EV Batteries Value Proposition for Ontario's Electricity Grid and EV Owners

A Preliminary Cost and Benefit Assessment | Full Report

July 2020

STRATEGIC POLICY ECONOMICS

PLUG 'N DRIVE

Executive Summary

With the advent of electric vehicles (EVs), it is becoming apparent that the purchase of an EV is more than just the purchase of a new car. What distinguishes EVs from traditional internal combustion engine (ICE) vehicles is that, in lieu of a gas tank, EVs contain large batteries that store electric energy and use that stored energy to power the vehicle when it is being driven.

Electricity system operators are increasingly looking to battery storage solutions to help manage the evolving complexities of the system and support the integration of distributed energy resources (DERs). However, battery energy storage is expected to remain costly for many years, delaying these benefits.

This report examines the potential for using EV batteries as energy storage to contribute to Ontario's electricity system, and assesses the value that EV owners and others may realize by supporting such use.

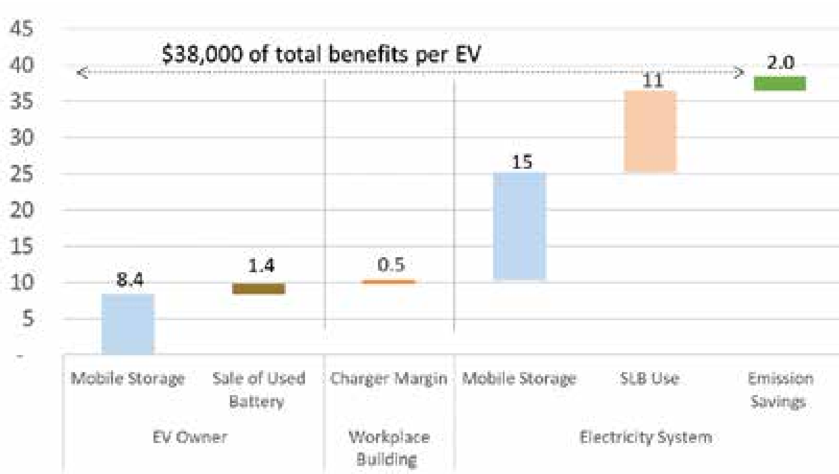
The potential to support the electricity system stems from two factors: (1) most EV owners do not make use of the full storage capacity of their EV battery; and (2) the batteries inside EVs are paid for when an EV owner purchases a vehicle, suggesting that any unused storage capacity could be a low-cost storage option for the electricity system. As a result, EV batteries can be leveraged for two applications:

1) ***Mobile Storage:*** When EV batteries are in vehicles, they can be used as potential mobile storage options for the electricity system when the vehicles are parked at commuters' workplaces. The best way to capture the value of mobile storage from a large number of commuter vehicles is at workplaces categorized as Class B electricity consumers.
2) ***Second Life of Batteries (SLB) as stationary grid storage:*** When EV batteries are no longer suitable for vehicle use, they could be repurposed as electricity system storage solutions.

Using a battery for mobile storage over an EV's useful life of 13 years and then a 10-year second life application as grid storage, an EV battery could create up to $38,000 of value. This value would be realized by EV owners, workplace buildings, and the electricity system in distinct ways as shown in Figure ES1. The majority of the value created would accrue to the electricity system, much of which is from access to low-cost storage, and could amount to over $129 million/year by 2035 assuming a conservative EV forecast.

Figure ES1: Lifetime Benefit of Using EV Batteries in the Electricity System

($000s per EV purchased in 2035)



1) **EV Owners** can derive value from providing both mobile storage services and selling their used batteries for second life applications:

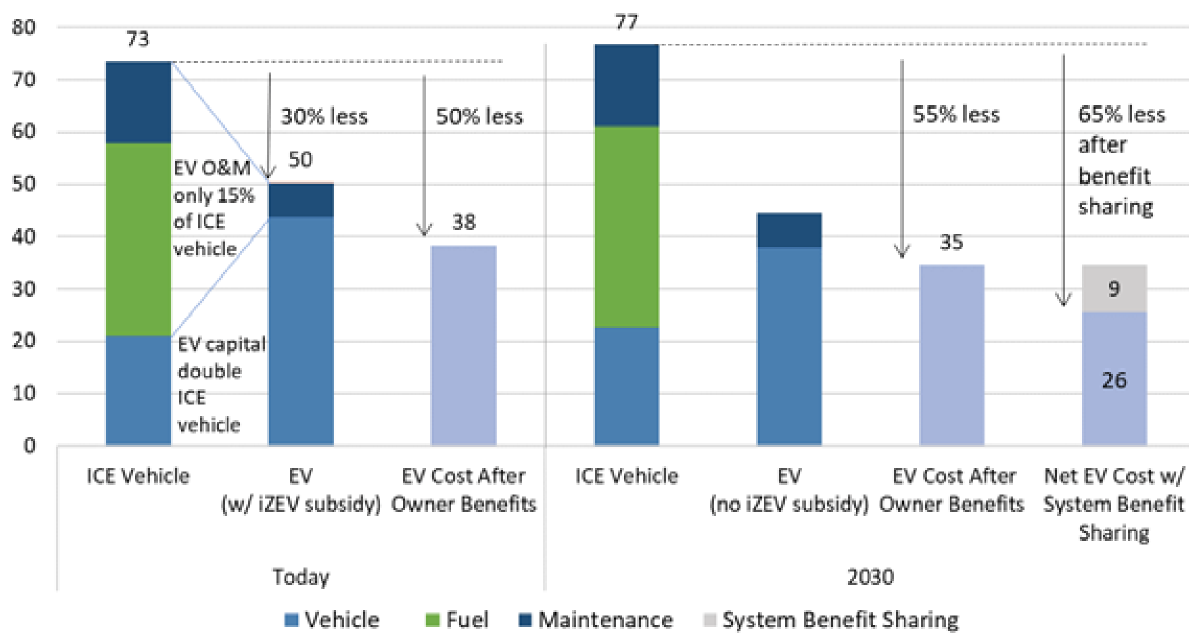
   a. ***Benefit from providing mobile storage*** – By charging EVs at home and at night using Ontario's inexpensive and virtually carbon-free base-load electricity supply, the cost of electricity under the current residential rate structure can be as low as $70/MWh. Under the potential federal Clean Fuel Standard (CFS) the cost could be reduced to practically zero if the CFS fully credits the carbon benefit of low emissions electricity at the targeted federal 2022 carbon price of $50/tonne. If EV owners sell this electricity to their workplace building at a 20% premium to the residential rates, EV owners could earn $8,400 over a 13-year life of their vehicle. Over 80% of this value to EV owners is estimated to arise from the assumed federal CFS.

   b. ***Benefit from sale of used EV battery*** – EV owners could sell the battery at the end of its driving life to earn up to 20% of the battery's initial purchase cost – almost $1,350 in 2030.

While the initial capital cost of an EV is currently over double that of an equivalent gasoline vehicle, over a 13-year lifetime and taking benefit of the Federal $5,000 EV rebate, EV ownership could already be 30% less costly than traditional cars. Adding the benefits from mobile storage and an EV's SLB could make the lifetime cost of owning an EV 50% less expensive than owning a new ICE vehicle today. This comparison is provided in Figure ES2 and will improve to a 55% cost advantage over the next 10 years as battery costs reduce. Furthermore, if 55% of the $28,000 electricity system benefit is shared with EV owners, the cost of EV ownership could drop to almost one third of an ICE vehicle by 2030 – a cost differential that has the potential to be a game changer for EV adoption.

Figure ES2: EV Lifetime Ownership Cost Advantage

($000s/vehicle)



2) **Workplace Buildings** can save on electricity costs by purchasing electricity from EVs parked on their premises at less than 60% of the cost of their normal higher daytime electricity rates. This model applies to Class B businesses, whether operating under general service or TOU rates. Commuter

patterns do not offer similar mobile storage benefits to Class A electricity consumers as most system peaks occur after a commuter’s workday ends. Upgrading to the Level 2 bidirectional charger required for mobile storage could cost $669/year. A markup on the costs of the charger could be easily allocated to create a positive business case to install these bidirectional chargers.

3) **The Electricity System** can obtain $28,000 worth of benefits over the 13-year life of every EV participating in mobile storage and the 10-year life of SLBs for grid stationary storage.

   a. Mobile storage reduces daytime demand, avoiding the use of natural gas, and makes more efficient use Ontario’s base-load hydro and nuclear resources. Funding their use at night could generate $15,000 of worth savings per participating EV. By lowering daytime greenhouse gas (GHG) emissions, each EV could avoid $2,000 of carbon prices for ratepayers.

   b. Second life EV batteries are expected to be 65% less expensive than brand new batteries. Integrating these into DER solutions could provide lower cost options for displacing natural gas-fired generation. Each EV could enable $11,300 of savings for the electricity system when integrating DER resources to reduce Ontario’s GHG emissions.

The significant amount of system benefits could be shared with either EV owners, workplace buildings, or both in order to enable business models that would unlock this value.

Recommendations

To maximize the benefits of EV batteries for the electricity system, proponents of EVs should consider:

1) ***Developing a business model*** whereby the value elements described in this report can be best used to optimize EV adoption and further enhance benefits to the electricity system. Business model considerations could include grid ready EV batteries, updated warranty considerations, and more aggressive TOU pricing.
2) ***Advocating for the federal CFS*** to accurately credit the GHG emission content of the electricity system at the specific times when EVs are being charged.
3) ***Developing a more refined forecast of EV adoption*** in Ontario over the next five to 10 years, to reflect not only the implications of using EV batteries in the electricity sector, but also trends such as changing consumer buying behaviour due to concern over climate change and plans in the auto sector to move away from ICE vehicle production. Given the benefits of EV adoption, other infrastructure recommendations may be warranted such as building code requirements for enabling future integration of residential EV chargers and bidirectional chargers in the work place.
4) ***Advocating for the low-GHG emission*** solutions to Ontario’s electricity capacity needs that are required to enable the value of the CFS. The forecast for Ontario suggests that increased natural gas-fired generation may eliminate EVs as a GHG emission reduction option.

Contents

List of Figures

List of Tables

1. Introduction

With the advent of electric vehicles (EVs), it is becoming apparent that the purchase of an EV is more than just the purchase of a new car. What distinguishes EVs from traditional internal combustion engine (ICE) vehicles is that, in lieu of a gas tank, EVs contain large batteries that store electric energy and use that stored energy to power the vehicle when it is being driven.

Electricity system operators are increasingly looking to battery storage solutions to help manage the evolving complexities of the electricity system and support the integration of other types of distributed energy resources (DERs). Effectively integrated, DERs can offer cost benefits by making more efficient use of grid infrastructure, and by reducing the GHG emissions from natural gas-fired generation.[1] However, battery energy storage is expected to remain costly for many years, delaying these benefits.

This report examines the potential for using EV batteries as energy storage to contribute to Ontario's electricity system and assesses the value that EV owners and others may realize by supporting such use.

The potential to support the electricity system stems from two factors: (1) most EV owners do not make use of the full storage capacity of their EV battery on a daily basis, much like ICE vehicle owners don't use up a full tank of gas every day; and (2) the batteries inside EVs are paid for when an EV owner purchases a vehicle, suggesting that for little incremental cost, any unused storage capacity within EV batteries could be a low-cost storage option for the electricity system when EV owners are not driving their vehicle or when they no longer want it.

The value EV owners can receive from providing these services has the potential to increase consumer adoption of the vehicles. The upfront cost of EVs is considered to be one of the main prohibitions to their widespread adoption, despite their potential to have a lower total cost than ICE vehicles.[2] With Ontario's recent reduction to subsidies that were designed to address the upfront cost of EVs, alternative mechanisms to deliver value to EV owners are desired.[3]

This report describes the benefits of using EV batteries to unlock value elements in two distinct ways:

1) ***Mobile Storage:*** When EV batteries are in vehicles, they can be used as potential mobile storage options for the electricity system when the vehicles are parked at commuters' workplaces.
2) ***Second Life of Batteries (SLB) as stationary grid storage:*** When EV batteries are no longer suitable for vehicle use, they could be repurposed as electricity system storage solutions.

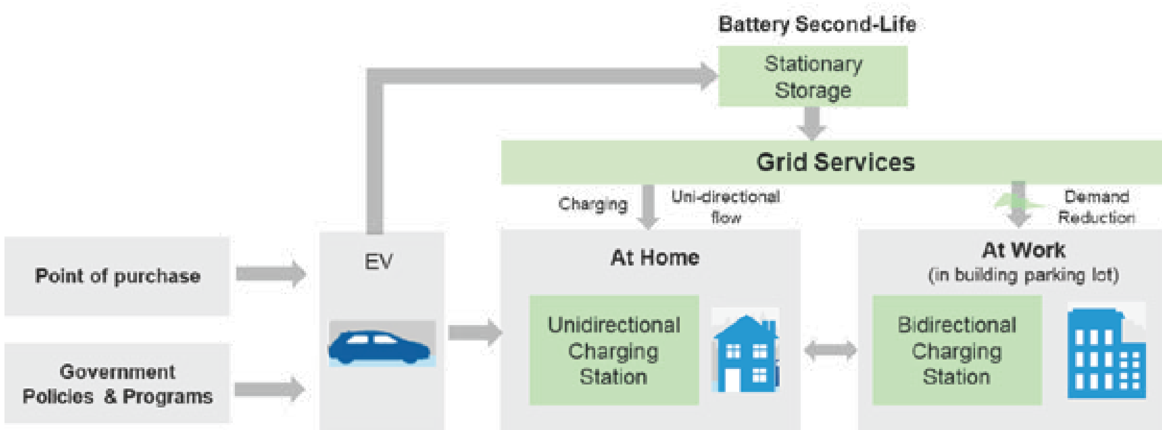
The value elements to be obtained from these two applications include those for EV owners, workplace building owners of charging infrastructure, and the electricity system itself. With these benefits understood, future efforts can examine how the value elements could be captured by business model options to increase EV adoption and reduce the need for fossil-based fuels in the electricity grid.

[1] CCRE, 2019.
[2] Pollution Probe, 2019.
[3] CBC, 2018.

1.1. Overview of Concept

The value premise for both mobile storage and stationary storage is to use low-GHG emission base-load generation at night when electricity prices are low to displace high GHG emission generation from natural gas plants during the day when electricity prices are high. The concept for creating the value is illustrated in Figure 1.

Figure 1: EV Battery Value Elements



a) Mobile Storage

Mobile storage is the use of EV batteries to transfer energy from one location to another, and requires smart bidirectional chargers at the discharge locations. For the purposes of this report, mobile storage is taken to mean only the act of charging a vehicle at one location and discharging its energy at another.

Patterns of usage for EV owners suggest that vehicles can charge at home overnight using their unidirectional charger at lowest TOU prices, and then discharge at work during hours of peak demand (and highest TOU prices). The specific scenario examined in this report is how commuter EVs can be used by their workplace parking location. Parked EVs can be used as a low-cost energy supply to workplace buildings. The price difference between the regulated electricity rates for these locations and at these hours creates a source of margin for EV owners and businesses that could make mobile storage economically viable.

EV owners also benefit from government policies and programs, such as the federal purchase subsidy (the iZEV incentive program) which gets applied at the point of purchase, and also possible future Clean Fuel Standard (CFS) policies that may give EV owners credit for charging vehicles when non-emitting generation sources are supplying the grid.[4]

The electricity system can also gain value from mobile storage by using EV batteries for daytime demand reduction, which could reduce the need for natural gas-fired generation and hence the purchase of natural gas for that purpose.

