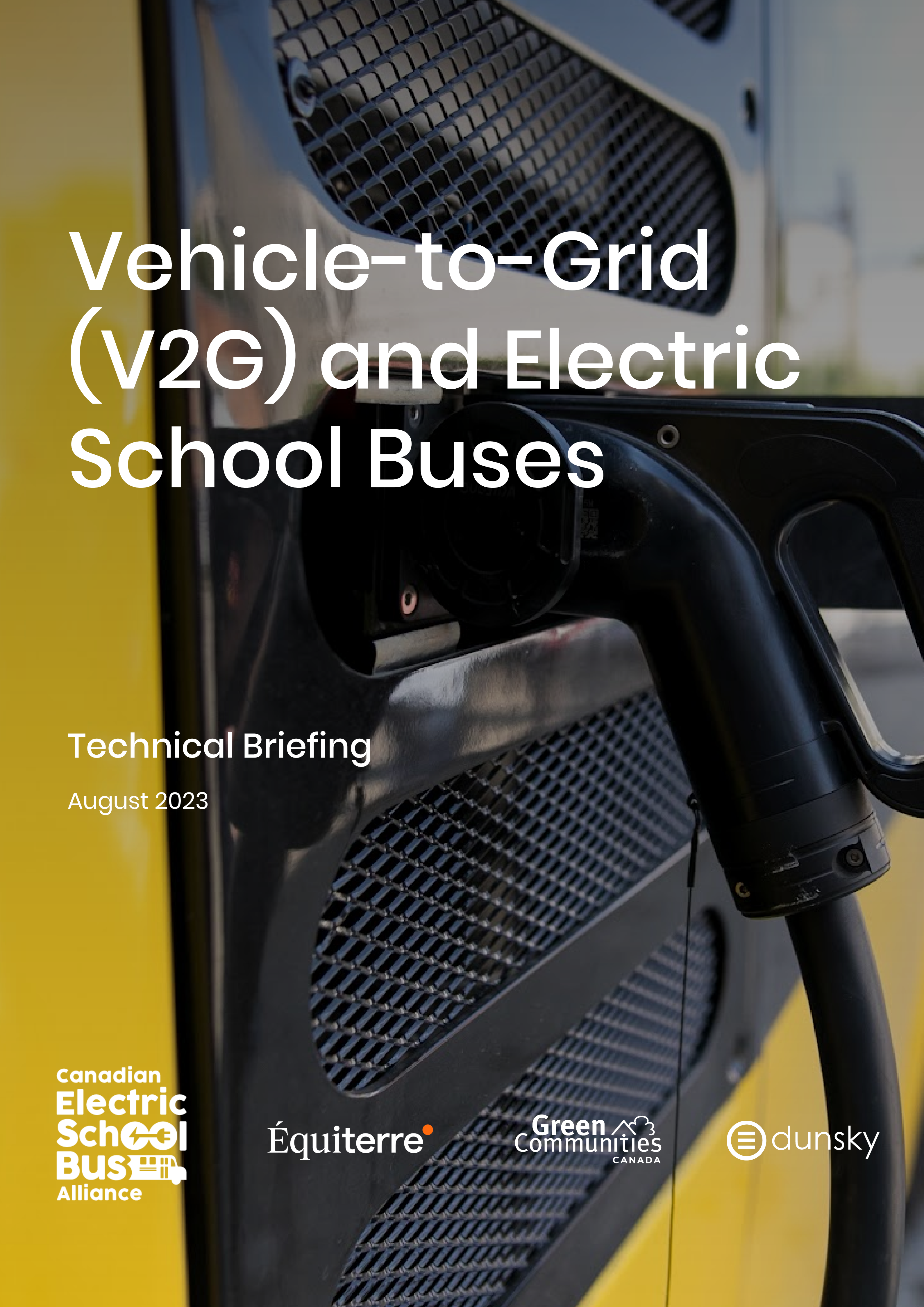

Vehicle-to-Grid (V2G) and Electric School Buses

Technical Briefing

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Canadian Electric School Bus Alliance

