Executive Summary

Novel transportation technologies such as electric vehicles (EVs) and fuel-cell electric vehicles (FCEVs) fueled with hydrogen present a unique opportunity for policymakers and utilities to play a vital role in implementing a strategy that can yield significant societal benefits. Adopting EVs and FCEVs, or zero-emission vehicles (ZEV), reduces harmful air emissions and yields benefits to electric utilities and their customers.

In Canada, federal, provincial, and municipal governments are undertaking increasingly aggressive policies and targets to reduce the generation of greenhouse gases (GHG). Domestically, EVs in British Columbia and Quebec reached 7.5% and 10% of new vehicle sales in 2019, respectively, replacing what would otherwise be internal combustion engine (ICE) vehicles. There is increasing momentum behind EV market growth as EVs sales experienced exponential growth in recent years (Statistics Canada, 2018).

While the benefits of transportation electrification are plentiful (e.g., GHG abatement, lower energy bills for Canadian and business opportunities for electric utilities), increased levels of EV adoption can disrupt the electricity sector as the load grows to charge battery-powered vehicles and generate green hydrogen from clean electricity.

Canadian electric utilities, federal and provincial governments have been monitoring the rise of EV adoption, forecasting the increased load, monitoring their impact on the grid, studying customer adoption behaviours, and continuously developing new tools to plan for grid upgrades.

Natural Resources Canada (NRCan) launched an Infrastructure and Grid Readiness Working Group (IGRWG) to inform infrastructure and grid readiness efforts. The IGRWG was created in 2016 to provide expert advice to NRCan and identify opportunities for collaboration and synergies.

At the beginning of 2020, NRCan retained ICF, a consulting firm, to carry out a study to help Canadian utilities to compare and discuss practices to understand better the expected electrical energy demands from future vehicle fleets in Canada and its potential impact on the Canadian electricity grids.

The objectives of this study entail:

Forecast the estimated ZEV fleet and electrical ZEV load over a 30-year period. The composition of the future vehicle fleet in Canada will significantly influence the study of future electrical load demand. An EV will charge its batteries at workplaces, at home, in commercial and industrial buildings, and on the road. FCEVs will be fueled by hydrogen, which may be generated through electrolysis – requiring large amounts of electricity.

Exploring parameters of grid readiness. With an impending risk of accelerated adoption, utilities across the country need to prepare for the incoming disruption on both the transmission and the distribution level.

Develop impact assessment tools for distribution assets. Canadian electric utilities agree that the EV charging load is likely to have the most impact on the distribution network assets (substations, feeders, transformers, all the way to the service drops to buildings) instead of the wholesale/transmission system. ICF developed a simple method to evaluate the impact of EVs on distribution assets.

Provide recommendations for action. With the continued adoption of ZEVs by Canadians, there exist the need for federal, provincial, and municipal governments and utilities to develop an array of tools and strategies to understand and prepare for future changes to how users interact and use the electrical grid.

ICF’s approach to assessing the readiness of Canada’s electrical system in preparation for increased uptake of ZEVs entailed desk research on ZEVs in Canada, an interview campaign of distribution companies and system operators, modelling of the EV loads across Canada and the electricity demand for hydrogen generated through electrolysis, developing a tool to assess the impact of EV on distribution assets, and using the tool to perform three case studies with Canadian distribution companies.

The study took place between February and December 2020, with the ZEV load forecast, the utility outreach, the determination of metrics to assess distribution system readiness, and the development of the distribution infrastructure impact assessment tool taking place from March to June, and the development of the case studies taking place in October through December.

The next pages of this executive summary present:

- The methodology and result of a Canada-wide ZEV load forecast,
- The results of ICF's utility outreach regarding the readiness of the wholesale/transmission system and the distribution system readiness,
- The tool ICF built to assess the impact of EV load on distribution assets, and
- The results of case studies ICF analyzed with the collaboration of three Canadian utilities.

