

Electric Vehicle Bi-Directional Charging Value Proposition

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Summary

NextEnergy examined the potential value proposition of V2X, identifying the high value applications for V2X. The demonstration tested demand charge mitigation, V2G, arbitrage, demand response and V2H applications. The tests found that the ability of V2B to deliver significant value to building owners with aggregated electricity to mitigate demand charges was the greatest value of the V2X services. The tests demonstrated the ability of vehicles to respond to grid aggregator messages, however battery degradation had an impact on the value proposition. The studies result in a rank order of V2X applications by value and implications to battery life. These benefits point to the potential interaction of V2X in smart city applications, including specifically, opportunities within car sharing fleets between vehicle engagements.

Keywords: V2G (Vehicle to grid), business model

1 Introduction

As the popularity of electric vehicles (EVs) grows, there is increasing interest in finding new opportunities to capitalize on the energy storage capacity of the batteries in these vehicles for economic and grid stabilization purposes. V2X considers batteries in the EVs as an electricity generation source for the building or grid. EVs could serve as decentralized energy storage in a smart grid and can act as either a load or a generator as needed.

This study examined the possibilities of V2G Commerce; the idea that electric vehicle owners and grid operators can benefit financially from the sale of battery power to the grid in 2012-2013. This research was completed with funding provided by FiatChrysler Automobiles, and REV Technologies. The Michigan Economic Development Corporation supported hardware upgrades for the research.

Upon completion of the V2G Commerce study, FiatChrysler chose to expand the project to examine the economic benefit for utilizing electric vehicles for bi-directional charging to benefit buildings (V2B). This research specifically identified the economic benefit for building owners' with various scenarios using EV battery power to support building energy needs. Both studies utilized the NextEnergy Center (NEC) Microgrid Research Pavilion, which allows researchers and companies to test how different power generation technologies interface with the grid, including bi-directional electric vehicle charging.

2 Analysis of V2G Market Opportunity

In summary, the V2G Commerce study proved that there is an economically viable model for V2G, even when taking into consideration the additional battery strain, but it is limited by several factors. By using a model developed by Jasna Tomic of CalStart[1]. NextEnergy recalculated the potential revenue using the

specifications of the vehicles provided for the test by FiatChrysler. This newly calculated baseline revenue came to \$608/year/vehicle when utilizing a 6.6 kW AC bi-directional charger.

