energy and

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renewable energy use and electric vehicle charging capacity	site consumption of fossil fuels[2]	efficiency, on-site renewable generation, purchased energy from zero-carbon fuels and energy storage in normal operation while providing EV charging capacity [22] [23]	providing adequate EV charging capacity
	Site and regional renewable energy recognized to a limited extent	Site and regional renewable energy is prioritized in urban planning and early stage design with respect to building orientation, selection of envelope strategies, windows, landscaping and on-site renewables [24]	Average annual fraction of operating energy for buildings in Canada under normal conditions supplied by site or regional renewable energy
	Smart buildings and microgrids not optimally connected with the grid	Smart buildings and microgrids help stabilize and decarbonize the grid and reduce the need for new central power plants [23]	Fraction of smart buildings that are connected interactively to smart grids
Toward coordinated grid and built environment decarbonization strategies [25]	Grid decarbonization path uncertain	Utilities commit to specific grid decarbonization path(s) informed by projections of changes in buildings' grid load and interaction [9]	Fraction of grid energy delivered to Canada's consumers through utilities with confirmed decarbonization commitment
Increase Energy-related Resilience			
Toward buildings designed for predictable resilience at site and community scale	Buildings designed for normal operation	Buildings designed to provide safety and comfort conditions during disruption [26]	Fraction of new buildings designed to be resilient (initially to generate their power and heat for a certain period)
	Building response to disruptions unpredictable	Building response to disruptions designed using modelling [27]	Fraction of new buildings with predictable response to disruption
	Limited urban modelling, limited data integrated from building modeling	Community response (including building response) to normal and disrupted operations is reliably modelled using calibrated integrated urban platform [28][131]	Fraction of Canada's urban population living in communities with reliable verified urban modelling
Change Design Process			
Toward building design and	Training and trained supervision	Established subdisciplines that are adequately trained,	Fraction of advertised positions for credentialled

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[2] Building codes only mandate efficiency standards, not fuel choice, and electric codes focus on safety objectives only

evaluation process that supports accountability and continuous improvement in changing environment	for subdisciplines in low supply	staffed, and certified (building energy modelling, energy manager, airtightness, envelope, comfort, climate risk assessment)	subdisciplines filled within one month
	Buildings designed without modelling or with only compliance modelling	Building performance modeled (including changing climate conditions) to optimize whole-building performance as part of the design process [29]	Fraction of new buildings designed using modelling and simulation software as a design tool, accounting for future climatic conditions
	Building performance not tracked	Building performance tracked, made public [30] and used to calibrate the as-built model and to verify and optimize performance, leveraging Building Information Modelling capability where possible [31]	Fraction of 3-year-old buildings with BIM-based calibrated model
	Fragmented responsibility for building's performance over the service life	Technical continuity is ensured between the design, construction, commissioning, and operation phases by reducing professional silos and improving warranty approaches.	Fraction of new buildings with a technical continuity strategy in place.
	Fragmented budgeting between capital costs and operating costs	Integrated budget strategy to ensure energy conservation measures are covered in the capital budget	Fraction of new buildings with integrated budget strategy in place
Evolve Building Energy Codes and Electrical Codes			
Towards building and electrical code strategies that support near and long-term goals	Multiple definitions of net-zero energy complicate code development and adoption	The definition adopted for net-zero energy and net-zero energy ready building [32]	Level of acceptance of definition by construction and utility community
	Codes based on past performance of a reference building under past conditions	Future-oriented building codes that are performance based and reference absolute targets (e.g., net-zero carbon) [33]	Fraction of new or renewed floorspace for which the jurisdiction has signalled intention to adopt the ultimate goal, along with stepping stones to reach that goal via tiers
	Airtightness is the only code	Occupancy approval based on performance-based	Fraction of new and renewed buildings receiving

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	requirement that can be proven in advance of an occupancy permit	building codes, proving compliance by reliably modelling performance under anticipated changing conditions	performance-based code approval with verification of performance during a commissioning period [132]
	Codes and standards lodged with levels of government and particular regulations for reasons of history and inertia	Allocate responsibility to governments and regulations in a manner that supports optimized energy performance of buildings on both the demand- and supply-sides [25]	Code policy is reviewed and updated throughout levels of government and jurisdictions and a policy Roadmap is established for each provincial and territorial jurisdiction

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4. Case Studies from Buildings and Communities

Andreas Athienitis and James Bambara

The three selected Canadian case studies overviewed in this section have been well documented and contain major innovations in project development, design and operation, to achieve close to net-zero energy or exceed it at a building or community level. In addition, energy use and renewable energy production data are available. The three projects are the following:

1. Drake Landing Solar Community (Alberta)
2. West 5 Net-zero Community and Smart Grid Project (London, Ontario)
3. Varennes Library (Varennes, Quebec)

They demonstrate some of the technological possibilities in Canada towards decarbonization through combinations of very high energy efficiency measures, seasonal solar energy storage and building-integrated renewable energy systems, at the time that these projects were built. They contain important lessons learned on the evolution of low-carbon buildings and communities in Canada and are useful for establishing different pathways towards carbon-neutral communities. Although the emphasis of the projects was on operational energy targets (net-zero energy based on on-site renewable energy systems), the carbon-neutral operation would also be expected to be simultaneously achieved with the net-zero energy target.

Case Study #1 – Drake Landing Solar Community

Development: An international team led by Natural Resources Canada (NRCan) has designed the Drake Landing Solar Community (DLSC) in the Town of Okotoks, Alberta. To see the DLSC through to fruition, NRCan (CanmetENERGY, the Program of Energy Research and Development and the ecoENERGY Technology Initiative) established partnerships with innovative, environmentally conscious companies that had longstanding, credible reputations within their industries. Ground was broken at the DLSC in the spring of 2005, with the system starting operation in the summer of 2007. The DLSC was the first community in North America to use seasonal storage of solar energy, which overcomes the major obstacle to the use of solar energy for space heating in cold climates – the cold temperatures and less sunlight during the winter. The project's innovation was recognized by several awards such as the energy Globe World Award (2011), the International Energy Agency Solar Heating and Cooling Program Solar Award (2013), the Canadian Solar Industries Association Solar Thermal Project of the Year (2006), the Federation of Canadian Municipalities Sustainable Communities Award for Energy/Renewable Energy (2006), and the International Award for Livable Communities Gold Award in the Environmentally Sustainable section (2005).

In Canada, approximately 86% of GHG emissions in the residential sector are generated from space and water heating due to the widespread use of fossil fuels [34]. The DLSC project was created to demonstrate the technical feasibility of achieving **conventional fuel energy savings of more than 90% by using solar energy collected during the summer to provide residential space heating during the following winter (seasonal storage)**. The solar community is comprised of **52 single-detached homes** whose space and water heating are mostly supplied by solar energy. Six different house models were available to buyers, with an average above-grade floor area of 145 m^2. The houses were built to meet Canada's **R-2000** performance standard, with upgraded building envelopes, including higher insulation, low-e argon-filled double panel windows, energy

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recovery ventilation, and improved air tightness and construction details. The higher standard was estimated to reduce space heating load by 30% when compared to baseline houses at the time of construction.

As shown in Figure 5, each house has two solar thermal collectors to heat domestic hot water and the adjoining garages are equipped with a total of **800 flat plate unglazed solar thermal collectors to harness solar energy for space heating with seasonal thermal storage**. A simplified schematic of the main components of the solar seasonal storage heating system is given in Figure 6. During the warmer months, the heated water is distributed from the solar collectors to the short-term storage tank and then to the seasonal energy storage system, comprised of **144 boreholes that stretch 37 m below the ground and cover an area 35 m in diameter.** As the heated water travels through the borehole piping, heat is transferred to and stored in the surrounding earth, whose temperature **reaches 80°C by the end of each summer**. When winter arrives and the homes require space heating, the heated water stored in the earth passes to the short-term storage tank in the energy centre and is then circulated to the homes through the district heating loop. A 22-kW photovoltaic (PV) array is installed on the roof of the energy centre to offset the energy used for pumps. The hot water and space heating systems are backed-up with high-efficiency gas-fired water heaters.

During the design phase, a detailed TRNSYS model was developed to simulate the system operation and optimize some of the main design parameters, such as solar collector area, short-term storage size and number and depth of boreholes. Because solar energy is collected in summer and stored for winter, the size of the solar collector area is significantly reduced compared to solar installations that are designed to satisfy short-term energy needs during winter. The ability to easily access detailed system operating data and compare actual operation against predicted is extremely valuable for the successful commissioning and the efficient operation of energy systems such as that used at Drake Landing.

Monitored operation: DLSC operation has been closely monitored since its commissioning in 2007 and the performance over 10 years can be found in Ref. [35]. The boreholes require time to charge with solar heat, resulting in an initial performance below what can be expected when the system has achieved steady operating conditions. After approximately 3 years, the average borehole temperature reached 80°C by the end of each summer and supplied **over 85% of the houses' space heat**. The combination of solar hot water and efficient fixtures and appliances saved 40-60% of the gas used for hot water. The use of solar energy displaces a significant amount of natural gas for heating which **reduces GHG emissions by approximately 5 tonnes per house** [36].

Lessons learned: The optimal size of a seasonal energy storage like Drake Landing in a region like Alberta depends on the price of natural gas, so a larger system could be more cost-effective. Subsequent feasibility studies show that larger systems of similar design can deliver solar energy at about half of the cost compared to Drake Landing due to economies of scale. Including the DLSC builder, land developer and municipality in the project planning process from the beginning helped build confidence in the project regarding the market acceptance of the unfamiliar technologies being applied. In addition, **early design stage simplified modelling tools** are needed.

Overall, the system has successfully **demonstrated the reliable operation of a high solar fraction solar district heating system with seasonal thermal storage in a very cold climate**. In addition to overcoming some of the longstanding obstacles in the use of solar energy at high latitude locations, seasonal energy storage systems increase resilience as home heating could be provided uninterrupted in the case of emergencies. Equipping the

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houses with additional PV plus battery storage would ensure the seasonal storage system could operate for prolonged periods while being disconnected from the grid.

Figure 5: View of houses and adjoined garages equipped with rooftop solar thermal collectors for hot water and space heating, respectively.

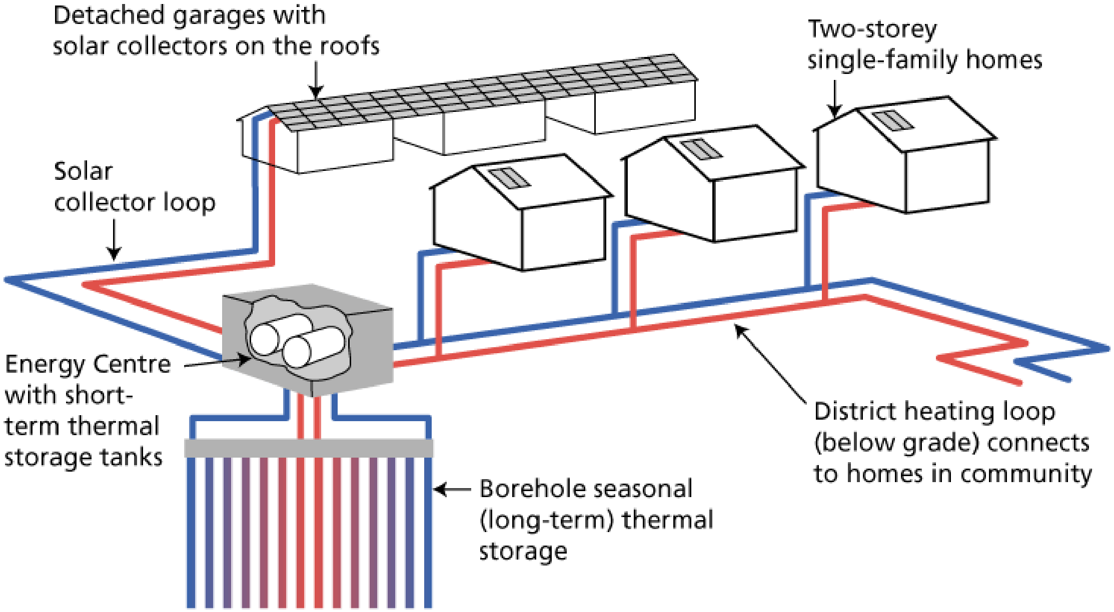

Figure 6: Schematic diagram of the solar seasonal storage heating system at Drake Landing Solar Community.

Case Study #2 – West 5 Net-zero Community and Smart Grid Project

Development: West 5 started in 2013 as an ambitious dream of s2e to develop a net-zero energy community and microgrid. Major goals were to build a mixed-use community powered by solar electricity, with electric vehicles for transportation and a microgrid concept based on a novel business concept. The energy-efficient buildings would be heated and cooled with air-source heat pumps. The team attracted Sifton Properties Limited which initiated the development in London Ontario. The team hired 90 students and worked with 11 Universities on a feasibility study to show that it is cost-effective to build communities with a lighter footprint. An initial concept for the community is shown in Figure 7. The nearly 20% completed development is shown in Figures 8 and 9.

The plan is for the entire community to consume up to about 10 megawatts of power which will be produced in the community through solar means according to Sifton Properties Limited, one of West 5's developers. That solar power will be generated from PV panels on the roofs of all of its buildings, including a parking garage, and solar arrays incorporated into many of the building's facades. When built out in 10 to 15 years, the neighborhood will have 41,800 m^2 of commercial space, a central park, and 2,000 households consisting of townhomes, condominiums, apartments and retirement residences according to Sifton Properties Limited. Initially, Sifton's objective was to create "a smart, healthy and walkable community" but its agenda expanded to include net-zero when Sifton partnered with s2e Technologies, which focuses on sustainable community development.

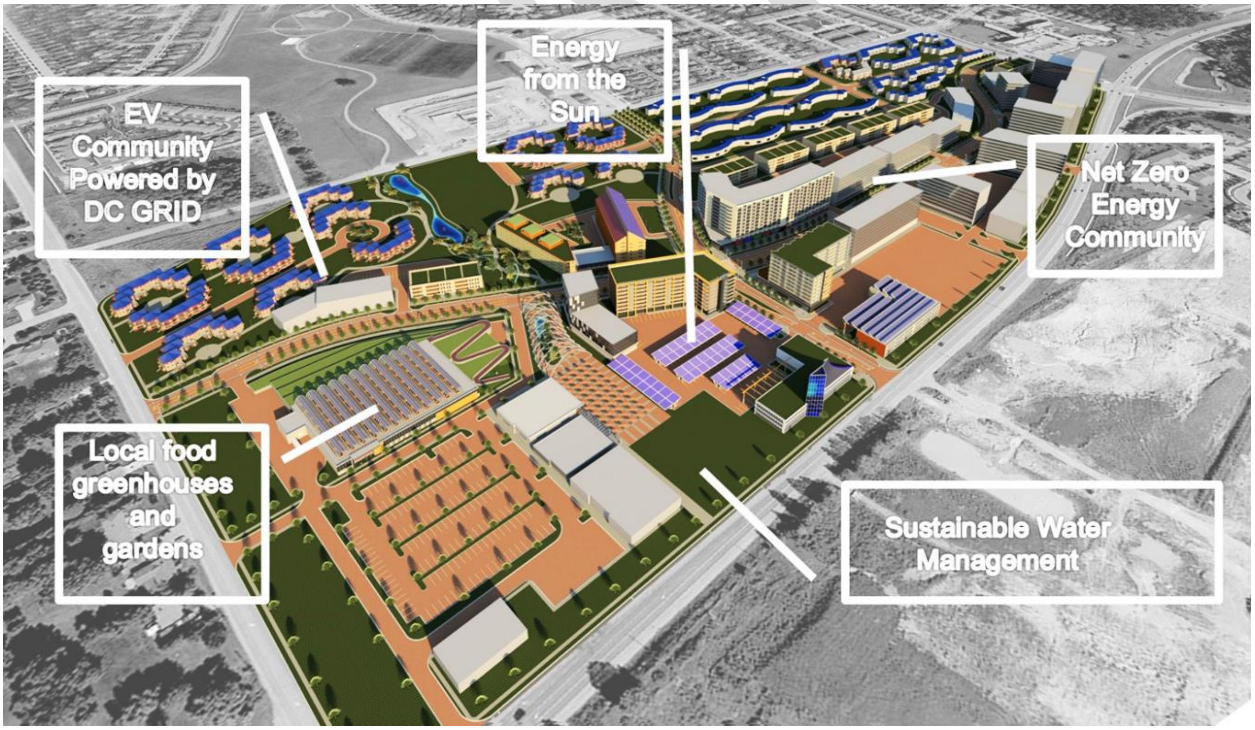

Figure 7: Initial simulation concept for the West 5 Community, in London Ontario.

The West Five Microgrid project began as a feasibility study with the Green Municipal Fund of the Federation of Canadian Municipalities. This project, number 15,053, considered the viability of implementing a microgrid within the West Five net zero community that would integrate DC-connected PV generation into the development. The study proceeded in parallel with the buildout of the 70-acre West Five community in London, Ontario, and was focused on means for integration of PV production behind-the-meter that would couple with DC loads such as EV charging and street lighting, as well as DC loads within the buildings. With the support of a research team at Western University in London, dynamic modeling with PSCAD was undertaken to understand the implications of a behind-the-meter DC loop within the West Five community.

Figure 8: The partly completed West 5 development will be the first net-zero mixed-use community in Ontario.

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Hybrid DC/AC microgrid: Based on a preliminary positive outcome from the feasibility study, the next step was to apply to the NRCAN Smart Grid Fund to develop and implement a hybrid DC/AC microgrid within the West Five community. There are several benefits of having a DC grid with an increased number of DC loads in a community. The main barrier is the economics with the cost of new technologies and associated safety controls being more expensive before widespread adoption. This microgrid development is now funded by GISG 3014, Smart Grid Demonstration and Deployment Program. The lead for this project is the local LDC, London Hydro. Although the technical feasibility of establishing a PV-supplied DC loop behind the meter of multiple buildings in West Five was considered viable, the regulatory aspects of this approach had not been considered in the GMF study. Further development of the preliminary design with London Hydro began to recognize the limitations from a regulatory standpoint, including restrictions regarding transferring energy behind meters and under or above public roads. These restrictions led to a consensus that the behind-the-meter design was not acceptable from a regulatory standpoint.