Équiterre

Green Communities Canada

dunsky

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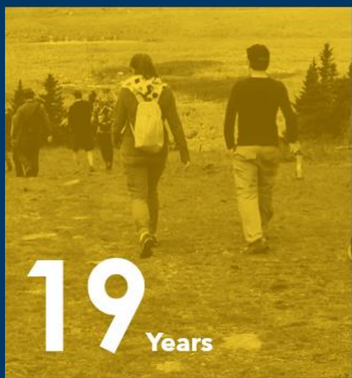

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1. V2G Overview

V2G Definition

Vehicle-to-grid (V2G) is a term used to describe the use of an electric vehicle's (EV) onboard energy storage system to provide power back to the electrical grid, sometimes also referred to as "bi-directional charging". This is considered the most advanced form of vehicle-grid integration (VGI), a more general term that can also include smart charging and behavioural responses to varying electricity rates. The following definitions are derived from the California Public Utility Commission's Vehicle-Grid Integration Communication Protocol Working Group[1]:

- **Behavioural VGI**: passive solutions such as a customer responding to time-of-use (TOU) rates by choosing to charge when demand for electricity is lowest and the grid is least constrained.
- **Smart Charging (V1G)**: central or customer control of EV charging to provide grid benefits, including ramping up or ramping down charging, or deferring charging to a later time. Unidirectional charging only.
- **Vehicle-to-Grid (V2G)**: energy from the EV battery flows to a facility circuit that is either connected to the electric power system or to the home (vehicle-to-home, or V2H). Bi-directional charging is required.

Equipment Requirements

AC vs DC Power

- Alternating current (AC) power: an electrical current that flows back and forth in alternating directions. Electrical grids supply AC power as it is much easier to increase or decrease the voltage of AC power to help minimize line losses in transmission and distribution.
- Direct current (DC) power: an electrical current that flows in one direction. Batteries supply DC current because of their positive and negative terminals that create a constant voltage. This voltage cannot easily be increased or decreased.

There are two primary approaches for EV charging:

1. **AC charging**: where the charge station provides AC power to the vehicle, and an onboard charger converts this to DC power.
2. **DC charging**: where the charge station includes the AC-to-DC converter (the actual "charger") and provides DC power to the vehicle.

V2G requires the use of a DC to AC inverter – a device that can convert the DC power stored in the vehicle's battery into the AC power required by the grid. This inverter is typically integrated into the same device that's used for charging the vehicle's battery, the "charger" which converts grid AC

[1] California Public Utilities Commission, *Draft Final Vehicle Grid Integration (VGI) Glossary of Terms*. https://www.cpuc.ca.gov/vgi/

power into DC. The combination charger/inverter is sometimes referred to as a "bi-directional inverter" or "bi-directional charger". Ultimately, if an EV is not equipped with an onboard bi-directional charger, it can only supply power to the grid using a DC charger.

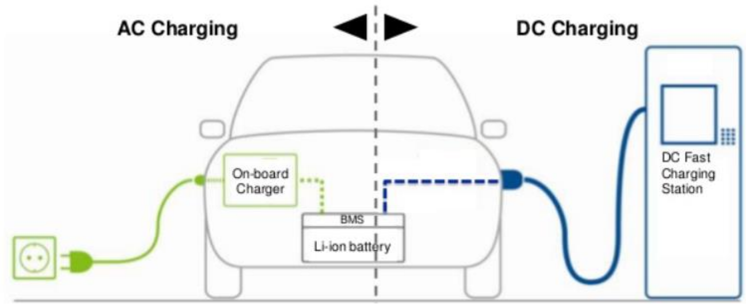

Figure 1. AC (on-board) versus DC (off-board) charging (Source: BC Hydro)[2]

There are pros and cons to V2G participation using a DC interface (V2G-DC) versus an AC interface (V2G-AC) (see Table 1). Overall, V2G-DC is expected to be preferred by utilities as the certification and interconnection process is simpler. Moreover, it does not rely on EVs being equipped with an onboard bi-directional charger.

