On the Way to Viability: Residential Bidirectional Charging

Efficiency Vermont R&D Project: Resilience

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Contents

Executive Summary

Bidirectional charging, also referred to as Vehicle-to-Everything (V2X), allows the two-way flow of energy to charge an electric vehicle's battery and to discharge energy to an external load, including individual appliances (Vehicle-to-Load, V2L), entire homes (Vehicle-to-Home, V2H), or the grid (Vehicle-to-Grid, V2G). This research paper explores the viability and economics of residential V2X applications, focusing on the emerging areas of V2H and V2G technologies and introducing potential resilience benefits along with economic ones.

Cost poses a significant barrier to residential adoption. As of late 2024, the cost for equipment and installation of bidirectional chargers was around $10,000 for commercially available systems. This does not include potential—and site-specific—electrical service and panel upgrade costs that can add thousands of dollars in additional costs. Despite their expense, these systems offer significant value to homeowners and the electric grid, while posing manageable daily and lifetime impacts to vehicle batteries. For homes with compatible EVs, the installation of V2H systems could be financially viable and beneficial for households wanting whole-home backup power as a result of frequent electricity outages.

The value of V2H systems is significantly enhanced when coordinated with aggregators and utilities to unlock additional grid value. V2G might enhance grid stability by providing additional energy storage and balancing supply and demand, especially during peak periods. It can defer the need for costly grid upgrades, supporting the integration of renewable energy sources and ancillary services to improve overall grid reliability.

A preliminary estimate of potential customer compensation for V2G services over the life of the vehicle and equipment suggests a value of $13,000. Rather than a comprehensive technoeconomic assessment, this is a theoretical exercise to encourage further in-depth exploration of V2G valuation. While grid benefits alone might not be substantial enough to justify residential V2X installations, the combined benefits of household resilience and backup power could make economic sense for some households.

Despite the potential value, V2G applications are still nascent nationwide, and important work is needed to develop communication and electrical standards. A major hurdle with current V2X technologies is the lack of interoperability, as these systems only work with specific EV manufacturers and models. Another challenge is the lack of industry consensus on the applicable standards governing the various aspects of V2X operations. Fortunately, V2X technologies in development for 2025 promise greater EV interoperability, which will likely be key to broader deployment in Vermont beyond niche household applications.

Continued advancements and cost reductions will be crucial for the long-term viability and adoption of these systems in the Vermont residential market. Coordination of aggregators and utilities to leverage V2X capabilities, easier and cheaper installation experiences, increased interoperability, and consensus on standards can make residential bidirectional charging mainstream.

Glossary

Aggregator: An entity that coordinates multiple distributed energy resources to provide grid services.

Ancillary Services: Grid services such as frequency regulation, voltage support, and spinning reserves, provided by distributed energy resources.

Bidirectional Charging: The ability for energy to flow both to and from an electric vehicle's battery, enabling it to charge and discharge energy to external loads.

CCS (Combined Charging System): A DC charging standard supported by a consortium of European and US auto manufacturers, allowing bidirectional operation.

CHAdeMO: A DC charging standard developed by a Japanese utility, supporting bidirectional charging for certain electric vehicle models.

Critical Loads Panel: A panel designed to power essential equipment during backup mode in V2H applications.

Forward Capacity Market (FCM): A wholesale mechanism ensuring the reliability of future electricity supply, paid for by market participants.

IEEE 1547: A standard for interconnecting distributed energy resources with the electric grid, ensuring safe and effective grid connection.

Interoperability: The ability of different systems and equipment to work together seamlessly, which is a challenge for current V2X technologies.

Inverter: A device that converts direct current (DC) from the vehicle battery to alternating current (AC) for use in powering loads or exporting to the grid.

Isolated Loads Panel: A panel that removes non-critical loads from the main panel during backup mode in V2H applications.

ISO 15118: A standard for communication protocols between electric vehicles and charging equipment.

ISO-NE (Independent System Operator - New England): An organization overseeing the electricity grid in the New England region, administering the wholesale electricity market.

NACS (North American Charging Standard): A combined AC and DC charging standard developed by Tesla, adopted by most automakers in the US.

Non-Wires Alternative (NWA): Solutions that defer or avoid costly distribution network upgrades by using distributed energy resources.

Off-board Inverter: An inverter external to the electric vehicle, used to convert DC to AC power for V2X applications.

