Economic and technical contexts of electric vehicle-to-building bi-directional charging

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Definitions

V2B: Vehicle to Building – Electric vehicles interacting with the home energy system based on scheduled demand requirements.

PHEV: Plug-in Hybrid Vehicle – A vehicle that can operate on a battery as well as an internal combustion engine based on working modes.

CHAdeMO – Trade name of a fast-charging method for battery electric vehicles via a special electrical connector commonly used in Japan.

CCS: Combined Charging System – Standard for charging electric vehicles more commonly used in North America and Europe.

BEV: Battery Electric Vehicle – A vehicle operating on power drawn from an onboard battery pack.

TOU: Time of use – A pricing mechanism offered by utilities where the cost for electricity is based on the time of the day.

Executive Summary

Electric vehicles (EVs) are increasingly seen as viable energy storage assets. Managed charging and energy storage can reap benefits specifically since utilities worldwide are looking at time of use rates. The use of the EV battery to power homes through the vehicle-to-building (V2B) concept can provide economic benefits to EV owners and help offset the significant capital cost of EVs. Further, it can also improve resiliency towards power outages. The V2B concept can also help utilities by reducing the demand during peak hours.

The Rocky Mountain Institute has estimated that electrifying all the light-duty vehicles on roads today would increase annual electricity demand by about 25% — which does not include medium and heavy-duty applications like freight and public transit with a host of other applications. Similar implications of large-scale transport electrification will be seen in Canada in general and B.C. in particular.

However, many critics of EVs are worried that the exponential increase in EVs over the next decade will overload utility capacities. However, to meet this rise with bi-directional charging schemes, it will take two types of success: (1) Developing V2B/V2H technology itself and (2) Elevating EV drivers' willingness to participate in V2B/V2H programs.

To understand the value streams V2B can provide, it is essential to understand the scale of energy storage that EV batteries can offer with high EV adoption rates in British Columbia. Furthermore, it is necessary to quantify the savings it can bring to EV owners. This will help uncover the potential of bi-directional charging and develop schemes to address the ever-growing EV demand. This report looks to understand the technical contexts of V2B, unfold the storage capacity through EVs, and assess the cost savings of home/vehicle owners concept based on projections for EV uptake in British Columbia.

Introduction

The current climate change targets have augmented the transition towards carbon-neutral transportation systems. Hence, electric vehicles (EVs) are viewed as the most desirable instruments to reduce the automobile industry's dependence on fossil fuels as they can integrate energy from clean sources for transportation. The electricity grid with a high penetration of renewable energy can enable travelers to travel free of emissions using state-of-the-art EVs. Due to population growth, the extensive EV demands at peak times and increased household/workplace electricity use have led to higher utility infrastructure investments.

Further, the adoption of the smart power grid concept has seen EVs being explored as energy hubs since they can be connected to the building energy system by implementing the vehicle to building (V2B)/ vehicle to home (V2H) concept. EVs interacting with the home energy system based on scheduled demand requirements can significantly impact society. Cars remain in parking spaces 95% of the time, thus with careful planning and the proper infrastructure, parked and plugged-in EVs could become mass power banks, providing potential cost savings to customers (Fortune, 2019). They can also power households and integrate renewable energy with storage systems. However, the successful implementation and widespread adoption of V2B presents a multi-faceted problem.

The availability and ease of access to the recharging infrastructure are critical enablers for the widespread commercialization of EVs. EV penetration is dependent on competitive capital costs, affordable utility tariffs, and social awareness. However, extensive electric demands at peak times and utility infrastructure investments with population growth are key challenges, which required the attention of the decision-makers. Several social and economic factors must be considered in the planning of EV recharging infrastructure and the demand side management of electricity for growing EV demands. However, the costs for setup, operation, and maintenance are shrouded due to vendor concerns around protecting proprietary information and competitive advantage; it has been challenging to identify and compare these costs across various vendors and installations.

Background

The EV market is one of the fastest-growing technology sectors in the global economy. EV projections state that they may have a market share amongst new sales of about 50% by 2030 (Chris Nelder, 2016). The future disruptive innovations at the component and system levels have given a significant impetus to rapid and unpredictable growth. The implications of the rapid growth on electric utilities, customers, EV owners, service providers, and regulators are far-reaching.

Based on existing studies (Taljegard, 2017), it has been seen that in 2030 with 23 % market penetration in California; without controlled charging, the peak load will increase by 11.14%, while with intelligent charging, the peak load would increase by 1.33% (Donadee et al., 2019). The current EV adoption rates have not affected the peak loads in BC; however, EV charging will impact the peak loads with massive EV uptake predicted. Hence, smart charging with managed charging would be essential to address the loads in the future.

Literature shows that EVs can be used as a part of the building level electricity distribution network to store and distribute electricity from the vehicle battery (Tuttle et al., 2013)(Galus et al., 2013), which allows the use of vehicle-to-building protocols (Sarker et al., 2015); (Erdinc et al., 2014). This will create a bi-directional electricity flow from the vehicle to the building energy system. The current transmitted can smoothen the electricity peak to reduce the cost to the consumers at the building or home. Further, during the recent power outage in Texas, EV owners used their charged vehicles to intermittently use the car's heater in temperatures of around 0°C.

Moreover, monitored and controlled use of V2B technology will,

- Avoid charging at peak tariffs and times of high demand.
- Provide extra battery storage capacity for energy generated using on-site renewable energy sources such as solar photovoltaics and wind.
- Provide a platform to reduce peak electricity demands.

The combined energy storage from sales of a single, modest selling EV model is greater than the entire stationary storage industry, including all U.S. stationary storage deployments by all companies in all sectors.

The Nissan LEAF has ~16K average annual sales, about 1/10th the sales of a Nissan Sentra or Tesla Model 3. Yet, these EVs on the road today represent almost twice as much energy storage as all stationary systems in the U.S. as of 2019. Assuming several bidirectional EVs enter the market at sales comparable to Sentra/Model 3 – energy storage rapidly becomes an abundant resource, considering infrastructure to access it (Fermata Energy, 2020).

Need for V2B/V2H

Increase in EVs on the road: EV cost is a significant barrier to widespread adoption. Because most electric vehicles are parked over 95% of the time, they can earn money by providing energy storage, possibly reducing the total cost of ownership of an EV below that of an internal combustion equivalent (Fortune, 2019).

Increased renewable energy penetration: Intermittent wind and solar energy require energy storage to provide continuous service when power is needed. EVs can cost-effectively provide this energy storage when parked. Off-gird solar PV installations in homes have used stationary EV batteries to store energy and utilize energy as needed.

Applications of V2B/V2H

- Electricity Bills Savings + Revenue Generation: Site buildings connected to chargers can reduce monthly demand charges and other costs by discharging fleet vehicles a few times a month. Further, charger systems earn revenue for fleets by providing services when the car is parked.

- Disaster Resiliency and Backup Power: EV batteries can be used for buildings during times of outage. They can provide power to crucial infrastructure by working together with on-site generators and solar. Further, EVs can be driven to safe areas during storms and then returned to offer a mobile energy supply. In BC, in rural areas, subject to more frequent power outages, EVs can provide emergency power instead of a diesel-powered generator.

- Renewable Energy Optimization: EVs can charge when the grid has much renewable energy generation and not enough demand. EVs can then discharge stored renewable energy to supply energy later when renewable generation is low.