The design was then reconfigured to a feeder-connected storage configuration, which will be the energy management topology. This configuration will tie a 1.5 MW/1.5 MWh battery at 27.6 kV to the Talbot feeder that supplies the community. There is also a second Wonderland feeder in a redundant loop to the community, that is unable to support the significant amount of distributed energy resource generation that is now tied to the Talbot feeder. These constraints will require the microgrid controller to manage the behind-the-meter net-metered PV production in the event of a grid outage or a transfer of the community to the backup feeder. Ultimately, the microgrid will be an opportunity for London Hydro to explore and test the use of energy storage as a means of providing stability on a feeder and will also demonstrate the use of load management within a community as a means of providing grid resiliency.

High-performance building design: The net zero design of the West Five community reduces loads on the London grid and maintains a lower GHG footprint for this site. Contrasted to code-minimum building performance, the net zero design improvement for the currently constructed buildings (1,2,3,4) is approximately 200 tonnes of GHG reduction on an annual basis excluding an offset created by rooftop PV. A lot of the energy savings were the result of using air-source heat pumps in place of natural gas heating. Other energy features at West 5 include LED lighting, smart controls, building siting for solar gain, low window-to-wall ratios and anti-thermal bridging measures in areas like balconies. The energy use intensities (EUI's) for the buildings are approximately 124 kWh/m^2 for building 1 (3,545 m^2 office, 2,206 m^2 retail), 92 kWh/m^2 for building 2 (4,189 m^2 health/institutional) and 91 kWh/m^2 for building 4 (13,185 m^2 multifamily, 1,754 m^2 retail). As the West five buildout continues, emissions offsets will continue to grow.

PV energy generation: That solar power will be generated from panels on the roofs of all its buildings, including a parking garage, and solar arrays incorporated into many of the building's facades. The net-metered PV capacity at West Five is currently about 1.7 MW, with a 2021 yield of 900 kWh/kW$_p$, with properly oriented rooftops at a maximum 1,150 kWh/kW$_p$. Between buildings 1, 2, 3 and 4 the PV production for 2021 offset about 75 tonnes of GHG emissions from the Ontario grid. With the addition of Building 15/16 and EVE Park, the PV capacity will approach 3 MW. Eight AC-tied Level II EV chargers have been installed and testing of vehicle-to-grid energy storage capabilities can be performed.

Buildings 1, 2 and 4 consume approximately 2,457,000 kWh/yr and total solar electricity production is currently 1,530,000 kWh/yr, which makes this **community net-zero energy** based on an estimated primary energy factor (PEF) of about 2.3 for Ontario[3]. Ontario's primary energy factor, which accounts for the extraction of the energy carrier and its transport to the utilization site, as well as processing, storage, generation, transmission, distribution, and delivery, is approximately 2.3 [37] [38]. Therefore, on-site solar electricity production would be equivalent to 3,520,000 kWh/yr being produced at the current grid energy mix, leading to a net positive design even for buildings with a high EUI and limited space for installing PV, such as the multistory commercial and residential buildings already built. While the low-rise townhouse component readily meets net-zero targets, buildings such as the 10-story 115-unit residence still consume more energy than they produce. The difference is overcome through community net metering where energy is "shared between them" to achieve net-zero goals across the development.

Lessons learned: The **micro utility business model represents a promising innovation**. Today, the long-term payback of a net zero energy community is appealing, but many real estate developers do not consider life cycle costs in the decision-making process. At EVE Park an 84-unit Net Zero Condominium neighborhood being built within West 5, an innovative business model was developed in response to the 10-20% additional capital investment required to achieve net zero designs. To eliminate this upfront cost, a separate company or micro utility was created. The micro utility owns all energy generation equipment and major loads such as heat pumps, water heaters and appliances, thereby reducing the developer's initial capital costs. The homeowner pays a

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[3] PEF is the ratio between primary energy and the produced electricity (accounts for conversion thermal losses and distribution losses). For example, one locally generated kWe is equivalent to 2.3 KWe of primary energy in the Ontario energy mix

smart fee, which is charged by the micro utility to cover the cost of the additional capital. Paying this fee would entail lower costs than if the homeowner would pay the utility bills of a conventional home and provides future proof against rising energy costs. Continued technological advancements also support the net zero shift since 275 watts was the solar roof panel standard five years ago but now panels are closer to 500 watts, making it easier to achieve net zero with building-integrated photovoltaics on facades and roofs.

The main barriers to implementing net zero design are no longer technology but stem rather from society's difficulty to change the status quo. For instance, regulatory barriers such as net metering, jurisdiction requirements for short circuit fault treatment of PV, and not being able to install wires under a public road, provided the largest challenges and caused unnecessary limitations for the adopted designs. Finally, it was found that involving as many stakeholders as possible from the start of the project is essential to avoid problems and delays. Nevertheless, resilience requirements will require more research for novel cost-effective solutions.

Figure 9: Various photos from the West 5 community [39].

Case Study #3 – Varennes Library – Canada's first net zero energy institutional building

Development: The city of Varennes is an off-island suburb of Montreal (latitude 45°N). With its growing population, the city needed a new library to replace its aging one. From 2010 to 2011, a team consisting of municipal representatives, CanmetENERGY researchers, academics and industry partners, was formed and adopted an Integrated Design Process (IDP) through several design charettes. Since the beginning, the objective was to make the library the first demonstration net zero energy institutional building in Canada with a building-integrated solar system. The NSERC Smart Net Zero Energy Buildings Research Network (SNEBRN) [40] was represented by a team from Concordia University who guided the development of the overall energy concept for a two-story 2100 m^2 building. Two key concepts determined the overall shape of the building and the integration of the technologies:

1. The design team estimated the annual energy consumption of a highly energy-efficient library around 70 kWh/m^2/yr, resulting in an anticipated energy consumption of about 140,000 kWh per year. To reach net zero (based on the strictest definition based on which, the energy produced is at least equal to the energy consumed in an average year), with solar electricity generated by a PV system optimally tilted and oriented due South, the building would need a 110-120 kW system that would generate about 1200 kWh/yr per kW installed based on well-established solar potential maps from NRCan [41]. This would require a roof area of 700 to 800 m^2 with PV panels of about 15-16% efficiency (commonly used at the time). A more widely used definition of net zero energy balance is based on an energy of primary energy.
2. The depth of the building would have to be 6 to 10 m to promote deep daylight penetration [42] and night free-cooling through motorized windows on opposite facades.

The early design charettes served to develop a common vision for the net zero energy building and to implement it into a practical design for the local climate. During the early design charettes, key energy features were decided: (i) the roof slope was set to be close to 40 degrees inclination and directed near due South to optimize photovoltaic electricity production while reducing snow accumulation; (ii) all facades would generally use triple-glazed low-e argon-filled wood-framed windows to minimize thermal losses in winter and the south facade would have double-glazed low-e argon-filled windows to increase passive solar gains; (iii) windows sizes were to be optimally selected to have sufficient views to the exterior but not have excessive heat gains or losses and lead to visual discomfort; (iv) for lighting, the target was set to < 7 W/m^2 and (v) the use of a ground source heat pump and building-integrated photovoltaic/thermal (BIPV/T) systems to reduce energy consumption for space conditioning. To condition the space, the design team selected a radiant slab for both heating and cooling on the southern perimeter of the building and an underfloor air displacement (UFAD) system for the rest of the upper floor; the first floor uses overhead diffusers. Fresh air was to be supplied by a dedicated outdoor air system (DOAS) based on the occupancy determined by CO2 readings throughout the spaces.

Opening and awards: The library, shown in Figure 10, with key energy intensity operational results, was inaugurated on May 16th, 2016, achieved LEED Gold certification, won an Award of Excellence 2014 in Real Estate for Innovation from the Urban Development Institute of Quebec and won an Award of Excellence from the Association of Consulting Engineering Companies of Canada [43]. An energy schematic of the key technologies implemented is shown in Figure 11.

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Summary of energy performance [44]: The Varennes Library produces electricity from a 110.5 kW_p building-integrated photovoltaic (BIPV) system where heat is also recovered from a section of the array and used to pre-heat the fresh air intake. The building's many architectural and mechanical features were integrally designed to achieve the net zero energy target over a 5-year averaging period with several key decisions made at the early design stage such as the shape, area and orientation of the roof that maximizes electricity production from the BIPV (part BIPV/T – with heat recovery) system and design layout that promotes daylight penetration and natural ventilation/free-cooling during the cooling season. Operational annual EUI is 70 $kWh/m^2/yr$ based on data measured since 2016. The energy production is about 54 $kWh/m^2/yr$, resulting in primary energy displaced equal to 81 $kWh/m^2/yr$ (for a primary energy factor of 1.5 for Quebec), making this a net zero energy building. The Canadian average commercial/institutional building in the category that includes libraries consumes over 300 kWh/m^2 of energy [45]. The Varennes library is 100% electrical (uses geothermal heat pumps as a main heating/cooling source). Smart energy management for such a building is important since the utility will buy up to 50 kW of power (any excess amount is given for free).

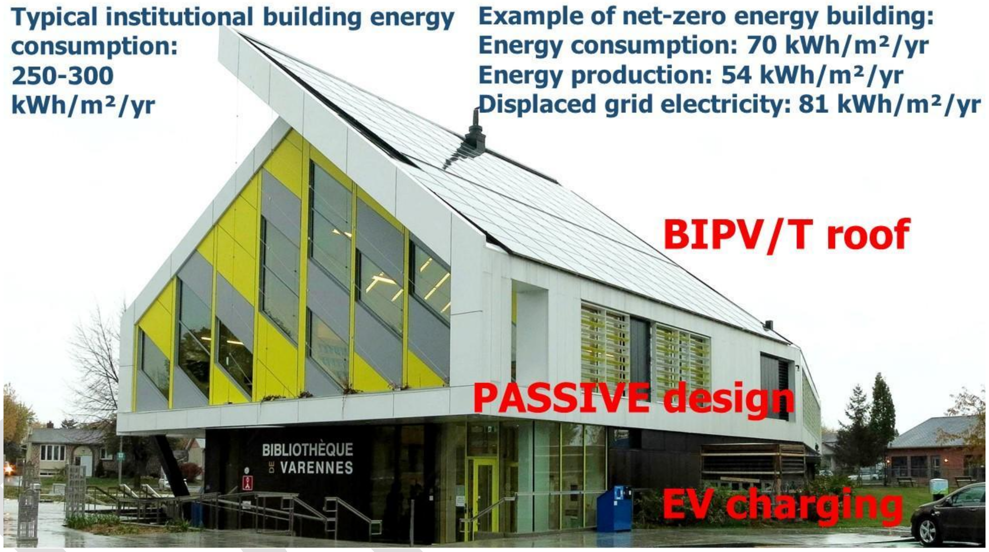

Figure 10: Photo of Varennes Library (inaugurated May 2016) with the most important annual energy statistics also shown.

Lessons learned: Buildings that are near net zero energy now can, in the future, become net zero energy or net-positive energy buildings as more advanced controls and higher efficiency equipment replace depreciated ones. For example, if the building was built in 2022, PV panels with an efficiency of at least 20% would be used (as compared to 16% for the installed system), meaning that for the same surface roof area, about 20% more electricity would be produced. Thermal and electrical storage solutions in conjunction with predictive control of the HVAC system can be added to better harness opportunities for load shifting and grid flexibility services [46]. net zero energy buildings as **prosumers** are becoming more common and are incentivized by dynamic tariffs offered by utilities.

The role of net zero energy and high-performance buildings will be paramount in the near future as more building-integrated decentralized renewables are connected to the grid. Renewable energy sources such as solar

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and wind are highly variable and can impose a burden on the grid when demand is low. However, such buildings can be part of the solution and may act as regulators of demand to aid the utility by relying on energy flexibility concepts such as optimally controlling their thermal and/or electrical storage systems, and even using electric vehicles as part of the solution with smart charging stations fully integrated with the building energy management system.

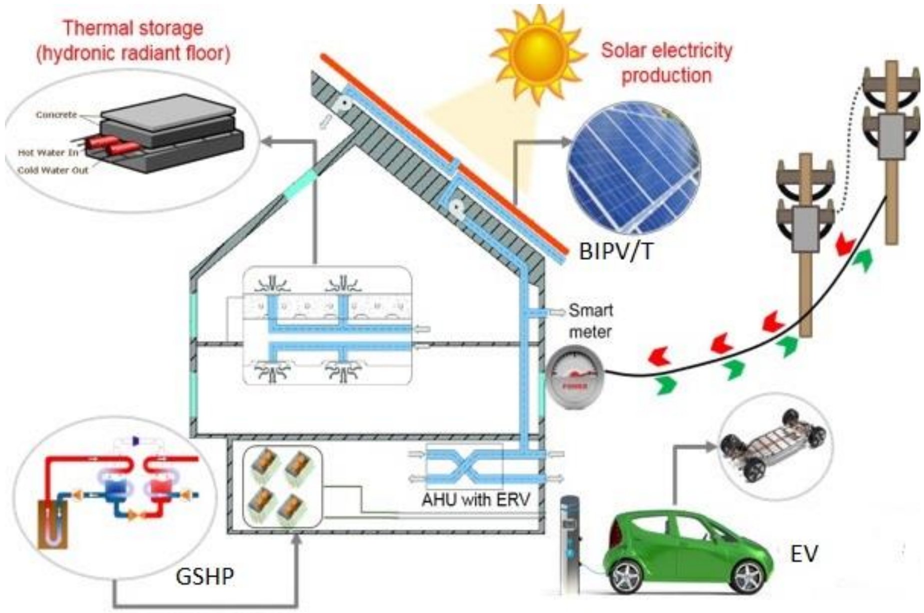

Figure 11: Varennes Library energy schematic cross-section illustrating key technologies implemented (BIPV/T: building-integrated photovoltaic/thermal system, ground source heat pump (GSHP): ground source heat pump; EV: electric vehicle).

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Case Study #4 – Williams Lake Net Zero Energy Building Retrofit

To be completed – by UVic Civil Engineering

https://acecbcawards.com/2022-awards/2022-buildings/williams-lake-net-zero-energy-building/

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Case Study #5 – the Belmont Building Deep Energy Building Enclosure Retrofit

To be completed – by UVic Civil Engineering

https://www.rdh.com/wp-content/uploads/2017/07/TB-8-Deep-Energy-Retrofit.pdf

https://www.bchousing.org/sites/default/files/rcg-documents/2022-04/Deep-Building-Enclosure-Energy-Retrofit-Studyf

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5. Market uptake of Net zero carbon and Net zero (or low) Energy Buildings

Market Update of Established Green Building Standards

Construction of net zero carbon and net zero energy buildings is already technically and economically viable in Canada, with well over a million m^2 of building space already certified (Table 2). There are some differences in the approaches to certification, and care should be taken to distinguish between net zero-carbon, net zero energy and net zero energy ready buildings – which typically may still require installation of photovoltaic panels or other renewable energy systems to reach net zero. Nonetheless, market uptake of all such buildings has grown in Canada over the past four years.

Table 2: Floor area of net zero carbon, net zero energy, net zero-energy ready, and Passive house certified buildings as of May 2022.

Organization	Region	Program	Total floor area (m^2)
Canadian Green Building Council	Canada	Zero-carbon certified	1,111,000
Canadian Home Builders Association	Canada	Net Zero energy or net zero ready	230,000
International Living Future Institute	International	Zero Carbon certified	46,000
Passive House	International	Passive house certified	over 3,000,000

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As of May 2022, over 1,100,000 m^2 of floor space was certified under the Canadian Green Building Council's (CAGBC) Zero Carbon Buildings standard. Growth in buildings registering for this certification grew from just under 200,000 m^2 in 2018, to almost 700,000 m^2 in 2021 (Figure 12). The CAGBC had both design-based and performance-based zero-carbon certification systems, but is phasing out the design-based approach [47].

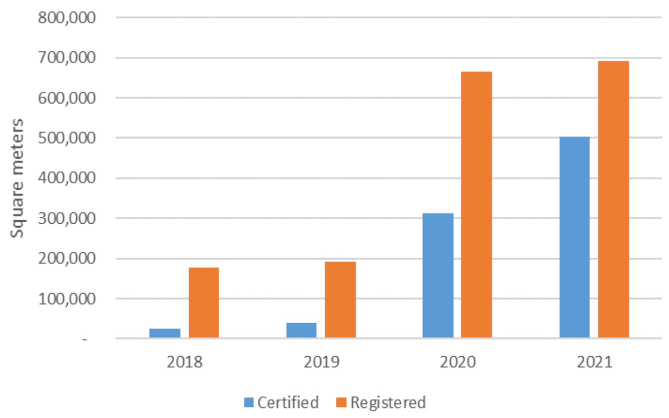

Figure 12: Building space registered for or certified as zero carbon by the Canadian Green Building Council.

The Canadian Home Builders Association recorded 209 fully Net Zero energy homes, and 693 Net Zero Ready energy homes, up to May 2022. The heated floor area of the 902 homes was 229,495 m^2. Figure 13 shows progress with the CHBA's labeling scheme from the Pilot in 2016, up until the end of 2021 (first 758 homes).

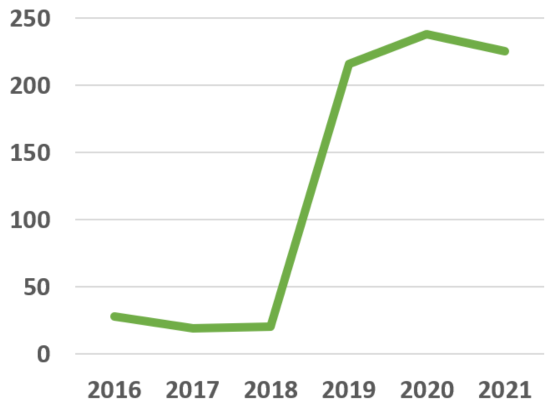

Figure 13: Number of units (homes or apartments) recorded in the Canadian Home Builders Association net zero-energy or net zero energy-ready 2016 to 2021.

Several international initiatives are also relevant to the Canadian net zero building markets. The most rigorous international certification scheme for a zero-carbon building is probably that of the Seattle-based International Living Futures Institute [48]. The ILFI performance-based standard requires the decarbonization of both operational and embodied carbon emissions. As of May 2022, ILFI had around 2 million m^2 of projects pursuing Zero Carbon Certification, while about half a 50,000 m^2 of the 2 million has achieved certification. Amongst approximately ninety projects around the world registered for Zero Carbon certification, six were in Canada.

Although not a zero-carbon or zero-energy certification, the very low energy goals of Passive House certification can readily help to render a building zero-carbon, through the addition of photovoltaic panels. Globally, as of January 2022, 33,000 units have been certified based on the Passive House Institute's certification criteria [49]. The treated floor area of Passive House buildings now exceeds 3 million m^2.