Table 1. DC-V2G versus AC-V2G

	V2G-DC *Offboard Inverters*	**V2G-AC** *Onboard Inverters*
Pros	• Certification/interconnection approval simplified by having the inverter in a fixed location • Vehicle only requires a DC charge port and compatible software	• Requires a less complicated and less expensive charging station
Cons	• Charging station is significantly more expensive	• Certification/interconnection approval is complicated due to the "roaming" inverter • Requires a bi-directional inverter/charger to be integrated into the vehicle, which most EVs are not currently equipped with, and which may come at a significant cost

[2] BC Hydro, *BC Hydro's DCFC Station Network – Existing and Planned* (2017), 2. https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/regulatory-planning-documents/regulatory-matters/VEVA-20170919-DCFC-Stations.pdf

V2G Services

V2G brings a myriad of services to the grid, utility, and customer. This is because V2G services mimic those of a battery storage system, and the benefits of battery storage are numerous. See the table below for these advantages, split out by utility and customer services.

Table 2. V2G services for utilities and customers

Type	Service	Description
Generation	Avoided Capacity	Reduce the need for peaking power plants to avoid or delay the need for new investments.
	Energy Arbitrage	Purchasing energy during low-price (off-peak) periods and selling it during high-price (on-peak) periods.
Ancillary	Operating Reserve	Serve as spinning and non-spinning reserve capacity resources capable of synchronizing to the grid within 10 and 30 minutes respectively in response to unplanned capacity losses.
	Frequency Regulation	Provision of immediate power to maintain generation-load balance and prevent frequency fluctuations on the grid.
	Voltage Support	Provide reactive power onto the grid in order to maintain a desired voltage level.
	Black(out) Start	Ability to support the reliable restoration of the grid following a blackout start without an outside electrical supply. Unlikely, however, to be V2G service in the near term.
Grid Infrastructure	Transmission / Distribution Deferral	Reduce loading on a specific portion of the transmission/distribution system, thus avoiding or delaying the need to upgrade the transmission/distribution system to accommodate load growth or regulate voltage.
	Transmission Congestion Relief	Discharging energy during high congestion periods to provide relief to the transmission system.
Customer	Backup Power	Reduce or eliminate power interruptions to customers in the event of a power outage.
	Time-of-Use (TOU) Bill Management	Energy stored in EVs equipped with bi-directional chargers can reduce customers' electricity bills by reducing electricity purchased during high-price peak hours.
	Demand Charge Reduction	Reduce customers' maximum monthly peak demand to reduce peak demand charges by leveraging energy stored in EVs equipped with bi-directional chargers.
	Increased PV Self-Consumption	Solar power from PV systems can be stored in the batteries of EVs equipped with bi-directional chargers for later use.

It is important to note that V2G does not provide all of the above services by default. To provide such services:

1. The V2G service must be in demand at the moment by the utility and/or the customer,
2. The appropriate technology and regulations must be available or in place, and
3. The vehicle must be hooked up to the grid and available for V2G participation.

While the third requirement may seem obvious, it needs to be mentioned due to its relevance. At times, the usage demands of the vehicle may conflict with V2G service demands.

Managing Vehicle Needs Against V2G Participation

The default method of charging for most EVs is to charge as soon and as fast as possible – upon connecting to a charging station, an EV will typically begin charging immediately at the highest power that the EV and charging infrastructure will support. Most forms of VGI involve slowing the charging process down, and in the case of V2G, even reversing the charging process altogether. In all cases, it's essential to ensure the primary purpose of the vehicle as a means of transportation isn't impacted, meaning that the vehicle receives a sufficient charge by the next time it's needed.

Incorporating these constraints into the management of VGI resources can help to maximize VGI participation while maintaining EV owner satisfaction. Smart charging platforms will typically allow an EV driver or fleet manager to set certain preferences that are intended to constrain smart charging activities against vehicle needs, including the following settings:

- **Departure Time**: a time setpoint for each day when a full charge is desired for a given vehicle.
- **Minimum State-of-Charge (SOC):** a state-of-charge threshold below which smart charging is disabled – in other words, the vehicle will always charge up to at least this SOC before it will curtail charging. This ensures that the vehicle has a minimum amount of range available if an unexpected trip is needed before the usual next departure time.