OCPP (Open Charge Point Protocol): A standard for communication between EV charging stations and management systems.

On-board Inverter: An inverter integrated within the electric vehicle, used to convert DC to AC power for V2X applications.

OpenADR: A standard for automated demand response, facilitating communication between utilities and energy management systems.

Reliability: The consistency of power availability, which can be enhanced by V2X technologies.

Resilience: The ability to recover quickly from power outages, supported by V2X technologies.

UL 1741: A standard for inverters used in grid-connected applications, ensuring safety and compatibility.

Vehicle-to-Everything (V2X): A term encompassing all bidirectional charging applications, including Vehicle-to-Load (V2L), Vehicle-to-Home (V2H), and Vehicle-to-Grid (V2G).

Vehicle-to-Grid (V2G): A bidirectional charging application where energy stored in the vehicle battery is exported to the grid, providing grid services such as energy storage and balancing supply and demand.

Vehicle-to-Home (V2H): A bidirectional charging application where energy stored in the vehicle battery powers home loads through permanently installed equipment, typically for backup power.

Vehicle-to-Load (V2L): A bidirectional charging application where energy stored in the vehicle battery powers plug loads such as power tools or camping accessories.

Efficiency Vermont

Introduction

Vermont is experiencing an increase in storm frequency and severity,[1] resulting in an increase in power outages[2] for many Vermonters. Simultaneously, Vermonters are increasingly purchasing electric vehicles[3] (EV) which have the potential to provide back-up energy during power outages through bidirectional charging. Bidirectional charging, also referred to as Vehicle-to-Everything (V2X), uses a vehicle's battery to either charge from or discharge to an energy source or load using Electric Vehicle Supply Equipment (EVSE) or a vehicle's built-in technology.

According to the [2024 Vermont Long Range Transmission Plan] (LRTP), electric vehicles (EVs) will make up 90 percent of non-fleet light duty vehicles by 2040. The estimated 300,000 EVs will drastically shift Vermont energy consumption from gasoline and diesel to electricity. This increase in electric consumption for Vermont has the potential to put significant strain on the grid; for example, the 2024 LRTP estimates that electric vehicles will add 400 megawatts to Vermont's annual peak load by 2040 if left unmanaged. This represents a 40 percent increase over current Winter Peak Load. At the same time, the batteries in these vehicles can store the same amount of energy that is necessary to power the Vermont grid for two days (~27 gigawatt-hours).[4] EVs simultaneously represent a challenge and an opportunity for the grid.

By implementing managed charging technologies, the impact of EVs on peak load growth can be reduced. Additionally, with bidirectional charging, EVs could become a valuable grid resource, aiding in the management of load growth from the electrification of other sectors like heating.

Bidirectional Charging

Bidirectional charging supports the reliability and affordability of the electric grid. When the grid is down due to storms or other unforeseen circumstances, bidirectional charging can energize[5] homes and buildings. Bidirectional charging technologies enable select loads in a building to be powered for hours to days, depending on the owner's energy consumption needs and the size of electric battery and the inverter of the bidirectional charger. In residential settings, there are three main categories of bidirectional charging:

1. **V2L (Vehicle-to-Load):** Loads are energized with energy stored in the vehicle battery. These loads are not interconnected (physically disconnected) from the grid and are typically plug loads such as power tools or camping accessories. These systems rely on traditional charging equipment to replenish the battery.

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[1] https://www.ncei.noaa.gov/access/billions/state-summary/VT
[2] https://www.vermontpublic.org/local-news/2025-03-19/can-ai-predict-where-climate-change-disrupt-power-grid-vermont-utility-thinks-so
[3] https://www.driveelectricvt.com/uploads/media/Documents/Maps/vt_ev_registration_trends.pdf
[4] This assumes 300,000 EVs by 2033 according to the VT Long Range Transmission Plan, with an average battery size of 90 kWh.
[5] ***Energized*** describes EVSE that transfers electricity from a vehicle's battery to a load, without a grid connection. Alternatively, ***interconnected*** describes equipment that is physically connected to the grid and capable of receiving and transmitting power from the EV, regardless of the ability to export power to the grid.