National ZEV Load Forecast

ICF performed a Canada-wide, province-by-province ZEV load forecast over a time horizon of 30 years (2020 through 2050). We projected both the annual load growth from EV charging and hydrogen production to fuel FCEVs. ICF also generated 24-hour load profiles associated with such load growth both for managed and unmanaged charging scenarios.

The ZEV load forecast entails a wide array of types of ZEVs:

- Light-Duty Vehicles (LDVs)
    - PHEV 50: for this load forecast, we assumed a typical range of 50 miles (80 km),
    - BEV 300 and BEV 100: a long-range BEV and a short-range BEV with estimated driving ranges of 300 miles (483 km) and 100 miles (161 km). We factored in the number and specific characteristics of the passenger cars and passenger light trucks (including sport utility vehicles and pickups).
- Medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs)
    - Battery-powered MDV and HDV, including school buses, urban transit, and inter-city buses, service trucks, freight light trucks, and heavy trucks.
    - FCEV HDV. We included hydrogen production, assuming 100% comes from electrolysis, assuming standard production efficiencies.

To develop a load forecast for the ten Canadian provinces, ICF started with historical fleet size and growth and built a forecast of vehicle sales. Next, ICF built adoption curves. Finally, ICF factored in the expected annual electricity consumption and load profiles for the different types of ZEVs included in the study.

ICF created adoption curves based on the federal government's policy goal. In total, three scenarios were developed: (i) federal target, (ii) business as usual (BAU) – Low, and (iii) BAU – High. For the three scenarios, ICF developed province-specific adoption curves by curve-fitting a standard Bass diffusion curve (S-curve) to the current level of penetration in different provinces, as well best expert judgement.

ICF developed LDV annual charging load and peak-day 24-hour profiles based on the data gathered through the FleetCarma Charge the North project (FleetCarma, 2019). Charging profiles for MDV and HDV were based on profiles derived as part of the study completed by ICF for the California Electric Transport Coalition on Comparison of Medium and Heavy-Duty Technologies (2019).

ICF also performed a forecast of the electricity required to produce hydrogen used in FCEV. ICF used the assumption that 60% of new HDVs sales would be hydrogen-fueled—excluding buses (U.S. Energy Information Administration, 2020). ICF assumed that FCEV would not have significant adoption in the other vehicle categories. It was assumed that 100% of the hydrogen required by FCEVs would be produced through electrolysis. We kept electrolysis load forecast was analyzed separately from that of the EV charging unless otherwise stated.

The resulting fleet of ZEVs considering the Federal Target scenario and the fleet turnover rate is presented in Exhibit 1. The exhibit shows three curves: one for LDV, another for MDV and the last one for HDV.

Exhibit 1 Forecasted Fleet of ZEVs as a Percentage of All Vehicles (Federal Target Scenario)

