CANADIAN INSTITUTE FOR **CLIMATE CHOICES**

Enabling broader decarbonization through Energy Systems Integration

By Dr. Madeleine McPherson, University of Victoria
With contributions from Madeleine Seatle, Robert Xu, Lauren Stanislaw, Tamara Knittel.

Executive summary

The conversation around decarbonizing Canada's energy systems is shifting, from one that was focused on displacing fossil-based generation in power systems to one that encompasses the breadth of demand sectors and the broader economy. Canada has found itself at the forefront of the power system decarbonization curve, owing in large part to substantial hydro endowments; while other jurisdictions have been focused on implementing supply-side decarbonization policies, Canada was afforded, in some sense, a head start. Where carbon-intensive sources remain on the supply side of Canadian power systems, policies including pricing carbon (carbon tax, output-based performance standard, cap and trade), coal phase-outs, and gas power plant performance standards, among others, have been announced or are in effect. However, a low-carbon power supply is insufficient as a standalone measure to achieve decarbonization targets. Now, focus must turn towards leveraging clean electricity to decarbonize the other parts of the energy system that continue to rely on fossil sources: transportation, buildings, and industry.

Energy systems integration (ESI), and the related concepts of electrification and sector coupling, is a framework that expands the scale and scope of decarbonization efforts beyond the power sector. Defined broadly, "*Energy Systems Integration (ESI) is the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost- effective energy services with minimal impact on the environment*" (O'Malley et al., 2016). This coordination across segments of the energy system could yield synergies that are vital for operating a power system characterized by variability and uncertainty. Some newly electrified loads, such as electric vehicles or heat pumps, can provide invaluable flexibility services to the power system. Meanwhile, low-carbon electricity—derived from renewables,

We thank Konrad-Adenauer-Stiftung for their financial support in producing this scoping paper.

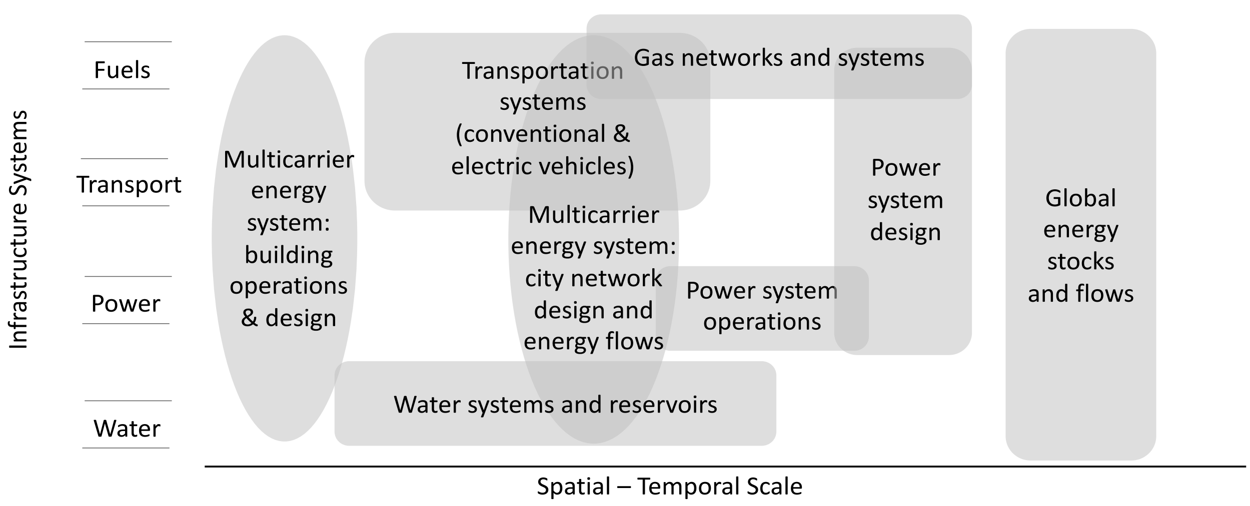
KONRAD ADENAUER STIFTUNG

nuclear, or thermal generation equipped with carbon capture and storage—can be leveraged to decarbonize the carbon-intensive parts of the energy system (i.e., electrification).

ESI encompasses electrification—switching loads' energy carrier from (usually) fossil sources to electricity—but is broader. Strictly speaking, hydrogen produced from steam methane reforming is not electrification, but it could provide invaluable services such as seasonal storage. Renewable natural gas, as another example, could decarbonize end uses that continue to rely on fossil fuels because they are difficult to electrify. ESI integrates the broad suite of built infrastructure that spans the supply side and demand sides as well as spatial scales (e.g., power system distribution and transmission) and temporal scales (e.g., short-term operations and long-term planning). ESI therefore demands a shift in perspective from one that is narrowly framed on individual infrastructure systems (such as those listed on the y-axis of Figure 1) or scales (increasing along the x-axis of Figure 1) to one that is holistic (including the examples shown in the bubbles of Figure 1) (McPherson, 2021). Representing ESI demands consideration of each system individually, as well as the interactions between them. But operationalizing ESI demands a shift in non-engineered infrastructure as well: the markets that define how products and services are remunerated; the institutions (NGOs, government, corporations) with differing policy levers (municipal, provincial, federal); and people (planners, operators, stakeholders, and decision-makers) fulfilling diverse mandates (provide reliable supply, provide a return for shareholders).

Figure 1

Energy systems integration spans infrastructure systems (y-axis) and spatial–temporal scales (x-axis) and encompasses a holistic set of interacting issues (bubbles)[1]



1 Multicarrier energy systems are defined as systems with "strong coordination in operation and planning across multiple energy vectors and/or sectors to deliver reliable, cost-effective energy services to end users/customers with minimal impact on the environment" (O'Malley et al, 2020).

ESI is a useful framing to drive the decarbonization efforts that are currently before us. While decarbonization may be possible without operationalizing ESI, the pathway will be costlier and slower and will ultimately lead to an inferior energy system. At this moment in time, as jurisdictions plan for massive new investments in infrastructure, key technologies advance towards maturity, and political will is favourable, the ESI frame is more relevant than ever.

This paper contemplates Canada's current ESI landscape, the challenges facing further ESI implementation, and some solutions to overcoming these challenges. We begin by taking stock of where what we term "ESI technologies" are along their evolutionary pathway from technology maturation through to policy support and widespread adoption. Next, the key challenges and gaps that are impeding ESI technology development and integration are discussed. ESI is difficult to operationalize in part due to familiar transition challenges (technology innovation, policy implementation) but more importantly because it redefines the underlying fabric of energy systems. ESI requires breaking down the long-standing silos between infrastructure systems and the institutions that govern them. Finally, we conclude with suggestions for overcoming the most fundamental of these challenges. We find that sector-specific challenges and remedies have a role to play: siloed power systems should be replaced with regional integration; demand response potential should be quantified and realized through appropriate pricing mechanisms; and subsidies should be replaced with market reform that remunerates services according to grid requirements. But stepping back from the challenges that are specific to an individual sector, operationalizing ESI must be accelerated by overcoming an information gap—understanding interactions between systems; a communication and governance gap—convening stakeholders and information across the decarbonization landscape; and an implementation gap—coordinating action across the energy system.

The current landscape: five ESI technologies

This paper begins with a review of the technology maturity and policy landscape for five ESI technologies or strategies: electric vehicles, heat pumps, demand response, distributed generation, and hydrogen. These five are considered ESI technologies or strategies because they sit at the nexus of two or more sectors, scales, or vectors, and thus operationalize the concept of ESI. Managing electric vehicles' battery charging integrates transport and power systems. Effective operation of heat pumps depends on insight into building heating characteristics as well as power systems. Demand response integrates individual loads with power system dispatch. Distributed generation integrates local distribution systems with provincial transmission systems and inter-provincial interties. Hydrogen deployment strengthens the linkages between the power and fuel systems.

We choose this technology focus because doing so reveals some of the most critical challenges at the forefront of decarbonization pathways through concrete examples. Because ESI technologies sit at the nexus of systems, they offer useful case studies for examining the intersecting space between systems. Furthermore, ESI technology development and integration are essential to the broader path to net zero. Given their intersectional function, these technologies will play an invaluable role in integrating and modernizing the energy system. However, by occupying this intersectional space, they also face a complex set of challenges. Effective decision-making in this intersectional space is critical to decarbonization. There are, of course, issues outside the realm illustrated by these technologies and strategies that are fundamental to decarbonization pathways; the other white papers presented in this series delve into pathways to decarbonize electricity, the governance and regulatory landscape, and policy challenges and solutions.

