

Field Study Demonstrates Financial and Grid Benefits of EV Bidirectional Charging

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ABSTRACT

At the seams of vehicle-grid integration, bidirectional electric vehicle (EV) chargers can unlock new value streams through dozens of use cases for residential and commercial buildings. Using only vehicle-to-building (V2B) use cases, one utility has demonstrated monthly gross savings that exceed the monthly lease cost of its EV.

Roanoke Electric Cooperative (REC), in collaboration with a team of clean energy organizations, quantified the value of V2B services using a 15-kilowatt (kW) Fermata Energy charger, the first UL-certified bidirectional EV charger. The utility dispatched the battery of a Nissan LEAF S Plus parked at its headquarters. Three use cases were demonstrated: load following, peak load reduction, and backup generator support while the building was islanded from the grid. REC also demonstrated support for reduced system peak demand through a simulated response to demand reduction signals sent by the transmission grid operator.

Over 12 months, the combined value streams produced gross savings for REC of more than \$3,200 per year per charger, exceeding the monthly lease cost of the EV. This finding underscores the opportunities to reduce the cost of integrating EVs and renewable energy into the grid. Furthermore, a review of home load profiles within REC's service territory revealed that a 6-kW bidirectional charger could produce approximately 50%-330% more grid value through vehicle-to-grid services than through V2B services alone, i.e., if energy dispatch were allowed to exceed host building demand.

This study showed that even a single EV with bidirectional charging can produce significant gross value streams, even in markets with low demand charges.

Introduction

Background

Electric vehicle (EV) registrations in North Carolina grew by over 50% in 2021 compared to 2020 (NCDOT 2022). Public charging station investment is following this trend, with around 2,400 Level 2 and Direct Current (DC) fast charge ports across the state (AFDC 2022). By 2030, Gov. Cooper's Executive Order 246 calls for 1.25 million EVs on North Carolina roads and for 50% of new light-duty vehicle sales to be zero-emission (NC Governor Roy Cooper 2022). North Carolina's electric utilities are supporting this market demand by deploying public charging stations and offering residential rebate programs for charging equipment as well as time-of-use rates and subscription programs to encourage off-peak charging, shifting load and saving drivers money (Duke Energy 2022; REC 2022).

However, while EVs have lower operating costs than internal combustion engine vehicles, their higher purchase prices can be prohibitive for many (Muratori et al. 2021). Financing models must be incorporated to encourage the win-win value proposition that light-duty EVs can bring drivers and utilities.

For Roanoke Electric Cooperative (REC), despite EV-related incentives and rebates, EV adoption and charging station deployment in its service territory are significantly lower than in other areas of the state (AFDC 2022). Tapping into EV batteries through bidirectional charging, though — in which the batteries can not only store energy but also send it back to a home, a building or the grid — represents a potential new value stream that can benefit REC’s member-owners and operations. (Bidirectional charging is also referred to as vehicle-to-everything, or V2X.)

By demonstrating the capabilities of a Nissan LEAF to act as a dispatchable battery that supports a building (or other localized load) at a time of increased demand, we have shown how this value stream can help scale up financial solutions for rapid EV deployment. These findings may be especially valuable in areas where EV registrations are low, where third-party EV charging station deployment lags or where community climate resiliency strategies are in immediate need.

Project Partners

This research project was a collaboration between Advanced Energy, REC, Fermata Energy, Enpira, the NC Clean Energy Technology Center, the Environmental Defense Fund and Clean Energy Works.

Advanced Energy. Advanced Energy is a nonprofit energy consulting firm that assists utilities with program design and electric transportation initiatives.

Roanoke Electric Cooperative. REC is an electric cooperative serving parts of seven counties in North Carolina (Figure 1). It has been a leader in advocating for and facilitating ownership of EVs in its territory. For example, starting in January 2020, REC offered EV owners up to 450 kilowatt-hours (kWh) of charging for a monthly flat fee of \$50, as well as a new home charging station with installation, valued at \$1,700. This program was expanded in February 2022 to provide options at \$31 and \$39 per month for 275 kWh and 350 kWh of charging, respectively. REC also debuted the first DC fast charge station in its service territory in April 2021.

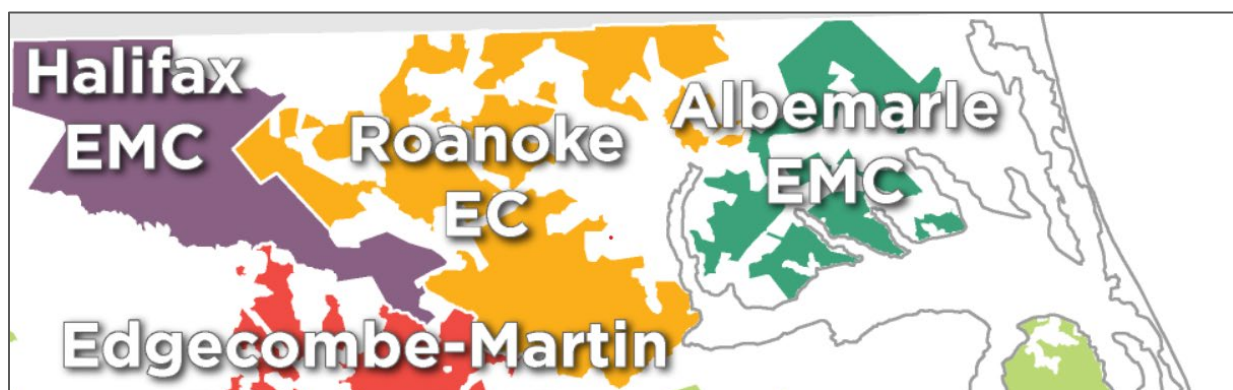


Figure 1. REC’s Service Territory (NRECA 2018).

The cooperative’s corporate strategy, *Vision 2025*, has a primary goal to mitigate wholesale power costs, about half of which are associated with peak demand charges. With this project, REC can already see the value of integrating dispatchable storage in its service area on

terms that generate positive cash flow for participating EV drivers and put downward pressure on electricity rates for everyone.

Fermata Energy. Fermata Energy's next-generation bidirectional, UL approved EV charger and accompanying proprietary management software platform help customers dispatch power from stored energy in EV batteries directly back into the grid (V2G), building (V2B), or home (V2H). This functionality turns EVs into energy storage resources, and in the process, unlocks and monetizes the massive energy storage potential of EVs.

