Scoping the Implications of Electric Vehicle Technology in Ontario:

A Report to the Environmental Commissioner of Ontario

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CLEAN AIR. CLEAN WATER.

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Introduction

Environmental stewardship and accountability in Ontario has expanded to include the impacts of energy use. Recently, transportation energy use has been added to the reporting mandate of the Environmental Commissioner of Ontario (ECO). Pollution Probe produced this scoping report to help inform the ECO on the implications of increased penetration of electric vehicles (EVs) in Ontario, focusing on the potential for EV technologies to achieve reductions of greenhouse gas emissions and air pollutants without disturbing the reliability of the electricity grid.

Light-duty vehicles are the primary mode of transportation for the majority of Canadians,[1] with more than 80 per cent of all trips occurring in personal automobiles. Similarly, medium and heavy-duty trucks are responsible for the vast majority of commercial deliveries and shipments. And more than 99 per cent of the energy that powers both personal and commercial vehicles in Canada is provided by the combustion of gasoline and diesel.[2] The combustion of transportation fuels contributes nearly one third of Ontario's annual greenhouse gas (GHG) emissions, mainly in the form of carbon dioxide (CO_2).[3] The combustion of fossil-based transportation fuels is also a major source of criteria air contaminant (CAC) emissions, including oxides of nitrogen (NOx) and oxides of sulphur (SOx).

Alternative fuels to gasoline and diesel, including natural gas and propane, comprise a marginal share, mostly confined to niche and regionalized markets (e.g., propane in city taxis). But even these alternative fuels are combusted to provide motive power, and result in the production of GHG emissions and air pollutants. Battery Electric vehicles (BEVs) use an electric motor powered by electricity that is stored in an on-board battery. There is no fuel combustion and therefore no direct (or tailpipe) emissions. Indirect emissions can be produced at the point of electricity generation however, and these must be considered when discussing the potential for EVs to achieve overall emissions reductions in Ontario. Throughout this report, electric vehicles (EVs) are considered vehicles that are 100 per cent powered by electricity from the provincial electricity grid.

EVs displace the demand for gasoline and diesel fuels with electricity. Provided the electricity is supplied by low-emitting generation facilities, EVs can achieve reductions in emissions of GHGs and CACs from the transportation sector.

Key Message: The degree to which emissions reductions can be achieved through EV deployment is mainly dependent on the emissions intensity of the electricity system. Because Ontario`s electricity sector emissions are highest during peak periods, maximizing emissions reductions will require a strategy to encourage off-peak charging.

Pollution Probe's analysis projects emissions reductions for EV deployment even in scenarios where 100 per cent of the incremental peak demand for EV charging is supplied by natural gas combustion facilities, a likely scenario for Ontario in the near term as it fulfills its commitments to phase out coal-fired generation.

Aside from mass transit subways, trams/streetcars and trolley buses, EV technologies are relatively new. Current penetration of EVs in Ontario is effectively zero, with electricity supplying less than 0.1 per cent of total transportation energy demand in the province. EVs are, however, beginning to penetrate the market in various forms, and there is considerable interest (and the focus of this report) on electrification of light duty vehicles. The future of Ontario's transportation system is expected to include electric mobility in increasing proportions, due to a combination of technology improvements, growing market demand for alternative vehicles and recently announced government incentive programs.

In the next five years, more types of EVs, ranging from electric scooters to mid-size sedans, are expected to become available. Consequently, the further integration of EVs into the lives of Ontario residents and into the daily affairs of Ontario businesses is expected. With increased penetration of EVs comes increased demand for electricity, which implies both increased need for electricity generation on a province-wide basis, as well as increased demand for capacity on transmission lines at a regional level and the distribution grid on a localized, neighbourhood level.

Key Message: Given the priorities of Ontario's government and electricity regulators, the emphasis on emissions reductions cannot come at the expense of grid stability or the reliability of the electricity sector as a whole. It is therefore imperative to consider the optimal penetration rate for EVs in Ontario within the context of the current and future electricity generation mix, as well as the capacity of regional transmission and local distribution grids to deliver power as required.

The optimal penetration rate of EVs will be the point at which overall greenhouse gas and criteria air contaminants are minimized relative to conventional vehicle use without introducing grid instability at the local level. Setting targets for overall provincial penetration is laudable, but it is likely that vehicle uptake will be concentrated in certain higher-income, urban neighbourhoods. The disproportionate uptake in these neighbourhoods will require a case-by-case assessment of the local distribution system capacity, including wires, transformer stations, sub-transformers and other equipment, along with individual household electricity service.

Furthermore, the varying nature of the electricity supply mix and fluctuating demand makes the time of charge a central determinant in the "sustainability potential" for electric vehicles in Ontario.

The magnitude of emissions reductions attributable to EV use and the potential for the increased electricity load to affect the reliability of the grid will be important considerations in determining how great or how small a role EVs should play in an overall sustainable transportation plan. In addition to reducing emissions, such a plan must include a major focus on reducing total vehicle kilometres (VKT) traveled or the broader issues of congestion, gridlock and sprawl will not be addressed.

Pollution Probe does not view electric vehicles as a "silver-bullet" solution to the challenge of achieving sustainable transportation. To maximize the benefits, EVs should be approached as a potential measure, to be used in conjunction with other efforts to reduce GHG and smog-forming emissions from transportation, with a focus on transportation demand management measures to reduce total VKTs.

Scope & Methodology

This report scopes the implications of increased penetration of electric vehicles (EVs) in Ontario, focusing on the potential for EV technologies to achieve reductions of greenhouse gas emissions and air pollutants without disturbing the reliability of the electricity grid.

The report is based on Pollution Probe's research, investigations and simulation work on EVs, drawing primarily on the report, *Moving Toward an Electric Mobility Master Plan for the City of Toronto*, where simulation and modeling work on EV penetration rates and emissions and grid implications have been extrapolated for an Ontario study area. This report includes the following sections:

1. A discussion of the potential barriers and opportunities for EV technology deployment across the major modes of transportation in Ontario.

2. An estimation of the net change in GHG emissions associated with different levels of EV use in the province, and an estimation of the net change in emissions of oxides of nitrogen and sulphur (i.e., smog precursors).

3. A discussion of the potential impacts on electricity generation, and the implications for supplying power at the local distribution grid level

4. A discussion of the enabling grid technologies needed to maximize the environmental potential for EV use in the province.

5. A review of the implications of increasing EV use in the context of other government objectives relating to energy and environment in Ontario

Note: In the context of this report, the term "electric vehicle" refers to vehicles where 100 per cent of the energy used for transportation is drawn from the electricity grid and stored in an on-board battery (i.e., BEVs). Other reports and publications may use the term electric vehicles in reference to all modes of transport that are partly- or fully-powered by energy drawn from the electricity grid, including, (but not limited to) plug-in hybrid electric vehicles (PHEV), extended range electric vehicles (EREV), battery electric vehicles (BEV), grid-connected transit vehicles and electrified locomotives.

1. Discussion of the potential barriers and opportunities for EV technology deployment across the major modes of transportation in Ontario

This section discusses the barriers to the introduction of EVs, in terms of both consumer markets and technology performance characteristics. Also considered are the opportunities for EVs, particularly how the performance of the technology matches the mobility patterns of Ontario drivers.

Key Message: The consumer barriers to EV technology deployment include: the higher purchase price for EVs relative to conventional vehicles, uncertainty with respect to the operation and maintenance costs of owning an EV, concerns over the shorter range of EVs on a full charge compared with a conventional vehicle with a full tank of gasoline and the longer charge times compared with filling up at the gas station.