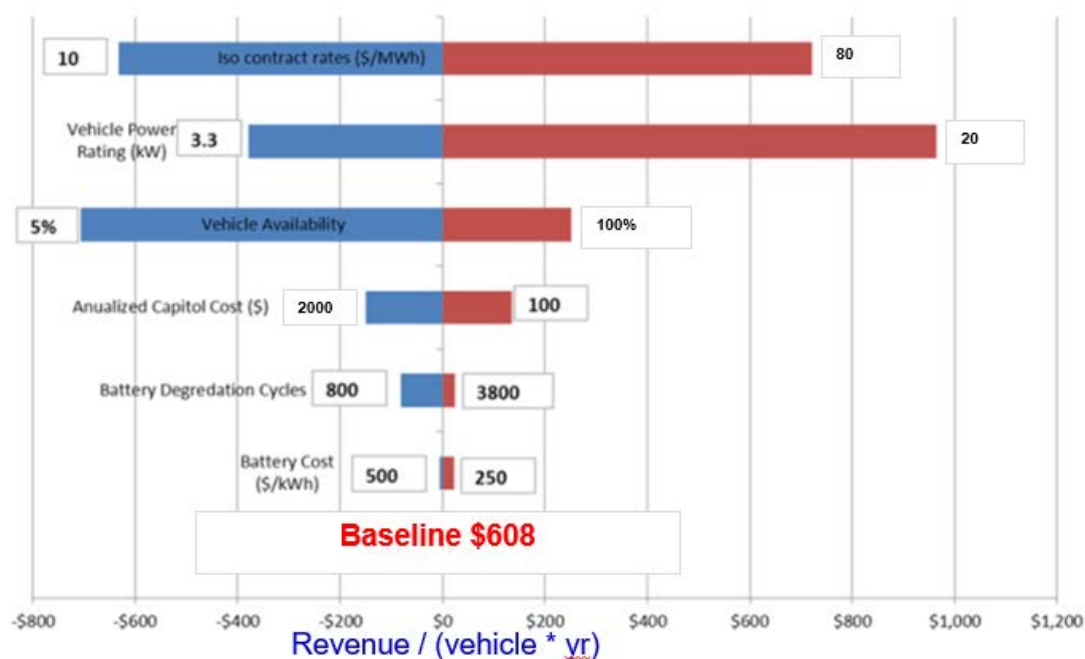


Figure1: Calculated baseline for V2G revenue targets [1]

The study parameters tested the V2G model with 20kW DC bi-directional chargers and incorporating an aggregator to bid into the wholesale market during the 2013 calendar year. This new study design allowed the study to identify potential opportunities for increasing the revenue generated with grid ancillary services.

The study was conducted comparing multiple different electricity models from independent system operators, including Midcontinent ISO (MISO), California ISO (CAISO), PJM, and the Electric Reliability Council of Texas (ERCOT).

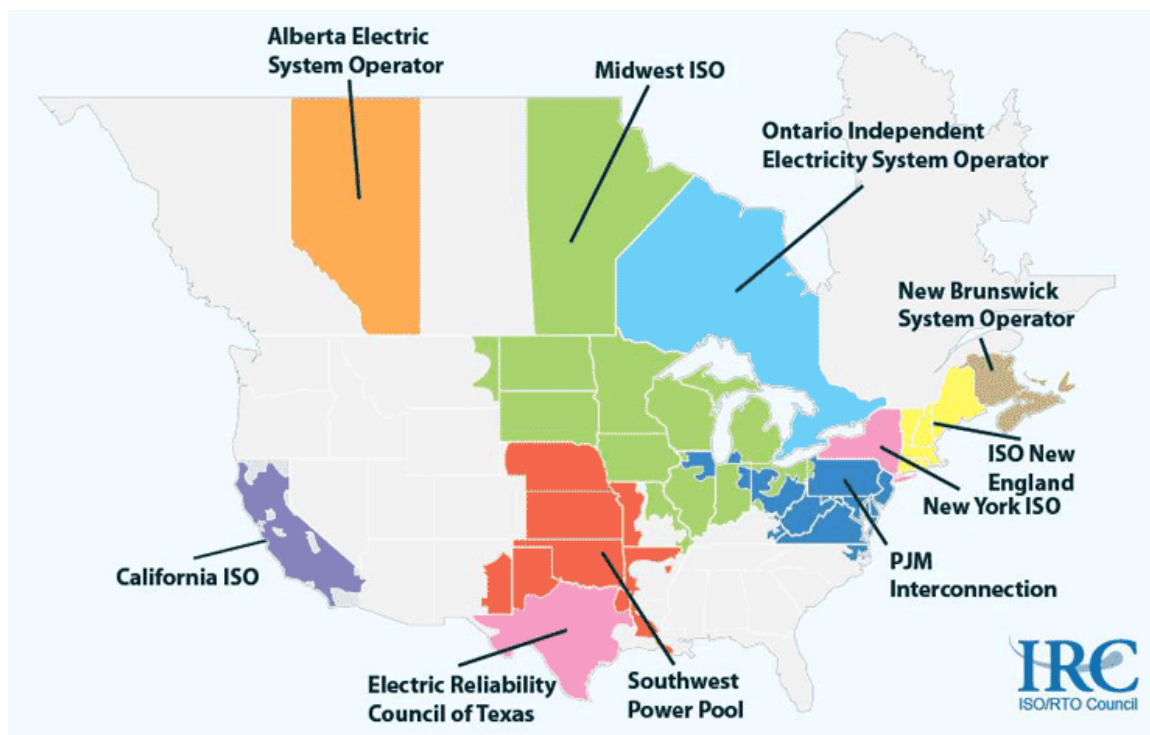


Figure 2: Independent System Operator/Regional Transmission Organization Map [2]

Each of these independent system operators have different requirements when it comes to bidding electricity into their systems. As a result, an electricity aggregator was used during the study to bid into the market. The targets for the V2G frequency regulations market are determined by the overall size of the market (Table 1) in each independent system operators.