Technology pathways: three phases

Thus far, global decarbonization policies have tended to focus on power generation, which, combined with effective planning and ambitious targets, have played a significant role in the unprecedented pace of renewables' progression over the past decade. Investments in new renewable power now exceed those for fossil-based capacity, and almost every country has adopted a renewable energy target. Now, renewables are considered a mature, cost-effective, environmentally sustainable and secure technology (IRENA OECD/IEA and REN21, 2018).

Like the pathway that has characterized many technology-driven transitions, including this recent evolution of renewable energy technologies, the following assessment of the ESI technology landscape can be framed around three phases: (1) research and development that prepares a novel technology for market; (2) preliminary adoption, usually supported by policy, that accelerates the race to commercial viability; and (3) full-scale commercialization and system integration (we return to phase three later in the paper).

Phase one: technology maturity

The degree of R&D maturation differs vastly across the landscape of ESI technologies. In a recent review, the International Renewable Energy Agency (IRENA) assessed technologies' maturity in terms of their ability to meaningfully contribute to emission reductions by 2050 (IRENA, 2017). According to their report, electric vehicles have matured substantially in recent years, are gaining market share quickly, and are "on track" to contribute substantially to decarbonization; however, further opportunities exist for innovations in high-performance and low-cost batteries and charging infrastructure. Overall, solar PV technology, and utility-scale installations in particular, is also "on track," but there are further opportunities for decentralized building-integrated PV. Solar water heaters, on the other hand, are "not viable at current pace": substantial cost reductions are needed for these technologies to realize their potential. Demand response holds promise, but development and deployment is "lagging but viable": technology improvements and a better understanding of their potential and deployment are needed. Similarly, heat pumps are "lagging but viable": deployment at scale as well as innovation in low-temperature building energy systems is needed. Further innovation is required to enable the plethora of hydrogen solutions: hydrogen vehicles and industrial hydrogen applications (e.g., iron making, hydrogen ammonia production) are "not viable at current pace", in part because the hydrogen energy systems at scale are not in place (IRENA, 2017). In sum, individual technologies' maturity is as diverse as ESI itself: well underway in some cases; requiring further progress in others.

Phase two: policy-supported technology adoption

Once a minimum degree of technology maturity is achieved, further improvements can be accelerated by early-stage technology adoption. Often, policies support technology adoption through financial means (e.g., subsidies) or regulatory means (e.g., legal requirement). For example, wind and solar PV adoption was accelerated by feed-in tariffs (financial subsidy) as well as resource portfolio standards (regulation). If successful, such policies spur a positive feedback loop: technology improvements precipitate increased adoption that fosters commercial viability and eventually system-wide adoption. Such a framing naturally brings the following question to the fore: *what is the policy landscape that is currently supporting ESI adoption?* In the case of ESI technologies, municipal, provincial, and federal policies each have a role to play.

Policy review and analysis

The annex contains five sets of tables—one for each ESI technology or strategy (electric vehicles, heat pumps, distributed generation, demand response, and hydrogen)—that list policies at the federal, provincial, and municipal levels (as applicable). There is a plethora of policies that could be considered; our review is not exhaustive. Instead, it provides an illustrative perspective on the ESI policy landscape. The following section analyzes this list of policies (found in the annex) for the purpose of identifying the challenges to operationalizing ESI (discussed in the following section).

Policies and supports for ESI technologies: a cross-Canada comparison

Canada has a diverse energy landscape: provinces operate under different regulatory structures, manage differing degrees of resource richness, and contend with an array of constituent attitudes. The policy landscapes for ESI technologies are no exception.

Provinces offer differing degrees of EV adoption incentives

Most provinces incentivize EV adoption, at least to some extent. A few provinces or territories have no EV incentives or strategic plans. Saskatchewan is the only province that has implemented a policy that acts as a disincentive for EV adoption. Most municipalities do not have any EV incentives in place, with the exception of several cities in British Columbia, Alberta, Quebec, and Ontario.

Most provinces have programs for distributed generation, but their implementation differs

Most of the provinces' distributed generation incentive programs are rebate programs and typically target solar PV. However, the administrating body differs: rebates are offered by the province or municipality in some cases, or by the electricity distributor in others. As discussed further below, the degree to which the distributed generation programs align with a broader energy policy framework (e.g., incentivizing distributed generation in areas where it is costlier than alternatives) is either unclear or lacking. Rebate programs also differ in terms of the size of the solar PV array that is eligible and the compensation rate. Furthermore, programs differ in terms of their eligibility rules and the risk they impose on the applicants. Many programs are only available to residential building owners. Typically, the programs offer post-install rebates, which shifts the risk to the building owner. Most provinces have a feed-in program that follows one of two basic structures: net billing (offsetting retail purchases from the local utility) or net metering (offsetting electricity consumption with self-generation). However, other implementation details differ. Provinces with larger populations and total electricity demand allow prosumers (an individual who consumes and produces power) to have larger installations . Most provinces compensate prosumer feed-in with the retail rate of electricity, with the exception of Manitoba and Saskatchewan, which remunerate at less than the retail rate, and the Yukon, which remunerates at more than the retail rate (higher still in isolated communities). Feed-in rates below the retail rate of electricity may be encouraging investment in battery storage, so that customers can avoid feeding excess generation back into the grid.

Comprehensive demand response programs are less prevalent and diverse

Demand response programs that target large industrial consumers are well established and prevalent. In these programs utilities can take control of a portion of an industrial load as needed; the eligibility size, warning time, and amount of reduction varies, but the overarching goal is consistent. Demand-response programs that target non-industrial loads are more varied between the provinces. Our review found a variety of pricing schemes that have been implemented. Furthermore, a diverse range of consumer actions were encouraged, including limiting energy use at certain times of day; putting a load on standby and remunerating the consumer if it is shut off; imposing stipulations on instantaneous energy use during specified portions of the day; and monitoring and potentially reducing a consumer's energy use during a demand response event. Some utility companies offer customized demand response schemes for individual commercial customers. Ontario's capacity auction is an innovative approach that appears to offer a fair amount of flexibility and breadth in terms of the type of demand response that is procured. Consumers submit bids on an annual basis that define the demand response resources they can provide. A wide variety of consumers can participate in Ontario's demand response auction, though large- to medium-sized ones tend to be the most successful. The majority of policies in Canada pertaining to heat pumps, one of the key loads that could be controlled through demand response, are rebates to subsidize consumer adoption, rather than incentives or structures to control load. Although such policies will decarbonize heating loads in buildings, they fail to take advantage of the flexibility that heat pumps could provide system operators.

The regulatory frameworks and deployment of hydrogen infrastructure is nascent

Hydrogen infrastructure deployment and regulation is in the early stages across Canada. Substantial gaps in codes and standards will need to be addressed in order to meet stated targets: 50 per cent hydrogen mixed into existing natural gas networks and the potential for 100 per cent dedicated pipelines in some regions of the country by 2050 (Natural Resources Canada, 2020). Specifically, Canada lacks injection and quality standards for blending hydrogen into natural gas grids, as well as a framework for inter-provincial coordination (Natural Resources Canada, 2020). Each province's perspective on the potential role of hydrogen is a reflection of the local electricity generation mix, the existing natural gas infrastructure, and the end-use demand profile. All provinces with the exception of Alberta have *renewable gas policies or plans* that extend until the end of this decade. Alberta established a longer-term target for hydrogen injection infrastructure to enable import/exports within Canada and internationally by 2040. British Columbia and Quebec (two hydro-dominated provinces) have *renewable gas targets* of 15 per cent and 10 per cent (respectively) by the end of the decade (Preston et al., 2020). British Columbia, Alberta, Saskatchewan, and Ontario have *renewable fuel usage policies* that stipulate hydrogen utilization contribute to decarbonizing natural gas grids (Natural Resources Canada, 2020). British Columbia, Alberta, Ontario, and Manitoba have *renewable fuel standards* which specify the fraction of renewable products in gasoline and diesel. Policy makers in Canada will have to contend with all administrative levels—from municipal to federal—when it comes to hydrogen injection into natural gas networks (Canada Energy Regulator, 2020).

