Wheels to Watts: What We Can Learn from a School Bus Vehicle-to-Grid Pilot

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ABSTRACT

Electric school buses (ESB) can provide clean, exhaust-free transportation for school children while also delivering benefits to schools, including energy bill savings and enhanced resilience, along with contributing to grid flexibility. However, the bidirectional, vehicle-to-grid (V2G) chargers that enable these benefits represent a relatively new technology with little real-world evaluation. As a result, key questions remain about how to reliably operate ESBs with V2G in practice. In particular, ensuring adequate charge for daily routes while supporting grid events introduces implementation challenges, including equipment reliability, charger-vehicle communication faults, and operational constraints.

To address these questions, this study evaluated a pilot that deployed ESBs with bidirectional chargers, serving as both student transport and mobile energy assets. We leveraged telematics and real-world test data to evaluate the technical performance and reliability of the V2G technology in ESBs and assess the environmental and societal impacts of the pilot. We also examined customer perceptions and financial considerations to assess the pilot's broader viability and inform scalability. Our findings provide insights for utilities and school districts considering similar technology deployments.

Introduction

The electrification of school transportation is accelerating nationwide, driven by growing interest in reducing diesel emissions, improving student and community health, and leveraging vehicle-to-grid (V2G) technology to turn electric school buses (ESBs) into flexible grid assets. This capability can help reduce operating costs and total cost of ownership while creating opportunities for additional revenue through participation in grid services. However, real-world deployments face challenges, such as charger-vehicle communication issues, equipment reliability, and the need to maintain sufficient state of charge for daily routes, all of which limit consistent and dependable grid participation.

The ComEd Beneficial Electrification School Bus V2G Pilot offers first-hand evidence on the operational performance of ESBs and bidirectional chargers during actual grid events. By partnering with three school districts across ComEd's service territory, the pilot tested how V2G-enabled ESBs perform under real-world conditions and examined how these systems interact with daily transportation schedules, charging windows, and V2G event needs. The pilot also evaluated broader impacts, including environmental and societal implications of V2G participation. This initiative is part of the Beneficial Electrification programs directed by the Illinois Climate and Equitable Jobs Act (CEJA) (ILGA 2021), which promotes innovative applications of electric vehicles to maximize environmental and economic value for communities across Illinois.

This paper provides a comprehensive evaluation of the pilot's technical, environmental, and societal outcomes using telematics data, V2G event records, and stakeholder surveys. The analysis highlights both the opportunities and the practical constraints of integrating ESBs as distributed energy resources (DERs).

The remainder of the paper is organized as follows. The paper begins with background on V2G technology and the pilot scope and objectives, followed by a description of the V2G test plan. It then presents findings on technical, environmental, and societal outcomes using operational and grid-event data and concludes with implications for future deployments and key considerations for scaling V2G-enabled ESBs.

V2G Technology and Market Context

ESBs are well positioned to take advantage of two-way charging technology since they operate on predictable daily schedules and spend long periods parked at depots. During these idle windows, V2G-enabled ESBs can remain plugged in and available to interact with the electric grid, transforming idle time into an opportunity to provide grid services.

V2G technology enables the two-way flow of electricity between an electric vehicle (EV) battery and the grid. Effective V2G operation depends on reliable charger-vehicle communication, coordinated scheduling, and the ability to manage state-of-charge requirements without disrupting transportation needs.

Early V2G pilots across the United States and internationally have demonstrated that bidirectional charging is technically achievable but have also highlighted persistence challenges. Common issues include hardware and software integration challenges, requiring substantial testing and troubleshooting to identify and resolve equipment communication failures, network connectivity issues, and interface compatibility challenges. Ensuring that ESBs maintain sufficient charge for morning and afternoon routes remains a central concern, along with participation in grid services given the narrow charging windows available during the school day. These challenges underscore the need for evidence on how V2G systems perform under actual operating conditions.

Despite growing interest in V2G-enabled ESBs, few studies provide an integrated evaluation spanning technical performance, environmental outcomes, and societal impacts. This study addresses that gap by examining how V2G technology performs in practice, how ESBs interact with operational schedules, and what benefits and constraints emerge for participating in schools. By combining telematics data, stakeholder surveys, and utility event records, the analysis provides a comprehensive view of the opportunities and limitations of using ESBs as DERs.