As we move toward this future of bidirectional EV charging, three essential elements need to happen for widespread adoption. First, automobile manufacturers need to introduce more vehicles that are capable of bidirectional charging. Second, industry regulation and the energy economy must be adapted to provide standardization and a viable business model. Finally, EV charging station manufacturers need to develop more accessible bidirectional charging technology for scale.

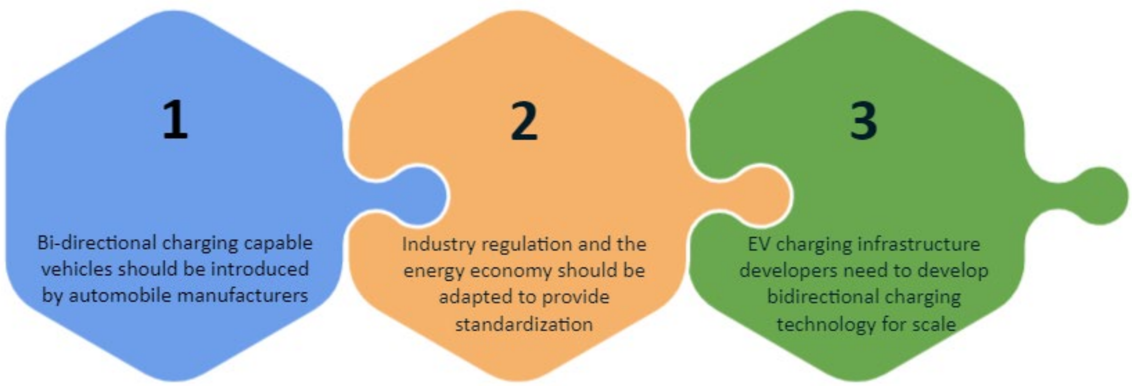

Figure 1. Pathway to widespread adoption of bi-directional charging

Bi-directional charging capable vehicles

Since 2013, the Nissan Leaf is the only car in Canada that is capable of bi-directional charging. Additionally, other automakers using the CHAdeMO standard, including Mitsubishi's Outlander PHEV, have been added to the global list of participants. Due to CHAdeMO protocol and connection, these early adopters have made this capability a reality very early on.

Both automakers have proven this concept by bringing forward demonstration projects like Nissan's Power Supply Ecosystem projects and Mitsubishi's Dendo Drive House. The real turning point will be when vehicles utilizing the CCS protocol and connector begin to enable this functionality.

Volkswagen (VW) unveiled more aggressive plans to compete with energy providers were unveiled by Volkswagen (VW) in 2020, which included tapping into the 350 gigawatt-hours of storage capacity in its electric car batteries. In addition to signaling Volkswagen's shift toward EVs becoming popular, Volkswagen's action may also signify a fundamental shift in EV business models. As a part of the bidirectional charging movement, it joins Nissan and Mitsubishi.

Recently, Ford's announcement of its 2022 Ford F-150 Lightning pickup truck has rekindled the industry's interest in bi-directional charging. The Lightning can be used as a powerful generator. It can offload up to 9.6 kW of power via eight 120V outlets and one 240V outlet. Using the battery, the Lightning can act as a power source for an entire home.

As the most extensively used DC charging protocol in North America, CCS has the potential to entice all other manufacturers to join the field. It has already been highlighted as a vital component of the next five-year CCS vehicle technology plan. Honda and BMW, which employ the CCS standard, have already piloted bidirectional charging. With other big consumer brands like VW declaring a substantial stake in bidirectional charging and energy management, this will be the tipping point for broad adoption from automakers in the coming years.

Bi-directional charging equipment

Bi-directional charging has not been widely seen in society since many questions are to be answered regarding its efficacy and benefit. Pilot studies are being undertaken that are aimed at understanding the use cases bi-directional charging can unfold.

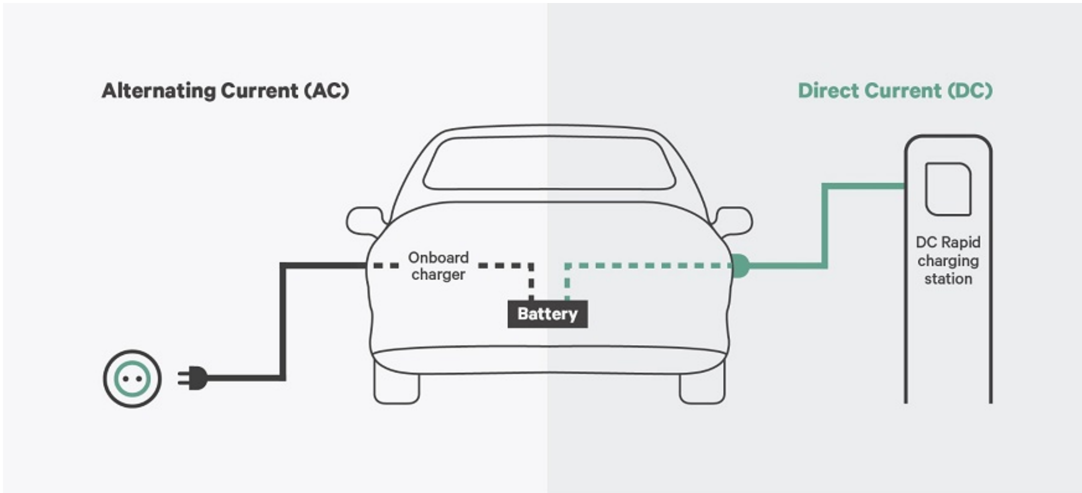

Figure 2. AC v/s DC bi-directional charging schemes (Source: Wallbox)

AC bi-directional charging

With this technology, the bi-directional charger is placed in the car itself. The vehicle can be connected to the grid through a cable. At the moment, different car manufacturers are experimenting with this technology. The most significant advantage of onboard bi-directional chargers is that car owners do not pay for an expensive DC charging station.

In the current state, most vehicle OEMs do not equip their vehicles to allow bi-directional energy transfer as it may lead to battery degradation. The cost for electronics in the car is intrinsically more expensive due to the strict automotive requirements and limited space. In addition, the electronics such as power converters, battery packs, and charging cables in the car are liquid-cooled. This way of cooling causes noise due to the pump. While driving, this is not a problem, but when the vehicle is parked next to your house and the V2G operation starts, the noise can cause discomfort. Another drawback is that the efficiency of the AC onboard charger. The round-trip efficiency will be (typically) 10% lower than for an off-board V2G. AC bi-directional charging is tricky at this stage as the price of the vehicle would be high due to the cost of the AC to DC converter onboard. Further, cheaper AC-DC converters used in most vehicle models lead to an imbalance in the power supply.

DC bi-directional charging

With off-board charging, the bidirectional charging hardware is not in the car but in the charging station. Nissan has committed to off-board bi-directional charging using the CHAdeMO protocol. CharIN is also working on a bi-directional DC protocol for CCS. When off-board charging is enabled, one of the most significant benefits is that charging is faster and more efficient. A bonus is the low noise level.