Provinces have varying degrees of policy alignment across institutions

There are significant differences across Canada in terms of the alignment between policies and plans made by the provinces and those of the utility or federal government. British Columbia has harmonized its EV provincial sales targets with the federal targets, and BC Hydro has incorporated those targets into their load forecast. Although Hydro-Québec is also incorporating targets into their load forecast, they do not quite align with the provincial targets: Hydro-Québec is planning for 0.9 million EVs in its supply plan, while the government is targeting 1.5 million EVs by 2030. The extent to which what Alberta may or may not be predicting (if anything) is in line (or not) with federal targets is unclear from publicly available documentation, but the Alberta Electricity System Operator considers a scenario with high EV growth in their long-term outlook. Saskatchewan does not have a target for EV adoption, and SaskPower does not refer to an EV adoption target in its long-term forecasts. Manitoba Hydro publishes an EV forecast, but it does not align with the federal targets.

While some provinces have gone further than others, there is a general lack of coordination between levels of government and limited consistency between government targets and utilities' forecasts. This discontinuity stems, in part, from disjointed authority for various parts of the system: municipal governments are charged with urban and transport planning; provincial utilities are tasked with planning and operating generation and transmission infrastructure; federal governments are mandated to enter into international commitments on behalf of Canada. However, the lack of harmonization across jurisdictions and scales is problematic. Municipal and federal policies for EV adoption, such as deploying charging infrastructure, non-financial incentives (e.g., access to HOV lanes), financial incentives (e.g., rebates), and education programs, need to be accounted for in transportation and power system planning as well as national targets. Distributed generation and other prosumer policies that span the municipal, provincial, and federal levels must align with the local utility's plan to ensure that sufficient capacity will be available to supply the newly electrified loads.

The policy landscape is dominated by “soft” policies (incentives) rather than cost-reflective tariffs, legal requirements, or mandates

Many of the policies and programs are voluntary incentives that may encourage individual action but are unlikely to precipitate transformative change. There are only a few examples where legal requirements mandate action or change. This state of affairs perpetuates a sustained history of voluntary actions that has dominated environmental and energy policy in Canada. Demand-side management policies, for example, often focus on education and promotion of energy-efficiency appliances and behaviour (Rivers and Jaccard, 2010). Such “soft” decarbonization strategies (opt-in strategies or financial incentives), which were dominant in the 1990s, have not been effective (Rivers and Jaccard, 2010). Canada ultimately failed to meet its Kyoto Protocol commitments due, in part, to insufficient adoption of the voluntary energy-saving measures. The country’s current landscape is uncomfortably reminiscent of Canada’s history of focusing on individual changes rather than systemic or transformational change. Restructuring markets or rate structures so that they remunerate residential and commercial customers who partake in grid-controlled demand response could, for example, offer substantial and much-needed grid flexibility. While attitudes towards energy-saving measures are more favourable today, mandatory legislation would go further to ensuring the wide-scale change required to significantly affect carbon emissions.

Policies tend to focus on sector-specific measures rather than on pan-system integration or transformation

The majority of policies presented in the Appendix target individual action: incentivizing EV adoption, regulating building efficiency codes, or providing rebates for distributed generation. Few of the policies or initiatives consider a system scope that extends beyond the entrenched boundaries that define individual sectors (power, buildings, transport, industry), planning scales (distribution, transmission), or political jurisdictions (municipal, provincial, federal). Integrating ESI technologies, by their very definition, relies on the coordination of multiple systems across many scales. For example, multi-system planning and operation of the power sector (generation and transmission capacity) and transport sector (locating charging stations) will be required to effectively manage EV charging, especially as adoption rates grow. However, as of yet, none of the utilities in Canada have incentives for responsive charging of private electric vehicles; Manitoba Hydro goes the furthest by issuing suggestions on its website to charge EVs at night (as does Ontario’s Ministry of Transportation). Multi-systems planning and operation of the power and building sectors, as another example, will be required to leverage the flexibility that could be derived from dispatching flexible loads (such as heat pumps) dynamically. However, demand-response policies tend to ignore residential loads. Multi-scale planning and operation of the distribution and transmission systems, as yet another example, will be important as meaningful shares of distributed resources come online. Yet existing net metering and net billing policies remunerate based on fixed, aggregated rates rather than time-varying, nodal prices that reflect the local grid reality.

When evaluating the policy landscape with the question *"what scope of integration is being considered?"* we find that most policies target individual systems as if they were stand-alone; in addition to being incentive-based, this siloed approach will prove ineffective when evaluated from a pan-system perspective. A suite of policies focuses on individual technologies: increasing appliance efficiency or incentivizing EV adoption and distributed generation. Few focus on systemic change or transformational change. There are no policies, for example, to reform markets so that they remunerate the new set of services (such as flexibility) that electrified loads can provide to the grid; such gaps miss the opportunity to incentivize infrastructure investments that would foster efficient decarbonization.

This state of affairs is consistent with classic policy arcs for new technologies: first subsidize the adoption of the technology itself, *then* implement policies that focus on integration. This "one step at a time" approach may sound logical. Why implement a demand response program when EV penetration is low and integration is not yet an issue—especially when the coordination task, spanning sectors and scales, is daunting? Implementing integrative policies may seem unnecessarily onerous and perhaps even risky. Such concerns are not entirely unfounded. The rollout of demand response programs, which are inherently systemic, have been compromised by their complex coordination. For example, Ontario's target to install smart meters in all homes and businesses failed to have the desired effect in part due to challenging coordination: energy prices increased and peak demand was not reduced as frequently as intended (Office of the Auditor General of Ontario, 2014 and 2016).

However, without actions or policies that take a holistic, system-wide approach, Canada risks locking into infrastructure pathways that are sub-optimal; for example, a capacity mix that results in compromised grid dispatch could reduce reliability and resilience. Furthermore, failing to take a holistic approach guarantees reactive decision-making in the future, which could raise costs for ratepayers and consumers, harm competitiveness, and undermine support for broader decarbonization goals. At the very outset, planning authorities should prioritize system integration. Instead of viewing widespread system integration as the third and final phase of a technology's maturation, they should shift their technology-centric perspective to one that encompasses the broader system into which it is being integrated.

Challenges to operationalizing energy systems integration

There are many technology- and sector-specific limitations that act as challenges to decarbonization. Realizing the full potential of distributed energy resources, for example, is impeded by high technology costs (Sigrin, 2021). However, the most formidable obstacles are those that encompass interactions between systems or jurisdictions. Returning to the example of distributed energy resources, such challenges include the rollout of a fully digitized system, the harmonization of transmission and distribution systems, and the remuneration of flexibility services, including the ability to ramp quickly (Sigrin, 2021); each of these challenges span multiple systems or scales. Taking a step back from any specific technology or sector, the greatest challenges are those that cut across historically disparate parts of the energy system.

The modelling landscape: an illustrative example

The modelling landscape is an illustrative example that exemplifies the crux of the issue. Models have been important tools for representing individual energy systems and facilitating sector-focused decision-making. Numerous platforms have been developed to help understand and manage the building, transport, and power systems across many spatial–temporal resolutions. However, the current model landscape is siloed (McPherson, 2021). Operational transport and building models typically don't connect to power system dispatch models, for example, which limits the capacity to operationalize electrification pathways. Going further, detailed engineering models of the transport, building, and power systems, which are spatially and temporally resolved, seldom link to economic equilibrium models, which represent broader impacts on trade, commodity prices, and demand dynamics. For modelling platforms, developed within or outside government, to continue to provide useful information to planners, they must evolve to encompass a holistic perspective that is conducive to navigating the energy system decarbonization pathway that lies ahead. This is not to suggest that developing holistic modelling platforms is the only, or even the most fundamental, challenge to decarbonization. Rather, integrating the siloed modelling landscape is a useful analogy for characterizing the structural issues of siloed planning, decision-making, and implementation of energy systems broadly.

EVs, heating, hydrogen, and storage: technology-specific examples

As we turn our attention to the challenges facing ESI technologies, we find that detailed system-specific information is not often matched by a holistic, pan-system perspective, much like the siloed modelling landscape. To effectively electrify the transport sector, for example, planners need information about the electricity system (where electricity is available for charging and how much it costs); the transportation system (how people and goods move through the city and between regions); and the intersection of these two sectors (EV charging infrastructure). To effectively electrify heating loads, planners need information regarding the characteristics of a building and its HVAC system, as well as how generation infrastructure will supply the newly electrified heating load. Arguments for hydrogen depend on demonstrating the capacity to provide long-term storage in power systems, the value of which is highly system-dependent: some systems need (or will need) the flexibility services that storage assets offer, while others, with flexible generation fleets or highly interconnected transmission systems, will rely on storage less. Each will place a different value on the services that storage assets provide. To plan investments appropriately, utilities must account for the impacts of electrification on peak load and load profiles. This list—EV charging, managing heating loads, integrating hydrogen, the value of storage, the impacts of electrification—are just examples that illustrate the key point: that good information that spans sectors and scales is required in order to achieve coherent, cost-effective, and context-appropriate outcomes.