Pilot Scope and Objectives

The ComEd Beneficial Electrification School Bus V2G Pilot was designed to test how ESBs and bidirectional chargers perform in V2G events while maintaining daily transportation operations, including whether peak-load reduction can be achieved and how reliably and efficiently the system operates. It also aimed to assess the environmental and community impacts of ESB deployment, examine the financial considerations of integrating buses into grid operations, and clarify the practical potential for scaling V2G adoption across future deployments.

The pilot partnered with three school districts that operated existing ESBs on daily routes prior to participating in the pilot. These buses fulfilled student transportation needs, returning to depots between routes and providing consistent windows for charging and grid service participation. Bidirectional charging was enabled through V2G-capable chargers that managed two-way power flows and communicated with both the vehicles and ComEd's utility systems. The communication architecture coordinated charging schedules, state-of-charge requirements, and grid event dispatch.

Operationally, the pilot was shaped by the constraints of the school day. Event scheduling during the summer was flexible as the buses were not regularly used for transportation. Once the school year began, buses were primarily available for charging between morning and afternoon routes and overnight, creating defined charging windows that had to align with grid event schedules. These operational realities provided valuable insights of how V2G systems perform when integrated into real-world transportation routines.

V2G Test Plan

The Pilot involved conducting events with one ESB at each site across three school districts. The pilot tested a small but diverse combination of buses and chargers with differing site constraints, creating meaningful variation in battery size, power limits, and operating conditions (Table 1). The effective discharge limit represents the maximum power out that the V2G system can provide. Effective discharge limits ranged from 20–60 kW, reflecting both charger ratings and site-specific infrastructure constraints.

V2G performance was tested across a range of power levels, with each site operating under different technical and operational constraints. As Table 1 indicates, event power levels depended on a combination of bus battery capacity, charger ratings, site infrastructure, and state-of-charge (SOC) requirements. Each site has a defined SOC operating range based on manufacturer recommendations and site-specific considerations.

Table 1. Vehicle and battery characteristics for participating sites

Site	Model	Battery capacity (kWh)	Bus power limitation (kW)	SOC operating range	Charger rated output (kW)	Effective discharge limit (kW)	Bus deployment date
Site 1	Micro Bird Gen 5	88	48	20% - 75%	60	48	03/19/2025
Site 2	Blue Bird Gen 2	155	60	10% - 97%	60	60	01/09/2023
Site 3	Blue Bird Gen 2	155	60	10% - 97%	20	20	03/31/2024

V2G Event Overview

Preliminary V2G testing was conducted in May 2025, with formal testing conducted from June 2025 through October 2025. Over this five-month period, the pilot tested ESB V2G performance using two event types designed to reflect distinct grid service needs:

Maximum duration: Can a bus consistently sustain the requested power level for a full 3-hour grid event?

Maximum power: How long can a bus sustain the maximum feasible power level, as defined by its effective discharge limit?

Maximum-duration events focused on sustained, consistent energy delivery over the full event window, reflecting potential applications such as longer-duration resilience services. Maximum-power events focused on peak output and rapid response capability, testing the combined limits of the vehicle, charger, and site infrastructure.

Several event windows were established to evaluate V2G power delivery performance. Each week, the PJM seven-day forecast was reviewed, and events were scheduled on days projected to exceed a megawatt-level threshold, which was adjusted as the pilot progressed. Events were scheduled based on location-specific feeder congestion and student transportation schedules.

Event timing varied by site and season to align with grid needs and school operations (Figure 1). During the summer, buses were not used regularly for transportation needs, allowing events to be scheduled as early as noon. During the school year, events were scheduled after buses completed their afternoon routes, with most events beginning around 5:00 PM.