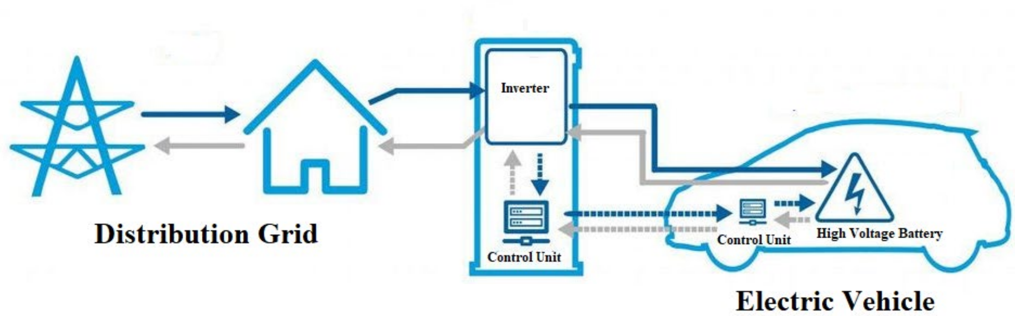

Figure 3. Schematic of DC bi-directional charging

The most significant disadvantage is the price, mainly due to the expensive DC cable and plug and charger. Further, since most of the charging at home happens through an AC charger, there are currently no available DC chargers for homes (PR-Electronics, 2021).

Chargers

In North America, Wallbox works with utilities, auto manufacturers, and other partners to test and validate Quasar (charger) to ensure compatibility with regional electrical standards and EV makes and models. The Quasar is a DC charger with a CHAdeMo or CCS plug for home charging. It is expected to go into production by late 2022.

Fermata Energy's bidirectional charging system was the first to be certified to a new North American safety standard from Underwriters Laboratories (UL), UL 9741, the Standard for Bidirectional Electric Vehicle Charging System Equipment. As a result, the system is the first commercially available charger to meet the North American bidirectional EV charger requirement. However, its production schedule is yet unknown (Utility Dive, 2021).

EV Adoption in British Columbia

B.C. is gaining ground in other jurisdictions in Canada as well as jurisdictions in North America. In 2020, new ZEV registrations accounted for 8.4 percent (15,211) of total new vehicle registrations in British Columbia, up from 7.8 percent the previous year. Nonetheless, new ZEV registrations fell by 1,769 in 2020 compared to the previous year. In 2020, about four-fifths of new ZEVs registered in British Columbia were BEVs (79.5 percent). Victoria had the most new ZEVs (12.9 percent, or 1,222 vehicles), followed by Vancouver (10.9 percent, or 10,594 vehicles)(Province of British Columbia, 2020; Statistics Canada, 2021a).

The highest concentrations of EVs can be found in British Columbia's major urban areas, such as Metro Vancouver and the Capital Region District on Vancouver Island. West Vancouver, North Vancouver, Port Moody, Coquitlam, Richmond, Vancouver, Port Coquitlam, and White Rock are among the municipalities in Metro Vancouver with more than 2% EV ownership. West Vancouver stands out with more than 4% EV adoption, maybe due to its unusually affluent demographic. Sidney (North Saanich) and Victoria have the most significant rate of EV adoption on Vancouver Island (Antweiler, 2021).

When only the 2020 and 2021 model years of new vehicles are considered in municipalities with at least 1,000 new vehicles of all sorts registered, numerous localities have EV adoption rates that exceed 10%. West Vancouver, Victoria, North Vancouver, Delta, Vancouver, Port Coquitlam, Langley Township, Coquitlam, and Port Moody are among them. Several other communities, like Burnaby and Surrey, are not far behind. In less densely populated parts of British Columbia, such as Interior BC and Northern BC, EV adoption rates are much lower (Antweiler, 2021).

The high EV adoption rates are seen as a result of the rapidly developing EV charging network across BC, increased awareness of EVs, the evolution of technology, and the provincial government grants for new EVs. Further, another contributor is to British Columbia's Zero-Emission Vehicles Act (ZEV Act) passed on May 30, 2019. The ZEV Act requires automakers to meet an escalating annual percentage of new light-duty ZEV sales and leases, reaching: 10% of light-duty vehicle sales by 2025, 30% by 2030, and 100% by 2040 (Government of British Columbia, 2020).

To project the EV uptake in British Columbia, two scenarios have been developed: Scenario I (pessimistic scenario), considering 30% ZEV sales by 2030 in accordance with the ZEV Mandate, and Scenario II (optimistic scenario), considering 50% ZEV sales by 2030. Scenario II has been included since it aligns more closely with the CAGR for recent years and assumes technology evolution (with pickup trucks and vans starting in 2023-2025).

The scenarios were projected using a quadratic curve fitting approach based on EV uptake over the past years (data obtained from Statistics Canada)(Statistics Canada, 2021b).

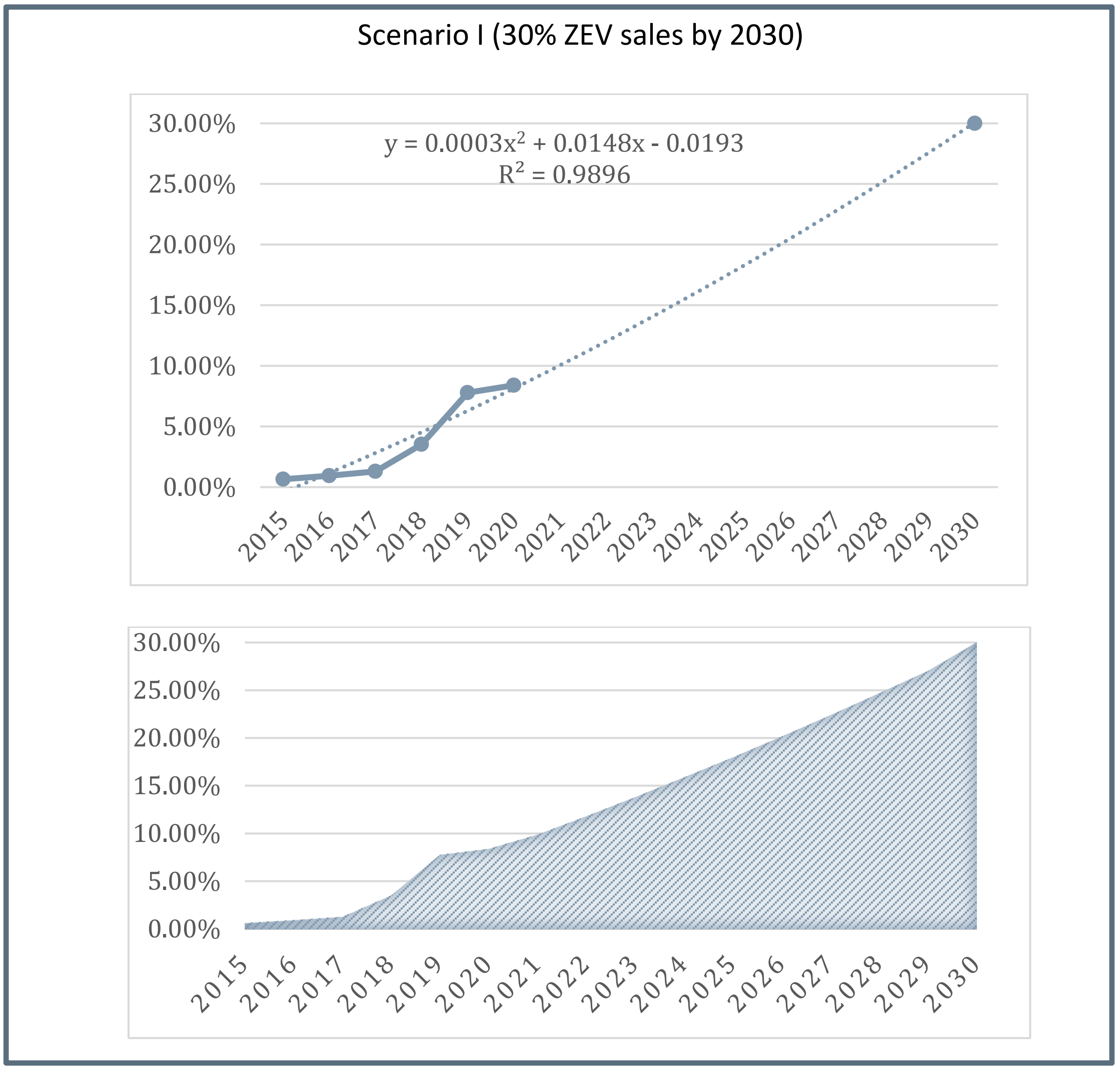

Figure 4. Scenario I- 30% ZEV sales by 2030

Scenario II (50% ZEV sales by 2030)