Beyond these consumer barriers, the local distribution companies (e.g. Toronto Hydro, Guelph Hydro, Hydro One) that supply electricity to consumers and are responsible for delivering electricity through their distribution grids face infrastructure and governance barriers. These include the need to develop new business models for EV charging, requirements for new and updated infrastructure, impacts on neighbourhood grid reliability and flexibility, and the need to develop charging technology standards and electricity information transfer protocols and systems.

The opportunities for EV technology deployment are more provincial in nature, in that EVs can potentially reduce emissions of greenhouse gases and criteria air contaminants and can potentially serve as a mechanism to make use of Ontario`s surplus baseload generation capacity during off-peak hours. EV deployment could also potentially provide for an energy storage pathway, whereby EV batteries would charge during off-peak hours when environmental impacts are lower and electricity costs are cheaper, and then could discharge back to the grid during peak periods, when electricity prices are at a premium and the environmental impacts of the electricity system are greater.

In the near-term, the most significant opportunity to achieve GHG and CAC emissions reductions while reducing grid impacts is in the electrification of commercial transportation. This is because delivery and other commercial vehicles operate primarily in urban areas, wherein drive cycles are dominated by stop-and-go operation, ideal conditions for the electric traction and low-emissions characteristics of electrified powertrains. In addition, it is likely that commercial fleets would be more responsive to time-of-use rates, and would charge during off-peak hours. This would help maximize emissions reductions while at the same time reducing grid impacts primarily associated with peak charging times.

Barrier: Vehicle Purchase Price

The purchase price of an EV is higher than that of an equivalent class of conventional vehicle. The *Chevrolet Volt*, which is an EREV (i.e., it has a gasoline engine, as well as BEV capabilities), is expected to cost US$40,000 when it is released in 2011. Nissan has priced its BEV, *the Leaf*, at approximately US$32,000, not including incentives or credits.[4] A North American price for the Mitsubishi iMiEV, another compact BEV, has not yet been set, but is expected to be comparable to that of *the Leaf*. Although not representative of the potential future mass BEV market, the high-performance Tesla Roadster is currently on the market and has a base price of US$109,000. Please note that these prices do not include any government rebates on offer in Ontario.

The main reason for the high EV price tag is the battery, although quantifying the incremental cost due to the battery and materials is a challenge. The present scale of EV battery manufacturing is so small that there is a significant premium attached to the price of the batteries, and therefore the selling price of EVs. The price of the battery materials is also a contributing factor to the elevated price of EV batteries.

Numerous studies have been conducted in an effort to gauge consumer attitudes toward purchasing EVs. They have found that the premium paid for EVs over conventional internal combustion engine vehicles (ICEVs) is a significant factor in the decision making process. The Government of Ontario has announced a rebate of up to CAN$8,500 for the purchase of qualifying EVs to help reduce the vehicle purchase price barrier.

Another question is the one-time cost of installing residential charging infrastructure – if the cost of installation is borne by all rate payers of the local distribution company, then installation costs will be lower for the EV user than if they had to pay for that installation themselves.

Barrier: Vehicle Operating Cost

On an annual basis, the price of operating an EV is equal to the sum of: the price of electricity used to power the vehicle; annualized maintenance fees; the annualized cost of battery replacement and any annualized maintenance costs associated with the residential charging infrastructure (the infrastructure installation costs were mentioned in the vehicle purchase price above).

At current electricity and gasoline prices, the cost of the electricity required to move an EV one kilometre when charging at peak hours is less than the cost of the gasoline required to move an ICEV one kilometre. Assuming proportionally lower electricity prices at off-peak hours, the energy cost of an EV is even lower than that of a gasoline-powered vehicle. But this only gives a partial picture. More “real, on-road” data is required to quantify the cost of EV operating expenses, including battery replacement and “real world driving” energy consumption. This will allow more accurate forecasting as to whether EVs present a potential operating cost or benefit relative to conventional vehicles.

Barrier: Battery Range
The distance a vehicle is able to travel between refueling is termed a vehicle's range. In general, conventional vehicles can travel further on a full tank of gas than proposed EVs can on a fully charged battery. This is because the *energy density* of EV batteries is lower than that of gasoline and diesel fuels. This means that for a given battery size, less energy is available than from the combustion of an equivalent volume of gasoline or diesel.

A simple solution to providing more energy to the battery, and thereby increasing its range, is to make it bigger. However, increasing the size of the battery generally means increasing its weight and volume, which negatively affects the energy use efficiency of the vehicle (i.e., more energy is required to accelerate a vehicle of greater weight). This is a balancing act that is one of the primary challenges in battery and EV technology development. As such, the range of most EVs currently offered or pending market availability tends to converge toward 160 kilometres.

Frost & Sullivan, a global consulting firm, found that a range of 160 kilometres is enough to make European consumers consider purchasing an EV.[5] A Pike Research study also found that 48 per cent of potential purchasers would be comfortable with only a 65 kilometre range, even though they might not trust the manufacturer quote range between charges.[6]

Range anxiety refers to the fear of running out of stored electrical energy and having no access to a charging location *while driving*. This can be a warranted concern, given that the range of an EV is heavily dependent on "duty cycle" (i.e., profile of speed and engine load during use), outside conditions (i.e., ambient temperature), driver behaviour and driving conditions (e.g., climate, topography). In fact, an EV can have a different range from one day to the next.[7] In a study conducted by Aerovironment, many drivers were unwilling to travel more than half the quoted maximum range of the vehicle. The Aerovironment study concluded that range anxiety is more a result of insufficient charging station availability than a mistrust of the quoted battery manufacturer specifications.[8]

A Tokyo Electric Power Company (TEPCO) study on charge station placement supports the findings of Aerovironment, suggesting that the availability of charging locations is directly related to the degree of range anxiety experienced by the operator of an EV. When more charging stations were made available to TEPCO fleet vehicle operators, EVs were driven further and returned to TEPCO facilities with lower states of charge than when there were fewer charging stations installed.[9] The range barrier can, therefore, potentially be alleviated by planning and implementing sufficient charging infrastructure.

Unfortunately there are no known studies concerning range anxieties for Ontarian or Canadian EV drivers from which Pollution Probe could draw any findings.

Barrier: Long Battery Charging Time
With the current state of battery technology, the time required to recharge an EV is expected to be significantly longer than that needed to refuel an ICEV with gasoline or diesel. This aspect

of EV ownership is perceived by consumers to be an unattractive feature and potential barrier to adoption.[10]

Depending on the type of charging used, EVs can take anywhere from 10 minutes to 13 hours to fully charge. In previous work, Pollution Probe found that extended charging periods represent disincentives to EV ownership.[11] Similarly, Frost & Sullivan reported that households will tolerate no more than four hours for charging.[12] Although high-level charging technology is being developed to alleviate this concern, the need for some degree of lifestyle change is inevitable among EV owners. Distribution “bottlenecks” could introduce some challenges to high-level charging; because individual houses have limited power draw, the potential for EV charging would be restricted to times of day with lower use of other electrical appliances. Similarly, transformers that distribute power to all houses in a neighbourhood or sub-division have a limited capacity – all houses could not use high-level charging at the same time without impacting local grid stability.