Market	Frequency Regulations Market Size (MW), 2009	# Vehicles opportunity (6.6KW, 50% availability)
PJM	1,357	~411k
ERCOT	1,192	~360k
CAISO	623	~200k
MISO	561	~170k
NYISO	506	~153k
ISO-NE	118	~35K
Total	4,375	~1.3M

Table 1: Market Size for Storage Applications [3]

The study included testing whether vehicles could respond to aggregator grid messaging to deliver energy in response to grid needs. There were also profiles of how much SOC and capacity were available in vehicles when they plugged in. These were used to calculate how much time and power would be available from a fleet of vehicles bidding into the electricity markets.

2.1 V2G Findings

There are a number of factors that impacted the ultimate return on investment for V2G services. In fact, NextEnergy identified over 4,000 test combinations that would need to be tested between the vehicle factors, independent system operator factors, and aggregator parameters. However, some findings did become clear through the testing:

- The region has a significant impact on profitability and the study confirmed that the larger markets were indeed more profitable, meaning PJM and ERCOT were specific target markets
- Regions with more renewables or higher consumption increased the need for more grid balancing, a fact recognized by the California Public Utility Commission in response to unprecedented renewable production in 2015[4].

While this study as completed in 2013 using that years wholesale prices, NextEnergy anticipates that if it were to be redone for 2016, the markets with the highest profitability may change as prices, renewable penetration and consumption trends shift.

During the study, FiatChrysler monitored the EV battery degradation through data collected by NextEnergy during the tests. While battery degradation has the obvious impact of shortening battery life, it played another important role in the economic equations for V2G from a revenue perspective. As the battery degraded, the test revised the depth of discharge from the EVs in order to not further damage the battery. New batteries were capped with upper and lower state of charge limits and older batteries had a narrower range and the level of state of charge was modified during the test as the battery aged. This contributed to an opportunity loss which lowered the profitability of the V2G.

Opportunity Loss (\$) = (Max Charge Rate – Power Responded) · Duration of Signal · Electricity Price (1)

The opportunity loss occurred when the car was either at the upper or lower limit of the state of charge and grid needed to either charge or discharge, respectively. The opportunity loss averaged approximately 10% of the total value of the V2G revenue[5].

The aggregator service required to combine the electricity needed from multiple EVs in different locations costs an additional 20%-25% (depending on the aggregator). These aggregators are required because in some cases the independent system operators require between 100 kW to 1 MW to sell the electricity back into the market (the specific minimum bid amount varies by independent system operator).

The battery degradation has the potential to be significant as well. The interactions with the grid (either discharging or charging) need to occur multiple times during the peak periods to reduce the opportunity losses. This reduces the ability for the battery to cool between events and the battery ages at between two and three times the rate of a normal EV drive cycle. In the end, the combination of the opportunity loss as well as battery degradation tipped the scales to make the value of V2G services only moderately attractive when compared to other V2X options.

3 Analysis of V2B Opportunity

The second phase of the study was designed to test arbitrage shifting electricity prices using V2B as the energy storage and to test the business case for demand mitigation with EVs. Conducted in 2014-2015, the goal of this phase was to prove the economic viability of a V2B business model for commercial building owners or operators. The test was done by using EV based V2B operation mode. In this test, FiatChrysler provided Fiat 500e's that were customized by a Tier 1 supplier to permit bi-directional DC charging. Additional project funding came from the New Economy Initiative.