2. **V2H (Vehicle-to-Home):** Like V2L, loads are energized using energy stored in the vehicle battery however that energy is distributed to loads through permanently installed equipment. In the current market, these systems are typically interconnected to the utility to provide charging functionality but tend to be for islanded[6] (back up) power only. While some V2H systems can supply power while interconnected (for peak shaving / avoidance for example), all V2H systems are non-exporting.
3. **V2G (Vehicle-to-Grid)**: Vehicle systems are energized, interconnected, and exporting[7]. These systems may be able to island or provide parallel services as needed.

To support Vermonters in using EVs to provide home and grid energy storage and in optimizing the scheduling of EV charging to minimize grid constraints and greenhouse gas emissions associated with electricity generation, Efficiency Vermont investigated V2X technologies available on the market today and potential value streams for leveraging those systems in Vermont.

Methods

The research team conducted a comprehensive desk review of various sources of industry research, utilizing a range of formats such as podcasts, webinars, research papers, and conference proceedings/presentations. The desk research included analyzing market assessments and overviews of V2X technologies, reviewing industry publications, and studying utility case studies. The team also examined V2X communication standards and manufacturer claims regarding V2X technology. Additionally, the team reviewed published information on the bidirectional functionality of electric vehicles (EVs), important for understanding the capabilities and limitations of current technologies.

Equipment price data for equipment was obtained from retailer websites. The values of wholesale energy and power services was sourced from the Independent Service Operator of New England's electric grid, also referred to as ISO-NE, which oversees Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont's regional high-voltage transmission network and wholesale electricity markets. Data from three Vermont managed residential charging programs were used to deepen the understanding of current unidirectional charging behaviors to inform initial estimates and assumptions around bidirectional residential charging to the Vermont electric grid.

In addition to desk research, the team conducted interviews with stakeholders in the industry. These interviews included discussions with:

- Five EVSE (Electric Vehicle Supply Equipment) manufacturers
- One auto Original Equipment Manufacturer (OEM)

[6] *Islanding* refers to a V2X system that supplies backup power to a home when it is disconnected from the grid, such as during an outage.
[7] *Exporting* refers to V2X systems that supply energy to the grid from the vehicle battery, as contrasted with *non-exporting* where the V2X system is connected to the grid and the EV battery powers building loads, but never supplies (exports) electricity to the grid.

- Two Vermont Distribution Utilities (DUs)
- One electrician (who primarily installs Level 2 chargers)
- One installer of home battery backup systems
- One Vermont homeowner who uses V2H (Vehicle-to-Home) technology

These interviews provided valuable first-hand insights and practical experiences, enriching the team's understanding of the real-world applications and challenges of V2X technologies.

The multi-faceted approach allowed the team to gather diverse perspectives on the current state and future potential of V2X (Vehicle-to-Everything) technologies. By examining these different formats, the team ensured a well-rounded understanding of the industry landscape, capturing both theoretical knowledge and practical applications.

This paper presents Efficiency Vermont's findings outlining equipment specifications and costs impacting bidirectional charging adoption, case studies of V2G applications, and implications for Vermont.

Equipment

Limited functionality, interoperability issues, and high costs pose significant challenges to the widespread adoption of bidirectional residential chargers. Currently, the available bidirectional charging models are compatible only with specific vehicle makes and models from particular years. Additionally, these chargers are prohibitively expensive; for instance, most homeowners could install a fossil fuel generator for less than the cost of a bidirectional charger, even without considering the need for compatible, costly EV models. Furthermore, the standards for vehicle-to-grid (V2G) technology are disparate, complicating integration and consistency across different systems. Significant variations in inverter technologies exacerbate these issues. Consequently, the use of V2X technology remains nearly non-existent in Vermont at present. The following sections delve into technology configurations, equipment standards, and equipment availability in greater detail.

V2X Inverter Configurations

In V2X applications, EV batteries discharge high-voltage direct current (DC) to convert the stored electrochemical energy into usable power at multiple points of use. To utilize the battery's stored energy for powering a plug, home, or grid load, an inverter is required to convert from DC to alternating current (AC) power and adjust the voltage and power quality to the appropriate level. This power conversion can occur either through stationary equipment external to the EV, known as "off-board" inverters, or within the vehicle itself, using an "on-board" inverter.

The off-board inverters in EVSEs can have the same functionality as existing stationary battery storage systems and inverters. These applications typically peak at around 10 kilowatts (kW) of power.