ASHRAE plays an influential role in developing and promoting market adoption of best practices, standards and design methodologies for high performance low carbon and energy efficient buildings. ASHRAE has recently released a position paper on building decarbonization [50] and a related ASHRAE BC - Building Sustainability & Resilience Guide has also been published [51]. Major ASHRAE positions and recommendations include:

- By 2030, the global built environment must halve its 2015 GHG emissions, whereby all new buildings must be net zero GHG emissions in operation, widespread energy-efficiency retrofits of existing assets must be well underway, and embodied carbon of new construction must be reduced by at least 40%;
- By 2050, at the latest, all new and existing assets must be net zero GHG emissions across the whole life cycle;
- Building decarbonization provides benefits beyond reducing GHGs, including reduced indoor and outdoor air pollution, energy savings, improved community health and wellbeing, enhanced social responsibility, and increased property valuation;
- Implementing building electrification such as switching from natural gas heating to electric heat pumps;
- Use renewable energy resources on site and/or off site. Optimize building envelope, orientation, and geometry to reduce energy use and maximize solar potential;
- Use grid-integrated control systems to optimize building energy storage and increase demand flexibility. Buildings can use energy storage (within the building and also EVs and associated refuel infrastructure) to modify their electric loads to match the availability of low-carbon electricity and/or reduce peak loads.
- Increased adoption of building codes and policies to move toward net zero operational emissions.

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6. Principles for Policymakers and Institutions

What if we could achieve the following outcomes?

- Canada achieves decarbonization (net zero emissions) for the building sector by 2050, with an earlier implementation in new construction.
- It does so at the least possible cost; for the public, utilities and government institutions.
- It maintains our global economic advantage.
- The energy transition and associated government policy are just, non-discriminatory and practical.
- It has co-benefits of improving health & safety in buildings.
- It aligns with goals for labour markets, housing supply and poverty reduction.
- It stimulates innovation and leadership roles for the private sector and professional engineers.

Building upon the CAE vision of a future state for buildings in Canada (chapter 2), the measurable benefits/outcomes of that vision (chapter 3), case studies (chapter 4) and Canadian market uptake (chapter 5), this chapter submits five key "principles" that governments can use to develop supportive policy, legislation, regulations, institutional frameworks, fiscal frameworks, programs and public sector leadership. Collectively, all the aforementioned government interventions are referred to as "Government Policy". They are summarized in the first sub-section below.

Government Policy Measures

All five levels of government have a slice of jurisdiction to influence the outcomes sought through this Roadmap. These include:

- Federal – Primary level responsible for national fiscal framework, including taxation. Infrastructure investment (leveraging provincial, territorial, Indigenous and local investment). National equipment standards. Governance for harmonized construction code development and publishing model building, plumbing, fire, and energy codes. Scientific research and development. Data and statistics. Inter-provincial trade. Energy efficiency programs.
- Provincial/Territorial – Primary government level responsible for building construction and real estate sectors, energy sector, climate mitigation, disaster risk reduction and resilience and resource management. Sales and carbon taxation and assessment for property taxation. Delegation of jurisdiction to local and Indigenous governments. Authority having jurisdiction for construction regulation, Including regulation of national model building codes, electrical codes, other safety standards, and equipment standards and variations to national codes and standards. Institutions and professional governance. Energy programs.
- Regional – Land use and transportation planning, community energy planning. Management of regional airshed and water, sewage treatment and solid waste. Public education on climate.
- Municipal – Land development planning, development permit area guidelines, neighborhood planning and zoning. Building inspections and in some cases, electrical/gas safety inspections. Community energy and emissions planning.
- Indigenous – housing policy, community planning, resource management.

Tables 3 and 4 illustrate the types of Government Policy measures that are used to influence the energy efficiency of buildings and to promote decarbonization. The first summarizes "demand-side measures" that are applied on the building side of the energy meter – influenced by the actions of the building owners and

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managers, and sometimes tenants. Appendix Y includes a citation to one or more government policy websites or documents that explains each measure. The responsible party is noted in the middle column, illustrating a significant overlap between levels of government. The target audience for each measure is noted in the third column. A detailed description of each measure is beyond the scope of this Roadmap which instead focuses on “principles”, noting that the determination of policy measures and even description is unique to each jurisdiction.

Table 3: Demand-Side Measures (building scale) for Efficiency, Decarbonization and Resilience.

Measure	**Responsible Party**	**Target Audience**
Carbon tax	Federal/Province/Territory governments (F/P/T)	Public – energy consumption
Utility Rate Design and Rates	Utilities, Public Utility Commission (PUC)	Utilities – rate design
		Public – operations
Equipment efficiency standards	F/P/T	Manufacturers, Contractors, Public
Utility Demand-Side Management (DSM) programs, including efficiency and fuel switching	Utilities, PUCs	Public, Contractors
Financing (e.g., property-assessed clean energy financing)	F/P/T, local government	Public – capital upgrades
Building codes	F/P/T, local and Indigenous governments	Builders, Manufacturers
Electrical codes	P/T, local and Indigenous	Electrical designers&trades
Planning & Reach codes (carbon)	Local and Indigenous governments	Developers/Builders
R&D,D and Commercialization	F/P/T, Utilities, PUCs	Manufacturers, Builders
Distributed energy, vehicle to grid	Utilities, PUCs	Public – capital and operating
Government procurement and infrastructure investment	F/P/T, local and Indigenous governments	

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The second summarizes “supply-side measures” that influence the sources and emissions of energy resources that are purchased by building owners and managers. These are introduced by provincial/territorial (P/T) governments and/or public utilities that are often “natural monopolies” and are regulated by public utility commissions under P/T legislation. These are all “enabling measures” for demand-side measures, as they affect the price of purchased energy, provide community energy supplies, and/or facilitate distributed energy resources on the customer side of the energy utility meter.

Table 4: Supply-side or Enabling Measures (sub-national scale) for Decarbonization and Resilience.

Measure	**Responsible Party**	**Target Audience**

Energy Management System (system control)	Utilities	Utilities
Carbon tax on supply	F/P/T	Utilities – upstream emissions
Clean Electricity Standard	P/T, Utilities, PUCs	Electric Utilities
GHG Cap for Gas Utilities	P/T, Utilities, PUCs	Gas Utilities, Gas District Energy
Micro-grids, storage, net-metering	PUCs	Electric Utilities
District Energy (zero-carbon)	Local, Utilities, PUCs	Developers
Grid hardening (risk mitigation)	Utilities	Utilities
Government infrastructure investment in capacity and energy supply decarbonization	F/P/T	Utilities

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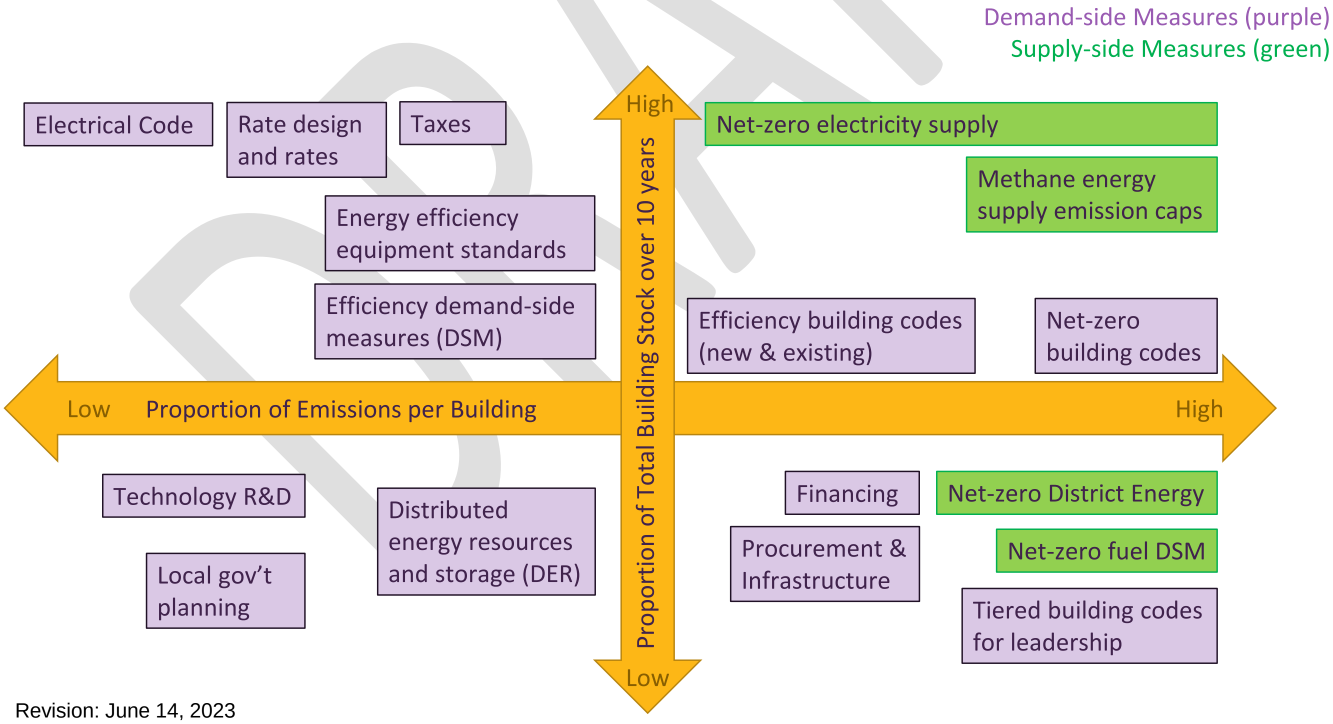
These “demand-side” and “supply-side” measures can work in tandem to achieve the Roadmap goals, as illustrated in Figure 14. The x-axis illustrates the magnitude of energy efficiency and emission reductions in buildings, while the y-axis illustrates the proportion of the whole building stock that each Government Policy Measure influences.



Revision: June 14, 2023

Figure 14: Government Policy Measures for Efficiency and Decarbonization of Buildings.

The top right quadrant in Figure 14 contains the measures with the highest potential overall emissions reductions, and the bottom left is measures with the smallest emissions reductions. Starting with the top left and moving clockwise, we detail these interventions and how they affect building emissions.

- Electrical Code: the Canadian Electrical Code (CEC), adopted by provinces, territories, local and Indigenous governments in regulation, is focused on safety for electrical workers and building occupants and to promote consistency in electrical installations across Canada. The most recent edition was published in 2021 by the Canadian Standards Association and includes new requirements in support of climate change adaptation [122]. This is relevant to the Roadmap in cases where electrification is used a means of reduction greenhouse gas emissions, as the CEC enables safe and resilient electrification.
- <u>Rate Design and Rates</u>: This is the domain of the public utility regulator in setting rates (prices) for electricity, natural gas, propane, district energy and hydrogen utilities that sell such fuels to consumers in buildings. Rate design determines components of energy expenditure such as energy and demand charges and connection charges for new service in buildings. Both can influence energy/fuel choice and overall consumption, and apply to all buildings. Energy consumption is the principal source of GHG emissions in buildings.
- <u>Taxes</u>: This is the domain of the FPT ministries of finance or revenue, with sales taxes applied to energy purchases and carbon taxes applied to the majority of combustion from building energy. Taxes affect the relative cost of different energy sources, which affects choice and consumption. These apply to all buildings. There are also tax credits such as the BC Clean Buildings Tax Credit that applies to major retrofits [123]; these programs act as a consumption subsidy for non-emitting energy, though they have much more limited reach as they rely on voluntary uptake.
- <u>Energy Efficiency Equipment Standards</u>: These include PT and NRCan Energy Efficiency Act standards that apply to new equipment that is installed in new construction or replacement of existing assets. This includes imported products and transfer of products between PT jurisdictions, triggering Natural Resources Canada legislation. It applies to a proportion of buildings each year when equipment is installed or replaced, but over time will touch most buildings, as the equipment lifetime is shorter than building lifetimes. The impact on building emissions is due to lower energy consumption but doesn’t prescribe fuel choice.
- <u>Demand-Side Efficiency Measures (DSM)</u>: These are programs that promote energy efficiency, including education, incentives, financing, and support to governments and standards development organizations to revise and implement codes and standards. These are often led by public utilities, as authorized through PT legislation, but can also include government programs such as the Canada Greener Homes Grant. These apply only to those buildings that participate in the DSM. However, over time, a large proportion of the building stock is expected to participate due to widespread accessibility to subsidies such as appliance rebates.
- <u>Net-zero Electricity Supply</u>: The electrical grids of BC, Yukon, Manitoba, Québec and Newfoundland and Labrador have been predominantly hydroelectric for several decades with very low Scope 2 emissions and zero Scope 1 emissions. Some jurisdictions have policy or legislation mandating low emissions from electricity systems, such as the BC announcement to create a 100% non-emitting electricity standard [10]. While this policy measure itself doesn’t deliver significant incremental GHG emissions reductions for buildings, it ensures that other policy measures that promote switching from fossil fuels to electricity deliver reductions. Other PT electrical grids use unabated fossil fuels for a substantial share of supply; electricity use in buildings then has moderate to high Scope 2 emissions, despite Scope 1 emissions being zero. These grids are transitioning toward low- and zero-carbon electricity supplies, recently bolstered by the 2023 federal budget. PTs may require legislation to mandate decarbonization of the electrical grid, reinforced by public utility regulators. The impact for decarbonizing buildings is most pronounced when

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the starting fuel source for the electric grid is coal or oil, and is transitioned to renewable or nuclear energy. It can also include natural gas with carbon capture and storage or RNG or hydrogen sourced power plants. These apply to all buildings. The extent of emission reductions depends on the proportion of energy use from electricity. A 100% electric building could be fully decarbonized with such a measure.

- Decarbonized Methane Energy Supply Caps: Modelled off the BC Roadmap [10] this supply-side measure gradually reduces the net emissions intensity of fuels transported in natural gas pipelines and compressed and liquified gases. This may include blending of fossil fuels such as natural gas with renewable natural gas and hydrogen. While in-building methane combustion produces Scope 1 emissions, and there may be fugitive Scope 2 emissions, the net emissions are reduced through use of renewable natural gas. This reduces Scope 3 emissions in sources such as landfills, sewage treatment, and forestry sites, among others. Use of carbon capture and storage also reduces Scope 3 emissions. Hydrogen combustion produces zero Scope 1 emissions. These apply to all buildings that have a natural gas, propane or district energy connection and have a significant emission reduction potential. As the carbon content of abated methane increases the magnitude of emission reductions per building and across the building stock increases. A 100% abated gas blend, coupled with 100% net-zero electricity supply could address 100% of emissions in the building stock.
- Efficiency Building Codes: These include energy efficiency standards at the time of construction or alterations to existing buildings. They apply to a small proportion of the building stock each year, but can yield significant emission reductions per building, including zero- or net-zero-emissions. BC is moving towards regulating building emissions via performance standards, intending to phase-in performance-based standards for new buildings over three tiers (in 2022, 2027 and 2032), leading to net-zero energy ready buildings (focused on efficiency). Few jurisdictions have building code standards for existing buildings, but those will be introduced in Canada in 2025 [124]. Over a 10-year timeframe, the building could influence more than half of the building stock, including new and existing buildings. The impact on building emissions is due to lower energy consumption but doesn’t prescribe fuel choice.
- Net-Zero Building Codes: Not yet implemented at the FPT level, this would add a greenhouse gas intensity standard to building standards in addition to energy efficiency, thereby influencing fuel choice to allow a variety of decarbonization options including electrification, low carbon fuels like renewable natural gas, and low carbon district energy [10]. This can have a substantial impact on building emissions over a 10-year timeframe.
- Financing: These programs are a direct subsidy to lower the cost of investments in reducing energy use or emissions. They include government backed programs such as property-assessed clean energy financing made available to building owners to install energy efficiency and decarbonization technologies. They are accessed voluntarily, applying to a small proportion of the building stock annually, but can deliver deep emission reductions of a similar or greater magnitude than the building code.
- Net-Zero District Energy: This local energy supply model provides thermal energy to buildings, mainly for new construction, and offers an opportunity for deep decarbonization potential compared to natural gas. Scope 1 emissions are zero, and scope 2 can be minimized through the use of renewable energy resources. Existing buildings can be retrofitted to accept district energy, provided the temperature is sufficient for the mechanical system. These are sometimes owned by local governments.
- Net-Zero Fuel Switching DSM: This is an emerging measure that enables utilities to incentivize fuel switching in existing buildings or new construction to use zero-carbon fuels. For example, BC’s *Greenhouse Gas Emission Reduction Regulation* enables public utilities to offer such incentive programs and cover the

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costs across the entire rate base [125]. The CleanBC program also provides direct subsidies to builders for efficient, zero-emission houses [126].

- Tiered Building Codes for Leadership: Recently taking affect in British Columbia these codes regulate carbon in a building regulation or bylaw led by local or Indigenous governments. These are ideally informed by voluntary PT building codes, but allow local governments to adopt one of the leadership tiers in advance of prospective or planned PT-wide adoption with the ultimate target of net-zero new construction. Emission reductions can be significant per building, but apply only to new construction in the communities of the participating local and Indigenous governments, so the overall impact is small. As an example, the 2023 amendments to the BC Building Code, effective May 1, 2023, include a new GHG reduction objective and voluntary targets for estimated annual emissions per square metre of floor area that can be mandated by local and Indigenous governments [127].
- Technology R&D: Research and development provides the basis for transformative or disruptive technologies such as gas heat pumps that can accept hydrogen fuel. It is funded by the federal government, universities, provincial agencies and public utilities. Research and development has limited direct effects, but over longer time frames with technology adoption can affect all aspects of building emissions.
- Local Government Planning: This defines the long-term urban design, building types and orientation, density, and community infrastructure such as district energy. In several cities development requests for more density than allowed under the zoning bylaw trigger local government policies that can include decarbonization objectives. The City of Vancouver Green Buildings Policy for Rezoning is an example, pre-dating building code requirements that have since been adopted for all new construction [128].
- Distributed Energy Resources and Storage**:** These are building-specific or neighborhood systems for electricity that mimic district thermal energy, including distributed resources such as solar photovoltaics or cogeneration, battery storage or resilient electrical microgrids that can operate autonomously, for example during a grid outage. They can also be used to control smart appliances such as space and water heaters that can be turned off for short periods. These are often considered to be demand-side measures by utilities, but could also be owned or implemented by public utilities (as is the case in other countries).

