The Potential of V2X

Challenges and opportunities for V2X, and how to accelerate market maturity in Xcel Energy's Colorado service territory

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Outwit *Complexity*

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Executive Summary

EV adoption is growing quickly and continues to evolve as the market expands. One advancement seeks to harness the bidirectional charging capability of EV batteries to support a variety of energy needs and services beyond the vehicle, such as powering other EVs, powering a home when the grid goes down, supporting renewables integration, and reducing energy costs.

Bidirectionality has been in R&D for years, with demonstrations as early as 2007 via the University of Delaware.[1] Now, following numerous improvements to EV batteries and charging standards, a growing list of OEMs are enabling bidirectionality for limited purposes. As of November 2022, one OEM—Nissan—has authorized bidirectionality for all purposes in what is known as vehicle-to-everything (V2X).

In Colorado, 78,242 EVs were in use[2] as of February 2023, with 8,647 authorized for V2X capabilities.[3] By 2030, Xcel Energy expects there will be 600,000 EVs in its Colorado service territory. Depending on OEM actions to enable V2X capability, the future EV population may present a significant energy resource opportunity. However, tapping this resource poses challenges. Guidehouse developed this report to provide an outlook for how and when such challenges may be overcome, leveraging interviews with industry experts and data from V2X pilots, demonstrations, and trials.

Guidehouse found that developments in V2X are currently best positioned for vehicle-to-home (V2H) and vehicle-to-building (V2B) deployments when specific conditions are met. Vehicle-to-grid (V2G) has potential, but deployment challenges need to be resolved before it becomes scalable. Key among these challenges are OEM battery degradation concerns, a fragmented market of infrastructure approaches and technical solutions, bottlenecks in the interconnection approval process, and uncertainties about V2G enrollment, participation, and compensation structures. Through its Partnership, Research, and Innovation program, Xcel Energy has shown an interest in helping the V2X ecosystem advance. To that end, Guidehouse has provided several recommendations to Xcel Energy:

- Incentivize V2X adoption to accelerate market development cycles
- Collaborate with equipment providers on demonstrations at the outset of product deployment
- Invest in tools to make interconnection processing more efficient
- Continue to initiate R&D pilots addressing key unknowns of implementation

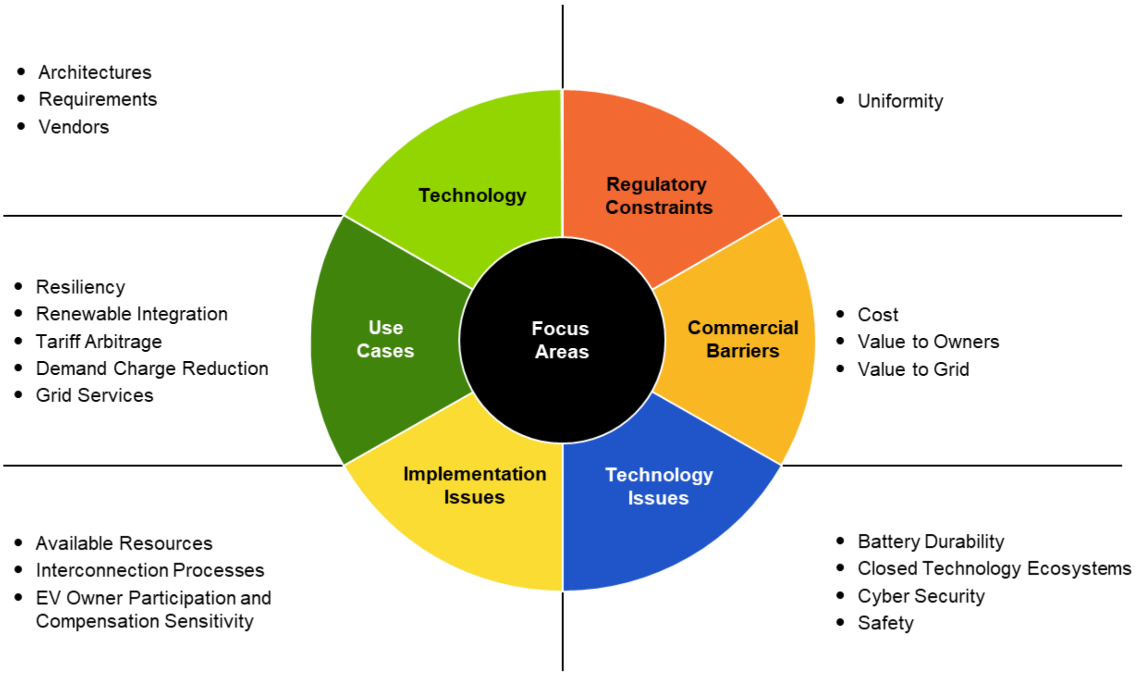
Xcel Energy is currently piloting V2X deployments at numerous customer sites in Colorado to better understand technology functionality; deployment costs; permitting and install processes; interconnection guidelines; vehicle availability; and customer participation, compensation structures, cost savings, and satisfaction. These activities are critical to establishing industry-wide best practices and moving the most advanced forms of V2X toward commercial-ready status.

Introduction

As EVs become more common, emerging developments in vehicle-to-everything (V2X) have the potential to enable EV batteries to be resources for the electric grid. V2X encompasses an ecosystem of technologies that allow EVs to discharge power into electric-powered devices and electrical infrastructure for a variety of purposes, such as charging other EVs, powering a home when the grid goes down, decreasing electricity costs, offsetting requirements for new generation capacity, and increasing renewable energy integration, among others. While V2X holds promise, it is a nascent technology with significant challenges to overcome before it can achieve widespread adoption.

The objective of this report is to provide an overview of the current state of V2X, outline the challenges of widespread adoption, and establish an outlook for how and when the challenges may be overcome. The areas of focus included in this report are represented in Figure 1.

Figure 1: Areas of Focus



(Source: Guidehouse)

To produce this report, Guidehouse interviewed industry experts, including charging equipment manufacturers, EV OEMs, electric utility providers, and V2X case study participants. Guidehouse also identified and analyzed data and insights from published reports covering V2X pilots, demonstrations, and trials. This work is referenced throughout the report.

Guidehouse found that current V2X technologies present clear opportunities for the development of vehicle-to-home (V2H) and vehicle-to-building (V2B) applications under specific conditions—V2H is likely a competitive solution for a portion of the market that both is interested in EVs and values resiliency, and V2B is competitive if property owners can effectively coordinate the availability of multiple EVs. Meanwhile, vehicle-to-grid (V2G) has potential, but significant challenges currently exist for wide-scale deployment.

The challenges for V2G are likely to abate as the emerging market for V2H and V2B applications matures. Key challenges that need to be addressed in this regard are battery degradation concerns; a fragmented market of technological approaches and solutions; bottlenecks in the interconnection approval process; and uncertainties about V2G enrollment, participation, and compensation structures. Meanwhile, cybersecurity is an underlying concern across all V2X applications, as the inherent connectivity required to enable V2X opens a new vector for cyberattacks. Such attacks could, for example, harness the bidirectional capability of V2X-capable EVs to disrupt grid stability or deplete EV batteries.

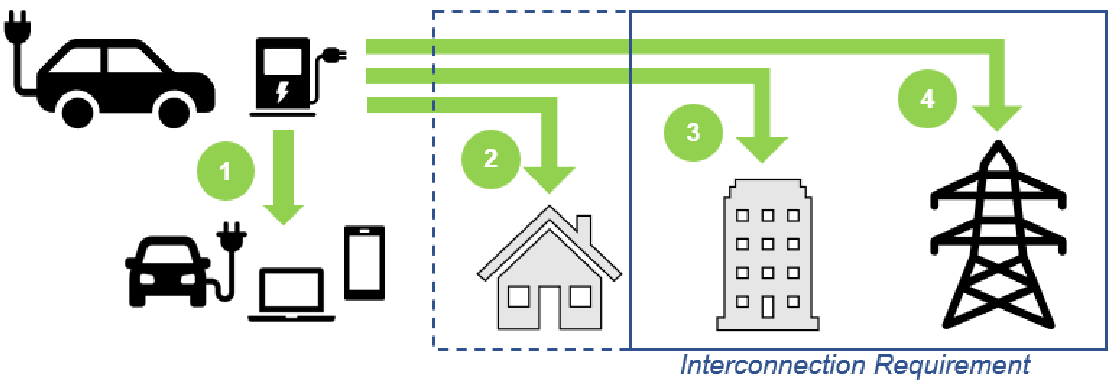
The Basics of V2X

V2X refers to both communications and the two-way energy transfer between an EV and another entity such as the grid, a home, a building, or another vehicle. Each of these applications uses its own abbreviation: V2G, V2H, V2B, and V2L (vehicle-to-load). V2L refers to an EV providing power to any electrical load, including other EVs. Because V2L does not impact the grid, it is not covered in depth in this report. All applications are enabled by vehicles and charging equipment that are designed for bidirectional charging. For V2G, V2H, and V2B, digital platforms are also required to manage energy flows between the grid, the home, or the building.

Digital energy management platforms leverage the communication technologies of the EV energy system—utilities, buildings, charging equipment, and EVs—to schedule and control the flow of electricity. This process is informed by the driver's motive energy requirements—a function of the driver's anticipated time of departure and the battery state of charge—which determines when and for how long an EV's charge may be managed or a battery discharged. This need for the time-of-departure data point means the platform must interface with owners and is dependent on their active participation. Once EV owner participation details are known, then a platform's interface with a building, utility, or grid service market enables it to optimize electricity flow. Upon completion of the EV's participation, the platform is responsible for compensating the EV owner. Most commercial EV charger networking platforms include charge management capabilities; a select few are used for discharge capability, such as those developed by Fermata Energy and Nuvve, as well as FordPass, which can be used to enable the home backup power capability featured on the F-150 Lightning.[4]

Figure 2: V2X Applications Relative to Grid Impact

1. Vehicle-to-Load (V2L): Does not impact the grid
2. Vehicle-to-Home (V2H): Can avoid grid impacts and interconnection requirements
3. Vehicle-to-Building (V2B): Interconnection required
4. Vehicle-to-Grid (V2G): Interconnection required



(Source: Guidehouse)

The most advanced and complex form of V2X is V2G. This is because V2G requires a safe interconnection with the grid that enables utilities to coordinate with EV owners. V2B is less complex, as power is not exported to the grid, yet it still requires coordination with utilities to ensure the system is interconnected safely and does not inadvertently send power to the grid. V2H avoids the interconnection requirement by isolating power flows from the vehicle to the home during power outages.

While V2G is complex, and the challenges significant, it has transformative potential for the grid. For example, the average EV has a battery pack capacity of nearly 70 kWh, and the average driver in the US would likely consume nearly 13 kWh a day[5] to power the average daily travel of 45 miles.[6] If the EV was connected to a power supply between 208 V and 240 V (common for Level 2 AC charging), the daily motive energy requirement could be replenished within 1.5 to 2 hours. This leaves a large portion of the day and night when the energy storage potential of the EV could be tapped for grid purposes.