Nevertheless, there is a convenience factor associated with charging a vehicle from an electrical outlet rather than filling up at a public gas station, in that the vehicle can be charged from the owner‘s home. If planned correctly, EV users could minimize the inconvenience of waiting for their vehicles to charge, by plugging them in while sleeping or when engaged in other activities. With a level of battery state-of-charge awareness, an EV user can partially charge the vehicle, as well as choose to charge when electricity rates are potentially at their lowest.

There are other options to “on-demand charging”. Some business models are looking at the potential to “swap” depleted batteries with charged batteries (Better Place). This model would have the EV purchaser lease the battery instead. While this potential solution would help alleviate concerns over long charging times and batteries could be charged during off-peak times ready for replacement during the day, it raises other challenges, including the need for standard battery sizes, models and interoperability and vehicle warranty issues.

Barrier: Infrastructure Development Business Model

Uncertainty exists as to the most effective approach to assigning ownership and management of, as well as responsibility for, charging infrastructure. The implications of different charging strategies are unknown in terms of the load on the electricity distribution system, as well as the potential for emissions reductions.

Cost: While infrastructure investments may alleviate some pressure for the advancement of battery technology, infrastructure providers may not be inclined to invest in charging stations until EVs become prevalent within the personal vehicle market.[13] Conversely, without sufficient charging infrastructure, consumer demand for EVs could be limited, which in turn could reduce manufacturer motivation to produce more vehicles. Nevertheless, the need for opportunistic charging, and the corresponding strategic placement of public charging stations, is still an area of study and the subject of pilot testing.

Privacy & Security: The centralized intelligence of the Smart Grid, and the possibility of alternative billing and metering systems, introduces the potential for reduced privacy and security.

Network Management and Power Quality: The installed capacity of the current electricity distribution system is likely to be capable of handling the incremental load of EVs in the near-term. In the long-term, however, physical improvements may be required to meet the demand for electricity posed by EVs. The location and degree of these improvements have not yet been identified or prioritized.

Mobile Applications: Mobile access to information about one's electricity use is an emerging service that utilities are beginning to develop. EV owners will expect to access information on public charging locations, and their EV's state of charge while connected to the grid.

On-Board Communication: Facilitating "grid-optimized" energy transfer requires energy storage systems, chargers or inverters, metering, communications, monitoring and controls. Information technologies for the road (telematics) that allow for data to be shared and stored in communications devices (e.g. GPS navigators) and smart metering systems can allow for communication between the vehicle, the charging infrastructure and the grid. This will allow for state of charge, energy price and time-of-use information to be monitored and shared. Whether the resources exist to implement all of these systems in time for the arrival of EVs so-equipped is difficult to predict.

Standards: Standardization of codes and practices between jurisdictions can enable a safer transition to electric mobility infrastructure development and use. However, procedures for best practices in the charging of EVs and their integration into transportation systems are still being developed.

Battery Charging Time: The time required to charge an EV battery is influenced by the capacity of the electrical outlet, the charging system level and specific battery chemistry charge capabilities. While high-level charging systems are being developed, the use of such systems and their associated impacts on the total useful life of a battery are still being investigated.

Opportunity: Reduction in emissions of GHGs and CACs, specifically carbon dioxide, SOx and NOx. Reducing emissions of pollutants caused by the combustion of gasoline and diesel will improve local air quality and help mitigate climate change.

Electrification of medium and heavy commercial vehicles (e.g. postal and delivery trucks and garbage/recycling trucks) could facilitate substantial reductions in emissions, accruing significant benefits in densely populated urban areas. Couriers, retailers and postal departments, as well as garbage and recycling trucks, operate primarily in urban areas, wherein drive cycles are dominated by stop-and-go operation — ideal conditions for the electric traction and low-emissions characteristics of electrified powertrains.

Opportunity: Potential to make use of surplus baseload generation during off-peak hours. By charging EVs during off-peak hours, EV owners maximize the financial and environmental benefits associated with EV use. Off-peak EV charging can also potentially serve as a grid stabilizer by making use of current and projected surplus baseload generation. Surplus Baseload Generation (SBG) is a condition that occurs when electricity production from baseload facilities is greater than Ontario demand[14]. This surplus supply available at off-peak is commonly sold well below Ontario residential consumer rates to Quebec and other jurisdictions and represents an inefficiency in Ontario`s electricity system.

EV charging could provide an off-peak load to make use of the surplus power, allowing baseload generators to recoup their operating costs during off-peak periods, which would contribute to a more cost-effective electricity market. While this is an opportunity, it will require sufficient rules and incentives to require off-peak charging and to encourage EV owners to use their vehicle as an energy storage device, discharging electricity from the EV battery to the grid (V2G or vehicle to grid) during peak times. Due to the considerable uncertainties involved in EVs providing energy storage and a source of low emitting electricity at peak, this was not included in the modeling results in the following section.

Opportunity: Job creation in EV technology sector. An EV mobility strategy for Ontario could potentially stimulate job creation in the EV technology sector, namely jobs in infrastructure design and construction, information technology and automotive parts and equipment manufacturing.

Opportunity: Reduced dependence on petroleum products and crude oil. Almost all of Ontario's petroleum products and crude oil are imported. Reducing demand for these imported fuels reduces Ontario`s exposure to price increases and price volatility that are largely beyond provincial government control compared to electricity prices, which are directly controlled by the provincial government and through its regulator, the Ontario Energy Board.

Based on an EV penetration rate of five per cent of all vehicles on the road in 2020 (with one quarter of these vehicles being commercial vehicles), Ontarians would offset the combustion of over 900 million litres of petroleum products annually (700 million litres of diesel and 200 million litres of gasoline), roughly the equivalent of 35 PJ of energy saved in terms of avoided petroleum product consumption. To power the equivalent annual vehicle kilometres traveled by those five per cent of vehicles with electricity would require about 4.5 TWh (4,500,000 MWh), equivalent to 16 PJ of energy. The total savings on a final consumption basis would therefore be about 19 PJ of energy annually. Caution must be taken in quoting these numbers however, as the net energy savings should consider the supply of electricity – if natural gas is the fuel used to generate all the electricity required to power the EVs, then more total energy would be required, as the efficiency of conversion in the natural gas-fired plants is roughly 40 per cent, requiring roughly 48 PJ of natural gas energy annually.

2. An estimation of the net change in GHG emissions associated with different levels of EV use in the province, and an estimation of the net change on emissions of oxides of nitrogen and sulphur (i.e., smog precursors).

To estimate changes in emissions levels resulting from the deployment of EVs across Ontario, this scoping report draws on the analyses of Pollution Probe's scenario simulations of EV use in Toronto, scaling up the results to reflect province-wide penetration of EVs.

Key Message: The simulation work indicates that EV use could potentially contribute up to 13 per cent of Ontario's 2020 greenhouse gas emission reduction target set out in its revised (2009) Climate Change targets, assuming a penetration rate of five per cent of on-road vehicles, where one quarter are commercial.

Further reductions are possible. The magnitude of the emissions reductions increases with increasing EV penetration rates; increasing proportion of medium and heavy-duty commercial vehicles within the EV fleet; and decreasing emissions-intensity of Ontario's electricity mix.

Several EV penetration rate scenarios were modeled out to 2015, 2020 and 2030, where the number of EVs for each scenario and year is based on an average historical growth rate of vehicle population in Ontario between 1999 and 2008. For details on the modeling methodology used, please see Appendix A.