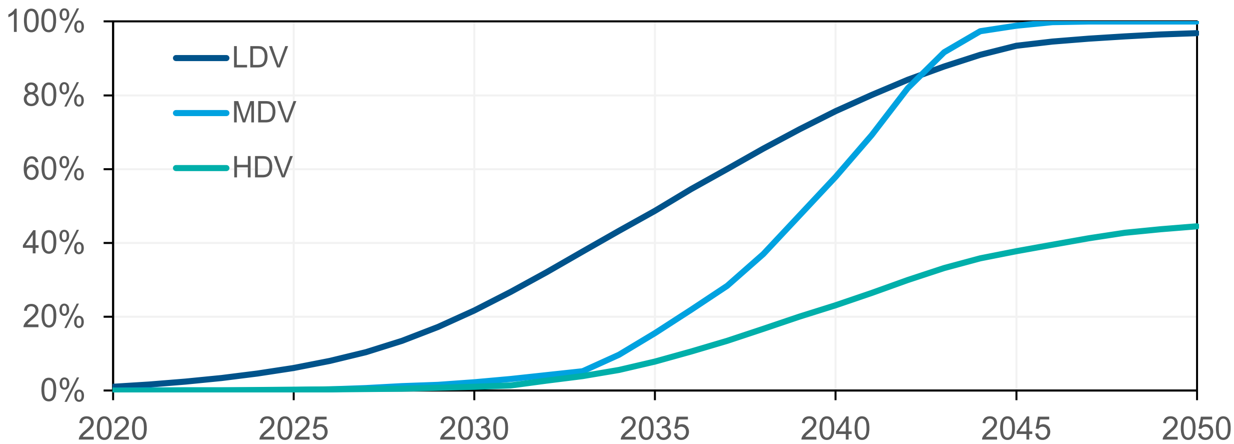


Exhibit 2 presents the national vehicle fleet's overall size based on the number of ZEVs and ICE vehicles.

Exhibit 2 Canada-Wide Fleet Size of ZEVs and ICE (Federal Target Scenario)

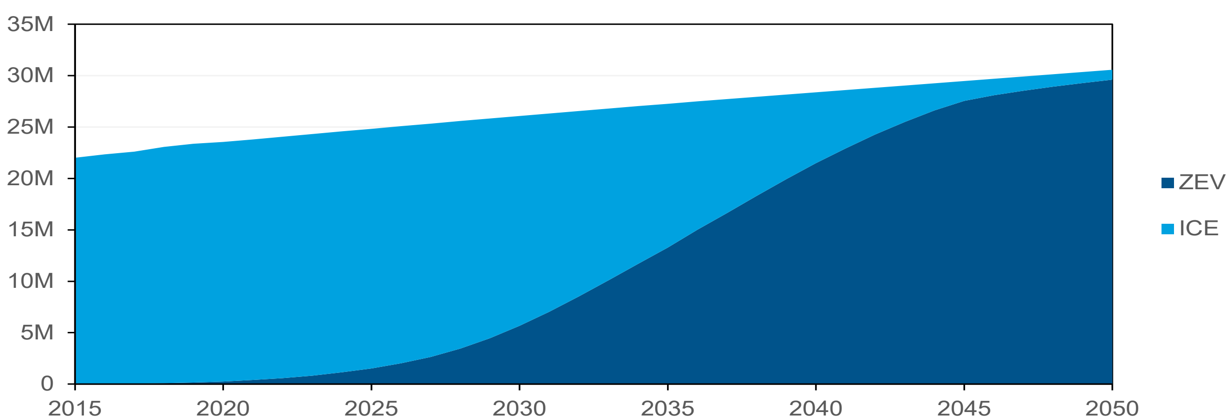


Exhibit 3 results from the load forecast at the national level for all EVs; it excludes FCEVs.

Exhibit 3 EV Charging Load Forecast (Federal Target Scenario)