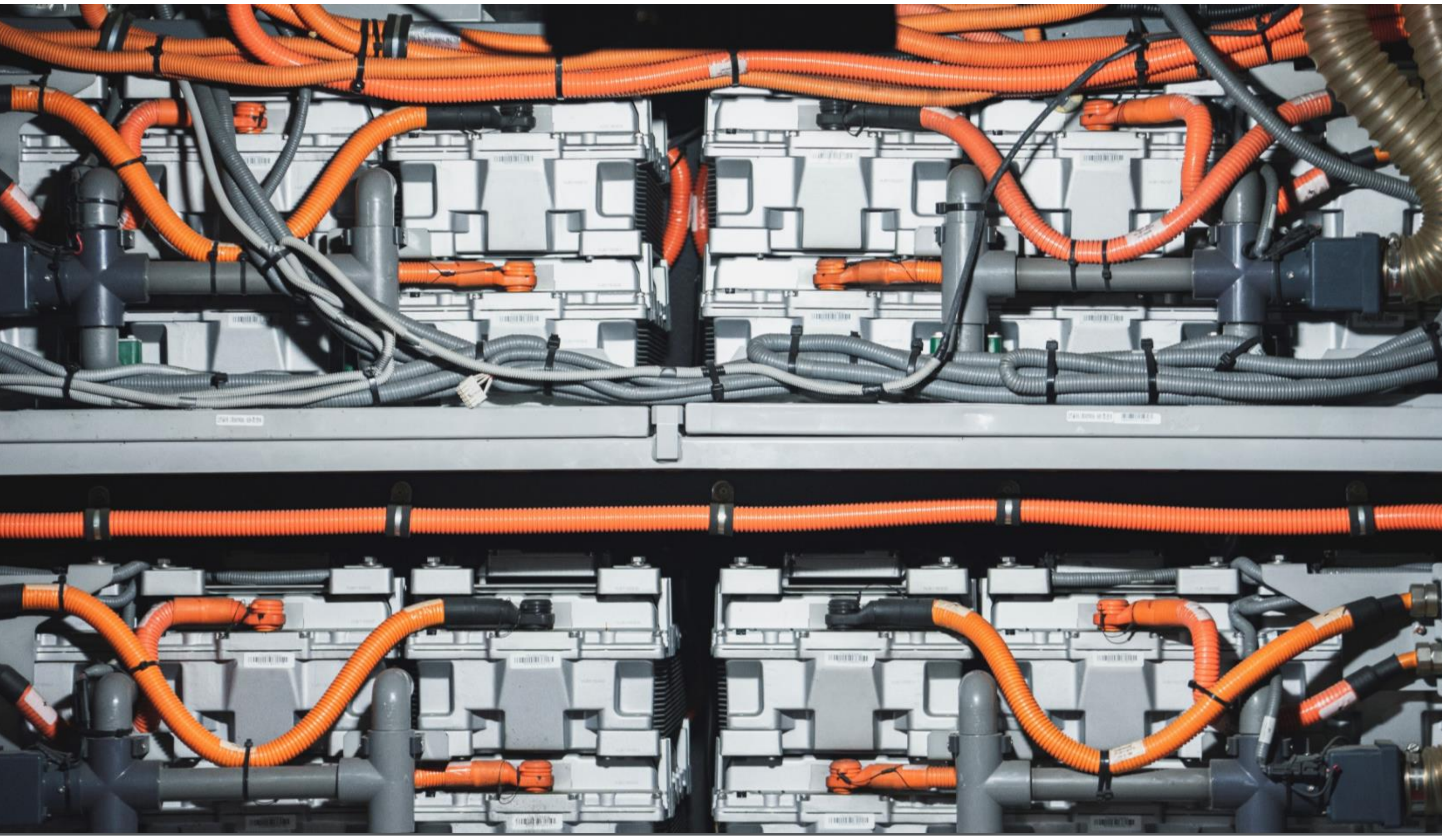
If one out of every five vehicles in Xcel Energy’s Colorado service territory is electric by 2030 (assumed in Xcel Energy’s net-zero energy vision[7]), there would be approximately 600,000 EVs. Assuming 70 kWh per EV, this amounts to 42 GWh of energy storage that could potentially absorb excess generation capacity, service high demand periods, increase renewable energy integration, or reduce needs for fossil power. Some studies suggest that with enough participation, V2G could even reduce the need to build future generation capacity.[8] Businesses, schools, and homes could also use V2B and V2H capabilities to reduce peak demand and its costs and keep critical electric loads up and running during outages. While these estimates are encouraging, specific challenges must be addressed before V2X can achieve its potential:

- **More OEMs need to enable V2X capability.** Few OEMs have enabled V2X capability on the EVs they have deployed, and only one, Nissan, has enabled V2X capability beyond V2H.[9]
- **More bidirectional charger options are needed.** The market for bidirectional chargers is fragmented between three distinct infrastructure approaches, each with limited UL-listed solutions.
- **Interconnection approval processes need to become more efficient.** Many interconnection reviews rely on manual processes that have trouble adapting to the large-scale request volumes that consumer markets present.
- **More data on V2G program metrics needs to be developed.** Too few V2G projects have taken place to provide solid data on key metrics (enrollment rates, participation rates, and compensation structures) on which to base a V2G program.

The challenges above are likely to abate as several market trends materialize. Primary among them is OEM adoption of V2X use under warranty provisions. Momentum is certainly growing in this direction as more and more OEMs are authorizing use of V2L and V2H capabilities.[10] Additionally, OEMs could authorize thousands of EVs already deployed via over-the-air updates. While this momentum is encouraging, OEM uncertainties regarding the impact of unlimited V2X use on battery degradation may moderate the trend.

EV batteries degrade as a function of use and climate. For example, full and fast battery cycling at extreme ambient temperatures is generally understood to degrade batteries the quickest. Under these conditions, most EV batteries are rated to last at least 2,000 cycles.[11] However, this scenario is rare because battery management systems typically prevent full discharging and moderate charge rates when the battery state of charge nears 100%. Additionally, EV owners generally prefer gentle charging behaviors that support durability—frequent use of slow chargers rather than periodic use of fast charging. As such, predictive modeling indicates EV batteries should last longer than the typical 8-year/100,000-mile warranty provided by OEMs.[12] However, V2X uses likely accelerate degradation. The extent is not yet well understood by OEMs, which are therefore hesitant to include all V2X uses within warranties.

Nevertheless, OEMs are moving toward V2X authorization, with the volume of V2L- and V2H-capable vehicles poised for growth. This is likely to create a market development cycle that can 1) support consolidation of technological approaches with many bidirectional charger solutions, 2) develop and spread best practices for interconnection approval processing, and 3) generate real-world data that can help utilities better understand the costs and values of V2G.



V2X Applications Are Emerging

The potential use cases for V2X are resiliency, renewables integration, tariff arbitrage, demand charge reductions, and grid services. These are not accessible across all V2X applications, and each application has a primary use case, as demonstrated in Table 1. While there are many use cases, the technology and market status for any use case is currently limited to niche market commercialization and R&D projects. The following sections provide an overview of each application.

Table 1: Common Current Use Cases for Different V2X Applications

Application	Resiliency	Renewables Integration	Tariff Arbitrage	Demand Charge Reductions	Grid Services
V2H	✓ (primary)	✓	✓		
V2B	✓	✓	✓	✓ (primary)	
V2G	✓	✓			✓ (primary)

Use case not applicable	(empty)
Use case applicable	✓
Primary use case	✓ (green)

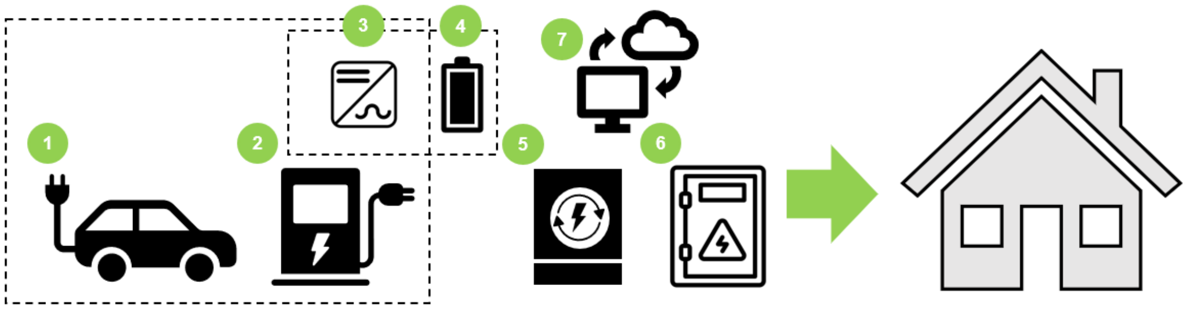
(Source: Guidehouse)

V2H Is a Cost-Competitive Resiliency Solution for a Niche Market

Emergency backup power for residential homes is the primary use case for V2H. Energy arbitrage and increasing use of excess rooftop solar generation are also possible but would require interconnection approvals to ensure that potential net power flows across the meter do not negatively impact the grid. As such, resiliency is the main appeal until interconnection issues are addressed.

Figure 3: V2H System Requirements

1. V2X-capable EV
2. Bidirectional charger
3. Inverter: Could be in vehicle, in charger, or in home energy management system
4. Blackstart battery: Provides power until main energy assets are online
5. Disconnect switch: Prevents back-feeding during outages
6. Critical load panel: Prioritizes load toward essential appliances and circuits
7. Digital energy management platform: Controls energy flows between vehicle and home



(Source: Guidehouse)

The only V2H solution on the market is provided through a partnership between Ford and Sunrun designed specifically for the Ford F-150 Lightning. Ford provides the bidirectional charger, while Sunrun provides a home integration system consisting of the system's required inverter, a disconnect switch, and a blackstart battery. Ford and Sunrun's deployment indicates that total cost for V2H deployment likely approaches $11,000, with costs split roughly evenly between equipment and installation. As shown in Table 2, this produces a premium over the standard residential L2 charger deployment of **$8,594 to $9,005**.