It is worth noting that the moderate scenario is representative of the Government of Ontario`s target for EVs to account for 5 per cent of all vehicles on the road by 2020. In this moderate scenario, commercial vehicles are assumed to make up 25 per cent of EVs in 2015, 20 per cent of vehicles in 2020 and 15 per cent of total vehicles on the road in 2030. The market share of commercial vehicles was assumed to decline relative to the share of passenger vehicles due to increased consumer familiarity and acceptance of passenger EVs, more models entering the market and increased public and residential charging infrastructure availability.

Table 1: Potential Electric Vehicle Penetration Rates and Vehicle Populations in Ontario

Scenario Year	Number of EVs on Ontario roads (% of vehicles on Ontario roads)				
	Mild Scenario			Moderate Scenario	Aggressive Scenario
2015	3,380 (0.05%)	6,755(0.1%)	23,650 (0.35%)	67,565 (1%)	135,130 (2%)
2020	149,195 (2%)			**372,985 (5%)***	745,975 (10%)
2030	407,970 (5%)			815,940 (10%)	2,039,850 (25%)

Assumptions that relate to emissions calculations include:

- All EVs in the modeling are assumed to draw 100 per cent of their energy from the electricity grid
- Average annual decrease in fuel consumption of 2 per cent for gasoline-powered motorcycles/scooters;
- The Government of Canada's draft regulation on GHG emissions from new light-duty vehicles achieves the forecasted 20 per cent reduction in GHG emissions from new vehicles sold in 2016, compared to new vehicles sold in 2007[1];
- Reductions in CAC emissions from light-duty vehicles of 5 per cent over baseline (2008) by 2030;
- 12 per cent fuel consumption reduction (L/km) for heavy-duty trucks over 2002 baseline by 2016; and
- 2010 heavy-duty truck CAC emissions regulations achieve forecasted improvements.

The emissions reductions estimates provided in the following three pages are all relative to a scenario where there is zero penetration of EVs – all of the vehicles are powered by gasoline/diesel. The estimated reductions as a result of EV use are equal to the reduced emissions from driving internal combustion engine vehicles, less the emissions from electricity generation required to operate the EVs.

As EV penetration rates increase, the emissions reductions increase, because there are fewer tailpipe emissions. As charging times move from times of peak electricity demand (when natural gas-fired generation is the marginal power supply) to off-peak times (when the electricity supply is nearly emissions free) the emissions from the electricity sector decrease.

[1] Subsequent to scenario development and analysis, the proposed regulations on GHG emissions from light-duty vehicles were published in the *Canada Gazette Part I* (April 17, 2010, Vol. 144, No. 16), in which reductions in GHG emissions ratings of 25 per cent by 2016 were projected. This makes the outputs of the model somewhat more conservative.

Figure 1: CO_2 emissions reductions using EVs relative to conventional vehicles, by electricity generation mix and EV penetration rate (2020, where 25 per cent of EVs are commercial).

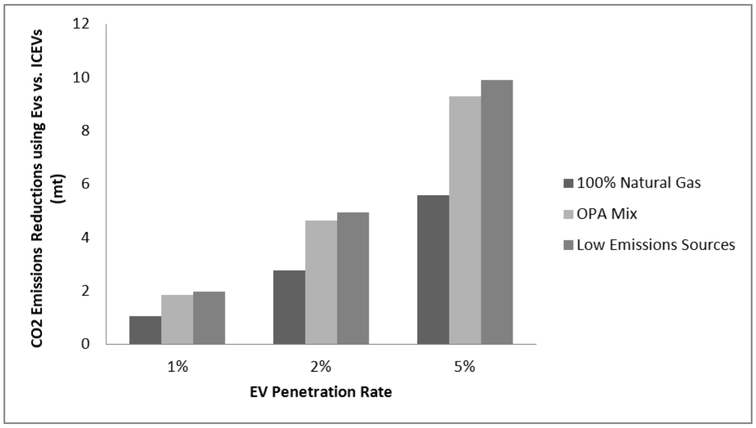


Figure 1 demonstrates two important trends. First, any penetration of EVs will result in CO_2 emissions reductions in Ontario, even if all of the electricity is generated through natural gas combustion, which is a good approximation for the incremental supply at or near peak electrical demand. The emissions reductions are greater with lower emitting sources, representative of the generation mix during off-peak hours. Second, the CO_2 emissions reductions increase with increasing EV penetration.

Figure 2 a and 2 b: CO_2 Emissions Reductions per year for a) only the commercial medium/heavy-duty portion and b) only the light-duty passenger vehicles

Figure 2 a: Commercial only

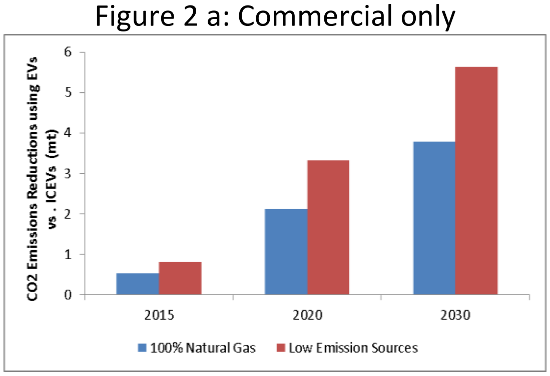
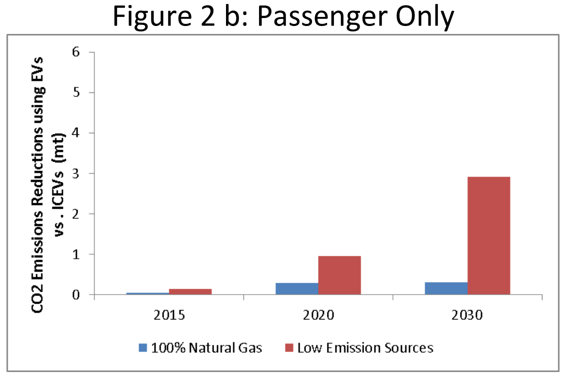


Figure 2 b: Passenger Only



Comparing figures 2 a and 2 b, commercial vehicles have the potential to deliver significantly more CO_2 emissions reductions than passenger vehicles on an absolute basis, due to the expectation that commercial EVs will consume more electricity per year than passenger EVs. The relative contribution of commercial vehicles is even more striking when one considers that in this moderate scenario, commercial vehicles make up only 25 per cent of the EVs on the road in 2015, 20 per cent in 2020 and 15 per cent in 2030.

Figure 3: SOx emissions reductions using EVs relative to conventional vehicles, by electricity generation mix and EV penetration rate (2020, where 25 per cent of EVs are commercial).

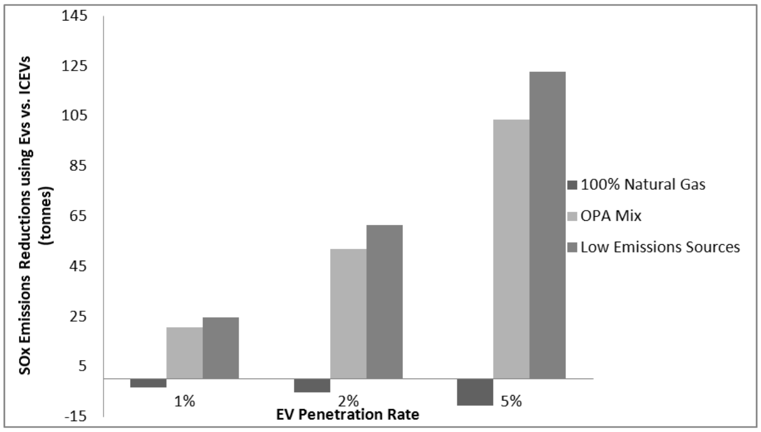


Figure 3 shows that SOx emissions show a slight increase if the electricity is all supplied using electricity generated from natural gas combustion. Reductions in SOx emissions are projected for scenarios where electricity is generated from lower-emitting sources than all natural gas. The magnitude of the increases and reductions in emissions increases with EV penetration.