At the present time, on-board inverters are generally much smaller, around 2 kW, and are currently used exclusively for Vehicle-to-Load (V2L) applications. For comparison, whole home generators typically start at 10 kW. Future vehicles may be equipped with larger on-board inverters that can simplify V2X installations in homes, as the inverter equipment and installation labor are significant cost drivers for V2X systems. On-board inverters incorporate the cost of V2X applications into the initial EV purchase, reducing the price required to enable bidirectional charging applications. However, original equipment manufacturers (OEMs) have not yet integrated on-board inverters large enough to power building loads. Even larger inverters, with capacities up to 10 kW, necessitate either prioritizing a home's load to a critical loads panel or isolating larger loads to a separate load panel with the installation of a transfer switch.

Understanding the V2X inverter technology configuration provides a framework for the various equipment standards that govern the functions and components of the system.

Equipment and Communication Standards

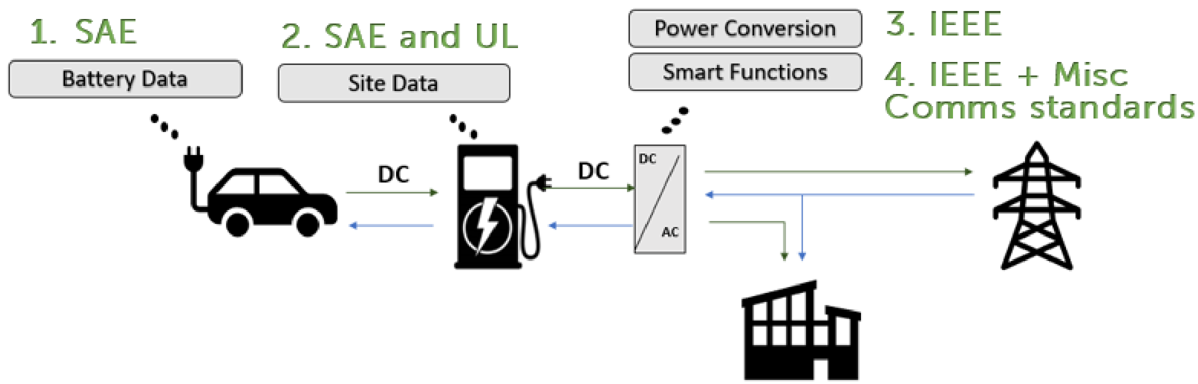
EV charging, safety, and certification standards ensure the safety and compatibility of EV equipment. These standards are essential for the efficient and safe operation of EV charging infrastructure. Established industry standards for unidirectional charging cover various aspects such as connector types, power levels, interoperability, and safety protocols. These standards cover the safety requirements and operational functionality of EVSE, ensuring that the equipment meets rigorous safety criteria and performs reliably under various conditions.

The new functionalities introduced by V2X technology require the development of new standards. However, industry consensus and consolidation have not yet been achieved to govern V2X applications. A broad spectrum of certification standards apply to V2G uses, spanning vehicle functionality to inverter communication standards. Various standards organizations have developed numerous standards relevant to different aspects of V2G such as:

- International Organization for Standardization (ISO 15118)
- Underwriters Laboratory (UL 9741 and UL 1741)
- Institute of Electrical and Electronics Engineers (IEEE 1547-2018 and IEEE 1547.1-2020)
- Society of Automotive Engineers (SAE J2847/3 also referred to as IEEE 2030.5-2018)

Figure 2 below shows how these standards overlap and apply to different aspects of the V2X system.

Figure 2: Overview of various standards governing different aspects of V2G[8]



As Figure 2 illustrates above, no single standard comprehensively addresses all aspects of the vehicle, EVSE, and grid interactions, posing a barrier to broader market adoption of V2G technology.

Of notable mention is that CHAdeMO, a legacy standard that is no longer being incorporated into new models, had long incorporated bidirectionality into its protocol, and is the only physical standard with interoperable bidirectional functionality available over multiple vehicle models and model years. Unfortunately, CHAdeMO chargers with bidirectional functionality were never released in United States. Equipment currently available in the United States is summarized in the following section.

V2X Equipment Available in the United States

Technical details specific to each of the five commercially available bidirectional chargers for residential applications are presented below. All five use two-phase 240V power. Additional details on technology configurations, equipment and communication standards specific to each product are summarized below.