Information, communication, governance, and collaboration: the broader landscape

Of course, operationalizing the integration of energy systems will require more than developing insights and exploring options. Effective integration of ESI technologies will require coordination across the breadth of political dimensions, institutions, and stakeholders. Beyond pan-sector *information*, actors face challenges associated with *communicating* insights across siloed governance structures and *implementing* cross-cutting solutions. The disaggregated and siloed approach that characterizes Canada's energy landscape is limiting progress towards the multi-scale and multi-system transition that is ahead. The solution space needs to consider not only options within each system but also those that integrate across sectors and scales. Continuing to examine solutions framed within a single scale or sector, without understanding the effects from or on other scales or sectors, will result in an incomplete picture and ineffective decisions. Fundamentally, the challenges ahead include information gaps for holistic planning, communication and governance gaps for convening decision-makers, and implementation gaps that span spatial–temporal scales and infrastructure systems.

Overcoming the challenges to decarbonization

As we delve into the possibilities and challenges of electrification and energy systems integration, we emerge into a landscape that encompasses the breadth of spatial–temporal scale, multiple sectors, and each energy vector. However, decarbonization challenges and their solutions can be categorized by their scope: those that pertain to a single sector and those that entail multiple sectors or stakeholders. This distinction is useful, because solutions that demand insights or actions that span multiple sectors present different challenges from a governance perspective than those that only pertain to a single sector.

Within each sector—power, transport, buildings, industry—there is a long list of recommendations to address specific issues. Regionally integrated power systems should replace siloed planning and operation. Voluntary opt-in programs or financial incentives in the building sector should be replaced by mandatory legislation. Demand response potential should be realized through accelerated technology development (e.g., increased R&D spending), deployment (e.g., pilot programs that collect and disseminate data and best practices), and system-wide integration (e.g., market reform that appropriately remunerates flexibility services). Smart devices and smart meters should be deployed en masse to enable widespread consumer demand response programs. More broadly, market reform that appropriately remunerates the services required by the grid should replace one-off subsidies (e.g., for EV adoption).

When we look beyond individual sectors, holistic information, pan-sector communication, redefined governance structures, and coordinated implementation will be critical. As a first step, a multi-sector, multi-scale, and multi-vector modelling platform could help navigate the information gap by providing insights of the broader system. For example, an integrated platform could inform the synergies between generation mixes dominated by variable renewables and loads that can offer flexibility. Doing so begins with a better understanding of solutions within each distinct area (load, generation, meteorology), as well as the intersection between them.

Next, actualizing decarbonization pathways rests on communicating insights—both sector-specific and integrated—to decision-makers and stakeholders who can then take tangible actions. Ensuring planners and policymakers have robust information is imperative from them to make informed decisions and actions, but this is challenging to actualize. For example, over a series of workshops, the Energy Modelling Initiative identified three components that are critical to integrating model-based evidence into the decision-making process but often lacking: insights must be timely, they must be delivered in a way that fosters trust, and they must be delivered in a way that fosters inclusiveness (Beaumier et al., 2020). More broadly, stakeholders from disparate parts of the system and each jurisdictional scale must coordinate on integrated decision-making.

Ultimately though, understanding the integrated energy system and bridging the information gap does not go far enough. Transformational decarbonization requires the implementation (planning and operation) of infrastructure that is coordinated across systems, scales, and vectors. Actors with differing jurisdiction must streamline their efforts. Institutions that operate in silos must collaborate. Governance structures must foster iterative, collaborative, and inclusive processes. Deep decarbonization demands deeply integrated solutions.

References

Beaumier, L., M. Esfahlani, M.-M Roy, N. Mousseau, and M. McPherson. 2020. *Energy Modelling Centre – Long-term plan proposal.* Energy Modelling Initiative. Montréal, QC.

Canada Energy Regulator. 2020. "Pipeline regulation in Canada." https://www.cer-rec.gc.ca/en/about/who-we-are-what-we-do/pipeline-regulation-in-canada.html

Gouvernement du Québec. 2021. "2030 Plan for a Green Economy." https://www.quebec.ca/en/government/policies-orientations/plan-green-economy

Government of Alberta. 2020. "Natural Gas Vision and Strategy." https://www.alberta.ca/natural-gas-vision-and-strategy.aspx

Government of British Columbia. 2019. "CleanBC." https://cleanbc.gov.bc.ca/

Heritage Gas. 2020. *An Integrated Energy System Pathway: A Better Way Forward to Net-Zero in Nova Scotia*. Heritage Gas. Dartmouth, NS.

IRENA. 2017. R*enewable Energy Innovation: Accelerating Research for a Low-Carbon Future.* International Renewable Energy Agency. Abu Dhabi, UAE.

IRENA OECD/IEA and REN21. 2018. *Renewable Energy Policies in a Time of Transition*. International Renewable Energy Agency, the International Energy Agency and the Renewable Energy Policy Network for the 21st Century. https://www.irena.org/publications/2018/apr/renewable-energy-policies-in-a-time-of-transition

Joi Scientific and New Brunswick Power. 2019. "Joi Scientific and New Brunswick Power to Develop World's First Hydrogen-Powered Distributed Electricity Grid." *Business Wire*, 26 February 2019. https://www.businesswire.com/news/home/20190226005512/en/Joi-Scientific-and-New-Brunswick-Power-to-Develop-World's-First-Hydrogen-Powered-Distributed-Electricity-Grid

McPherson, M. 2021. "Modelling sustainable energy transition pathways." In S*ustainable Energy Transitions for Canada: Challenges and Opportunities*, eds. S. Hill, M. Winfield, and J. Gaede. Vancouver, B.C: In development for UBC Press.

Natural Resources Canada. 2020. H*ydrogen Strategy for Canada – Seizing the Opportunities for Hydrogen*. Government of Canada. Ottawa, ON.

O'Malley, M., B. Kroposki, B. Hannegan, H. Madsen, M. Andersson, W. D'haeseleer, M.F. McGranaghan, C. Dent, G. Strbac, S. Baskaran, and M. Rinker. 2016. *Energy Systems Integration. Defining and Describing the Value Proposition.* U.S. Department of Energy, Office of Scientific and Technical Information. Oak Ridge, TN. https://doi.org/10.2172/1257674

O'Malley, M.J., M.B. Anwar, S. Heinen, T. Kober, J. McCalley, M. McPherson, M. Muratori, A. Orths, M. Ruth, T.K. Schmidt, A. Tuohy. 2020. "Multicarrier Energy Systems: Shaping Our Energy Future." In *Proceedings of the IEEE* 108 (9): 1437-1456.

Office of the Auditor General of Ontario. 2014. 2*014 Annual Report of the Office of the Auditor General of Ontario: Chapter 3, Section 3.11 – Smart Metering Initiative*. Office of the Auditor General of Ontario. Toronto, ON.

Office of the Auditor General of Ontario. 2016. 2*016 Annual Report of the Office of the Auditor General of Ontario: Chapter 1, Section 1.11 – Smart Metering Initiative – Follow-up on VFM Section 3.11, 2014 Annual Report*. Office of the Auditor General of Ontario. Toronto, ON.

Preston, N., A. Maroufmashat, H. Riaz, S. Barbouti, U. Mukherjee, P. Tang, J. Wang, E. Haghi, A. Elkamel, and M. Fowler. 2020. "How can the integration of renewable energy and power-to-gas benefit industrial facilities? From techno-economic, policy, and environmental assessment." *International Journal of Hydrogen Energy* 45(51): 26559–26573. https://doi.org/10.1016/j.ijhydene.2020.07.040

Rivers, N. and M. Jaccard. 2010. "Talking without Walking: Canada's Ineffective Climate Effort." In *Governing the Energy Challenge: Canada and Germany in a Multilevel Regional and Global Context*, eds. Burkard Eberlein and G. Bruce Doern. Toronto, ON: University of Toronto Press. https://doi.org/doi:10.3138/9781442697485-013

Sigrin, B. 2021. "Better Planning for Future Adoption of Distributed Energy Resources (DERs)." Webinar in Energy System Integration Group – DER Working Group Summer 2021 Session, June 2021.