Figure 4 a and 4 b: SOx Emissions Reductions per year for a) only the commercial medium/heavy-duty portion and b) only the light-duty passenger vehicles

Figure 4 a: Commercial Only

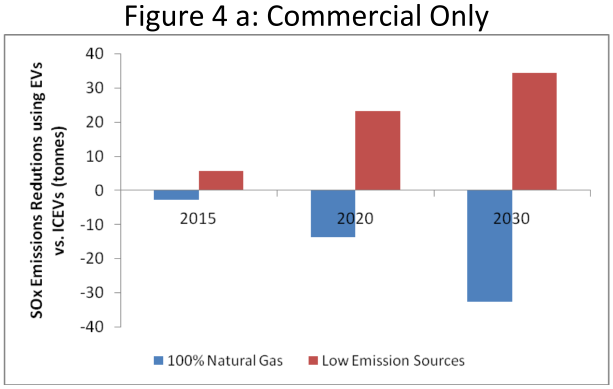


Figure 4 b: Passenger Only

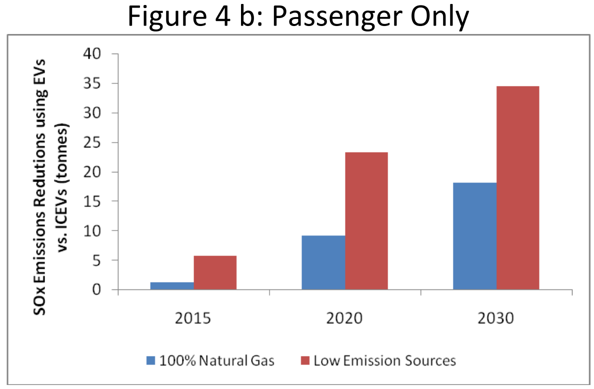


Figure 4 a clearly shows the link between the SOx emissions profile of commercial electric vehicles and the electricity generation supply mix. Commercial EVs result in a slight increase in SOx emissions in a 100 per cent natural generation scenario because more natural gas is required to deliver the required electricity when compared to gasoline or diesel fuel, resulting in a higher per-km SOx emission factor. Figure 4 b shows the resulting change in SOx emissions reductions for passenger vehicles, with net SOx emissions reductions even in a 100 per cent natural gas generation scenario, doubling with a low emissions electricity supply.

Figure 5: NOx emissions reductions using EVs relative to conventional vehicles, by electricity generation mix and EV penetration rate (2020, where 25 per cent of EVs are commercial).

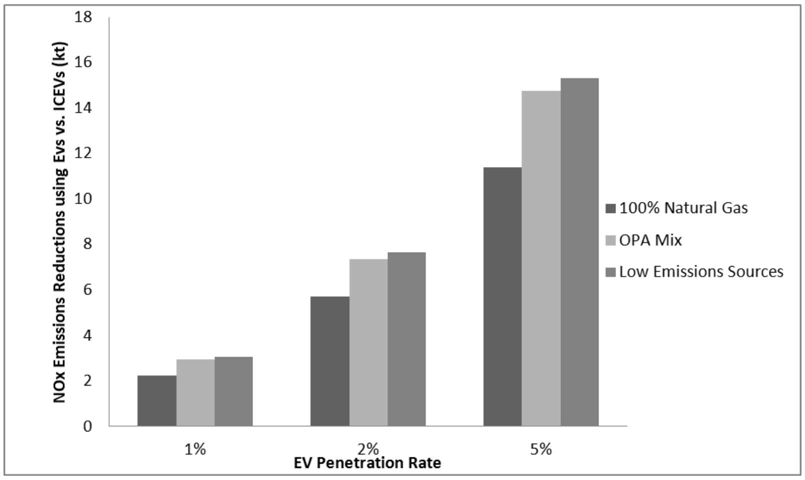


Figure 5 shows that EVs can result in significant NOx emissions reductions, even if all of the electricity is generated through natural gas combustion. Emissions reductions increase with lower emitting electricity generation sources and with increasing EV penetration.

Figure 6 a and 6 b: NOx Emissions Reductions per year for a) only the commercial medium/heavy-duty portion and b) only the light-duty passenger vehicles

Figure 6 a: Commercial Only

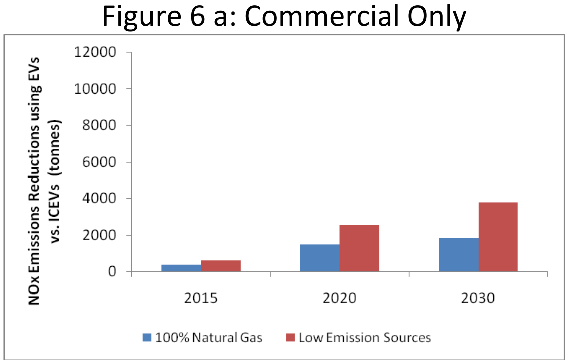
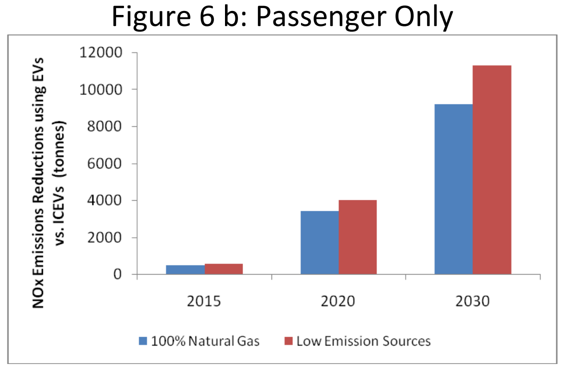


Figure 6 b: Passenger Only



Figures 6 a and 6 b show that passenger vehicles are projected to achieve significantly higher NOx emissions reductions than commercial vehicles regardless of electricity supply mix. There is a mix of factors influencing this result. First, regulated limits on CAC emissions from light-duty vehicles are more stringent compared to medium- and heavy-duty vehicles – new regulations being introduced to heavy vehicles (of which many commercial vehicles are) will bring them more in-line, but that will take time to equal out on a per-km basis. Second, the assumption that there will be more passenger vehicles than commercial vehicles on the road is influencing the outcome. This is tempered somewhat by the assumption that commercial vehicles will drive on average more kms per day.

3. Discussion of the potential impacts on electricity generation, and the implications for supplying power at the local distribution grid level

Key Message: EVs and EV technology introduce a new and important variable into Ontario's transportation system. The manner in which EVs are integrated could determine the overall social, economic and environmental impacts of the technology. A thoughtful and strategic deployment of EVs and the enabling infrastructure could help to ensure the optimal contribution to regional targets for air quality, public health, economic productivity and climate change.

Conversely, a random and unplanned approach to EV integration might fail in addressing predictable barriers to successful uptake. This could, in turn, limit the potential benefits and set back the development of a sustainable transportation system in Ontario

Time of Charging

The infrastructure impacts vary substantially when considering charging during peak hours versus during off-peak hours. Charging during the day or during peak periods results in higher peak demand for electricity, posing an increased risk of system overload and potential power outage, compared to charging during off-peak, where excess baseload supply is available.