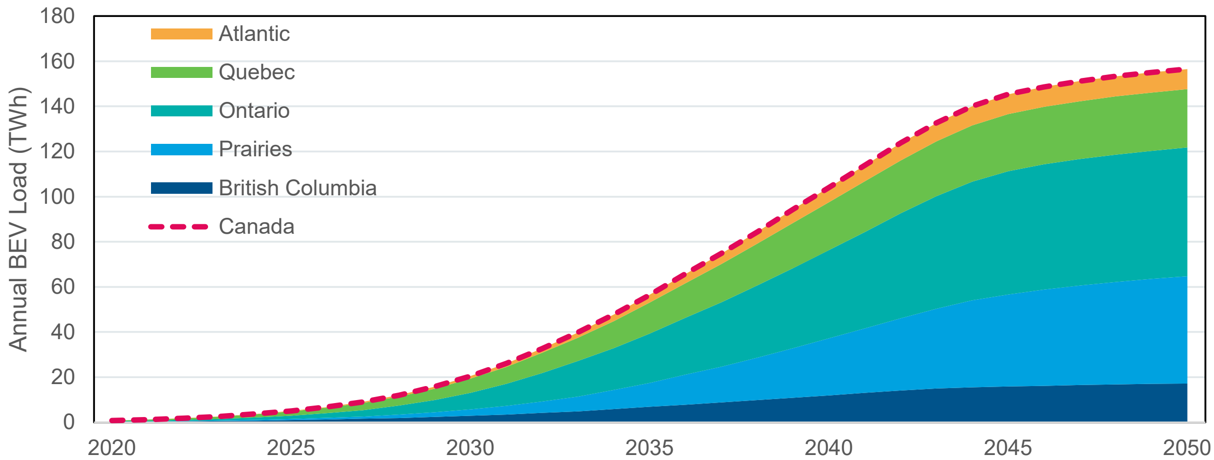
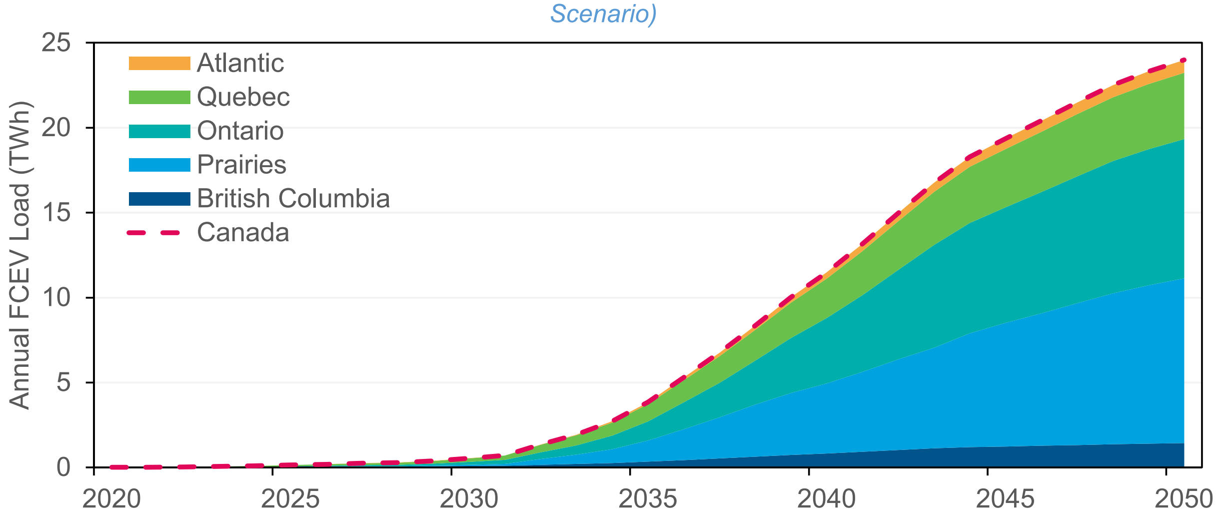


Exhibit 4 presents the results of the load forecast at the national level for FCEVs

Exhibit 4 Electricity Demand to Supply Hydrogen Production through Electrolysis for FCEV (Federal Target Scenario)



Based on the Federal Target, ICF's forecast suggests a 156.5 TWh EV load per year by 2050, representing 22.6% of current domestic annual electricity consumption.

Wholesale/Transmission System Readiness

During interviews, wholesale system planners told ICF that they perceive a relatively low vulnerability level associated with EV load growth. Instead, Canadian system planners communicated that they see EVs as a business opportunity instead of a risk or a vulnerability. The EV charging load can provide additional revenue and serve as a means to improve the load factor of the system because of managed charging opportunities.

The load forecast in Section 2.1 reinforces FleetCarma's conclusion that there is currently little ground for being preoccupied with the rise of EV charging load on the wholesale system in the near to mid-term.

Exhibit 5 presents a comparison between the result of our ZEV load forecasting work compared with the current annual electricity demand in each province. The table presents province-by-province results in ten columns from West to East and the Canadian total.