[4] Federal purchase incentive based on Government of Canada Federal CFS Proposed Regulatory Design, 2019.

b) Stationary Grid Storage Using SLBs

Batteries that have reached the end of their useful vehicle life can be given a second life in grid applications, meaning that EV owners will be able to sell their used EV batteries to grid storage operators and recoup some of their remaining value. Many car manufacturers including Hyundai, Renault, Nissan, Toyota, and GM are exploring pilots today for SLBs in grid storage applications.[5]

The value produced from these two applications can be realized by the stakeholders involved: EV owners could be compensated for the use of their batteries by their workplace and gain additional value from their used EV battery at the end of its useful vehicle life; the workplace buildings receiving power from the EVs get a return on their investment in EV infrastructure and save on electricity costs; and the electricity system can benefit from lower-GHG and lower-cost storage options.

1.2. Structure of Report

This report is structured to convey how the study was carried out, explain how the scenarios and potential benefits were analysed, and show how the concept may deliver value to stakeholders:

- The **methodology** used in this report is discussed in Section 2, which provides the key sources used for market sizing and costing, and reviews the high-level assumptions.
- The **electricity system considerations** relevant to the use of EV batteries as mobile storage are discussed in Section 3. This section characterizes Ontario's electricity rate structure, and identifies viable methods by which commuter EVs can contribute to the electricity system and enable mobile storage benefits.
- The **value to EV owners** is outlined in Section 4, which compares the lifetime cost of EV ownership to conventional ICE vehicles.
- The **value to workplace buildings** that host mobile storage is outlined in Section 5, demonstrating the electricity cost savings available at peak times.
- The **value to the electricity system** is discussed in Section 6, which highlights the grid benefits from reducing costs to decarbonize the system, and identifies the total GHG emissions that may be saved.
- The **summary** of the results is provided in Section 7.

[5] Greener Ideal, 2018.

2. Methodology

Strategic Policy Economics (Strapolec) was engaged to conduct this study. The methodology deployed in preparing this report involved three primary activities:

1) Secondary research was conducted on Ontario's electricity rate structure, the market size for mobile storage use and second-life batteries, and the costs of vehicles, batteries, chargers, and repurposing of second-life batteries;

2) Electricity system modeling was performed to optimize the mobile storage benefits based on Ontario's TOU electricity pricing scheme; and

3) Discussions were held with Plug'n Drive and the Ontario Independent Electricity System Operator (IESO) to confirm the approach and relevance of initial results.

This section describes the key sources used to inform the results in this report, and provides a high-level summary of the key assumptions.

2.1. Key Sources

This report undertook research and analysis in five main areas:

1) Vehicle characteristics, costs, and forecast

   Cost and attributes of vehicles, batteries, and chargers are based on data from Plug'n Drive, the EV Database, and BC Hydro. Bidirectional charger costs are based on National Renewable Energy Laboratory (NREL) 2017. The EV forecast is based on IESO's Annual Planning Outlook (APO) 2019 and International Energy Agency (IEA) 2019 and is considered conservative.

2) Use of batteries in second life

   Cost of battery repurposing is based on Element Energy 2019. The owner margin for sale of used batteries is based on Debnath et. al. 2014. Lazard's Levelized Cost of Storage Analysis 2017 and Strapolec's Renewables-Based DERs in Ontario 2018 were used as a basis to compare the cost of new batteries.

3) Commuter patterns

   Commuter patterns and Ontario's market for mobile storage are based on data from Statistics Canada, including home-to-work commute distances, work hours and number of employees by size of businesses.

4) Electricity system rate structure

   Electricity system considerations are based on the Ontario Energy Board (OEB) electricity rate structure, IESO hourly Ontario electricity price (HOEP) data, IESO monthly Global Adjustment (GA) costs, IESO market rules and Strapolec's database of electricity use patterns. IESO data downloaded from IESO website.

5) Modelling electricity system impacts of battery usage

Strapolec's Ontario electricity system model is used to optimize EV battery use for mobile storage. The demand profile is based on IESO actuals 2015-2017, downloaded from IESO website. Forecast developed based on IESO 2016 LTEP long-term hourly demand forecast.

2.2. High-Level Assumptions

Several assumptions are made to simplify the analysis. Further details on these can be found in Appendix A: Assumptions for EV and ICE Vehicle Cost.

1) Only commuter battery EVs (BEVs) are considered, meaning that plug-in hybrid vehicles, fuel cell EVs, trucks, and fleet vehicles were excluded from the analysis. Lithium-ion (Li-ion) batteries are assumed to have a round-trip efficiency of 85%.[6] EV owners are assumed to have a charger and smart charging software installed in their home.

2) Commercial parking lots are assumed to already be planning for having Level 2 EV chargers, and so only the incremental cost of adding the bidirectional chargers in place of 'regular' Level 2 chargers has been modelled.

3) The same commute pattern is assumed for all workdays, allowing the use of a single-day model. Two seasonal temperature impacts on battery range were used, a sample winter day and a sample summer day.

4) With regards to the electricity system, the network is assumed able to support EV home charging, and no grid connection fees are applied for EV mobile storage used behind-the-meter (BTM). EVs are assumed to charge at night using virtually GHG emission-free electricity, an assumption that will remain valid until Pickering Nuclear Generating Station retires after 2024.

5) Financial assumptions include:

    a. A carbon price of $50/tonne added to ICE vehicle fuel in 2030, reflecting Canada's currently planned carbon price for 2022.

    b. A $50/tonne carbon price is also used to determine the value of CFS credits to EV owners, which is supported by the assumption that the energy used to charge EVs will be GHG emission-free.

    c. For energy, 0.10 cents/kWh is taken to be equivalent to $1/MWh.

    d. All numbers shown in this report are in CAD.

    e. An exchange rate of $1.30 Canadian Dollar (CAD) to $1.00 United States Dollar is used.[7]

---

[6] Strapolec, 2018.

[7] Based on Bank of Canada currency converter, 2019.

3. Electricity System Considerations

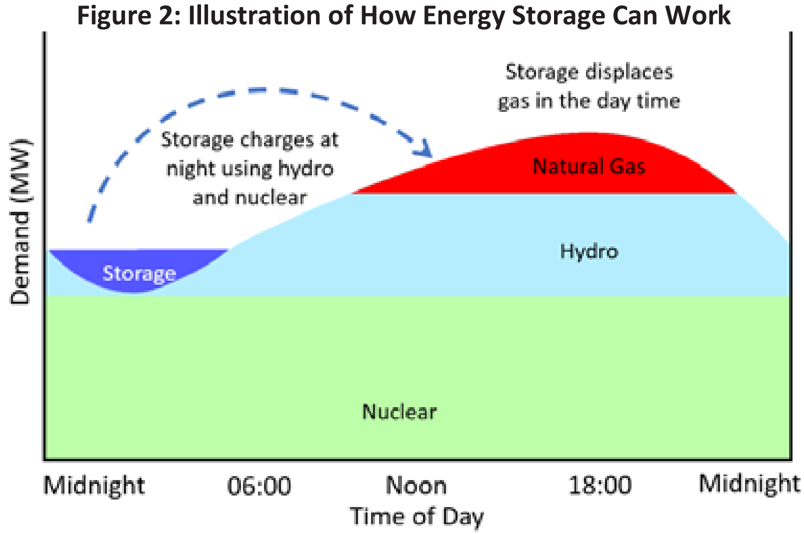
This section discusses the electricity system considerations relevant to using EV batteries for mobile storage. It characterizes Ontario's electricity rate structure as it may apply to different consumers, specifically Class A, Class B businesses, and residential consumers., and identifies viable methods by which commuter EVs could contribute mobile storage benefits to the electricity system.

3.1. Ontario's Electricity Price Structure

When EV batteries are charged overnight, they use the virtually GHG-free electricity that makes up Ontario's supply at that time, which is primarily made up of nuclear and hydro resources (Figure 2).

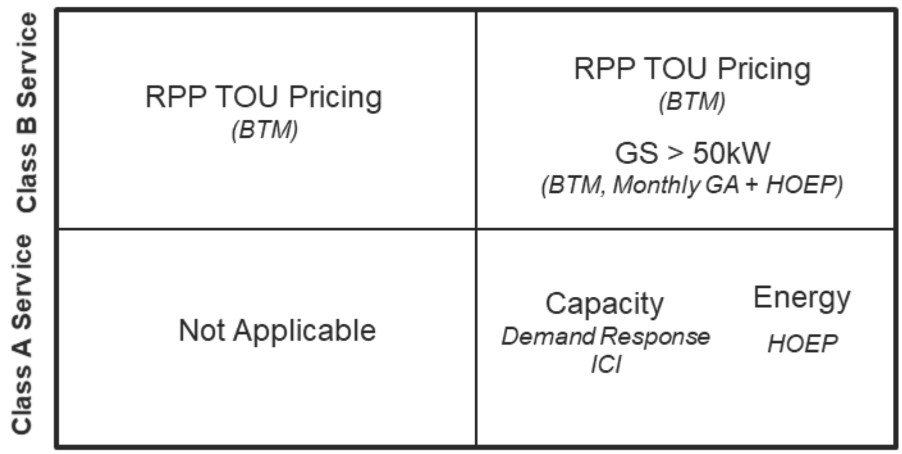
When parked in a workplace parking lot in the daytime, EV owners can allow for the discharge of their excess stored energy for use by the local workplace building or business. This typically occurs during times when the grid uses natural gas-fired generation to meet demand, allowing the workplace building to use clean electricity from the night instead of the carbon-intensive electricity available in that moment.

Figure 2: Illustration of How Energy Storage Can Work



The value of mobile storage is derived from Ontario's electricity pricing regime. Several pricing options straddle Ontario's electricity rate structure, as shown in Figure 3. These pricing mechanisms influence how EVs can provide value to various stakeholders, including EV owners and the grid itself.

Figure 3: Ontario's Electricity Pricing Structure



Ontario has two classes of electricity customers, Class A and Class B, with different electricity rates for each. Workplaces can be classified as either Class A or Class B, depending on the size of the load. Eligible Class A customers are those with a peak monthly demand over 500 kW and who have signed up to participate in the Industrial Conservation Initiative (ICI) program. Class B consumers include everyone else, both residential and commercial consumers with less than 500 kW of monthly peak demand.

Electricity costs for Class B consumers are based on energy consumption and are determined either by Ontario Energy Board's Regulated Price Plan (RPP) TOU electricity prices or, for customers with greater than 50kW peak demand, by the General Service (GS) electricity rates identified by the IESO for the GA and the HOEP.[8] For the purpose of at-home EV charging, the price that residential consumers pay for electricity is purely a function of the RPP TOU rates. No residential customers are eligible for Class A status.

Class A consumers pay their electricity bill through two components: capacity and energy. The capacity charge is based on their share of the total GA charged to all consumers, as determined by the proportion of the electricity consumed during Ontario's five peak demand hours in the previous year.[9] Class A customers could also choose to participate in the IESO's Demand Response (DR) program whereby the customer can be paid to reduce their demand when the IESO asks them to.[10] The energy charge is determined by the HOEP established by the IESO-administered energy market in Ontario.

The value that a workplace building would get from mobile storage depends on its rate class and the rate program it is eligible for.

3.2. Potential for Mobile Storage Benefits to Class A Customers

In theory, EV batteries could be available for customers to take advantage of the ICI and DR programs. However, worker commuting patterns are not consistent with the constraints of these programs,

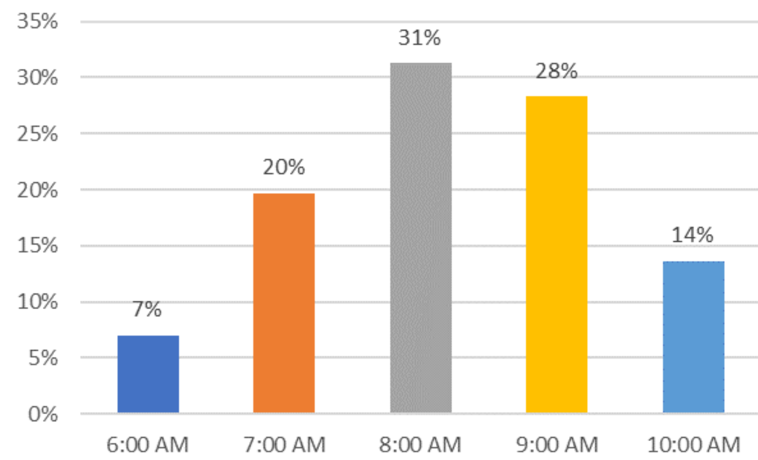
[8] OEB, 2019.

[9] IESO, Global Adjustment Class A Eligibility ,2019.

[10] Note that DR programs are not limited to Class A, but are analyzed for only this one case in this study.

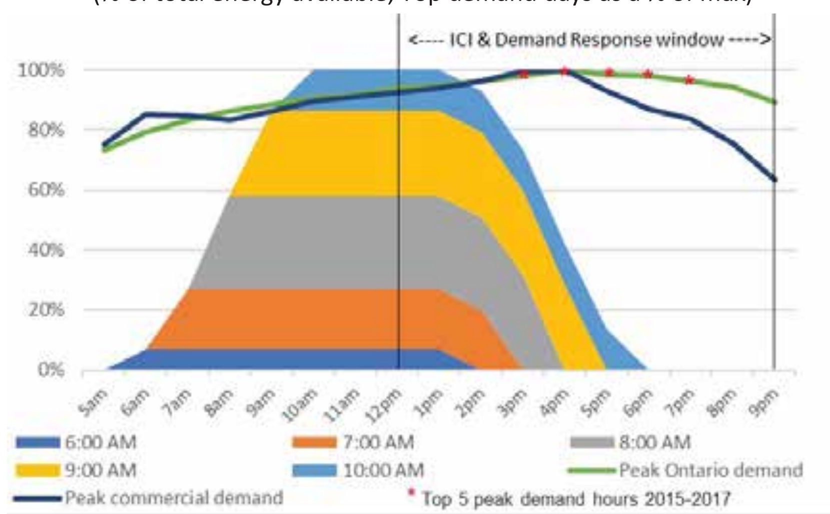
impacting the amount of value EV batteries could unlock for these customers. Most workers (80%) arrive at their workplace between 7am and 9am, as shown in Figure 4.[11]

Figure 4: Vehicle Time of Arrival at Work
(% of commuters considered)



If individuals are assumed to stay at work for eight hours, then any stored energy from their parked EV would be available to their workplace for that period. Figure 5 shows the net average electricity availability profile for EVs, based on the distribution of commuter driving patterns.

Figure 5: EV Storage Availability as a Function of Work Hours
(% of total energy available; Top demand days as a % of max)



[11] Commuters that arrive at work between 10 am and 5 am represent 16% of commuting vehicles and consist mainly of shift workers. Vehicles available to provide a discharge during this window are unlikely to benefit from electricity rate arbitrage (charge/discharge profile likely to be out of phase with electricity prices) and hence not used in the analysis. Vehicles are assumed to stay at work for 8 hours from the time of arrival (e.g. a vehicle that arrives by 9 am is available for discharge until 5 pm).

With the current market rules, worker commute patterns prevent EV owners and workplace buildings from providing capacity services through mobile storage. Benefits from the ICI and DR programs are contingent on aligning battery discharge with system peaks. Figure 5 above also shows the peak commercial demand, and the top five peak hours for which the ICI and DR programs are typically expected to operate. These peaks generally occur between noon and 9pm, with the main peak occurring between 5pm and 9pm after commuters leave work. Similarly, DR participation requires availability from noon to 9pm, part of which is outside of the usual 9am to 5pm work hours. In both cases, worker commuting patterns miss the window for benefits from these market rules and thus do not offer the ability for the grid to gain capacity value from mobile storage services.