Scheduling of private EV fleets to charge in off-peak periods, or programs that promote off-peak charging by individual EV users, may enable some degree of load levelling. Furthermore, off-peak charging results in the highest emission reductions (relative to the emissions that would result if all vehicles were conventional gasoline/diesel) as the electricity supply at these hours is made up of nearly emissions-free sources.

One of the challenges facing local distribution companies (LDC) charged with the dual responsibilities of supplying retail power and maintaining a reliable and stable distribution grid is that there is no firm mechanism available to limit charging. The only program currently in operation is the peaksaver program, which is voluntary and allows the LDC to remotely turn down participating customers' air conditioners. Time of Use (TOU) rates will help to introduce a price signal to encourage off-peak charging, but the signal might not be sufficient for higher income households/neighbourhoods where uptake of EVs is expected to be highest given the relatively high purchase price. LDCs will have to work with the Independent Electricity System Operater (IESO), the Ontario Energy Board (OEB) and the Ministry of Energy to determine the best mechanism to encourage (and potentially to force) off-peak charging.

Penetration Rate

The Government of Ontario's goal of a five per cent penetration by 2020 is treated as the moderate scenario. This level of penetration can be serviced by the projected system capacity based on the simulation. However, the simulations indicate that the potential for system-wide impacts increases in more aggressive scenarios. It is important to note that penetration rates are not expected to be uniform across the province, and disproportionate impacts could occur at the local distribution grid level.

To manage the impacts seen in the aggressive scenarios, electrical system infrastructure upgrades, electricity generation capacity development, as well as some combination of modal shift to reduce overall transportation demand (i.e., fewer total EVs on the road and/or fewer vehicle kilometres travelled) may be required.

Charging Level

Charging level (i.e., Level 1, 2 or 3) defines the rate at which energy is transferred from the grid to the vehicle (i.e., power). Level 1 charging is the base charging level (120V AC single phase, 15 or 20A). The scenarios assume increasing use of Level 2 charging (240V AC single phase, 40A-80A) for personal vehicles over time and increasing use of Level 3 charging ("Fast Charging", up to 500V DC; 208 or 480V AC three-phase) for commercial vehicles over time. As more vehicles with larger batteries charge at Levels 2 and 3, the overall demand increases.

Implications: The power draw from the charging of EVs is expected to increase over time. Consumer preferences are expected to drive charging infrastructure toward faster levels of service. If Level 2 and 3 charging systems are increasingly the norm, electricity infrastructure vulnerabilities may be exposed as EV uptake increases.

Vehicle Fleet Mix

The total incremental EV load increases as the share of commercial medium- and heavy-duty vehicles comprising the EV fleet increases in a given year. When compared to the load imposed by personal EVs *only* (i.e., no large commercial trucks), vehicles with larger batteries (e.g., 160 kilometre range vs. 35-kilometre range) using faster charging (e.g., Level 3 vs. Level 1) demand a substantially higher amount of electricity over a given time period. High EV penetration rates combined with high commercial EV uptake further compound the risk of system overloading. In contrast, fleet mixes containing low penetration levels of large commercial EVs appear to be more manageable based on the capacity of Ontario`s electricity system.

Couriers, retailers and postal departments, as well as garbage and recycling trucks, operate primarily in urban areas, wherein drive cycles are dominated by stop-and-go operation — ideal conditions for the electric traction and low-emissions characteristics of electrified powertrains. By using commercial EVs in urban pick-up and delivery applications, up to 40 per cent less fuel is consumed because electric power is used to accelerate the heavy vehicles from a stand-still. See Appendix B for information detailing the state of product development of commercial EVs.

Implications: At aggressive rates of EV penetration, the relative distribution of commercial trucks and passenger vehicles should be considered. Due to the high rate of charge and resulting high electricity demand from these vehicles, charging scheduled around off-peak hours could better accommodate the introduction of large volumes of commercial EVs.
The simulation outputs confirmed that careful planning is needed to ensure introducing EVs on Ontario's roads is consistent with the capacity of the electricity grid to support the added EV charging load, and net reductions in emissions resulting from EV use are maximized.

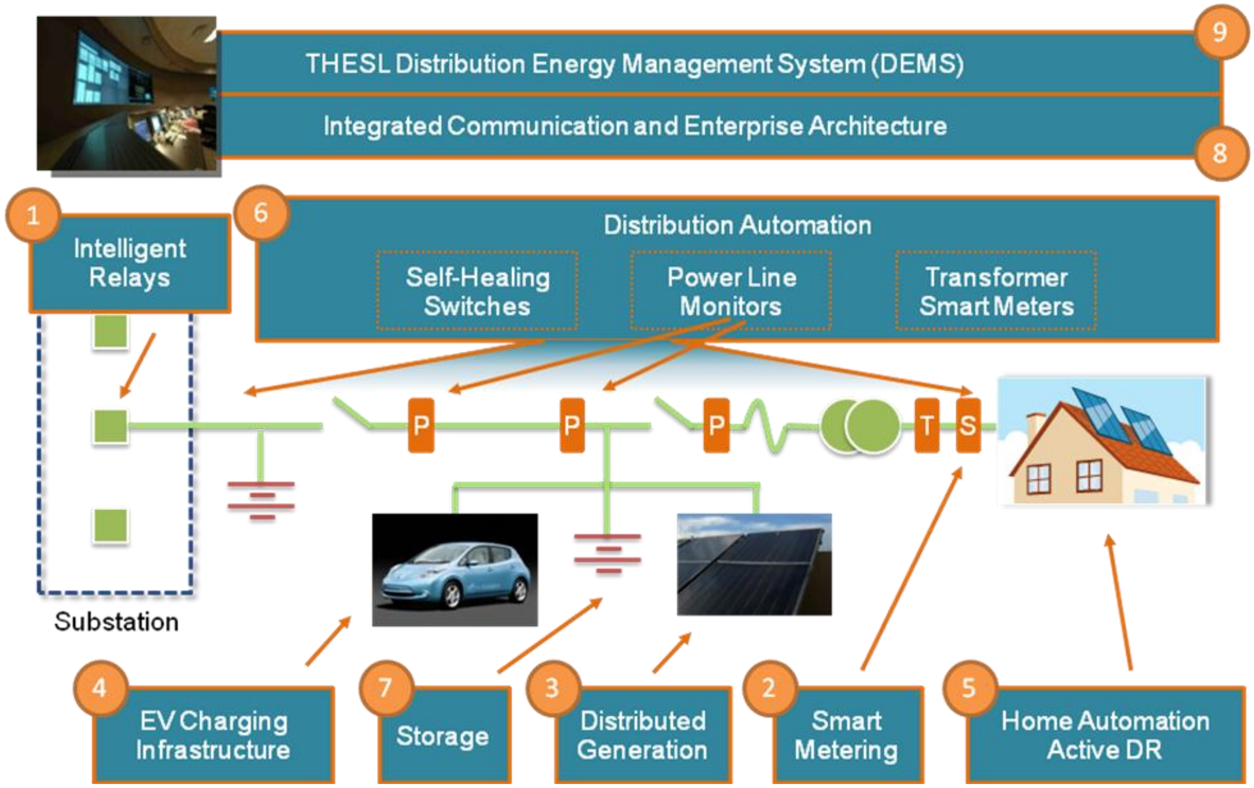
4. Discussion of the enabling grid technologies needed to maximize the environmental potential for EV use in the province.