Enpira. Enpira is a software platform that enables electric utilities, building portfolios and local governments to better manage energy use.

NC Clean Energy Technology Center. The NC Clean Energy Technology Center participated through its Clean Transportation Program, which propels the development, awareness and use of alternative fuels and advanced transportation technologies.

Environmental Defense Fund. The Environmental Defense Fund, a leading international nonprofit organization, creates transformational solutions to the most serious environmental problems, including supporting policies that accelerate transportation electrification to create a zero-emission future.

Clean Energy Works. Clean Energy Works partners with policymakers and community advocates to advance equitable clean energy solutions that work for everyone and provides advisory services for accelerating investment in grid-edge solutions.

Codes and Standards

EV charging, and V2X charging, is subject to a variety of codes and standards that cover everything from communications to safety. Fermata Energy's bidirectional EV charging system is the first to be certified to UL 9741, the "Outline of Investigation for Electric Vehicle Power Export Equipment (EVPE)."

Methodology

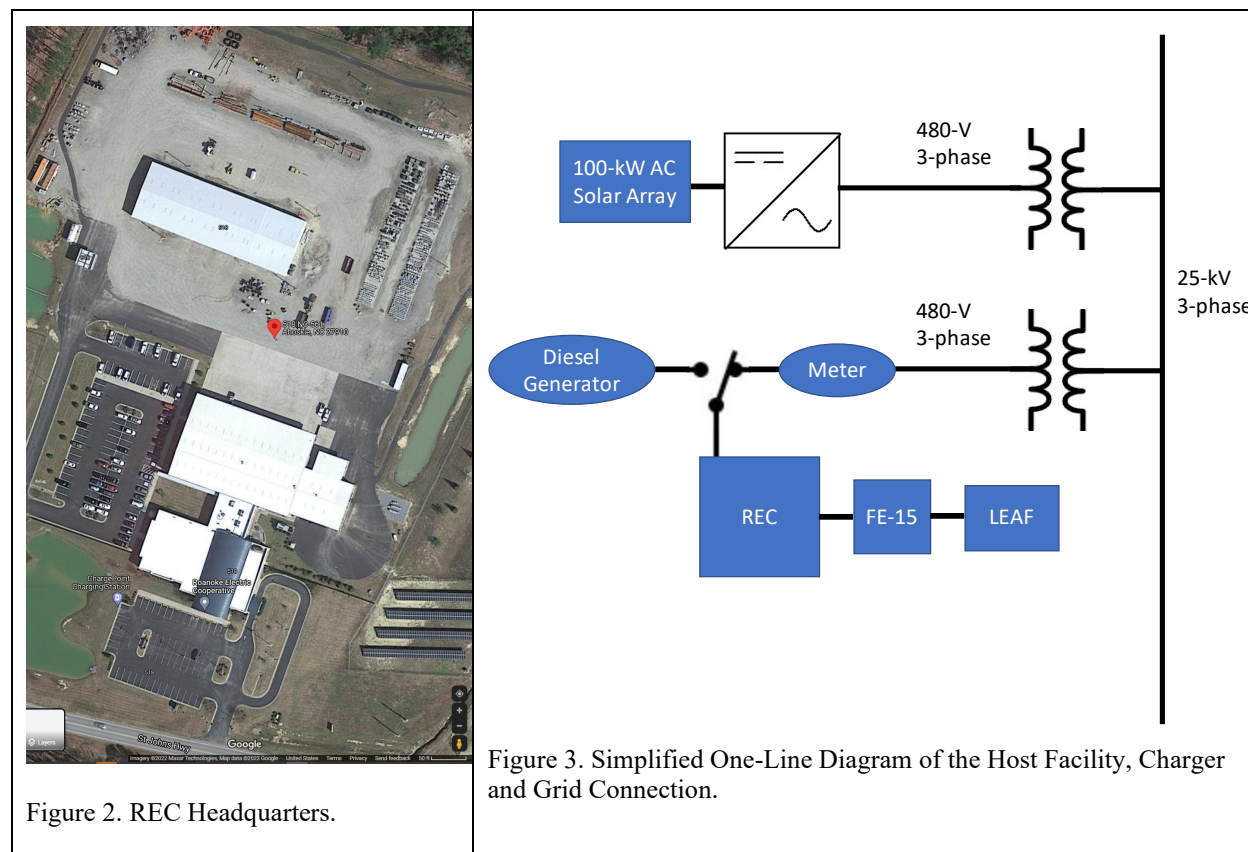
The overall goal of this project was to demonstrate and quantify some of the potential value offered by V2X implementation. Based on REC's primarily rural residential load, we looked to emulate uses that would be representative of possible broader deployment. In collaboration with Clean Energy Works, Fermata Energy and Nissan, REC arranged for the installation of Fermata Energy's latest bidirectional charging solution.

Site Selection and Construction Layout

Testing was performed at REC's headquarters in Aulander, North Carolina (Figure 2) between November 2020, and December 2021. REC had previously demonstrated several technologies and initiatives at this facility that are new or unique in the area, including a 100-kilowatt (kW)_{AC} solar array, broadband service that enables dispatchable loads, a diesel generator for backup power and grid islanding, and a public EV charging station. These projects ensured there was little need to upgrade or modify existing on-site electrical infrastructure. The

Fermata Energy charging equipment was connected by 480-volt service and was accessible from a secure parking space behind the REC headquarters.

Additionally, the facility's relatively large peak demand (greater than 130 kW) ensured there was a low chance that the charging equipment would need to throttle its discharge capacity to prevent the net negative flow of electricity to the grid. This load was sufficient to fully use the output of the charger. These assets allowed us to consider a wider variety of use cases, including backup power support. A simplified one-line diagram of the facility, charger and grid connection is presented in Figure 3.



Equipment Description

Nissan LEAF. Two 2020 Nissan LEAF S Plus electric cars, each with a 62-kWh battery pack, were leased by REC under special agreement to allow for bidirectional charging with the assurance that the leasing agent would be able to sell the car later to a known buyer who was comfortable with that use and its effect on the battery warranty. At the time, the LEAF was the only commercially available light-duty vehicle in the U.S. capable of bidirectional charging. The S Plus trim was selected for its increased battery capacity, which approximately doubled the total available energy for dispatch compared to other trims with 40-kWh battery packs (accounting for necessary reserves).

