Beneficial Transportation: How Vehicle-Grid Integration Makes Fleet Electrification a Win-Win

Contents

01 **Executive Summary**

01 **List of Acronyms**

02 **Current State of Fleet Electrification and Distributed Energy Resources**
- *Fleet Vehicle Electrification*
- *The Role and Value of Distributed Energy Resources Today*
- *Meeting Private and Public Sector Climate Goals*

08 **Transforming Fleet EVs into DERs**
- *What is Vehicle-Grid Integration?*
- *Why VGI In the First Place?*
- *VGI Unlocks New Opportunities for Fleets*

11 **Vehicle-to-Grid**
- *Charging and Discharging EVs around Time-of-Use Rates*
- *Demand Response: LoadShifting and Peak Shaving*
- *Ancillary Service Markets*

14 **Vehicle-to-Building**
- *Reducing Grid Dependence During Peak Demand*
- *EV's, Stationary Batteries, and the Perfect Microgrid Ecosystem*

16 **VGI and Battery Health**
- *What is Battery Degradation?*
- *VGI as a Tool to Manage Battery Health*

18 **Analysis of EV Charge Management Methods**
- *Unmanaged, Managed, and Bidirectional*
- *Cost Comparison*
- *Payback Period*
- *Battery Life Comparison*
- *Emissions*

22 **Energy Equity and Vehicle-Grid Integration**
- *Environmental Justice and Energy Equity*
- *Lessening Dependence on Fossil Fuel Peaker Plants*
- *Distributed Energy Resources as a Localized Energy Solution*
- *Vehicle-Grid Integration in Various Communities*
- *Improved Local Air Quality and Social Considerations*
- *Equitable Electrification*

26 **VGI As Resiliency Solution**
- *The Value of Resiliency*
- *Wildfires*
- *Extreme Weather Events*

29 **Ideal Applications for VGI Technology**
- *Predictable Schedules and Routes*
- *Sufficient Battery Capacity*
- *Available During Peak Energy Demand*
- *OEMs and Bidirectional Charging*
- *Other Potential Fleets*

32 **Recommendations**
- *Recommendations for Fleet Owners*
- *Recommendations for Utilities*
- *Recommendations for Local Governments,Public Agencies, and Policy-Makers*
- *Recommendations for Transit Managers*

34 **Conclusion**

35 **Acknowledgements**

36 **Works Cited**

Executive Summary

As electric vehicle (EV) adoption amongst public and private fleets increases, meeting the energy needs of these vehicles with clean electricity is imperative to the transition to a carbon-free future. Because of the variable and intermittent nature of renewable energy technologies, energy storage will be essential. Today's grid has been built on the concept of constantly available, stand-by power; tomorrow's grid must capture and store energy when the sun doesn't shine or when the wind is still.

At scale, vehicle-grid integration, or VGI, has the potential to balance energy demand by storing electricity in the vehicle's battery during the day when solar is widely available, and releasing it back to the grid during peak evening demand periods. Distributed energy resources (DERs), VGI technology, and electrification of medium- and heavy-duty fleet vehicles have the capacity to reshape the future of the sustainable transportation sector—as well as the power grid—for the better.

When vehicle batteries interact with the grid in a two-way flow of energy, EV fleets can serve the dual purposes of mobility and as a DER. Not only this, but EV fleets can act as sources of additional revenue by selling their stored energy back onto the grid. This can lower overall cost of EV ownership and reduce payback periods for the transition from internal combustion engines. When combined with rooftop solar or stationary batteries, the technology can play a significant role in shaping localized energy solutions.

One unique application of VGI services is vehicle-to-building (V2B) where vehicles discharge energy to individual buildings rather than the grid. V2B allows projects to bypass some permitting requirements that are required for V2G interconnections. By managing the EV battery with VGI when not in use for its primary function, intelligent battery cycling can manage the battery's state of charge to minimize degradation risk while also providing these services.

VGI also can extend the benefits of electric vehicles to more members of the community, lessen dependency on fossil fuel peaker plants, which only come online when demand is high, and provide energy security in areas that are more vulnerable to power outages or other climate impacts. By providing supplemental energy storage during peak demand, EV batteries can smooth high demand periods and lower utility costs. Energy from EV fleets can also be used to power critical facilities in emergency situations or provide invaluable grid services during extreme weather events. Respective fleet managers should ensure that the distribution of environmental and economic benefits of VGI are shared equitably among the population.

The feasibility of integrating fleet EVs with the grid depends on many factors. Although fleet type, duty cycle, EV and battery compatibility are all important determinants, feasibility is also determined by other factors that vary geographically. Transmission organizations, system operators, state regulators and utility companies with VGI project experience should transfer their learnings to design better policies that incentivize project development. VGI can provide a wide-array of benefits for fleets, utilities, governments, people and society depending on their individual values, whether that is resiliency and cost savings, clean energy and storage, or simply reliable transportation and clean air.

List of Acronyms

BEB - Battery Electric Bus

BEV - Battery Electric Vehicle

BMS - Battery Management System

DER - Distributed Energy Resource

EV - Electric Vehicle

EVSE - Electric Vehicle Supply Equipment

ICE - Internal Combustion Engine

OEM - Original Equipment Manufacturer

SOC - State of Charge

TOU - Time-of-Use

V2G - Vehicle-to-Grid

V2B - Vehicle-to-Building

VGI - Vehicle-Grid Integration

Current State of Fleet Electrification and Distributed Energy Resources

At the beginning of 2021 WSP sought to investigate emergent technologies to bolster future efforts in ZE technologies, and explore the capabilities of fleet vehicles to interact with the grid for greater resiliency and economy-wide decarbonization. Using its considerable ZE expertise, WSP first identified vehicle-to-grid (V2G), and then more broadly vehicle-grid integration (VGI), as keys to unlocking the true value of electrified fleet vehicles. This white paper focuses on the numerous benefits that are realized by the integration of fleet vehicles with the grid and other localized distributed energy resources (DERs). Before diving into the defining characteristics of vehicle-grid integration, this section provides a background on the status of fleet electrification and DERs, and public and private sector decarbonization efforts today.