The testing demonstrated the economic value of V2B to building owners/operators. The basic structure of the study was to use five different driver habit profiles developed by FiatChrysler from a combination of traditional vehicle drivers and EV drivers data that they collected in previous research. Data was captured via the NEC's Supervisory Control and Data Acquisition (SCADA) system for analysis.

The V2B mode is used when demand is high or grid supply is lost since the stored electric energy can be released from the EVs in an aggregated way. The aggregation is important because similar to the V2G study, the quantity of power released matters to the economic benefit, and required multiple EVs. The testing included TOU and energy pricing scenarios from different utilities in different regions of the U.S., including the piloted pricing tests of real-time pricing. Real-time prices for energy increases the fluctuation of energy prices and as a result improves the benefits of V2B.

In the NextEnergy study, there were four EVs with 24kWh sized batteries available for V2B testing. The tests were completed using 19.2 kWh DC bi-directional chargers. During the test scenario the campus utilized 1,739.1 kWh of energy, of which 29.9 kWh was generated from solar. The remaining energy used was generated from a combination of EV discharging and the grid.

Figure 3 demonstrates a typical day in the test in which the total NEC campus demand. The amount of power used from the grid to capped at 100 kW for arbitrage with TOU pricing, and the EVs were used make up the difference between the capped grid supply, the solar supply and the campus energy demand.

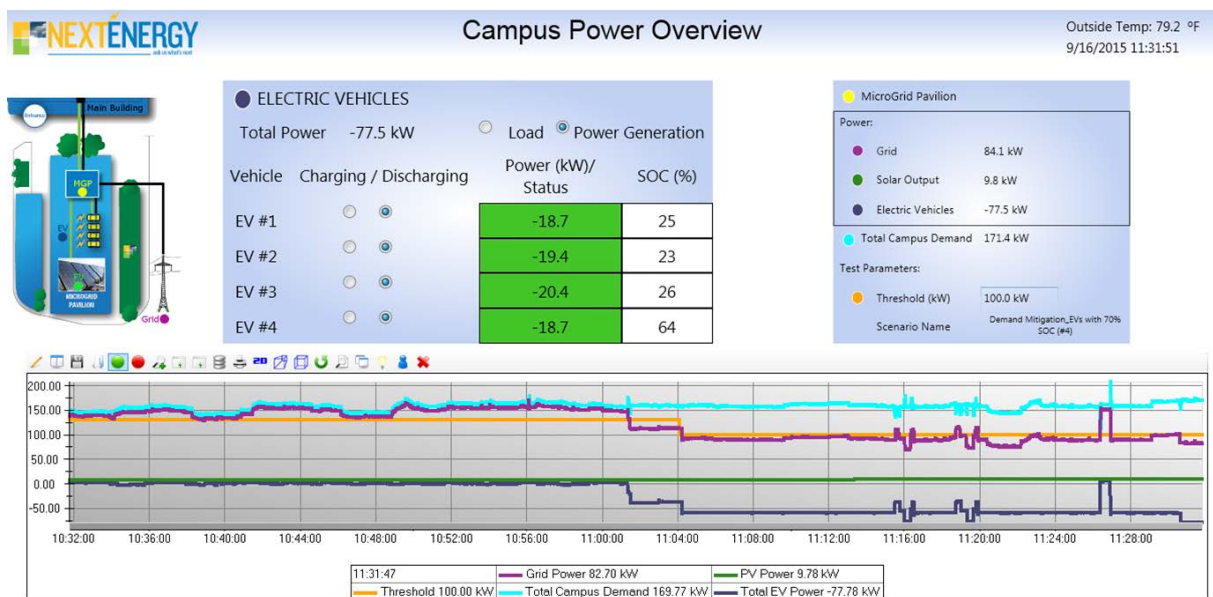


Figure 3: NextEnergy Campus Power Overview with V2B [6]

The economic benefit of conducting V2B charging in DC rather than AC was driven by the reduced cost of equipment on the vehicle. The DC bi-directional EVSE has the controls and inverter to use the 480V AC from the grid. By moving the AC/DC converter from the vehicle to the EVSE, the FiatChrysler's vehicle cost was reduced significantly, improving the business case for offering V2B. The specific financial results of the test are proprietary, because these results are driven by specific technological choices in the vehicle charging systems.