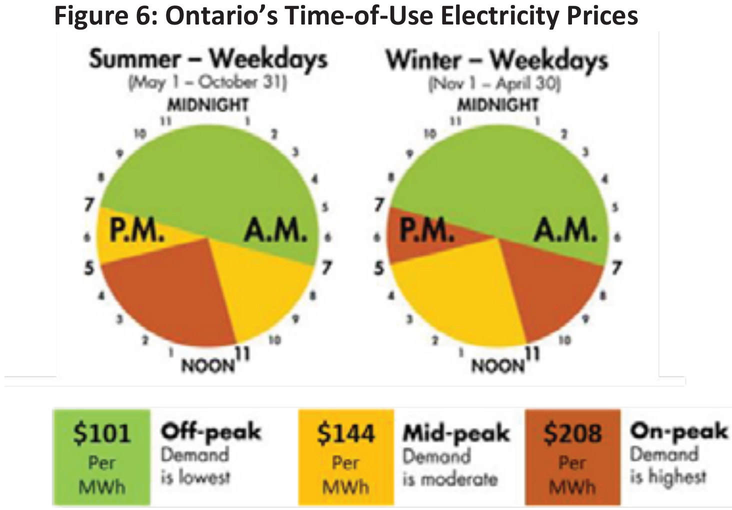
With these timing constraints, Class A mobile storage benefits may only be available by engaging in HOEP arbitrage. Unfortunately for this purpose, with the average daytime HOEP for 7am to 11pm on weekdays being $34/MWh, the HOEP is significantly lower than the Class B overnight TOU rate of $101/MWh, undermining any potential arbitrage benefit.[12]

Ultimately, current market rules and commuter driving patterns do not offer any mobile storage benefits through Ontario's ICI or DR programs.[13]

3.3. Pricing Arbitrage for Class B Customers

Mobile storage allows energy to be shifted from homes during the night to workplaces in the day. Because residential consumers are covered by the Regulated Pricing Plan (RPP), they can take advantage of the off-peak TOU rates to charge their EVs with inexpensive electricity overnight. Weekday TOU rates are structured as off-peak, mid-peak, and on-peak as shown in Figure 6.[14]

Figure 6: Ontario's Time-of-Use Electricity Prices



[12] Reflects average HOEP when large commercial natural gas-fired generation is operating between 7am and 11pm.
[13] Other pilot programs that do not rely on broad commuter driving patterns are being explored to determine if the use of EVs can enable ICI or DR benefits. These scenarios were not examined in this study.
[14] Figure modified from OEB, 2019.

Class B workplace electricity charges come in two forms: smaller businesses could be billed under the RPP TOU rates, while larger businesses with more than 50 kW of peak demand could be classified as general service customers who pay an average monthly GA rate plus the HOEP. The difference between the residential off-peak TOU rates and on-peak TOU or general service pricing creates the potential for electricity price arbitrage for BTM Class B storage devices.

There are two TOU pricing seasons, summer and winter, which change the time of day when peak TOU prices apply, as shown in Figure 6. In the summer, peak pricing occurs in mid-day when most vehicles are parked at work. In the winter, peak pricing occurs in the morning while cars are arriving at work and in the evening as they are leaving the workplace. This difference will warrant the implementation of different seasonally-dependent battery discharging strategies, which is discussed in Section 4. Beyond this three-peak structure, TOU pricing is independent of the hourly fluctuations in demand enabling daily arbitrage.

For general service customers, the GA charges vary month to month and the HOEP varies hourly. HOEP variations on any given day are not significant during the working day hours relevant to the commuter patterns that have been assessed. As the HOEP is currently less than 15% of the total charges, the main variation in pricing is in the form of the monthly average GA fluctuations. As a result, the potential for mobile storage benefits that can be consistently captured on a daily basis is similar to that offered by TOU workplaces, although some months may be more lucrative than others.

Mobile storage benefits are possible for Class B workplace buildings, regardless of their rate structure.

3.4. Residential EV Owner Electricity Pricing Arbitrage

The benefits to EV owners arise primarily from the ability to gain a margin from performing arbitrage on TOU pricing. Vehicles can be charged at home in the night-time using clean electricity, which is inexpensive due to the night-time Class B off-peak TOU rate.[15]

There are two additional benefits for EV owners:

- The Ontario provincial government currently provides an Ontario Electricity Rebate (OER) of 31.8% of the energy component of the residential electricity bill, lowering the cost of charging even further.[16]
- EV owners may be eligible for a CFS credit.[17] The CFS is a program proposed by the federal government to reduce GHG emissions from the fossil fuel sector, and is expected to come online

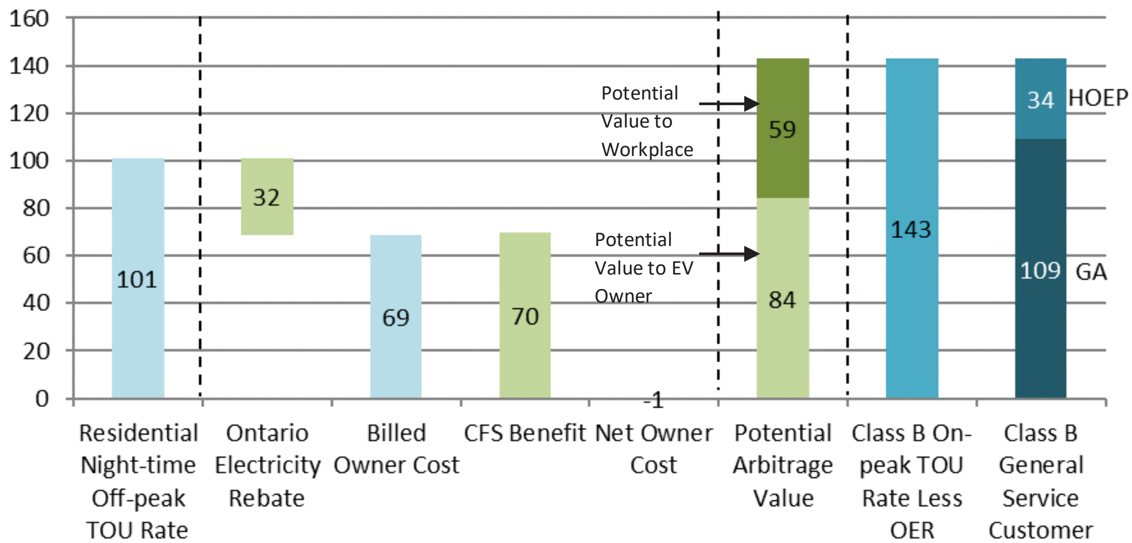
[15] Residential TOU rates based on OEB, 2019.
[16] Government of Ontario, 2019; IESO, Ontario Electricity Rebate to take effect on November 1, 2019.
[17] Government of Canada, Federal CFS Proposed Regulatory Design, 2019.

by 2022. Depending on how this is implemented, EV owners may be able to gain an electricity cost credit of up to \$70/MWh for their avoided GHG emissions when charging their EVs.[18,19]

The potential value of EV price arbitrage based on all of these elements is shown in Figure 7. When the residential TOU rate, 32% OER, and the CFS credit are taken into account, EV owners could be able to charge their batteries overnight at a cost of effectively \$0/MWh.[20]

Figure 7: Illustration of Residential EV Price Arbitrage Benefit Components

(\$/MWh)



In the daytime, EVs can discharge excess stored energy to the local building while parked at work. When they do so, the workplace building will pay them for that electricity.

If the workplace is subject to TOU electricity rates, the on-peak rate of \$208/MWh will be discounted by the OER to \$143/MWh. Coincidentally, the average GA for general service Class B consumers of \$109/MWh[21] added to the average daytime HOEP of \$34/MWh, yields \$143/MWh as well.[22] In both cases,

[18] 4.63 t CO_2/year of ICE vehicle GHG emissions / 20,000 km/yr = 0.232 kg of ICE vehicle GHG emissions per km. 0.232 kg/km of avoided emissions x \$50/t carbon price / 0.166 kWh per km EV fuel efficiency = \$70/MWh. Strapolec recommendations to Federal Government CFS plan, based on charging with virtually non-GHG emitting nuclear and hydro at night and displacing ICE vehicle use. Strapolec recommended that the IESO administer the CFS and as such would be able to easily compute the GHG emissions being generated by the least efficient marginal supply at the time of EV charging. In this manner, full CFS credits would be earned when the entire supply is virtually emission free. Strapolec identified this as the only method by which the CFS would achieve its stated objective.

[19] CFS benefit calculated assuming \$50/tonne is provided for the avoided GHG emissions of an equivalent ICE vehicle and reflects the Government of Canada's 2022 expected carbon price.

[20] OER rounded up from 31.8%, \$0/MWh assumed for the -\$1/MWh shown in the figure.

[21] IESO, 2019 Class B GA Actuals, 2019. Using straight average for the year.

[22] The HOEP for daytime hours between 7am and 11pm when Ontario's large gas plants were operating was \$34/MWh based on IESO data from 2015 and 2017.

the difference between the free residential night-time electricity and the daytime rate of $143/MWh creates the potential for arbitrage value[23] – up to $14,000 over the lifetime of an EV.[24]

The arbitrage value could be split between the EV owner and the workplace building in a variety of ways. If the workplace building pays the EV owner $84/MWh for the electricity they used to charge the vehicle at home, the workplace building would derive a benefit by way of energy savings, of approximately $59/MWh. This split of the savings reflects an assumption that would provide workplace buildings with the minimal economic basis to invest in bidirectional charging stations, as discussed further in Section 5.

3.5. Summary of Electricity System Considerations

Ontario's electricity rate structure and market rules allow commuting EV owners to provide mobile storage benefits to the electricity system. While commuting patterns undermine the potential for mobile storage synergies with Class A customers, there are substantial mobile storage benefits available for EV owners from rate arbitrage with Class B TOU or GS workplace buildings. The next section will further explore the value EV owners can achieve from providing mobile storage to the electricity system.

[23] By assuming the potential to leverage the CFS credit for mobile storage, it is inferred that the reason for a residential EV owner to charge the EV every night would not be discernable by the program and hence be an eligible practice for achieving EV adoption and GHG emission reduction.

[24] Calculated as $143/MWh of arbitrage value x 36 kWh of available battery capacity per day x 85% battery storage efficiency x 251 days of mobile storage per year x 13-year lifetime.

4. Value to EV Owners

This section outlines the EV range and commuting pattern factors that impact on the amount of electricity that EV batteries can contribute to a mobile storage application, defines the value elements for EV owners, and compares the lifetime cost of EV ownership to conventional ICE vehicles.

4.1. EV Driving Range

Two sample vehicles have been used to characterize an average EV in this report. The EVs and their average costs are shown in Table 1.[25]

Table 1: Sample EV Cost and Range

Vehicle	Upfront cost 2020 CAD	Range per charge (km)
Chevrolet Bolt	44,800	383
Hyundai Kona (EV)	44,999	415
Average	$44,900	399
Estimated 440 km EV	$46,560	440

EVs in Canada are expected to have an average driving range of 440 kilometer (km) for a fully charged vehicle.[26] Based on this, Table 1 provides an estimated upfront cost for a vehicle with a 440 km range.[27]

Two high-level factors characterize driver habits that determine the available capacity within EV batteries that can be used for mobile storage:

- Vehicle owners are assumed to drive 20,000 km per year, or 385 km per week.[28]
- In Canada, vehicles have an average life of 13 years.[29]

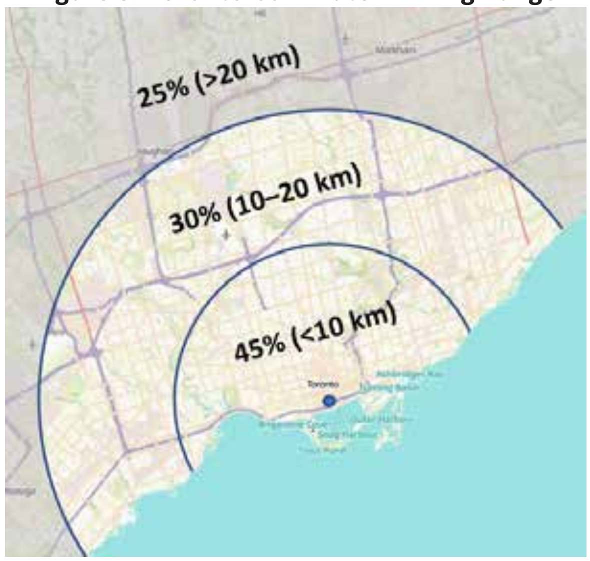
4.2. Implications of Commuting Patterns on Available EV Range

The daily driving needs of EV owners determine how much of a battery's total range may be underutilized and hence potentially available for mobile storage use. Most commuters in the greater Toronto area (GTA) travel less than 20 km to work each day as illustrated in Figure 8.[30] The average round-trip commute

[25] Hyundai Canada, 2019; Chevrolet Canada, 2019; Plug'n Drive, 2019; and, Strapolec analysis.
[26] BC Hydro, 2019.
[27] The two sample EVs used in this study had an average driving range of 399 km per charge. In order to scale costs to a vehicle with 440 km of driving range, the ratio of 440 km to 339 km was multiplied by the cost of the vehicle's battery, which is expected to account for 36% of the vehicle's cost in 2020 (BNEF, 2017), and added to the non-battery portion of the average vehicle cost.
[28] Statistics Canada and the IESO suggest that the average distance travelled by passenger cars is 16,000 km/year. Plug'n Drive assumes 20,000 km/year. The 20,000 km/year assumption is used here for three reasons: (1) commuter vehicles are assumed to be driven more than the average; (2) most vehicle OEM warranties assume 20,000 km/yr; and (3) a higher driving distance is conservative as it reduces the electricity assumed available for mobile storage purposes.
[29] Lantz, 2018.
[30] Commute range based on Statistics Canada, 2016; Google Maps data; and, Strapolec analysis.

distance for GTA commuters is 36 km per day.[31] With this taken into account, an EV with a range of 440 km would only use 8% of its total range for a daily round-trip work commute.

Figure 8: Toronto Commuter Driving Range



Over a year, commuting EV owners would drive on average about 9,000 km for work commutes, based on 251 of work days per year.

The available range of an EV is determined not only by the commuting distance that an EV owner would drive, but also from two other factors:

a. Battery management

   It is recommended that EV owners limit their battery utilization to within 20%-80% of its state of charge, in order optimize the useful life of the battery.[32] Allocating 40% of range for an EV with 440 km of range results in 88 km on either side of the recommended operating practices. This corresponds to 176 km of total range saved for battery optimization.

b. Additional personal use and range anxiety

   It is assumed that the average EV owner would use the balance of the annual 20,000 km for other activities. On a daily basis, that balance of 11,000 km per year would be an average of 30 km/day driven for other personal needs unrelated to work (e.g. grocery shopping, gym, etc.).[33]

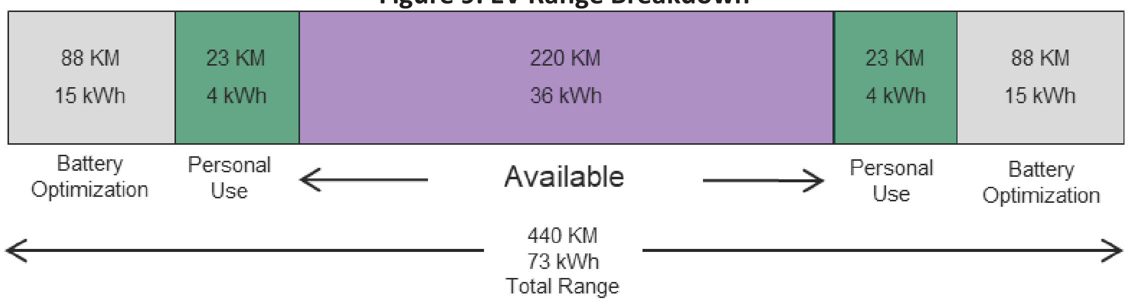
   It is assumed that most of this travel would occur on weekends, with only 10 km/day habitually driven on workdays. This adds up to 46 km/day of total personal driving when including the 36 km round-trip commute to work.