With experience developing more than 100 zero-emission (ZE) fleet projects worldwide, WSP has developed a global understanding of the unique challenges of the ZE transitions while forging creative and innovative solutions to confront them. WSP offers planning, engineering and project management services to fleet owners and operators that include:

- Performing feasibility studies and performance modeling of fleets to determine technology compatibility with current operations.
- Assessing the outlook on battery technology to provide future-ready transition procurement schedules.
- Developing charging strategies with consideration to yard management, operational efficiency, minimal disruption to the legacy fleet and capital investments.
- Coordinating utility upgrades required based on the charging management plan.

Fleet Vehicle Electrification

Fleet vehicles are responsible for the economic vitality of cities: they transport goods and services and support jobs throughout all industries in the United States. Although the upfront costs of electric fleet vehicles are typically more than internal combustion engine alternatives, when factoring in external health costs such as air quality and noise, combined with the climate costs of emissions, **the total cost of ownership of electric vehicles (EVs) is less than existing diesel alternatives today.**[1]

High capital costs for EVs are generally driven by lithium-ion battery prices, but with EVs becoming more ubiquitous, battery costs are decreasing rapidly. The transition to EV fleets is also supported by state, local and federal incentives. Even with increasing funding support, decreasing battery costs, and improving technology, the costs of electrification can still be out of reach for many organizations.

Distributed energy resources are any physical or virtual technology that generates, stores or manages electricity on the distribution grid, such as rooftop solar, stationary batteries, demand response (load shifting and shaping), energy efficiency (technologies that reduce energy use/intensity), and ***electric vehicles.***[2]

1 Transitioning to Zero Emission Technology: A guide to ensuring a smooth transition towards future-ready vehicles, WSP, 2021. https://www.wsp.com/-/media/Insights/Global/Documents/WSP--Zero-Emission-White-Paper.pdf
2 Behind the Meter: Distributed Energy Resources Capabilities Guide, Smart Electric Power Alliance, 2016. https://sepapower.org/resource/distributed-energy-resources-capabilities-guide/

The increased electricity required for fleet EV charging can also lead to expensive utility upgrades which can be passed to the operator. Utility infrastructure upgrades are not only costly, but time consuming, often requiring years to complete. Added expenses may be realized for fleet operators who lack a detailed understanding of their electricity rate structure and do not manage fleet EV charging around utility rates. Fleet managers must find a way to further minimize the costs of electrification in the short term, while continuing to pursue electrification as part of their plans to reduce emissions.

Fleet electrification serves as a critical step to addressing emissions throughout the economy, but it can also have positive impacts outside the organization. Traditional fossil fuel fleet vehicles have a disproportionate impact on transportation emissions and air quality: medium- and heavy-duty vehicles represent 5% of all road vehicles but account for 30 percent of emissions.[3] Electrification is a critical component to reducing transportation tailpipe emissions, but it can also lead to unintended consequences for the electric power grid.

As fleet EV adoption rates increase over the next decade, their additional demand for electricity from the grid will require utilities and grid operators to source new generation to meet the increased demand. **The system-level consequences of not integrating fleet vehicles with the grid as they transition to electric include an over reliance on fossil fuel generation, and a misuse of variable renewable energy resources like wind and solar.** One way in which fleets can overcome the cost and energy challenges that come with fleet electrification is to invest in onsite generation and storage and integrate technologies that actually transform their fleet into a distributed energy resource.

3 Global EV Outlook 2021: Accelerating ambitions despite the pandemic, International Energy Agency, 2021. https://www.iea.org/reports/global-ev-outlook-2021

The Role and Value of Distributed Energy Resources Today

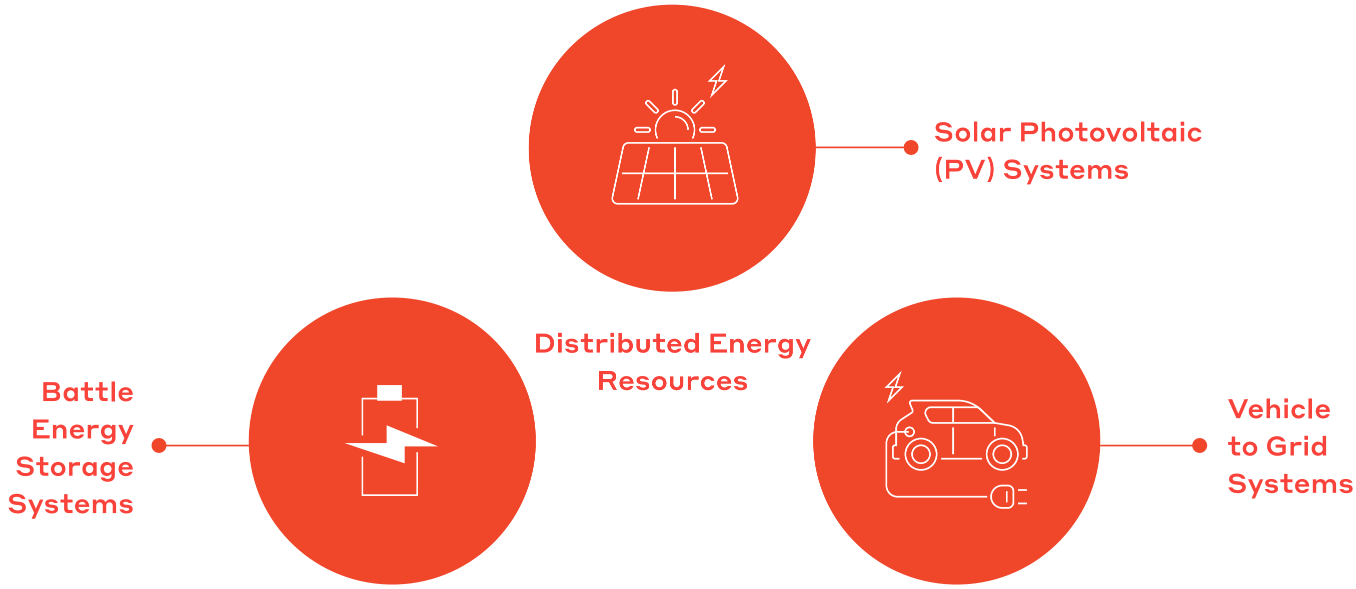
Unlike centralized large-scale power generating facilities which connect to the high voltage transmission networks, DERs are small and connect to medium or low voltage distribution grids at residential, commercial and industrial buildings.