The lease cost per vehicle was \$244 per month for 36 months. The lease was paid as a lump sum and included an available federal EV tax credit. For reference, the market-advertised 36-month lease cost of a 2022 Nissan LEAF S Plus is \$361 per month, and the financed purchase cost is \$542 per month over 60 months.

Each vehicle was designated as a company car with a single employee as its main user. The primary use for the vehicles was the support of broadband services as an ancillary business of the cooperative to enable smart grid functionality and other essential economic benefits in REC's service area. Employees were instructed to drive the vehicles normally, without special consideration for how their use might impact V2X performance.

Fermata Energy Charger. Fermata Energy installed one FE-15 bidirectional charger at the marked location in Figure 2. This charger was the first charging system compliant with UL 9741 and IEEE 1547. These certifications were of paramount importance to REC's primary considerations of safety and performance. The extensive testing by UL also eliminated the need to demonstrate the functionality of the bidirectional charging equipment, moving the focus instead to demonstrating the value of that functionality. Its utility-facing interconnection operated at a nominal voltage of 480/277 Vac and was rated to 21 A_{rms}, 15 kW. The DC connection to the EV was rated to a nominal voltage of 380 VDC and 73A, 15 kW. The FE-15 used a JAE CHAdeMO connector, and it was pedestal-mounted within a NEMA 3R rainproof enclosure. System efficiency was 95% for both charging and discharging.

Live Metering Equipment. In addition to the FE-15 charger, metering was provided by a Measurlogic DTS-310 revenue grade meter using Magnelab RCT-3600 Rope CTs. Readings were verified against the existing advanced metering infrastructure (AMI) present at REC's headquarters. The frequency of data sampling from the Measurlogic equipment was higher than the utility's standard settings for AMI equipment. Wireless remote communications and control were supplied by a cellular modem and wired VPN router.

Use Case Analysis

Use cases for the research were selected from those detailed in the *Final Report of the California Joint Agencies Vehicle-Grid Integration Working Group* (CPUC 2020). A comprehensive list of materials produced by the VGI Working Group is hosted by Gridworks at gridworks.org/materials-produced-by-the-vgi-working-group/. The Use Case Assessment Database was reviewed for suitability to the test conditions, relevance for REC and degree of testing difficulty. After initial discussion, the 12 light-duty vehicle use cases in Table 1 were highlighted for closer consideration. Priority was provided by REC based on its corporate goals.

The dollar value per EV per year, as well as the total benefit value provided in Table 1 were the result of survey responses from working group participants, and were only intended to be representative of the California market. Participants selected from five multiple-choice options, for both value per vehicle, and population of participating vehicles: \$1-50, \$50-150, \$150-300, \$300-600, \$600-1000; and 1-5,000 EVs, 5,000-25,000 EVs, 25,000-100,000 EVs, 100,000-300,000 EVs, 300,000-900,000 EVs. The calculated average response was based on the mid-point of these ranges. Total benefit was the product of these two responses.

Table 1. Initial Use Case Selection

Priority	Use Case ID(s)	Sector	Application	\$/EV/Year Avg (range)	Total Benefit (range)
1	826, 826.1, 826.2, 827, 827.1, 827.2 and 828	Commercial - Workplace	Customer - Bill Management	\$430 to \$800	\$3.16 million to \$158.5 million
1	959	Commercial - Workplace	System - System Capacity	\$267	\$15.8 million
1	1028 and 1436	Commercial - Public, Commute	Customer - Bill Management	\$375	\$12.6 million
1	10 and 7	Residential - Single Family	Customer - Bill Management	\$454 and \$586	\$39.8 million and \$50.1 million
1	416 and 419	Residential - Multi-Unit	Customer - Bill Management	\$220 and \$175	\$1.99 million and \$1.6 million
2	884, 886 and 887	Commercial - Workplace	System - Backup, Resiliency	\$231	\$7.9 million
2	932, 934 and 935	Commercial - Workplace	System - DER Integration	\$163 to \$258	\$630,000 to \$7.9 million
2	1544	Commercial - Public, Commute	System – DER Integration	\$238	\$15.8 million
2	31 and 34	Residential - Single Family	Customer - Backup, Resiliency	\$188 and \$293	\$15.8 million and \$25.1 million
2	67 and 70	Residential - Single Family	System - Backup, Resiliency	\$140	\$6.3 million
2	115 and 118	Residential - Single Family	System - DER Integration	\$144 and \$200	\$10 million and \$12.6 million
3	82	Residential - Single Family	System - Voltage Support	\$25	

Given the vehicle's use as a fleet vehicle at a commercial workplace, three use cases were chosen for testing, all based on the Commercial Workplace Sector: Customer Bill Management, System Capacity, and System Backup and Resiliency.

Testing and Communications

Figure 4 presents the terms and convention used in the remainder of this article. Please note the sign convention for charging (negative) and dispatch (positive). Vehicle-to-building (V2B) activity (dispatch) is signed positive but is subtracted from actual demand to find the effective demand. This sign convention was adopted to match outputs from Fermata Energy's metering equipment.

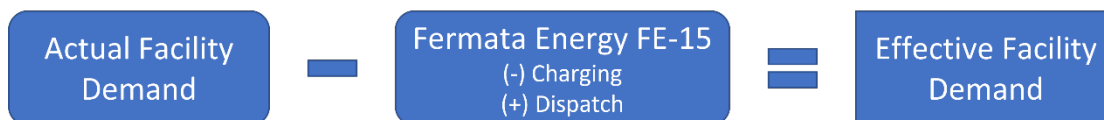


Figure 4. Definition of Terms.

The commercial workplace bill management use case was tested using the preprogrammed behavior from the Fermata Energy charger. This behavior monitored the actual facility demand and compared it to the previous peak effective facility demand recorded within that month. The charger would then dispatch to keep the effective facility demand below the previous peak. If the actual facility demand exceeded the previous effective demand peak by more than the dispatch capacity of the charger, a new effective peak would be recorded. As testing progressed, we discovered that without a preset peak demand, each new month would begin with unneeded dispatch of the battery until a realistic midday peak was reached.