[31] Distance from home to work was used as a proxy for the distance travelled to work.
[32] Battery University, 2019.
[33] Calculated based on 365 days of use per year.

To address other unexpected personal needs, provisions for range anxiety must also be included. Research shows that on average, a 50 km range buffer is sufficient to meet most driver needs.[34] It has been assumed that this buffer can be served by the margin saved for battery management practices.

Figure 9 shows the combined impact of these factors and the remaining battery range of 220 km that might be available for mobile storage applications.

Figure 9: EV Range Breakdown



Converting Range to Battery Capacity in kWh

For the average EV considered, the vehicle consumes energy at a rate of 0.166 kWh per km.[35] This means that an EV with a range of 440 km would have a battery capacity of approximately 73 kWh under ideal conditions. However, available range is impacted by the ambient temperature when the vehicle is being used. In winter, there is an 18% range reduction, corresponding to 8 km, mainly due to heating requirements.[36] Thus, on average, as shown in Figure 9, an EV can be expected to have approximately 220 km of range, or 36 kWh, available for mobile storage every day.[37]

4.3. Value for EV Owners of Mobile Storage Electricity Provision

EV owners can sell their battery's 36 kWh of unused capacity to the owner of the parking lot at their workplace. Each vehicle can charge at home in the night-time with free electricity. If they sell their stored electricity to their workplace building in the day at the off-peak TOU rate of $84/MWh (see Figure 7 in Section 3), the EV owner would earn $84/MWh of electricity sold. If an EV is available to provide mobile storage services for 251 days per year, the owner could earn $645 per year, or $8,400 over the lifetime of the vehicle.[38,39,40]

---

[34] Erdogan, 2018.

[35] Average of the two sample EVs used in this study.

[36] The winter range reduction is only applied to the battery capacity used for driving, not the range saved for battery optimization or mobile storage.

[37] In the winter 34 kWh is available per EV due to weather-related range reduction.

[38] Approximate estimate of earnings. Actual earnings depend on optimization of TOU arbitrage.

[39] 36 kWh usable battery capacity x $0.084/kWh x 251 days/year x 0.85 battery storage efficiency = $730 per year. If not all work days are utilized for mobile storage, these savings could be commensurately smaller.

[40] Future vehicles are assumed to come equipped with bidirectional charging hardware and software (estimated to cost ~$592 based on Smith and Costello, 2015) with the cost included in the purchase price of the vehicle as for the 2019 Nissan LEAF (Nissan Global Newsroom, 2018).

4.4. Charging Implications and Battery Life

Battery life is an important concern by many EV owners, as the data and statistics on how long batteries will last is still emerging. Some EV owners are also concerned about the warranty of their battery. Battery life is determined by a number of factors, the most significant of which is the number of charging cycles that are undertaken over its lifetime. Charging cycles in turn are influenced in several ways:

1. Average km per charging capacity of the battery

   Based on 20,000 km of driving per year, an EV with a 440 km range could require an average of no more than one charge per week or 50 charges per year.

2. Additional cycles to support battery management

   Battery management considerations result in more charges being needed beyond the base commute and personal needs. It is recommended that charge/discharge cycles remain in the 20% to 80% range of the EV battery's capacity in order to optimize the battery life.[41] As a result, charging should occur whenever 60% of the battery capacity has been consumed. This translates to a need to charge a battery with 440 km of range every 264 km.[42] If the owner drives 20,000 km per year or 385 km per week, and the vehicle needs to be charged every 264 km, then the battery will require 1.5 charges per week or 78 charges per year. For the 13-year life of the vehicle, this equates to approximately 1,000 charges over its lifetime.

3. Provisions for unexpected off normal driving conditions

   Other factors also impact range such as highway driving, weather, hilly terrain, etc.[43] The analysis in this report conservatively assumes that an additional charging cycle could arise every two weeks, leading to an average of two full charges per week. With this applied, the EV will require 1,300 charges over its lifetime.

4. Aging effects of the battery

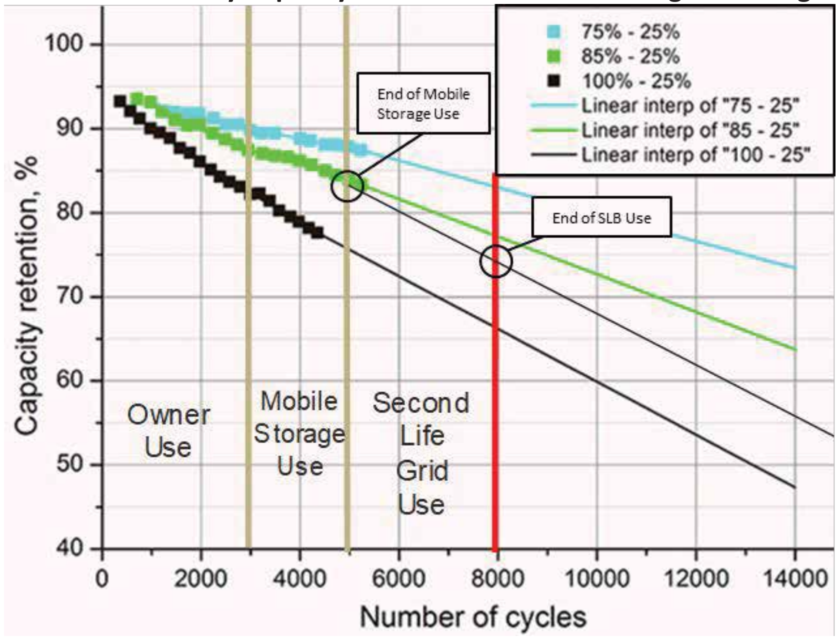
   Finally, as the EV ages, the charge-discharge range is reduced.[44] To account for this, this report doubles the total charges required over the vehicle's lifetime, meaning that it will require a total of 3,000 charges over the course of its life.

EV batteries have been tested to determine the implications of charging cycles on battery life. With proper battery management practices, after the 3,000 lifetime cycles estimated above for 13 years of driving, an average EV battery is expected to have over 85% of its battery life remaining, as shown in Figure 10.[45] This is consistent with GMs expectations at over 80% of the batteries' capacity will still be useable after a vehicles' end of life.[46]

---

[41] Battery University, 2019.
[42] Assuming charging and discharging up to 60% of the battery capacity is a full cycle, to be conservative.
[43] Battery University, 2019.
[44] Battery University, 2019.
[45] Figure adapted from Battery University, 2019.
[46] Wired, June 2015.

Figure 10: Lithium-ion Battery Capacity Loss as a Function of Charge-Discharge Bandwidth



Using EV batteries for mobile storage increases the number of cycles used to five cycles per week (one each work day) from the base of two cycles described above. This would add 150 cycles a year or 1900 over 13 years. Even after 13 years of mobile storage applications, an EV will still likely have almost 85% of its battery capacity available.

Using an EV's battery for mobile storage purposes is unlikely to have significant effects on the battery's warranty. For example, Nissan recently approved their EV model, the LEAF, for mobile storage use with no impact on the battery's warranty.[47] In a world where vehicle batteries are increasingly used for energy storage, other original equipment manufacturers (OEMs) are likely to follow suit.[48]

The batteries will still be capable of a large number of cycles, and will be suitable for use in a second life application such as storage on the electricity grid, where they can provide various services such as peak shaving or frequency response. Used EV batteries are ideally suited to applications where there are needs for less frequent battery cycling and in which they are ideally suited to providing reliability services at less cost than combined cycle gas turbines (CCGTs). This is being developed by Renault's Advanced Battery Storage Programme for 2020 operation.[49]

4.5. Benefits from Second Life Battery Use

After an owner's personal driving use and mobile storage use, EV owners will only have used a small percentage of the vehicle's battery life. Used EV batteries can therefore be sold to the grid for use in a less intensive second-life application. Batteries consigned to grid applications are expected to only need

[47] Nissan Global Newsroom, 2018.
[48] Notably, Tesla has stated publicly that they are opposed to the use of their EVs' batteries for either mobile storage or SLB use (Leggett, 2017).
[49] Smart Energy, 2019.

to complete 175 cycles per year, or 1,750 cycles for 10 years – a relatively modest rate of use.[50,51,52] The actual life expectancy for SLBs is difficult to estimate, as numerous factors such as calendar aging, internal resistance, and the number of cycles impact the battery life. Nevertheless, research suggests that it is economic to purchase a second life EV battery that has undergone between 4,490 and 5,821 cycles in its automotive life before starting its second life.[53,54] As shown in Figure 10Figure 11, even after expected mobile storage use, 13-year-old EV batteries will likely have only experienced 5,000 cycles, which is well within the range of desirable cycles for second life applications described above.

The value of EV batteries in a second life means that EV owners will be able to sell them at a material price. Research suggests that EV owners can sell their used batteries for up to 20% of the battery share of the original purchase price, effectively recouping a portion of their original investment in their car.[55]

Nuvve has recovered batteries and repackaged them to store and discharge energy to PJM. Nuvve's Delaware facility participates in PJM's frequency regulation market and sees the purchasing of used batteries from EV OEMs as a better revenue opportunity for OEMs than simply recycling used batteries. These savings can be passed on the consumers to help with EV adoption.[56]

4.6. EV Ownership Cost Advantage

Several factors combine to make EVs cost-competitive with traditional ICE vehicles, as shown in Figure 11:

1) Cost of Vehicle Ownership

The cost of vehicle ownership consists of three main components: the purchase price of the vehicle, fuel, and maintenance. The purchase price shown includes the price of the battery, a home smart charger, as well as the on-board electronics and control module for mobile storage. A federal EV rebate of $5,000 per vehicle, the iZEV rebate, is included in the purchase price of the vehicle for today (assuming the vehicle qualifies), but it is assumed to be phased out by 2030. For an EV, fuel means electricity, whereas for an ICE vehicle fuel is gasoline, and includes any carbon price that might be applied.

The initial purchase price of an EV (including a home charger) after the federal rebate, is currently almost double that of an ICE vehicle. The ongoing fuel and maintenance costs, however, are only 15% of an ICE vehicle.

2) Benefits

EV owners are also afforded $20,000 worth of benefits. These include:

- ***The net profit of selling clean electricity to the grid***, which is composed of the value derived from electricity rate arbitrage, which is $8,400 of mobile storage benefits based on selling electricity $84/MWh, as well as $8,200 CFS benefit from mobile storage use. This comes to a total of $16,600 in benefits for EV owners.

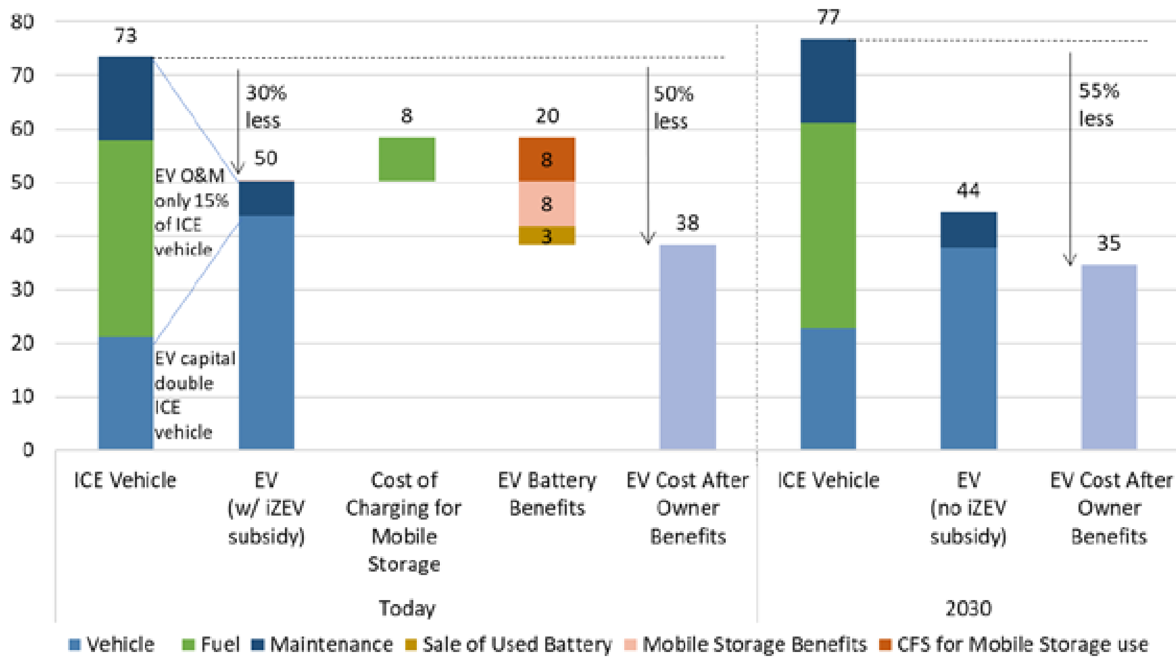
---

[50] New batteries assumed to last 10 years based on Lazard, 2017.
[51] Number of cycles based on Strapolec's nuclear distributed energy storage scenario. See Section 6.
[52] Mercedes Benz is confident EV SLBs will have at least 10 more years of useful life, PV Magazine, 2016.
[53] Debnath et. al., 2014.
[54] Calendar aging and increasing resistance are factors impacting the total cycles available per battery.
[55] Debanth et. al., 2014.
[56] Nuvve, 2019.

- ***The value gained from selling the EV's battery for re-use as grid storage***. Based on the previous section, EV owners are assumed able to receive 20% of their battery's initial purchase price from resale, which is estimated to be $3,500 today and $1,350 in 2030.[57]

With these benefits, the lifetime cost of EV ownership is estimated to be as low as $35,000 by 2030. Considering the projected lifetime cost of $77,000 for gasoline vehicles,[58] EV ownership could be almost half the cost of an ICE vehicle by 2030, even without the federal government EV purchase rebate.

Figure 11: EV Lifetime Ownership Cost Advantage
($000s/vehicle)



4.7. Summary of Value to EV Owners

EV owners can derive substantial value from providing mobile storage services and selling their used batteries for second-life applications. Commuting patterns show that EV owners will have enough spare battery capacity to provide mobile storage, allowing them to earn up to $8,400 over the lifetime of their vehicle. Additionally, once the EV's battery has reached the end of its useful life in the vehicle, it can be sold for grid services, allowing the owner to recoup a portion of its value. Combined with other benefits available to EV owners, these factors make EVs less expensive to own than traditional ICE vehicles today, even without the grid benefits factored in and will be significantly cheaper in 2030.

---

[57] An EV battery estimated to be 36% of a vehicle's 2020 cost in Figure 11 and 18% in 2030 (See Appendix A).
[58] Based on Hyundai Kona, Chevrolet Cruz and BNEF forecast ICE vehicle cost trends.

5. Value to Workplace Buildings

This section examines the cost and benefits to workplace buildings of enabling mobile storage on their premises. It examines the costs and requirements of bidirectional charging equipment, the implications of commuting patterns on the economics of mobile storage for workplace buildings, and lays out the business case for workplace buildings to invest in bidirectional chargers.

5.1. Cost to Workplace Buildings

In order for EV owners to earn money by providing mobile storage services in the daytime, they need to park their vehicle at a location with bidirectional charging capability, such as a workplace. It is assumed that the parking is connected to a building with sufficient demand to make use of all the available vehicle battery capacity parked there.