Recent modeling has shown that DERs not only complement existing large scale renewable energy resources, they enable more to be built, and together they can save money for the overall system.[4] First, by placing DERs closer to consumers' electricity usage, DERs defer transmission and distribution grid upgrades.[5] DERs also integrate well with variable centralized utility-scale renewable energy resources because they make the demand-side a controllable asset. Rather than controlling electricity generation to meet demand, as has been done for over a century, DERs offer flexibility and control of electricity demand to meet the available electricity supply (generation).

EVs can act as distributed energy resources, where they can be charged during times of low demand and low costs, and be discharged back to the grid during times of high demand.

4 Clack, Christopher T M, Choukulkar, Aditya, Coté, Brianna, and McKee, Sarah A., Why Local Solar for All Costs Less: A New Roadmap for the Lowest Cost Grid, Vibrant Clean Energy, LLC, 2020. https://www.vibrantcleanenergy.com/wp-content/uploads/2020/12/WhyDERs_TR_Final.pdf

5 Final Report of the California Joint Agencies Vehicle-Grid Integration Working Group, California Public Utilities Commission DRIVE OIR Rulemaking (R. 18-12-006), 2020. https://gridworks.org/wp-content/uploads/2020/09/GW_VehicleGrid-Integration-Working-Group.pdf



If fleet EVs are treated solely as electricity users, and electrification projects do not integrate other distributed energy resources such as solar and storage, the increased demand for electricity will add significant costs to fleet electrification projects. For fleet owners specifically, DERs, including fleet EVs with large battery capacities, can provide an alternative to costly electrical upgrades by better utilizing and managing demand, while also adding resiliency and reliability.[6] EVs can act as distributed energy resources, where they can be charged during times of low demand and low costs, and be discharged back to the grid during times of high demand. Through optimized utilization of existing grid assets and cost savings in the form of reduced electricity costs, the benefits of integrating EVs with the grid are realized by all.[7] This especially includes public and private sector fleet operators that in addition to having vehicle electrification goals, are also pursuing aggressive emissions reductions and sustainability goals.

Meeting Private and Public Sector Climate Goals

There is more pressure than ever on corporations to create meaningful and actionable sustainability policies. Businesses of all sizes are starting to take note of the shift in priorities among younger generations to greener business practices, and adjust accordingly.[8] With influential companies like private equity firm BlackRock taking a firm stance on the importance of climate action, it is apparent that the private sector is making a low carbon economy a higher priority.[9] Companies searching for a way to bolster their efforts in sustainability can implement distributed energy resources in their projects as a way to provide clean energy resources, and lead the electrification transition. Decarbonizing transit or freight operations is a sure way to reduce emissions, and VGI can take this a step further by creating additional revenue streams and even putting energy back onto the grid. As there are currently no universal metrics for analyzing corporate sustainability, companies are looking for ways to stand out amongst the "net-zero" crowd.

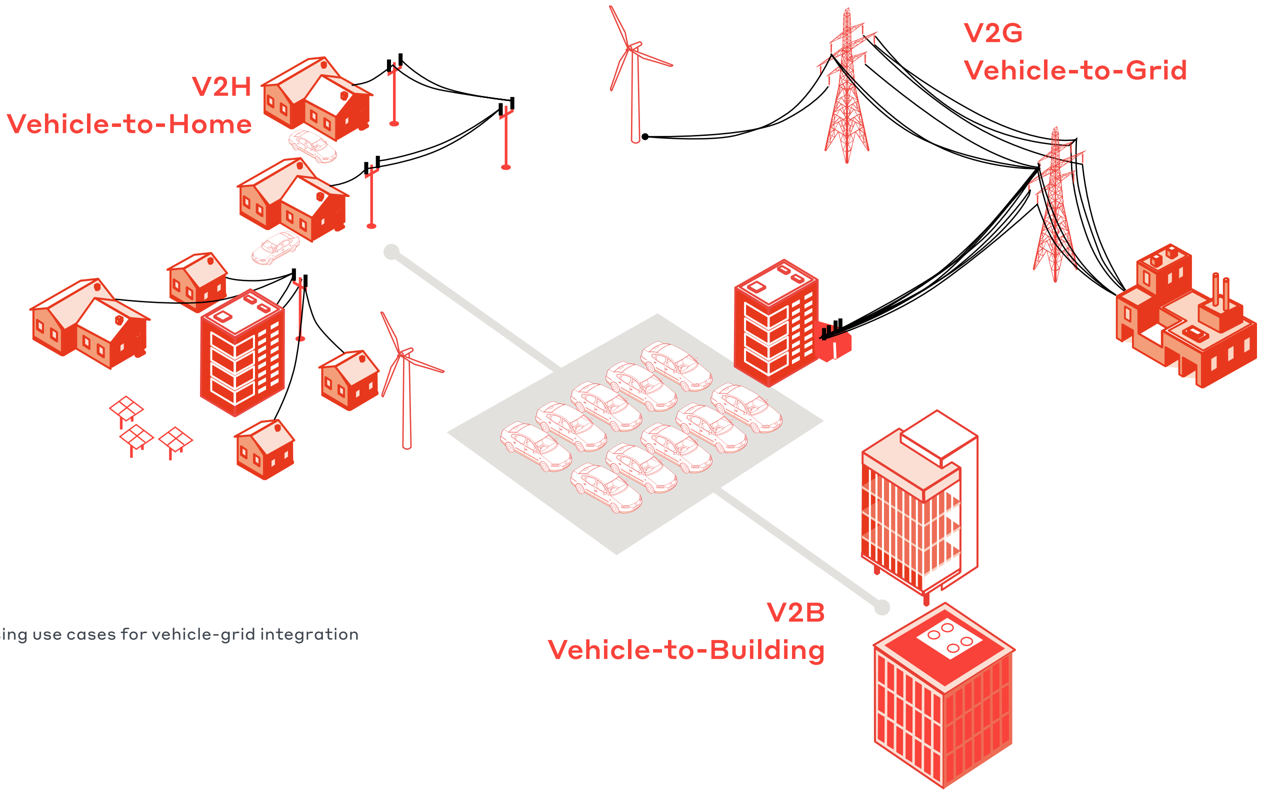
6 The Role of DERs in Today's Grid Transition, Gridworks and Gridlab, 2018. https://gridlab.org/works/role-of-distributed-energy-todays-grid/
7 California Heavy-Duty Fleet Electrification Summary Report, Environmental Defense Fund, 2021. http://blogs.edf.org/energyexchange/files/2021/03/EDF-GNA-Final-March-2021.pdf
8 GreenPrint Survey Finds Consumers Want to Buy Eco-Friendly Products, but Don't Know How to Identify Them, Business Wire, 2021. https://www.businesswire.com/news/home/20210322005061/en/GreenPrint-Survey-Finds-Consumers-Want-to-Buy-Eco-Friendly-Products-but-Don%E2%80%99t-Know-How-to-Identify-Them
9 Fink, Larry, A Fundamental Reshaping of Finance, 2020. https://www.blackrock.com/ca/investors/en/larry-fink-ceo-letter