2. V2G and Electric School Buses

School Bus Duty Cycles

Electric school buses (ESBs) have emerged as a leading segment of the transportation sector for V2G due to their significant amount of downtime both on a daily and annual basis. On average, school buses are only used for 4-5 hours per day and approximately 190 days per year.[3] In other words, they spend **80% of weekdays** during the school year sitting idle, and for nearly **50% of the year** they're not used at all. The potential to harness the energy stored in these mobile batteries is significant, provided this downtime aligns with periods when V2G resources would be beneficial to the grid.

Revenue Potential of V2G

Determining the future revenue potential of V2G participation for ESB fleets is a complicated exercise given the large degree of uncertainty around future V2G programs and the fact that utilities may weigh utility-side V2G services in different ways (see Table 2 for a summary of these benefits).

Dunsky performed a high-level analysis to determine the magnitude of revenue ESB fleets can expect from V2G in the near term. To simplify our analysis, we selected three provinces across Canada as case studies: New Brunswick, Quebec and Ontario. Across the three provinces, we have estimated the revenue potential of V2G stemming from three utility-side services:

1. **Avoided capacity**
2. **Arbitrage**
3. **Ancillary**

We have compiled cost forecasts for how major utilities in the selected regions are expected to value these services. Note that the utilities we examined may not benefit from all three of these primary services. Instead, most expect to benefit from 2/3 of these services. Using the cost forecasts we compiled, we estimated the revenue potential for a Type C ESB (which represents over 70% of school buses on Canada's roads) that is participating in a V2G program mid-shift during the day on weekdays, over the weekends and during the summer holidays. See Table 3 for our results.

Table 3. Estimated annual V2G revenue potential for a Type C ESB in select Canadian provinces

Province	2023	2024	2025	2026	2027	2028	2029	2030
New Brunswick	$1,210	$1,260	$1,310	$1,360	$1,410	$1,460	$1,520	$1,580
Quebec	$3,770	$3,800	$3,840	$3,880	$3,910	$3,950	$3,990	$4,020
Ontario	$3,170	$3,140	$3,120	$3,170	$3,210	$3,250	$3,290	$3,340

[3] Statistics Canada, "Calculation of Instruction Time by Jurisdiction." https://www150.statcan.gc.ca/n1/pub/81-604-x/2011001/tbl/tbl1-eng.htm

Across all three provinces, avoided capacity is the biggest contributor to revenue. The greatest potential for revenue generation in the sample of provinces we have selected is for Quebec given that the primary utility, Hydro Quebec, values avoided capacity services more than the other two provinces examined. New Brunswick, meanwhile, shows the lowest potential for revenue generation given that estimates for avoided capacity costs are lowest and the utility has not provided a valuation for arbitrage or ancillary services. Ontario sits slightly below Quebec given that the valuation for avoided capacity services is slightly lower, however, revenue from arbitrage services makes up some of the difference.

In addition to our analysis for the provinces above, NS Power in Nova Scotia has provided an estimate for V2G revenue in their regions. It's currently estimated at **$1,100 - $1,500 per ESB** per year based on availability during school break periods and winter weekends.

Note that school buses are used in a variety of different ways, which may impact the relevancy of our estimates. The results of this analysis are not directly transferrable to other provinces given regional differences in grid constraints and the valuation of V2G utility-side services. Moreover, utilities within the provinces we have assessed may value these services to different degrees.

Impact of V2G on an ESB Payback Period

Annual revenue from V2G can help reduce the payback period of an ESB relative to a diesel baseline, however, not significantly enough that the incremental upfront cost of the ESB is recovered within the typical 12-year lifetime. Table 4 shows the payback period for different ESB types with and without V2G revenue, assuming an average revenue of $3,000 per bus per year. While V2G revenue can reduce the payback period by 2-3 years, this revenue alone will not offset the higher cost of ESBs – additional funding is necessary to reach price parity with diesel buses.