The workplace building will need to purchase bidirectional charging stations for its parking area. This study assumes that workplace buildings will use Level 2 chargers with a capacity of approximately 10 kW, meaning that a vehicle with a range of 440 km can discharge 50% of its capacity in approximately four hours.[59]

Mobile storage compatibility costs can be broken down into three main components:

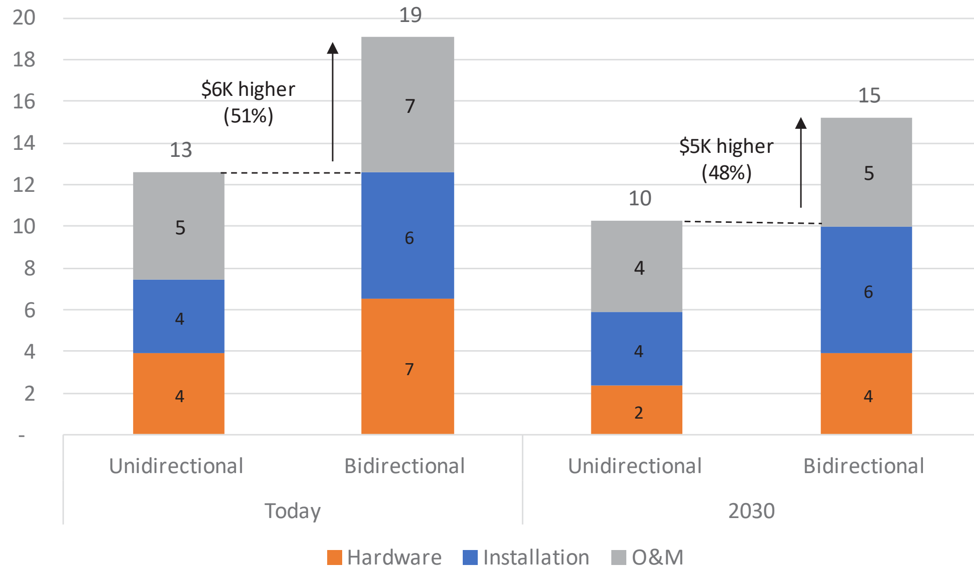
- Bidirectional charging station hardware, including smart software technology to optimize battery usage and time of discharge;
- Installation, which includes BTM building integration costs; and
- Operation and maintenance (O&M), which includes a 5% annual maintenance cost (an annual network fee of $325 is assumed to already be included in the cost of a unidirectional charger).[60]

Figure 12 shows the cost components to workplace buildings of both traditional unidirectional charging stations and the bidirectional charging stations required to enable mobile storage, both today and in 2030.[61,62,63] Assuming that workplace buildings would otherwise choose to install unidirectional chargers[64] in the future, the incremental lifetime cost of bidirectional charging equipment and installation is estimated at $6,000 per charger today, and could drop to $5,000 per charger in 2030.

Incremental costs in 2030 include the additional capital to purchase the bidirectional charging station (an extra $2,000), installation (an extra $2,000), and $1,000 of additional O&M based on 5% of the hardware costs over the 10-year life of the charger.[65]

[59] NREL, 2017.
[60] O&M cost based on NREL, 2017 and network fee based on RMI, 2014.
[61] Uni-directional charger: hardware costs based on Smith and Costello 2015, installation and maintenances costs based on NREL, 2017, network charges based on RMI 2014. Interviews suggest costs are conservatively high.
[62] Hardware price decline from today to 2030 uses price trend from Innovate U.K., 2019 – based on solar inverters
[63] According to UCLA, 2012: a public Level 2 EV charger is expected to have a ten-year lifetime.
[64] Unidirectional charging means one-way energy flow from the grid to charge EVs using smart controllers that optimize charging according to the needs of the owner, electricity grid and the battery. It does not allow for bi-directional charging.
[65] The costs of unidirectional chargers bear the cost of network connection which is assumed to have no additional increment for bidirectional chargers.

Figure 12: Lifetime Cost of Level 2 Bidirectional Chargers for Workplace Buildings
($000s per charger)



When financed at 6% over a 10-year life, the annual incremental cost of a bidirectional charger is $669/year.

5.2. Optimizing EV Discharge Patterns

The number of chargers a workplace needs to purchase can be optimized based on the number of vehicles that require charging at the same time. This depends on when the vehicles are parked at the facility and the optimal time for discharging the batteries for mobile storage purposes given the TOU pricing. If charging can be toggled to reduce the number of chargers needed, this can reduce costs.

Using the commuting patterns and estimated EV arrival times discussed in Section 3, Figure 13 illustrates the optimal discharge pattern for EVs parked at the workplace that would be governed by TOU rates. By letting the late-arriving commuters use the charging stations after the early-arriving commuters' batteries have been discharged, on average three chargers are sufficient for every five EVs. This strategy is viable as it is expected that bidirectional chargers will be able to discharge the available electricity from an EV within four hours, leaving sufficient time in the latter half of the day to use the charger to discharge a second vehicle. [66]

This pattern also optimizes the TOU pricing arbitrage. The TOU pricing in effect at various times of the day is indicated by colour in Figure 13. Even though the summer and winter TOU pricing windows are different, the same use of three chargers for every five vehicles remains optimal in both seasons.

[66] Each charger is assumed to have two ports, so cars do not need to be jockeyed (MIT, 2019).

Figure 13: Optimization of EV Charging Profiles

Summer

Arrival Time	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
6:00 AM	x	x	x	d	d	d	d	x				
7:00 AM		x	x	d	d	d	d	x	x			
8:00 AM			x	p	d	d	d	p	p	p		
9:00 AM				x	x	x	x	d	d	d	d	
10:00 AM					x	x	x	d	d	d	d	x

Winter

Arrival Time	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
6:00 AM	x	d	d	d	d	x	x	x				
7:00 AM		d	d	d	d	x	x	x	x			
8:00 AM			d	d	d	d	x	x	x	x		
9:00 AM				x	x	x	d	d	d	d	x	
10:00 AM					x	x	x	x	d	d	d	d

Off-peak	Mid-peak	On-peak
x	d	p
Vehicle at work	Vehicle discharging	Possible discharge

While discharge at mid-peak hours does not offer as large a financial benefit as discharge during on-peak hours, there are still revenue benefits for using a given charger as many hours in a day as possible in order to avoid the purchase of more chargers.[67] Workplaces classified as general service electricity consumers have less pricing variation between different hours of the day and should, as a result have simpler scheduling criteria to optimize.

5.3. Business Case for Workplace Buildings

Ontario's electricity rate structure, the costs of EV charging equipment, and the capabilities of EV batteries combine to create a positive business case for workplace buildings to invest in bidirectional charging infrastructure on their properties.

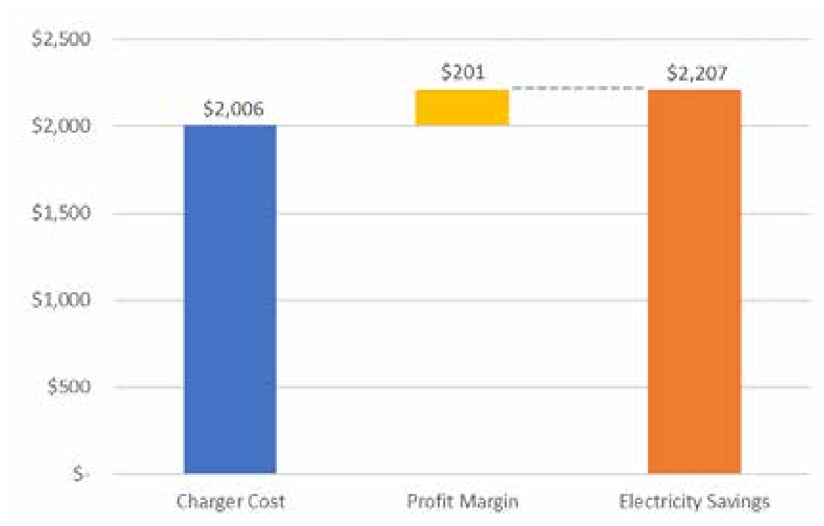
The value to workplace buildings comes from electricity savings. As discussed in Section 3, workplaces in the Class B rate category pay for electricity based on TOU rates, which are typically high during the day, and low during the night. Through mobile storage, workplace buildings will be able to purchase their electricity from EVs connected to their charging stations, taking advantage of the available battery capacity. While the price the building may pay EV owners for this electricity may vary, this report assumes it will be the night-time TOU rate. This rate is much lower than the daytime TOU rate the workplace building would otherwise pay for its electricity, allowing it to achieve savings. A simulation of the potential annual savings based on the discharging patterns described above suggests that workplace buildings can achieve electricity savings of $610/year per EV, or $2,027 annually based on a group of three charging stations serving five EVs per day.

[67] Scenarios were also evaluated whereby batteries could be topped up during mid-peak pricing and then discharged during on-peak pricing. However, there were no net financial benefits identified.

On the cost side, the incremental annual cost of three bidirectional EV charging stations is $2,006 after financing, or $401 per EV.[68] For illustrative purposes, workplace buildings are assumed to require a minimum 10% mark-up on the cost of each charging station, and therefore earn a profit of $201/year for a set of three stations.

Figure 14 summarizes the elements of the mobile storage business case for workplace buildings. The share of the potential electricity savings has been illustratively allocated to provide for the annual cost of the chargers and assumed profit margin to the building (the allocation was set at $59/MWh in Section 3.4). Further profits could be generated through benefit sharing with EV owners and the electricity system, depending on the business model.

Figure 14: Annual Cost & Benefit of Mobile Storage for Buildings
($ per five EVs, or three chargers)



5.4. Summary of Value to Buildings

The interactions between Ontario's electricity rate structure, commuting patterns, EV battery capabilities and mobile storage economics form a viable business case for workplace buildings to invest in bidirectional chargers on their premises.

[68] Calculated based on cost of $492 per charger and financed at 6% for ten-year life of charger.

6. Value to the Electricity System

This section presents the potential benefits EV batteries could provide to Ontario's electricity system, both while in use through mobile storage, and during their second life as stationary grid storage.

EV batteries have the potential to deliver benefit to Ontario's electricity grid through four mechanisms:

1) Mobile storage shifts electricity demand from on-peak hours to off-peak hours:
    a. Making better use of Ontario's surplus base-load supply;
    b. Avoiding the variable cost of gas-fired generation; and
    c. Reducing electricity prices for ratepayers
2) EV SLBs offer a lower cost option for acquiring storage.
3) Together, mobile and SLB stationary storage applications improve the effectiveness and benefits of DER.
4) These effects combine to reduce GHG emissions from Ontario's electricity generation.

6.1. System Benefits of Mobile Storage Application

Widespread adoption of mobile storage has the potential to impact patterns of electricity demand in Ontario, potentially providing benefits to the system. Assessing these benefits requires estimating the amount of storage that could be available, and determining what impact the charging and discharging cycles of that storage would have the on the system.

Available EVs for Mobile Storage

The system benefits of mobile storage are dependent on the number of participating vehicles.

Ontario's market potential for mobile storage is substantial. The province is expected to have between 580,000 and 1.1 million EVs on the road by 2030, according to IESO's reference and high demand scenarios (Figure 15).[69] In the high demand scenario, approximately 500,000 vehicles will be light duty BEVs, making up 5.6% of all passenger vehicles.[70,71]

In this study, a workplace is defined as a building that has a parking lot with 200 or more spaces. Large commercial business sites are assumed to be the most suitable for mobile charging infrastructure, which would typically be general service Class B consumers, but could also be smaller Class B TOU consumers. As discussed earlier, the benefits case is similar for both. Despite only making up 1% of business locations

[69] IESO, Preliminary 2019 Long-Term Demand Forecast, 2019.

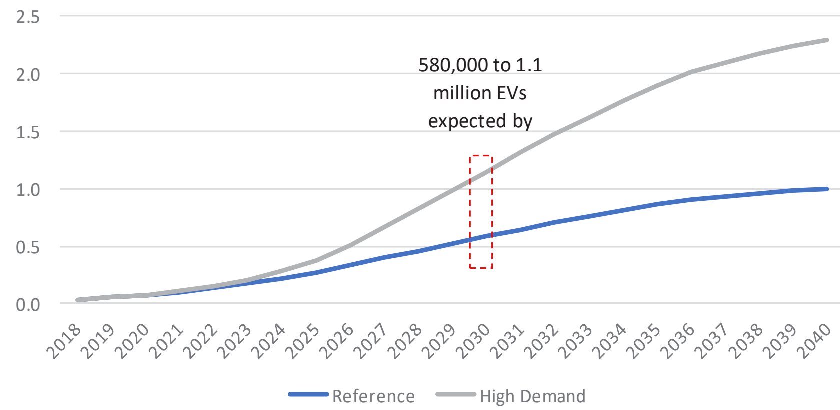
[70] According to the high demand scenario from IESO's Preliminary 2019 Long-Term Demand Forecast, 2019, there will be 1.1M EVs on Ontario roads by 2030, 50% of which or 550,000 are expected to be BEVs (OPO 2016, IEA 2019). A small percentage or 50,000 are assumed to be non-passenger vehicles (IEA, 2019), leaving 500,000 passenger BEVs on roads. Assuming 2016 OPO assumption of 50% BEVs.

[71] Approximately 9 million passenger vehicles are expected on Ontario roads by 2030 (based on Ontario Power Authority's 2013 LTEP assumptions).

overall, a full quarter of the 3.8 million individual vehicles that commute to work daily in Ontario commute to businesses of this size. This corresponds to one million vehicles.[72] Of those commuters, 68% or approximately 680,000 arrive at work between 6am and 9am.[73] This represents approximated 7.5% of the passenger vehicles on the road in Ontario.

Figure 15: IESO Forecast of Annual EVs in Operation

(Million EVs by Year)



Applying this 7.5% statistic to the assumed 500,000 passenger BEVs suggests 38,000 EVs may be candidates for mobile storage applications. Studies suggest that 40% of these vehicles could be willing to participate in a mobile storage program, making 18,000 vehicles available.[74] Toronto also has several very large parking lots that serve workers from multiple employers. For the purposes of this analysis, an additional 555 vehicles are added representing 2.5% of the capacity of Toronto's 25 largest parking lots,[75] bringing the potential total number of participating EVs to 18,555 vehicles.[76]

Impact of Shifting Demand to Off-Peak Usage

The deployment of mobile storage would increase Ontario's electricity demand at night when EVs are being charged, and reduce daytime demand when the batteries are discharged. Mobile storage from the 18,555 participating vehicles would increase the average daily demand at night by 665 MWh across the province, while reducing average demand in the day by 565 MWh, as shown in Figure 16.[77]

---

[72] 25% of employees work at businesses with 500+ employees. Percentage derived assuming average business of a given size category is the midpoint of each range (e.g., 2.5 employees for 1 to 4 employee range) with an average of 600 for businesses with 500+ employees. Statistics Canada, 2016; and, Strapolec analysis.

[73] Statistics Canada, 2016.

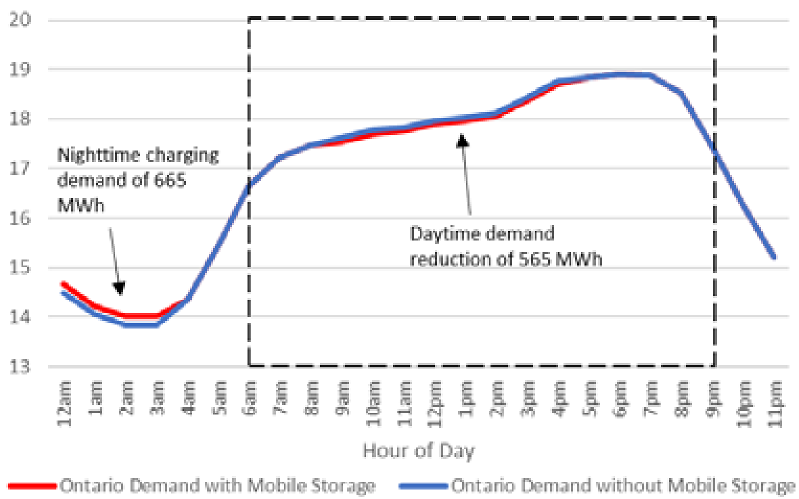
[74] 40% participation rate based on Erdogan, 2018.