Currently, with bundled renewable energy credits (RECs), companies can offset their energy usage and carbon emissions and be considered net-zero, even if they are technically powered by fossil fuels. While these offsets are successful in boosting company image, they do little to bring additional carbon-free resources online. Environmentally conscious consumers are beginning to ask more from the companies they are supporting. As an alternative to net-zero, some corporations are focusing efforts on a new strategy called "true zero," which "focuses on purchasing round-the-clock clean energy each hour and on each regional grid where electricity consumption occurs."[10] For example, the Google 24/7 Carbon Free Energy project aims to provide all of Google's global facilities with 100% carbon-free electricity by 2030.[11] Depending on fleet schedules, EV batteries can serve as distributed energy resources themselves and add to this carbon-free electricity production. Due to their intermittency, other distributed energy resources such as rooftop solar will need supplemental forms of energy to meet these ambitious climate goals. As more of the private sector begins the transition to carbon-free, fleet operators should be analyzing the role their EV batteries can play in providing energy storage support.

In the public sector, on the other hand, one of the main drivers to transition fleet vehicles from diesel to electric are progressive policy mandates.[12] According to the Natural Resource Defense Council, one in three people in the United States now live in communities with 100% clean energy targets, and 37 states have some form of clean energy mandate as of 2020.[13] Decarbonization of this magnitude will require creative energy storage solutions to fill in for the gaps renewable power cannot cover. If municipalities can tap into the available storage in their new or existing electric fleets, they will have additional resources to meet their energy targets. Allowing this added power to be for community benefit shares the emission reduction and air quality benefits among local populations. Cities that successfully transform their EVs to DERs will create new opportunities for revenue, as well as forging a path to a more resilient future energy grid. Through federal funding and public-private partnerships, cities can enable their electrified fleets to provide multiple community co-benefits. As more climate action policies are written into law, there will be increased incentive for local agencies to find energy solutions that help keep the power on for homes and businesses. Investment in DER technology can play a critical role in community resiliency, stronger energy security, and supplement clean power. Early adopters of this technology will be considered innovative, and benefit both economically and environmentally.

10 Asad, Harun, Are We Pivoting From Net Zero To True Zero?, Environment Leader, 2021. https://www.environmentalleader.com/2021/06/are-we-pivoting-from-net-zero-to-true-zero/
11 Operating on 24/7 Carbon-Free Energy by 2030., Google, 2021. https://sustainability.google/progress/energy/
12 Interview with Danny O'Connor, City of Boulder Transit Manager, 2021.
13 Race to 100% Clean, National Resource Defense, Council, 2020. https://www.nrdc.org/resources/race-100-clean#:~:text=More%20than%20150%20cities%20and,that%20target%20through%20varying%20methods

Transforming Fleet EVs into DERs



Showcasing use cases for vehicle-grid integration

What is Vehicle-Grid Integration?

Vehicle-grid integration, or VGI, is the integration of EVs with the grid through hardware, software and communications systems that utilize the battery as an energy storage asset to dispense energy back to the grid. VGI technology and intelligent management of EVs as DERs not only optimizes charging schedules to reduce the impact of additional electricity demand for EVs, it enables EVs to be an energy asset to fleet managers and their organizations.

Why VGI In the First Place?

Transitioning fleets to electric and integrating with the grid means that when the vehicles are not in use, they become localized energy storage systems. For example, a single transit bus battery can hold upward of 500kWh of stored energy, enough energy to power 17 average U.S. households for a day.[14] That same bus can also provide community energy resiliency during a power outage with enough energy to provide nearly 2 hours of backup power for an average U.S. supermarket.[15] Similarly, there are 480,000 school buses in the U.S. that sit idle for long periods throughout the year as well as long periods of each school day and weekends.[16] Assuming a 120kWh battery capacity for each electric school bus, that's enough storage to power 5,400 homes for a year. **From a power generation perspective, if each electric bus was connected to a 20kW bidirectional charger, that would supplant 9,600 MW onto the grid, more than the total natural gas peaker plant generation capacity in Boston and Los Angeles combined.**[17] The benefits of integrating fleets with the grid are seen both far and wide, unlocking new opportunities previously out of reach.

14 How much electricity does an American home use? Energy Information Administration. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3
15 Supermarkets: An Overview of Energy Use and Energy Efficiency Opportunities, ENERGY STAR, https://www.energystar.gov/sites/default/files/buildings/tools/SPP%20Sales%20Flyer%20for%20Supermarkets%20and%20Grocery%20Stores.pdf
16 American School Bus Council. http://www.americanschoolbuscouncil.org
17 Phase Out Peakers. Clean Energy Group. https://www.cleanegroup.org/ceg-projects/phase-out-peakers/

VGI Unlocks New Opportunities for Fleets

For fleet operators, whether school districts or public transit operators, integrating EVs with the grid or with a building opens up opportunities to save money, increase resiliency, and earn additional revenue to offset the upfront capital costs associated with transitioning to electric.

At the most basic levels of integration, VGI can manage fleet vehicle charging around utility tariffs, controlling things like when EVs charge and how fast to minimize the necessary peak demand required for fleet EV charging. Further integration would allow fleets with other DERs to optimize onsite energy usage with a fully connected generation and storage system to significantly reduce energy costs and minimize the amount or extent of utility upgrade costs incurred to supply the necessary power. VGI can also enable the EVs to discharge power back to another source, such as an onsite building (known as vehicle-to-building, or V2B) to offset building energy usage and avoid excessive utility demand charges.