Key Influencers

While the source of significant change is frequently enabled by government policy, the bulk of the change process and ongoing momentum is further catalyzed by institutions, including professional regulators, that ultimately lead to market transformation, consumer demand and industry products and services. A brief description of such institutions is provided below, and a detailed list is included in Appendix G.

The primary “arms” of government include Crown Corporations, non-profit agencies, tribunals and other levels of government that provide functions that are formally delegated through legislation. These can include the enforcement of building codes and safety standards for equipment, oversight of professional registrants via professional regulatory bodies for each province and territory, data repositories that support vital market functions and regulators of natural monopoly energy providers and arbitrators to appeals, among other functions. Effectively, these organizations are policymakers, but with a narrower scope than the government that establishes their governing legislation. They play vital leadership roles and are key influencers for this Roadmap.

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The second category are those organizations that oversee self-governing professions, also established by legislation. These include provincial/territorial (P/T) engineering regulators that oversee ethical and professional practice, along with Engineers Canada which provides accreditation of engineering schools. Depending on P/T jurisdiction the professional regulators can play a substantial role in guiding building sector professionals to lead or preside over the transition highlighted in this Roadmap. The case study of British Columbia is exemplary. The self-governing status of engineers was modified in 2021 under the Professional Governance Act that mandat41rofessprofessional regulator Engineers and Geoscientists BC (along with five other professions) to establish a standardized code of ethics, Council procedures, continuing professional development, firm registration, and other requirements [52]. These equip EGBC to play a greater leadership role in regulating the profession and shaping the future, with significant overlap with this Roadmap in areas such as climate change risk mitigation, letters of assurance for the building code, and whole building energy modelling and building enclosure engineering services professional practice guidelines [53]. Architects are also key influencers as they are responsible for the building envelope in the context of building codes. In British Columbia, they are designated as the “registered professional of record” for the building envelope of complex buildings, and often play the ro“e of "coordinating registered professional” for new building construction, overseeing the work of all professionals of record such as mechanical, electrical, structural and other disciplines [129].

A third category are standards development organizations (SDOs) and certification organizations (COs) that are accredited by the Standards Council of Canada [54], the American National Standards Institute [55] and other organizations around the world [56]. Stated simply, the SDOs develop “model” consensus standards with expert input that include both test procedures, minimum performance standards for buildings and equipment and professional practice guidelines. COs verify that products and professionals and provide certification that they meet the standards and guidelines of SDOs. SDOs are generally non-profit and in some cases, are cross-subsidized by COs that operate at arms length. The two most prominent standard and code development organizations in Canada are Codes Canada, operated by the National Research Council and the Canadian Standards Association (CSA) operated under the CSA Group which includes a CO called CSA International. It is noted the model codes and standards do not have any effect in law until federal, provincial and territorial (F/P/T) legislation and regulations reference them. Model codes play a vital role in promoting harmonization across jurisdictions, reducing trade barriers, increasing productivity, and reducing costs for Canadians. This is recognized by the Canadian Free Trade Agreement Regulatory Reconciliation and Cooperation Table [57].

The fourth category of key influencers is research and education institutions, including academia. These institutions are parties to the innovation ecosystem which includes the innovation continuum of research and development, demonstration, deployment and commercialization. Universities, industry and government research agencies, research funders and umbrella organizations build content and momentum for innovation that when commercialized can become common practice. An example of innovation collaboration can be found with low-emissivity windows that reduce heat loss and solar heat gain which were a space-age technology in the late 1990s and currently are the minimum standard [58].

The fifth category is investment fund governance, including investment agencies and institutional investment fund managers that apply environmental, society and governance (ESG) criteria to determine their investment portfolios. The investment regulators establish governance expectations and criteria to align with the public interest and promote related strategies, risk management, metrics and targets among the investment organizations they regulate. For example, the Canadian Securities Administrators 2021 consultation on proposed

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climate-related disclosure requirements [59]. By extension, institutional investment organizations such as the Canada Infrastructure Bank can fuel market transformation, including the Bank's $2 billion fund for green infrastructure and building retrofits, including components for public and commercial buildings and zero-emission vehicles [60]. Special purpose funds co-fund building sector investments, including the CMHC, BC Housing Hub, the FCM Green Municipal Funds and the Atmospheric Fund, the latter establishing Efficiency Capital Corporation that offers risk management instruments for building retrofits, including engagement of pre-qualified professionals that are specialized in energy efficiency [61]. Industry associations such as Building Owners and Managers association provide a forum for integrating the various real estate interests an enabling action.

In many P/Ts the Crown-corporation energy utilities play a key role in advancing public policy objectives and fuelling demand-side measures. These include energy conservation, efficiency, load management, district energy, zero-emission vehicle fuels, and enabling measures for privately owned on-site generation, storage and microgrids. The aforementioned utility regulators indirectly influence these types of initiatives for investor-owned utilities. Some utilities have historically provided on-bill financing for Roadmap related building improvements as summarized in a paper by the Pacific Institute for Climate Solutions [62].

Finally, the seventh group of key influencers includes agencies that implement many facets of demand-side measures and distributed energy resources to influence the decision-making of property owners and managers and sometimes tenants. These include "efficiency utilities" such as those in Manitoba and Nova Scotia, the local government-focused transformation initiatives such as FCM's Low Carbon Cities Canada [63], technical support organizations such as the Zero-Emission Building Exchange, property-assessed such as PACE Nova Scotia [64] and zero-carbon energy fuel development organizations such as the BC Hydrogen Office and QUEST-Canada.

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Principle #1 – Facilitate Integrated Demand- and Supply-side Resource Planning

Each of the five levels of government has distinctive jurisdiction and measures to influence the building construction and real estate markets and collectively can catalyze the achievement of the desired outcomes covered in Chapter 2. This requires a common policy and planning framework across all jurisdictions and institutions.

This principal calls for provincial and territorial (P/T) governments to lead the development of integrated demand-side and supply-side Roadmaps for the buildings sector, including SMEs and interface with utility grids and zero-emission vehicles in the energy supply and transportation sectors respectively. Furthermore, it calls for the federal government to provide capacity support to those lead jurisdictions, along with empowering local and Indigenous governments to participate.

The Canadian Academy of Engineers (CAE) submits the following objectives and strategies to guide this integrated demand- and supply-side planning for the buildings sector:

- Establish common measurable goals across multiple levels of government – this allows all five levels of government to harmonize the targeted outcomes of their measures to increase the overall effect. It also allows for multiple levels of scrutiny for achieving the same targeted outcomes. CAE submits the goals could align with the desired outcomes summarized in Chapter 3.
    - For example, a risk management framework [65] could be added to consider unintended consequences on other policy goals such as those noted below in the “co-benefits” section.
    - Furthermore, “structured decision-making” could be applied to co-optimize the least economic cost solutions against other objectives.
    - A simplified approach is a “balanced scorecard” method, as summarized in this paper [66].

- Minimize overall cost to society including incremental capital costs of achieving desired outcomes, transaction costs for policy interventions (including overlapping of multiple jurisdictions), ongoing costs of operations, energy and maintenance, the financial value of lost opportunities and costs of unintended consequences such as reduced durability (i.e., more frequent capital replacement).
    - For example, “scenario planning” could be done nationally with granularity at the P/T level to provide a consistent approach across 13 P/T jurisdictions.
    - Both the BC and federal governments have completed such cost-minimization analyses for their respective decarbonization plans in 2021 and 2022. These government studies suffer from focusing on the single issue of decarbonization, despite resultant impacts on energy system reliability, safety, equity/inequity of impacts, and resilience.
    - Individual energy utilities have also done scenario planning across the economy, such as the Guidehouse study for FortisBC [67], BC Hydro’s Electrification Plan [68], and the ICF study for the Canadian Gas Association [69].

- Consider optimizations and solutions from a building sector standpoint across multiple policy frameworks and institutions by framing integrated plans around the circumstances of stakeholders that use buildings (i.e., owners and occupants) and are the source of investment in and construction of buildings (i.e., property manager, building owner, developer).

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- For example, the scope of integrated planning could flip from the current "horizontal silos" of institutions across multiple consumer sectors to "vertical silos" of the sectors themselves across all institutions – see Figure 15.
- This approach could be achieved by effectively merging the work of the CleanBC Roadmap to 2030, Canada's 2030 Emissions Plan, building strategies of major local governments, gas utility decarbonization and electric utility electrification plans, and adding additional dimensions of other policy goals noted below.

Regulatory Frameworks for Buildings	Residential	Commercial	Institutional	Rental & Social Housing
Land Use Planning	Local / Regional / Indigenous Government Planning			[P/T Emerging]
New Construction	Building Codes, Advanced Energy Efficiency Standards, Energy Efficiency Programs			
Equipment	Federal and Provincial Energy Efficiency Act, Energy Efficiency Programs			
Asset Management	Mandatory Depreciation Report	N/A	Capital Asset Management Framework	
Building Renewal	Building Codes, Energy Efficiency, Tax credits			+ Design guidelines, Rent control, Government funds
Real Estate	Real estate labelling	Benchmarking	Greening government buildings	Tenant protection
Electricity Supply	Public Utility Commission (planning, projects, supply, rates), clean electricity standard			
Fossil fuel and other methane and H2	Public Utility Commission (planning, projects, supply, rates), emerging carbon cap			
Distributed and District Energy	Public Utility Commission (planning, projects, supply, rates), net metering, government ownership, connection bylaws.			

Figure 15: Silos of the Buildings Sector versus Governance.

- <u>Maximize co-benefits</u> for other policy goals beyond energy efficiency and decarbonization, such as energy system reliability and resilience, safety, housing supply, public health (indoor air quality), economic renewal, flexibility/adaptability, circular economy and comprehensive resilience[4]. This is the opposite of "tunnel vision" around one policy goal such as decarbonization; noting that governments collectively have multiple areas of market intervention through legislation for matters such as safety; and that decarbonization and resilience of buildings must not compromise aspects such as public safety. This honors the sector-specific approach to this Roadmap, noting that investors aim to achieve more than one performance improvement when investing in buildings, rarely just pursuing decarbonization.

[4] Elaboration of these co-benefits are topics for future research, starting with circularity of materials (life-cycle energy and emissions) and the structural and life-safety resilience of buildings against acute shocks.

  - For example, for new and existing buildings a high-performance building envelope, improved airtightness, balanced air pressure (e.g., compartmentalization), elimination of thermal bridges, heat-recovery ventilators, heat pumps and peaking units also improve resilience against extreme heat events, wind-driven rain and power outages, along with improved indoor air quality with continuous fresh air (e.g., diluting viral contaminants), comfort with less cold spots and drafts. Excellent references are available from BC Housing [70] [71] [72].

- <u>Leverage all sources of data to track performance, inform policies, and avoid leakage</u> – this links to Principal #5 below to ensure that planning is initially informed by the evidence and data, with political adjustments made after to address conflicts.

Indeed, there will be variations in approaches across the 13 P/Ts, synonymous to a "Roadmap" with three modes of transport and routes at different paces to the same destination:

1. <u>"Bullet-train" fastest pathway to resilience and decarbonization</u>; front-loading costs and achieving targets with regulatory measures that limit market choices; for example, Vancouver's Zero-Emission Buildings Plan [73]. This is a highly proactive approach that could position jurisdictions as leaders with resultant economic spinoff benefits such as investment from ESG institutional financing that rewards early adopters. The downside is around technology risk and the potential of stranded investment should the jurisdiction drive fledgling solutions that ultimately fail or be sub-optimal under future market conditions. It also risks jurisdictions acting outside of their appropriate sphere of influence, such as local governments driving energy supply planning. Finally, there may be issues related to social equity, as the heavy emphasis on regulation could lead to unintended consequences such as costs being borne by those least able afford them.
2. <u>"Trans-Canada Highway" balanced approach</u>; suitable for all Canadian jurisdictions with a combination of "carrots" such as tax credits, evaluation of readiness, and mid-term "sticks" in sub-sectors that have the capacity and geographic areas with accessibility and acceptance to embrace a regulatory approach; for example, the CleanBC Roadmap to 2030. This is heavily weighted on demand-side measures as a means of adapting to future market conditions, including decarbonization of supplies and climate change.
3. <u>"Cruise ship" cost-minimization approach</u> that is education and incentive orientated with mounting pricing measures that will gradually influence investment decisions, and rear-loading internationally-driven performance standards in regulation. This provides significant leeway to the building sector to autonomously adapt to changing market conditions, leading to a version of the IEA framework for 2050 [74] [75], albeit with significant cost pressure on future generations and risk of economic hardship from being unable to react to global conditions. The best analogy for this example is the global oil industry and government's lack of direct intervention until major unexpected events occur, such as the COVID-19 pandemic and the war in Ukraine (with its major impact on fuel prices and even energy infrastructure becoming Russian war targets). The challenges for governments are highlighted in reports such as the BC Fuel Price Transparency Act Retail Pilot [76].

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Principle #2 – Focus on Performance Outcomes that Foster Competition and Enable Innovation

This principle focuses on modernizing the way building performance is determined, designed and measured. Indeed, many energy codes for buildings such as ASHRAE 90.1, 189.1, National Energy Code for Buildings, EnerGuide for Houses and local government Reach Codes have "performance" standards with singular metrics such as energy consumption per square meter of conditioned floor area, or heat loss/gain through a building envelope. This is in contrast to "prescriptive" standards that specify requirements for building components, including insulation, air barrier, windows, equipment and controls.

Performance standards are often specified in tables with metrics that inform the building design by professionals, replacing dozens of pages of prescriptions and menus, the latter being conducive to broad application with or without professional oversight. Performance standards require investment in professional oversight that owners, managers and developers may endeavour to avoid in favour of "cookie-cutter" prescriptions and menus. However, professional oversight is intended to optimize designs and minimize overall costs, and to implement innovative solutions, both offsetting the costs of professional services.

There continues to be a role for prescriptive requirements with respect to houses and low-rise buildings, as depicted in Part 9 of the Model National Building Code of Canada. By definition, these buildings do not require the work of a registered professional and as such, objectives and standards are set out in specific language.

Other building performance objectives beyond energy efficiency are rarely specified in terms of performance metrics. These include the health and safety of occupants, fire and structural protection of the building, accessibility for people with disabilities and water efficiency. Other performance aspects are defined by public utilities as part of their interconnection requirements, energy and safety standards for equipment, design guidelines by municipalities, and others. While energy efficiency can be optimized via performance standards, the lack of performance standards in other categories does not allow for trade-offs to occur for the "co-optimization" of multiple performance objectives. Efforts to prevent overheating in buildings are quickly evolving, including the 2023 proposed amendment to the BC Building Code [127].

Canada has taken steps toward performance-based codes with the implementation of an objectives-based code. Since 2005 and the three editions that followed, the National Building Code of Canada (NBC) has included Objectives, Sub-Objectives and Functional Statements, supporting an evolution toward performance outcomes, reinforced by documented analysis of the intent of each code provision and an application statement (Archer 2005). Converting the NBC to an objective-based format has made it more accommodating to innovation by clarifying its scope as well as the intent behind its requirements. In the NBC 2020 (released in 2022), the five objectives include Safety, Health, Accessibility, Fire and Structural Protection of Buildings and Environment.

Furthermore, in 2005 NBC shifted the approach to "equivalencies" in performance to a new "Alternative Solutions" compliance path in Division C. This permitted the use of materials, equipment, systems, methods of design or construction procedures not specifically prescribed if the alternative solutions provide at least an equivalent performance to the "acceptable solutions" in Division B of the NBC [77]. The analysis and proof of equivalency are often completed by registered professionals and submitted to the authority having jurisdiction, often local government building inspectors.

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Local government building inspectors vary in their level of acceptance of Alternative Solutions. Some interpret it widely, including allowance for variations on building size and use (otherwise known as "Innovative Solutions"[5]), and even allowing the services of "Certified Professionals" in some jurisdictions such as Vancouver and Surrey, BC to supplement local government compliance oversight [78]. Others are cautious about the acceptance of alternative solutions with respect to the avoidance of risk and liability. It is noted that local governments have "immunity concerning approval of certified building plans" under the Local Government Act section 743, protecting them from liability if a registered professional engineer or architect certified that the plans complied with the current Provincial building regulations [79].

A purely performance-based approach that is integrated across the building code, equipment standards, local government guidelines and energy utility requirements would enable trade-offs to enable innovations in design, market competition and cost reduction, and other benefits, all in the interest of co-optimizing the outcomes sought. This would require empowering the professional community to lead on design solutions across all institutional silos, and careful coordination of policymakers at all levels of government. It would also require the removal of duplicate and inflexible regulatory interventions and institutions that prevent such co-optimization.

The CEO of Southern Company (2nd largest energy utility in the USA) is quoted as recommending an innovation approach to transitioning the energy sector to decarbonization, as opposed to a regulated approach that gels a compliance mindset [80].

Ultimately, this principle calls for establishing an "Innovation Ecosystem" that is premised on performance-based standards for desired outcomes sought through government interventions, empowering design professionals in the building sector to lead this innovation in the design, management and renewal of buildings.

The ecosystem could be forward-looking to anticipate future conditions and enable adaptable design solutions, as opposed to a compliance mindset that is rigidly focused on current requirements and historic market conditions. For example, it is widely accepted that climate change impacts are increasing and predictions are available of future baseline conditions that current buildings will face in two to three decades. Yet, codes are currently based on historic weather data and may lead to "dead ends" that could result in obsolescence due to factors such as excessive energy costs or overheating that cannot be repaired. Fortunately, the 2025 national model construction codes will incorporate future-looking climate projections to inform building design, necessary given the long operating lifetime of buildings.

The adaptive design solutions could respond to future risks and projected vulnerability to, and consequences of those risks, to build in resilient mitigation measures that minimize future "damage costs" for a moderate "control cost". An Insurance Bureau of Canada study has reviewed cost data associated with mitigating the impact of climate change and extreme events, versus the future benefits of avoided impacts, illustrating a ratio of 6:1 across the study scope [81], meaning that is as low as one-sixth of the cost to address risk factors in advance of a natural disaster, versus repairs after the disaster.

The Innovation Ecosystem could ultimItely inform the prioritization of investment in the building sector. Far too often building owners and managers face competing or conflicting objectives and do not have an opportunity or enough information to co-optimize. The regulatory framework with the biggest stick or the incentive scheme with the largest carrot informs the limited investment dollars, along with short-term benefits to the investor.

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[5] Author's terminology, included in research reports not released publicly.