In addition to reducing the peak building demand of REC's headquarters, the Fermata Energy charger and LEAF vehicles were used as distributed energy resources (DERs) to reduce systemwide peak demand for the North Carolina Electric Membership Corporation (NCEMC). The project team worked with NCEMC and its Distributed Energy Resource Management System (DERMS) provider, Open Access Technologies International (OATI).

At full deployment, the Fermata Energy charging system is intended to behave like other battery-based DERs, meaning it would respond to signals from the DERMS. However, as this was a first-of-its-kind test of the OATI product integration with such capability, OATI could not produce a signal for dispatching bidirectional charging equipment with the functionality sold to NCEMC. Instead, we simulated the signal manually. Demand events were communicated by OATI via email to REC's engineering staff, who automatically forwarded those notices to Fermata Energy. Software engineers at Fermata Energy then programmed a scripted response to the demand event. This hard-coded approach prioritized responding to the system peak, which occasionally sacrificed the peak building demand management.

Finally, system backup and resiliency testing was performed using the existing diesel backup generator and grid-isolating equipment (Figure 3). On initial installation, Fermata Energy equipment experienced an un-recovered, over-frequency fault in response to regularly scheduled generator operation every week. This undesired behavior led to a firmware update that resolved the automatic recovery issue as of February 2021. Since the update, the weekly cycle of operation of the diesel generator has shown the charger able to consistently respond and autonomously reconnect to the islanded diesel generator circuit within one minute.

Results

Vehicle Use

Based on follow-up interviews with vehicle drivers, both Leaf EVs were driven daily for a minimum of 1-3 hours. Typical operating hours were between 8am and 5pm, and average daily mileage was ~60 miles. While staff were not directly aware of any peak demand events or system demand reduction calls, staff did try to have a vehicle plugged in during common high demand times. This included on winter mornings and summer afternoons provided doing so did not hinder staff's work. The EVs were procured for the primary purpose of fleet use, not providing grid services. Despite this priority, across one year of testing we only saw two instances of missed grid services due to the vehicles being in use.

Parent Site Peak Load Reduction

The bidirectional charging system lowered demand charges for REC in 8 of the 12 months of testing. These events showed the system operating as desired, with an average demand reduction of 11.4 kW, 95% C.I. [8.18 kW, 14.5 kW].

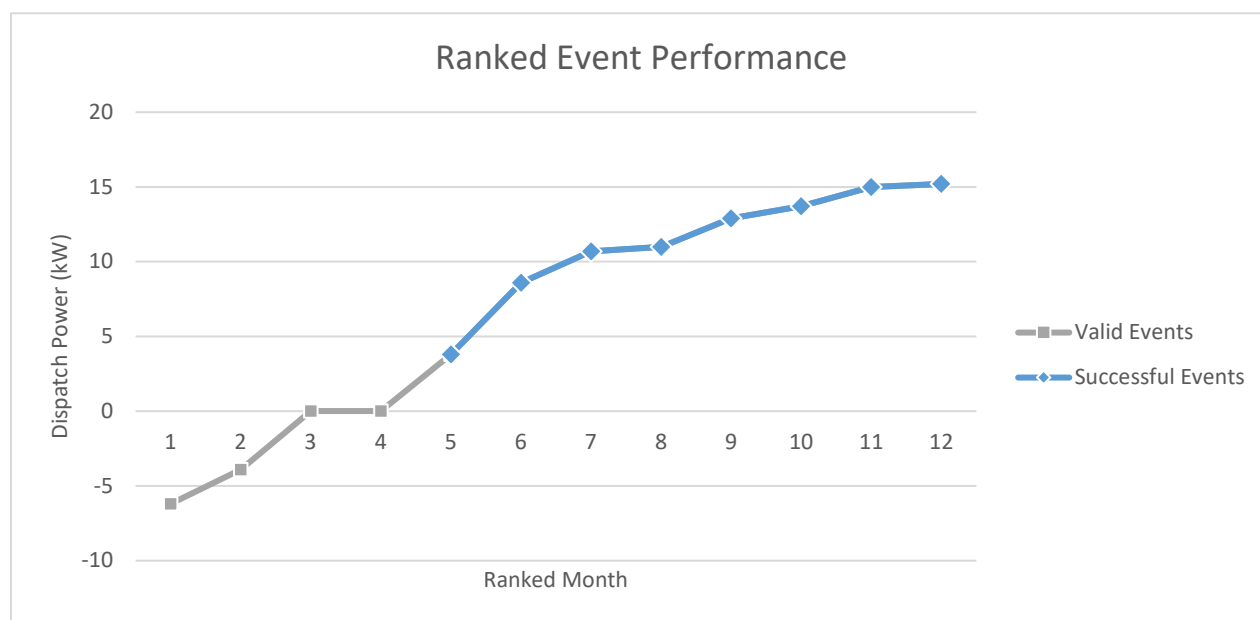


Figure 6. We See a Significant Impact on Overall Performance from Counter-Productive and Unproductive Events (Grey), Compared to Successful Events (Blue).

Table 2. Monthly Bill Management Performance

Billing Period Start Date	Actual Facility Demand (kW)	Fermata Energy FE-15 Dispatch (kW)	Effective Facility Demand (kW)	Notes
2020-11-20	170.40	3.8	166.60	

2020-12-21	177.60	11	166.60	
2021-1-21	190.80	13.7	177.10	
2021-2-20	199.44	15.2	184.24	
2021-3-21	182.76	0	182.76	Car not plugged in
2021-4-20	155.64	8.6	147.04	
2021-5-20	138.96	12.9	126.06	
2021-6-20	164.12	-6.2	170.32	System peak conflict – Peak Increase
2021-7-20	154.80	-3.9	158.70	System peak conflict – Peak Increase
†2021-8-19	†154.80	†0	†154.80	†Software bug
2021-9-20	158.16	0	158.16	Car not plugged in
2021-10-20	147.60	10.7	136.90	
2021-11-20	171.84	15	156.84	
†2021-12-20	†185.28	†6.6	†178.68	†Averted peak early in the month; actual billed peak, charger malfunction — unit replaced.

†Entries were excluded as nonrepresentative equipment malfunctions.

Two peak reduction events were missed due to the vehicles being in use and unplugged, and two building peaks were exacerbated by charging scheduled in advance of planned system demand reduction calls (Figure 5). These two charging events, on June 28, 2021, and July 28, 2021, increased building demand by 6.2 and 3.9 kW, respectively.