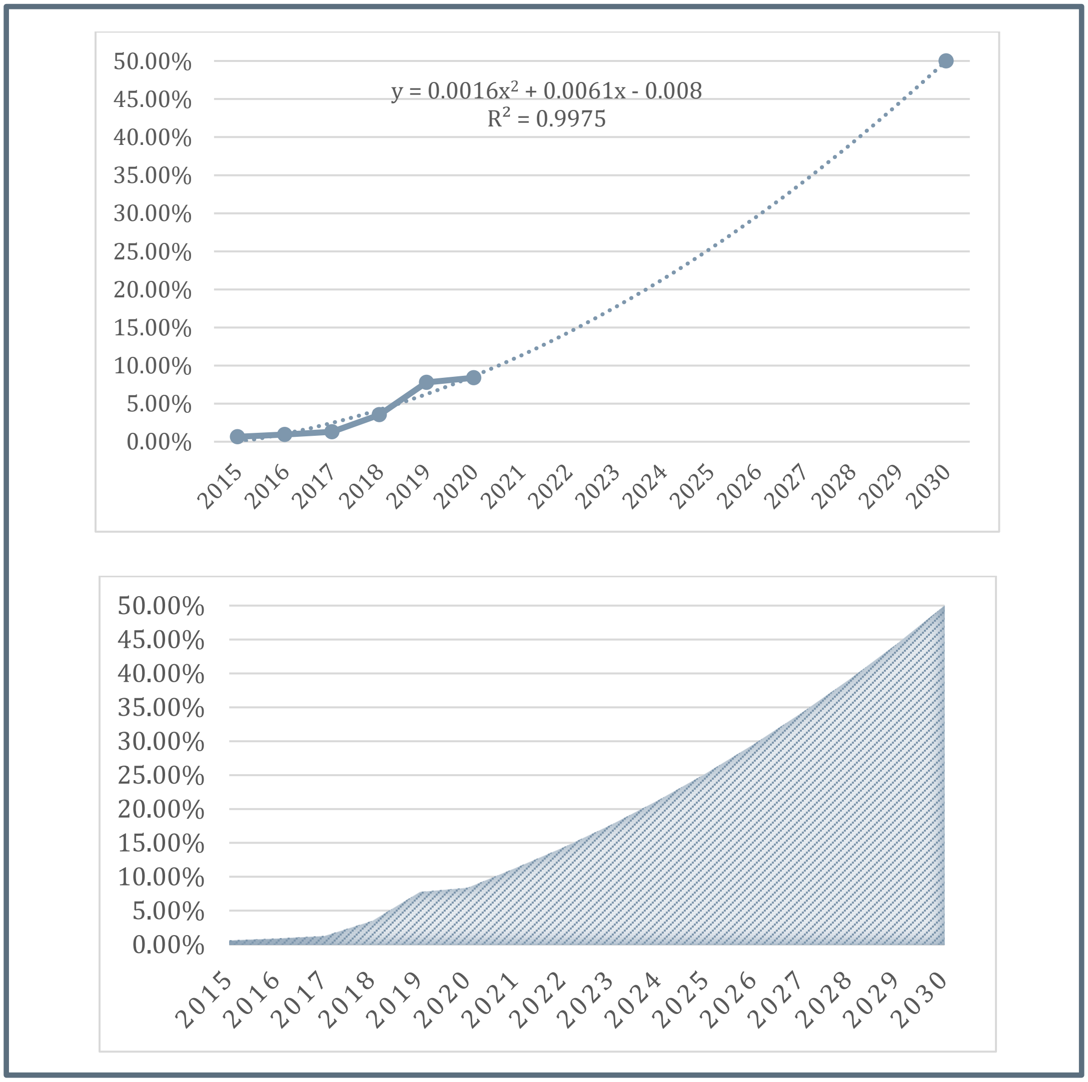

Figure 5. Scenario II- 50% ZEV sales by 2030

Based on the developed scenarios, as shown in Figure 6, the sales of ZEVs (around 80% BEVs) will increase due to B.C.'s ZEV Mandate, and the number of on-road ZEVs will be 515,054 (Scenario I) and 738,468 (Scenario II) by 2030.

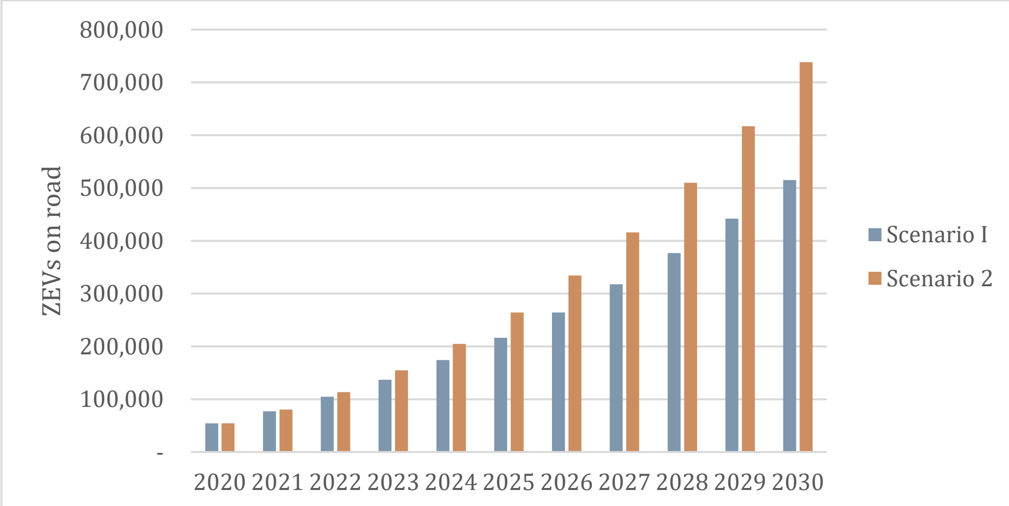

Figure 6. ZEVs on the road in B.C. based on Scenario I and Scenario II

Battery Size Trends

Over the years, there has been a massive increase in electric vehicle batteries' size and capacity, leading to a rise in the range of the vehicles. The range of the Nissan LEAF has increased from 163 km (24 kWh battery) in 2012 to 363 km in 2021 (60 kWh battery). Further, since vehicles are parked 95% of the time, these large battery packs can store energy and provide monetary benefits to EV owners.