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This may result in market activity that is disproportionate to the value to society and unintended consequences of even compromising other objectives, in particular those with long-term benefits.

The engineering and other professional communities have a unique insight into the conflicts between regulatory frameworks, sub-optimal performance outcomes, future conditions and dead ends. By extension, the professions are uniquely positioned to communicate these issues to all levels of government, if appropriately resourced to do so.

In summary, the following strategies are recommended under this principle:

- Establish common performance metrics across all categories of building performance outcomes, including objectives across regulatory frameworks.
- In the spirit of Alternative Solutions in the NBC, empower building sector professionals to design to those goals and co-optimize design across objectives and regulatory frameworks.
- Harmonize all regulatory frameworks to avoid conflicts preventing co-optimization.
- Maximize flexibility on pathways to achieve goals for those objectives, thereby enhancing innovation, competition and cost-minimization.
- Establish an “innovation ecosystem” within key professional and institutional communities
- Develop adaptative design solutions and avoid prescriptions with dead ends, despite known changing conditions.
- Focus on risk identification, vulnerability assessment and mitigation versus exposure to recovery and damage costs.
- Communicate extensively with governments on potential adjustments to policy frameworks to enhance performance, innovation and resilience, as opposed to a “compliance mindset”.

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Principle #3 – Efficiently Allocate Jurisdictional and Institutional Responsibility

A natural extension to Principle #1 around integrated demand- and supply-side planning is to efficiently allocate responsibility between the five levels of government and their associated regulatory frameworks and institutions.

The first strategy is to establish an orderly transition of the buildings and energy sectors and to avoid fragmentation. In doing so, government interventions in the market would align with the ultimate goals (for desired outcomes) of the integrated plan, despite slight differences in pathways to account for differing market and political circumstances in each sub-jurisdiction. This is possible with strong provincial leadership in harmonizing with national model codes and standards and delegating jurisdiction to other levels of government (e.g., regional, Indigenous, municipal).

Despite its best efforts under the Modernization of BC's Building Regulatory System that culminated in the introduction of the 2015 Building Act, the system in BC continues to have significant fragmentation due to a lack of guidance on the method of implementation of provincial building codes by local authorities and significant influence by other regulatory systems. For example, the BC Energy Step Code, referenced as a set of voluntary standards in the BC Building Code, provides a technical roadmap to the transformation of energy efficiency standards over the next decade to "net zero energy ready" construction by 2030 [82]. The authors submit this multi-jurisdictional coordination effort was influential in the development of the tiered energy codes in the 2020 National Building Code of Canada and the National Energy Code for Buildings, both released in March 2022. This illustrates a second strategy to harmonize government levers at multiple levels of government.

Provincial efforts to promote consistency takes time, and interim steps of other levels of government may appear to be contradictory. For example, British Columbia's Energy Step Code is implemented via concurrent authority of both local governments and the Province whereby the latter sets a technical roadmap with multiple steps and the former mandates one of the steps in bylaw. This has led to a diversity of differing bylaws which on the surface may appear to show disharmony as illustrated in Figure 16. However, future editions of the BC Building Code, applied across the Province every five years resets the steps (to step 3 in 2023) and the early adopter communities have prepared the market for that mandate.

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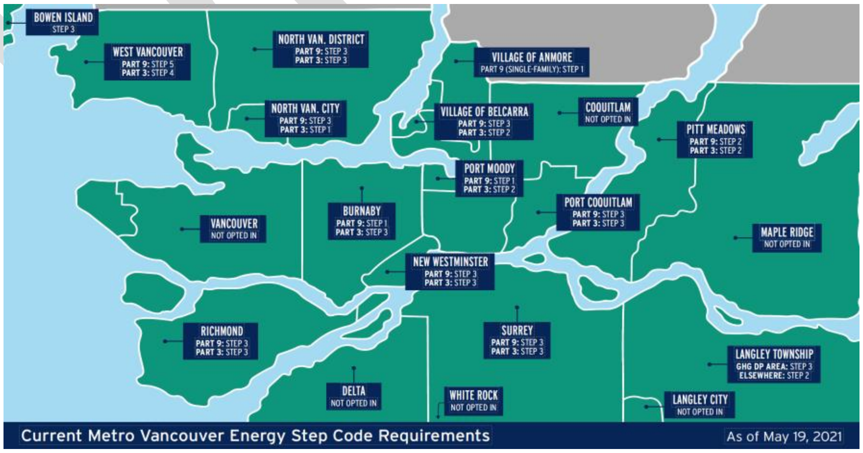

Figure 16: Fragmented BC Energy Step Code Implementation in Greater Vancouver (2020).

Not included in the map, but in the reference document, ten of these local governments have used a loophole in the provincial regulatory framework to provide a “low-carbon energy system” option that allows builders to reduce energy efficiency requirements in return for not installing natural gas. While this results in the decarbonization of buildings and lowers the capital cost of construction, it does so at the expense of energy efficiency standards that are justified for low-carbon energy supplies and would support the affordability of energy for multiple owners and occupants of buildings over the coming decades. It also inserts local governments into provincial energy resource planning, the domain of provincial institutions, that could result in significant and unintended consequences around energy system reliability, planning, investment in distribution systems and concerns about stranded assets. These practices are misaligned with principle #1 around integrated planning that would both reduce demand and decarbonize energy supplies simultaneously.

Indeed, the conflict within and fragmentation between the city halls of British Columbia has created an impetus for the evolution of policy and leadership by the province, culminating in the CleanBC Roadmap to 2030. This raises the third strategy which is to allocate responsibility to the highest point of governance that is practical, as that jurisdiction will have the largest reach of influence for a given institutional cost. It also avoids incompatible directions and fragmentation that can compromise public support. Further, it avoids overlapping interventions that have no incremental impact, thereby avoiding unnecessary implementation costs. Finally, it aligns with a deliberate effort to focus on areas with the greatest impact, otherwise known as the “surgical approach” to policymaking.

Figure 17 depicts a hypothetical example of allocating responsibility to the highest point of governance. The triangle on the left illustrates the target audience of policy intervention, with the top representing all buildings in a jurisdiction such as British Columbia with 1.8 million households. The triangle on the right illustrates the policy measures and their relative impact per stakeholder in terms of market transformation, with the carbon tax having a small influence on all households (and buildings) at the top, and caps and portfolio standards on energy utilities having the largest impact on approximately four major players.

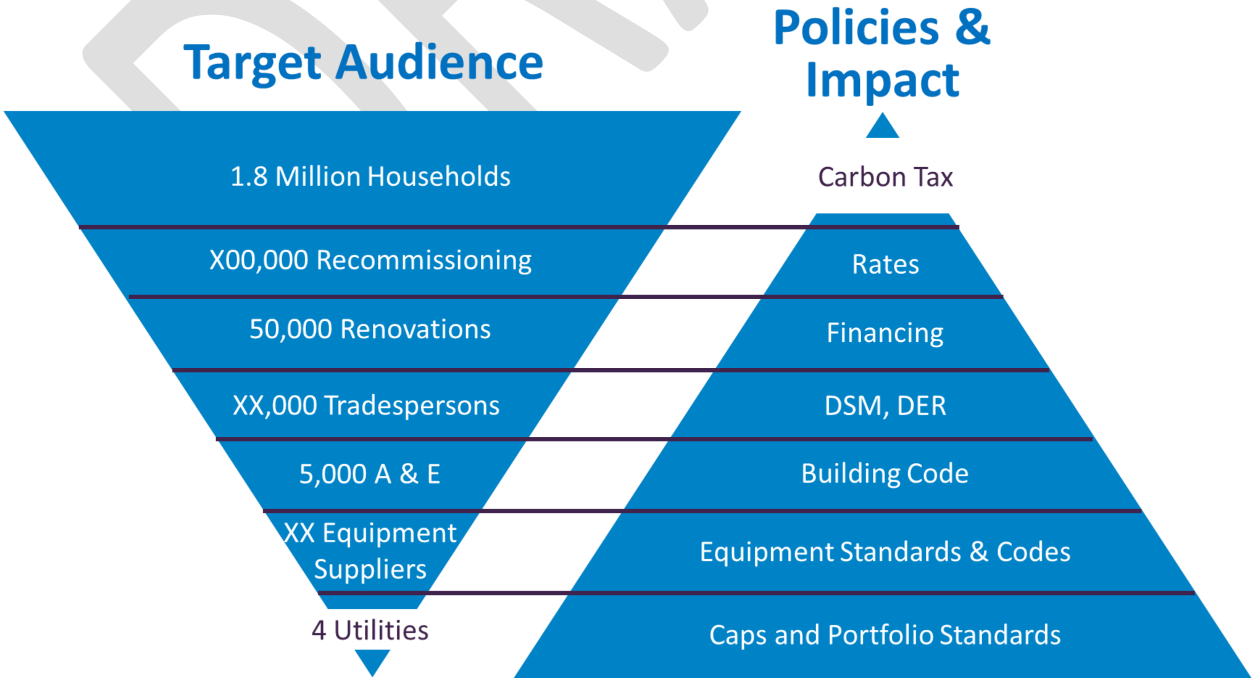

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Figure 17: Approach for Influencing Market at Highest Jurisdiction of Influence (BC example).

The layers in the double triangle diagram include (from top to bottom):

- Total consumer base, influenced by carbon taxes.
- Hundreds of thousands of homes and buildings installing controls such as smart thermostats and energy management software through recommissioning efforts, influenced by rates.
- 50,000 buildings undergoing major renovations within a year, influenced by financing, demand-side measures (DSM), distributed energy resources (DER) and future building codes.
- Tens of thousands of tradespersons influenced by DSM in particular, including trade-ally programs of energy utilities and the Home Performance Stakeholder Council [83].
- Thousands of architects and engineers designing new buildings, regulated by the building and electrical codes.
- Tens of equipment suppliers, including manufacturers, wholesalers and distributors, whoever is influenced by the energy efficiency standards for equipment within the jurisdiction (i.e., federal and/or provincial).
- Less than ten major gas and electric utilities, influenced primarily by caps on emissions and portfolio standards for zero-carbon fuels.

The CleanBC Roadmap to 2030 embraces this surgical approach and provides an impetus for an orderly transition among all levels of government. Before late 2021 when it was released, in the absence of coordinated action on energy utility emissions, several sub-optimal interventions were made to affect utility emissions at the bottom of the right triangle, but for a very small population of one municipality and new construction only, a rounding error of a province-wide effort.

The fourth strategy aims to support social equity in the implementation of policies and regulations and to prevent disproportionate impacts on vulnerable populations, building and housing types and regions. This is not easy to do at the P/T level, and as such local and Indigenous governments could be empowered to flexibly apply sub-national mandates. While this creates some inconsistency and goes against the principle of policies being applied by the highest level of governance practicable, as noted above, empowering communities creates opportunities for leadership and enhancing resilience in response to regional risk factors. Codes and standards can be adapted to provide such flexibility for leadership and reflecting local conditions, such as the tiered energy codes.

In summary, this principle includes the following strategies:

- Orderly transition of the buildings and energy sectors
- Harmonized government levers at multiple levels of government
- Allocate responsibility to the highest point of governance that is practicable
- Support social equity in the implementation of policies and regulations

The traditional “market transformation” approach [85] [86] was coined by the US and Canadian federal governments to drive permanent improvements in the energy efficiency of equipment and buildings, starting with the early adoption of new technologies and design practices and building market share toward mass adoption of the most effective approaches. The extent of market transformation is determined by market readiness indicators of “availability”, “accessibility”, “awareness”, “affordability” and finally “acceptance”. These are otherwise known as the “5 A’s of market transformation”. Various government and energy utility levers

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support different stages of the market transformation during the process of fulfilling those “5 A’s”. Figure 18 illustrates a new approach toward market transformation that includes integrated demand-side and supply-side measures, contrasting against the traditional approach that only considered demand-side measures and energy efficiency, keeping energy resource mixes and costs outside of the scope of the strategic effort.

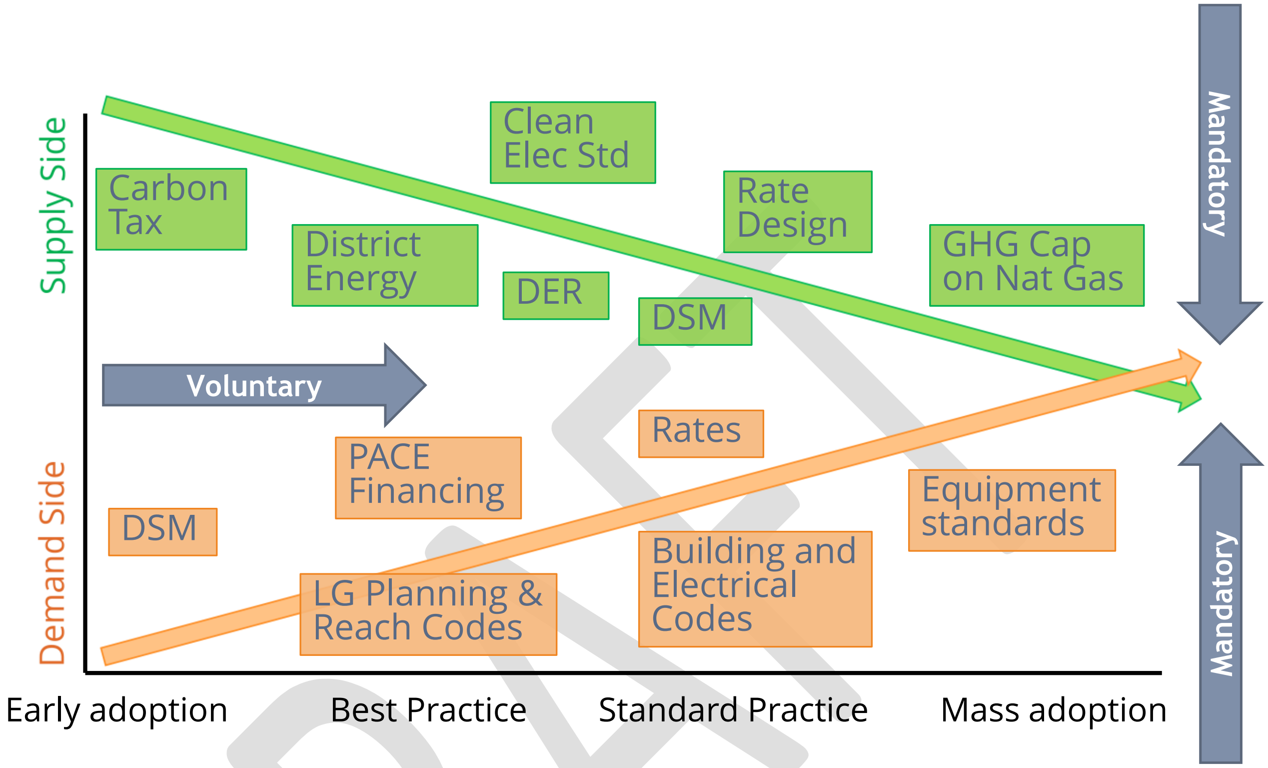

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Figure 18: Market Transformation Approach between Supply-Side and Demand-Side Measures.

Principle #4 – Leverage Building Lifecycle Investment Triggers

This principle pertains to the common triggers for investment in new and existing buildings and the associated objectives of government policy that is applied at the time of investment. The objectives and outcomes sought from this Roadmap include energy efficiency, resiliency against extreme weather events and chronic stresses, decarbonization, the flexibility of energy systems and resiliency of the indoor environment for building occupants. These are a subset of the overall "objectives" of building codes highlighted under Principle #2.

The principle supports an alignment of the timing of building improvements across multiple objectives to achieve the most cost-effective building construction and renewal over the long-term life-cycle of the building. It seeks economies of scale for professional services to co-optimize design solutions that deliver multiple objectives, economies of scale for construction and commissioning, minimized disruption of occupants and building functions, in particular those with cost implications, and economies of scale for financing, depending on the capital structure of the building ownership.

For new buildings, this practice is standard – the objectives of building codes are all achieved simultaneously. What is missing are objectives not included in codes that have long-term economic value such as resilience against natural disasters. Building codes have life-safety objectives, but generally not economic objectives such as mitigating damage costs from extreme weather events, as outlined in Principle #2. Studies illustrate that incorporating post-disaster resilience or risk mitigation into the construction costs a fraction of the costs of rebuilding from those disasters, averaging one-sixth of the cost [81]. A more recent study pegs the multiplier of damage cost versus mitigation cost at 13:1 [87].

For the renewal of existing buildings, this is more complicated, as investment triggers are often voluntary, except for building failures such as a structurally unsound roof, wall assembly or foundation, significant water damage, end of life for mechanical and electrical equipment and building enclosure components.

Many building owners conduct planning processes to develop a "capital asset management plan" or "depreciation report" in concert with technical studies that consider the condition of those capital assets, including roofing, windows, cladding, and mechanical and electrical equipment. These studies are mandated in several provinces for stratified housing, or condominiums. For example, the BC Strata Property Act requires depreciation reports to be completed every three years with a planning duration of 30 years [88]. This creates an ideal opportunity to consider the timing of building renewals that address multiple objectives in an orderly fashion.

The result of capital asset management planning is that some building improvements would occur earlier than they are needed for the end of life to achieve the aforementioned economies of scale in design and construction, and others may be delayed with temporary life-extension measures. Indeed, many building owners do the latter (i.e., deferred maintenance) as a natural course of cost minimization, but in some instances the cost of replacement skyrockets with excessive delays.

The approach taken for stratified housing could be extended to all building types. Other sectors do so voluntarily, including commercial real estate and public sector buildings.

Figure 19 illustrates the natural "triggers" for investment in buildings. These include:

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1. Careful land-use planning to consider community objectives, the orientation of buildings for access to daylighting and on-site renewable resources (e.g., solar access), interconnecting with utilities, use of topography and landscaping for energy conservation and resilience (e.g., shading to reduce vulnerability to extreme heat events) and other objectives.
2. For new construction, integrated design process by developer and professionals to co-optimize multiple objectives that are mandated in building and safety codes and other objectives of an economic nature such as risk mitigation and building durability. A key aspect is commissioning to ensure design performance objectives are implemented.
3. Building operations can include "continuous optimization" practices to maintain ongoing energy performance or explicit re-commissioning or retro-commissioning efforts and real-time energy management [89]. Collectively, these can result in 5-25% energy improvements relative to no action [90].
4. Completion of a capital asset management plan to comply with legislation (e.g., for stratified housing), pursue the objectives in this Roadmap, upgrade buildings to current building code standards and future-proof buildings to prevent future obsolescence.
5. Implementation of a capital asset management plan for individual components within a budget and with timing to optimize economies of scale.
6. A decision to undertake a comprehensive building renewal or,
7. A decision to pursue demolition and building replacement.