[75] Impark, 2019; Brookfield, 2019; Park Indigo, 2019; City of Toronto, 2019.

[76] As a reference case, it is deemed reasonable to assume that all of these vehicles would be parked at Class B workplaces on the basis that 32% of commuters have been excluded. To the extent that this may be marginally overstated, other smaller workplaces may choose to participate depending on their own policies for encouraging EV adoption, thus compensating for larger workplaces that do not participate.

[77] Daytime demand reduction is less than the increase in night-time demand due to the batteries' 15% efficiency losses.

Figure 16: Impact of Mobile Storage on Ontario's Daily Demand Profile
(GW by hour; 2035, average summer demand)



Assuming 251 working days in a year, this daily commuter behaviour leads to 164 GWh of night-time charging per year and 140 GWh of daytime discharging.

These changes in demand create several benefits for the electricity system. The increase in overnight demand has the potential to boost revenues for the clean power that composes Ontario's night-time base-load. These are primarily nuclear and hydro facilities that operate at a fixed cost. The 164 GWh of night-time demand from mobile storage creates an increase in revenue for these suppliers without an increase in costs, resulting in a straight injection of $17 million/year to the system.

Meanwhile, the decrease in demand in the daytime from mobile storage could displace 140 GWh of natural-gas fired electricity. This in turn could reduce electricity system costs by avoiding $5 million in HOEP costs annually.[78] Reducing annual natural gas generation by 140 GWh could also result in 55 kt less GHG emissions per year.[79] These reduced emissions could deliver savings to the system in the form of avoided carbon taxes, saving $3 million annually at the projected federal carbon price of $50/tonne.

Mobile storage may, as a result, deliver both cost and emissions benefits to Ontario's electricity system. Other benefits not assessed by this report may also exist such as implications for optimizing the future supply mix as a result of the change in the daily demand profile and reducing the costs to government of the OER. These may offset avoided rate payer costs from the reduced daytime energy consumption.

6.2. Direct Cost of EV Battery Storage

The cost of Li-ion battery storage for electricity system purposes is very high. Using repurposed EV batteries could reduce this cost. These cost comparisons are examined in two ways:

1) The cost of new storage versus SLBs from EVs; and

[78] Winter temperature impacts on the battery leads to 638 MWh/day of charging and 543 MWh/day of discharging.
[79] Assuming 0.4t/MWh of CO_2 emissions from Ontario's gas-fired generation fleet.

2) The cost benefit of EV SLBs as an electricity system solution to new and used gas plants.

Cost of Purchasing New versus SLB Storage

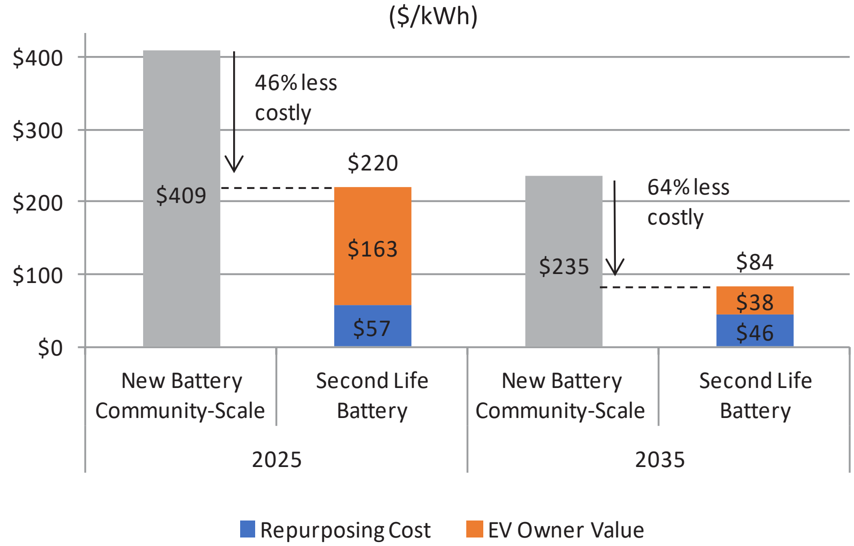
New batteries used for community-scale storage are expected to cost $409/kWh in 2025. By 2035, due to anticipated declines in costs due to innovations, batteries are expected to cost $235/kWh in 2035.[80]

To be used in a second-life application, EV batteries must be integrated into a new package suitable for connection to the electricity system. This price is composed of two components:

- Repurposing costs – these include the dismantling of the battery pack, potential separation or replacement of the battery module and reassembly into new packs, and the OEM's extended producer responsibility to properly dispose of an EV battery. The total cost of this battery repurposing is estimated at $57/kWh in 2025 and $46/kWh in 2035.[81]
- EV owner value – EV owners are assumed to obtain 20% of their battery's original cost when they sell them for reuse.[82] This margin adds $163/kWh to the cost of a repurposed battery pack in 2025. Cost reductions are expected to reduce this to $38/kWh in 2035.

In total, the cost of an SLB is expected to be $220/kWh in 2025 and $84/kWh in 2035. This is in line with the cost of Nissan LEAF batteries currently being refurbished in Japan.[83] Comparing these costs with new batteries, as illustrated in Figure 17, shows that SLBs could cost 46% to 64% less than new battery storage in 2025 and 2035 respectively.

Figure 17: Cost of New vs. Second Life Battery Storage
($/kWh)



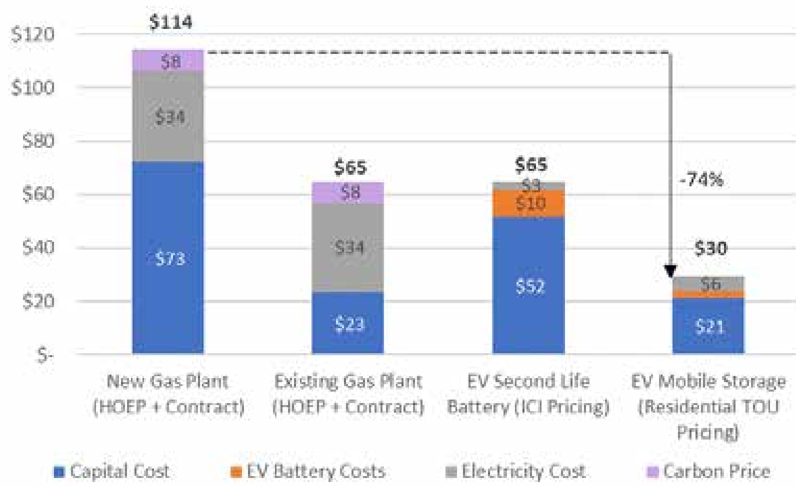
[80] Lazard, 2017; Strapolec analysis.
[81] Element Energy, 2019.
[82] Debnath et. al., 2014. Note: PV Magazine, 2018 suggests market for SLBs in China will be $100/kWh in 2025. Inside EVs, 2019, reports that Eaton's solution today with Nissan Leaf batteries is 20% cheaper than new batteries.
[83] Inside EVs, 2019.

Batteries as an Alternative to Natural Gas Use for Intermediate Daytime Electricity Supply

Reducing the cost of storage lowers the cost of alternative electricity supply options relative to natural gas-fired generation. In order to illustrate the relative costs of storage to natural gas-fired options, these options are assessed against their ability to serve Ontario's average intermediate daytime electricity demand profile, which is defined as the electricity which cannot be supplied by the province's nuclear and hydro base-load capacity. Figure 18 compares the costs of several generation options for meeting this intermediate demand:[84]

- **New gas plants,** which typically have their fixed costs covered by a capacity contract and incur variable costs due to the cost of fuel when actually generating electricity. The cost of fuel is approximately reflected in the HOEP and includes a carbon price;
- **Existing gas plants,** which are modelled on the same basis as new gas plants except with lower capacity contract values;
- **EV SLB storage,** reflecting the cost of purchasing the used battery from an EV owner, repurposing it and then operating it using electricity obtained at night under an ICI pricing assumption; and
- **EV mobile storage**, which reflects the cost of using existing EVs under a mobile storage scenario where residential TOU pricing is leveraged for charging at night.[85]

Figure 18: Cost Comparison of EV Storage Options with Natural Gas
($/MWh)



Each option's capital cost differs based on the technology being employed. For EV mobile storage, the capital cost is the cost of bidirectional charging stations in buildings. In the case of EV SLB storage, it is the cost of repurposing EV batteries themselves plus the margin battery cost to purchase from the EV owner. For gas plants, the costs reflect the annual price that the plants are paid for their capacity.

[84] Cost of SLBs and EV mobile storage financed at 6% over 10 years (10-year charger life for mobile storage based on UCLA, 2012; 10-year SLB use based on Lazard, 2017).
[85] Cost of EV mobile storage does not reflect sharing of benefits between EV owner and building.

The variable cost is the electricity cost for these options. EV mobile storage uses virtually emission-free electricity at a discounted residential rate of $0/MWh as discussed in Section 3. SLB energy provision costs use the average overnight HOEP that Class A consumers would pay under the ICI program. The variable cost for both existing and new gas plants are assumed to reflect the average daytime HOEP when gas is being produced.[86]

On the basis of these cost assumptions, and under these idealized average demand profiles, mobile storage could represent a 74% cost benefit compared to building new gas plants. Storage using SLBs is expected to cost less than an existing gas plant at a carbon price of $20/tonne.[87] EV mobile storage has the lowest net cost at $30/MWh, although this value does not reflect the need to share margins with the EV owner and the workplace building.

The above two comparisons in Figure 17 and Figure 18 both indicate that the use of EV batteries for electricity system applications should offer some cost savings. The long-term implications of this illustration are that as the carbon price rises, battery prices continue to fall, and more used batteries become available, the economic viability of gas plants as the lowest cost option will erode. To properly quantify the benefits, however, requires a proper simulation of the hourly supply and demand dynamics within Ontario's electricity system over the course of a year.

6.3. Integrating EV SLBs into DER in Ontario

To assess the electricity system benefits of using SLBs for DER in Ontario requires quantifying the expected amount of SLB storage that could become available, and conducting a simulation of how that storage could be used to interact with other generation to supply intermediate demand.

Estimating the Potential Storage Capacity of SLBs

Used EV batteries offer a growing source of useable grid storage as greater numbers of EVs are purchased. The future capacity that might be available for electricity system applications can be estimated from projections of EV vehicles on the road. Based on historical EV sales and projected EV adoption rates, there may be 85,000 to 100,000 used EV batteries available for second life applications by 2035, with an average of 93,000.[88,89,90] This equates to between 4.0 to 4.7 GWh of usable battery storage capacity available by 2035, yielding an average of 4.4 GWh as shown in Figure 19.[91]

86 IESO, Market Renewal Benefits Assessment, April 2017.

87 $20/tonne is the carbon price at which SLBs match the price of existing gas plants, calculated using 0.4 tonnes of GHG emissions per MWh as the average emissions from a CCGT plant in Ontario (Government of Ontario, 2019).

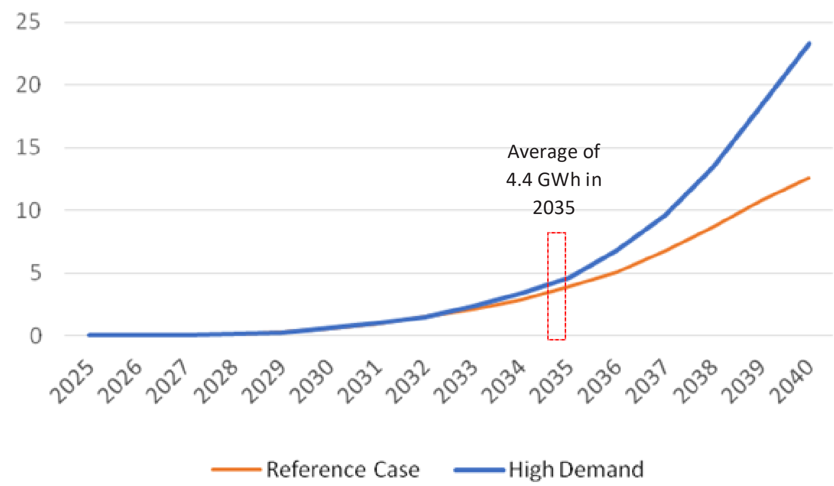
88 Reference case and high demand estimates of EVs based on IESO's reference and high adoption cases, respectively.

89 Number of used batteries from 2025 to 2030 based on historical BEV sales from 2012 to 2017 (Fleetcarma, 2018). Number of used batteries from 2030 to 2035 based on IESO's forecast (IESO, Preliminary 2019 Long-Term Demand Forecast, 2019).

90 Estimate assumes that batteries are used for grid applications for around 10 years. Thus, batteries that came into service in 2025 are taken out of service after 2035.

91 Batteries are assumed to maintain 80% of initial capacity after being used in an EV (see Section 4). Battery capacities are modelled to increase historically, with an average capacity of 48 kWh remaining per battery in 2035.

Figure 19: Cumulative Ontario SLB Capacity Available
(GWh by year, based on BEVs)



At an initial capital cost of \$84/kWh, purchasing 4.4 GWh of SLB capacity would cost about \$370 million in 2035, a saving of almost \$665 million over purchasing new batteries that are expected to cost \$235/kWh as shown in Figure 17.

Impact of EV SLBs on DER Solutions to Supply Ontario's Intermediate Demand

DER scenarios for supplying Ontario's intermediate demand could include various configurations of renewables, storage, and nuclear generation. The costs of these scenarios have been compared to that of using natural gas-fired generation.[92] Two DER scenarios have paired battery storage with generation for the purpose of emulating the behaviour of natural gas-fired generation (CCGT) in supplying intermediate demand:

1) A solar DER scenario co-locates storage capacity with community scale solar panels to optimize the effectiveness of pairing those technologies.
2) A nuclear distributed energy storage (DES) scenario, used community scale storage options to store grid scale new nuclear energy at night and use it during the day.

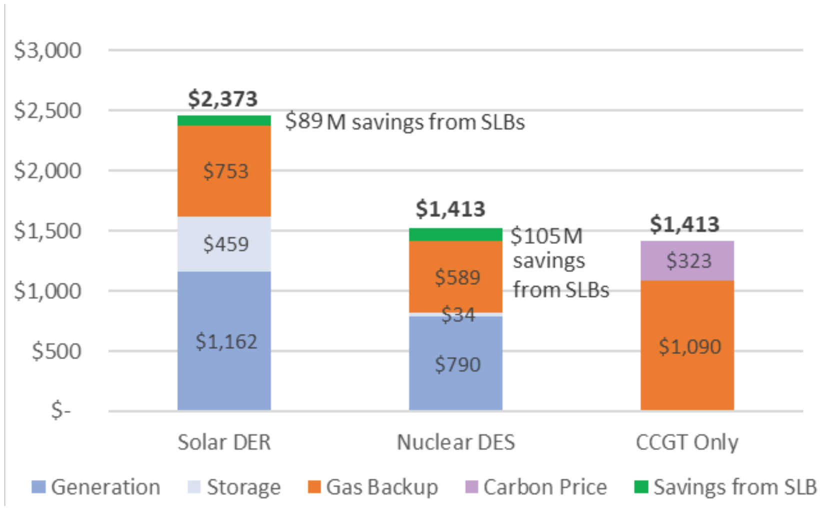
These scenarios were reassessed for this study based on the above derived 4.4 GWh of SLB capacity that could be available in 2035. The total energy provided by these scenarios is 7.8 TWh/year. The cost results of these scenarios are provided in Figure 20. The analysis confirmed that neither scenario could fully eliminate the need for natural gas-fired generation capacity, which remains a significant cost in all scenarios. Other than that, the nuclear DES option requires much less generation and storage capacity than does the solar case and uses it more cost effectively. To compare these lower GHG emission options with a CCGT option, a carbon price has been applied to the natural gas output of each scenario.