3.1 V2B Findings

The biggest opportunity for building owners to capitalize on V2B is through demand charge mitigation. The demand charges for companies vary significantly depending on the region, but most are impacted by only a few days in the year. The demand charges are based on the maximum rate in which energy consumed in a specified period of time, usually 15 or 30 minutes. Demand charges represent the high costs that electric companies pay for generating and transmission capacity that sits idle most of the time (for example, "peaker" power plants).

The NEC demand charge is between 35% and 60% of the total energy cost and therefore a significant portion of NEC's annual energy cost being driven by high energy use in a handful of summer days. By offsetting these demand with EV storage, the annual energy cost for the campus can be significantly reduced.

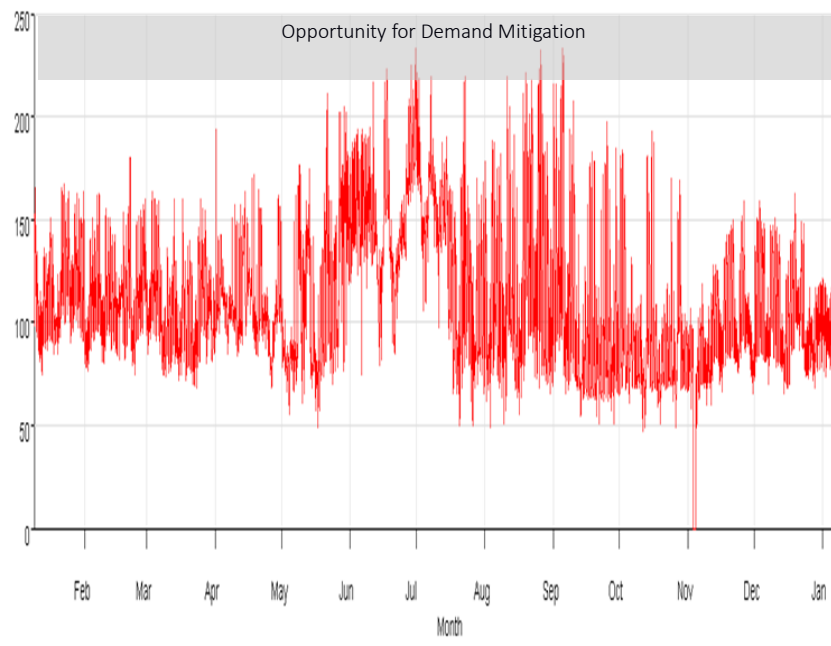


Figure 4: NextEnergy Demand Profile 2014[7]

In addition, because the demand mitigation is only required for a few specific days or times, the demand on the battery is not as great. The battery is not cycled as frequently and degradation is significantly lower than in V2G applications. However, because the EV will need to respond quickly to a demand mitigation event, the opportunity is best capitalized on when it is discharging at a high rate (20kW) in DC. It is not critical, but it makes the response time shorter and the amount of energy in response faster. Utilizing the EVs for demand mitigation proved to be the most profitable of the different scenarios at approximately \$15,000 per year in the NextEnergy testing.