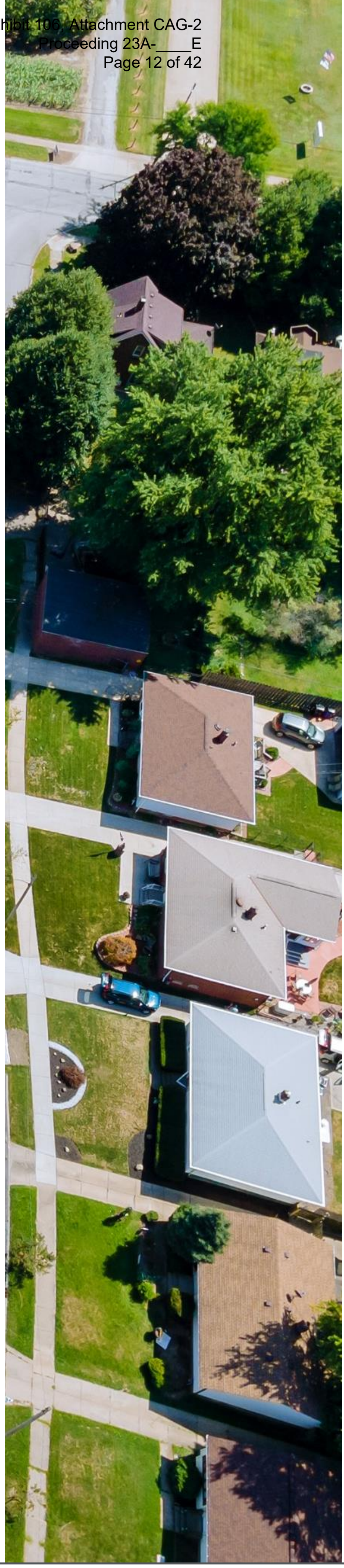
Table 2: V2H Deployment Cost Premium

Deployment Cost Component[13]	Ford-Sunrun V2H Solution	L2 Home Charger[14]
Charger	$1,310[15]	$380–$689
Power Management Equipment	$3,895[16]	NA
Equipment Total	$5,205	$380–$689
Bundle: Power Management Equipment and Install + Charger Install	$9,400	NA
Install Cost (Charger + Bundle – Equipment Total)	$5,505	$1,325–$1,427
Deployment Total	**$10,710**	**$1,705–$2,116**
V2H Premium	**$8,594–$9,005**	

(Source: Guidehouse)

Figure 4: Ford-Sunrun Illustration of V2H System with Rooftop Solar

(Photo courtesy of Sunrun)



Outside of Ford's V2H deployment, no other solutions have yet been commercialized. Ford has indicated that deployment monitoring is ongoing but no data on adoption is yet available. Additionally, Ford interviewees noted they are taking a "crawl, walk, run" approach that begins with home backup power. Ford has also begun internal testing on other V2X capabilities, including a pilot V2G program with PG&E,[17] but has not provided further details.

Industry standards are a key challenge for V2H. Current bidirectional chargers have compatibility limitations with upcoming V2X-capable EVs. For example, Ford's system can only work with the Ford F-150 Lightning. Similarly, Lucid's bidirectional charger is only compatible with Lucid vehicles, and current bidirectional Fermata chargers are only compatible with CHAdeMO connections. These types of compatibility issues lock customers into specific technology ecosystems, posing a risk of asset stranding if the charger outlasts the EV or vice versa.

In terms of capability, V2H systems are more than capable of providing power for temporary outages, but not for sustained ones. For example, if an extended-range F-150 Lightning was fully charged, Ford and Sunrun estimate it could support a home's power needs for three days at an average of 30 kWh per day[18] while still retaining some energy in the battery for driving. This is substantial; however, for many customers, the value of such resiliency over the cost of a standard home charger may not be equivalent to the premium paid. A study by PG&E indicated this may be the case, as it concluded that customer willingness to pay for a V2H system was lower than the estimated cost.[19]

While costs for bidirectional chargers are likely to decline, other costs for power management equipment and installations are unlikely to see similar declines because these technologies and services are mature. This likely limits mass-market adoption unless consumers value resiliency more. Until then, **V2H is likely competitive for a portion of the market that is interested in EVs and sufficiently values resiliency**, as the V2H system premium is competitive against fossil fuel-powered whole home generators[20] and battery backup systems.[21]

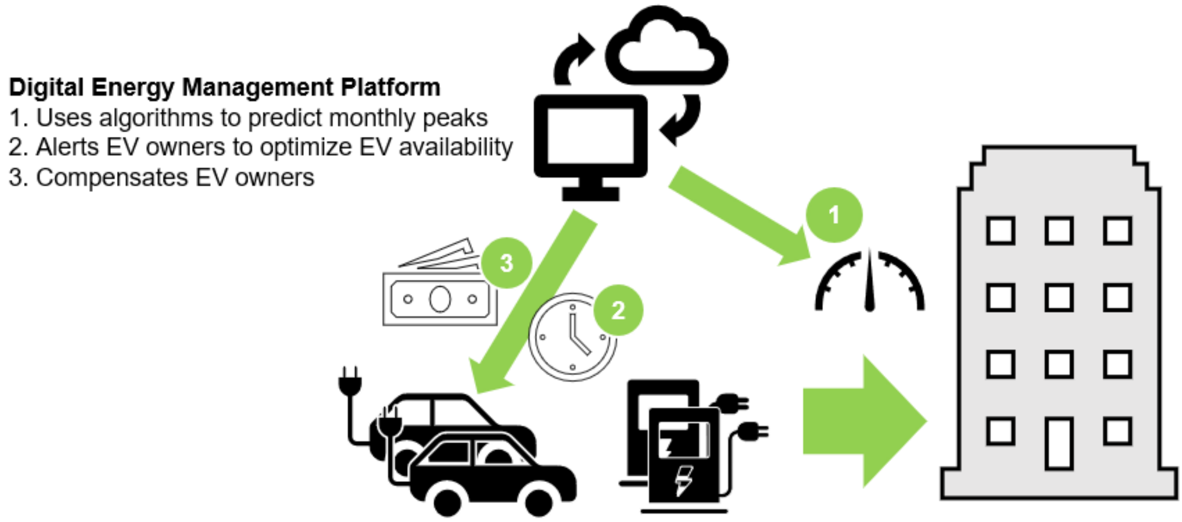
Currently, Xcel Energy is piloting a limited V2H deployment at three customer sites. During this pilot, Xcel Energy will be testing the backup power capability and limitations of EVs for residential homes. Additionally, the pilot seeks to better understand the permitting and installation processes and gauge performance and customer satisfaction for V2H systems.

V2B Costs and EV Scheduling Challenges Limit Adoption Potential

The primary V2B use cases are energy cost savings via demand charge reductions and tariff arbitrage. Like V2H, V2B also has potential to take advantage of onsite renewable power and be a resiliency resource. Time-of-use rates and demand charges are distinct pricing components common within commercial property utility rate structures. Coordinating vehicle batteries to charge during off-peak times and to discharge at peak times increases the property's utilization of off-peak rates and can also reduce the monthly peak.

As the primary V2B use cases require EVs to back-feed building infrastructure while it is also being powered by the grid, an interconnection study must accompany deployment to ensure net power flow across the meter does not negatively impact the grid. Beyond this study, V2B functionality needs the same components as a V2H system. However, the digital energy management platform will likely require more advanced functions, as demonstrated in Figure 5.

Figure 5: V2B System Requirements



(Source: Guidehouse)

V2B has been explored through R&D projects focusing on energy cost reductions via tariff arbitrage and demand charge reductions. In Colorado, V2B R&D projects have resulted in monthly energy cost savings of around $240 per month, as demonstrated in Table 3.

Table 3: Examples of V2B Peak Shaving Project Results

Project	Location	Chargers	Months	Total Savings	Savings/ Month
Alliance Center/Colorado CarShare[22]	Colorado	1	4	$950	$238
Boulder Recreation Center[23]	Colorado	1	12	$2,963	$247
Electric Frog/Burrillville Wastewater[24]	New York	1	1	$222	$222[25]
Roanoke Electric Cooperative[26]	Virginia	1	2	$235	$118

(Source: Guidehouse)

Figure 6: Nissan Leaf with Fermata Bidirectional Charger at Boulder Recreation Center

(Photo courtesy of City of Boulder)

However, achieving the savings comes with a high cost. Figures provided to Guidehouse and Xcel Energy indicate that commercial L2 DC bidirectional chargers cost approximately $10,000, additional power management equipment costs approximately $8,000, and install costs range from $10,000 to $25,000—not including costs associated with completing interconnection approvals, which vary depending on site-specific factors. As demonstrated in Table 4, these costs translate to simple payback periods of 6 to 12 years.

Table 4: V2B Simple Payback Analysis in Colorado

Cost Component	V2B ($/charger)	Commercial L2 ($/charger)[27]	V2B Premium ($/charger)
Charger	$10,000	$4,900–$7,210	$2,790–$5,100
Power Management Equipment + Install	$18,000–$33,000	$4,173	$13,827–$28,827
Deployment Total	**$28,000–$43,000**	**$9,073–$11,383**	**$16,617–$33,927**
Annual V2B Savings	**$2,900**	**NA**	**$2,900**
Simple Payback (years)			**6–12**

(Source: Guidehouse)

Notably, the high costs are associated with three-phase electrical infrastructure requirements, increasing costs for both power management and installs. Expanded availability of single-phase solutions would likely see power management equipment and install costs fall significantly. Additionally, as a building may host multiple chargers and EVs, deployments of more than one bidirectional charger would likely realize some scale benefits and a faster payback. Government financial assistance and agreements with equipment providers can also greatly reduce site deployment costs. For example, one pilot program participant reduced overall upfront costs to $10,000[28] via grants and an agreement to share operational cost savings with the V2B provider.

An additional challenge to achieving energy cost savings is managing vehicle availability. Digital platforms can dispatch EVs in time with the building's peak load, but only if the EVs are plugged in. Ensuring availability is a manual task, as was noted by a V2B pilot participant.[29] This means property staff must be aware of the V2B strategy and manage EVs accordingly to attain monthly savings. There may be opportunities where peak loads coincidentally align with EV availability. This will, however, vary case by case and may be difficult for property owners to understand. As such, achieving a payback ahead of an assumed 10-year charger lifespan is uncertain.[30] Thus, **V2B is likely to serve niche markets** until deployment costs decline.

Currently, Xcel Energy is piloting a limited V2B deployment at two customer sites. During this pilot, Xcel Energy will test V2B technologies to understand the costs to deploy and operate, gauge vehicle availability and cost savings, and evaluate other potential deployments.

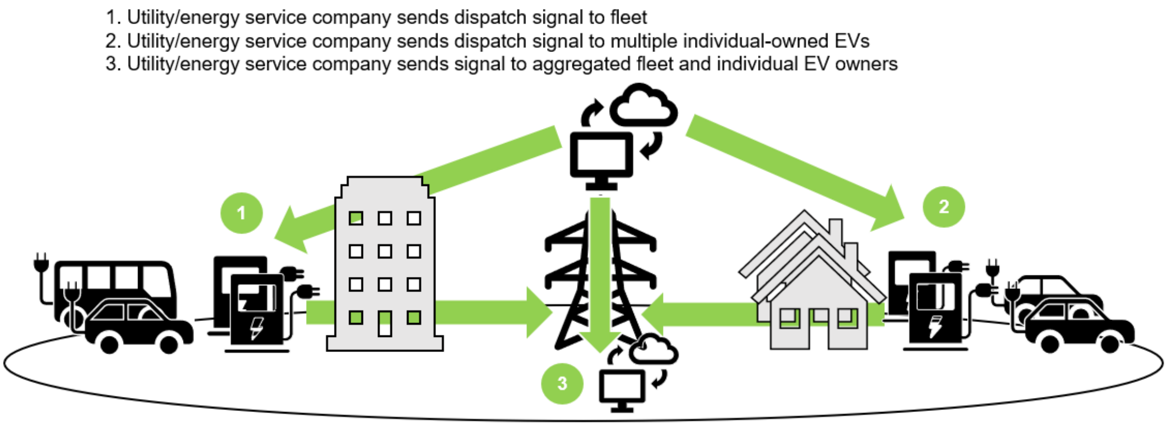
V2G Has Potential, but Other V2X Applications Need to Develop First

V2G has many potential uses, including reducing peak demand on a grid-wide basis, integrating renewables, and providing grid services such as frequency and voltage regulation, among others. As the grid becomes more intelligent and decentralized, V2G could also be used for other localized services to reduce grid management costs.