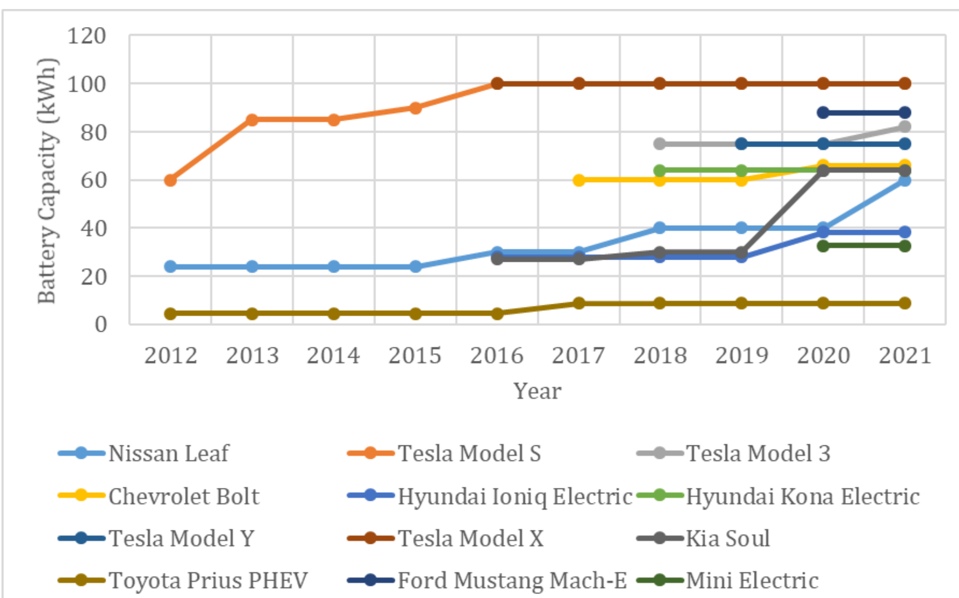

Figure 7. Increase in battery capacity for popular EV models

As seen in Figure 7, there has been a massive increase in battery capacity since 2012; the capacity of the Tesla Model S has increased from 60 kWh (2012) to 100 kWh (2021). The capacity of the Nissan LEAF has doubled, rising from 24 kWh (2012) to 60 kWh (2021). The capacity of the battery packs is expected to increase soon as advancements in battery research are expected. The battery pack forms a significant cost component of the electric vehicle contributing to 21% of the vehicle cost (Bloomberg New Energy Finance, 2021). Further, as the cost of energy storage onboard vehicles reduces, the cost parity between electric vehicles and internal combustion engine vehicles will be seen.

Electric Vehicle Battery Cost Trends

Battery electric vehicle (BEV) pack prices are $126/kWh on a volume-weighted average basis, according to BNEF's 2020 Battery Price Survey. At the cell level, typical BEV prices were just $100/kWh. This means that the battery pack part of the overall price accounts for 21% of the total cost on average. At this pricing point, manufacturers should be able to develop and sell mass-market EVs at the same price (and with the same margin) as equivalent internal combustion vehicles in various areas. This assumes no subsidies are available, although actual pricing tactics will differ by carmaker and location (Bloomberg New Energy Finance, 2021).

With the increase in demand for energy storage, the battery pack price is expected to decrease drastically in this decade. Price reductions in 2020 are seen due to increasing order sizes, growth in BEV sales, and the introduction of new pack designs. New cathode chemistries and falling manufacturing costs will drive prices down in the near term. The values for battery pack prices for the period 2021-2025 are extrapolated based on the previous five-year battery price trends, as shown in Figure 8.

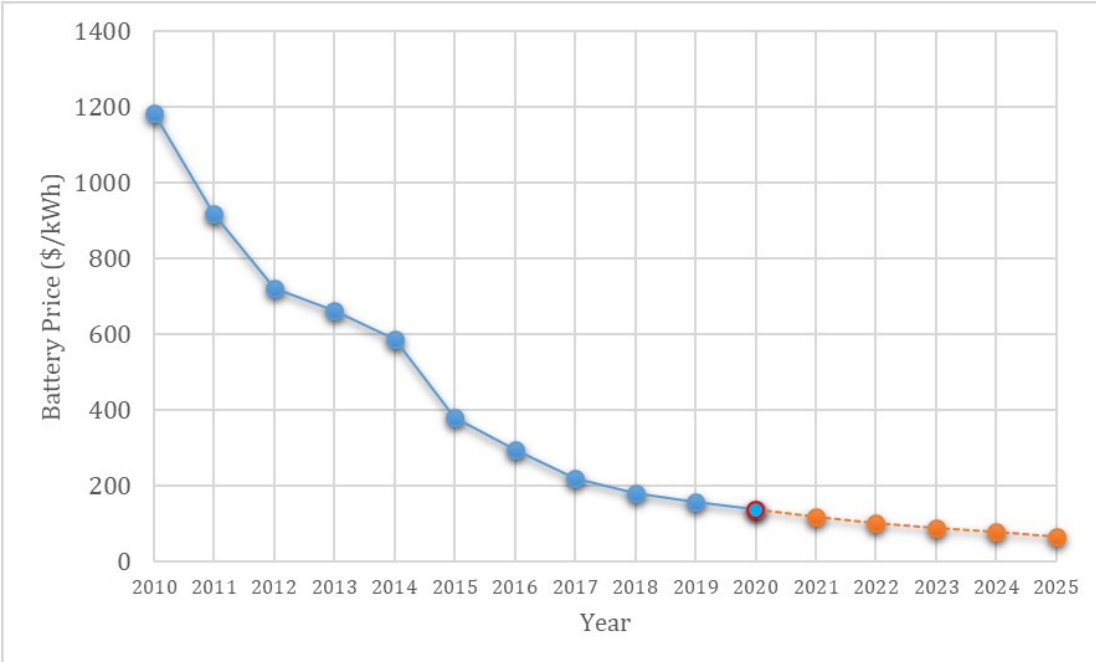

Figure 8. The projected reduction in battery prices over the years

The increase in EV demand will eventually increase the demand for onboard storage battery packs, leading to mass manufacturing of these batteries. The large-scale demand, technological advances in battery chemistry, and manufacturing improvement will eventually bring down battery prices. Hence, the EV batteries can be used for purposes other than powering the EVs.

Storage capacity added through EV batteries

The increased uptake of EVs can allow the usage of EV batteries as distributed energy resources by implementing the vehicle-to-building or vehicle-to-grid concept. Based on the above scenarios, by 2030, the total grid storage capacity through EVs is shown in Figure 9.