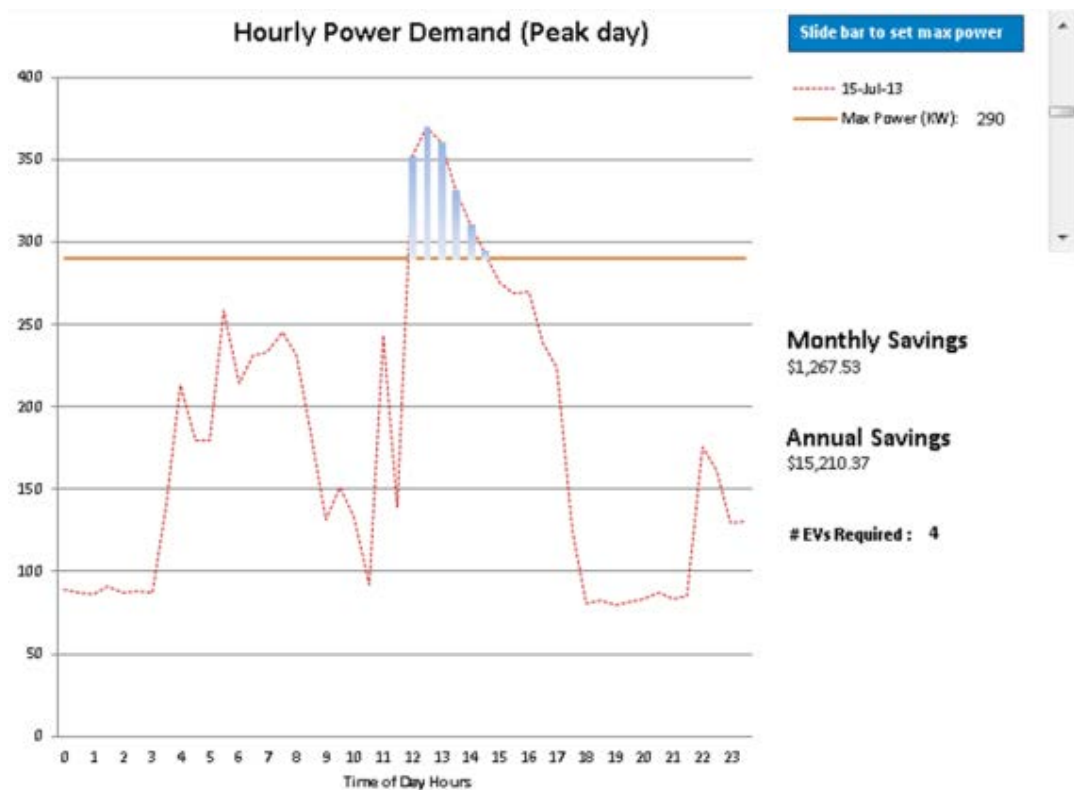


Figure 5: NextEnergy Peak Power Demand Mitigation 2015 [8]

In the arbitrage tests, the region is important to ensure the biggest difference in pricing spread, as is the ability to automate the management of charging and discharging for the most advantageous price differences. In areas where the spread between the off-peak and on-peak pricing is greatest, the value is highest. Regions with higher prices for energy that do not have a large spread between off and on peak may not be as profitable as those regions with significant spreads. The additional advantage of arbitrage is that for most days it can be combined with other V2B services in order to maximize the value of the electric vehicle.

As utilities move towards real time pricing[9], the opportunity to increase the value of arbitrage with V2B increases because of the increase changes in prices. As Figure 6 shows there are opportunities to recoup costs from any increase in a real-time pricing scenario, though the costs recovered may be very small.