The benefit of V2G to EV owners is reduced electricity cost. For grid operators, V2G could reduce grid management costs and make the grid more greenhouse gas (GHG) efficient. This would occur if the process of aggregating V2G assets and compensating owners for participation fell below the costs of using other, more centralized assets commonly used for grid services like natural gas peaker plants or dedicated battery energy storage systems. Use of V2G assets, alongside energy storage systems, would also displace use of GHG-intense assets and thus help reduce GHG content on the grid.

V2G requirements are effectively the same as those for V2B. The difference, however, is that the digital energy management platform leverages connectivity to utility programs or energy markets to inform charge/discharge scheduling. Depending on where EVs are located, these programs or markets may not be accessible. Where utilities and energy markets are accessible, V2G R&D activities have been accomplished leveraging EVs at homes and buildings. As demonstrated in Figure 7, V2G programs can be managed by utilities or energy service companies, both of which use grid data to send charge/discharge signals to EVs and compensate owners according to participation rates.

Figure 7: Approaches to V2G Implementation



(Source: Guidehouse)

R&D for home-based V2G is rare; however, activities in the UK have aggregated upwards of 400 home-based V2G deployments.[31] Development of V2G in the rest of Europe and in the US has focused more on commercial fleets, which are generally more attractive for V2G given larger and more reliable energy storage potential per interconnection. For example, electric school buses have large batteries, leverage centralized depots for maintenance and refueling, have predictable routes and energy requirements, and have attractive availability for stationary energy storage during summer electrical usage peaks. As such, the costs to activate a fleet of electric school buses for V2G is proportionally much less than to do so for a single home or V2X-capable vehicle. Additionally, reaching minimum capacity requirements for energy market participation is much easier than aggregating hundreds of individually owned EVs. In the US, V2G demonstrations leveraging school buses are increasingly common, as shown in Table 5.

Table 5: School Bus V2G Projects in the US

Location	Bus OEM	Buses	Project Start
Torrance, California[32]	Blue Bird	6	2017
Multiple school districts, Virginia[33]	Thomas Built	50	2019
White Plains, New York[34]	Lion Electric	3	2020
Pekin/Peoria, Illinois[35]	Blue Bird	2	2021
Ann Arbor/Roseville, Michigan[36]	Thomas Built	6	2021
Beverly, Massachusetts[37]	Thomas Built	1	2021
El Cajon, California[38]	Lion Electric	6	2022
Durango, Colorado[39]	Blue Bird	1	2022
Ramona, California[40]	Blue Bird	8	2022
South Burlington, Vermont[41]	Thomas Built	4	2022

(Source: Guidehouse)

Figure 8: Blue Bird Electric School Bus Connected to Nuvve Bidirectional Charger in Durango, CO

(Photo courtesy of Nuvve Holding Corp.)

Lessons from the school bus V2G projects are ongoing; however, early indications suggest that V2G has had little impact on the availability of buses for their primary transportation use[42] and can play a meaningful role in reducing total cost of ownership.[43] Projects have also identified efficiency losses of 15% tied to the additional power conversion and parasitic draws of V2G systems, and battery degradation rates from V2G have been equivalent to degradation under motive power conditions. Findings do not yet clearly indicate the financial viability of V2G.

A key challenge for V2G will be clearly achieving a positive cost-benefit ratio. This is because the conditions of V2G are highly variable, depending on the value of grid services in a utility service territory or electricity market compared with the cost of financing equipment installation and incentivizing sufficient EV owner participation levels.

The value of grid services is not consistent geographically or temporally. Geographically, grids with high penetration of intermittent renewables (solar, wind) likely value distributed energy resources (DER) more than grids with more reliable renewables (hydro) or more reliable low carbon generation sources (nuclear). Temporally, the value of grid services fluctuates over the course of the day, often a function of the alignment of grid demand and generation profiles. As such, times when DER values are high may not coincide with high availability of V2G-capable EVs.

To evaluate the financial viability of a V2G deployment in Xcel Energy's Colorado service territory, Guidehouse assessed the simple payback for a 60 kW DC V2G charger deployment of an electric school bus using Xcel Energy's Interruptible Service Option Credit.[44] As demonstrated in Table 6, simple payback is not achieved until year 13, longer than an assumed 10-year charger lifespan.[45]

Table 6: V2G Simple Payback Analysis in Xcel Energy's Colorado Service Territory

Cost Component	V2G ($/charger)	DC Fast Charger ($/charger)	V2G Premium ($/charger)
Charger	$65,650	$39,390	$26,260
Power Management Equipment + Install	$129,952	$103,962	$25,990
Deployment Total	**$195,602**	**$143,352**	**$52,250**
V2G Revenue ($/year)	**$4,042**	**NA**	**$4,042**
Simple Payback (years)			**13**

(Source: Guidehouse)

The result is not encouraging—deployment costs need to come down to speed payback. Beyond electric school buses, V2G opportunities are severely limited by a lack of vehicle and charger options. For example, the only V2G-authorized light duty vehicle is the Nissan Leaf, and the only UL-listed bidirectional charger that supports the Leaf requires three-phase electrical infrastructure. This makes the technology prohibitively expensive to install in a vast number of residential and commercial scenarios. Hence, for an aggregator or utility to develop **a wide-scale V2G program today would be premature**.

Currently, Xcel Energy is piloting a limited V2G deployment at two customer sites. During this demonstration, Xcel Energy will test the availability and functionality of electric school buses for use as a grid resource. Additionally, Xcel Energy seeks to better understand the system components and costs, develop interconnection guidelines, and gain insights into customer participation and compensation structures.

The Road toward V2G

While development of a wide-scale V2G program today is premature, it may be feasible in the not-too-distant future. Emerging V2X technologies show promise under specific, limited conditions for both V2H and V2B that likely support a small but growing volume of V2X-capable EVs. As these volumes grow, industry stakeholders need to address battery degradation concerns, a lack of technology solutions, complicated interconnection approval processes, and participation rate uncertainties to make wide-scale V2G program development possible.

Battery Degradation Concerns Need to Diminish

Repeated cycling of an EV's battery likely contributes to degradation, which affects the depreciation of the EV. Understanding the relationship between battery charging/discharging cycles and depreciation is key to OEMs authorizing V2X use cases, warranty guidance, and appropriate compensation rates for EV owners.

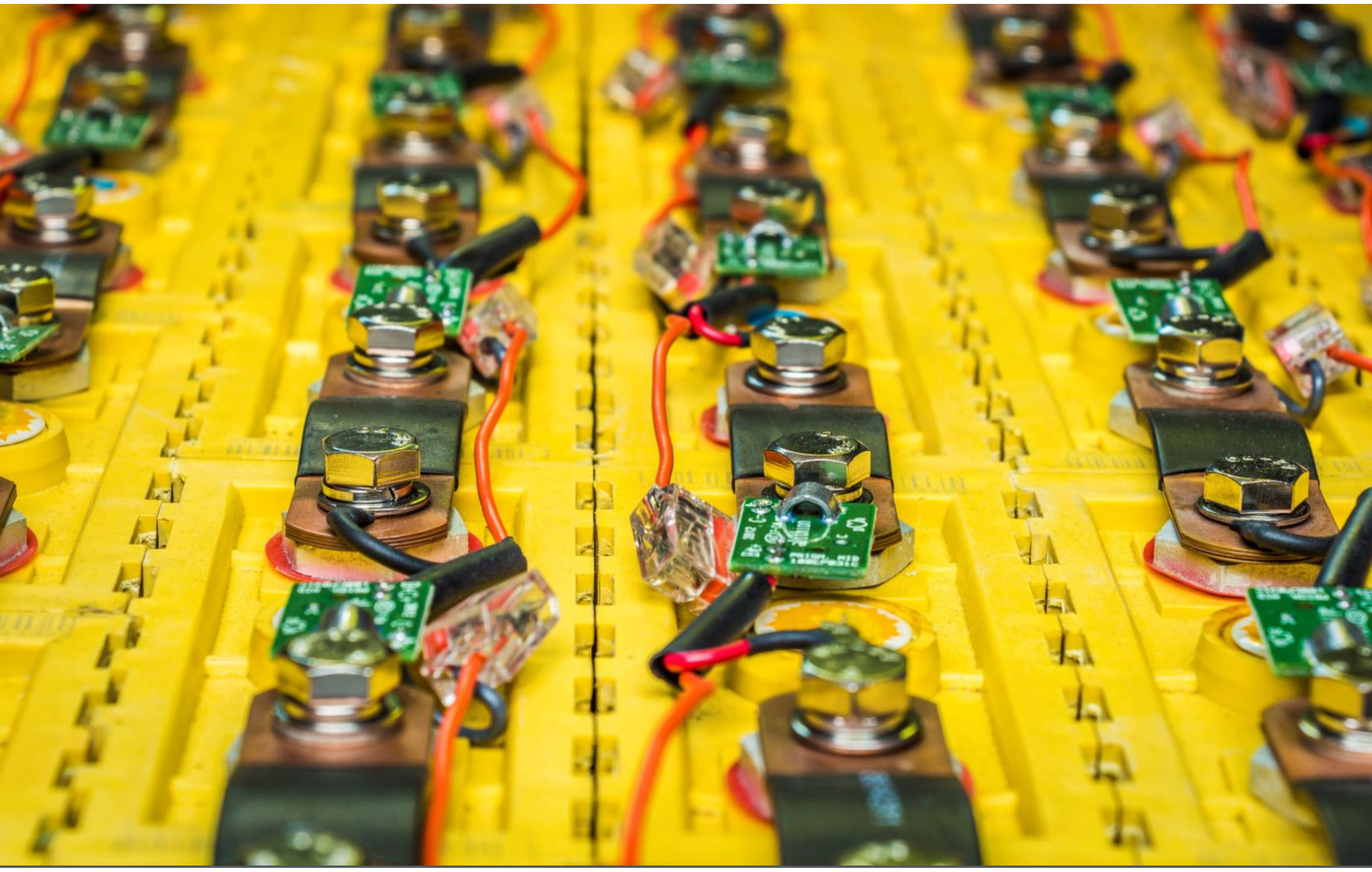
The rate of degradation depends on numerous factors; generally, however, the deeper and faster the discharge, the greater the degradation. Notably, shallow, gentle cycling may have marginal to beneficial impacts, as was found in a study published by the Royal Society of Chemistry.[46] The study modeled V2G battery degradation and determined that the energy cost savings likely outweigh the depreciation impact. While this finding is encouraging, more real-world data is likely necessary for each V2X use case to enable widespread OEM authorization and warranty incorporation. To this end, R&D activities are continuously evaluating battery degradation impacts. Additionally, innovations in battery and charging technologies are also diminishing the degradation threat and its financial impacts.