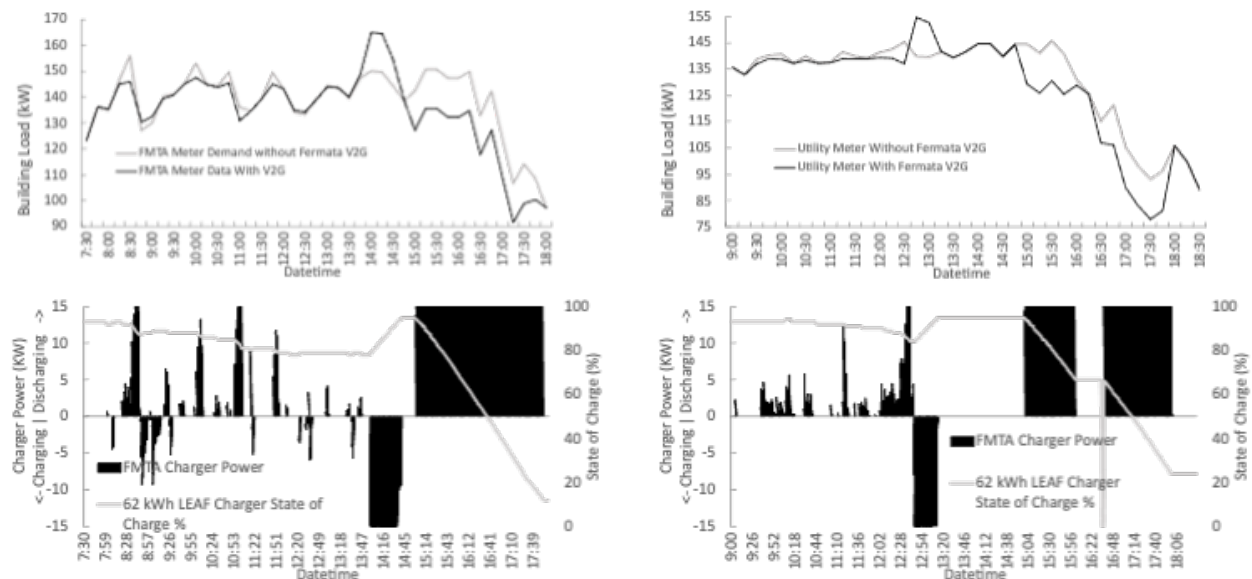


Figure 5. Event Reports from Fermata Energy Showing June 28, 2021, and July 28, 2021. Actual Demand (Light Gray) and Effective Demand (Black) are Shown in the Upper Plots. Activity on the FE-15 is Shown in the Lower Plots. Note Effective Demand Peaks Above Actual Demand at ~14:00 (Left), and ~12:45 (Right).

Including these four affected events reduced the average demand reduction to 6.73 kW, 95% C.I. [1.87 kW, 11.6 kW] (Figure 6).

Across all events, we observed seven instances of peak shifting, in which actual demand was altered such that the peak effective demand, i.e., the billed demand, occurred on a different day and time from the peak actual demand. Among these seven events, there were five instances of effective peak reduction and two instances of effective peak increase. We also observed that the effective peak was, on average, time-shifted earlier in the billing day ($M = 2$ hr. 18 min., $SD = 3$ hr. 17 min.). The variance of the phenomenon was large enough to prevent statistical significance ($t(6) = 1.84$, $p = .115$), but given the small number of samples, we believe additional testing is warranted on this effect. We did not observe a statistically significant day-to-day shift per billing month ($M = -5$ days, $SD = 11.2$ days, $t(6) = -1.18$, $p = .284$).

Two events were affected by either software or hardware malfunctions, which have since been resolved. As these events were unrepresentative of a larger deployment, we have excluded them from the preceding statistics. They are included in Table 2 for completeness.

Response to Demand Reduction Calls

Between February 18, 2021, and February 15, 2022, REC received 52 demand reduction calls covering 142 hours. These calls were typically provided to REC with day-ahead notice. Of those, Fermata Energy was successfully notified of 50 events (136 hours) and responded to 47 events (128 hours). Across all events, notified events and responded events, the Fermata Energy charger delivered an average of 12.96 kW, 13.43 kW and 14.25 kW, respectively. Detailed statistics across all three categories can be found in Table 3.

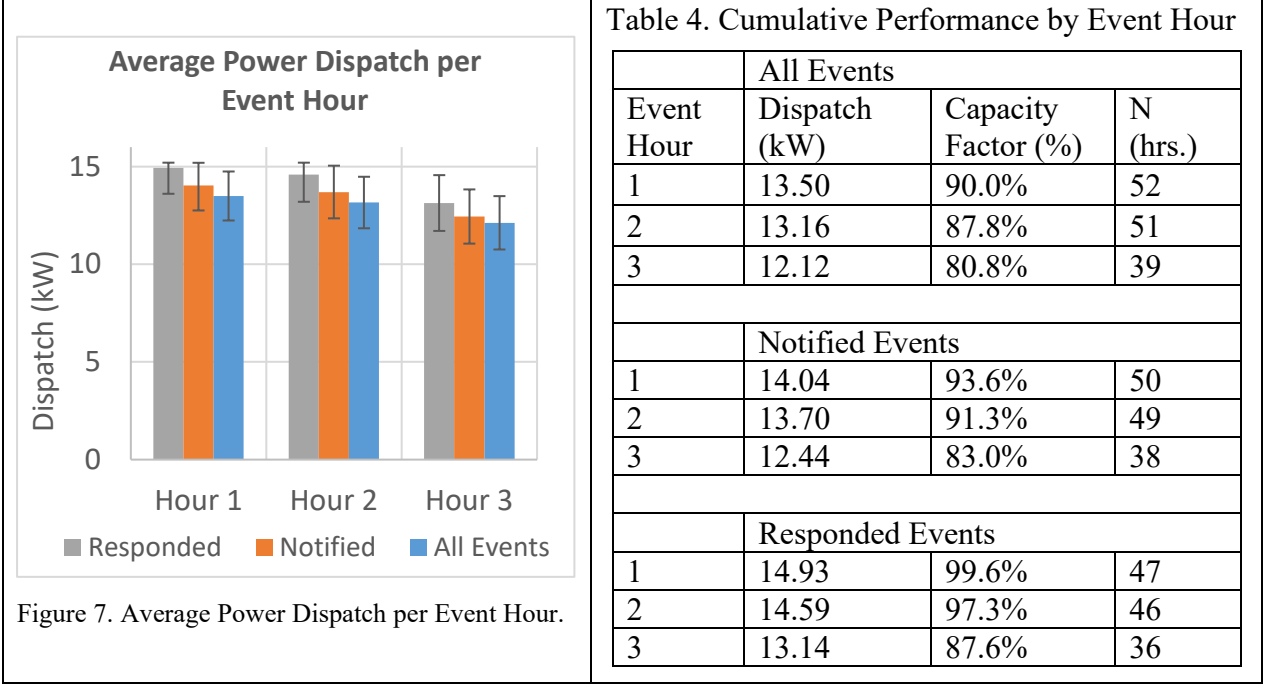
Table 3. Cumulative Statistics Across Event Hours