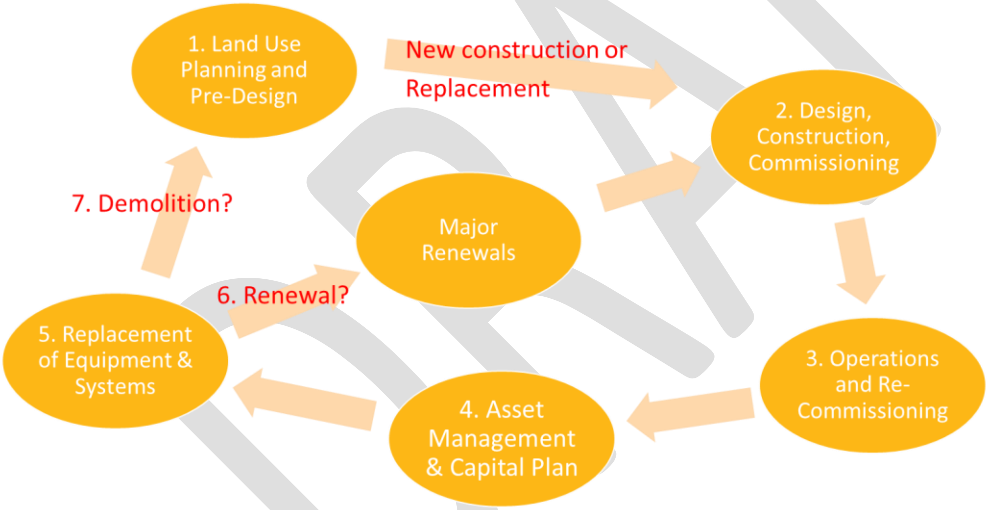

Figure 19: Current Investment Triggers through the Life-Cycle of Buildings.

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Principle #5 – Facilitate Data-driven Outcome-based Policymaking

The premise of this Roadmap is to promote outcome-based policymaking and to align government policy interventions around the vision of Chapter 2 using the metrics of Chapter 3. The BC Policy Approaches Playbook highlights "Outcomes-based Instruments" as a regulatory approach that is designed to focus on measurable outcomes, rather than prescriptive processes, techniques or procedures. This approach shifts the focus of regulation to the end results or outcomes, rather than inputs or theoretical outputs, although outputs may be used as proxy measurements. Outcomes-based regulations reduce the degree of government intervention by allowing businesses and individuals to choose how they will comply with legislated requirements [91].

Within this Chapter, Principle #2 highlights performance-based approaches that focus on outcomes, while maximizing competition and innovation. For Principle #5 the authors submit that the building sector would benefit from a significant increase in the use of data to drive performance-based standards and outcome-based instruments. This could include the collection of data related to the desired outcomes at all stages of the building life cycle – see Figure 20. Given the importance of data in advancing outcome-based instruments, its collection could justifiably be standards, along with appropriate reporting of those data to advance the policy objectives while protecting private information. For each of the five stages of a building life-cycle, inherent data sets include:

1. Land-use planning – risk factors, resource opportunities
2. New construction design – assumptions, parameters, modelled performance
3. Commissioning and validation at time of occupancy – observed differences between design and construction, including aspects removed for "value engineering"
    - The data set from commissioning can be used to develop mitigation measures to address those differences which could compromise building performance
4. For building operations, measurement of multiple data sets at various scales such as whole-building, individual systems, equipment, and/or circuits, followed by verification of design against measured performance data using evaluation tools such as machine learning of trends, leading to a rejigging of continuous optimization operating strategies (i.e., every 3-5 years), including occupant engagement and building management priorities around energy use and GHG emissions.
    - Following this learning step opportunities may be identified to adapt to changes in building occupancy and usage patterns for continuous optimization and to inform future retrofit priorities due to deficiencies or impact assessments.
5. For building capital renewal, the condition assessment of equipment, capital asset management plans (specifying target replacement dates), energy audits, calibrated energy modelling based on measured data, and prospective building usage.
    - Following this learning step guidance can be advanced to inform innovations in new construction design, codes and standards, based on the performance of existing buildings, as verified by data sets.

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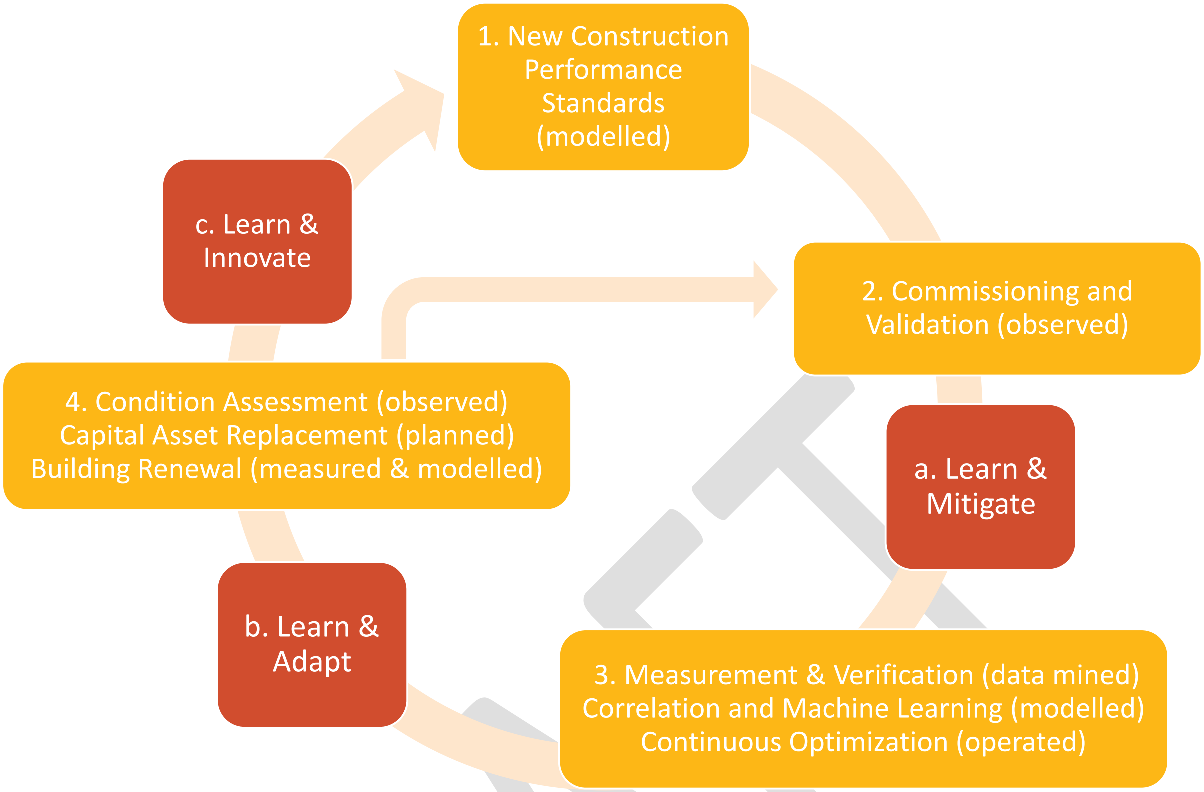

Figure 20: Collection of data related to the desired outcomes at all stages of the building life-cycle.

The ASHRAE 100 standard, Energy Efficiency in Existing Buildings, is data-driven in that the Energy Use Analysis and Target Requirements, the minimum energy performance standards, are based on measured data from thousands of buildings across the continent [92]. Supplemental studies for British Columbia and Washington State have been completed from cohorts of building energy performance measurements and are summarized in the ASHRAE 100 User's Guide [93].

With a data-driven, outcome-based policy framework comes significant responsibility for market participants. A side effect is perceived and actual risks of market valuation impacts based on performance, in other words, the highest performing buildings will command greater market value. Within that comes an ethical responsibility among professionals to balance the protection of owners and public interests as manifested by government policy.

Also, with a data-driven policy framework comes a burden of data collection, storage, analysis and dissemination which is increasingly common across all facets of Canadian society and the economy. There is a unique opportunity for the academic sector and other learning institutions to steward the emerging "big data" and analytical engines driving this transformation, under the privacy protection of government legislation. There are also complementary institutions such as statistics agencies, land title offices and/or property assessors for market value for property taxes. In British Columbia, these include BC Stats (and of course Stats Canada), the Land Title and Survey Authority and BC Assessment, both legislative institutions.

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Further, the data sets need to be used to inform codes and standards such as ASHRAE 100. To do that requires institutional capacity (e.g., academic learning organizations) and a strong liaison with codes and standards authorities (e.g., Codes Canada and ASHRAE).

Finally, with data collection and analysis emerges an opportunity for public education. For example, the City of Seattle has a longstanding data collection mandate on “building energy benchmarking” and their ongoing data dissemination and specialized reporting provides significant value to multiple sectors including real estate, building management, energy utilities (i.e., resource planning and demand-side measures), and government (for strategy development and evaluation of policy impact) [94].

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7. Call to Action and Roadmap for Engineers

Rosamund Hyde

This chapter proposes an expanded role for engineers to support an orderly, cost-effective and resilient transition to ultra-low energy buildings, distributed energy resources and decarbonization. The profession is ideally suited to be a core partner of governments, institutions and building sector associations for the following reasons:

- The engineering profession interacts with all aspects of the topics covered in this Roadmap and serves multiple building sector stakeholders;
- Engineering practice collectively bridges across government, institutional and sectoral silos and provides service in a manner that addresses a diversity of drivers for building design and operations;
- Professional practice aligns with codes of ethics, which include an obligation to, "hold paramount the safety, health, and welfare of the public, including the protection of the environment and the promotion of health and safety in the workplace" [95];
- Professional advice supports multiple objectives and goals in policy, regulation, codes and standards; and,
- Engineers are in a unique position to catalyze meaningful action on policy goals while highlighting limitations of design solutions in the context of management practices, local context and a changing climate.

This chapter provides a call to action for engineering leadership, innovation, and active participation in informing policymakers and policymaking. The specifics of this effort will be discussed at a workshop at the Canadian Academy of Engineering Annual Conference in 2023.

This form of leadership was present under an initiative of Engineers Canada called "Bridging Government and Engineers Committee" which included an annual meeting with the Federal Government on Parliament Hill [96]. It also called upon the participants to individually meet with the federal government elected representatives [97] to discuss the issues statements of Engineers Canada [98]. While Engineers Canada no longer sponsors this Committee, the initiative could serve as a template for efforts with provincial and territorial governments (P/Ts) who hold significant influence on public policy in the domain of buildings.

This Roadmap has presented a vision of a resilient, ultra-low energy use and decarbonized building sector in Canada, metrics to track outcomes through the transition process, case studies of relevant innovations, and principles to guide a nationwide policy transition in the fluid context of a changing environment. This chapter identifies opportunities for and expectations of professional engineers to grow and exercise their skills in this process.

Many engineers in Canada support the construction and renewal of buildings in Canada, recently amplified due to the housing shortage and pandemic renovation boom, both of which benefited from government investments. This call to action includes asking engineers to:

- Collectively establish a vision for professional practice to support future proofing of buildings around the various risk factors such as ultra-low energy design, energy resilience, decarbonization and ability to withstand future risks.

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- Individually evaluate risk factors and mitigation measures associated with building designs across the broad performance metrics highlighted in this Roadmap. This is aligned with the risk management approach championed in the EGBC Climate Change Action Plan [99].
- Engineers involved in building operations: measure the performance of their buildings and learn from the data; support property owners and managers for continuous optimization in the day-to-day management of building operations, enabling ongoing service contracts that pay for themselves through efficiencies.
- Bring their knowledge and measured performance data to policy development processes, including participating in the development of codes.
- The examples offered in the Case Studies invite building design engineers further to collaborate with academe in proposing demonstration projects for buildings that go beyond current standard practice, also supporting research and innovation.
- Collaborate with the Canadian Academy of Engineering to establish an innovation ecosystem to explore new possible design strategies and new business models, informed by a template from the Petroleum Technology Alliance of Canada [100].

Figure 21 summarizes an example of how professional practice can evolve to support one of the goals and measurable outcomes sought by this Roadmap. This can serve as a Roadmap for professional engineers, along with the other professions supporting the buildings sector such as professional planners. The orange boxes on the left depict individual actions that support the goal in the blue box on the right. The middle, white boxes represent opportunities for continuous improvement over time.

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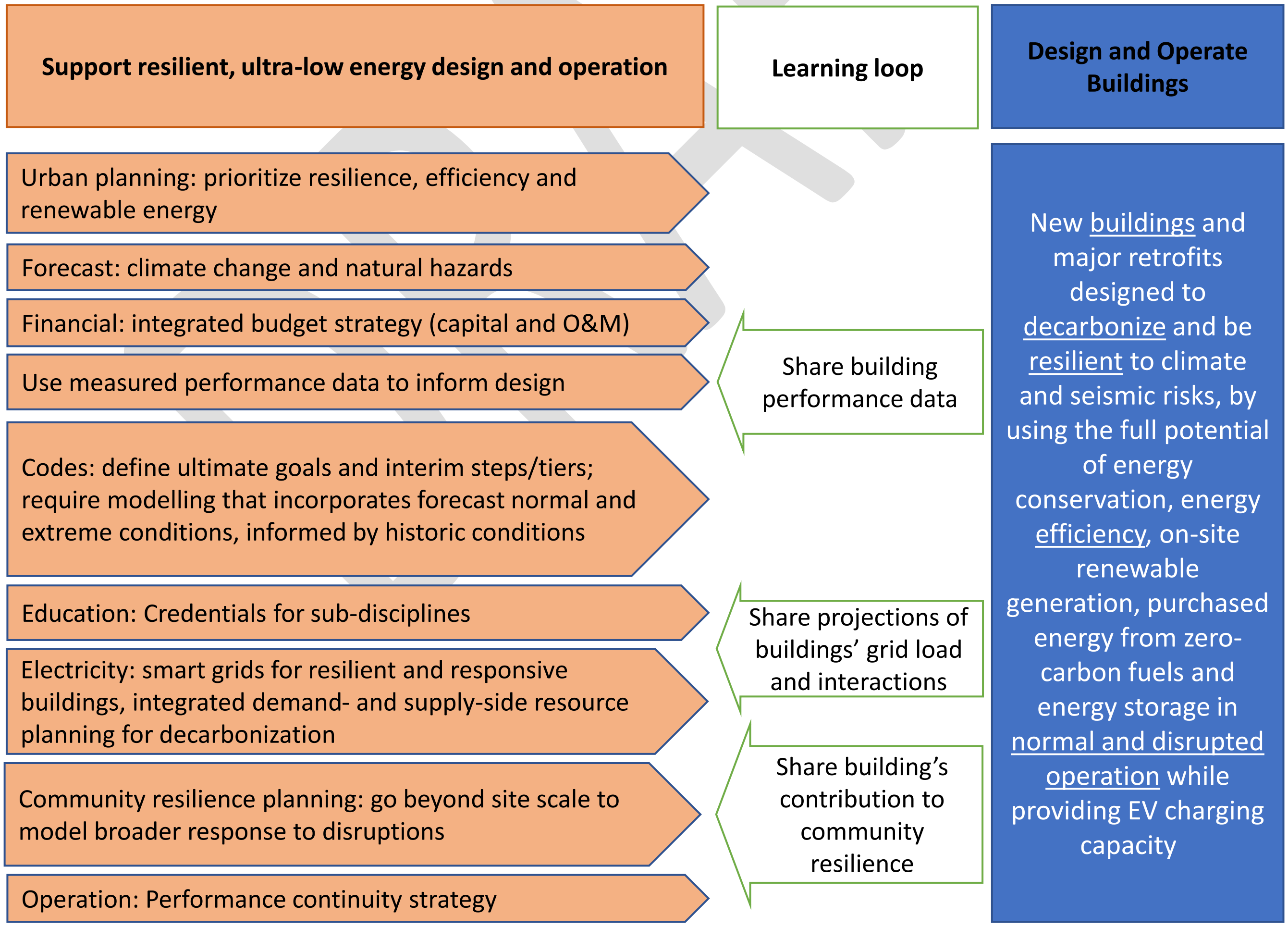

Figure 21: Roadmap for Engineers and other Professional Practitioners

This broadening of building design engineers' scope is not trivial. However, it offers many advantages. The changes can enable the industry:

- To serve clients better and to strengthen competition between designers based on innovation and engineering evidence of superior performance rather than on marketing claims of pre-eminence;
- To move toward a more harmonized and strategically structured system of codes, that can make ultra-low energy, resilient and decarbonized Canadian building stock possible;
- To elevate building design to a more sophisticated level, with an increased dimension of stewardship throughout the service life of the building;
- To address the long-standing gap between building design practice and university research on building design, which has resulted from an academic focus on building simulation in the absence of available building performance data;
- For purposes of succession and renewal of the industry, to attract recruits who want to improve building design and address the energy performance gap (between designed and actual performance) by learning from building performance data;
- To engage with design professionals and engineers in other fields, bringing data that can help to solve big-picture problems; and,
- To participate strategically in climate action.

Again, the Canadian Academy of Engineering will be discussing the potential for its Fellowship of inducted professional leaders to disseminate the messages in this Roadmap to the buildings and sector and climate action departments of P/Ts through individual meetings.

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Appendix A – Roadmap Advisory Committee Membership

- Dr. Marianne Armstrong, National Research Council
- Dr. David Bristow, University of Victoria
- Waleed Giratalla, Green Municipal Fund, Federation of Canadian Municipalities
- Roland Charneaux, Pageux Morel, Montreal
- Chantal Guay, Standards Council of Canada
- Dr. Caroline Hachem-Vermette, University of Calgary
- Julie Hewlett, Technical Safety BC
- William Larson, Pacific NW Building Resilience Coalition
- Dwayne Torrey, Canadian Standards Association

- Harshan Radakrishnan, Engineers and Geoscientists BC

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Appendix B – 2019 Montreal Workshop Position Paper

Background

Canada's long-term goal of reducing greenhouse gas (GHG) emissions by 80% by 2050, aligns with the global scientific consensus of stabilizing the atmospheric concentration of GHGs and limiting average temperature rise to less than 2˚C. The goal is referenced (relative to the year 2005) in Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy (2016), and is legislated in British Columbia (relative to the year 2007). Many different pathways to achieve this goal are being debated in different contexts and from different perspectives. These discussions include the CCA "Expert Panel on Energy Use and Climate Change Report" [101], with recommendations related to buildings as well as the transportation, community infrastructure, and industry sectors[6], the CAE Trottier Energy Futures Project ([102]; *e.g.,* scenario 8), and the Pan Canadian Framework on Clean Growth and Climate Change (2016) and aligned jurisdictional initiatives such as the CleanBC Plan (2018).