Sood, S. and V. Gallardo. 2020. *A Primer on Distributed-Connected Generation in Canada.* Canadian Energy Research Institute. Calgary, AB.

Ye, J. 2021. "Canadian Provincial Renewable Fuel Standard." Center for Climate and Energy Solutions. https://www.c2es.org/document/canadian-provincial-renewable-fuel-standard/

Appendix

EV (and ZEV) adoption & integration

Federal

Policy name	Category	Target	Description
iZEV Program	Financial rebate	Prospective EV purchasers	Provides up to $5,000 rebate for the purchase of a new electric vehicle
Tax Write-off	Tax benefit	Businesses	Budget 2019 proposed a 100-per-cent write-off for zero-emission vehicles to support business adoption (businesses cannot receive both the federal rebate and the write-off)
Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI)	Funding for charging infrastructure	Utilities/ Companies/ Governments/ Institutions	Offers repayable contributions to support the construction of an electric vehicle (EV) fast charging, coast-to-coast network
Zero Emission Vehicle Infrastructure Program (ZEVIP)	Funding for charging infrastructure	Utilities/ Companies/ Governments/ Institutions	Targets ZEV infrastructure projects in public places, on-street, multi-unit residential buildings, workplaces and light-duty vehicle fleets Focus on local charging as opposed to coast to coast (EVAFIDI)
Zero Emission Vehicle Awareness Initiative	Funding for awareness projects	Utilities/ Companies/ Governments/ Institutions	Supports projects that aim to increase awareness of ZEVs, and public charging and refueling infrastructure, through education and capacity-building activities to ultimately support a greater adoption of ZEVs by Canadians
100% ZEV passenger vehicle sales by 2035	Mandatory target	Government	Sets a mandatory target for new light-duty cars and passenger truck sales to be 100% zero emission by 2035

Provincial and Territorial: Governmental/Non-Governmental (in bold italics)

Location	Policy name	Category	Target	Description
BC	Go Electric Public Charger Program	Financial rebate	Indigenous communities, rural and northern areas, and city centres experiencing long queues	Offers rebates for fast charger installation, from $20,000 to $130,000 depending on charger power
	ZERO Emission Vehicles Act	Legal requirement	Automakers	Requires automakers to meet an escalating annual percentage of new light-duty ZEV sales and leases, reaching: 10% of light-duty vehicle sales by 2025, 30% by 2030 and 100% by 2040 (harmonized with federal target). Bans sales of internal combustion engines by 2040.
	SCRAP-IT	Financial rebate	Prospective EV purchasers	Offers up to $6,000 rebates for purchasing a new EV after trading in an older gas vehicle; $3,000 for purchase of a used EV
	Go Electric Vehicle Rebates (Passenger, Commercial, and Fleet vehicles)	Financial rebate	B.C. residents, businesses, non-profit organizations, and local government organizations	Offers various rebates depending on the category (passenger, commercial, fleet) Funding for infrastructure/assessments for fleet program only
	Go Electric Home and Workplace Charger Rebates	Financial rebate	Charger installations	Offers financial support for Level 2 charging and funding for electrical upgrades/assessments (up to $300 for homes; $2,000 for apartments)
	Use of HOV lanes	Non-financial incentive	EV drivers	Allows EVs to use provincial highway HOV lanes
AB	Electric Vehicles for Municipalities Program	Funding for various initiatives	Municipalities within Alberta	Offers funding for municipalities (not individuals) for things such as EV feasibility studies and a variety of EVs including passenger vehicles, medium-heavy duty vehicles, and Zambonis
SK	Tax on EVs	Financial disincentive	EV owners	$150 annual tax on passenger EVs
MB	Electric vehicle roadmap	Strategic plan	Various	Lays out key actions include creating partnerships with companies and institutions to demonstrate technology and raise public awareness; creating an EV advisory committee; and developing an EV learning and demonstration centre
ON	Green Vehicle Licence Plate Program	Non-financial incentive	EV drivers	Allows vehicles with green plates to access HOV lanes and enjoy free access to High Occupancy Toll (HOT) lanes on 400-series highways and the Queen Elizabeth Way (QEW)
	Used Electric Vehicle Incentive	Financial rebate	Prospective EV purchasers	Offers $1,000 toward the purchase of a used fully electric car
	Scrappage Incentive Program	Financial rebate	Prospective EV purchasers	Offers a rebate for purchasing an EV after trading in an older gas vehicle
QC	New vehicle rebate	Financial rebate	Individuals, businesses, municipalities	Offers a rebate of up to $8,000 on the purchase or lease of a new electric vehicle
	Used vehicle rebate	Financial rebate	Individuals, businesses, municipalities	Offers a rebate of up to $4,000 towards the purchase of a used electric vehicle

Location	Policy name	Category	Target	Description
QC, cont.	Charging station rebates	Financial rebate	Charger installations	Offers rebates of varying amounts depending on the program (Home, Multi-Unit Residential Building, Workplaces)
	Toll-free bridges and ferries	Financial incentive	EV drivers	Offers free access to toll bridges, highways 25 and 30, and Société des traversiers du Québec ferry services
	Access to HOV Lanes	Non-financial Incentive	EV drivers	Allows EVs to use HOV reserved lanes in provincial highways
	Zero Emission Vehicle Standard	Legal requirement	Vehicle manufacturers	Manufacturers accumulate credits for the sale of zero emissions vehicles in QC
	Ban of ICE sales by 2035	Legal requirement	Dealerships	Part of Quebec's Green Economy initiative, applies to new vehicle sales
NB	—	—	—	No major rebates or incentives available in the province
NS	Electric Vehicle Rebate program	Financial rebate	Prospective EV purchasers	Offers rebates for the purchase or lease of BEVs, PHEVs and e-bikes (up to $3,000 for new vehicles, $2,000 for used)
PEI	Electric Vehicle Incentive and free charger	Financial rebate	Prospective EV purchasers	Offers rebates for the purchase of a new EV from a licensed dealership, plus free level 2 charger (up to $5,000)
NL	—	—	—	No major rebates or incentives available in the province
YK	Electric vehicle rebate	Financial rebate	Prospective EV purchasers	Offers rebates for the purchase or lease of a new EV (up to $5,000)
	Charger rebate	Financial rebate	Charger installations	Offers rebates for personal level 2 chargers at residences and commercial/apartment buildings, amount depending on building and charger type
NWT	Electric vehicle and charger rebate	Financial rebate	Prospective EV purchasers and charger installations	Offers rebates for new EVs, PHEVs, and Level 2 charging stations (up to $5,000 for vehicle, $500 for charger)
NU	—	—	—	No major rebates or incentives available in the province

Municipal

City	Policy name	Category	Target	Description
Montreal	Montreal 2020–2030 Climate Plan	Strategic plan	Various	Identifies key action items related to transportation electrification, such as setting targets for EV registration in the city
Toronto	City of Toronto EV Strategy	Strategic plan	Various	Identifies opportunity areas that the City will take advantage of to become an EV-ready city, such as on-street charging pilot programs
Edmonton	City of Edmonton EV Charger Rebate	Financial rebate	Homeowners and businesses	Offers rebates of up to $600 for existing residential properties and $2,000 for existing commercial properties
	City of Edmonton EV Strategy	Strategic plan	Various	Identifies opportunity areas that the City will take advantage of to become an EV-ready city
Calgary	City of Calgary EV Strategy	Strategic plan	Various	Identifies actions related to increasing EV adoption, such as partnering with organizations to improve charging infrastructure, raising awareness, and implementing charging infrastructure requirements for new buildings
Vancouver	Charger requirements for new buildings	Legal requirement	Developers	As of January 1, 2019, requires that 100% of residential parking stalls, except visitor stalls, must be EV-ready for all new development permit applications
	Dedicated parking	Non-financial incentive	EV owners	Provides dedicated zero emission vehicle parking stalls in parking lots across the city
	HOV lane access	Non-financial incentive	EV owners	Allows EVs to use municipal HOV lanes in addition to provincial ones
Surrey	City of Surrey EV Strategy	Strategic plan	Various	In development; identifies actions to accelerate EV adoption in the City and supports a long-term vision for Surrey where all vehicles are zero-emission
Burnaby	Electric Vehicle (EV) Charging Bylaw	Legal requirement	Developers	Requires all required parking spaces for new dwelling units to provide Level 2 electric charging