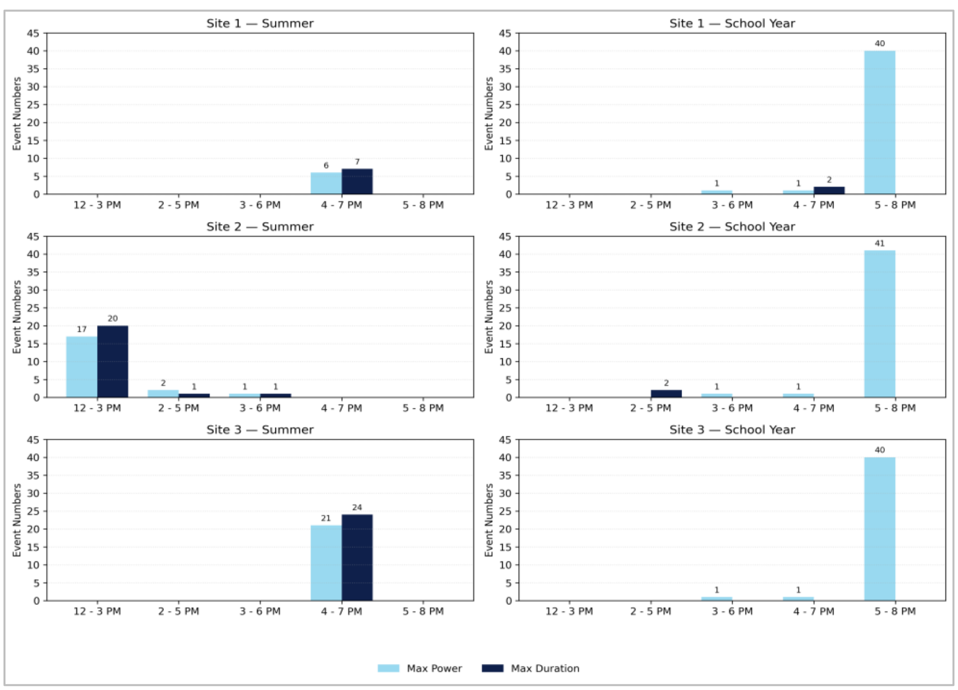

Figure 1. Scheduled V2G event windows by location, period, and event type

Maximum-duration events were generally limited by usable battery capacity, while maximum-power events were constrained by charger output, with SOC limits applied in all cases. Differences in enrollment timing resulted in variation in the number of events, while site infrastructure contributed to variation in tested power levels across sites.

Technical Findings

The pilot evaluated whether V2G-enabled electric school buses can deliver grid services reliably and predictably without disrupting daily transportation operations. Technical performance was assessed across three dimensions critical to grid value: power delivery, availability and reliability, and operational efficiency. For each event type (maximum duration and maximum power), the analysis focused on:

How power was delivered over time, including average load shapes during events and one hour before and after events, by site, season, and start time
How performance compared to expectations, including delivered power, event duration, and initial and ending SOC
What grid impact was achieved, measured by delivered power, delivered energy, and event duration

Event Success

We evaluated the overall performance of V2G operations based on event success, defined as the percentage of scheduled V2G events in which a site participated and a bus successfully discharged power. This metric serves as a primary indicator of the reliability of V2G systems to respond when grid support is requested. Table 2 summarizes event success across the three pilot locations by season and event type.

Across all sites and event types, the ComEd School Bus V2G Pilot achieved an overall event success rate of 82%. Performance varied by season and event type: Success rates were highest during summer operations, near or above 90% for both maximum-duration and maximum-power tests, due to longer charging windows and fewer transportation demands. In contrast, in-school events had lower success rates (72–76%) due to shorter charging windows, SOC limitations, and greater daily transportation needs. These seasonal differences highlight that aligning V2G participation with school schedules supports greater reliability.

Table 2. Event Success Summary by Location and Event Type

Location	Period	Event type	Total events	Successful events	Success rate
Site 1	Summer	Maximum duration	7	7	100%
	Summer	Maximum power	6	5	83%
	In-school	Maximum duration	2	2	100%
	In-school	Maximum power	42	32	76%
	All events		57	46	81%
Site 2	Summer	Maximum duration	22	22	100%

	Summer	Maximum power	20	17	85%
	In-school	Maximum duration	2	0	0%
	In-school	Maximum power	43	31	72%
	All events		87	70	80%
Site 3	Summer	Maximum duration	24	22	92%
	Summer	Maximum power	21	20	95%
	In-school	Maximum power	42	31	74%
	All events		87	73	84%
Overall	All events		231	189	82%

Table 3 summarizes the reasons for missed or unsuccessful V2G events, highlighting three primary categories of interruption: technical, operational, and communication-related factors. Technical issues were the most common cause of missed events, driven primarily by firmware updates and occasional unplanned replacements of charger components. Operational factors, including buses being unplugged or constrained by SOC limitations, were the next most frequent causes. Communication-related failures, such as cloud connectivity issues or telematics session interruptions, also contributed to event disruptions, while weather played a minor role. Together, these findings indicate that system readiness and reliable connectivity are essential for consistent V2G performance. Addressing these challenges will require a combination of technical improvements, clearer operational protocols, and staff training to support dependable V2G participation at scale.