Key Message: Grid technologies that enable EV charging and connectivity, without compromising the integrity of electricity supply and service to other customers, will be needed to maximize the environmental benefits of EVs in Ontario. Technologies that can be used to encourage and facilitate off-peak charging will be particularly important.

Grid technologies could also be used to draw power from EV batteries during peak periods under extreme circumstances, such as brownouts, system-wide or localized power surges, or if a neighbouring jurisdiction declares an emergency.

Smart Grid technology deployment is viewed as a critical step to providing robust control over EV charging. "Smart Grid" refers to the application of information, communications and technology to optimize the electricity infrastructure, its operation and its management. In effect, a Smart Grid inserts a level of intelligence into the distribution system, to increase the degree to which power and distribution systems are flexible, secure, reliable, efficient and safe.[15] "Intelligence", in the context of the Smart Grid, is the ability of circuits or points along circuits to reconfigure automatically when an outage occurs and quickly reroute power to customers.[16]

Figure 7: A schematic of Toronto Hydro-Electric System`s (THESL) Smart Grid, in the context of EV connectivity[17]



1. Intelligent Relay – Relays are electrically operated switches located within substations. Relays protect transmission and distribution lines by quickly responding to faults and overload conditions. Relays are made intelligent by adding microprocessors, which add security, increase functionality, decrease maintenance and improve data storage capabilities. A substation is a subsidiary station within the electricity distribution system, which serves to alter voltage levels using transformers. By adding intelligence to this point in the grid, remote monitoring, near real-time data reporting and optimized performance can be achieved.

2. Smart Metering – A Smart Meter is like a conventional electricity meter that measures the amount of electricity a home or business consumes, but with added intelligence that provides for energy demand and time-of-use data to be monitored. Smart metering systems facilitate billing based on demand during peak, mid-peak and off-peak periods. This can provide consumers with information needed to better manage their energy use.[18]

3. Distributed Generation – The generation from numerous small energy sources, such as residential rooftop solar panels, produces intermittent generation and bidirectional power flow. The components of the Smart Grid allow for the monitoring of this intermittent flow and dispatch of power at the levels and times required by demand.

4. EV Charging Infrastructure – The Smart Grid allows for EV charging infrastructure to communicate with the distribution network and manage metering, billing and accounts. With vehicle to grid (V2G), the vehicle can also provide electricity from the battery back to the grid.

5. Home Automation Active Demand Response –Smart appliances and home area networks (HAN) apply intelligent controls within the home to collect information on energy use (e.g., faults, scheduled use based on peak or off-peak hours etc.). Through home automation, response can also be dispatched according to the level of demand detected by the intelligent controls.

6. Distributed Automation – This is a term that describes the interaction of the following components:

    a. Self-healing switches – Intelligent switches can automatically detect faults in the system and subsequently reroute power to isolate the point of failure and service the customer while also restoring the fault. Communication among switches and the ability to respond to faults, significantly improving reliability, is why these points are termed, “self healing”.

    b. Powerline monitors – Distributed generation, small scale generation and EV charging can cause power flow to be constant, bidirectional or intermittent. Monitors within the distribution lines can account for these variable flows in order to preserve power quality, identify and report outages or faults, confirm restorations and monitor real time impacts.

c. Transformers and transformer Smart Meters – Smart Transformers enable operators to control power flows. By installing Smart Meters on transformers, power quality can be maintained (despite power variations due to distributed generation and EV charging), outages can be detected and reported, restoration of faults can be confirmed and real time effects of time-of-use rates can be monitored.

7. Storage – Energy storage within the electricity distribution system is very important in the event of high demand, fluctuating supply and outages. Sufficient storage provides for power quality mitigation, load-leveling, spare capacity and buffering to mitigate power intermittency that can result from distributed generation and EV charging. In some cases, the batteries in EVs can be sources of energy storage. Currently, Toronto Hydro uses flywheels and large batteries to service its ever growing storage needs.

8. Integrated Communication and Enterprise Architecture – Providing overarching communication between the Smart Grid components listed above is the Integrated Communication and Enterprise Architecture. It allows for cyber security and data management.

9. Toronto Hydro's Distribution Energy Management System (DEMS) - Using the centralized body of intelligence (Integrated Communication and Enterprise Architecture), energy distribution can be managed by the Distribution Energy Management System (DEMS). This system balances supply and demand while monitoring and controlling the system.

Combined, the component technologies of the Smart Grid allow utilities to improve the reliability of electrical service by responding to outages with increased efficiency. Customers can also make more informed decisions to optimize their energy use and associated expenses.

Areas where people work (and park) during the day are expected to be among the early venues for *public* EV charging infrastructure. Charging during peak hours is expected to take place in these public charging zones, supporting the commuting population during the day. Fast charging services (Level 3) are expected to dominate in the public context over the long term. Infrastructure for *private* charging may be better suited to off-peak, overnight charging at the home of an EV owner or at a parking facility for vehicle fleets. Level 1 and Level 2 charging is expected to be used predominantly in the private charging context.

The impact on the grid for an hour of charging may be as much as 5-17 times higher (in kWh) for vehicles charged at Level 2 or Level 3, than for the same number and type of vehicles charged using Level 1 connections. The rate at which electricity is delivered to the vehicle using these faster charging systems is expected to lead to higher instantaneous loading conditions. Therefore, the level of demand for charging infrastructure will be different for public settings than in private neighbourhoods.

The introduction of "grid-aware" charging stations that adjust power levels in real-time, according to conditions detected through communications with the local utility, may also be used to manage the risk of system overload.

5. Implications of increasing EV use in the context of other government objectives relating to energy and environment in Ontario

Incorporating EVs into Emissions Offsets Programs in Carbon Cap-and-Trade Systems
The ability of fleets to recover the costs of EV technologies is limited, which discourages the uptake of these vehicles. The monetization of reductions in GHG emissions resulting from the use of EVs would allow adopters to recover some initial expense and improve their business case. A GHG emissions pricing system could be linked to the development of protocols for monitoring and reporting mobile emissions. Such a system needs to be compatible between jurisdictions across which Ontarians travel (such as across provincial and national boundaries) to ensure price parity across markets. For those companies that exceed the benchmark or are early adopters, emissions offsets can act as a financial incentive for future efforts.

It is unclear at this time given the evolving picture of cap and trade schemes in Ontario such as the Western Climate Initiative, to what extent (if at all), private firms will be able to take credit and "own" the environmental attributes of emissions reductions achieved as a result of adopting electric vehicles. This is a policy question facing the Government of Ontario as it proceeds with negotiating the rules governing private firms in Ontario relating to WCI and other evolving cap and trade programs.

Implementing System-Wide Infrastructure Upgrades
Electric mobility could become a significant part of the transportation system in Ontario. Therefore, in addition to the strategic, near-term improvements to the electricity distribution systems to accommodate early adoption of electric vehicles, broad-scale upgrades to aging electricity infrastructure are also necessary.

Conservation and Demand Management (CDM) Targets for Ontario
In March of 2010, the Minister of Energy and Infrastructure issued a directive to the Ontario Energy Board with regard to electricity conservation and demand management (CDM) targets to be met by local distribution companies (LDCs). The targets include a requirement to achieve reductions in electricity consumption of 6,000 GWh and reductions in peak provincial electricity demand of 1,330 MW over a four year period beginning January 1, 2011.