	All	Notified	Responded
N (hrs.)	141	136	128
Mean (kW)	12.96	13.43	14.25
Std. Dev. (kW)	4.51	3.84	1.95
95% C.I. (kW)	± 0.75	± 0.65	± 0.34
High (kW)	13.71	14.08	14.59
Low (kW)	12.21	12.78	13.91

Among notified events, two separate responses (6 hours) were prevented due to hardware malfunction and one separate response (2 hours) was prevented due to software malfunction. Additionally, two response hours were negatively impacted by a) an under-frequency error created by early generator testing, and b) a driver unplugging the vehicle near the end of an event. These negative impact events are realistic of wider use and were included in the statistics presented.

We also examined the performance of the charging equipment by event hour (Figure 7, Table 4). We define event hour from the start of the event, and independent of time of day. This allows us to combine winter and summer events, which may happen at different times of day. Across all events, the Fermata Energy charger was able to provide, on average, 12 kW or more of demand response for three hours. Performance was best in the first hour and decreased in the second and third hours. This pattern corresponds with observed charger behavior, where the vehicle battery was less likely to be charged sufficiently to support longer-duration events. We observed a 10-12% decrease in average power dispatch over three hours in all event categories. The 95% confidence interval across all hours, in all categories, was between ± 1.25 kW and ± 1.5

kW. Positive error bars have been truncated to 15.2 kW, the maximum observed output of the charger. We also present the data as a capacity factor, i.e., a percentage of nameplate output.



Backup Generator Support

The presence of a diesel backup generator was not initially considered during deployment of the V2X charging infrastructure. This proved problematic, as weekly testing of the generator soon revealed a software anomaly in the charging equipment. During these tests, the REC facility was put through an islanding scenario drill that involved starting the diesel generator, disconnecting the main grid service and creating a diesel-powered microgrid. In this process, the charging equipment prompted an over-frequency error and halted activities, which accorded with design. However, the system repeatedly failed to autonomously reconnect to the microgrid established by the diesel generator, which was outside the design intent of the equipment.

Upon realizing the issue, Fermata Energy worked with REC to diagnose and remedy the problem with multiple rounds of testing and, later, a firmware update. Since this update, the Fermata Energy charging equipment has been able to successfully reconnect to the established microgrid on multiple occasions. No issues have been observed with reconnecting to the main grid system, either.

Discussion

The performance of the EV and charging equipment in this study reveals the potential grid savings available to REC and other electric utilities in similar market conditions. These savings are further impacted by the deemed value of each service. For REC, we value avoided site peak load at \$9.50 per kW (per the REC commercial service rate schedule) and avoided system demand during a reduction call at \$15.71 per kW (per interviews with REC staff). Without clear price signals we were not able to specifically calculate the size of the value stream for the backup generator support use case.

Value Stream Calculations

Table 5 presents a summary of average monthly savings. Looking first at the eight successful peak load reduction events, we see \$107.94 in savings per month, 95% C.I. [\$77.75, \$138.14]. By comparison, including all valid events reduces monthly savings by 41%, to \$63.97, 95% C.I. [\$17.80, \$110.14]. In absolute numbers, 20% of this reduction was due to cars being unplugged during critical hours, and 21% was due to timing conflicts with system peak response. These two factors should be carefully considered in future studies that assess multiple value streams. The impact of timing conflicts in particular highlights the desirability of intelligent forecasting and response software.

We observed greater savings from response to demand reduction calls. Across all events, the charging equipment saved REC an average of \$203.57 per month, 95% C.I. [\$191.77, \$215.37]. This average improved by 3.6% when only considering notified events ($M = \$210.95$, $SD = \$60.33$) and 10% when considering responded events ($M = \$223.93$, $SD = \$30.59$).

Table 5. Average Monthly Savings

	All Events	Successful Events
Peak Load Reduction	\$63.97	\$107.94
Demand Reduction Calls	\$203.57	\$223.93
Total	\$267.54	\$331.87

Impact on Standard Vehicle Usage

During the year-plus of testing, REC staff never reported having their vehicle use negatively impacted by the charger.

Review of Home Load Profiles

For several reasons, including the safety of linemen, it is common for utilities to discourage or control the backflow of power on their grid. The Fermata Energy FE-15 charger is certified to prevent backflow of power out of the parent facility onto the main grid. This strict self-consumption limit did not impact testing at REC's headquarters, which maintained a baseload well above 15 kW, but is critical to consider for individual homes. Fermata Energy is currently developing a 6-kW residential system. Based on this, we estimated how many homes would be impacted by this self-consumption limit, to compare the demand reduction capabilities of V2B with V2G in a residential setting.

We worked with REC and Enpira to study the average residential demand during demand response events. The dataset was created using a random sample of 1,000 homes in REC's service territory between January 2015 and December 2018 (Figure 8). We evaluated 288 event hours across the winter heating season (December through March), the summer cooling season (May through September) and the shoulder seasons (April, October and November). Two variables were determined, first, the number of homes with hourly demand below 6 kWh, and second, the total kWh demand, with individual homes capped at 6 kWh.

We can imagine that if charging equipment were installed in these 1,000 homes, it would provide a nameplate demand response capacity of 6,000 kWh. However, we found that most homes were limited by the self-consumption cap (Figure 8). Comparing the nameplate capacity

with the total kWh demand, with individual homes capped at 6 kWh, allows us to create a capacity factor.