Table 4. ESB payback period with and without V2G revenue

ESB total cost of ownership scenario	**Type A** *Short school buses*	**Type C** *"Classic" large school buses*	**Type D** *Flat-front large school buses*
Baseline (no funding or revenue)	20.7 years	19.3 years	23.3 years
V2G revenue ($3,000 per bus per year)	17.8 years	17.3 years	20.6 years
Federal funding + V2G revenue	5.4 years	3.6 years	4.6 years

V2G Benefits Beyond Utility Revenue

Note that the revenue potential estimates outlined above only reflect revenue from the utility-side benefits of V2G. ESB fleet operators may benefit from V2G in several other ways. For instance:

- V2G can enable fleet operators to reduce their monthly electricity bills through demand charge reduction and TOU bill management.
- Alternatively, V2G can promote resiliency by enabling fleet operators to act as a source of backup power for buildings and equipment during an outage.

3. Key Limitations and Uncertainties

Lack of Existing Utility Programs and Rates

Other than backup power functionality, the primary incentive to adopt V2G-capable vehicles and charging infrastructure will be driven by utility benefits. Utilities that see value in V2G will need to develop programs and/or rates that provide some form of incentive for fleet operators to make their vehicles available to the grid. While some programs or incentives may already provide a form of incentive (e.g., existing TOU rates), V2G-specific programs, rates and accompanying educational resources may deliver stronger market signals and encourage more uptake. While the design of these programs and rates will require careful consideration of the costs and benefits of V2G resources for utilities and ratepayers, ongoing trends towards electrification of transportation and other sectors will likely drive utilities to leverage distributed energy resources like V2G-enabled ESBs as much as possible.

Regional Variation

The value that V2G brings to the grid will likely vary significantly from one region to the next. For example, while school bus availability aligns well with the needs of utilities that experience their peak annual demand during the summer (typically as a result of air conditioning used to combat hot summer weather), winter-peaking utilities (whose demand spikes during the winter months as a result of heating demands) will likely see less overall value from school buses participating in V2G. Moreover, as was observed in our analysis above, different regions may value utility-side V2G services in different ways.

V2G and Battery Degradation

A common question regarding V2G and VGI, in general, is how this functionality will affect the lifespan of the vehicle's battery. The lithium-ion batteries found in most modern EVs have a lifespan that is dependent primarily on usage cycles[4] and calendar life[5]. The "back and forth" power flow involved in V2G introduces additional usage cycles and will therefore have an impact on battery life. The impact of V2G participation on battery life will depend on the specific V2G use case and how deeply the battery is cycled. For example, an ESB with a 250-kWh battery providing 25 kW of power back to the grid for 2 hours every day would see 50 kWh of throughput per day for V2G purposes, contributing an additional full battery usage cycle only every five days. Given the relatively low utilization of school buses, batteries in some cases might outlast the vehicles themselves. In these cases, additional cycling may fit within the typical lifetime of the bus.

[4] A usage cycle of a battery is defined as one full discharge from 100% to 0% state-of-charge followed by a recharge back to 100%, with "shallower" discharges counting proportionally (e.g., a discharge from 80% down to 30% followed by a charge back to 80% would count as one-half cycle).

[5] Kandler Smith et al., *Life Prediction model for Grid-Connected Li-ion Battery Energy Storage System* (NREL, 2017). https://www.nrel.gov/docs/fy17osti/67102.pdf

4. V2G Pilots in Canada and the U.S.

Canada

While a number of utilities across Canada are encouraging simpler forms of VGI through smart charging pilots and broader implementation of time-of-use rates, pilots of V2G in Canada have been limited to date:

- **Nova Scotia Power** announced a V2G demonstration in September 2021[6], as part of the broader Smart Grid Nova Scotia project, which also includes demonstrations of distributed solar and storage, as well as residential EV smart charging. Nova Scotia Power partnered with Nova Scotia Community College for its V2G demonstration, which involved the use of a bi-directional DC charger designed for commercial settings. Going forward, Nova Scotia Power intends to demonstrate V2G across a wider range of locations, with up to an additional 20 bi-directional chargers, including chargers designed for a residential context. This project was funded in part by Natural Resources Canada's Electric Vehicle Infrastructure Demonstrations initiative.[7]
- **Ontario's Independent Electricity System Operator (IESO)** announced funding for multiple bi-directional charging demonstration projects in November 2021 via the Grid Innovation Fund.[8] Among these projects is a demonstration developed jointly by Hydro One (electricity transmission and distribution provider in Ontario) and Peak Power (Ontario-based company specializing in distributed energy resources and energy management), which will include 10 Nissan Leafs and bi-directional DC chargers.[9] The project will demonstrate bi-directional charging to support both backup power functionality during outages, as well as grid-interactive V2G functionality providing services to the grid.

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[6] Nova Scotia Power, "Bidirectional charging: A first in Atlantic Canada," September 10, 2021. https://www.nspower.ca/about-us/articles/details/articles/2021/09/10/bidirectional-charging-a-first-in-atlantic-canada

[7] Natural Resources Canada, "Nova Scotia Vehicle Grid Integration Pilot." https://natural-resources.canada.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/nova-scotia-vehicle-grid-integration-pilot/22991

[8] IESO, "Gearing up for the Electric Vehicle of the Future: IESO announces $1 million investment in Vehicle-to-Grid projects," November 9, 2021. https://www.ieso.ca/en/Corporate-IESO/Media/News-Releases/2021/11/Gearing-up-for-the-Electric-Vehicle-of-the-Future

[9] Hydro One Inc., "Hydro One and Peak Power launch innovative new pilot program to enhance power resiliency using electric vehicle chargers," November 10, 2021. https://www.newswire.ca/news-releases/hydro-one-and-peak-power-launch-innovative-new-pilot-program-to-enhance-power-resiliency-using-electric-vehicle-chargers-830349145.html

United States

A wide range of V2G pilot programs have been conducted or are underway across the United States. According to a recent World Resources Institute article, 15+ utilities across 14 states are leading pilots, many of which involve ESBs. We highlight the success of three pilots below:

- **National Grid** in partnership with Highland Electric Fleets and Beverly Public Schools demonstrated the use of V2G using an ESB over the summer of 2021. The ESB was successfully leveraged as a distributed energy resource for the regional utility providing electricity for more than 50 hours. The school bus provided additional capacity for the grid during periods of peak demand thereby reducing the need for often highly emitting and expensive "peaker" plants to be turned on.[10]
- **Con Edison** in partnership with Lion Electric Company, Nuuve, White Plains School District and National Express deployed three V2G-equipped ESBs in White Plains New York. Con Edison successfully transmitted energy from the ESBs back into the grid during a pilot between 2020-2021. The results of the pilot led Con Edison to conclude that V2G is technically and operationally feasible. To improve technology feasibility and reliability, however, the utility recommends the implementation of V2G technology certifications. Battery degradation of the ESBs was measured and found to occur at a similar rate to other forms of energy use such as driving.[11]
- **San Diego Gas & Electric (SDG&E)** installed six 60 kW bi-directional chargers in the yard of Cajon Valley Union School District that have been sending power back to the grid starting in the summer of 2022. By participating in SDG&E's Emergency Load Reduction Program, the school district will be paid $2/kWh when they export energy to the grid or reduce energy use during grid emergencies.[12]

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[10] Green Car Congress, "Massachusetts electric school bus delivered power back to grid for 50+ hours over the summer; V2G," October 14, 2023. https://www.greencarcongress.com/2021/10/20211014-proterrav2g.html
[11] Con Edison, "Con Edison and Partners Go To School With Findings From E-School Bus Project," April 12, 2022. https://www.coned.com/en/about-us/media-center/news/2022/04-12/con-edison-and-partners-go-to-school-with-findings-from-e-school-bus-project
[12] San Diego Gas & Electric, "SDG&E and Cajon Valley Union School District Flip the Switch on Region's First Vehicle-to-Grid Project Featuring Local Electric School Buses Capable of Sending Power to the Grid," July 26, 2022. https://www.sdgenews.com/article/sdge-and-cajon-valley-union-school-district-flip-switch-regions-first-vehicle-grid-project

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