Ford F-150 Intelligent Home Backup System — V2H (V2G pilots)

The F-150 system consists of a hybrid solar / battery / EV inverter, transfer switch, and charger that connects with the Ford F-150 Lightning. The system is primarily marketed as a home backup system. While the charger can dispense AC and DC to the vehicle, V2H functionality is only achieved though the DC connection to the vehicle. The 9.6 kW inverter can back-feed solar to the grid, but it does not support discharging the vehicle battery to the grid. The system connects to the vehicle using a standard Combined Charging System (CCS) plug and

[8] Modified from "Vehicle to Grid Integration Using On-Board vs. Off-Board Bi-Directional Chargers," presented by Jordan Smith at the 2024 Distributech Conference.

communicates with the vehicle using Bluetooth. While this system does comply with some industry standards, such as CCS and UL 1721, some design choices are proprietary.

Ford has partnered with a handful of other organizations (Duke, PG&E, Resideo) to trial their system in a grid communicating and full V2G scenario. This suggests the system can provide these services, but it is unknown how market-ready these solutions are.

Tesla Cyber Truck System — V2H (Beta Release)

The cyber truck system consists of an onboard power converter, specialized charging cord, and integration with a Powerwall gateway or transfer switch. This product is unique in the market in that it uses AC connections to the building and that most of the functionality—including the 11.5 kW power converter—is contained within the vehicle. The system can integrate with Powerwall storage or storage plus solar installations. Given that the onboard power converter can provide power independently of and in tandem with a Powerwall, it is likely that the system can connect with the grid if given proper firmware. There are multiple installations of hardware (charging connector and gateway transfer switch), but systems in the field will not be operational until Tesla releases new vehicle firmware.

Wallbox Quasar 2 Bidirectional Charger

Quasar 2 can charge all CCS2 vehicles. Bidirectional functionalities, however, are only permitted with certain EV manufacturers, though more are expected to enable bidirectionality with Quasar 2 in the near future. At present, only Kia EV9 2024 and later models have this functionality.

Dcbel Ara System — V2G (Pilot Release)

The Ara system consists of a wall-mounted power converter that uses a DC connection - CHAdeMO currently with CCS and North American Charging Standard (NACS) - soon to interact with the vehicle. This system can provide up to 15.2 kW and can also connect with solar and storage sources. The system is also able to connect to smart grids and energy markets to provide utility services that benefit the owner. This equipment is being used in a pilot program with PG&E. The company has limited public information about their product.

GM Energy V2H Bundle

GM Energy's bundle requires a PowerShift Charger and GM Energy's V2H Enablement Kit to enable bidirectional charging of one of GM's compatible EV models (2024 and later EV models of Chevrolet, GMC and Cadillac including the Blazer, Equinox, Sierra Denali, LYRIA, ESCALADE IQ and OPTIQ). The system includes the charger, invertor, home hub, and Dark Start Battery. The home hub manages the home's energy, including seamless transition from grid power to EV battery power of selected home loads. The Dark Start Battery is required to jump start the system in the event of a grid power outage

Multiple bidirectional chargers exist for commercial applications such as Fermata's FE-20 CHAdeMO bidirectional charger for 3-phase commercial applications. The FE-20 has completed many successful V2G pilots for commercial Nissan LEAF fleets.

Equipment Cost

Bidirectional equipment is expensive, often costing $10,000 or more—even before installation costs are considered. For example, the GM Energy PowerShift Charger and GM Energy V2H Enablement Kit is $7,299, excluding installation costs, according to the GM Energy website. For the Ford Charge Station Pro, the base price ranges from $8,900 to $9,400 which includes the Home Integration System hardware and installation according to the website of the preferred installer, Sunrun.

Costs for extra hardware or work, such as additional conduit, trenching, or an upgrade to the main electrical service, will further increase the cost. These increased costs are similar to the additional cost for unidirectional home charging (moderately fast 240-volt "Level 2" charging using 30–60-amp dedicated circuits).

Current V2H chargers (with their compatible EVs) are only capable of supplying 10–15 kilowatts (kW) of power, which is much less than the theoretical peak load of the average 200-amp residential service: approximately 50 kW. As a result, additional internal electrical work is needed either to create an isolated loads panel, which removes the largest non-critical loads (such as the EV charger and sump pump) from the main panel when the system is in backup mode, or a critical loads panel that is designed to power essential equipment/loads during backup mode. This additional electrical work is similar to what is often required when installing a moderately sized whole-home standby generator.