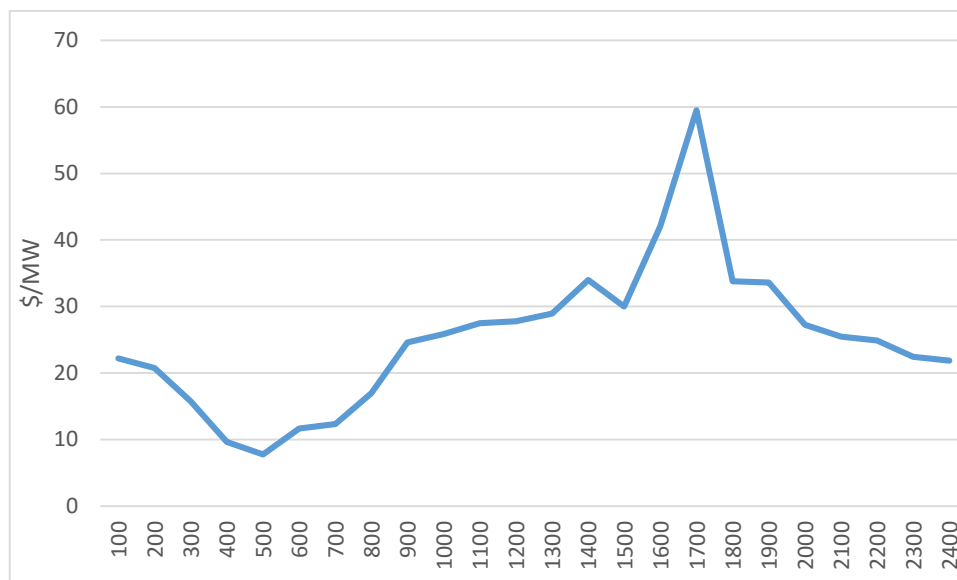


Figure 6: PJM Real-Time Electricity Pricing on August 1, 2015 [10]

At the same time, research into the V2H business model was also investigated. NextEnergy's home demonstration platform, NextHome is a DC connected smart home demonstration platform that includes bi-directional vehicle charging, 3.1 kW of photovoltaic solar panels, a 13.2 kWh lithium ion stationary battery unit, and DC powered lighting and heating systems. The system includes a home energy management system that allow a user to manage real-time electricity generation, loads, and energy purchase decisions or to automate the decision based on available sources of energy. This platform was used to demonstrate and test the resiliency and economic benefit of V2H.

This test demonstrated that a home energy system to control the start and stop charging based on pricing and the battery go into discharge mode during a grid outage. The test was done in DC as a proof of concept to prove that interaction with the home's DC grid was reliable and cost effective. V2H proved economically viable when compared to residential generators designed to provide backup power. In addition, the concept of resiliency was demonstrated during the 2014 ITS World Congress in Detroit and received significant interest from participants in the event[11].

4 Comparing V2X Opportunities

Overall, the testing found that the highest value applications for V2X were demand charge mitigation, V2G, arbitrage, and potentially for V2H applications:

1. Demand charge mitigation: fleet operators and building owners are likely to see significant benefit, but will require fast charging/discharging (tested at 20 kW DC) over only a handful of days to achieve full value without concerns of battery degradation
2. V2G Services: potential for significant value benefit for first million vehicles serving V2G applications, but has potential to significantly impact the battery life since interactions will be daily. Fast charging is not required, but fast discharging is required to minimize the number of vehicles needed to aggregate.

3. Arbitrage: benefit to fleet owners, building owners, and vehicle owners is potentially high in markets with significant differences between peak and off-peak electricity pricing. Fast charging is not required and potential to impact the battery life is comparable to demand charge mitigation
4. Demand response: With larger batteries, it has the potential to offer greater economic value during demand response events, if the vehicles are used for V2B or V2H applications, rather than just shutting off charging (as is typical with current DR programs and EV charging). Fast charging is not required.
5. V2H: Potential to increase value of EV ownership, particularly in markets and homes where renewables and peak pricing is a reality. Additional value in lower cost than backup home diesel or natural gas generators. Fast charging not required and testing found minimal impact on battery life.

Table 2: Summary Implications from V2X Scenarios

	Demand Charge Mitigation	V2G	Arbitrage	Demand Response	V2H
Battery Life Impact	Minimal	High	Moderate	Moderate	Minimal
Value Implications	High value with multiple EVs	High value up to 1 million vehicles	Better with larger battery (>25 KWh) EVs and higher spread TOU pricing	Better with larger battery (>25 KWh) EVs	Better with larger battery (>25 KWh) EVs to serve emotional benefit as backup generator

5 Implications for Smart City Integration

The demonstration of the value proposition of V2X can be further expanded to include an investigation into Internet of Things and smart city integration. As vehicles become more connected it is anticipated that there is an increased opportunity to utilize analytics to more accurately predict when vehicles may be available or may be needed for transportation and therefore unavailable for V2X services. This more connected version of the V2X model is expected to improve the predictability of the amount of power available to the grid.[12]

This research is being contributed to by support for a new Smart City Technology Challenge, an industry sponsored global open source innovation challenge. The Smart City Challenge is seeking the best demonstration ideas that allow for better connected, interactive and data driven solutions that address needs in urban areas. The Smart City Technology Challenge will be open to global innovators with special focus on nurturing ideas from start-up companies and small to medium sized enterprises.