The momentum of the overall EV market is driving significant investments in battery innovations. From a V2X perspective, the most relevant and impactful innovations would see a market shift away from nickel-rich battery chemistries toward alternate, cheaper, and more durable chemistries like lithium iron phosphate (LFP), as well as toward new, more durable cell architectures like solid-state. LFP adoption is growing now, as it is the most common EV battery technology in China and is emerging in the US and Europe. LFP is considered to be far more durable and stable than nickel-rich chemistries, with the ability to withstand multiple thousands of charge cycles with minimal degradation.[47]

However, with minimal deployment of V2X today and LFP's lower energy density compared with nickel-rich cells, the real driver for wide adoption of LFP is the 30% to 40% lower cost. A shift away from current modular battery pack architectures to cell-to-pack (a.k.a. structural pack) architectures is leading to a doubling of the fill ratio of active cell material, overcoming the lower energy density of LFP.

Solid-state technology is in R&D phases, with the first real-world deployments expected to occur mid-decade in non-plug-in hybrids. Successful testing under the hybrid use case and successful scaling of the manufacturing process would likely lead to deployment within EVs near the end of the decade. Beyond these innovations, durability improvements are also being explored through technologies that manage electron flow and temperature. Additionally, significant investments are driving innovations that indirectly mitigate degradation threats by reducing battery manufacturing costs and decreasing battery depreciation. In addition to the shift to cell-to-pack architectures that simplify the pack, there are numerous efforts to commercialize dry electrode coating, which would bring manufacturing cost reductions of 25% or more regardless of the chemistry.

As a sign of this trend, light duty OEMs are moving toward V2X and V2L adoption.[48] Notably, however, the full suite of V2X capabilities is only authorized for the Nissan Leaf.[49] Among commercial vehicle markets, V2G capability has focused on the school bus market, where most suppliers—Thomas Built, Blue Bird, IC Bus, Lion Electric, Trans Tech, Collins, Starcraft, and BYD—now offer V2G as an option or as standard.[50]



Technological Approaches Need to Consolidate

The suite of bidirectional chargers available now have limited compatibility with V2X-capable EVs. This is a risk for consumers, as it locks them into closed technology ecosystems. As the market matures, more V2X infrastructure solutions are likely to be made compatible with more V2X-capable EVs, allowing customers to mix and match solutions as they see fit. Currently three distinct architectures are used by OEMs, as shown in Table 7. These architectures are distinguished by the inverter's location.

Table 7: V2X System Architectures

Inverter Location	Charger Type	Pros	Cons	Market Examples
EV	AC	Lower charger cost	Increased EV cost Limited discharge	Lucid Air (J1772)
Charger	DC	Lower EV cost	Higher charger cost	Nissan Leaf (CHAdeMO)
Other equipment	DC	May benefit onsite generation and storage Lower charger cost	Higher overall infrastructure costs if no onsite generation and storage opportunity	Ford F-150 Lightning (CCS)

(Source: Guidehouse)

An additional distinction among the architectures is connection standard. The Combined Charging System (CCS) has emerged as the leading fast charge connector in the US and Europe for all non-Tesla EVs. However, the competing CHAdeMO standard remains relevant in V2X because it has long defined requirements for V2G communications. Only recently has the Charging Interface Initiative (CharIN), which defines requirements for CCS-related standards, published certificate policies[51] for V2G communication protocols. This is encouraging and will help consolidate the market toward a more uniform charging solution. However, the market is fragmented, and UL-listed supply for any given approach is limited.[52] Before wide-scale V2G program development can occur, greater technological consolidation is needed alongside increased product availability. Notably, Tesla's North American Charging Standard is the dominant standard in terms of EVs in use and public DC fast charger deployments.[53] While the standard is now open for adoption by other EV makers, it is currently only used by Tesla.

Interconnection Approvals Need to Be More Efficient

Interconnection issues are a challenge for V2G. To quote a report commissioned by UK Power Networks and Innovate UK, “Onerous interconnection requirements were repeatedly flagged in interviews (Grid Motion, France; JumpSMARTMAui, USA; Parker, Denmark).” [54] Furthermore, the distributed nature of V2X is a challenge to a rigid regulatory structure built to serve centralized energy distribution. This is summarized well in a report by Kaluza, which states, “As is often the case, policy and regulatory change tends to lag behind technological innovation, and the same is true in the case of V2X.”[55]

The interconnection process is important to maintaining safe and reliable grid operations. It is, however, a bottleneck. As illustrated by challenges observed with residential solar installations, each install requires the utility to complete an interconnection study to ensure that back-feeding the grid does not create negative impacts or safety risks to local distribution systems. These studies are not easily or quickly completed, and as market adoption increases, they create challenging backlogs for utilities.

Utilities are seeking to address this complication via automation. For example, the National Renewable Energy Laboratory (NREL) partnered with the Sacramento Municipal Utility District in California to create an automated interconnection assessment tool called PRECISE. Since the tool launched in February 2022, it is reported to have processed an average of 13 applications per day (as of November 2022).[56] NREL states that the tool’s potential on a daily basis is in the hundreds. If the tool proves successful, it will be an encouraging development for the industry that could mitigate current and future interconnection challenges.

Participation Rates Need to Be Better Understood

The value of V2G to the grid depends on when EVs are available and what level of incentive is required to stoke participation. Potential coincident periods of low vehicle availability and high electricity demand could mean most EVs are unavailable for the highest value times. Additionally, even if EVs are available, they may not participate given any number of circumstances.

Better understanding EV availability and participation relative to incentive level is critical to determining how many V2G-capable EVs are needed within a geographic area for a utility or aggregator to meet minimum requirements for grid service markets or targets for utility programs. The first step in this process is gauging physical vehicle availability against grid needs. This may be modeled using data on vehicle travel and EV charging behaviors and then compared against data on renewable generation, peak demand, or grid service markets. The output of this exercise is likely to vary by utility.

Physical vehicle availability must be significantly greater than the minimum capacity requirement. This is because enrollment within a given DER program likely captures a small minority of the overall resource base, as demonstrated in Table 8.

Table 8: Enrollment Rates in Similar Opt-In DER Programs

Location[57]	Program	Incentive	Program Enrollment Rate
UK	Kaluza V2G trial	$41/month (average)	14%
Colorado	Xcel Energy AC Rewards	$50 rebate, $100 sign-up, $25/year	10%
Colorado	Xcel Energy Charging Perks	$100 sign-up, $100/year	1%
Colorado	Xcel Energy Optimize Your Charge	$50/year	3.3%
Mountain States	Retail demand response programs	Varies by market specific factors	12%
US	Retail demand response programs	Varies by market specific factors	8%

(Source: Guidehouse)

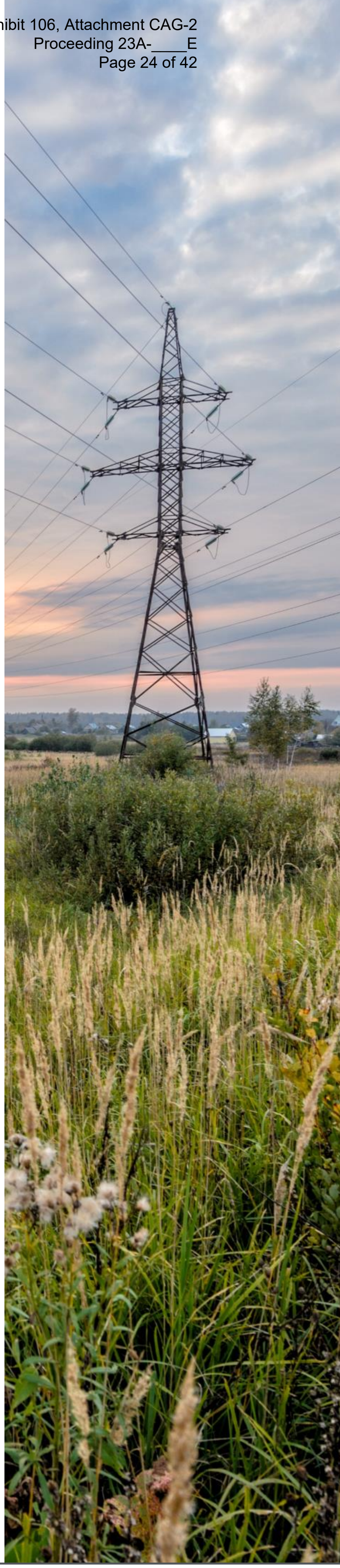
The enrollment rate only informs part of the participation picture. Actual program participation will depend on EV owner choices, as an enrolled, plugged-in participant may choose to defer participation. The rate at which enrollees will participate likely depends on what incentives program managers provide. In this regard, there is little real-world data. As the market develops, R&D projects will be key to better understanding owner sensitivity and thereby gauging the appropriate market volumes required to deploy wide-scale V2G programs.

Timing V2G Potential in Xcel Energy's Colorado Service Territory

For a wide-scale V2G program to be viable, a minimum capacity threshold defined for a specific grid service within a specific geography must be determined. This is likely to vary by geography for a variety of reasons. In geographies covered by independent system operators (ISOs) and regional transmission organizations (RTOs), the minimum capacity threshold for electric storage participation in capacity, energy, and ancillary markets is regulated by the Federal Energy Regulatory Commission (FERC) at 100 kW.[58] While Colorado is not included within an ISO/RTO market, this regulation may provide an indicative value from which to evaluate the readiness of V2G in Xcel Energy's Colorado service territory.

Assuming that each V2G-capable EV can provide an average of 7 kW when plugged in, at least 14 need to be plugged in and ready to participate at any given time. This may be easy to achieve at night with a few vehicles, but it is likely very challenging during the day when vehicles are most active. As such, a utility or aggregator would need to enroll greater volumes of EVs to maintain a diverse body of V2G resources that would maintain a consistent 100 kW minimum. R&D projects in the UK[59] and Massachusetts[60] indicate at least five EVs need to be enrolled, so that one may be plugged in at any given time. The Massachusetts project further indicates that at least two need to be plugged in to reliably assume that one participates. Hence, at least 10 EVs would need to be enrolled so that one is always ready and available to participate. Meeting the 100 kW minimum would therefore require enrolling at least 143 V2G-capable EVs. Based on enrollment rate data, demonstrated in Table 8, Guidehouse assumes Xcel Energy could enroll 10% of a V2G-capable EV fleet within its service territory. This would mean 1,430 V2G-capable EVs would need to be in use in Xcel Energy's service territory.