The results in Figure 20 show that using SLBs in an environment where mobile storage is also active can reduce the cost of DER. When compared to non-EV battery use scenarios, the new solar DER scenario can

[92] CCRE, 2019.

save $89 million annually. The nuclear DES scenario, however, can save $105 million per year on an already lower-cost solution. Nuclear DES can provide the same services as a natural gas-fired generation only scenario and do so at a cost equivalent to assuming a carbon price of $105/tonne.[93,94]

Figure 20: Annual Cost of DER Using Repurposed EV Batteries
($M, 2035)



Nuclear DES offers potentially greater cost savings than solar DER because the simulation suggests that the batteries are expected to see 175 cycles annually, 30% less than the 253 cycles/year forecast for solar DER.[95] As a result, batteries used to support nuclear DES can be expected to have a longer life, further reducing the relative annual cost of storage.

6.4. GHG Emission Reduction Reliance on Low-emission Base-load

Reducing emissions is one of the consumer priorities when purchasing an EV. The benefits of mobile storage in GHG emission reduction are dependent on the supply mix available to charge the EV batteries. Section 6.1 describes the potential GHG emissions reduction benefit from mobile storage to be up to 55 kt/year assuming a typical supply mix profile of GHG emission free charging at night and displacement of GHG emitting gas-fired generation during the day. This is an ideal case that doesn't reflect actual supply mix dynamics.

Prior to considering the implications of mobile storage on the demand curve illustrated in Figure 16, the nuclear DES option would reduce GHG emissions from Ontario's electricity system by 6.9 Mt. It could be argued that this reduction would be enabled by the potential for low cost SLBs should that decision be

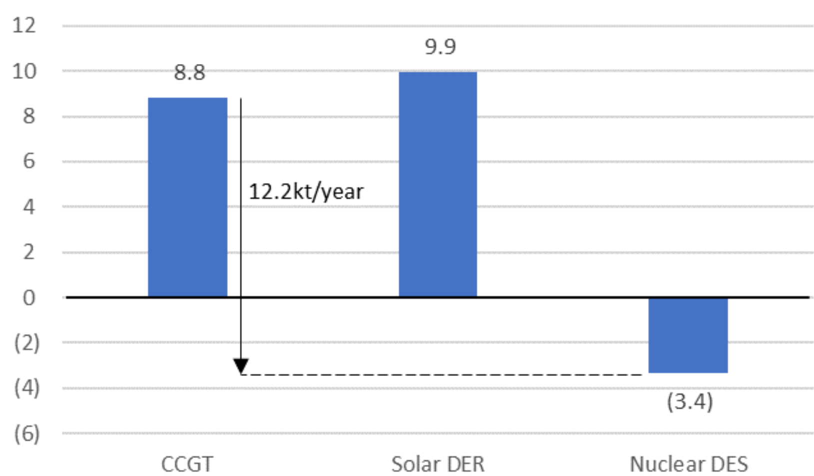
---

[93] Represents the cost for meeting 40% of Ontario's future need for intermediate supply, which is equivalent to a nuclear DES scenario with 4.4 GWh of SLBs in 2035. The results reflect adjusted demand due to mobile storage.
[94] Illustrated carbon price of $105/tonne is price where nuclear DES becomes competitive with the CCGT (Combined Cycle Gas Turbine) scenario.
[95] A charge/discharge cycle here simply refers to switching from charging the battery to discharging. This is a conservative estimate of the total number of cycles as each instant is only a partial cycle in reality.

based on SLB costs. Regardless, GHG emissions savings for the scenarios in Figure 20 vary as a result of the demand shifting created by mobile storage.

Figure 21 illustrates the impact on GHG emissions of each of the supply mix options when EV mobile storage shifts demand. Emissions increase in the solar DER and natural gas-fired CCGT scenarios due to natural gas being used in both scenarios to meet the additional night-time demand from EV mobile storage charging. These scenarios see GHG emissions increase by 9.9 kt and 8.8 kt respectively. The solar DER case has higher emissions compared to the natural gas-fired CCGT case because solar power is generally available at the same time as mobile storage discharging. As the solar power would have already displaced gas-fired generation, mobile storage has less opportunity to further reduce emissions during the day.

Figure 21: Incremental GHG Emissions Impact of Time Shifting Demand from Mobile Storage
(kt/year)



The nuclear DES scenario, on the other hand reduces the amount of natural gas being used, resulting in less GHG emissions. This is because the nuclear DES scenario is able to provide low GHG emission generation at night when EVs are charging at home, and then, when the mobile storage discharges during the day, it has the opportunity to augment the SLB storage and displace GHG emissions from natural gas fired generation. The nuclear DES solution is also unique in that it avoids using natural gas fired generation at night to displace natural gas fired generation during the day. This would be an inefficient process due to the efficiency losses in storage and contribute to emissions increases in the solar and CCGT scenarios. The nuclear DES, coupled with mobile storage, can further reduce net system GHG emissions by 3.4 kt/year, a net benefit of 12.2 kt/year compared to the CCGT result. This is the practically expected benefit in Ontario instead of 55 kt.

6.5. Summary of Potential Annual Value of EV Batteries to the Electricity System

Combined, the use of EV batteries for mobile storage and second life applications create four value elements for Ontario's electricity system, as shown in Figure 22. Altogether, there is a potential for $129 million/year of benefits.

Mobile storage benefits arise from the cumulative impact that the projected 18,555 participating EVs could have on demand reduction savings, new electricity revenues, and emissions reduction benefits.

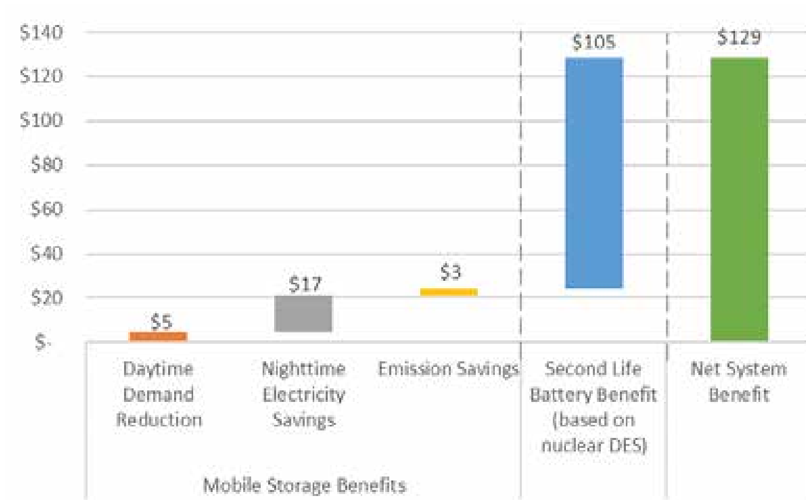
Potential mobile storage benefits of $25 million/year include:[96]

1) Discharging EV batteries during the day will reduce the daytime demand on the grid, which in turn will reduce the demand for natural gas-fired generation. The 140 GWh of EV battery discharge will reduce system costs due to the purchase of natural gas by $5 million.[97]
2) The 164 GWh of night-time charging will create new demand and new revenue for the system. The resulting $17 million of revenue will be a direct contribution if supplied by Ontario's hydro and nuclear base-load, which are driven by fixed costs.[98]
3) The ideal scenario of using clean night-time electricity to displace 140 GWh of natural gas-fired generation during the day could result in 55 kt less GHG emissions per year. At a carbon price of $50/tonne, this could result in a benefit of $3 million annually in avoided carbon taxes on natural gas-fired generation.

Using SLBs for storage also creates $105 million/year of potential savings:

4) SLBs should be less expensive than new Li-ion batteries. The potential availability of 4.4 GWh of EV SLB storage in 2035 could reduce the cost of batteries in a nuclear DES system by $105 million per year, effectively reducing the total system costs by that amount should a policy of displacing natural gas fired-generation be pursued.

Figure 22: Total Electricity System Impact
($M/year)



96 Other benefits not assessed by this report may also exist such as implications for optimizing the future supply mix as a result of the change in the daily demand profile and reducing the costs to government of the OER. These may offset avoided rate payer costs from the reduced daytime energy consumption.
97 The HOEP for daytime hours between 7am and 11pm when Ontario's large gas plants were operating was $34/MWh based on IESO Generator Output and Capability data from 2015 to 2017, and IESO Yearly Hourly HOEP OR Predispatch Report data from 2015 to 2017.
98 Night-time charging electricity off-peak TOU price of $101/MWh would be system revenue to the (see Section 3).

Benefits on a Per Vehicle Basis

Dividing the $25 million/year benefit from mobile storage shown in Figure 22 by the assumed 18,555 participating vehicles, suggests that the annual system savings from mobile storage could be $1,300/year per vehicle or $17,000 over the 13-year life of an EV, $2,000 of which arises from GHG emissions cost avoidance. The $105 million/year of second life benefits applies to the 93,000 batteries that would become available by 2035, as estimated earlier. This would contribute another $1,130/battery per year. For EVs participating in the mobile storage program, SLB use could add another $11,300/vehicle over the 10-year lifetime of an EV's SLB use.

EV batteries can reduce electricity system costs, improve the cost effectiveness of non-emitting DER solutions, and help reduce GHG emissions.

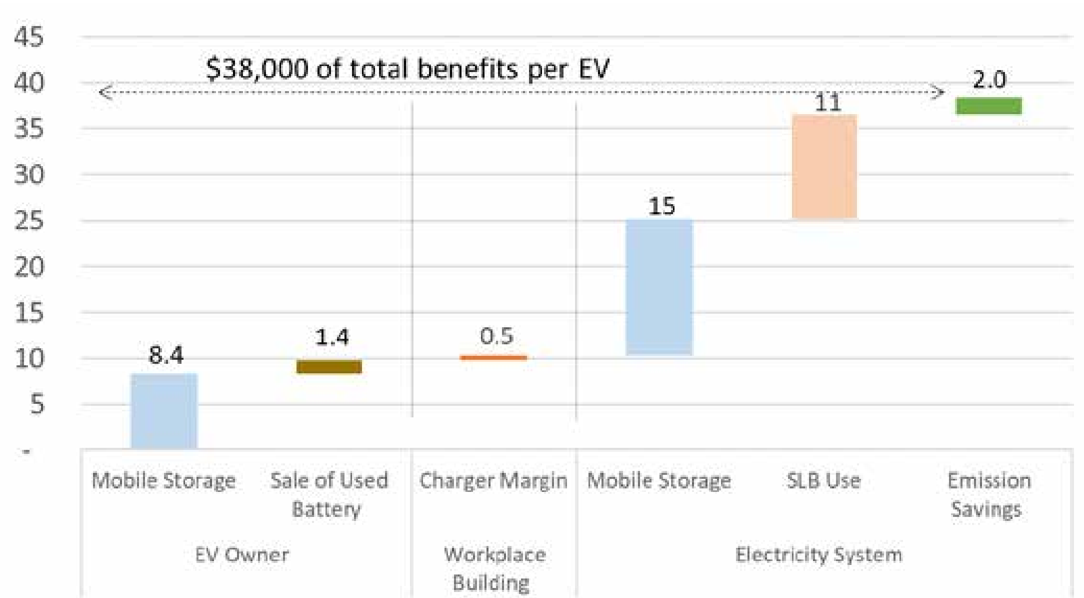
7. Summary and Recommendations

So much more than just a tool to drive a vehicle, EV batteries could offer a wide variety of positive effects for EV owners, the electricity system and the province as a whole. By making use of the EV batteries, EV owners can support their workplace building with low cost low emissions electricity through mobile storage and provide the electricity system with low-cost storage for DERs applications through SLB, both of which can help reduce the GHG emissions generated by natural gas to generate electricity. These factors also have the potential to lower costs in Ontario's electricity system, resulting in lower rates for consumers.

The best way to capture the value of mobile storage from a large number of commuter vehicles is at workplaces categorized as Class B electricity consumers.

Using a battery for mobile storage over an EV's useful life of 13 years and then a 10-year second life application as grid storage, an EV battery could create up to $38,000 of value. This value would be realized by EV owners, workplace buildings, and the electricity system in distinct ways as shown in Figure 23. The majority of the value created would accrue to the electricity system, much of which is from access to low-cost storage, and could amount to over $129 million/year by 2035 assuming a conservative EV forecast.

Figure 23: Lifetime Benefit of Using EV Batteries in the Electricity System
($000s per EV purchased in 2030)



This value arises in distinct ways for EV owners, workplace buildings, and the electricity system:

1) **EV Owners** can derive value from providing both mobile storage services and selling their used batteries for second life applications:

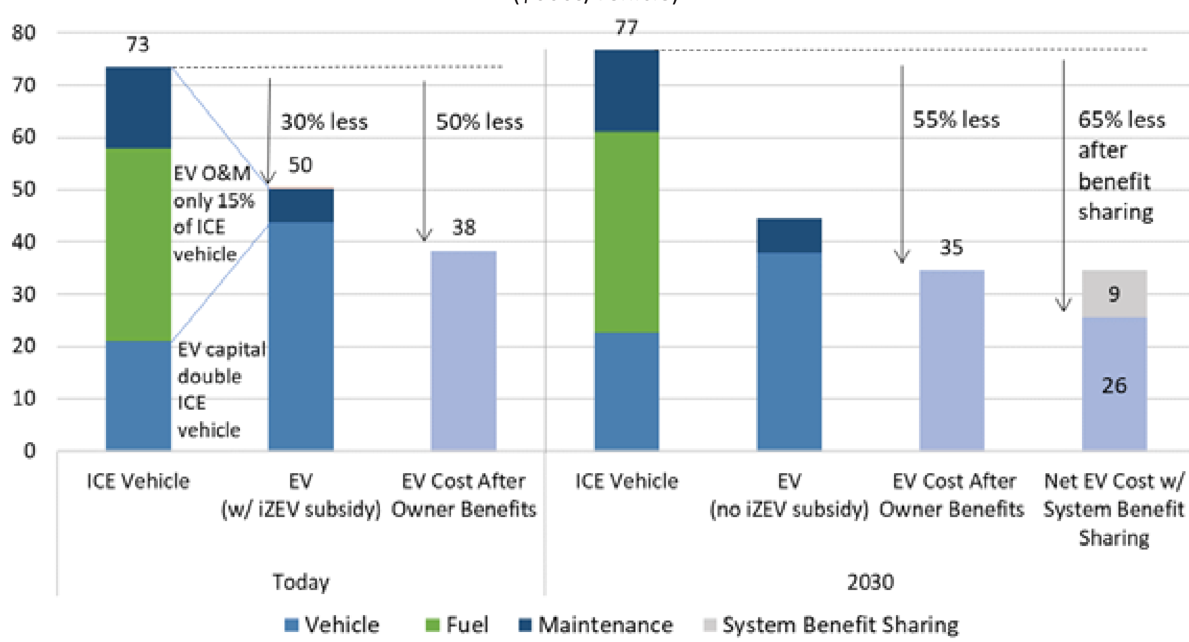
    a. ***Benefit from providing mobile storage*** – By charging EVs at home and at night using Ontario's inexpensive and virtually carbon-free base-load electricity supply, the cost of electricity under the current residential rate structure can be as low as $70/MWh. Under the potential federal Clean Fuel Standard (CFS) the cost could be reduced to practically zero if the CFS fully credits the carbon benefit of low emissions electricity at the targeted federal 2022 carbon price of $50/tonne. If EV owners sell this electricity to their workplace building at a 20% premium to the residential rates, EV owners could earn $8,400 over a 13-year life of their vehicle. Over 80% of this value to EV owners is estimated to arise from the assumed federal CFS.

b. ***Benefit from sale of used EV battery*** – EV owners could sell the battery at the end of its driving life to earn up to 20% of the battery's initial purchase cost – almost $1,350 in 2030.