Table 3. Reasons for Missed V2G Event Participation

Category	Reason for interruption	Number of events
Technical	Firmware update	18
	Unplanned charger component replacement	2
Operational	Bus unplugged	7
	SOC constraints	4
Communication	Cloud-to-charger and cloud-to-cloud connectivity issue	4
	Bus telematics closed session before V2G handshake	3
Weather	Bad weather	1
Overall		39

Maximum Duration Events

We evaluated maximum-duration V2G events to assess whether ESBs could consistently sustain power delivery over a three-hour event window, focusing on delivered power, event duration, and operational factors influencing performance.

Site 1 operated a Micro Bird electric school bus with the smallest battery capacity in the pilot (88 kWh). The bus operated within a 20%–75% SOC range, providing approximately

48 kWh of usable energy, equivalent to an average discharge of about 16 kW over a three-hour event. A total of nine maximum-duration events were conducted (seven summer and two in-school), all scheduled from 4:00–7:00 PM with expected power delivery of 15–16 kW. Overall, the bus delivered power close to requested levels, though recurring power oscillations were observed, including a noticeable dip in delivered power during the latter portion of the events as SOC approached its minimum limit.

Site 2 operated two 155 kWh Blue Bird electric school buses, with one primarily assigned to V2G participation and the second serving as a backup. Buses operated within a 10%–97% SOC range to maximize usable capacity. During the summer, Site 2 completed 22 maximum-duration events, primarily scheduled from 12:00–3:00 PM to align with midday peak demand periods. Most events targeted 33 kW discharge; however, several events were limited to lower power levels (11.5–20 kW) due to temporary charger module outages or low initial SOC. Despite these constraints, average delivered power remained close to expected levels.

Site 3 also operated a 155 kWh Blue Bird electric school bus with a similar SOC range and usable energy over a three-hour period. All maximum-duration events were scheduled from 4:00–7:00 PM and targeted 20 kW of discharge. Across all events, Site 3 successfully sustained discharge for the full three-hour duration with minimal deviation from expected power output.

Overall, ESBs delivered power close to expected levels (91–98% of requested output), demonstrating the ability to sustain discharge over a full three-hour grid event when sufficient state of charge is available. Site 3 showed the most consistent performance, sustaining nearly the full three-hour duration at 20 kW, while Site 1 also performed close to expectations with average event durations of 2.9 hours and 98% of expected power delivered. Site 2 achieved strong average performance but exhibited greater variability, driven by battery, charger, and operational or communication constraints rather than event timing or season.

Maximum Power Events

We evaluated maximum power V2G events to test whether ESBs could deliver the highest requested power and sustain that output for as long as feasible. We assessed performance based on delivered power and energy, and event duration. We benchmarked event duration and energy against a theoretical maximum based on each bus's battery capacity, SOC operating range, and requested power output. Table 5 summarizes maximum power event energy impacts across all sites.

- Site 3 delivered the most consistent energy performance across seasons, achieving 87–89% of the maximum possible energy in both summer and in-school periods. The remaining shortfall largely reflects event durations that were 9–12% shorter than the theoretical maximum, rather than limitations in power delivery.
- Site 1 delivered 94% of the maximum possible energy during summer events but only 46% during in-school events. The lower in-school performance was driven primarily by early terminations, with events ending an average of 24 minutes early. Contributing factors included low initial SOC (on average 53%) and lower battery voltage during the school year. Voltage reductions resulting from lower state of charge and heavier usage earlier in the day limited the charger's ability to deliver the requested power level.

Site 2 delivered 75% of the maximum possible energy during summer and 47% during in-school events. Despite strong power delivery, shorter durations, often linked to low initial SOC (average 68%) and early terminations averaging 60 minutes, reduced total energy delivery. Lower battery voltage further constrained sustained output.

Overall, maximum power results show that SOC and voltage constraints, more than charger capability, limited delivered energy during in-school operations, especially at Sites 1 and 2.