Case Studies

To illustrate the practical implementation and benefits of V2X residential applications, the following case studies provide detailed insights into real-world examples and outcomes. The first case study featured is from the United Kingdom. The second and third case studies describe the two known pilots underway in the United States. The three programs featured in the case studies present results and relevant program design examples for the Vermont market.

Residential 2020 V2G trial in the UK

OVO Energy is a major energy supplier based in Bristol, England. They have 13% of the home electricity market and 11% of the gas market. OVO Group partner Kaluza, an intelligent energy platform that uses AI and machine learning to optimize smart home devices for a more flexible and resilient energy system, led a large V2G trial project for OVO energy customers in the UK to test residential bidirectional charging, beginning in early 2020 and lasting for over three years.

This trial was available to customers with Nissan LEAF vehicles. These 330 customer households were provided with Indra bidirectional chargers.[9]

Customers were compensated for participation; in some cases, active participants received up to $960/£800 per year, approximately double the amount they originally paid for charging. Average household participation resulted in energy bill savings of $477/£420 per year.[10] The up-front V2G costs, including installation, were approximately $3,725/£3,000 (approximately 3x the cost of a standard charger). The home received the charger at no up-front cost, the loan is paid off with the grid export value, and once the loan is paid off the home owns the charger and is able to receive monthly payments compensating them directly for the grid benefits. The V2G function is designed to occur only 1–2 times per month, minimizing the impact on the battery. Nissan assured vehicle owners that participation did not impact their vehicle and battery warranty. The trial shifted a total of 2.19 GWh of demand.

California with PG&E — Multiple EV and V2G Charger OEMs (planned for 2024)

PG&E started a $7.5 million residential V2G pilot program in 2024 for light-duty vehicles, aiming to serve 1,000 customers. They are offering a $2,500 up-front incentive with a $500 disadvantaged community bonus, plus an ongoing $2,175 annual incentive for performance through enrollment in their emergency load reduction. The V2X Residential Pilot will test five applications:

- Backup power
- Customer bill management
- System real-time energy
- System renewable integration
- EV export for grid services (such as system RA and system capacity)

Systems not initially capable of V2G operation can be installed as backup generation only, and an interconnection application can be submitted later. Participating technology providers encompass four to five automotive manufacturers (including BMW of North America, LLC and Nissan North America, Inc.), one EVSE supplier (dcbel) and one system integrator (Nuvve). Additional technology providers such as Wallbox (Fermata, Ford Charge Station Pro) may be onboarded over the course of the pilot.

North Carolina with Duke Energy and Ford F-150 Lightning (planned for 2024)

Duke Energy launched a V2G residential pilot program in 2024 in partnership with Ford. As part of the pilot program, Duke Energy will enroll up to 100 customers who lease electric vehicles that include the Ford F-150 Lightning. Duke Energy will provide a financial incentive to customers in the form of reducing lease payments for program participants—providing

[9] Vehicle-to-Everything Inflexion survey findings - Kaluza.pdf
[10] What's next for Vehicle-to-Everything? Kaluza December 2022 whitepaper. What's next for vehicle-to-everything? - Kaluza White Paper - Dec 2022.pdf

payments directly to the vehicle manufacturer—in exchange for allowing Duke Energy to draw power from their EVs.

The pilot program will allow Duke Energy to draw power up to three times per month during higher peak winter and summer months, and one time per month during the remaining months of the year, for testing and research purposes and to support the energy grid during peak usage hours. Stored energy drawn from the electric vehicles' batteries will help balance the power grid during periods of highest energy demand.

The UK case study showcases the successful outcomes of a three-year pilot involving over 300 customers, which resulted in the shifting of 2.19 GWh of demand. The two US examples featured programs that launched in 2024. These US case studies highlight two alternatives to participant enrollment and compensation to the UK pilot program. Although no initial findings from US efforts were publicly available at the time of writing, the research team recommends closely monitoring these initiatives to gain insights to inform Vermont market adoption and potential program design.

Vermont Market Readiness

It is anticipated that technology experience and equipment availability will rapidly increase in 2025. Developing interconnection agreements, appropriately valuing V2G, and educating perspective customers are policy and planning steps that enable Vermont to be fertile soil to benefit from V2X technology expansion.

Interconnection Agreements

Establishing interconnection agreements for bidirectional chargers will advance Vermont's regulatory environment. Solar and battery interconnections for devices with grid-exporting capabilities are relatively mature, but similar interconnection procedures has not been developed for bidirectional EV chargers. V2H chargers would largely fit under the existing ability for homes to install a generator without utility notification. For V2G chargers, a utility interconnection agreement would be required.