Exhibit 5 ZEV Charging Electrical Energy Growth through 2030 and 2050 Compared with Grid Demand (Scenario: Federal Target)

Battery Charging Load for BEVs and PHEVs

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Canada
2020 Grid Annual Demand, GWh	63,626	86,536	26,455	26,528	134,303	185,500	14,363	11,300	2,906	11,271	562,787
2030 EV Annual GWh	2,852	1,829	577	484	7,337	6,233	329	517	62	242	20,463
2040 EV Annual GWh	11,945	17,328	4,522	3,373	39,093	21,237	1,916	2,802	341	1,481	104,038
2050 EV Annual GWh	17,224	32,847	8,794	5,847	57,047	25,883	2,763	3,782	570	1,780	156,537

Hydrogen Production Through Electrolysis Load for FCEVs

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Canada
2030 FCEV Annual GWh	83	62	9	12	161	210	3	4	0	2	547
2040 FCEV Annual GWh	816	3,122	572	432	3,856	2,323	133	151	16	69	11,489
2050 FCEV Annual GWh	1,443	7,301	1,374	1,011	8,210	3,903	276	301	36	136	23,990

Sources: Row 1 CER Provincial Profiles, Alberta AESO Long Term Outlook 2017, IESO Reliability Outlook and Technical Conference Data for Growth Rates, Nova Scotia Power 2019 Load Forecast, New Brunswick IRP, NERC 2018 ES&D Outlook. Rows 2 to 10: ICF calculations.

The results shown in Exhibit 5 and Exhibit 6 are based on many simplifying assumptions, which are detailed in this report. These results should be viewed with caution and should be considered for illustrative purposes only.

The total annual load growth due to EV charging has the potential to be 20.4 TWh in Canada by 2030, 104 TWh by 2040, and 156.5 TWh in 2050. This represents 3.4%, 16.1%, 22.6% of the electrical power demand in 2030, 2040, and 2050, respectively. For a sense of scale, the forecasted ZEV load is equivalent to adding Ontario's 2019 annual electrical load to the national grid. This number is significant, but since the growth is spread over 30 years, with most of the growth happening during the 2030-2050 timeframe, Canadian utilities have ten years to refine the load forecast and plan for grid expansion.

Exhibit 6 presents a comparison between the result of our EV load forecast with a focus peak-coincident demand. ICF modelled the impact that managed charging could have on the provincial system's peak coincident EV charging load; i.e., the charging at the existing grid's peak operating demand. Of note, the peak charging loads of each province are not coincident with each other. The Canadian totals are reflective of the aggregated EV charging increases of each province that is coincident with the system peak hour of the province.

Exhibit 6 EV Charging Peak-Coincident Demand through 2030 and 2050 Compared with Grid Peak (Scenario: Federal Target)

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Canada
System Peak Hour Ending at:	18:00	17:00	18:00	16:00	16:00	5:00	5:00	15:00	5:00	9:00	N/A
Unmanaged EV Charging											
2030 EV MW at Peak Hour	378	317	90	61	1,157	571	15	75	3	54	2,720
2040 EV MW at Peak Hour	1,766	4,446	769	378	5,584	1,754	70	392	13	304	15,477
2050 EV MW at Peak Hour	2,585	9,199	1,587	622	7,778	2,096	95	505	20	344	24,381
50% Managed EV Charging											
2030 EV MW at Peak Hour	189	158	45	30	578	286	8	37	1	27	1,360
2040 EV MW at Peak Hour	883	2,665	385	189	2,792	877	35	196	6	152	8,181
2050 EV MW at Peak Hour	1,292	6,087	1,089	311	4,129	1,048	48	253	10	172	14,440

Sources: Rows 1 to 4 CER Provincial Profiles, Alberta AESO Long Term Outlook 2017, IESO Reliability Outlook and Technical Conference Data for Growth Rates, Nova Scotia Power 2019 Load Forecast, New Brunswick IRP, NERC 2018 ES&D Outlook. Rows 5 to 18: ICF calculations.