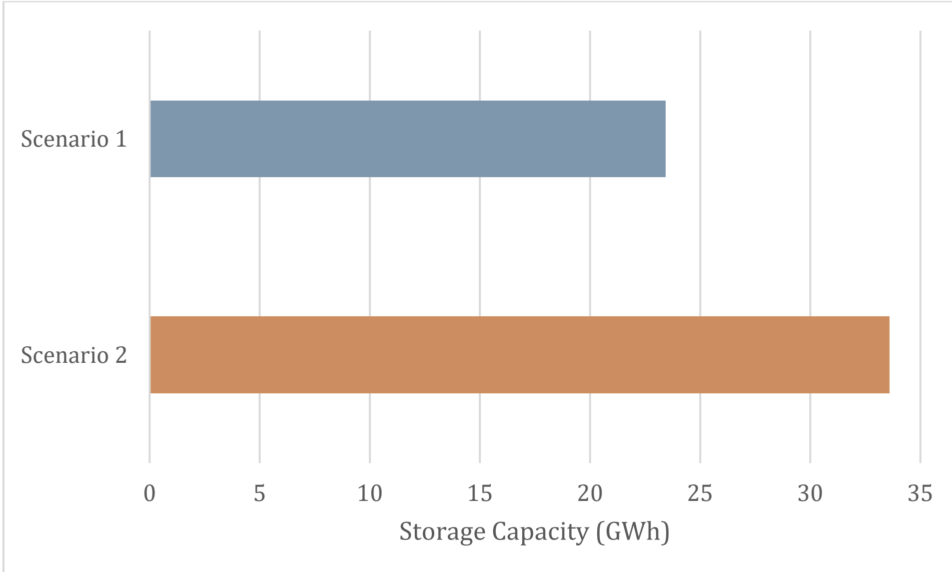

Figure 9. Storage capacity added through EV batteries

The storage capacity added due to EV batteries in 2030 has been calculated considering the number of ZEVs on the road in Scenario I and Scenario II with a battery capacity of 70 kWh (current average) and considering that 65% of the battery will be available for energy storage, while the remaining capacity may be needed for travel needs of the EV owners.

Charging Infrastructure for V2B

When a vehicle owner links a car to a building or house, the building energy management system can regulate the charging and discharging of the vehicle's battery. Although each individual car provides relatively little energy and is not constantly connected to the grid, a large number of vehicles aggregated together can offer sufficient dependable capacity. (Briones et al., 2012). The primary physical elements of V2B systems are, 1) The electric vehicles equipped with battery-management software and hardware that allow a two-way flow of electricity; 2) Communication technologies mediating between vehicles and homes; and 3) Electric vehicle supply equipment (EVSE) or alternative technologies connecting vehicles to homes. In standard connections between the home and vehicles, power flows from the house to the vehicle to charge the vehicle's battery (Norris et al., 2020). In order for energy to flow from the car to the home, the direct-current (DC) battery output must be converted to alternating-current (AC) power at the appropriate frequency to match the AC power supply. Figure 10 demonstrates the modes of bidirectional charging.

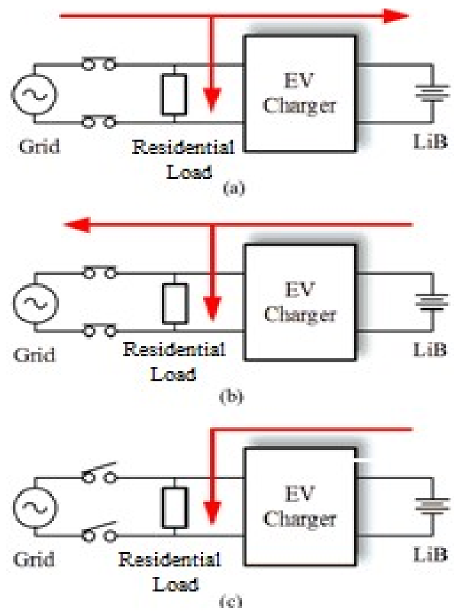

Figure 10: Bi-directional charging modes (Ammous et al., 2018)

Implementation of V2B requires communication technologies and algorithms to sense status, determine whether vehicles should be providing or drawing electricity from home at any given time. It is further essential to ascertain the status and availability of vehicles for delivering the services needed (Chris Nelder, 2016). Financial incentives can be given by tracking the services provided by vehicles so owners can be paid for making their vehicles available in buildings or condos. Numerous modeling studies have been conducted to examine how cars may be aggregated to maximize economics while accounting for driving behavior and conforming to laws governing owners' needs for vehicle availability. Other research has focused on finding the best placement and needs for communications hardware and software. Currently, EVSE (Electric Vehicle Supply Equipment) owners may pay a fee from $100 to $900 annually, depending on the type of EVSE and the unit's features, for network communications and back-office support. The interaction of the vehicle with the building management system requires the installation of make-ready hardware for feeding power(Chris Nelder and Emily Rogers, 2019).

Data Collection

As utilities begin to move beyond the early pilot stage and start building or supporting the development of charging infrastructure for electric vehicles (EVs) at scale. It is increasingly vital for utility regulators and utility procurement agents to understand what components should and do cost to ensure that ratepayer dollars are invested wisely and in the public interest. This is particularly true where utilities own, operate, and recover the cost of non-residential EV charging infrastructure through the general rate base (National Renewable Energy Laboratory, 2017).

There is an urgent need for current and comprehensive data about the costs of charging infrastructure. However, the wide variability in the price of nearly every element of charging infrastructure and vendors' desire to protect proprietary business practices to maintain their competitive advantage has been challenging to identify and compare these costs across various vendors and installations.

While hardware costs today appear to be high and present a challenging business case for V2B, it should be acknowledged that V2B is an emerging technology, and significant cost reductions can be expected with standardization and mass production.

According to the Rocky Mountain Institute, non-networked charging station hardware costs are falling at typical rates for technologies as manufacturers learn how to refine their production processes. Charging station hardware costs will likely continue to decline without any particular intervention or regulatory guidance; as the EV charging industry matures, demand for charging infrastructure increases, and manufacturers scale up production. The cost of a 7.7 kW unidirectional Level 2 charger has gone from USD 1,200 (2010) to USD 400 (2019) (EVConsult, 2018).

Unlike the trends in hardware costs, soft costs for non-residential charging stations—such as the costs of acquiring permits, meeting local building codes and participating in extended processes for obtaining utility interconnections, easements, and local building permits—are not so easily reduced. Further, the soft costs are frequently cited as more significant cost drivers than charging station hardware. Soft costs were also identified as some of the most problematic and unpredictable costs that developers of charging networks encounter (Chris Nelder and Emily Rogers, 2019).

It is difficult to quantify cost data due to the following reasons:

- In most data publicly available data from the body of knowledge, many components of chargers and their installations were aggregated, obscuring costs at the component level.
- Vehicle chargers come in such a wide variety of configurations; it can be challenging to compare their costs. For example, there is a range of USD 380 to USD 4,900 for Level 2 chargers, which reflects differences such as residential or commercial installations, power ratings (2.88–19.2 kW), levels of weatherproofing, numbers of ports, payment systems, communications systems, and types of cable management systems. Without distinguishing the costs of individual components of each of these chargers because of the way they are manufactured or procured or to obtain cost data from multiple vendors for a specific configuration of a charger, comparing charger costs is challenging.
- Installation costs were often calculated and reported on a per-site basis. Because utilities and installers calculate installation costs such as trenching based on a specific site and number of chargers, it was challenging to convert these costs to something that would enable a comparison on a per-charger or per-kW-of-capacity basis. For example, if a project's total trenching cost is summed and reported across several sites, each with different numbers of chargers and unique distances to the electrical power source, it would be incorrect to calculate an average trenching cost per site or charger.
- Soft costs are hard to rationalize and compare because they vary widely among projects. For example, delays in obtaining utility easements and grid interconnections can add weeks, months, or more than a year to a project schedule. The cost of complying with specific regulations can be negligible in one location and extremely expensive in another.