Residential V2G Valuation

Residential vehicle-to-grid (V2G) systems in Vermont offer a range of potential value streams, particularly those that combine energy and grid services with backup building power systems, as described below. This overview of potential value streams is not intended to be a full economic analysis, for the following reasons:

- Valuation on both the revenue and the cost side has a wide margin of error, as the implementation of this technology is in its infancy.
- The frequency and duration of bidirectional energy flow to the grid is not yet defined.

- The ability of residential vehicles to aggregate and participate in the wholesale market is less clear than (for example) fleet participation of 10+ vehicles.[11]
- Though it's possible to compare up-front costs for backup power, the lifetime operational cost savings anticipated for a V2H over a delivered-fuels generator backup system is dependent on the annual backup power usage.

To identify V2G system value streams, Efficiency Vermont used wholesale values relevant to Vermont provided publicly by the ISO-NE. ISO-NE administers the wholesale electricity market, including the cost allocation of shared high-voltage transmission infrastructure, Pool Transmission Facilities (PTFs), whose cost is allocated to market participants through the Regional Network Service (RNS) mechanism. The ISO-NE Forward Capacity Market (FCM) is a wholesale mechanism that ensures the reliability of future electricity supply (also referred to as generation capacity), paid for by market participants on a per kilowatt (kW) basis, which is determined through annual auctions that secure capacity commitments three years in advance. Generation energy costs are also priced on the wholesale market on a per kilowatt hour (kWh) basis, and distribution system costs can be estimated per kW of peak load. However, unlike RNS and FCM, distribution values are determined at the distribution utility level and do not participate in a wholesale market. Ancillary services are priced through the ISO-NE wholesale market on both per kW and per kWh basis.

The ISO-NE wholesale values for potential V2G value streams in Vermont are provided in Tables 1 and 2 below. Table 1 provides the power value per kW over one year (kW-year) and Table 2 provides the energy value per kWh supplied. Though the compensation for the wholesale values listed is divided between the customer, the utility and the aggregators, the final value listed is what is expected to be available to the customer. To reflect the need for program administration and equitable value distribution among non-participating ratepayers, only 50% of the maximum potential value is attributed to the participating customer, presented in Tables 1 and 2 below, assuming that the measure life of the V2X charger aligns with the expected lifespan of the vehicle—10 years.

For the purposes of this analysis, a discharge capacity of 10 kilowatts was assumed, reflecting the capabilities of current bidirectional chargers, which typically include 10 kW inverters. Event duration was set at two hours, aligning with the operational windows of many demand response programs, which often span two to three hours. This results in an energy discharge of 20 kilowatt-hours per event. For context, this level of discharge would reduce the state of charge by approximately 22% for a typical electric vehicle equipped with a 90 kWh battery—an amount that balances grid support with preserving vehicle usability.

[11] It's important to note that this exercise would look different for commercial fleet customers. Singular residential households are not large enough to bid into the wholesale market, and would need to be aggregated to participate, meaning that the value stream would be shared between the parties involved: the aggregator, the utility, the homeowner, and potentially other technology vendors. Additionally, residential customers are billed solely based on energy consumption, so would not be able to see deeper cuts in their electric bill through demand charge reduction as a commercial fleet owner might expect.

A participation rate of 50% was also assumed for each event. This conservative estimate accounts for the inherent mobility of electric vehicles, recognizing that they may not always be at home or plugged in when events are called. It also reflects the reality that drivers may occasionally prioritize maintaining vehicle range over participating in grid services, depending on their personal schedules and travel needs.

Table 1 Power (kW) Value Streams (Wholesale and Utility)

Value Stream	Associated Market/Mechanism	Value per kW-year
Transmission	Wholesale — RNS (2025)[12]	$185
Generation (Capacity)	Wholesale — FCM (2025)[13]	$30
Distribution	Utility — DPS estimate[14]	$300
Ancillary Services	Wholesale — frequency regulation	Not accounted for
	Subtotal (per kW-year):	**$515**
	50% of the Lifetime Cumulative Value over 10 years:	**$12,875**

Table 2: Energy (kWh) Value Streams (Wholesale only)

Value Stream	Associated Market/Mechanism	Value per kWh
Generation Real-time Energy Prices	Wholesale market	$0.05[15]
Ancillary Services	Wholesale - frequency regulation, voltage support, spinning reserves	Not accounted for
	50% of the Lifetime Cumulative Value over 10 years:	**$90**

Tables 1 and 2 present the estimated lifetime cumulative value of V2G functionality within V2H systems. A key insight from this analysis is that the value derived from providing power capacity (measured in kilowatts) significantly outweighs the value of energy delivery (measured in kilowatt-hours). This disparity suggests that V2G systems are best suited for infrequent, high-impact events rather than regular daily or weekly use.