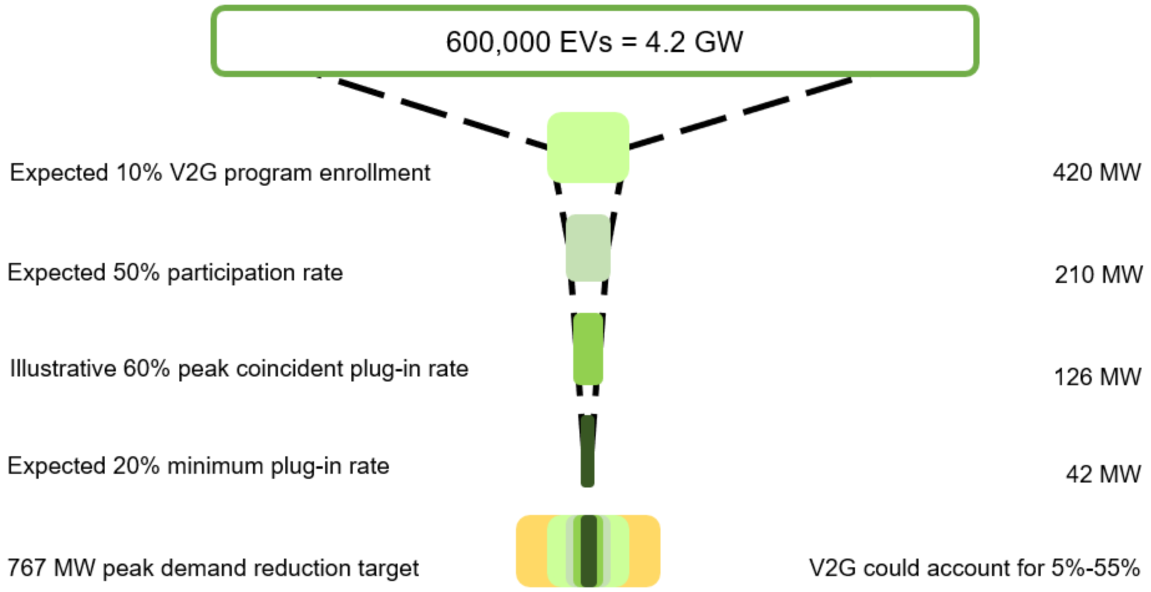
Currently, there are just under 6,400 V2G-capable EVs in the service territory (11.6% of all EVs).[61] These are all Nissan Leafs, as the Ford F-150 Lightning is not yet authorized for V2G. It is possible that the Ford F-150 Lightning could become V2G capable via over-the-air updates; this is true of many EVs, and as such, the number of V2G-capable EVs could surge. However, OEM plans in this regard are not clear, and few OEMs have indicated an update is coming beyond V2L or V2H. Regardless, under the assumed logic, a V2G program could enroll 640 V2G-capable EVs, of which 64 could be assumed plugged in and providing nearly 450 kW at all times, thus exceeding the 100 kW minimum capacity requirement.



This would be the case if bidirectional charging solutions leveraging residential single-phase electrical infrastructure existed. If it can be assumed that such solutions will emerge, then the V2G picture will look different by 2030. For example, Xcel Energy expects the EV fleet within its territory to grow over 10 times, such that 600,000 EVs would be in use. If the current share of V2G-capable EVs to overall EVs (11.6%) remained the same, Xcel Energy could expect a V2G program to produce close to 4.9 MW at any given time.

Alternatively, if OEMs authorized V2G such that it was standard on all EVs, a V2G program could expect to aggregate at least 42 MW of capacity at any given time. As of November 2022, Xcel Energy has proposed a 2030 demand response goal of 767 MW for its Colorado service territory.[62] Depending on the coincidence of vehicle availability with peak demand, the V2G resource base could make a significant contribution to meeting the 700 MW demand response target by 2030. For example, if 60% of the V2G-capable EVs were available during the system peak, V2G could support 18% (126 MW) of the target, as demonstrated in Figure 9.

Figure 9: 2030 V2G Potential in Xcel Energy's Colorado Service Territory



(Source: Guidehouse)

Ways to Accelerate the Market

Developments in V2X technologies show promise for V2H, V2B, and V2G. There are many challenges for the technology ecosystem to overcome, but there are also clear business cases for deployment of V2H and V2B now that could generate positive market development cycles to enable V2G later. Therefore, Guidehouse recommends:

- **Incentives** for bidirectional chargers, and the installation costs thereof, to accelerate adoption and market development cycles. Encouraging this is necessary for industry standards to consolidate and more products to enter the market. A focus on V2H and V2B deployments for resiliency purposes, rather than use cases that would require interconnection studies, is suggested to avoid current processing complications. Additionally, incentive design must be mindful of the potential to increase inequity in the market. In this regard, focusing on support for public transit systems such as school busing is recommended.
- **Collaboration** with equipment providers on demonstrations at the outset of product deployment. Early V2X adoption will yield data about vehicle usage and customer sentiment that Xcel Energy needs to access so it can better understand the technologies and the behaviors of the customers that use them.
- **Investment** in tools to make interconnection processing more efficient. While targeted investments in V2X technologies will help the market development cycle churn, these investments may not result in a viable V2G resource if interconnection processing is not more efficient. Xcel Energy should position itself at the forefront of market developments in this regard and exploit opportunities to test developers' tools. This could support near-term challenges with rooftop solar interconnection processing and lay the foundation for streamlined V2G interconnections in the future.
- **R&D pilots** to launch projects targeted at addressing key unknowns of V2G implementation such as enrollment rates, EV availability relative to grid values, and owner participation relative to incentive levels. Better understanding these variables will improve Xcel Energy's ability to plan and time potential wide-scale V2G rollouts.

Appendix 1: Interview Notes

Interview #1

Industry: Nonprofit
Organizational Focus: Demonstrate sustainable solutions to climate change issues using the built environment
V2X Experience:

- Organization saw potential intersection between V2X and its physical building
- Coordinated demonstration with EV supply equipment (EVSE) manufacturer for a V2B pilot focused on maximizing energy efficiency to vet battery technology
- Pilot outcome:
    - Utilizing car battery to reduce utility bill with demand charge structure (5% savings)
    - Developed economic model with project partners to ensure there was not a big payback period for initial investment
    - Next step is planning to reach out to Xcel Energy to explore opportunities for tariff structure and use it as a grid resource

V2X Applications and Use Cases:

- Primary use case is reduced demand charges by using the car battery

Technical Challenges of V2X Adoption:

- Very manual process right now to set up, and limitations in identifying which cars can be utilized
- Challenges balancing personnel with anticipating when the car can be connected to the building to participate in demand events
- Predictive algorithms and AI may alleviate the need for manual scheduling. Need to more gracefully managing car availability based on grid signals.

Financial Challenges of V2X Adoption:

- V2X pilot was only cost-favorable due to a grant that covered the installation of car charger
- Total upfront costs are $10,000 including ~$1,000-$2,000 for electrical infrastructure

Incentivizing Adoption of V2X:

- Utility is a big driver for creating a win-win incentive for building owner that aligns with existing billing
- In terms of making it happen, there is a deployment of infrastructure, and shifting infrastructure is critical
- Car partnership and utilizing car battery for voiding warranting (car manufacturers)
- Adoption will follow once there are rate structures that make economic sense

Assessing Value for V2X:

- Simple cost-benefit analysis
    - Calculate the upfront cost and potential lease/cost for car
    - Identify payback period and ROI
    - Organization is willing to take on some risk, but need assurance of lowering bill credit
    - Resiliency is not a primary benefit for this location

Interview #2

Industry: EVSE
Organizational Focus: Design, supply, and operate technology that integrates EVs with buildings and the electricity grid
V2X Experience:

- Organization provides V2G-capable charging software and hardware that empowers EV owners to earn money and protect the environment while contributing to a more resilient and renewable-energy-based power grid
- Currently operates commercially available Nissan Leaf V2G deployments
- Currently functioning as an aggregator, but can help coordinate with the utility to serve nodal needs

Pilot Programs:

- Behind-the-meter (BTM) demand side management project (reducing electric costs by at least the cost of a Nissan Leaf lease—paying for itself)
- Demand response: One customer used a 15 kW charger, which earned $4,300 per year. This pilot was designed to help them understand optimization of response capabilities.

Growth of V2X Market:

- More V2G-compatible cars. Nissan Leaf now (and Mitsubishi Outlander), expecting a dozen more models to be compatible by 2023.
- Bidirectional chargers. Can be onboard or offboard, AC or DC. Organizational preference for offboard DC with a utility partner program.
- Software platform to manage power flow and optimize revenue and remaining charge for duty cycle. Must also work with different communication protocols: OCCP, Open ADR, Open FMB.

Technical Challenges of V2X:

- All L2 chargers will need to be replaced if there is onboard AC or DC charging
- CCS, common in Electrify America, does not have certification; nothing to certify

Industry Standards and Government Regulations for V2X:

- Xcel Energy can accommodate mobile storage; this is not true for all utilities, and customers may be limited to stationary only
- CCS chargers were heavily adopted and expected to be standard, so a lot of vehicles were built with this
- Communication channels:
  - Data sent up to the utility
  - Data sent back to the vehicle
- Organization currently use CHAdeMO connectors, which are certified for V2G
- Interested customers need to begin planning for the correct vehicle charger type
- Work with industry partners and regulators to ensure the right communication protocols are being used to streamline communication to chargers—whether it is done by an aggregator or the utility

Interview #3

Industry: Transportation
Organizational Focus: Provides school bus services, working with districts to carry students to and from school
V2X Experience:

- Currently doing a pilot using school buses for full-scale V2G
- Separate pilot ongoing for V2B using separate school bus model
- Full-scale fleet pilot involving 20 buses
- Goal of organization is to be a trusted partner for the utility to understand load considerations as more vehicles are added to the grid market

Growth of V2X Market:

- Lots of discussions are occurring in the space around microgrids
- They recognize that the switch to EV is happening, but the pace is not yet possible to predict based on the uncertainty of incentive levels and the speed of cost reductions with manufacturing scale
- There will also need to be a lot of investment done in transmission and distribution and BTM

Financial Challenges of V2X Adoption:

- Organization will go from being a small electricity consumer to an extremely large one and wants to understand how utilities will want them to cover infrastructure investments
- They will need to plan far ahead of time to plan scaling from 0 ESB, to 1-10, to 10-50, to 50-250

Technical Challenges to V2X Adoption:

- Standardization of communication between vehicle, grid, and utility as well as policy
- Policy needs to be ironed out for how the ISOs control the power from the buses
- Dealing with seven different battery geometries, which can make planning complex
- Vehicle second life: There may still be value in the drivetrain and battery for electric school buses

Interview #4

Industry: Automotive manufacturer
Organizational Focus: Manufacture and sell automobiles with several electric models of cars/crossovers and trucks
V2X Experience:

- Using current for home backup power only (to start); could eventually (looking ahead) operate in parallel with the grid
- Testing has been done internally on more complete capabilities and partnering with West Coast utilities to participate in V2X pilots

Organizational Approach to V2X:

- Wants to take crawl, walk, run approach. Start with home backup power (it is simple and tangible like a home generator).
- Need to see the policy side catch up because the programmatic pathways are unclear to determine how much revenue the organization and customer can keep
- Eager to get data in from the first months and years to see how many people are buying the supporting hardware/software. Wants to keep an eye out for how many vehicles are being sold with this capability.