Table 5. Maximum-power events energy impact summary

Site	Period	Event numbers	Maximum possible energy (kWh)	Delivered energy (kWh)	Delivered vs maximum possible energy (%)
Site 1	Summer	5	242	229	94%
	In-school	32	1,549	713	46%
	Overall	37	1,792	942	53%
Site 2	Summer	17	1,918	1,436	75%
	In-school	31	4,180	1,961	47%
	Overall	48	6,099	3,397	56%
Site 3	Summer	20	1,200	1,038	89%
	In-school	31	1,860	1,613	87%
	Overall	51	3,060	2,692	88%

Environmental and Societal Impact

In addition to the direct benefits that ESBs and V2G provide to participating school districts, ESBs also deliver broader community advantages by reducing air pollution along their routes. Diesel buses rely on internal combustion engines that emit greenhouse gases (GHGs) and harmful pollutants linked to significant health risks. Nitrogen oxides (NOx) and fine particulate matter (PM2.5) are among the most prevalent pollutants from diesel vehicles and are associated with respiratory illnesses, cardiovascular diseases, and other health issues (CARB 2019). To quantify the air-quality benefits of replacing diesel buses with ESBs, we estimated reductions in GHG, NOx, and PM2.5. Table 6 summarizes the estimated daily reductions in these pollutants resulting from ESB operation.

Table 6. Estimated Daily Emission Reductions from Electric School Bus Operation

Location	GHG reduction (tons CO2e/day)	NOx reduction (lb./day)	PM2.5 reduction (lb./day)
Site 1	0.05	0.08	0.005
Site 2	0.02	0.05	0.001
Site 3	0.02	0.03	0.001

The scale of these reductions varies by site, reflecting differences in the baseline emissions of the diesel buses being replaced (older, less efficient buses produce more emissions) as well as the efficiency and energy use of the ESBs themselves. ESB emissions were calculated by applying emission factors to each ESB's average weekday electricity consumption, using carbon-intensity values from the U.S. Environmental Protection Agency (EPA)'s Greenhouse Gas Equivalencies Calculator (EPA 2025). Diesel bus emissions were estimated using average fuel economy data and emission factors applied to the typical daily mileage of each ESB. GHG emissions for equivalent diesel buses were derived from U.S. Department of Energy fuel economy data (DOE AFDC 2024) and EPA GHG emissions factors (EPA 2025). Air quality emissions (NOx and PM2.5) were estimated using factors from the U.S. Energy Information Administration (EIA 2024), the EPA (EPA 2020), and the California Air Resources Board (CARB 2024).

Building on the environmental benefits outlined above, we also examined the societal implications for the participating buses, with attention to equity and community accessibility. To assess accessibility, we analyzed ESB travel patterns in relation to socioeconomic boundaries in Illinois by mapping geographic coordinates of each bus to identify the most frequently traveled routes, excluding one-time deviations. A primary route was identified for each vehicle and time period, and these routes were compared against several social and economic indicators:

- *Environmental Justice (EJ)* communities as defined by the Illinois Power Agency, excluding racial and ethnic indicators
- *Low-income (LI)* census tracts with data from U.S. Census Bureau's American Community Survey and Department of Housing and Urban Development's income limits
- *Restore, Reinvest, and Renew (R3)* zones

The main routes for the participating ESBs did not intersect with any EJ, LI, or R3 zones. However, routes occasionally ran along the edges of EJ and LI communities, which commonly follow major roadways. Because vehicle emissions are typically most concentrated along high-traffic routes, operating ESBs along these boundary routes may provide modest localized air quality benefits to nearby communities.

Scalability Factors

Having assessed the pilot's technical performance and community-level impacts, the next step is to consider how these findings translate to broader deployment. To understand the potential for scaling V2G-enabled ESBs across ComEd's service territory, we evaluated the technical, financial, and behavioral factors that influence V2G adoption and integration. A feeder load-flow analysis was conducted to assess how a larger fleet of ESBs would affect local transformers and feeders under various charging and discharging scenarios. In parallel, school district stakeholder surveys were used to gather insights surrounding V2G technology, including perceived benefits, concerns, and barriers to V2G adoption. Together, these analyses provide a foundation for understanding the conditions under which V2G can be expanded reliably and effectively across the region.

Customer Perceptions

Surveys were distributed to a wide range of stakeholders across Illinois school districts to capture perspectives on the benefits, concerns, and barriers associated with V2G technology. Survey respondents included school personnel in diverse roles ranging from superintendents to staff supporting building and fleet operations. Responses were collected from the three pilot participants as well as eight school districts not yet participating but interested in future pilots.

Financial considerations around V2G technology emerged as a recurring theme across survey responses. Districts expressed strong interest in understanding the financial implications of V2G, including both potential benefits and the costs required for implementation. Technical considerations followed closely, with respondents citing concerns about ESB battery degradation, the reliability of V2G systems, and the compatibility of existing facilities with V2G infrastructure.