5.1 Car Sharing Fleets Opportunity

Based on the previous V2X research, NextEnergy is proposing that one of the markets that would benefit from V2X services would be car sharing fleets. The number of vehicles needed to bid into the energy markets or arbitrage shifting electricity prices for buildings indicates that a fleet of vehicles would be best to serve the market.

EV sharing with V2X capabilities also addresses the concern of over production during peak times in California and other markets with high penetration of distributed photovoltaic generation. The value assigned to this however is likely to come in the future as TOU pricing is updated to better reflect the new later peak load (4-9pm in California[13]). This change in TOU pricing is being piloted this year in residential rates.

According to data from Metavera[14], the average car sharing engagement is 5-7 miles, which would require approximately 2.1 kWh of capacity (assuming a 300wh consumption per mile). It is unclear how close in time each these engagements may occur, but with low utilization rates that could leave significant capacity for other services. In a typical EV that has 80-120 miles of range, these batteries are typically 22 to 25 kWh. This would leave a lot of capacity per vehicle to use for V2X services after a single engagement.

In that same document, Metavera indicates that car sharing vehicles have average utilization of 35%-45%, which would seem to leave more than half the day for grid or building services. However, data on the usage profile still needs additional research as intuitively it seems that during peak hours would likely be when the vehicles are being used for commuting purposes. Using big data mining of connected, shared vehicles may help to better understand how specific cars within the car sharing programs are getting used and looking for patterns and opportunities to capitalize on the under-utilization for V2B or V2G services to improve the revenue from the vehicle.

6 Conclusion

The greatest value of V2X that NextEnergy found in its comparison studies are recognized in the demand mitigation services for V2B. The demand charges have the lowest impact on the battery life, the greatest financial upside. The ancillary services for the grid present a respectable payback depending on region and the cost of the aggregator service, yet willingness to accept increased battery strain even with financial compensation for it remains a significant unanswered question. As cars become increasingly connected, new research into how different business models could be incorporated into V2X schemes, such as in car sharing, will be needed.

7 About NextEnergy

NextEnergy is a 501(c)(3) non-profit organization established in 2002 to drive advanced energy investment and job creation in Michigan. Located in Midtown Detroit's innovation corridor, NextEnergy serves as a catalyst for advanced energy technology demonstration and commercialization in the state. NextEnergy's mission is to develop and commercialize energy technologies, build and disseminate critical market intelligence, and work with federal agencies on energy strategies, funding priorities, and advise on relevant programs. Since its inception, NextEnergy has helped to attract more than \$1.5 billion of new investment, including over \$160 million generated by programs in which NextEnergy has directly participated.

A map of the NextEnergy 2.8 acre campus in Detroit is shown in Figure 7. The NextEnergy Center is comprised of eight R&D laboratories, an Alternative Fuels Platform, which houses infrastructure for several types of alternative fueling stations (including biodiesel, hydrogen, and electricity), a Stationary Microgrid Power Pavilion, a 120-person seat auditorium, exhibition space, training rooms, and offices.



Figure 7: Overview of NextEnergy Campus and Testing Facilities in Detroit [15]

The testing and validation equipment at NextEnergy used in the V2X tests described in this paper complies with SAE J1772 standards where applicable. Minor modifications to the test platform enable the evaluation of various energy storage and discharging devices. Available testing and validation equipment on-site at NextEnergy includes:

- Four (4) level I/level II AC chargers
- One (1) level II AC chargers
- Four (4) level I DC chargers bi-directional
- Two (2) bi-directional level I/II chargers
- One (1) programmable load bank

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