Challenges to V2X Adoption:

- Communication protocols impact the organization's ability to provide a solution using an industry standard. They want it to be interoperable with the rest of the installed chargers. They want to be able to fall back to the ISO standard.
- The ISO 15118-20 communication protocol was released too late to implement as part of the launch, so the organization had to do some themselves
- There is some risk in the OEMs charting their own paths now. OEMs in industry groups are not sharing full sets of information because business decisions about new vehicle lineups are made 2-3 years ahead of time (even longer for EV development because it is an innovative technology that needs R&D).
- Standards may limit the type of computing chip used as well

Potential Solutions to V2X Challenges:

- Hopefully, OEMs are building their software to be back-compatible with ISO15118-20 so the technology and communication split does not continue for too long
- Regarding the chipsets: It is challenging because each company has their own needs and supply chains, and this could make things difficult if all players are limited in their ability to offer a solution
- It is hard to predict what competitors will do. It will depend on the available value streams from doing it alone vs. using a standard.

Other Barriers to Adoption of V2X:

- Companies are still in the process of figuring out where they can capture value. This may depend on the interconnection process throughout the country. Customers and OEMs are navigating this.
- Offboard inverters and transfer switches are more expensive, so that is a barrier because it is trickier than just buying a standard L2 charger for your home
- Interconnection process is different across the US (approvals, permitting). Customers may see navigating this as a barrier. Approval process may also be slow to get interconnection to happen.

Interview #5

Industry: Software
Organizational Focus: Coordinate, control, and aggregate EVs and their data using software platforms and solutions to optimize charging
V2X Experience:

- Organization working internally on proof-of-concept-type projects
- More support within Europe for extending projects beyond just proof of concept
- Projects occurring domestically have been done years prior in Europe
- Most commercialized deployments have been in buses, but some have involved cars as well as solar optimization

V2X Applications and Use Cases:

- V2B is optimizing loads, solar, but not actually exporting energy to the grid (or emergency backup power, but this is a different technology)
- V2G implies you are exporting energy to the grid—could be in response to a price signal or direct request from a system operator, net exporter of energy

Role of Utilities in V2X Adoption:

- Utility partners can drive significant value for aggregators and other EV stakeholders by recognizing the value add of vehicle-to-grid
- Need to produce an appropriate rate to incentivize EVs to discharge energy
- Opportunities to incentivize adoption include offering rebates or funding to lay the necessary wires

Infrastructure Needs for V2X:

- Necessary electrical wiring for V2G was included in the existing funding schemes and facilities, especially for schools
- Customers really look to the approved products list so available funding is often used up on unidirectional chargers
- Challenges arise when customers look to install make-ready infrastructure and/or meter these devices separately

Challenges to V2X Adoption:

- Communications protocols
    - Different standards have different purposes
    - They follow the normal pathway for installing standard inverters: UL1741 and UL1741SA
    - Organization defers to using what utilities and automakers use
    - Signals can be translated into open charge point protocol (OCPP)
    - They also use OpenADR, which is used to simplify and automate demand response and DER integration for utilities and aggregators

Interview #6

Industry: Transportation
Organizational Focus: Provide fleet operations and services for educational school district
V2X Experience:

- Minimal exposure to most of team
- Recently deployed pilot program involving seven buses as first project

Challenges to V2X Adoption:

- Internal challenges with soliciting funding to implement new pilot programs
- Grants are needed to cover the incremental cost of the buses, infrastructure, and transformer upgrades
- Issues with fiber installation at their bus depots and deployment sites
- Operating at scale:
    - Implementing fleet-level solutions involves identifying significant sources of funding for procurement
    - Concern from facilities for infrastructure upgrades and unknowns in consumption

Potential Benefits of V2X:

- Organization sees opportunity to reduce emissions in bus fleet and eliminate exposure of carcinogens to students
- Catalyst for implementing other sustainable practices. Planning to install solar on campus too, along with 1.5 MW bus canopy.

Incentivizing V2X Adoption:

- Local, regional, and federal grands can offer funding to procure buses
- Need specific funding sources for future-proofing infrastructure with V2G
- Operator needs to retain control of vehicles to use them for business purposes
- Value of resiliency:
    - Need to dispatch electricians when an outage occurs—can associate dollar figure with avoided labor
    - Most schools have backup generators, which can only do emergency; buses might be able to handle the load
    - Would like the microgrid option to island instead of just sending electricity back to full grid

Interview #7

Industry: Automotive manufacturer
Organizational Focus: Electric transit bus manufacturing, EVSE manufacturing and installation, and drivetrain manufacturing
V2X Experience:

- Bidirectional charging pilot with other vehicle manufacturers and utility
- Pilot programs are entirely self-funded, no direct utility participation in the funding mechanism
- Organizational involvement: Active in controls on the vehicle side and on the charger side, and it has been essential for them to have controls on both vehicle side and EVSE

V2X Application and Use Cases:

- Electric school buses: Reduce operating costs for school districts
- Transit: Reduce operating costs for school districts
- Resiliency: For transit, may not be great for V2G, because on the road during best times, but for emergency scenarios, can be useful

Technical Challenges to V2X Adoption:

- Communication: How to get the variety of assets to talk together
- Interconnection: Challenges with scaling and integrating into the grid
- Hoping for greater diversity of suppliers that can do V2G; space is nascent, so they do not have options to get other chargers
- Building toward communication protocols, future of communication
    - This has been a problem in basic communication between charger OEMs and vehicle OCPP
    - Nascent standards for V2G is slowing progress
    - 15118-20 will hopefully shore up uncertainty
    - Curious to see impact of Ford F-150 Lightning because of its ability to get customers to be noisy and advocate for more V2G
    - Makes it more challenging for customers if everyone has individual proprietary communication protocols

Incentivizing V2X Adoption:

- Need to develop funding for multiyear programs to understand adoption and participation
- Need consistent financing to scale
- Develop and communicate best practices to answer major technical questions for communication and interconnection
- Need to get past small pilots and one-offs, get more real adoption at scale

Market Barriers to V2X Adoption:

- Which vehicles able to participate and at what time?
- What does participation mean? Works with all chargers?
- Overall customer education (not yet like plugging in a gas car)
- Explaining wholesale participation to customers that never had to think about it is tricky; going to bidirectional will require a lot of education

Appendix 2: Case Studies

Project	Project Start	Application and Use Case	Number of Vehicles	Results	Key Takeaways
BMW ChargeForward	2015	V1G Managed Charging	100	209 demand response events 19.5 MWh	Customer behavior is highly responsive to incentives and prompts
Lion Electric, White Plains, NY	2018	V2G	5	First successful deployment of V2G in New York	V2G has minimal impact on bus availability for transportation
PG&E Epic (2.03b)	2016	V2H	2,486 (survey)	Determined customer sentiment around V2H technology	Customer willingness to pay was lower than estimated V2H system cost
Rialto Electric School Bus Project	2017	V2G	8	Modeled substantial revenue generation potential from grid services, indicating V2G may play a meaningful role in TCO	V2G drives value for distribution grid, and environmental impacts of carbon reduction can be driver for vehicle adoption
Torrance Electric School Bus Project	2017	V2G V2B	6	Demonstrated demand charge management and frequency response	V2G revenue can be substantial; tariffs can help offset initial price
UCSD INVENT	2017	V2G	50+	Demonstrated several applications for vehicle-grid integration	V2G can succesfully be used for targeted demand response
Queens College, NY	2019	V1G V2G	6	Demonstrated demand charge management and emergency backup with solar integration	Utility can initiate strategic partnerships with landmark institutions for mutual benefit in V2X space
Hydro One V2H Backup Power	2021	V2H	10	Pending results seek to assess reliability, duration, and efficiency of EVs, and owner charge/discharge habits	Pending

Appendix 3: Additional Tables

Table 9: Scenarios of V2G Potential in Xcel Energy's Colorado Service Territory

Year	EVs		% V2G Capable		Enrollment Rate		Plugged In		Participating		kW/V2G-Capable EV		V2G Capacity (MW)
2023	55K		11.6%				20%						0.45
2030	600K		11.6%				20%						4.9
2030	600K	X	100%	X	10%	X	20%	X	50%	X	7	=	42
2030	600K		100%				60%						126
2030	600K		100%				100%						210
2030	600K		100%				100%		100%				420

Table 10: V2X-Enabled EV Deployments in the US

Vehicle	Compatible Model Year Start[63]	V2G/V2B	V2H	V2L Only
Nissan Leaf	2013	✓	✓	✓
Ford F-150 Lightning	2022	-	✓	✓
Genesis GV60	2022	-	-	✓
Hyundai Ioniq 5	2022	-	-	✓
Kia EV6	2022	-	-	✓
Lucid Air	2023	-	✓	✓
Volkswagen ID.4	2023	-	-	✓
Hyundai Ioniq 6	2023	-	-	✓
Genesis Electrified GV70	2023	-	-	✓
Genesis Electrified G80	2023	-	-	✓
Kia Niro EV	2023	-	-	✓
Volkswagen ID. Buzz	2024		✓	✓
Chevrolet Silverado EV	2024	-	✓	✓
Volvo EX90	2024	-	✓	✓
Ram 1500 EV	2024	-	✓	✓
Chevrolet Equinox EV	2024	-	-	✓

Table 11: Bidirectional Charger Deployment in the US

OEM	Market	Inverter Location	Connector	AC/DC	kW	UL	Available
dcbel	Res	Other equipment	CCS/ CHAdeMO	DC	7.6–15.2	Yes	Yes
Ford	Res	Other equipment	CCS	DC	19.2	Yes	Yes
Emporia	Res	Other equipment	CCS	DC	11.5	No	No
Lucid	Res	EV	CCS	AC	19.2	No	No
Wallbox	Res	Charger	CCS	DC	11.5	No	No
Fermata	Comm	Charger	CHAdeMO	DC	15	Yes	Yes
Fermata	Comm	Charger	CHAdeMO	DC	20	No	Yes
Rhombus	Comm	Charger	CCS	DC	60–125	Yes	Yes
Nuvve	Comm	EV	CCS	AC	19.2–52.3	Yes	Yes

Acronyms and Abbreviations

AC .... Alternating Current

ADR .... Automated Demand Response

AI .... Artificial Intelligence

BTM .... Behind the Meter

CCS .... Combined Charging System

CHAdeMO .... Charge de Move

CharIN .... Charging Interface Initiative

DC .... Direct Current

DER .... Distributed Energy Resources

EV .... Electric Vehicle

EVSE .... Electric Vehicle Supply Equipment

FERC .... Federal Energy Regulatory Commission

FMB .... Field Message Bus

GHG .... Greenhouse Gas

GWh .... Gigawatt-Hour (1,000,000 kWh)

INVENT .... Intelligent Electric Vehicle Integration

ISO .... Independent System Operator

kW .... Kilowatt

kWh .... Kilowatt-Hour

L2 .... Level 2

LFP .... Lithium Iron Phosphate

MW .... Megawatt

MWh .... Megawatt-hour (1,000 kWh)

NREL .... National Renewable Energy Laboratory

OCPP .... Open Charge Point Protocol

OEM .... Original Equipment Manufacturer

PG&E .... Pacific Gas and Electric

PRECISE .... Preconfiguring and Controlling Inverter Setpoints

R&D .... Research and Development

ROI .... Return on Investment

RTO .... Regional Transmission Organization

TCO .... Total Cost of Ownership

UCSD .... University of California, San Diego

UK .... United Kingdom

US .... United States

V .... Volt

V1G .... Vehicle-to-Grid Communications for Charge Management

V2B .... Vehicle-to-Building

V2G .... Vehicle-to-Grid

V2H .... Vehicle-to-Home

V2L .... Vehicle-to-Load

V2X .... Vehicle-to-Everything

Glossary of Key Terms

Digital energy management platforms: Software-based tools leveraging communication technologies to manage electricity flow between electricity-consuming devices and the grid.