Crucially, the analysis reveals that if 50% of the total grid value generated by V2G participation (assuming a 50% participation rate per event) were returned to the electric vehicle owner, the resulting benefit—approximately $13,000 over 10 years—would be sufficient to cover the cost of installing a bidirectional charger. While V2X systems do involve substantial upfront investment, there are scenarios in which their total cost of ownership may be slightly lower than that of

[12] Augelli, Jim. "Regional Rates Notice". https://www.iso-ne.com/static-assets/documents/100012/notice-of-effective-schedule-1-and-9-rates-6-14-24.docx

[13] ISO New England. "Forward Capacity Auction (FCA) 18 Results." https://www.iso-ne.com/static-assets/documents/2018/05/fca-results-report.pdf

[14] Vermont Department of Public Service. "Innovative Rate Design Study." https://publicservice.vermont.gov/document/rate-design-initiative-final-report

[15] Efficiency Vermont. "Revised Work Paper for Efficiency Vermont's Support of Flexible Load Management." https://epuc.vermont.gov/?q=downloadfile/407108/144020

conventional fossil fuel generators, particularly when accounting for lower electricity costs and the added value of grid services.[16]

Additional Considerations for Residential V2G

Beyond the economic analysis outlined above, several important considerations for residential V2G applications remain. A significant advantage of V2G systems is that homeowners can avoid the concerns associated with onsite fuel storage and the hassle of periodic fuel delivery. Fortunately, concerns about battery degradation and vehicle battery warranties are likely manageable, as the state of charge of the battery typically decreases by only 20 percent. The impact of V2H systems on battery health and vehicle usage is largely site-specific, depending on the frequency and duration of backup power usage. For instance, OEMs might permit EV battery use within warranty for occasional backup power provision, but not for daily time-of-use rate optimization.

Despite the benefits of residential V2G, several issues with current technologies remain significant. First, current technologies lack interoperability, and V2X systems can become stranded assets if the EV or home ownership changes. This is unlike whole home generators, which retain their value despite changes in EV model or home ownership. Another significant challenge is that the EV might be unavailable when backup power is needed, posing an additional disadvantage for V2X systems compared to whole home generators.

When aggregated, residential EVs can also offer grid services in the wholesale market, such as resource adequacy (ensuring sufficient capacity for future needs) and V2G can provide a valuable Non-Wires Alternative (NWA) to defer or avoid costly distribution network upgrades. V2G can also provide ancillary services typically provided by dispatchable fossil fuel generators, like frequency regulation, but valuation of ancillary grid services was beyond the scope of this research.

[16] The upfront cost of a generator installation varies widely based on specifications, but a 10-kilowatt whole-home system typically costs around $10,000 installed according to https://www.homedepot.com/p/Generac-10-000-Watt-Dual-Fuel-Air-Cooled-Whole-House-Home-Standby-Generator-Smart-Home-Monitoring-100-AMP-Transfer-Switch-7172/311540263.

Conclusions and Recommendations

This research identified the high upfront cost of bidirectionally enabled charging equipment as the primary obstacle to deploying bidirectional chargers in residential settings. This challenge is further compounded by the early stage of current market offerings, which often lack interoperability between different OEMs and vehicle models. However, the research indicates that for households with compatible EVs prioritizing the elimination of fossil fuel use and storage, installing home power backup systems using V2X technology can be financially viable.

With appropriate utility compensation for future V2X applications and advancements in technology, V2X has the potential to become an economical alternative to generators for home backup power, extending beyond niche applications. The study encourages further exploration of V2X systems, emphasizing the importance of monitoring technological advancements, costs, and installation experiences. Continued progress and cost reductions will be crucial in determining the long-term viability and adoption of these systems in the Vermont residential market. Finally, further exploration and quantification of grid benefits of residential V2G is recommended for future research.