Heat Pumps

Federal: Governmental/Non-governmental (in bold italics)

Policy/ program name	Category / type	Target	Details
Install or replace a ground source heat pump	Funding grant	Homeowners in all provinces	Provides $5,000 towards the new installation of a full heat pump system or $3,000 towards the replacement of a heat pump unit. The new system must meet efficiency standards, be purchased in Canada, and be installed by a licensed professional.
Install or complete new or replacement air source heat pump system	Funding grant	Homeowners in most provinces	Provides either $2,500 or $4,000 towards a new or replacement air source heat pump that meets certain criteria. Funding amount depends on system size, and residents of Quebec and Nova Scotia may face more stringent requirements in order to receive funding.
Install or replace a cold climate heat pump	Funding grant	Homeowners	Provides $5,000 towards a new or replacement cold climate heat pump system that meets performance and other standards and is used to service the entire home.
Royal Bank of Canada: RBC Energy Saver Loan	Discount on services	Homeowners	Offers a discounted interest rate or discounted home energy audit for customers who upgrade their home, including the purchase of energy-efficient products

Provincial

Province	Administered by	Policy/ Program name	Category / type	Target	Details
ON	Enbridge Gas Inc.	Home Efficiency Rebate: Furnace/ Boiler	Rebate	Homeowners	Offers $250 for upgrading to a high-efficiency condensing natural gas furnace or $1,000 for upgrading to a high-efficiency condensing natural gas boiler
ON	Enbridge Gas Inc.	Affordable Multi-Family Housing Program	Incentive cheque after completion of upgrades	Owners of multi-family buildings	Offers up to $9,000 for upgrading to a condensing or high-efficiency boiler or furnace
ON	Enbridge Gas Inc.	ERV/HRV Incentives	Custom incentives for business partners	Commercial property managers/ owners	Offers per-unit installation incentives to commercial buildings that install new energy recovery ventilators (ERV) or heat recovery ventilators (HRV)
ON	Municipal governments (with help from the province)	Ontario Renovates Program	Forgivable loan assistance	Low-to-moderate income households and people with disabilities	Offers homeowners $15,000-30,000 of assistance towards repairs and renovations that may include increasing energy efficiency (details depend on the municipality)
BC	BC Hydro	Home renovation rebates	Rebate	Homeowners	Offers rebates up to $10,000 for various home efficiency improvements (including heater upgrade)
BC	FortisBC	Natural Gas Furnace Rebate	Rebate	Homeowners	Offers rebates up to $1,000 for ENERGYStar certified natural gas furnace, plus $150 more for eligible thermostats

Province	Administered by	Policy/ Program name	Category / type	Target	Details
BC	CleanBC	Better Homes Combined Space and Hot Water Heat Pump Rebate	Rebate	Homeowners	Offers a rebate of up to $4,300 for installing a combination space and water heat pump system and a $500 electrical service upgrade rebate for converting a fossil fuel primary space or water heating system to an electrical primary space or water heating system
BC	Fortis BC	Heat pump service rebate	Rebate	Homeowners, property maintainers	Offers $50 for service on your heat pump
MB	Efficiency Manitoba	Ground Source Heat Pump Program	Unspecified financial incentive	Homeowners, property maintainers	Offers an incentive of unspecified value once a heat pump has been installed (participants must front the money and be pre-approved before installation; they must apply through their installer to receive the funding)
NB	Daikin	Heat Pump Rebates in New Brunswick	Rebate	Homeowners	Provides $1,550 from the manufacturer towards the purchase of select heat pumps
NB	NB Power	Total Home Energy Savings Program	Mortgage insurance refund programs	Homeowners	Offers money towards renovations to increase energy efficiency
NL	Newfoundland Power	Electric Heating Systems & Heat Pumps	Financing plan	Homeowners	Offers up to $10,000 for electric heating systems, including heat pumps
NL	takeCHARGE	Rooftop Air Source Heat Pumps Rebate	Rebate	Commercial buildings	Based on the size of the installed unit, participants receive $300 per ton of capacity on installation or upgrade of rooftop air source heat pumps
NS	Access Nova Scotia	Your Energy Rebate	Rebate	Homeowners	$150 to $2,500 deducted from your energy bill if you purchase energy for your home. Participants may need to apply to receive the rebate, and the amount of the rebate is based on the amount and type of energy purchased.
NS	Efficiency Nova Scotia	Home Energy Assessment	Rebates	Homeowners	Based on the size of the installed unit, participants can receive $300 - $600 per ton capacity, up to a maximum of $5,000 total
PEI	efficiencyPEI	Energy Efficient Equipment Rebates	Rebate	Homeowners	Offers $1,200 to $2,500 on upgrading to (or improving existing) heat pumps
QC	Énergir	Chauffez vert	Financial assistance	Homeowners	Offers up to $1,650 for eligible low-temperature heat pumps that are ENERGY STAR certified

Municipal

Province	City	Administered by	Program Name	Type	Target	Description
ON	Toronto	City of Toronto	Home Energy Loan Program (HELP)	Low-interest loan	Homeowners	Offers up to $75,000 for home energy improvements
BC	Lantzville	CleanBC	Better Homes and Home Renovation Rebate	Rebate	Residents of Regional District of Nanaimo Electoral Areas and the District of Lantzville	Offers $250 for switching from oil heating to a heat pump

Distributed Generation/Prosumer

Federal

Administered by	Policy/ Program name	Category/type	Target	Details
Government of Canada	Tax Incentive for Clean Energy Equipment	Financial incentive	All provinces	Allows taxpayers to fully deduct capital costs of clean energy generation/energy conservation equipment (CCA rate of 100%).
NRCan	Smart Grid Program Year: 2020–2024 *refer to programs described in this document	Funding grant	Utility companies	Funds the widespread installation and deployment of smart meters in homes by utility companies. Seventeen projects collectively received $100M over four years; projects ranged from exploratory to operational.
NRCan	Smart Renewables and Electrification Pathways Program (SREP)	Direct financial support	Eligible renewable energy and grid modernization projects	Provides financial support during the construction phase of projects, including established renewables (PV, wind, small hydro), emerging technologies (geothermal, storage), and grid modernization (micro-grids, virtual power plants, and hardware/ software to enable grid services)

Provincial[1]

Location	Administered by	Policy/ Program name	Category/ type	Target	Details
BC	Provincial government	2002 Energy Plan: Energy for Our Future	Financial rebate	Homeowners, businesses, First Nations communities Target year: 2002–2019	Offers funding for distributed-connected generation and smart meters
BC	BC Hydro	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month-to-month and unused credits are paid out annually. Maximum system size of 100 kW. Feed-in rate is the retail rate.
BC	BC Hydro	Smart Metering Program	Action by utility (replace existing meters with smart ones)	Customers Target year: 2010–2012	Replaced 1.8 million existing customer meters with digital smart meters. Objectives: allow consumers to be informed about their energy use; reduce operating costs.
BC	Government of BC	PST Tax Exemption	Financial incentive	Businesses, homeowners	Exempts alternative energy generation and energy conservation equipment from PST in BC (includes insulation, weather stripping, solar PV, micro-hydro, and more)

1 Refer to Sood and Gallardo (2020) for a summary

Location	Administered by	Policy/ Program name	Category/ type	Target	Details
AB	Alberta Utilities Commission	Net billing Micro-generation	Financial incentive	Homeowners, businesses, small power plants Target year: 2008–present	Allows excess electricity generation to be sold to electricity distributor at the cost of grid-drawn electricity. A net billing credit towards the system owner can carry forward month to month and be paid out in full at least annually. Maximum system size is 150 kW, though "large micro-generators" can exist under net billing and have a maximum system size of 5 MW (note that large micro-generators have different billing regulations). Feed in rate is the retail rate
MB	Manitoba Hydro	Net billing	Financial incentive	Consumers, homeowners, businesses Target year: 2003–present	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. These monetary credits are applied monthly against the system owner's consumption costs. Maximum system size of 100kW. The Excess Energy Price is adjusted annually to reflect the current market value of excess electricity, currently set at $0.024/kWh until March 31, 2022 (note that residential retail rate is typically $0.09/kWh).*
MB	Government of Manitoba	Green Energy Equipment Tax Credit	Financial incentive	Businesses, homeowners	Offers a tax credit of 7.5–15% of the capital costs for installing a geothermal heat pump system, or 10% of the capital costs for installing a solar thermal energy system. Available for any property owner.
SK	SaskPower	Power Generation Partner Program	Financial incentive	Small Power Plants Target year: 2007–2018	Allows excess electricity generated to be sold to the electricity distributor (SaskPower). System size must be between 100 kW and 1 MW. The feed-in rate is based on application bid price.
SK	SaskPower	Net metering	Financial incentive	Consumers, homeowners, businesses Target year: 2019–2021	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month for perpetuity, although they will never be paid out. Maximum system size of 100 kW. Feed-in rate is $0.075/kWh (note that residential retail rate is typically $0.14/kWh).
ON	Local electricity distributor	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, for up to 12 months, The feed-in rate is the retail rate.
ON	Provincial Government	Ontario Smart Metering Initiative	Legal mandate	Consumers, homeowners, businesses Target year: 2004–2010	Installed smart meters in all Ontario homes and businesses.
QC	Hydro-Québec	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated is to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, although they expire every two years. Maximum system size is 20 kW for single-phase buildings or 50 kW for three-phase buildings. The feed-in rate is the retail rate.