When asked about the key benefits of V2G, survey respondents most frequently highlighted financial advantages, including reduced electricity bills and opportunities for revenue generation. Additional perceived benefits include the potential for backup power and support for renewable energy integration. Concerns largely mirrored these themes. Financial uncertainty was the most commonly cited issue, with respondents expressing particular concern around upfront costs, compensation for discharged energy, and long-term cost-effectiveness. Other frequent concerns included the impact on ESB battery life, as well as the reliability and performance of V2G technology.

Among non-participants, the leading barrier to joining a future V2G pilot was again upfront costs and financial concerns. Many expressed interest in more detailed financial modeling to better understand required capital investments, revenue potential, and expected return on investment. Respondents also noted technical concerns regarding ESB battery degradation and bus-to-facility compatibility.

Participation Incentives

Given the strong emphasis districts placed on financial considerations, it is important to outline the pilot’s approach to participant incentives. Participants received a fixed enrollment incentive upon joining the pilot. During the five-month V2G testing period, sites could also earn monthly incentives, with amounts determined by their participation rate in scheduled V2G events. Full participation over the course of the pilot allowed sites to earn the maximum allowable incentive, with amounts pro-rated for missed events. At the conclusion of the pilot, each district received a fixed completion incentive.

Sites were not penalized for circumstances beyond their control, such as firmware updates that temporarily prevented discharging. However, no incentives were awarded for events in which a bus was not plugged in during the designated event window.

Conclusion

The ComEd School Bus V2G Pilot demonstrates that ESBs can play a meaningful role in supporting grid services, while also revealing the operational and organizational conditions necessary for successful large-scale deployment. By testing both maximum-duration and maximum-power events, the pilot evaluated two essential capabilities: the ability to sustain energy delivery over extended periods and the capacity to provide rapid, high-power discharge for the longest feasible duration to support grid needs.

The results show that V2G performance is highly dependent on operational context. Event success rates were high during summer periods, when buses are idle for longer periods and charging schedules are flexible. These outcomes highlight the strong potential for V2G integration for applications such as peak shaving and demand response when operational constraints are minimal. In contrast, in-school events exhibited lower event success rates, underscoring the challenges of coordinating V2G operations during active service periods. Limited charging windows, lower initial states of charge, and day-to-day operational demands introduce variability that can compromise performance. These findings indicate that V2G programs may be most effective when aligned with off-peak operational windows that allow predictable charging and discharging or integrated into use cases that tolerate variability, such as renewable energy integration, rather than applications requiring strict adherence to critical capacity commitments.

Beyond technical performance, the pilot underscores the central role of stakeholder engagement in the adoption and long-term success of emerging technologies. Effective implementation requires alignment across leadership, fleet management teams, and facility staff, each of whom brings critical expertise and operational insight. Fleet operations personnel are particularly essential to daily execution and troubleshooting. Their buy-in directly influences the reliability and scalability of V2G systems. Without strong engagement, even well-designed programs risk encountering operational friction, inconsistent participation, or gaps in execution.

The pilot also highlights the broader environmental and societal benefits of ESB deployment. Replacing diesel buses with ESBs reduces GHGs and harmful air pollutants such as NOx and PM2.5, contributing to improved public health along bus routes. While the primary routes in this pilot did not travel through EJ, LI, or R3 communities, ESBs may still provide localized air-quality improvements and increase visibility of clean transportation investments. These findings point to significant opportunities to expand ESB deployment in ways that more directly benefit communities historically burdened by transportation-related pollution.

Finally, the pilot provides insight into the conditions necessary for scaling V2G-enabled ESBs across the region. Stakeholder surveys reveal strong interest tempered by financial and technical concerns. Clear incentive structures, transparent financial modeling, and continued education around battery health and system reliability will be essential to building confidence among school districts and stakeholders.

Altogether, the pilot represents an important milestone for future V2G initiatives and the broader advancement of clean energy innovation through ESB fleets. The findings point toward several priorities for successful expansion: aligning V2G operations with periods that maximize performance, designing programs that can accommodate real-world operational variability, and investing in strong, ongoing stakeholder engagement. By doing so, school districts and utilities can build the foundation for scalable, resilient, and community-centered V2G deployments capable of delivering meaningful grid value and societal benefits.

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