While currently, EV inverters use Insulated gate bipolar transistors (IGBTs), new types of inverters are being developed for applications in V2B and battery storage markets. They are expected to enable a significant reduction of size and weight due to their higher switching frequencies as well as better automation of the assembly of inverters. They furthermore allow reducing the energy losses in inverters significantly, which enables the product to be smaller in size and with less weight dedicated to component cooling. The most prominent semiconductor materials being used in newly developed inverters are Si-C and Ga-N. The above technologies may enhance the volume of production in the future, which may reduce the unit cost of the product due to the economies of scale and the overall reduction in weight and volume (Element Energy, 2019).

Costing Data

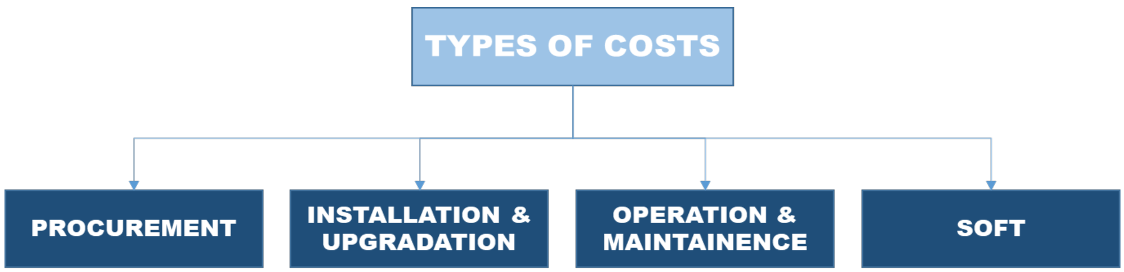

Figure 11: Types of costs associated with V2B setup

The range of costs tabulated below has been collected for capital, installation, and contracts for network/ maintenance. All prices are given in Canadian Dollars (CAD).

Table 1: Bi-directional charger (IRENA, 2019)

Chargers		
	Rating (kW)	Cost ($)
Wallbox Quasar	7.4	3000-4000
Fermata Energy – V2H System	15	TBA

Most of the bi-directional chargers currently are only available for pilot projects through partnerships between infrastructure developers and utilities. Currently, no commercial bi-directional chargers are available to homeowners (Fermata Energy, 2020). Underwriters Laboratories (UL) stated that Fermata Energy's bidirectional electric vehicle (EV) charging system is the first in the world to be certified to UL 9741, the Standard for Bidirectional Electric Vehicle (EV) Charging System Equipment (EEPower, 2021).

Table 2: Contract costs per EVSE per year (Chris Nelder and Emily Rogers, 2019)

Contracts		
	Minimum Cost ($)	Maximum Cost ($)
Data	84	240
Network	200	250

In addition to hardware and installation costs, electric vehicle supply providers (EVSPs) usually procure network, data, and maintenance contracts (shown in Table 2). These can vary in length of time and level of service. In general, shorter contracts provide more opportunities to renegotiate, especially with data contracts, where costs are expected to decline over the coming years.

New buildings v/s retrofit

To understand the cost estimates for V2 B-ready homes/buildings or retrofitting existing buildings/homes, interviews were conducted with electricians and EVSE providers. The interviewees highlighted that the costs were heavily subject to the location and the existing electrical infrastructure. Further, the cost of procurement of bi-directional chargers would remain the same in both applications. However, the significant differences in costs would be due to labor and supporting electrical infrastructure such as switches.

Setting up a bi-directional charger at home by retrofitting would cost around $4000 for the charging equipment and about $4000-$5000 as labor costs for installation. Further, it would cost around $500-$1000 for the procurement of transfer switches. In the case of new constructions, labor costs would be about $2000 - $2500 (approximately half of the labor costs for existing homes).

Cost Benefits to EV owners

The savings that EV owners can reap through using their vehicle batteries to reduce energy consumption has been analyzed through two scenarios: (1) electric utilities offering tiered pricing, (2) utilities offering time of use pricing (TOU). Currently, in British Columbia, both large electric utilities B.C. Hydro and FortisBC offer only tiered pricing. FortisBC previously offered a TOU rate but was rolled back.

The analysis assumes the following parameters:

- Average Battery Capacity: 70 kWh

- Canadian Household Energy Consumption: 11135 kWh/year

- B.C.'s Household Energy Consumption: 11% below national average, 9910.15 kWh/year or 27.52 kWh/day

Tiered Pricing:

B.C. Hydro offers a tiered pricing mechanism as shown below:

Step 1: 0.0941 $/kWh, Step 2: 0.141 $/kWh

Threshold: 22.1918 kWh/day

Minimum charge: 0.208 $/day

Considering the price of a Wallbox Quasar charger to be $4000, the total savings using the EV battery to offset the Step 2 rate is $274.63/year. Hence, the payback period to recover the invested value would be around **14 years and 10 months**. EV owners would need to use other sources of electricity to charge EVs, such as off-grid solar, to achieve economic benefits.

Time of use Pricing:

Currently, Hydro One offers an attractive time of use pricing mechanisms for its customers; hence, a similar rate may be made available in B.C. and has been assumed for this analysis.

Table 3: Time of use pricing mechanism offered by Hydro One

Type	Rate	Hours	% Energy Consumption
Off-peak	0.082 $/KWh	7 pm to 7 am	20%
Mid-peak	0.113 $/KWh	7 am to 11 am	30%
On-peak	0.17 $/KWh	11 am to 7 pm	50%

In this case, two ways cost savings can be achieved:

(1) Using the EV battery to offset the Mid-peak + On-peak energy usage

(2) Using the EV battery to offset only the On-peak energy usage

Offsetting mid-peak + on-peak energy use:

Savings through offsetting on-peak energy use: $854.062/year

Savings through offsetting mid-peak energy use: $340.620/year

Cost for off-peak charging: $659.135/year

Total savings: $535.547/year

Payback period: **7 years 6 month**

Offsetting on-peak energy use:

Savings through offsetting on-peak energy use: $854.062/year

Cost for off-peak charging: $411.959/year

Total savings: $ 442.102/year

Payback period: 9 years 1 month

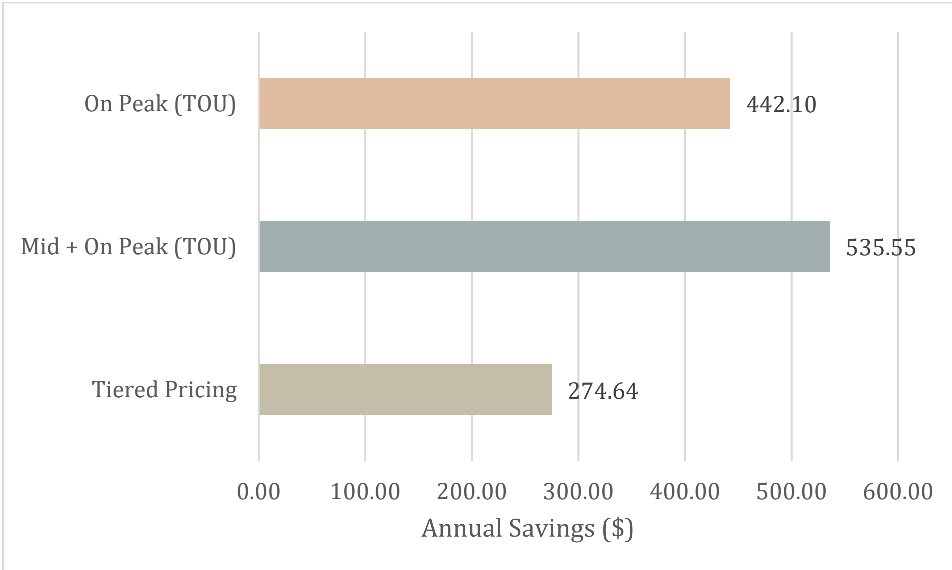

Figure 12. Savings through implementing V2B for households in B.C.