Interconnection: The process by which a connection to the grid is authorized to back-feed into local grid infrastructure systems.

Degradation: Associated with the charge/discharge cycling of batteries. V2X use cases likely increase cycling and therefore likely increase degradation.

Depreciation: The devaluation of assets as a function of use, closely tied to degradation.

Three-phase: An electrical infrastructure architecture common for grid distribution systems and within some commercial and industrial buildings. It is rare in residential buildings, where the single-phase architecture is more common.

Nickel-rich battery chemistries: A collection of battery chemistry technologies that use varying quantities of nickel in battery cathodes such as nickel manganese cobalt or nickel cobalt aluminum.

Technology ecosystems: A collection of distinct technologies that can be used together to produce a solution. Described as closed or open: closed indicates limited interoperability with technologies from multiple suppliers; open indicates multiple suppliers providing multiple interoperable technologies.

Endnotes

[1] Vermont Energy Investment Corporation and RAP, *In the Driver's Seat: How Utilities and Consumers Can Benefit from the Shift to Electric Vehicles* (2015), pg. 11.

[2] Per Atlas Public Policy's EValuateCO dashboard, February 7, 2023.

[3] Per the EValuateCO dashboard, February 7, 2023; includes 7,644 Nissan Leafs, 646 Mitsubishi Outlanders, and 357 Ford F-150 Lightnings.

[4] Ford, Ford Intelligent Back-up Power (2022).

[5] Assumes a 240-mile range and efficiency of 3.54 miles/kWh, based on U.S. Department of Energy (DOE), Alternative Fuels Data Center, Average Range and Efficiency of U.S. Electric Vehicles (2021).

[6] American Association of State Highway and Transportation Officials, *Commuting in America 2021*, Appendix A, p. 28.

[7] Xcel Energy, *Driving Toward a Carbon-Free Future: Electric Transportation Vision* (2022).

[8] Emre Gençer et al., "Can Vehicle-to-Grid Facilitate the Transition to Low-Carbon Energy Systems?" *Energy Advances* 1 (2022): 984-98.

[9] See Appendix 3, Table 10.

[10] See Appendix 3, Table 10.

[11] Jason Porzio and Corinne D. Scown, "Life-Cycle Assessment Considerations for Batteries and Battery Materials," *Advanced Energy Materials* 11, no. 33 (2021), Table 1, p. 2.

[12] DOE, Alternative Fuels Data Center, Electric Vehicle Benefits and Considerations.

[13] Installation costs are derived from the Sunrun website when Home Integration System purchase and installation are bundled with Ford Charge Station Pro installation—applicable in 22 states where Sunrun provides installation service.

[14] Chris Nelder and Emily Rogers, *Reducing EV Charging Infrastructure Costs*, RMI (2019).

[15] The Charge Station Pro is included with the extended-range version of the F-150 Lightning but can be purchased separately for the standard-range model at $1,310.

[16] Sunrun Home Integration System hardware price.

[17] Ari Vanrenen, "PG&E and Ford Collaborate on Bidirectional Electric Vehicle Charging Technology in Customers' Homes," PG&E Currents, March 10, 2022.

[18] Based on Ford, "F-150 Lightning Power Play: First Electric Truck to Enhance Your Home Energy Independence," February 2, 2022. Estimate assumes some battery capacity is reserved for driving.

[19] See Appendix 2: Case Studies, PG&E Epic (2.03b).

[20] According to Home Depot's website, the average cost to install an air-cooled generator is $6,897; prices for Generac house generators range from $4,000 to $7,000.

[21] A single Tesla 13.5 kWh battery costs $12,850, based on Alexis Carthan, "How Much Does the Tesla Powerwall Cost? (2023 Guide)", *This Old House*, February 23, 2023. A 9 kWh Generac battery costs $18,000, based on Lee Wallender, How Much Does a Generac PWRCell Battery Cost and Is It Worth It?, *Forbes*, October 18, 2022.

[22] Colorado CarShare, "Colorado CarShare Ups Our Climate Efforts."

[23] City of Boulder, Colorado, "Innovative Electric Vehicle Charger Shows Financial Promise in First Year," March 29, 2022.

[24] Business Wire, "Electric Vehicle Generates Revenue and Energy Savings Paving the Way for Mainstream Adoption of Vehicle-to-Everything (V2X) Technology," January 27, 2022.

[25] This trial also generated $4,200 in V2G revenue from National Grid's ConnectedSolutions demand response program, which annualizes to $350 per month.

[26] Jonathan Susser and Daniel Real, "Roanoke Electric Cooperative, Fermata Energy Show Promise of Vehicle-to-Everything Technology," Advanced Energy, October 5, 2021.

[27] Based on Chris Nelder and Emily Rogers, *Reducing EV Charging Infrastructure Costs*, RMI (2019). Additional operational costs (e.g., networking and data contracts, maintenance) will vary based on site requirements and types of technologies used. For commercial L2 chargers, networking and data contracts have been surveyed at no more than $250/year, while DOE guidance indicates station owners should budget maintenance costs at $400/year per charger. These costs are likely higher for V2B systems, but it is not clear by how much.

[28] See Appendix 1: Interview Notes, Interview #1.

[29] See Appendix 1: Interview Notes, Interview #1.

[30] "For budgeting purposes, some industry stakeholders assume EVSE has at least a 10 year lifespan," per DOE, *Costs Associated with Non-Residential Electric Vehicle Supply Equipment* (2015), p. 21.

[31] Includes 286 participants in Kaluza's V2G trial, summarized in *What's Next for Vehicle-to-Everything?* (2022), https://info.kaluza.com/whats-next-for-vehicle-to-everythingand 135 participants in Powerloop's V2G trial, summarized in Energy Saving Trust, *Powerloop Vehicle-to-Grid Trial: Customer Insights and Best Practice Guide* (2022).

[32] See Appendix 2: Case Studies, Torrance County Electric School Bus.

[33] Dominion Energy, "Electric School Buses."

[34] Taylor Ekbatani, "V2G Findings Announced from New York State Electric School Bus Project," *School Transportation News*, April 26, 2022.

[35] Nuuve, "Blue Bird Delivers North America's First-Ever Commercial Application of Vehicle-to-Grid Technology in Electric School Bus Partnership with Nuvve and Illinois School Districts," March 23, 2021.

[36] DTE Energy, "DTE Energy Partners with Manufacturers and Dealership to Deploy Electric Buses to Schools," February 2, 2021.

[37] Thomas Built Buses, "Beverly Massachusetts Electric School Buses Make V2G Energy Transfer History," November 19, 2021.

[38] Ryan Gray, "First West Coast School Bus V2G Pilot Project to Begin," *School Transportation News*, July 28, 2022.

[39] Christian Burney, "Durango's Electric School Bus Is Like a Huge Battery on Wheels," *Durango Herald*, January 5, 2022.

[40] Nuuve, "San Diego County's Ramona Unified School District, Blue Bird and Nuvve Unveil 8 New V2G-Enabled and Qualified Electric School Buses," October 11, 2022.

[41] Vermont Community Newspaper Group, "Four New Electric Buses Come Online in South Burlington," *The Other Paper*, September 1, 2022.

[42] "Drivers and student riders indicated they were pleased with vehicle performance and bus availability," per Taylor Ekbatani, "V2G Findings Announced from New York State Electric School Bus Project," *School Transportation News*, April 26, 2022.

[43] See Appendix 2: Case Studies, Torrance County Electric School Bus.

[44] Xcel Energy, "Colorado Interruptible Service Option Credit (ISOC)" (2021), ISOC Credits per kW Monthly Credit, 40 hours, unconstrained, 10-minute notice.

[45] DOE, *Costs Associated with Non-Residential Electric Vehicle Supply Equipment* (2015).

[46] "Wang *et al.* shows degradation to be minimal when vehicles are selectively utilized for peak shaving and regulation service on 'high demand' days, rather than used around the clock," per Emre Gençer et al., "Can Vehicle-to-Grid Facilitate the Transition to Low-Carbon Energy Systems?" *Energy Advances* 1 (2022): 984-98, p. 987.

[47] Jason Porzio and Corinne D. Scown, "Life-Cycle Assessment Considerations for Batteries and Battery Materials," *Advanced Energy Materials* 11, no. 33 (2021), Table 1, p. 2.

[48] See Appendix 3, Table 10.

[49] Nissan, "Nissan Approves First Bi-directional Charger for Use with Nissan LEAF in the U.S.," September 7, 2022.

[50] See VEIC, "Electric School Buses Available for Purchase," https://www.veic.org/Media/Default/documents/resources/reports/types-of-electric-school-buses.pdfand BYD, "BYD Introduces Innovative and Safe Type A Battery Electric School Bus with V2G Technology," January 26, 2022.

[51] See CharIN, Position Papers and Regulation.

[52] See Appendix 3, Table 11.

[53] Tesla, "Opening the North American Charging Standard," November 11, 2022.

[54] Everoze, EVConsult, UK Power Networks, and Innovate UK. *V2G Global Roadtrip: Around the World in 50 Projects* (2018), p. 28.

[55] Kaluza, *What's Next for Vehicle-to-Everything?* (2022), p. 19.

[56] Robert Walton, "SMUD Tests Tool to Accelerate Rooftop Solar Interconnections, Utility Dive," November 10, 2022.

[57] Mountain states and US participation determined from Federal Energy Regulatory Commission (FERC), 2022 Assessment of Demand Response and Advanced Metering (2022), and U.S. Energy Information Administration, 2021 Total Electric Industry – Customers table.

[58] FERC, "FERC Issues Final Rule on Electric Storage Participation in Regional Markets," February 15, 2018.

[59] Energy Saving Trust, *Powerloop Vehicle-to-Grid Trial: Customer Insights and Best Practice Guide* (2022), Figures 18 and 19, pp. 20-21.

[60] National Grid and Guidehouse, *National Grid EV and PHEV Demand Response Evaluation* (2022), Figure 7, p. 6.

[61] Number derived from Atlas Public Policy, EValuateCO (last updated September 2022), which is based on registration data from the Colorado Department of Revenue, Division of Motor Vehicles.

[62] Xcel Energy, *2021 Electric Resource Plan and Clean Energy Plan: Updated Modeling Inputs & Assumptions* (2022), Table 2.14-6, p. 12.

[63] Nissan announced bidirectional charging for the Leaf in 2022, with backward compatibility to model year 2013. Other OEMs, like Volkswagen, have indicated they may also make prior model year EVs bidirectional capable with over-the-air updates.

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