Through VGI, EVs can also discharge power back to the grid (known as vehicle-to-grid, or V2G) to provide various grid services. Where electricity is deregulated and energy markets exist to compensate for grid services, **VGI-enabled EVs can provide services for the grid and generate a new source of revenue for fleets.** Alternatively, in regulated electricity markets, fleet EVs can participate and earn revenue in demand response programs such as peak shaving and load shifting. V2G not only provides benefits to fleet operators, the grid benefits from the services provided by EVs. **For grid operators and utilities, fleets with VGI-enabled EVs can help make the grid cleaner by better utilizing renewable energy resources, preventing the addition of new fossil fuel generators, and accelerating the transition to a carbon free economy.**

WSP has identified **Vehicle-to-Building** and **Vehicle-to-Grid** as the two most important applications of bidirectional charging and VGI for fleet EVs, both of which are described in detail below.

18 Brown, Stephen, Pyke, David, Steenhof, Paul, Electric vehicles: The role and importance of standards in an emerging market, Energy Policy, 2010.

How is EV charging infrastructure different in VGI?

Specific hardware, software and communications systems are required to enable an EV to send power bidirectionally and fully integrate with the grid and other resources. There are three critical components that VGI systems must integrate with to maximize potential value and ensure fleet availability for providing transportation services: the EV battery management system (BMS), the physical EV charging equipment (electric vehicle supply equipment, or EVSE), and the grid.

At a high level, the BMS in an EV is responsible for monitoring energy flow into and out of the battery to determine the state of charge. The critical information pertaining to the status and health of the EV battery is then used by the BMS to maintain operations within manufacturer limits. VGI-enabled charging equipment is required to connect an electric vehicle to the grid or building with physical hardware (the EVSE itself), software, and communications systems. In VGI applications, the EVSE has two primary functions: to manage power flows to and from the EV, and to manage the communication network between the BMS, EVSE and the grid. (Note that often DERs such as EVs may not communicate directly with the grid, but rather other intermediaries such as aggregators and DER or general energy management systems. However, the process is generally the same and the differences do not impact the high-level explanation below.)

Manage Power Flows

For bidirectional DC power flow, the inverter in the EVSE must convert between AC and DC power bidirectionally. Conversely, in bidirectional AC, the onboard inverter in the EV must convert between AC and DC power bidirectionally. Many EV OEMs, including medium- and heavy duty EVs, offer VGI-capable vehicles and have experience participating in VGI pilot projects across the world. Both AC and DC charging are common amongst EV and EVSE OEMs.

Manage Communications

In practice, a VGI-enabled EVSE communicates with the grid by receiving signals to transmit information needed for real-time decision making, such as rates and tariff prices, the current carbon intensity of grid generation resources, when there may be excess renewable energy, or calls for specific grid services. From the EV, the BMS sends signals to the EVSE like the current state of charge, the charging time needed to full charge, and the time until the EV is needed for primary mobility services. The EVSE and/or accompanying DER management system then determines the next steps: charge or discharge, at what rate, and for how long, all the while continuously receiving information from both the grid and the EV.

The adoption of open source industry-wide standards (such as OpenADR 2.0b and Open Charge Point Protocol, or OCPP) for the entire ecosystem of communication between the EVSE, BMS, and the grid are critical to enabling the adoption of the technology, and optimizing its capabilities and its value for fleets. Standards ensure cross-compatibility with different manufacturers, electric utilities, and market regulators. Specifically for VGI-enabled fleet electrification, standards for the infrastructure and communications will make scale up and adoption more feasible and cost effective.[18]

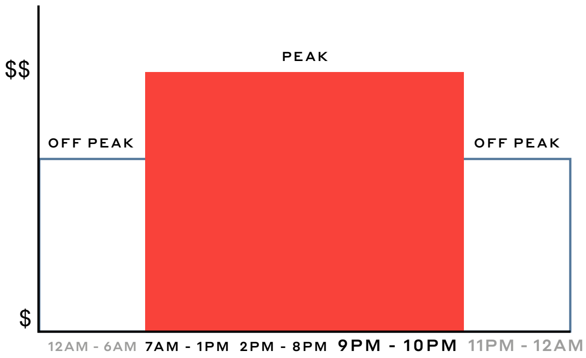
Vehicle-to-Grid

The value of V2G systems for EVs is directly tied to the market's ability to put systems in place to aggregate multiple EVs into a larger network, which then offers more generation and storage capacity to the grid as a DER.[19] EV fleets are an ideal candidate for V2G because of their natural co-location and ability to offer bidirectional services as a single entity. For example, EVs can provide benefits to markets with high renewable energy resources by supplying backup power when intermittent renewable energy generation is low, and charging during times when there is excess renewable energy.[20] This result could increase the overall efficiency and productivity of renewable generation, requiring less investment and build-out of these resources, and decarbonizing the grid in less time and with less capital investment.

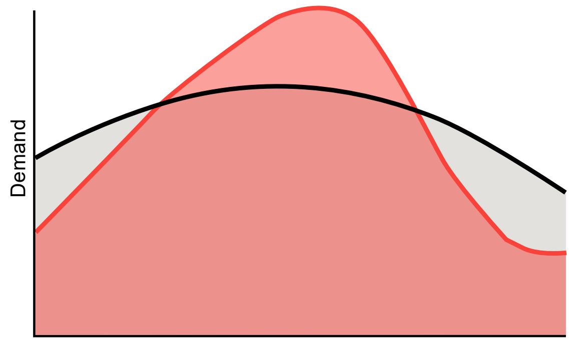
Charging and Discharging EVs around Time-of-Use Rates

Time-of-day dependent rate tariffs, such as time-of-use (TOU) rates and dynamic tariffs offered by utilities, allow for managed charging and discharging of electricity from fleet EVs when idle. VGI-enabled fleet EVs optimize charging management around utility TOU rates to minimize costs and maximize revenue. Optimizing around utility TOU rates can provide significant cost savings for fleet operators if done responsibly and with proper charge management systems taking into consideration the long-term battery health and overall fleet availability. Opportunities for optimizing around TOU rates do vary throughout the US as some utility companies still do not offer dynamic rate tariffs, and even if they do the schedule may not completely align with the fleet's duty cycle.[21]