As EVs increase market penetration, their demand for electricity will increase – the impact of EV penetration on rising demand for electricity must be considered by the LDCs responsible for designing CDM programs and by the OEB for allocating targets among the LDCs. The impact of EV penetration on peak reduction targets will depend on measures taken by the government and LDCs to encourage off-peak charging.

Raw and Auxiliary Material Extraction
Primary metals are extracted from the earth for use in the manufacture of vehicles and vehicle parts. Extraction involves mining processes that can release hazardous metals into the air, land and water, as well as emissions of CACs and GHGs. The cost of acquiring certain metals required in EV batteries, and the possible scarcity of supplies, could lead to unbalanced supply chains. Such an imbalance could introduce geopolitical issues similar to those surrounding oil (used in conventional vehicles). The use of secondary (recycled) metals can ease the demand for new primary resource mining and enable more sustainable use of available reserves (or identified resources).

Lead: Significant levels of secondary lead (i.e., recycled lead) are used in the production of lead-acid batteries, displacing the demand for primary lead extraction and processing. The environmental impacts of lead recycling are notably lower than those of primary production processes.[19]

Nickel: Nickel can be obtained from primary extraction operations and from recycled steel. Primary nickel refining produces SO_x and NO_x emissions, but recycled nickel production produces fewer emissions. In addition to the nickel in nickel-cadmium, nickel metal-hydride and sodium-nickel batteries, other hazardous metals and low-alloy steels are present. EVs with nickel-based batteries may, therefore, be associated with more environmental impacts during the extraction phase of the lifecycle, compared to conventional vehicles that do not employ nickel-based batteries.[20]

Lithium: Known lithium reserves are most abundant in Bolivia, Chile, Argentina and China, with worldwide reserves totalling over 13 million tonnes.[21] The concentration of a valuable resource can give rise to geopolitical issues. The long-term supply of lithium has been questioned and compared to “peak oil”. However, according to the U.S. Geological Survey, lithium reserves and undeveloped resources currently exist to meet the coming decades’ demand.[22] Lithium extraction is energy intensive, but the impacts are not as significant as those associated with the extraction of nickel or lead.

Disposal/Recycling
When a vehicle reaches the end of its useful life, its components are dismantled and disposed of. Vehicle components may be recycled, directed to landfill or directed to waste storage. Some components can present health hazards if they enter the general waste stream. However, at the end of normal EV battery life, 70 to 80 per cent of rated capacity remains. As an alternative to recycling or disposal, batteries that have reached the end of their useful lives within EVs can be used for stationary electric storage applications. Considering post-vehicle applications for EV batteries could potentially reduce costs to the user, while extending the useful life of the valuable battery technology. Possible applications for “second-life” batteries include storage of intermittently produced, renewable power (e.g., from photovoltaic and wind power), back-up power supply, uninterruptable power supply and load leveling for the electricity grid.[23]

Appendix A

Grid-response modeling simulation was conducted using Toronto Hydro Electric System Limited's (THESL) Electric Vehicle Demand Forecasting Model (hereafter referred to as, "the THESL Model" or "the model"). The model estimates loading levels as a result of EV charging and electrified transit use within City of Toronto boundaries. The scenarios applied to the THESL Model were developed by Pollution Probe.

Combined, the scenarios and the THESL Model take the following factors into account:

- Year;
- Human population growth in the city;
- Vehicle ownership trends and rates;
- Commuting patterns;
- EV penetration/adoption rates;
- Vehicle types and the evolution of available models;
- Battery capacity and technological improvements over time;
- Charging levels and times; and
- Future levels of electrified transit operation and ridership levels.

The outputs of the THESL Model were input to analyses conducted by Pollution Probe to investigate the following:

- Energy supply impacts – comparing EV charging load demand with existing and projected system capacity; and
- Emissions accounting – calculating the potential GHG and CAC emissions reductions that could be achieved by displacing use of conventional ICE-powered vehicles with EVs.

Results from the model were applicable to the City of Toronto, and were scaled up using the total number of vehicles for Ontario, as reported by Statistics Canada. A growth rate of 2% per year of the vehicle ownership was assumed going out to 2030. This provided for an estimate of the total additional electricity load from EVs above the baseload and peak without EVs, as well as the potential for emissions reductions for the Province of Ontario.

From an emissions perspective, reductions offered by EVs represent the quantitative difference between the emissions produced at the tailpipe of an ICEV and the emissions produced through electricity generation for the charging of an EV that travels the same distance in a given scenario year. Any EV assumed to be in use in a given year is assumed to replace an ICEV of equivalent size (for example a gasoline-powered sport utility vehicle would be replaced by an electric sport utility vehicle). Emissions considered are "tank to wheel", that is no upstream emissions from the production of gasoline fuel, diesel fuel or natural gas are considered.

Appendix B

A number of EV models have been developed for utility applications – some examples are listed below.

ZAP, makers of the electric personal vehicles listed above, also makes the ZapTruck XL and the ZapVan Shuttle. The ZapTruck can be used in warehouses, factories, farms, campuses and for municipal operations where moderate movement of cargo or materials over short distances is required. The Shuttle can carry passengers or a combination of passengers and cargo. Both vehicles have a maximum speed of 40 kilometres per hour and a range of 50 kilometres. Micro-Vett, a European leader in electrically powered vehicles, manufactures a variety of utility EVs for the purpose of moving goods and people, as well as collecting garbage. These vehicles have ranges between 70 and 150 kilometres based on urban duty cycles, a maximum speed of 60 kilometres per hour and cargo load capacities over 1,600 kilograms.[24] In 2009, the only U.S.-built electric truck offered for sale in the U.S. was the ZeroTruck, made by Electrorides Inc. It is a Class 4 (medium duty) delivery truck with full highway capability.[25] In addition, Ford Motor Company is developing a fully electric TransitConnect commercial van in collaboration with Azure Dynamics, for release in 2011 in Canada and the U.S.

Figure 8: ArvinMeritor/Unicell Quicksider Electric Van used by Purolator Courier Ltd.[26]

Automotive systems providers, ArvinMeritor and Unicell, have collaborated to develop the Quicksider electric delivery van. Eventual production of this vehicle is planned after a successful pilot program. The payload is 2,560 kilograms and the range during typical use is approximately 65 and 100 kilometres in the winter and summer, respectively.[27] Notably, the business case supporting the use of the Quicksider is based mainly on labour savings and productivity resulting from its low-riding design – a feature facilitated by its wheel-hub electric motor drive system.[28] Smith Electric Vehicles' Newton is the world's largest electric delivery truck. It can travel up to 160 kilometres per charge and has a payload of over 6,300 kilograms.[29]

In the heavy vehicle class, Balqon Corporation produces the Nautilus E30 and E20 as well as the Mule M-150. The Nautilus E30 is designed to transport containers in terminal or on-road applications. It can carry up to 60 tonnes of cargo over a reduced range (from 100 kilometres unloaded, to 50 kilometres fully loaded) and at a lower maximum speed (70 kilometres unloaded).[30] The E20 model is an electric terminal tractor designed to transport containers at ports and in warehouses. It has the same cargo capacity and range as the E30, with a slightly lower maximum speed (40 kilometres per hour unloaded).[31] The M-150 is a newly released model and is to be used in on-road applications. It has a seven tonne cargo capacity and extended range (up to 240 kilometres unloaded).[32]

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