*This passage has been updated from the original version.

Location	Administered by	Policy/ Program name	Category/ type	Target	Details
QC	Transition énergétique Québec	Rénoclimat program	Financial rebate	Homeowners	Offers post-installation rebates for residential geothermal heating systems. Available for only residential property owners.
NB	NB Power	Total Home Energy Savings Program (solar PV add-on)	Financial rebate	Homeowners	Offers post-installation rebates of $0.20-0.30/W of solar capacity installed. Available to only residential property owners who meet home insulation levels as specified by NB Power.
NB	Provincial government	Embedded Generation program	Financial incentive	Small-scale generators	Offers a fixed price for selling electricity back to the grid.
NB	NB Power	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, although they expire on March 31 each year. Maximum system size of 100 kW. The feed-in rate is the retail rate.
NS	Nova Scotia Power	Enhanced Net Metering	Financial incentive	Consumers, homeowners, businesses Target year: 2015–present	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month and unused credits are paid out annually. The system must be sized for typical annual electricity consumption, with a maximum size of 100 kW. The feed-in rate is the retail rate
NS	Efficiency Nova Scotia	SolarHomes Program	Financial rebate	Homeowners	Offers post-installation rebates of $0.60/W of solar capacity installed, to a maximum of 1 kW. Available only for residential properties.
PEI	Maritime Electric	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, for up to 12 months. The maximum system size is 100 kW. The feed-in rate is the retail rate
PEI	EfficiencyPEI	Solar Electric Rebate Program	Financial rebate	Businesses, homeowners	Offer post-installation rebates of $1.00/W of residential solar capacity, to a maximum of 10 kW (or rebates of $0.35/W of commercial solar capacity, to a maximum of 28.5 kW). Available for both residential and commercial property owners.
NL	Newfoundland Labrador Hydro	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month for up to 12 months. Maximum system size of 100 kW. The feed-in rate is the retail rate.
NT	Northwest Territories Power Corporation	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, although they expire on March 31 each year. The maximum system size is 15 kW. The feed-in rate is the retail rate.

Location	Administered by	Policy/ Program name	Category/ type	Target	Details
NT	Arctic Energy Alliance	Alternative Energy Technologies Program	Financial rebate	Homeowners, businesses (off-grid or in communities that do not use hydroelectricity)	Offers a post-installation rebate of 50% of capital costs of a renewable system (solar PV, wind turbines, micro-hydro, etc.), to a maximum of $20,000 (residential) or $50,000 (commercial). Available for any projects on off-grid buildings or in communities that do not use hydroelectricity.
NU	Qulliq Energy Corporation	Net metering	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month, although they expire on March 31 each year. The maximum system size is 10 kW. The feed-in rate is the retail rate.
YK	Government of Yukon	Micro-generation	Financial incentive	Consumers, homeowners, businesses	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits are paid out annually. The maximum system size is 50 kW. The feed-in rate is $0.21/kWh on the Yukon's Integrated System or $0.30/kWh in electrically isolated communities powered by diesel generation (note that residential retail rate is typically $0.19/kWh).
YK	Government of Yukon	Renewable Energy Incentives Program	Financial rebate	Homeowners	Offers post-installation rebates of $0.80/W of solar capacity installed, to a maximum of 6.25 kW. Available for residential properties only.

Municipal

Location	Policy/program	Administered by	Category/Type	Details
Regional District of Nanaimo, BC	Renewable Energy System Rebate	Regional District of Nanaimo	Financial rebate	Offers post-installation rebates for homeowners for any of the following technologies: • Solar hot water; • PV; • Geoexchange (ground-source or water-source); and • Micro (under 1 kW) and small wind (1 to 10 kW). Available for residential property owners only.
Banff, AB	Solar PV Rebate Program	Town of Banff	Financial rebate	Offers post-installation rebates of $0.75/W of solar capacity installed, to a maximum of 20 kW. Available for both residential and commercial property owners.
Canmore, AB	Solar Incentive Program	Town of Canmore	Financial rebate	Offers post-installation rebates program for businesses and homeowners with minimum system requirements of 3 kW solar capacity installed.
Edmonton, AB	Change Homes for Climate Solar Program	City of Edmonton	Financial rebate	Offers post-installation rebates of $0.40/W of solar capacity installed, to a maximum of 10 kW. Available for residential properties only.
Medicine Hat, AB	HAT Smart Residential Incentives Program	City of Medicine Hat	Financial rebate	Offers post-installation rebates program of $1.00/W of solar capacity installed, to a maximum of 6 kW. Available for residential properties.

Location	Policy/program	Administered by	Category/Type	Details
EQUS service area (26 municipalities across AB)	EQUS Micro-Generator Incentives	EQUS (partnered with ReWatt Power)	Financial rebate	Offers post-installation rebates for businesses and homeowners, with a rebate of $0.10/W of solar capacity installed, to a maximum of 5 kW. Available for EQUS members only.
Saskatoon, SK	Net metering	Saskatoon Light and Power	Financial incentive	Credits excess electricity generated to the system owner and uses it to offset electricity costs from grid-drawn electricity. Credits can be banked month to month for perpetuity, although they will never be paid out. The maximum system size is 100 kW. The feed-in rate is the retail rate.
Saskatoon, SK	Small Power Producers Program	Saskatoon Light and Power	Financial incentive	Allows excess electricity generated to be sold to the electricity distributor (SL&P). The maximum system size in 100 kW. The feed-in rate is $0.115/kWh

Demand Response

Provincial

Location	Administered by	Policy/ Program name	Category/type	Target	Details
BC	BC Hydro (partnered with mCloud)	Automated demand response trial	Financial rebate	Businesses Target year: 2021–2022	Automated demand response involves automating your systems to reduce energy use during peak electricity consumption "events." These peak events last four hours, typically 11 a.m. to 3 p.m. on weekdays during peak summer and winter periods. Trial participants get $4,000 compensation, meant to be put towards offsetting costs of hardware and services required for the trial.
AB	Capital Power	Coincident Peak Demand Management Tool	Information service	Consumers	Smart dashboard informs customers of approaching peak demand periods, allowing customers to avoid charges
AB	Alberta Electric System Operator	Load Shield Service for Imports	Financial incentive	Businesses 2011–present	Based on Alberta-British Columbia interconnection conditions, participants will sometimes be asked to "arm" certain loads, which can be turned off immediately if needed. Plans are tailored to each participant.
AB	Alberta Electric System Operator	Operating Reserves Program	Financial incentive	Large consumers Ongoing	Participants are on standby to reduce load within minutes of notification.
SK	SaskPower	Demand response	Financial incentive	Large consumers Ongoing	Consumers are compensated for shifting or reducing loads at times that the utility chooses. Available to large industrial consumers with consistent load characteristics who can reduce load by 5 MW from a single location. Load-shifting events occur for 4 hours, up to 15 times per year and notice can range from 12 minutes to 2 hours (depending on program chosen). Compensation rates are based on the amount of effective interruptible power committed, although they vary based on the program chosen.
ON	Hydro One	Time of use pricing	Financial incentive	Consumers Ongoing	Time-of-use periods are defined for each day in a six-month interval based on the time of day and the type of day (weekday or weekend/holiday). Each period is associated with a pre-defined price.