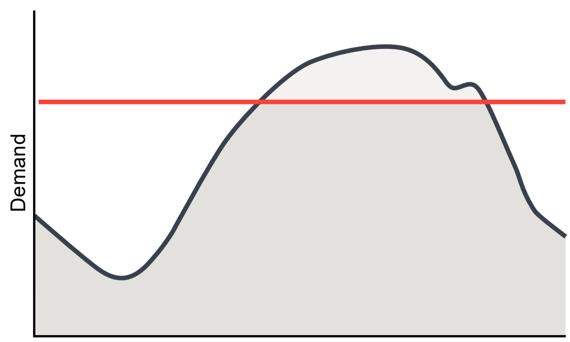
19 Guille, Christophe, and Gross, George, A conceptual framework for the vehicle-to-grid (V2G) implementation, Energy Policy, 2009. https://doi.org/10.1016/j.enpol.2009.05.053
20 Nelder, Chris, Newcomb, James, and Fitzgerald, Garrett, Electric Vehicles as Distributed Energy Resources, Rocky Mountain Institute, 2016. http://www.rmi.org/pdf_evs_as_DERs
21 Residential Electric Vehicle Rates That Work: Attributes That Increase Enrollment, Smart Electric Power Alliance, 2019. https://sepapower.org/resource/residential-electric-vehicle-time-varying-rates-that-work-attributes-that-increase-enrollment/



Time-of-use charging rates for a single day



Load Shifting



Peak Shaving

Demand Response: Load Shifting and Peak Shaving

Load shifting is when both the rate (faster or slower charging) and the time (now versus sometime later) that an EV battery is charged or discharged can be manipulated to accommodate demand for electricity on the grid. This is a type of demand response service that is offered by utilities, and that fleet EVs are prime candidates to participate in. This type of demand response service is needed because of the increased generation of electricity from weather-dependent renewable sources that cause electricity generation to fluctuate throughout the day. On top of the intermittency of renewables, the demand for electricity fluctuates by time of day, decreasing when people are asleep and increasing at the end of the day when people are returning home. EVs can be used as a flexible and dispatchable resource to manage changes in demand and supply throughout the day when the vehicle is not in use.

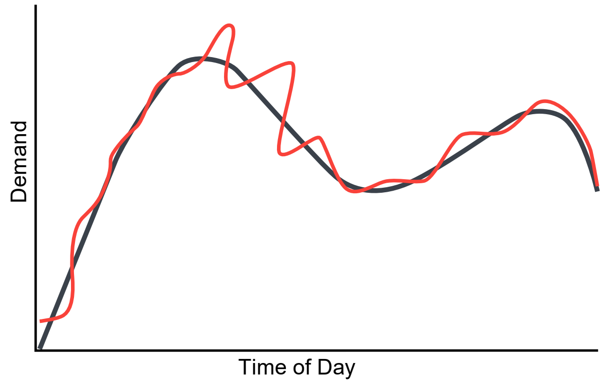
By not charging during times of high demand and instead during "shoulder" times, load shifting can reduce the strain or burden placed on the grid. Not only is this beneficial for utilities and the grid, but also for fleet operators themselves, since utility TOU rates and other rate tariffs are cheapest during times of low demand. These times of low rate and low demand typically occur during the middle of the day and overnight, which coincides with high renewable energy generation. **Ultimately, by shifting load away from peak demand times, a fleet can decrease energy costs and charge with electricity generated with a higher share of renewables.**

Due to their intermittency, renewable energy resources require a dispatchable resource to fill the gaps when both solar, wind and other zero-emission resources are not sufficient. Electricity generation from solar energy peaks during the middle of the day and decreases around the same time that electricity demand increases in the late afternoon and evening. Electricity rates during this time increase due to expensive fossil fuel plants that are only needed to come online for a short duration each day to meet the increasing demand. These plants offer value because they are highly dispatchable, meaning they can supply electricity on demand as needed by the grid. However, EV fleets that have optimized charging during times of low demand, low cost, and high renewables can also provide dispatchable energy to meet the increasing demand on the grid. The result is less dependency on fossil fuel generation, and an additional revenue opportunity for fleet operators all while their fleet sits idle and their availability for service is uncompromised.[22]

22 Oldfield, Frank, Kumpavat, Krunal, Corbett, Rebecca, Price, Andrew, Aunedi, Marko, Strbac, Goran, O'Malley, Cormac, Gardner, Darren, Pfeiffer, Dominik, and Kamphus, Jan-Torben, The Drive Towards a Low Carbon Grid: Unlocking the value of vehicle-to-grid fleets in Great Britain, Nissan Motor GB, E.ON Drive and Imperial College London, 2021. https://www.eonenergy.com/content/dam/eon-energy-com/Files/vehicle-to-grid/The%20Drive%20Towards%20A%20Low-Carbon%20Grid%20Whitepaper.pdf

Ancillary Service Markets

Ancillary services procured in deregulated energy markets are offered by grid operators to provide standby capacity to be used on demand as needed to maintain grid stability.[23] For example, frequency regulation services (services that maintain the frequency of AC power grids) are required to manage the constant instantaneous fluctuation of demand and supply on the grid. Grid operators offer frequency regulation markets for resources that are able to provide flexibility and correct these offsets in real time. Like stationary batteries, EVs are excellent candidates to participate in these services because they are able to rapidly respond to grid signals and provide quick and short-term power supplies. **In most markets, frequency regulation participation is compensated by the capacity that is dedicated for the service, not the actual energy provided, so a fleet of EVs with large aggregated battery capacities can thus provide significant revenue to fleet operators for minimal use of the battery without compromising mobility range.**



Frequency Regulation

23 Olson, Arne, Hull, Sanderson, Ming, Zach, Schlag, Nick, and Duff, Charlie, Scalable Markets for the Energy Transition: A Blueprint for Wholesale Electricity Market Reform, Energy and Environmental Economics, Inc., 2021. https://www.ethree.com/wp-content/uploads/2021/05/E3-Scalable-Clean-Energy-Market-Design-2021.05.25.pdf