The feasibility of new net zero energy buildings that **integrate ultra-high energy efficiency with on-site renewable energy generation** to produce, in an average year, as much energy as they use, has been demonstrated both for detached houses and low- to mid-rise commercial and institutional buildings, both in Canada and other developed countries [103]. Many definitions exist for net zero energy buildings, most recently documented and discussed under IEA SHC Task 40 / EBC Annex 52 [102] and new design approaches are being developed [104] [42]. It is currently recognized that the renewable energy technologies, such as photovoltaics, required to reach net-zero are limited by up-front costs, despite being cost-effective for standalone systems, along with **market and institutional barriers**, depending on the jurisdiction and local resource availability. Standalone PV is the lowest cost electricity resource in the world at roughly $0.65/watt, but is limited by intermittency, associated grid issues, institutional barriers, lack of market capacity and other major barriers to integration in buildings and public spaces.

Driven by the need to make high performance housing affordable, governments have come up with less stringent short-term targets such as **net-zero ready** (no widely accepted definition) and **nearly zero** (China, APEC). Also, **carbon neutral** and **zero carbon** buildings are being advocated, which can be challenging to enforce when emissions due to manufacture and transportation of materials are considered, along with the upstream production and transmission of energy resources. For example, if transportation is through electric vehicles/trains 10 years from now, in theory there would be low or no emissions from transportation, providing that the electricity is generated from renewable energy sources.

Aside from the **multitude of high-performance building targets**, there is broad agreement that three strategies need to be integrated in achieving the targets for new buildings/communities and for retrofits:

1. **Ultra-low Energy Design** (for buildings and communities, including public spaces and adjacent infrastructure) that enable buildings to meet most of their needs from on-site or community-based renewable energy supplies (e.g., net-zero energy ready).

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[6] - Space and water heating account for most energy use and carbon dioxide emissions in the buildings sector
Buildings that incorporate features such as passive solar design; enhanced use of insulation; and air-, ground-, and water-source heat pumps can reduce heating and cooling demands by 60 to 90% over conventional construction.
- Dramatic efficiency gains can make it economically viable for buildings to convert to low-emission electricity to meet all remaining energy needs, resulting in substantial reduction of emissions in this sector.
- Low-emitting district energy systems powered through renewable energy and cogeneration can also reduce emissions.
- Governments can support emission reductions through building codes, energy efficiency standards, capacity development, and urban planning.

2. **Deep integration of renewable energy** (BIPV, energy waste capture, geoexchange, air-source heat pumps, on-site hydrogen, storage, smart micro-grid) on the buildings or near the buildings and public spaces/local infrastructure. This will enable net-zero energy buildings/communities.

3. **Smart buildings and energy utility infrastructure** (smart buildings, smart grid, regional renewable energy centres, storage, interaction with electric vehicles, energy management information systems, biofuels including renewable natural gas, waste-to-energy, and district energy) to support efficient buildings and zero-carbon supplies and storage, load management (including demand response) and consumer engagement.

Another important aspect, increasingly being recognized to be of equal importance to the reduction of GHG emissions and "future-proofing" buildings is **resilience**. **Resilience** is defined by the 100 Resilient Cities network as, "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" [105], and for the purposes of this paper, may be broadly split into several categories:

1. **General resilience** against chronic stresses that are disruptive to the operations, maintenance and economic viability of buildings, including **health**, **indoor environmental quality** (*e.g.,* criteria air contaminants), **comfort** (*e.g.,* overheating), and long-term **durability** (*e.g.,* avoiding structural damage from water ingress)**.**

2. **Energy resilience:** for how many days/weeks can a community/building satisfy basic services (possibly with integrated electric vehicles) to occupants (minimum heating and electrical appliances) after energy supplies from utilities are cut under extreme weather conditions or other events?

3. **Structural resilience**: occupancy and function of buildings in a short timeframe following an acute shock (*e.g.,* resistance to earthquakes and extreme weather events)?

Most suggested solutions to the net zero energy buildings target involve ultra-efficient building envelopes, solar energy and both electrical and thermal energy storage. One challenge with **solar energy systems** during the heating season (when Canada has the highest emissions) is that they usually produce power during off-peak periods when the **grid** may not need it. Hence **energy storage** is needed, which is also necessary for resilience. Thus, in addition to **energy efficiency measures and renewable energy**, **energy storage** is important to optimizing energy flows with building needs and smart grids, thus facilitating penetration and integration of intermittent renewable energy resources (wind, solar). This includes electrical and chemical storage, tanks of water or other fluids, building thermal mass and seasonal thermal storage. Thermal mass is present in different levels in all buildings and can be used to store passive solar gains in the heating season, while in other seasons this "mass" can reduce overheating and improve comfort. Increasingly, **buildings will be active prosumers** in the power system that can play the role of local energy storage and production, adjusting their behaviour to contribute positively to the operation of the grid, and hence contributing simultaneously to the resilience of the smart grid in an affordable and efficient manner.

Furthermore, the importance of system integration to achieve net-zero energy buildings and communities in an affordable way cannot be overemphasized: It is increasingly being recognized that buildings and their energy & HVAC systems need to be **designed and operated in an integrated manner** to be effective and affordable. Challenges include:

1. Current **building and electrical codes do not include resilience as an objective**. The health, safety, structural protection and energy efficiency objectives of the National Building Code (NBC)[7] and safety objective of the Canadian Electrical Code (CEC) support many aspects of resilience for new construction, particularly for acute shocks. However, chronic stresses are largely overlooked due to a lack of future-facing climate data, particularly as they relate to overheating and critical air quality events. Furthermore, long-term durability is not an objective

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[7] Other NBC objectives include fire protection, accessibility for people with disabilities and water efficiency.

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of the NBC, potentially exacerbated by chronic stresses. Should resilience to probable shocks and stresses be considered in code design parameters?

2. The **existing building stock is largely overlooked by the NBC and CEC** due to a lack of guidance on suitable standards for existing buildings that may need to be less stringent that those for new construction due to the limited options for improving building performance, post occupancy. Furthermore, the NBC only applies during building alterations with a building permit, occurring on average once every ten years, with “energy related” permits occurring every thirty years, but in one jurisdiction there is inconsistent enforcement [106]. The CEC applies for equipment installation.

3. Current **building codes do not consider integration of renewables**. They are however covered by the CEC and equipment standards. Should they be included in the National Building Code? One example is BC’s “Solar Hot Water Ready Regulation” for municipal opt-in that requires conduit and structural support for solar water heaters to be installed at the time of construction, improving the economics for owners to install solar collectors in the future. There may be similar drivers for energy resilience, even installing back up power, with storage capability for a period of time. This will intersect with community-scale utility infrastructure planning with the potential for shared supply and storage, along with micro-grids.

4. New technologies such as BIPV and active solar systems, active building envelopes, do not have enough **standards** developed, hindering their adoption. What is the appropriate scope of a BIPV standard [107]?

5. **The role of architects and engineers** in the construction process could be enhanced, enabling greater emphasis on building performance. Options include innovation/performance based codes (including alternative solutions and “step” codes), certified professional designation for greater professional reliance under the building regulatory system, improvements in the procurement of design services (*e.g.,* need for qualification-based selection), project management (*e.g.,* construction management or integrated project delivery), and broadened requirements for system “commissioning” prior to occupancy permit. What are the gaps that hinder deep design integration and other opportunities?

6. Integration of **thermal with structural building design, durability**; Concrete or wood? Concrete production causes increased emissions compared to wood but has major structural and thermal advantages (*e.g.,* can store a lot of heat (**thermal mass**), reduce overheating through free night cooling/natural ventilation). What is the appropriate use of concrete in mass timber net zero energy buildings?

7. Integral role of **urban, community and regional planning** to enable building and neighbourhood resilience and sustainability. Options include broadening the scope of urban planning departments to consider energy resilience and enable community-based, smart energy supply and storage, as well as the interactions of buildings and neighborhoods with the smart power grids of the future, and symbiotic sustainable transportation systems that could provide energy storage. **Should energy storage be mandated in codes, or at a community-based scale, or both**? Furthermore, community planning could advance other policy objectives such as complete communities and active transportation modes. Should resilience be a component of regional planning?

Workshop Scope

The topic under consideration, resilient, ultra-low energy buildings with integrated renewables, invites an impractical breadth of issues, and thus the precise definition of scope is critical. Of particular importance here is to identify “system boundaries”. For example:

- Balancing building design considerations between emphasis on building envelope, construction materials, mechanical and electrical systems, renewable energy system choices and smart grid integration of equipment. Presumably all in scope?

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- Renewable energy systems can be integrated in the buildings themselves, and/or public spaces adjacent to buildings and infrastructure, connected with a smart utility infrastructure. For a community energy plan where is the boundary drawn?
- How do we balance access to daylight and other amenities of traditional urban form, versus densification and transportation advantages? What are the lessons learned from other countries about sustainable communities and urban planning [108]? Interaction with electric vehicles?

Target and Key Questions

In the context of the above discussion, the planning workshop will address the following key questions:

- How can Canada develop a bold but flexible plan (adaptable to different provincial energy contexts) to achieve the deep **80% reductions in GHG emissions** for new and existing buildings by designing for net-zero **resilient** communities for 2050? What are the pathways to achieve/approach this goal for existing communities?
- A key approach in market transformation programs and policy **roadmaps** is often to lock in energy savings through progressively stringent energy codes and standards (*e.g.,* BC Energy Step Code). What are the key barriers and opportunities to achieve this approach? It is recognized that the context is different in different regions/provinces and different pathways may be followed.
- How can future-drivers be incorporated into building designs and retrofits today, thereby enhancing the **resilience** against acute shocks and chronic stresses in the built environment and the associated community energy infrastructure?
- What is the role of **innovation and performance-based design**, versus a conservative approach that emphasizes prescriptive standards based on historic evidence and postpones consideration of probable design drivers such as climate change and other resilience factors?
- What can we learn from **transformative technologies such as low-emissivity windows that took nearly 30 years** for full adoption [109] and how can the process of adoption be sped up for other transformative technologies such as building-integrated photovoltaics, cold-climate heat pumps, climate-responsive building materials (e.g., windows that can change solar heat gain depending on heating versus cooling loads), thermal and electrical storage, and smart predictive controls?
- What is the **optimal institutional framework** for advancing the aforementioned objectives, with respect to the national building and electrical code development system, provincial and territorial adoption in regulation, enforcement institutions (mainly local governments), professional reliance models, the "objective-based" premise of performance in building codes (despite continued adherence to prescriptive "acceptable-solutions"), and the opportunities for data-driven performance verification. What can we learn from other countries on innovation and resilience in building regulatory systems? What tweaks and comprehensive shifts could Canada benefit from?
- What is the audience for the output of the workshops? How should the results be communicated?
- Who should be invited to the two symposiums (tentatively the first technical symposium in 2020 and the second policy-focused symposium in 2021)?
- Further planning and communication of results?

Steering Committee

- Andreas Athienitis, Ph.D., Eng., FCAE, FIBPSA, FASHRAE, Professor, Concordia University (Co-Chair), Director, Concordia Centre for Zero Energy Building Studies

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- Andrew Pape-Salmon, P.Eng., MRM, FCAE, FCSSE (Co-Chair)
  Executive Director, Building and Safety Standards Branch
  British Columbia Office of Housing and Construction Standards
- Christopher Kennedy, P.Eng., Ph.D., FCAE, Professor, University of Victoria
- Diane Freeman, P.Eng., FEC, FCAE, Senior Project Engineer, Masri O Architects
- Kevin Goheen, PhD, P. Eng., Canadian Academy of Engineering
- Miguel F. Anjos, Ph.D., FHEA, SMIEEE, FEUROPT, FCAE, Professor, Polytechnique Montreal

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Appendix C – 2019 Montreal Planning Workshop Agenda and Communiqué

Program – Workshop on Roadmap to Resilient Ultra-low Energy Built Environment with Deep Integration of Renewables in 2050

Thursday, March 21st - Concordia EV Building, Room EV 2.309 (2nd floor), 1515 St. Catherine Street West

19:25 Welcome remarks by Marius Paraschivoiu, Associate Dean, G. Cody School of Engineering & Comp. Sc

19:30 Working dinner

- **Icebreaker activity – Deep Green Vision for the Built Environment**
    - What will your city look like in 2050 with 80% less emissions, while being resilient?
    - 30 sec elevator pitch to the Prime Minister of Canada or the CEO of the largest real estate investment trust or pension fund on how to achieve that big vision.

Friday, March 22nd - Concordia EV Building, Room EV 2.260 (2nd floor), 1515 St. Catherine Street West

8:00 Breakfast

8:15 Welcome remarks by Dr. Christophe Guy, FCAE, VP-Research Concordia

8:20 Opening remarks by Yves Beauchamp, FCAE, CAE President-Elect

8:30 Framing the Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables

- **Trottier Energy Futures Study** **Kevin Goheen**. Overview of Scenario 8. (20 min)
- **Current State of Play** – **Andreas Athienitis**. Overview of Canadian Academy of Engineering Position Paper. Proposed NSERC Smart Solar Buildings and Communities Strategic Network. (25 min)
- **Proposed CAE Symposia** in 2020, 2021 – **Andreas Athienitis**. (10 min)
- Discussion. (20 min)

9:45 Break

10:15 Pervasive Challenges and Responses (6-10 min each + questions)

1. **Towards developing the technical basis for increased resiliency** Speaker: **Trevor Nightingale**
2. **Standards for existing buildings** Speaker: **Andrew Pape-Salmon**
3. **Integration of renewables (standards, energy storage, grid optimization)** Speakers: **Miguel Anjos and Andreas Athienitis.**
4. **Role of architects in integrating renewables and energy efficiency** Speaker: **Toon Dreessen**
5. **Integration of durability, thermal and structural design** Speaker: **Ted Stathopoulos**
6. **Urban, community and regional planning** Speaker: **Caroline Hachem-Vermette**
7. **Role of cities**: **Diane Freeman**

12:00 Working Lunch

- Extra time to cover themes from the morning

12:45 Tying it together – Synthesis of problem statement

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- First half of "Communiqué" **– Andrew Pape-Salmon**
- Discussion

13:15 "Roadmap" Development – key questions from the CAE Position Paper
Format: **1-5 slides introduction (target 2-5 min)**, followed by comments from participants.

- Deep Reductions in GHGs – Speaker: **Genevieve Gauthier**
  - Insights from energy utility demand-side measures (education, incentives, pricing, codes & standards). What are the pathways to achieve/approach deep 80% reductions in GHG emissions in 2050 for existing communities?
  - 15 min total (13:30 end)
- Technical Roadmaps – Speaker: **Andrew Pape-Salmon**
  - Case study of the BC Energy Step Code. What are the key barriers and opportunities to achieve this approach? It is recognized that the context is different in different regions/provinces and different pathways may be followed.
  - 15 min total (13:45 end)
- Resilience – Speaker: **Liam O'Brien**
  - Taking a long-term perspective on planning. How can we enhance the resilience of buildings against acute shocks and chronic stresses in the built environment and the associated community energy infrastructure?
  - 15 min (14:00 end)
- Innovation – Speaker: **Rosamund Hyde**
  - What is the role of innovation, and performance-based design versus a conservative approach that emphasizes prescriptive standards based on historic evidence and postpones consideration of probable design drivers such as climate change and other resilience factors?
  - 15 min (14:15 end)
- Transformative Technologies and Performance Based Design – Speakers: **Ian Beausoleil-Morrison and Michel Bernier**
  - What can we learn from transformative technologies such as low-emissivity windows and how can the process of adoption be sped up for other transformative technologies such as building-integrated photovoltaics, cold-climate heat pumps, climate-responsive building materials, thermal and electrical energy storage, and smart predictive controls? How can performance-based design be aided with building simulation tools?
  - 20 min (14:35 end)
- Affordability, and socioeconomic - housing industry perspectives – Speaker: **Kathleen Maynard**

  Innovation, energy efficiency and the need for resilient housing through integration of renewable energy poses several challenges. How do we achieve the long-term objectives while reducing costs through integration and prefabrication?
  - 15 min (14:50 end)
- Institutional Framework – Speaker: **Andrew Pape-Salmon**
  - What is the optimal institutional framework for advancing the aforementioned objectives, with respect to the national building and electrical code development system, provincial and territorial adoption in regulation, enforcement institutions (mainly local governments), professional reliance models, the "objective-based" premise of performance in building codes (despite continued adherence to prescriptive "acceptable-solutions"), and the opportunities for data driven performance verification. What can we learn from other countries on innovation

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    and resilience in building regulatory systems? What tweaks and comprehensive shifts could Canada benefit from?
    - 15 min (15:05 end)

15:10 Break

15:25 Communiqué Part 2 – the CAE Work Program

- **Summary of document** – **Andrew Pape-Salmon**
- Feedback

15:50 Planning (2020 and 2021 Chairs Andreas and Andrew)

- **Symposium Attendance**
    - Who should be invited to the two symposiums (tentatively the first technical symposium in 2020 and the second policy-focused symposium in 2021)?
    - (15 min)
- **Symposium Planning**
    - Further planning and communication of results?
    - (15 min)

16:20 Closing Remarks – Andreas

16:30 Adjourn

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COMMUNIQUÉ – CANADIAN ROADMAP FOR RESILIENT BUILDINGS

April 23, 2019

Canadian Academy of Engineering: www.cae-acg.ca

The Canadian Academy of Engineering (CAE) assembled Thought Leaders from the professional community, construction industry, academia and three levels of government to begin to work on a national "Roadmap to Resilient, Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050", with an aim to achieve at least an 80% reduction in greenhouse gas (GHG) emissions in new and existing buildings and associated community infrastructure.

The CAE's Trottier Energy Futures Pathway project described scenarios for reducing energy supply emissions by up to 70% below 1990 levels across all energy uses, requiring an investment of 20-30% of Canada's non-residential business capital up to 2050. This represents a significant opportunity for diversification and economic growth.