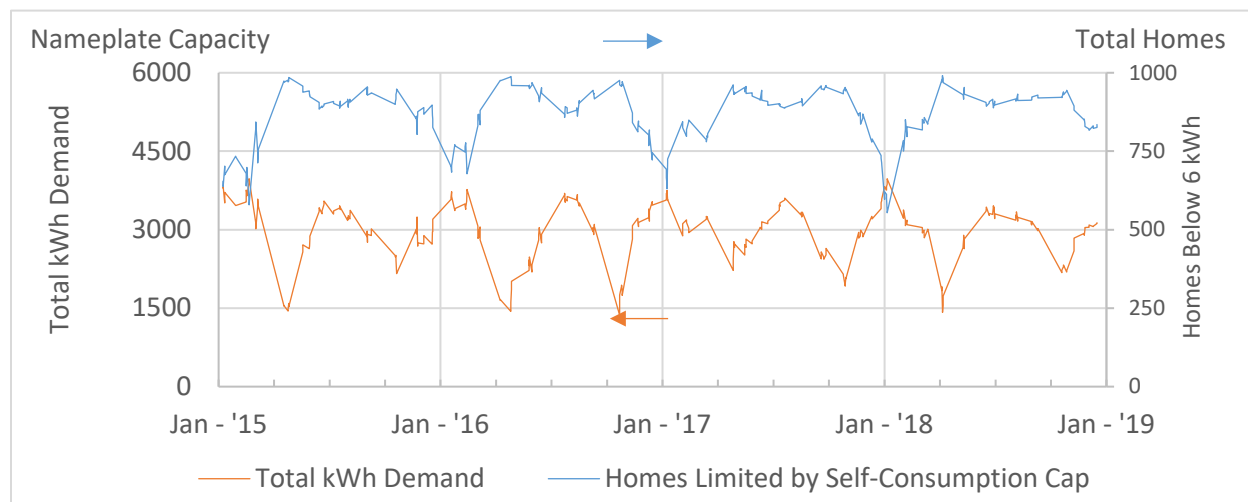


Figure 8. In Orange, the Total kWh Demand Accessible to 6-kW Bidirectional Chargers Among 1,000 Randomly Selected REC Homes Under a Strict Self-Consumption Cap. In Blue, the Number of Those Homes with Individual Demand Below 6 kWh.

We found strong seasonal trends in the percentage of homes limited by a self-consumption cap below 6 kW (Figure 9). Greater than 80% of all homes would be limited by a self-consumption cap during the shoulder and summer seasons. While there was more participation during the winter season, more than 50% of homes would still be limited by such a cap. Approximately 48% of peak hours would have less than 10% full participation among homes, and approximately 80% of hours would have less than 20% full participation. These results show that a 6-kW self-consumption cap effectively prevents using the charger's maximum 6-kW capacity for large portions of the year.

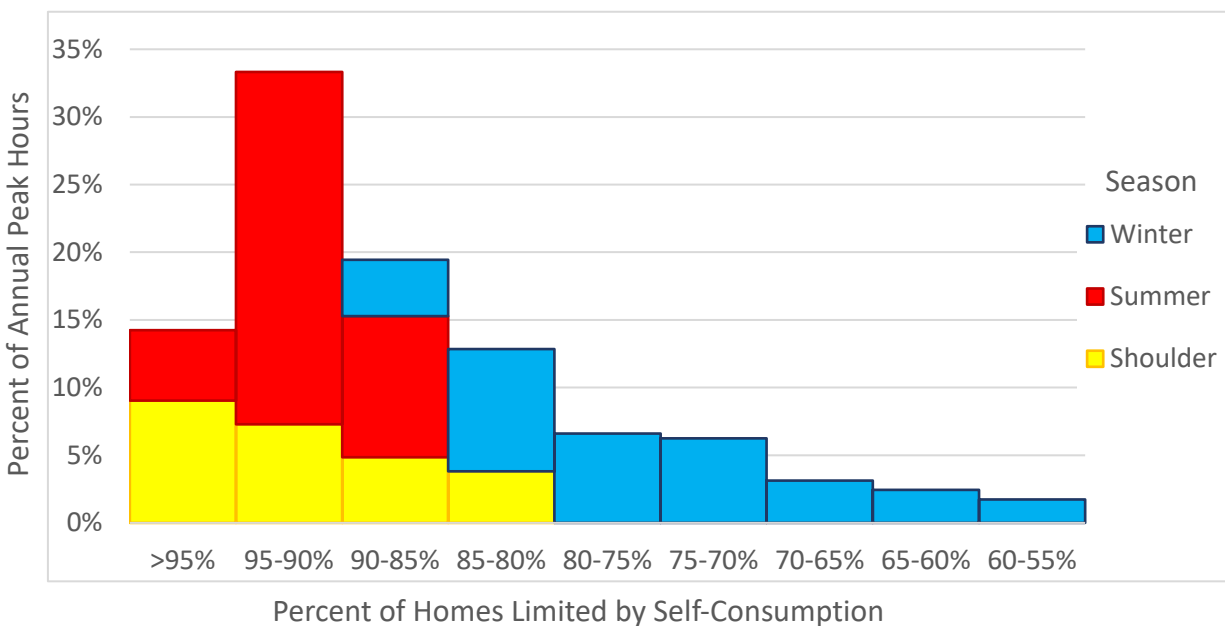


Figure 9. Most Homes Would be Limited by a Self-Consumption Cap Using a 6-kW Bidirectional Charger.

Shifting focus from participation to demand, we can see that a self-consumption cap imposes a greater than 30% reduction in available capacity (Figure 10). Interestingly, low summer participation does not seem to lead to greatly reduced cumulative summer demand compared to winter demand. The shoulder season was particularly impacted by the self-consumption cap, never exceeding a 55% capacity factor. Over 40% of peak hours have capacity factors at or below 50%. Expressed reciprocally, 50% - 330% more values is potentially available through V2G services than through V2B services alone.