Vehicle-to-Building

A unique application of VGI services is to discharge energy directly to a building, rather than onto the grid. This can bypass some permitting requirements that are required for V2G interconnections (which can take a majority of the project development time), which allows the EV operator to choose exactly how they want to utilize their EV battery. This is an interesting use of the technology, as it provides multiple benefits to the EV operator, assuming they own/ operate the connected building as well. One of the advantages of V2B is reduced peak demand charges, given that these charges can be extremely high for buildings that use large amounts of energy. Two V2B specific benefits are expanded on below:

Reducing Grid Dependence During Peak Demand

As stated above, demand charges for buildings can be a majority of their electricity bill, and are increasing 8% each year.[24] Ideally, buildings would have the potential to greatly reduce their peak demand loads, depending on how large the integrated fleet is. However, there can still be realized benefits for smaller-sized fleets. In interviews with the Director of Building Operations for the Alliance Center in Denver, he described a V2B pilot project that is in the beginning stages. Already, the building has seen reduced utility bills through demand management practices.[25]

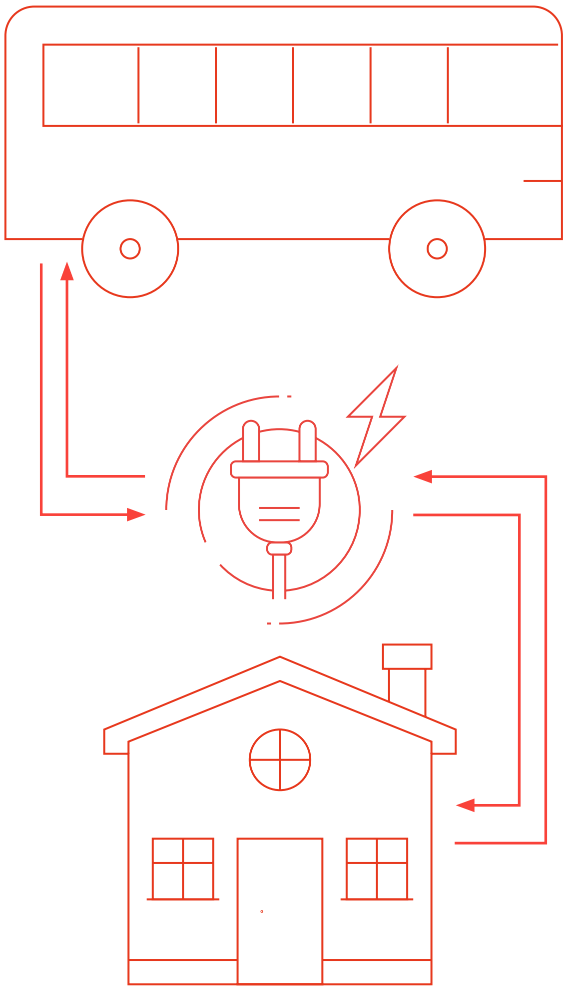
24 Demand Charges Explained, DemandQ, 2021. https://www.demandq.com/demand-charges-explained
25 Interview with Christopher Bowyer, Alliance Center Director of Building Operations, 2021.

EV's, Stationary Batteries, and the Perfect Microgrid Ecosystem

Some types of buildings like hospitals, laboratories, and universities have strict requirements for backup generation. Typically, these are diesel powered, but the steady reduction in battery costs have pushed stationary batteries into the market for backup power and resiliency purposes. A unique element of V2B projects is that they are inherently backup power, and therefore reduce the need for stationary battery requirements. Essentially, an EV battery can be utilized for two different services with only one battery. They can still serve their intended purpose of being a transportation vehicle, while also providing energy storage and discharge services while not being used for transportation. Given the continued supply chain issues with current battery materials (mining and processing), reducing the need for more battery production has global benefits.

In an ideal scenario, a fleet of EVs would be integrated with stationary batteries, buildings, and onsite DERs to create a microgrid that would be self-sufficient from the grid. If this microgrid ecosystem has excess generation, it could send that energy back to the grid for additional revenue. On the other hand, if grid infrastructure were to fail, this ecosystem will be able to continue producing and using its own electricity.

One emerging market that could reduce the cost of stationary batteries is coming from the secondary useful life of EV batteries. Currently, an EV battery is deemed "dead" or out of warranty after it dips below 60-80% of its initial usable capacity, depending on the manufacturer. Of course, these batteries still work fine for storage purposes; they just lack the capacity to perform transportation operations. California is incentivizing the use of these secondary batteries, which should be analyzed for projects in this area.