As seen in Figure 12, the implementation of the V2B concept can offer savings by using EV batteries to provide energy to homes during peak hours. Maximum savings can be obtained by charging the EVs during off-peak hours and using the batteries to power homes during mid-peak/off-peak hours. This would reduce the stress on the electricity grid and benefit the utility and provide savings for EV owners. Further, using off-grid energy generation such as solar may provide more significant savings in comparison.

Since B.C. has a clean energy grid and large-scale electrification being an effective plan in B.C., the development, propagation, and implementation of such schemes/mechanisms can improve resiliency, increase EV adoption, and reduce grid side investments. However, at the current market adoption of EVs, utilities are unwilling to make the first move due to the perceived additional complexity/risk to grid management if load moves on/off the grid at scale. The lack of available bi-directional chargers and EV models also contributes to this cause.

Summary

The current provincial and federal policies indicate extensive scale vehicle electrification in British Columbia. These policy instruments in the form of rebates and incentives are accelerating the transition to EVs. The existing barriers to the adoption of EVs can be eliminated through the particular implementation of these policies.

In expanding the public availability of electrical transport recharges, recharging infrastructure deployment plays a significant part. Mobility using clean energy requires an extensive network of charging stations. Although customers are unwilling to buy EVs until chargers are adequately positioned, investors are not ready to invest in refueling infrastructure owing to doubts about the recharging demand. The uptake of EVs has been exceptionally high in societies where range anxiety amongst car owners has been eliminated through a widespread recharging network.

Further, the potential of V2B can be realized through regulatory frameworks supporting the development of large-scale bi-directional charging schemes in the future. Regulatory authorities and system operators can implement these schemes for developing pilot studies by encouraging electric utilities. Utilities should take the lead to develop business cases and promote partnerships with vehicle OEMs to provide bi-directional charging-enabled vehicle models. Overall, the concept of V2B can decarbonize the transportation sector through electrification and the power sector through energy storage using EV batteries. It can also offer several benefits to EV owners, such as increasing energy security and offsetting capital costs.

Since battery technology and energy exchange economics are critical factors, the regional governments and utilities must ensure sufficient incentives to encourage wide-scale technology adoption. Future work requires an assessment of the ownership of the batteries to see if they can be owned and leased to the EV proprietors by the government or utility companies. The multi-faceted problem needs to be addressed by integrated research amongst different areas. The implementation of V2B needs to be backed by non-technical areas such as cultural customs and social deeds.

References

Ammous, M., Khater, M., & Almuhaini, M. (2018). Impact of vehicle-to-grid technology on the reliability of distribution systems. *2017 9th IEEE-GCC Conference and Exhibition, GCCCE 2017*, 1–6. https://doi.org/10.1109/IEEEGCC.2017.8448072

Antweiler, W. (2021). *The state of electric vehicle adoption in British Columbia*. https://www.sauder.ubc.ca/news/insights/werners-blog-state-electric-vehicle-adoption-british-columbia

Bloomberg New Energy Finance. (2021). *Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh | BloombergNEF*. https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

Briones, A., Francfort, J., Heitmann, P., Schey, M., Schey, S., & Smart, J. (2012). *Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes Review by the AVTA*.

Chris Nelder and Emily Rogers. (2019). *Reducing EV Charging Infrastructure Costs* (Issue January). https://doi.org/10.13140/RG.2.2.26490.03525

Chris Nelder, J. N. and G. F. (2016). *Electric Vehicles as Distributed Energy Resources*.

Donadee, J., Shaw, R., Garnett, O., Cutter, E., & Min, L. (2019). Potential Benefits of Vehicle-to-Grid Technology in California: High Value for Capabilities beyond One-Way Managed Charging. *IEEE Electrification Magazine*, *7*(2), 40–45. https://doi.org/10.1109/MELE.2019.2908793

EEPower. (2021). *Fermata Energy Receives the First UL Certification for Bi-Directional EV Charger - News*. https://eepower.com/news/fermata-energy-receives-the-first-ul-certification-for-bi-directional-ev-charger/

Element Energy. (2019). *V2GB – Vehicle to Grid Britain: Requirements for market scale-up*.

Erdinc, O., Mendes, T. D. P., & Catalão, J. P. S. (2014). Impact of electric vehicle V2G operation and demand response strategies for smart households. *T&D Conference and Exposition, 2014 IEEE PES*, 1–5.

EVConsult. (2018). *V2G - A Global Roadtrip - Around the World in 50 Projects*. *October*, 1–38.

Fermata Energy. (2020). *EPRI Presentation*. www.fermataenergy.com

Fortune. (2019). *Today's Cars Are Parked 95% of the Time*. https://fortune.com/2016/03/13/cars-parked-95-percent-of-time/

Galus, M. D., Vaya, M. G., Krause, T., & Andersson, G. (2013). The role of electric vehicles in smart grids. *Wiley Interdisciplinary Reviews: Energy and Environment*, *2*(4), 384–400. https://doi.org/10.1002/wene.56

Government of British Columbia. (2020). *Clean BC Zero-Emission Vehicle Update*.

IRENA. (2019). *Innovation Outlook: EV Smart Charging*.

National Renewable Energy Laboratory. (2017). *Critical Elements of Vehicle-to- Grid (V2G) Economics* (Issue September).

Norris, J., Jackson, J., & Arora, M. (2020). *Best Practices on E-Bus and Grid Integration: A Guide for California Transit Fleets Primary Authors*.

PR-Electronics. (2021). *On-board V2G versus Off-board V2G (AC versus DC)*. http://www.pr-electronics.nl/en/news/88/on-board-v2g-versus-off-board-v2g-ac-versus-dc/

Province of British Columbia. (2020). *Go Electric Program*. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program

Sarker, M. R., Pandzic, H., & Ortega-Vazquez, M. A. (2015). Optimal Operation and Services Scheduling for an Electric Vehicle Battery Swapping Station. *IEEE Transactions on Power Systems*, *30*(2), 901–910. https://doi.org/10.1109/TPWRS.2014.2331560

Statistics Canada. (2021a). *The Daily — Zero-emission vehicle registrations down slightly in 2020*. https://www150.statcan.gc.ca/n1/daily-quotidien/210422/dq210422e-eng.htm

Statistics Canada. (2021b). *Zero-emission vehicles in Canada, third quarter of 2020*. https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2021012-eng.htm

Taljegard, M. (2017). *The impact of an Electrification of Road Transportation on the Electricity system in Scandinavia*.

Tuttle, D. P., Fares, R. L., Baldick, R., & Webber, M. E. (2013). Plug-In Vehicle to Home (V2H) duration and power output capability. *2013 IEEE Transportation Electrification Conference and Expo: Components, Systems, and Power Electronics - From Technology to Business and Public Policy, ITEC 2013*. https://doi.org/10.1109/ITEC.2013.6574527

Utility Dive. (2021). *2021 Outlook: The future of electric vehicle charging is bidirectional — but the future isn't here yet*. https://www.utilitydive.com/news/2021-outlook-the-future-of-electric-vehicle-charging-is-bidirectional-bu/592957/