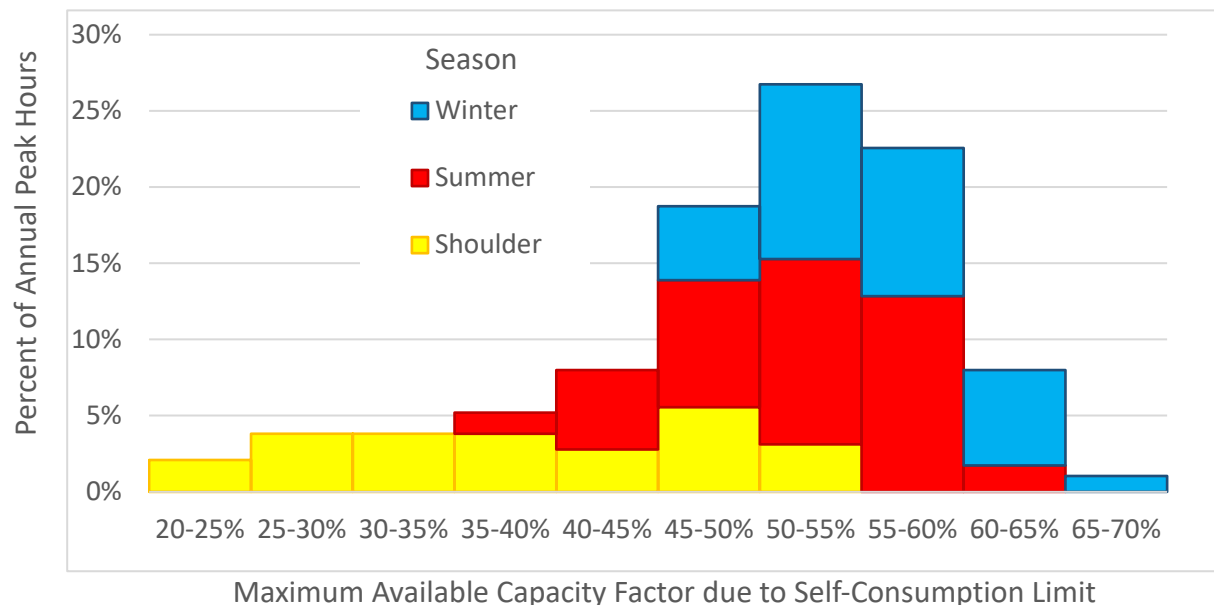


Figure 10. Winter and Summer Seasons Have Similar Available Capacity Under a Self-Consumption Limit. This Suggests More Homes Are Contributing Smaller Individual Loads During the Summer Season Compared to Fewer, Higher-Demand Homes in the Winter Season.

Conclusion

This study demonstrated one of the first examples of V2B charging in the U.S. We were able to show three use cases and two value streams for a prototypical corporate EV fleet vehicle. Using the Fermata Energy FE-15 charger and a 2020 Nissan LEAF S Plus, we demonstrated average peak load reduction of 6.73 kW, or \$63.97 per month, and demand response capacity of 12.96 kW, or \$203.57 per month. We also demonstrated the possibility of exercising both value streams simultaneously.

Taken together, this study suggests a monthly potential value of \$267.54, 95% C.I. [\$219.89, \$315.19] and an annual potential value of \$3,210.48, 95% C.I. [\$2,638.68, \$3,782.33]. This exceeds the \$244 per month lease cost paid by REC. Likewise, we observed opportunities to improve communications protocols, hardware and software reliability, and the optimization of multi-use case management algorithms that would benefit the potential value of vehicle-to-grid (V2G) services. If these opportunities were implemented, our study suggests the potential annual value of services would increase to \$3,982.44, 95% C.I. [\$3,614.40, \$4,350.48]. This would cover 91.9% of the advertised cost of a 36-month lease of a 2022 Nissan LEAF S Plus, and 61.2% of the 60-month financed cost to purchase the EV.

It remains to be seen how lease prices, warranties, used car values and similar factors will be influenced by the adoption of V2X; however, REC was able to secure its lease terms with the dealership's understanding the vehicle would be used as a grid asset, and some manufacturers are publicly embracing V2X as a selling point, as in the Ford F-150 Lighting.

This study also shows that light-duty vehicles in residential settings are more likely to be impacted by self-consumption caps. Even in such areas, though, a 6-kW bidirectional charger is capable of effectively removing 80% of homes from the summer and shoulder load considerations of the utility and 55% of homes during the winter season. Based on our review of REC's homes and the performance observed in this study, utilities could rely on a 6-kW bidirectional charger delivering greater than 1.9 kW of demand response during the summer season and greater than 2.4 kW during the winter season. In areas without such caps, we would expect a 6-kW system to deliver greater than 5.4 kW of demand response year-round.

Access and Equity for Rural Communities

Quantifying these value streams allows utilities to begin considering incentive payments and other EV program options for customers and members. We hope that by demonstrating significant positive value, this study encourages utilities in similar market conditions to help customers overcome the upfront cost barriers to purchasing an EV. Such programs could be particularly effective in low- and moderate-income areas where these costs are prohibitive and would otherwise restrict EV adoption. This population, in particular, could stand to benefit from the reduced operations and maintenance costs of EVs.

Opportunities with Other Vehicle Types

The Fermata Energy FE-15 bidirectional charger may be a first of its kind, but many other bidirectional charging systems are expected to reach the market in the next few years. Medium- and heavy-duty vehicles with intermittent use are ideal candidates for bidirectional charging. These vehicles are often associated with commercial or industrial facilities that would be able to self-consume any dispatch from the vehicles. In particular, interest has arisen in V2G-enabled school buses. This type of vehicle, with a predictable schedule and significant downtime, lends itself to the use cases discussed above. It is important, however, to verify that the times of use do not overlap with the times of peak system demand.

Battery capacity factors into the response duration, but with a 15-kW charger and a 62-kWh battery, we observed a 10 to 12% drop-off in capacity across three hours. This decrease is expected to become less pronounced over time due to increases in EV battery capacity. It would also be a smaller effect in residential markets, where charger output is lower.

Candidate Sites and Applications

This study demonstrated a use case for sites and entities operating fleet vehicles throughout REC's service territory. Primary operators for this V2B application could include municipal and government buildings; K-12 schools; higher education institutions, such as community colleges and universities; churches and more. In cases where the upfront cost of an EV may be otherwise cost-prohibitive, or where the cost to install and operate a DC fast charger may be too high or rarely utilized, this demonstration reduces the operating costs of a vehicle and

offers an opportunity for non-residential utility members, customers and the community to benefit from electric transportation technologies.

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