ICF did not include hydrogen generation (electrolysis) load for FCEV as part of the peak-coincident demand because hydrogen production facilities can be directly connected to the transmission grid. Since the production facilities do not need to be located where the hydrogen is being used and since hydrogen can be stored, the production facilities can be expected to have a degree of operational flexibility that would not apply to battery electric vehicles. As such, it was assumed that electrolyzer facilities would have little or no impact on the system peak.

Canadian utilities, including provinces where EV penetration is the highest, told us that they are planning relatively little near-term investment (5-year time frame) because of EV uptake. The adoption of EV is expected to have a minimal short-term impact on the system, with the increased EV load impacts occurring outside of the next five-year time frame when the EV load is expected to be more significant.

While Canadian utilities do not perceive EVs as a vulnerability on wholesale/transmission systems in the short-term, in the long run, however, ICF heard a consistent message from Canadian system operators that they are working on load management solutions for EVs. By the time the incremental system peak caused by EV charging becomes significant, the utilities had expressed that they anticipate that strategies to manage the EV charging load will have been implemented by that point. These strategies are expected to minimize impacts on system peak demands and improve system utilization to reduce the long-run average total cost of production for consumers.

Utilities across the country are piloting many EV charging management solutions, including time-differentiated rates (time-of-use rates and critical peak pricing being salient examples) to influence charging behaviour.

Distribution System Readiness

Most utilities in Canada confirmed that they see a higher degree of vulnerability to EV charging at the distribution system level rather than at the transmission/wholesale.

The distribution companies ICF spoke with are following EV uptake with varying degrees of attention, driven by the current level of penetration and the perceived level of impact. While many distribution system planners told us that they do not anticipate a widespread spur in adoption within the five- to ten-year time window, most of them are monitoring the steps taken by leading-edge utilities in provinces with higher rates of EV adoption. The initiatives undertaken by Hydro-Québec, BC Hydro, as well as the large Ontarian distribution companies serving the Greater Toronto Area, provide examples and strategies to inform the planning surrounding EV adoption.

Distribution system load forecasting can get complicated. As the forecaster zeroes in on a smaller area of the grid, the load has a lower load diversity. For example, there are fewer end-use electrical loads, fewer different EV types and charging loads, and a lower volume of users on the grid segment. The smaller the distribution system, the greater the volatility is expected to be, and the larger the impact of unmanaged EV charging. Furthermore, the adoption pattern will also be volatile, as some zones of the distribution system may see accelerated adoption compared to the average zone. Clustered accelerated adoption is a phenomenon that was observed, for instance, with the adoption of first-generation hybrid cars and the adoption of home solar PV systems. Accelerated local adoption provides a microcosm of what challenges and opportunities exist for future grid operations.

The concept of load diversity refers to the temporal aspect of when different customer loads are drawing power. In general, load diversity increases at higher system levels, smoothing out the load curve. In other words, zoomed out to the system level, a predictable percentage of total EVs will be charging at the same time. Zoomed in to the neighbourhood level, the coincidence of EV charging becomes less predictable than at the province-wide level, and a higher probability exists that many or all chargers could be drawing power simultaneously.

Canadian distribution companies have generally confirmed that the most vulnerable areas of their distribution grid are older residential neighbourhoods where load diversity is at its lowest or high-income neighbourhoods with accelerated EV adoption. In both cases, early EV adopters can lead to increased load demand that cannot be serviced existing electrical infrastructure, causing outages or damage, forcing distribution companies to replace the assets prematurely.

Canadian distribution companies also reported that the visibility on EV adoption could become a challenge. There is no mandatory reporting requirement for a residential customer to report having purchased an EV.

Case Studies of Clustered Accelerated Deployment

ICF developed a spreadsheet-based tool to evaluate the impact of EV interconnection on utility distribution grids. The Electric Vehicle Grid Impacts Screening Tool (EV-GIST) includes information on circuit topology and characteristics, electrical equipment, customer load profiles, EV charging profiles and EV chargers.

The intent of the tool is to enable a distribution system engineer to conduct quick analyses based on available circuit and EV adoption information. The tool's outputs may indicate the need for more detailed studies and provide a perspective of design changes required to accommodate EV adoption.