While the initial capital cost of an EV is currently over double that of an equivalent gasoline vehicle, over a 13-year lifetime and taking benefit of the Federal $5,000 EV rebate, EV ownership could already be 30% less costly than traditional cars. Adding the benefits from mobile storage and an EV's SLB could make the lifetime cost of owning an EV 50% less expensive than owning a new ICE vehicle today. This comparison is provided in Figure 24 and will improve to a 55% cost advantage over the next 10 years as battery costs reduce. Furthermore, if 55% of the $28,000 electricity system benefit is shared with EV owners, the cost of EV ownership could drop to almost one third of an ICE vehicle by 2030 – a cost differential that has the potential to be a game changer for EV adoption.

Figure 24: EV Lifetime Ownership Cost Advantage

($000s/vehicle)



2) **Workplace Buildings** can save on electricity costs by purchasing electricity from EVs parked on their premises at less than 60% of the cost of their normal higher daytime electricity rates. This model applies to Class B businesses, whether operating under general service or TOU rates. Commuter patterns do not offer similar mobile storage benefits to Class A electricity consumers as most system peaks occur after a commuter's workday ends. Upgrading to the Level 2 bidirectional charger required for mobile storage could cost $669/year. A markup on the costs of the charger could be easily allocated to create a positive business case to install these bidirectional chargers.

3) **The Electricity System** can obtain $28,000 worth of benefits over the 13-year life of every EV participating in mobile storage and the 10-year life of SLBs for grid stationary storage.

a. Mobile storage reduces daytime demand, avoiding the use of natural gas, and makes more efficient use Ontario's base-load hydro and nuclear resources. Funding their use at night could generate $15,000 of worth savings per participating EV. By lowering daytime greenhouse gas (GHG) emissions, each EV could avoid $2,000 of carbon prices for ratepayers.

b. Second life EV batteries are expected to be 65% less expensive than brand new batteries. Integrating these into DER solutions could provide lower cost options for displacing natural gas-fired generation. Each EV could enable $11,300 of savings for the electricity system when integrating DER resources to reduce Ontario's GHG emissions.

The significant amount of system benefits could be shared with either EV owners, workplace buildings, or both in order to enable business models that would unlock this value.

Recommendations

To maximize the benefits of EV batteries for the electricity system, proponents of EVs should consider:

1) ***Developing a business model*** whereby the value elements described in this report can be best used to optimize EV adoption and further enhance benefits to the electricity system. Business model considerations could include grid ready EV batteries, updated warranty considerations, and more aggressive TOU pricing.

2) ***Advocating for the federal CFS*** to accurately credit the GHG emission content of the electricity system at the specific times when EVs are being charged.

3) ***Developing a more refined forecast of EV adoption*** in Ontario over the next five to 10 years, to reflect not only the implications of using EV batteries in the electricity sector, but also trends such as changing consumer buying behaviour due to concern over climate change and plans in the auto sector to move away from ICE vehicle production. Given the benefits of EV adoption, other infrastructure recommendations may be warranted such as building code requirements for enabling future integration of residential EV chargers and bidirectional chargers in the work place.

4) ***Advocating for the low-GHG emission solutions*** to Ontario's electricity capacity needs that are required to enable the value of the CFS. The forecast for Ontario suggests that increased natural gas-fired generation may eliminate EVs as a GHG emission reduction option.

Appendix A: Assumptions for EV and ICE Vehicle Costs

The assumptions used in the analysis of the cost of EV and ICE vehicle ownership are listed below, organized by the timeframe in question (today versus 2030). The sources used in each analysis are also provided.

Present-day

ICE Vehicles:

- Vehicle cost is the average MSRP of a Hyundai Kona and Chevrolet Cruze.[99]
- Fuel cost is calculated based on a rate of $1.20 per litre, average fuel efficiency of 8.5 litres per 100 km and a lifetime driving distance of 260,000 km, based on 20,000 km annually over a 13-year vehicle life.[100]
- Maintenance costs are around $100 monthly.[101]

EVs:

- Vehicle cost is calculated as the average MSRP of a Hyundai Kona and Chevrolet Bolt.[102]
- Fuel cost is calculated by assuming an average night-time electricity price of effectively $69/MWh less an equivalent offset by the anticipated CFS (see Section 3). If it was non-zero, the cost of electricity is multiplied by the average electric efficiency of the EVs used in this study and a lifetime driving distance of 260,000 km.[103]
- Maintenance cost is 42% of an ICE vehicle.[104]

2030

ICE Vehicles:

- Vehicle cost is the price of an ICE vehicle today plus a 7% price increase based on BNEF.[105]
- Fuel cost adds a $20/tonne carbon price multiplied by the average emission efficiency of ICE vehicles used in this study.[106]
- Maintenance costs are assumed to be the same as today.

EVs:

- EV vehicle cost is based on the average price of an EV today, minus the battery price reduction from 2030 to 2020. An EV battery is expected to represent 36% of a vehicle's cost in 2020 and only 18% in 2030.[107]
- Maintenance and fuel costs are assumed to be the same as today.

[99] Hyundai Canada, 2019; Chevrolet Canada, 2019a.
[100] Plug'n Drive, 2019; Jabs, 2018.
[101] Jabs, 2016.
[102] Chevrolet Canada, 2019b; Hyundai Canada, 2019.
[103] Plug'n Drive, 2019.
[104] MIT, 2019.
[105] BNEF, 2017.
[106] Government of Canada, 2019.
[107] BNEF, 2017.

Appendix B: Acronyms

APO – Annual Planning Outlook
BEV – Battery Electric Vehicle
BTM – Behind–the- Meter
BNEF – Bloomberg New Energy Finance
CAD – Canadian Dollar
CCGT – Combined Cycle Gas Turbine
CFS – Clean Fuel Standard
DER – Distributed Energy Resources
DES – Distributed Energy Storage
DR – Demand Response
EV – Electric Vehicle
GA – Global Adjustment
GHG – Greenhouse Gas Emissions
GS – General Service
GTA – Greater Toronto Area
GW – Gigawatt
GWh –Gigawatt Hour
ICE – Internal Combustion Engine
ICI – Industrial Conservation Initiative
IEA – International Energy Agency
IESO – Independent Electricity System Operator
km – kilometer
kt – Kilotonne
kW – Kilowatt
kWh – Kilowatt Hour
Li-ion – Lithium-ion
Mt – Megatonne
MW – Megawatt
MWh – Megawatt hour
MSRP – Manufacturer's Suggested Retail Price
NREL – National Renewable Energy Laboratory
OEM – Original Equipment Manufacturer
O&M – Operation and Maintenance
OPO – Ontario Planning Outlook
RPP – Regulated Price Plan
SLB – Second Life Battery
Strapolec – Strategic Policy Economics
TOU – Time-of-Use

Appendix C: References

AAA. EV Range Report. 2019.

Bank of Canada. Currency Converter. 2019. Retrieved from https://www.bankofcanada.ca/rates/exchange/currency-converter/

Battery University. 2019. Retrieved from https://batteryuniversity.com/.

BC Hydro. EV Road Trip Report. 2019.

BNEF. Lithium-ion Battery Costs and Markets. 2017.

BNEF. EV Outlook. 2019.

Brookfield. 2019. Retrieved from https://www.brookfieldproperties.com/.

Canadian Temperature Normals 1981-2000 Toronto Station Data.

CBC. Ontario Government Ends Electric and Hydrogen Vehicle Incentive Programs. 2018. Retrieved from https://www.cbc.ca/news/canada/toronto/ontario-electric-hydrogen-vehicle-charging-incentive-program-ends-1.4743579.

Chevrolet Canada. 2019 Chevy Cruze. 2019a. Retrieved from https://www.chevrolet.ca/en/cars/cruze.

Chevrolet Canada. 2020 Bolt EV. 2019b. Retrieved from https://www.chevrolet.ca/en/electric/bolt-ev.

City of Toronto. 2019. Retrieved from https://open.toronto.ca/dataset/green-p-parking/.

CleanTechnica. The Secret Life of an EV Battery. 2018.

Council for Clean and Reliable Energy (CCRE) Renewables-Based Distributed Energy Resources in Ontario: 3 Part Series of Unfortunate Truths. 2019.

Debnath et. al. Quantifying Economic Benefits of Second Life Batteries of Gridable Vehicles in the Smart Grid. 2014 Retrieved from https://doi.org/10.1016/j.ijepes.2014.05.077.

Element Energy. Batteries on Wheels: The Role of Battery Electric Cars in the EU Power System and Beyond. 2019.

Erdogan. A Fast and Efficient Coordinated Vehicle-To-Grid Discharging Control Scheme For Peak Shaving And Power Distribution SystemsEV Database. 2019 Retrieved from https://ev-database.org/compare/efficiency-electric-vehicle-most-efficient.

EVAdoption. EVs as Demand Response Vehicles for the Power Grid and Excess Clean Energy. 2018. Retrieved from https://evadoption.com/evs-as-demand-response-vehicles-for-the-power-grid-and-excess-clean-energy/.

Fleetcarma. Electric Vehicle Sales Canada: Year-End Update 2017. Retrieved from https://fleetcarma.com/electric-vehicle-sales-canada-2017/.

Government of Canada. Clean Canada: promoting the environment and growing our economy. 2019 Retrieved from https://www.canada.ca/en/environment-climate-change/services/climate-change/clean-canada.html.

Government of Canada. Federal CFS Proposed Regulatory Design. 2019.

Government of Ontario. Fix the Hydro Mess Act. 2019.

Greenbiz. RMI: What's the True Cost of EV Charging Stations. 2014. Retrieved from https://www.greenbiz.com/blog/2014/05/07/rmi-whats-true-cost-ev-charging-stations.

Greener Ideal. Hyundai Will Use "Second Life" EV Batteries to Store Energy. July 2018. Retrieved from https://greenerideal.com/news/hyundai-will-use-second-life-ev-batteries-store-energy/.

Hyundai Canada. 2020 Hyundai Kona. 2019. Retrieved from https://www.hyundaicanada.com/en/showroom/2020/kona.

IEA. Global EV Outlook. 2019.

IESO. Ontario Planning Outlook. September, 2016.

IESO. Market Renewal Benefits Assessment. April, 2017.

IESO. 2019 Class B GA Actuals. 2019.

IESO. Global Adjustment Class A Eligibility. 2019. Retrieved from http://www.ieso.ca/en/Sector-Participants/Settlements/Global-Adjustment-Class-A-Eligibility

IESO. Annual Planning Outlook. January, 2020.

IESO. Preliminary 2019 Long-Term Demand Forecast. January, 2019.

IESO. Yearly Hourly HOEP OR Predispatch Report, 2017. Retrieved 2019.

IESO. Yearly Hourly HOEP OR Predispatch Report, 2016. Retrieved 2019.

IESO. Yearly Hourly HOEP OR Predispatch Report, 2015. Retrieved 2019.

IESO. Hourly Demand Report, 2015. Retrieved 2016.

IESO. Hourly Demand Report, 2016. Retrieved 2019.

IESO. Hourly Demand Report, 2017. Retrieved 2019.

IESO. Generator Output and Capability, 2017. Retrieved 2018.

IESO. Generator Output and Capability, 2016. Retrieved 2017.

IESO. Generator Output and Capability, 2015. Retrieved 2016.

IESO. Ontario Electricity Rebate to take effect on November 1. October 2019. Retrieved from http://www.ieso.ca/en/Sector-Participants/IESO-News/2019/10/Ontario-Electricity-Rebate-to-take-effect-on-November-1

Impark. 2019. Retrieved from https://impark.com/toronto/.

Innovate UK. Requirements for Market Scale-up (WP4) Public Report. 2019.

Inside EVs. Nissan Introduces $2,850 Refabricated Batteries For Older LEAF. 2019. Retrieved from https://insideevs.com/news/337360/nissan-introduces-2850-refabricated-batteries-for-older-leaf/.

Inside EVs. Nissan LEAF Batteries To Power Soccer Stadiums In Europe. June 2019. Retrieved from https://insideevs.com/news/356320/nissan-leaf-batteries-power-soccer-stadiums/.

Jabs. How much to budget for Car Maintenance? 2016. Retrieved from https://www.fivecentnickel.com/how-much-to-budget-for-car-maintenance/.

Lantz. Longer vehicle life expectancy is a testament to research and technology. 2018 Retrieved from https://www.wheels.ca/news/longer-vehicle-life-expectancy-a-testament-to-research-and-technology/.

Leggett. How Your Electric Vehicle Could be a "Virtual Power Station". 2017 Retrieved from https://www.bbc.com/news/business-42013625.

MIT. Insights into Future Mobility. 2019.

Nissan Global Newsroom. Nissan to create electric vehicle 'ecosystem'. 2018. Retrieved from https://global.nissannews.com/en/releases/release-860852d7040eed420ffbaebb2241c3ea-nissan-to-create-electric-vehicle-ecosystem.

NREL. Critical Elements of Vehicle-to-Grid (V2G) Economics. 2017a.

NREL. Vehicle-Grid Integration: A Global Overview of Opportunities and Issues. 2017b.

Nuvve. Giving Used Batteries A Second Life. January 2019. Retrieved from https://nuvve.com/2019/01/31/giving-used-batteries-a-second-life/.

OEB. RPP. 2019.

Ohm Home. EV Charging Station Cost. Accessed from https://www.ohmhomenow.com/electric-vehicles/ev-charging-station-cost/.

Ontario Power Authority. 2013 Long-Term Energy Plan (LTEP). 2013

Park Indigo. 2019. Retrieved from https://ca.parkindigo.com/.

Plug'n Drive. Accelerating the Deployment of Plug-In Electric Vehicles in Canada and Ontario. 2016

Plug'n Drive. Electrify your Ride. 2019.

Pollution Probe. 2019.

PV Magazine, 'Second-life' EV batteries could drive low-cost storage sector, says BNEF report. 2016. Retrieved from https://www.pv-magazine.com/2016/08/25/second-life-ev-batteries-could-drive-low-cost-storage-sector-says-bnef-report_100025911/.

PV Magazine. Second-life EV battery market to grow to $4.2 billion by 2025, August 2018, Retrieved from https://www.pv-magazine.com/2018/08/03/second-life-ev-battery-market-to-grow-to-4-2-billion-by-2025/.

Rate Hub. How Much Does an Electric Car Charging Station Installation Cost? Retrieved from https://www.homeadvisor.com/cost/garages/install-an-electric-vehicle-charging-station/#installation.

Smart Energy. Bringing a second life EV batteries. June 2019. Retrieved from https://www.smart-energy.com/industry-sectors/electric-vehicles/bringing-a-second-life-ev-batteries/.

Statistics Canada. Long Commutes to Work by Car. 2016.

Strapolec. Renewables-Based Distributed Energy Resources in Ontario: A cost and Implications Assessment. 2018.

UCLA. Financial Viability of Non-residential Electric Vehicle Charging Stations. 2012.

Wired. GM's Using Old Chevy Volt Batteries to Power a Building. June 2015. Retrieved from https://www.wired.com/2015/06/gms-using-old-chevy-volt-batteries-power-building/.

Contact Information

Strategic Policy Economics

Marc Brouillette
Principal Consultant
(416) 564 - 4185
marc@strapolec.ca

www.strapolec.ca