The CAE Roadmap will articulate resilient solutions for community planning, building form and design, existing building renewal, "smart" community energy infrastructure, and on-site renewable energy generation to provide a supplemental perspective on the Trottier project. These solutions could enable achievement of the 80% by 2050 goal, while simultaneously increasing the resilience of communities to acute shocks and chronic stresses that are anticipated this century.

In recent history, we have experienced such shocks as the 1998 central/eastern Canada ice storm that resulted in up to 5-week power cut, 4.7 million people displaced in Québec and Ontario and economic loss of over $6 billion. This led to significant damages to buildings after their occupants evacuated them due to utility outages, resulting in extensive water damage from frozen water pipes and contributing to the economic loss. Such damage could be greatly reduced through resilient solutions that enable on-site electricity and heat production with building-integrated renewables. We anticipate that climate change will increase prevalence and intensity of chronic stresses as well as acute shocks. We need to increase our resilience to these and other acute shocks, such as a catastrophic earthquake in British Columbia or the Yukon where much of the older building stock could be destroyed in some cities, depending on the location and scale of the event. Solutions that address the three objectives of resilience, deep reductions in GHG emissions, and optimized energy efficiency plus on-site renewables can future-proof buildings and infrastructure and maximize long-term economic benefits for building owners, occupants and society.

At the March 22 Thought Leaders' Workshop, we discussed many technological and systems solutions already demonstrated by leaders across Canada, including the Varennes Library in Québec, Canada's first institutional solar net-zero energy building. Inaugurated in 2016, this building is designed to produce approximately as much energy as it uses in an average year through a building-integrated photovoltaic system. In fact, the solar energy potential across most of the populated areas of Canada is significantly higher than most of northern Europe. Peak utility demand can be reduced through smart grids, with smart buildings being active participants to provide load flexibility and services to the grid, including short-term curtailment of water heaters, thermal storage on-site, and additional storage from electrical vehicles. Energy utility resource planning, consumption and production rate structures, and the development of building codes and standards will benefit from access to measured data from building operations, requiring information infrastructure aligned with privacy legislation.

The CAE and its partners have launched a major effort to consider many of the questions raised at the workshop, reflecting various constituencies represented, to identify practical technical, policy, standards development and institutional solutions, and to develop the Roadmap document by 2021. The Roadmap could be used by all levels of government, including Indigenous communities, the construction and real- estate industries, energy utilities, the associated professional communities, product manufacturers, academia, and other key influencers. The vision is for a resilient built environment that is economically optimized in design, operation, retrofit/renewal and energy over a long-term horizon equivalent to the lifetime of the building/infrastructure (at least 50 years).

Further research will build upon existing strong evidence that energy efficiency and on-site renewable energy generation are required for broader resilience of the building stock and associated community infrastructure. To accelerate the innovation cycle, we will look to reframe the problem statements, continue to learn from existing building operations, and enable "double-loop" learning. We will aim to integrate "silos" in the professional community (*i.e.*, engineering, planning, architecture, real estate, and the administration and management of construction, buildings, utilities, governments and others).

Finally, we will develop win-win approaches and solutions adapted to the different regional contexts for new and existing buildings and community energy infrastructure by identifying the design solutions that optimize the multiple objectives of building code objectives, energy efficiency, GHG reductions, on-site renewable energy generation and durability.

The first order of business is to clarify the scope of the Roadmap. We will then define the range of questions that correspond with technical, market and human behavioural barriers. The Thought Leaders discussed concerns around the durability of modern construction, fuel and material choices, maintenance of existing affordable housing stock, procurement of professional services and "value engineering" (often cutting construction costs by installing lower performing components than envisioned in the design), market acceptance of innovative designs, management of risk and liability, and capacity of the industries to deliver solutions at scale. Consideration of key related barriers and research questions is being addressed through a network of leading Canadian researchers from about 15 universities across all major regions and over forty partners covering

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major stakeholders, including the built environment designers, energy utilities, municipalities, builders, and manufacturers.

The Roadmap will articulate existing and emerging societal goals, highlight all available government policy levers and market mechanisms, and provide at least three "pathways" to achieve the vision. Pathways are expected to include, but not limited to the following: evolving objectives for the national building code development system; adoption/ implementation of these codes by provinces, territories Indigenous communities and local governments; public/ industry awareness and education; opportunities through incentives/ insurance/ financing/ leadership investments; technical synergies of having buildings be active participants in the energy grids; energy pricing strategies for energy efficiency and models to facilitate integration of on-site renewable energy systems; qualification-based/ financial outcome-based (best net-present value design) construction procurement; alternative institutional frameworks, and community planning.

In 2019 and 2020 the Thought Leaders' Workshop participants and associated partners will endeavour to develop the "near final" draft Roadmap in time for a symposium in Montreal in the fall of 2020, co-hosted by the CAE and the Concordia Centre for Zero Energy Building Studies. At the Montreal meeting, a broadened audience of all stakeholders and key influencers will be invited to submit papers and discuss the draft Roadmap in progress with a dual emphasis on technological win-win solutions and government policies.

In 2021 a symposium will be held in Victoria BC, focusing on policy solutions for all four levels of government (local/regional, Indigenous, provincial, federal) that are analyzed and vetted by the CAE and partners, along with options for the roles and responsibilities of the key institutions that develop, implement and support building codes and standards, community energy infrastructure, and construction and building management.

The resultant draft Roadmap will be posted by mid-2021 with an opportunity for public input to the Canadian Academy of Engineering. It will be practical and digestible by layperson audiences and decision makers alike. It will provide multiple pathways that will appeal to the diversity of Canadian jurisdictions.

For additional information or interviews, please contact:
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Appendix D - 2021 Communities Workshop Agenda

CAE Roadmap to Resilient Ultra-Low Energy Built Environment with Deep Integration of Renewables in 2050 – Low-Carbon and Positive Energy Resilient Communities Webinar – October 12, 2021 [7]

Scope: The webinar will focus on lessons learned and experiences from existing and ongoing developments in high profile low-carbon and positive energy communities in Canada and Europe, and informing the CAE Roadmap on current status and future opportunities and challenges

Online connection	10:55– 11:00
Opening/Welcome Remarks **Yves Beauchamp**, FCAE/FACG, President CAE, VP Administration & Finance, McGill University **Mourad Debbabi**, Dean Gina Cody School of Engineering & Computer Science, Concordia University **Setting the Framework for Zero Carbon Communities** **Andreas Athienitis**, FCAE, **Roadmap Co-Chair**, Professor and NSERC/Hydro-Québec Industrial Research Chair & Concordia Chair, Concordia University **Andrew Pape-Salmon**, FCAE, **Roadmap Co-Chair**, Adjunct Professor, University of Victoria **Ursula Eicker**, Professor, Canada Excellence Research Chair and **IEA Positive Energy Districts Subtask Leader**, Concordia University **Caroline Hachem-Vermette**, Associate Professor and **IEA SHC Solar Neighborhood Planning Subtask Leader**, Environmental Design, University of Calgary	11:00 – 11:30
CASE STUDIES - SESSION I	
Co-Chairs: Bruno Lee and Mohamed Ouf, Concordia University	
Dirk Pietruschka, Stuttgart University, Germany: **Low Depth Geothermal District Energy System in Wüstenrot**	11:30 – 11:45
Daniele Vettorato, Eurac, Italy: **The European Project SINFONIA: Building and District Energy System Retrofit in Bolzano**	11:45 – 12:00
Gilles Desthieux, HEPIA, Switzerland: **Cité Carl Vogt Heritage Neighborhood Retrofit in Geneva**	12:00 – 12:15
Rongling Li, Technical University of Denmark, Denmark: **Energy Flexibility in Buildings – Heating Energy Flexibility in Copenhagen**	12:15 – 12:30
David-Olivier Goulet, Hydro Quebec, and **Stéphane Vachon**, City of Lac Mégantic, QC, Canada **Lac-Mégantic Microgrid: A community is mobilizing around the energy transition**	12:30 – 12:45

BREAK		12:45 – 13:00
CASE STUDIES - SESSION II		
Co-Chairs: Hua Ge and Leon Wang, Concordia University		
Walter Mérida, University of British Columbia, BC, Canada: **Feathers and Dinosaurs: A Living Laboratory for Smart Energy Districts**		13:00 – 13:15
Bill Wong, NRCan, ON, Canada: **Drake Landing Solar Community – Lessons Learned**		13:15 – 13:30
Milfred Hammerbacher, S2e Technologies, ON, Canada: **West 5 Net Zero Community and Smart Grid Project**		13:30 – 13:45
Nayeem Ninad, NRCan, ON, Canada: **PV-Storage-Diesel Hybrid Microgrid of Colville Lake**		13:45 – 14:00
BREAK		14:00 – 14:05
PANEL DISCUSSION: Co-Chairs: **Ted Stathopoulos, FCAE and Andreas Athienitis, FCAE** **All presenters**		14:05 – 14:25
Closing remarks	Webinar Chair and Roadmap Co-Chair: **Andreas Athienitis**	14:25 – 14:30

In collaboration with IEA Positive Energy Districts (Annex 83) and SHC Solar Neighborhood Planning (Task 63):

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Appendix E – Examples of Government Policy Measures

In the 1990s the Canadian federal government undertook planning and leadership for energy efficiency under the leadership of the NRCan Office of Energy Efficiency with significant planning, programs and regulations, including targets for new buildings (e.g., 25% better than the 1997 Model National Energy Code for Buildings and EnerGuide 80 for new construction by 2010) and equipment standards (e.g., condensing furnaces). These efforts included significant collaboration with provinces and territories such as harmonized equipment efficiency standards [110] [111], and the creation of the Green Municipal funds to support local governments [112]. BC's 2005 [113] and 2008 Energy Efficient Buildings Strategies [114] adopted national energy efficiency targets for new buildings, coordinated with federal codes and standards and incentive programs and acknowledged the critical role of local governments and Indigenous communities, effectively advancing "market transformation" for buildings through measures at all levels of government [115]. Despite a shift in jurisdictional "turf" in the mid-2000s the multipartite coordination continued into the late 2000s culminating in the policy framework, "Moving Forward on Energy Efficiency" [116]. The Provinces and Territories asserted their jurisdiction via the Council of the Federation, but generally aligned with previous NRCan leadership [117]. A tangible outcome of all these efforts was changes to the National Building Code (NBC) of Canada, including the National Energy Code for Buildings in 2011 and the EnerGuide 80 standards in the NBC in 2012. What was not included in this coordinated planning was integrated demand- and supply-side planning, only demand-side.

The coordinated planning with meaningful results was paused for a decade, but then restarted in the context of the Council of Energy and Mines Ministers, and the Pan-Canadian Framework on Clean Growth and Climate Change to the "Build Smart: Canada's Buildings Strategy" which again was focused on demand-side measures and energy efficiency [118].

An integrated approach was achieved in BC under the 2021 CleanBC Roadmap to 2030. It optimized supply-side and demand-side measures and was premised on integrated analysis that sought the least-cost solutions to reduce emissions. It included a "Buildings Pathway" that aimed to address emissions and referenced climate adaptation, including:

- Reduction of building sector emissions by an additional 1.3 megatonnes by 2030, over and above the 2018 CleanBC Plan, targeting total emission reductions of 59-64%, as compared to 2007 levels [119];
- Economy-wide, input/output modelling to demonstrate the least-cost technology solutions and policy measures;
- Zero-carbon new construction by 2030, including a diversity of fuel choices;
- Highest efficiency standards (100%+) for new space and water heating equipment by 2030;
- Enhancing energy efficiency programs of utilities and introducing Property-Assessed Clean Energy (PACE) financing;
- Home energy labelling;
- Low-carbon building materials; and,
- Supportive carbon pricing, government leadership, climate preparedness and adaptation, community land-use planning, circular economy initiatives for materials and energy supply decarbonization, including a cap on natural gas emissions, enabling renewable natural gas and green/blue hydrogen.

A subsequent 2022 Budget announcement provided a further boost for the retrofit of existing buildings with a 5% tax credit for building renovations that result in achieving the ASHRAE 100 standard and matching the energy-use intensity of the top 40% most efficient buildings in BC [120] [93].

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This a model integrated plan that could be replicated in all other P/T jurisdictions. In March 2022 the federal government released Canada's 2030 Emission Reduction Plan could provide the impetus for those additional P/T plans, as this lays out an integrated demand- and supply-side approach in areas of federal government jurisdiction [9]. It is anticipated that future P/T plans will reference measures within this federal Plan such as:

- increasingly stringent, performance-based model building codes, including to introduce net-zero energy-ready model codes for new construction and the code for retrofits to existing buildings [9];
- a Low Carbon Building Materials Innovation Hub to drive further research, building code reform, and demonstration activities, all promoting the use of lower carbon construction materials (e.g., wood, steel, cement, etc.) in the built environment;
- regulatory standards, and an incentive framework to support the transition off fossil fuels for heating systems;
- an approach to require EnerGuide labeling of homes at the time of sale, and design a complementary Climate Adaptation Home Rating Program;
- a new Net Zero Building Code Acceleration Fund to accelerate adoption and implementation of the highest performance tiers of the national model energy codes, incentivizing stakeholder participation while addressing persistent challenges in Canada's codes system and paving the way to a code for alterations for existing buildings;
- federal capacity and technical support to provinces, territories and key stakeholders for the development and adoption of net zero emission codes, and alteration to existing buildings codes; and,
- an approach to increase the climate resilience of the built environment [9].

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Appendix F – Key Influencers – Institutions and Others

- Agencies, Tribunals, Crown Corporations empowered by legislation, including those delegated in legislation to implement mandates and/or regulations:
    - Building codes and standards
        - Local governments
        - Régie du bâtiment du Québec
    - Equipment and safety standards
        - Technical Safety BC
    - Public energy utility regulators
        - Alberta Utilities Commission
        - Alberta Market Surveillance Administrator
        - British Columbia Utilities Commission
        - Canada Energy Regulator
        - Manitoba Public Utilities Board
        - New Brunswick Energy and Utilities Board
        - Newfoundland & Labrador Board of Commissioners of Public Utilities
        - Northwest Territories Public Utilities Board
        - Nova Scotia Utility and Review Board
        - Nunavut Utility Rates Review Council
        - Ontario Energy Board
        - Prince Edward Island Regulatory and Appeals Commission
        - Régie de l'énergie du Québec
        - Saskatchewan Rate Review Panel
        - Yukon Utilities Board
    - Real estate regulators
        - BC Land Title and Survey Authority
- Professional regulators that oversee the work of registered professionals and universities:
    - Engineers and Geoscientists BC under the Professional Governance Act (EGBC).
    - Engineers Canada that accredits engineering schools, among other functions.
- Standards development organizations that establish "model" technical standards that can be referenced by legislation and/or used as best practices for professional practice:
    - Canadian Standards Association (e.g., Canadian Electrical Code).
    - Codes Canada (e.g., National Building Code, National Energy Code for Buildings).
    - ASRHAE (e.g., Standard for Energy Efficiency in Existing Buildings).
- Research and Education Institutions, including Academia
    - Concordia Centre for Zero Energy Building Studies (e.g. NSERC Smart Net-zero Energy Buildings Strategic Research Network)
    - University of Victoria Civil Engineering (e.g., Net-Zero Navigator, ReBuild)
    - Pacific Institute for Climate Solutions
    - Petroleum Technology Alliance
    - NSERC
    - Mitacs
    - Sustainable Development Technology Canada
    - BC Hydrogen Office

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    - FP Innovations
    - Zero-emission Building Exchange
    - CANMET
    - NRC
    - DOE Labs
    - Northwest Energy Efficiency Alliance
- Investment governance and institutional investors that apply Environment, Society and Governance (ESG) criteria:
    - Canadian Infrastructure Bank (e.g., $2B in building retrofits)
    - Canada Mortgage and Housing Corporation (e.g., criteria for mortgage insurance)
    - BC Housing Hub (e.g., $2.8B in affordable housing partnerships)
    - The Atmospheric Fund (Toronto/Hamilton) and Efficiency Capital Corporation
    - Green Municipal funds
- Government-owned energy utilities with demand-side measures that enable or promote energy conservation, efficiency, load management, zero-emission vehicle fuels, on-site generation, micro-grids, biofuels, green hydrogen, and other initiatives:
    - P/T Electric utilities – Crown Corporations
        - Yukon Energy Corporation
        - BC Hydro
        - NWT Power Corp
        - SaskPower
        - Manitoba Hydro
        - Hydro Québec
        - Newfoundland and Labrador Hydro
    - P/T Methane utilities – Crown Corporations
        - Manitoba Hydro
    - Municipal utilities
        - Lonsdale Energy Corporation (North Vancouver)
        - Toronto Hydro
- Programs agencies - Energy efficiency and clean energy offices that administer programs
    - Energy efficiency (e.g., Efficiency Manitoba, Efficiency Nova Scotia);
    - Local government sustainability (e.g., Federation of Canadian Municipalities);
    - Technical support (e.g., Zero-emission building exchange);
    - Financing (e.g., Clean Foundation / PACE Nova Scotia); and,
    - Zero-carbon energy (e.g., BC Hydrogen Office, QUEST-Canada).

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Appendix G – 2022 PNWER Summit Panel Discussion

Bridging Silos to Catalyze Decarbonization and Resilience of Buildings [4]

Description

Increasing the resilience of buildings against natural disasters, coupled with decarbonization, are daunting challenges for the market and institutions that govern building codes and standards, registered professionals, community planning and the energy sector. Current jurisdictional, institutional and professional silos are fragmenting the market and creating unnecessary conflict that threatens public confidence. Sub-national governments and the engineering profession are positioned to drive the evolution of the real estate, property management and energy sectors to catalyze investment toward optimal levels of building performance. This includes a principled approach to mitigate risks, maximize public benefits and minimize costs, while allocating responsibilities to the key influencers.

Speakers (highlighted names contain links to presentations on CAE website)

- **Andrew Pape-Salmon** (Moderator). University of Victoria, Adjunct Professor
- **Harshan Radhakrishnan** (Speaker). Engineers and Geoscientists BC, Manager, Climate Change and Sustainability Initiatives
- **Soheil Asgarpour** (Speaker). PTAC, President &CEO and President of the Canadian Academy of Engineering
- **Evan Reis** (Speaker). US Resiliency Council, Executive Director
- **Paul Chang** (Speaker). Codes and Standards Development, Community and Technical Support, Municipal Affairs, Government of Alberta, Provincial Building Administrator

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Appendix H – 2020 Montreal Symposium Proceedings (Papers)

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