A few key inputs have the largest influence on the outcomes of the EV-GIST model.

First, the charger rating is a major factor. Residential chargers, for instance, range from just over 1 kW to over 19.2 kW. Even a small number of the higher power chargers clustered together can cause voltage or thermal issues for upstream equipment.

Second, is the number of EVs clustered together. As several mid-sized chargers have the potential to affect a constrained system adversely.

Finally, the system design, for example, the equipment sizing and line distances, has a significant impact on the modelling outcome. Smaller equipment and longer conductor runs can pose challenges for maintaining system operation within acceptable limits.

ICF used the tool to develop three case studies to cast light on possible vulnerabilities in a utility distribution system. ICF analyzed the impacts of EV adoption on the electric distribution grids of three electric utilities, Hydro Sherbrooke, NB Power, and Alectra.

The case studies represent the bookends of the distribution system. On one end, there is a substation serving thousands of customers, and on the other end, a distribution transformer and conductors serving a small number of customers.

On the latter, the results showed potential impacts in the near term at the more granular customer level from the likelihood of coincidental charging. The former case, the substation, was quite different in that load smoothing from diversified charging patterns caused projected capacity constraints to emerge further out in time.

ICF concluded that it would be prudent for Canadian utilities, from shore to shore to shore, to re-evaluate their planning sizing criteria and equipment capacities for street transformers and other grid-edge assets. This would ensure that additional electrified loads can be interconnected safely at the customer premise level.

Conclusions

The requirements for EV readiness, including but not limited to grid readiness, are multifaceted and will require considerable investments in supporting infrastructure, policy, and education. While manufacturers are working to continue to develop vehicles that meet the needs and expectations of consumers, private and public sectors will need to work on EV charging infrastructure.

Without underestimating the magnitude of the challenge of transportation electrification, nor the challenges that grid planners will be facing over the course of the next 30 years to sustain EV charging load growth, hydrogen production load for FCEV (if electrolysis turns out to be the production method of choice), grid readiness to ZEVs in 2020 is more about developing capabilities surrounding planning and solution deployment within the utilities and with the partnering vendors surrounding the utilities. For example, through our utility outreach, ICF has spoken with numerous Canadian utilities that are acting now to improve preparedness through studies and pilots.

There are several actions that have been taken or will need to be taken by, firstly, system operators and transmitters and, secondly, by distribution companies to ensure a sufficient level of grid readiness to EV.

At the wholesale/transmission level, better-prepared system operators, transmitters and vertically-integrated utilities:

- Seek to acquire and improve their ability to forecast EV charging load – both the annual demand and the peak-coincident demand.
- They are looking for better data to refine their EV charging load profile.
- Explore, keep appraised of, and possibly pilot time-differentiated rates including but (importantly) not limited to TOU.
- Develop means to gain better visibility into EV adoption in their service territory. Utilities need to appreciate the number, types, and location of EV adoption on their distribution network.
- They are tackling the challenge of interoperability between both sides of the transformer substation; i.e., between the wholesale and the distribution system.

At the distribution level, better-prepared distribution companies:

- Study many remote EV charging management solutions to justify the right solutions to their utility commission when the EV will have reached a sufficient level of penetration that they cause requirement for costly grid upgrades.
- Focus not only on EV charging but also on a wider array of DERs, including EV charging management, vehicle to home/building, vehicle to grid, and many other DER technology solutions.
- Bolster their business case for full-scale deployment of an AMI.
- Engage with utility commission staff and stakeholders to plan for investments supporting EV growth and management.
- Pursue broad, comprehensive beneficial electrification customer programs.
- Adopt or develop methods to assess EV charging load impact.
- Review design standards for new development, as well as replace on burnout of distribution assets.

Finally, Canadian utilities should undertake a thorough review of their distribution system design practices and possibly change the standard design rules in preparation for a higher load per customer due to EV charging.