Location	Administered by	Policy/ Program name	Category/type	Target	Details
ON	Independent Electricity System Operator	Time of use and tiered pricing	Financial incentive	Consumers Ongoing	Some consumers pay time of use rates, such as the ones described above. There is also a tiered pricing scheme, in which the electricity rate price is based on monthly usage.
ON	Independent Electricity System Operator	Capacity auction	Financial incentive	Large consumers, small generators	Consumers bid annually to be able to contribute demand response resources to the grid. Most successful auction participants are large and medium-sized industrial and commercial consumers that can reduce their demand for electricity as needed. The participants are selected based on their bid price, so clearing price (compensation) varies from year to year.
QC	Hydro-Québec	Winter Credit Option	Financial incentive	Consumers Ongoing	Customers' typical energy use is measured, and customers are notified of peak demand events one day in advance. When peak demand occurs, customers receive a credit based on how much they reduce their energy usage relative to their own normal usage.
QC	Hydro-Québec	Rate Flex D	Financial incentive	Consumers Ongoing	Customers pay an extra-low price during "regular" times and an extra-high price during peak demand events, which are announced in advance.
QC	Hydro-Québec	Demand response	Financial incentive	Large consumers	Consumers are compensated for shifting or reducing loads at times that the utility chooses. Available to consumers who can reduce load by 200 kW. Load-shifting events occur for 3–4 hours, up to 100 hours per year, and notice is at least 4 hours in advance. Compensation rates are based on the amount of effective interruptible power committed.
QC	Hilo by Hydro-Québec	Demand response, direct load control	Financial incentive	Residential and commercial consumers	Customers are rewarded if they contribute to shifting their demand through different smart devices.
Maritimes	Multi-Utility Consortium involving New Brunswick Power Corporation, University of New Brunswick, and several other Maritime utility companies	PowerShift Atlantic	Technology demonstration	Residential consumers; Businesses Target years: 2010–2015	Pilot/demonstration project. Participants received smart devices with some energy storage capabilities. An energy management system connected to these devices shifted load without customers being affected.
NL	Newfoundland Labrador Hydro	Demand charges	Financial incentive	Businesses Ongoing	Customers are charged if their instantaneous demand ever exceeds a certain amount.
YK	Yukon Energy and NRCan	Peak Smart	Incentive (free device)	Consumers Target year: 2018–2021	Part of NRCan's Smart Grid Program Consumers are given smart thermostats or water tank controllers that can be controlled remotely in order to manage peak demand.

Renewable Fuels

Provincial

Province	Implemented policies	Planned policies/goals
BC	In 2008, British Columbia established a *renewable fuel standard* and a *low carbon fuel standard*. • The *renewable fuel standard* requires fuel suppliers to blend at least 5% renewable products into their gasoline and 4% renewable products into their diesel. • The *low carbon fuel standard* builds upon the *renewable fuel standard* by adding an additional requirement that leads fuel suppliers to progressively decrease the average carbon intensity of their fuels to achieve a 10% reduction in 2020 relative to 2010 (Ye, 2021).	The *CleanBC initiative* aims to work with natural gas providers to put in place a minimum requirement for 15% renewable content in natural gas by 2030 (Government of British Columbia, 2019).
AB	In 2010, Alberta established a renewable fuel standard that requires fuel suppliers to blend 5% renewable products into their gasoline and 2% renewable products into their diesel in an effort to achieve a greenhouse gas intensity level that is 25% less than that of gasoline or diesel (Ye, 2021).	Goals (Government of Alberta, 2020): • Large-scale hydrogen production with carbon capture, utilization and storage (CCUS) and deployment in various commercial applications across the provincial economy by 2030. • Exports of clean hydrogen and hydrogen-derived products to jurisdictions across Canada, North America, and globally by 2040.
SK	In 2007, Saskatchewan established an *ethanol fuel mandate*, requiring fuel suppliers to blend at least 7.5% ethanol into their gasoline and 2% ethanol into their diesel (Ye, 2021).	
MB	In 2007, Manitoba enacted a regulation that established a *renewable fuel standard*. The standard requires fuel suppliers in the province to blend their fuel to contain at least 8.5% ethanol for gasoline and 2% ethanol for diesel (Ye, 2021).	
ON	In 2007, Ontario enacted regulations establishing a *renewable fuel standard*, requiring fuel suppliers to blend 5% ethanol into their gasoline and 5% ethanol into their diesel (Ye, 2021).	As part of the Ontario's 2016 *Climate Change Action Plan*, the province intends on developing a *new renewable fuel standard* for gasoline that is expected to reduce greenhouse gas emissions by about 5% by 2020 (Ye, 2021).
QC	No regulations are in place that target renewable fuel injection into natural gas grids.	The province aims to achieve 10% renewable gas in its natural gas network by 2030 (Gouvernement du Québec, 2021).
NS	No regulations are in place that target renewable fuel injection into natural gas grids.	The province is planning on implementing a standard that regulates the blending of low-carbon hydrogen into the natural gas grid in an effort to convert its existing natural gas grid to 100% clean hydrogen. The mixture of the low-carbon hydrogen/natural gas blend is not specified; neither is the timeframe (Heritage Gas, 2020).
PEI	No regulations are in place that target renewable fuel injection into natural gas grids.	
NB	No regulations are in place that target renewable fuel injection into natural gas grids.	The province and Joi Scientific is co-developing a hydrogen production system that will represent the world's first electricity grid that uses hydrogen as a baseload, where hydrogen will be extracted from unprocessed seawater with water vapour being the only emission factor (Joi Scientific and New Brunswick Power, 2019).

Municipal

Location	Program	Links
Fort Saskatchewan, AB	The utility provider ATCO has announced a blending project, where up to 5% hydrogen will be blended in a section of the residential gas distribution network, with construction starting in early 2021. ATCO was awarded $2.8 million in funding from the Emission Reductions Alberta's Natural Gas Challenge in an effort to significantly reduce the carbon intensity of natural gas grids.	ATCO Gas. 2020. "ATCO to Build Alberta's First Hydrogen Blending Project with ERA Support."
Markham, ON	Hydrogenics and Enbridge Gas are planning the city's first multi-megawatt electrolyzer, which will blend renewable hydrogen into the natural gas network by fall 2021. In 2018, the city started operating a power-to-gas facility which will be the centre of the newly announced project that feeds green hydrogen into the natural gas grid. The 2.5 MW power-to-gas facility has been converting excess renewable energy into hydrogen via electrolysis and using the hydrogen to balance electricity supply and demand in the city. The power-to-gas facility is a pilot project for energy storage solutions of surplus electricity. Once hydrogen is produced, it can be stored for later use, converted back into electricity when needed, or blended into the natural gas distribution system to reduce the carbon content of the gas. The hydrogen injection project will enable the municipality to provide the hydrogen-natural gas mixture to more than 3,600 customers, reducing carbon emissions by 117 tons. Following on from the start of the project, Enbridge is now proposing to blend the hydrogen into the natural gas grid at a volume of up to 2%.	Enbridge. 2021. "Groundbreaking $5.2M hydrogen blending project aims to green Ontario's natural gas grid"
Gatineau, QC	The utility provider Enbridge announced plans for Canada's largest green hydrogen injection project in collaboration with Evolugen in early 2021. Within the city of Gatineau, a 20MW electrolyzer plant will produce green hydrogen via electrolysis from renewable energy and inject hydrogen into a new 15 km pipeline into the city's natural gas network. The $90 million project is expected to produce approximately 425,000 GJ of green hydrogen annually while decreasing the level of greenhouse gas emissions in the natural gas network by roughly 15,000 metric tons each year.	Enbridge. 2021. "'Hydrogen's time has come': Gazifère, Evolugen announce injection project for Gatineau."
Halifax, NS	HalifACT, a long-term climate action plan aiming to reduce greenhouse gas emission levels, was introduced in early 2021. HalifACT plans to ensure that all new pipelines will be able to handle 100% hydrogen for a future transition. In the fall of 2020, the municipality announced plans to collaborate with Heritage Gas on a green hydrogen plant. Heritage Gas is working on plans to develop a clean hydrogen pilot project through its "Green Infrastructure Projects that Reduce Greenhouse Gas Emissions" Program. The utility provider aims to construct a 4 MW electrolyzer facility that will be able to generate approximately 40,000 G and will be connected directly to a new wind farm.	Halifax Regional Municipality. 2021. "Hydrogen and Decarbonizing Halifax."