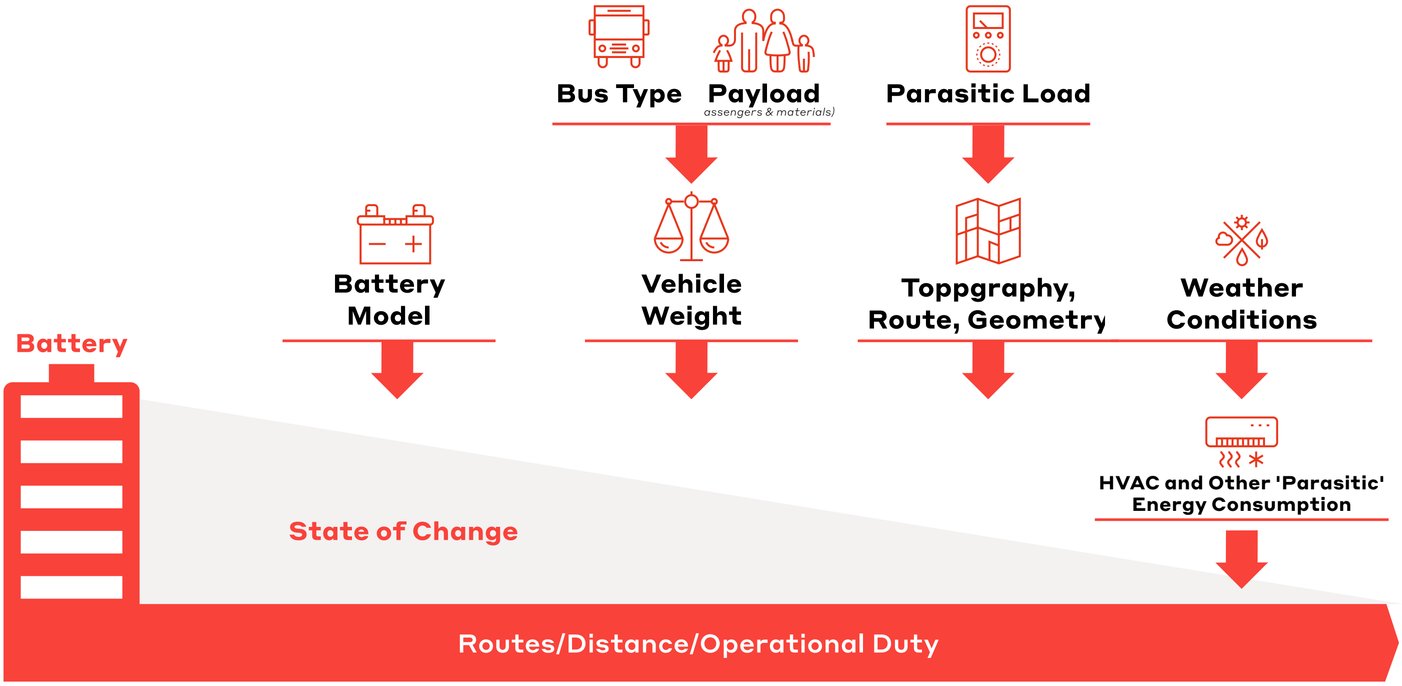
VGI and Battery Health

Electrification requires a paradigm shift in how fleet operators manage and service their fleets. In an EV, the battery is now the most important component, and it is possible to mismanage, misuse, and decrease the usable life of the battery. EV batteries will degrade over time, but the speed of degradation depends upon battery management and operation practices.[26]

What is Battery Degradation?

Battery degradation is the loss of usable capacity in a battery, which reduces the amount of energy that can be stored. For EVs, the direct consequence of battery degradation is less range for mobility. Lithium-ion batteries degrade through multiple mechanisms: over time (calendar time, independent of how the battery is used), the frequency of the duty cycle (how often it is used), the charging rate (how fast the EV is charged - and discharged), and the depth of charge and discharge (how low or high the state of charge in a battery is left to sit, and for how long).

26 Wang, Dai, Coignard, Jonathan, Zeng,Teng, Zhang, Cong, and Saxena, Samveg, Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services, Journal of Power Sources, 2016. https://doi.org/10.1016/j.jpowsour.2016.09.116



Shows factors that impact battery state of charge

Charging and discharging energy from the battery without controls in place to maintain battery health will lead to excessive battery degradation and reduce the usable life of the EV for mobility purposes. The risk of increased battery degradation can result in an increased total cost of ownership; however, there may be economic incentives from grid services that can offset this cost. For fleets wishing to pursue VGI for active bidirectional charging, the costs to battery degradation should be included in economic assessments up-front to ensure full transparency.

VGI as a Tool to Manage Battery Health

By managing the EV battery with VGI when not in use for its primary function, modeling has shown that the primary mechanisms responsible for battery degradation can actually be reduced. **Intelligent battery cycling can manage the battery's state of charge to minimize degradation risk while also providing grid or other services.**[27] An intelligent and integrated management system with sufficient technology, infrastructure, and communications can mitigate the effects of unmanaged charging and discharging on battery degradation by setting limits on when an EV is available to the grid.[28] The results from the various studies and modeling are being used today to prescribe how VGI systems make these decisions in real time to ensure that batteries are being dispatched economically, weighing both the costs and benefits of using the battery for uses beyond mobility.

27 Battery Health and V2G, Nuvve, 2021. https://nuvve.com/battery-health/
28 Uddin, Kotub, Dubarry, Matthieu, and Glick, Mark B., The viability of vehicle-to-grid operations from a battery technology and policy perspective, Energy Policy, 2018. https://doi.org/10.1016/j.enpol.2017.11.015

Analysis of EV Charge Management Methods

There are three different approaches to charging a fleet of EVs, which creates significant differences in cost, payback period, battery life, and related emissions during the lifetime of the vehicles. This section aims to define these charging methods and describe the disparities that exist between them.

When comparing the different levels of charging in terms of cost, it should be clear that unmanaged charging will be the highest, primarily due to time and period-based demand and energy pricing.

Unmanaged, Managed, and Bidirectional

The first approach, which is the most common, is called **unmanaged charging**. This charging method is when a fleet operator charges their EVs when needed, regardless of associated economic and environmental impacts. If the fleet returns to the depot and begins to charge during peak energy demand times, this will result in not only an increase in carbon emissions from generation, but also will likely yield an increase in electricity rates.[29] These burdens intensify with a larger fleet of vehicles, which is why EV fleet operators should avoid any instance of unmanaged charging.

29 Trabish, Herman K., Rate Design Roundup: Demand Charges vs. Time-Based Rates, Utility Drive, 2016. https:/www.utilitydive.com/news/rate-design-demand-charges-time-based-rates/419997/

	Unmanaged Charging	Managed Charging	Biodirectional Charging
Cost	Incurs Demand Charging	Does incur Demand Chages	- Avoids Peak Demand and Pricing - Creates Revenue
Payback Period	No decreaded costs or additional revenue	Reduced charging costs	- Reduces TOC - Allows for revenue generation for useful life of EV battery
Battery Life	Extreme high and low SOC can strain battery	Proper management can reduce battery degradation	- Well managed can increase battery life - Poorly managed can decrease battery life
Emissions	Peak demand charging will increase emissions from generation	Charging during offpeak hours will reduce emissions from peaker plants	- Used as daily storage to increase capacity factor or renewable energy - Reduce need for peaker fossil fuel generation

The other means of charging require a more active role from the fleet owner than unmanaged charging. These methods can greatly reduce the need for additional energy generation, transmission lines, and other infrastructure upgrades that will come with the influx of EVs over the next decade.

The second strategy is **smart charging**, or managed charging, in which an EV operator willingly charges their vehicle at times that are optimal for the grid (typically any time outside of evening peak demand from around 5 to 9 pm, depending on location and time of year). If charging during peak demand times is unavoidable, another way to implement smart charging is to reduce the charging rate.

The final method of charging is **bidirectional**, which is similar to smart charging with the addition of a two-way flow of energy. Bidirectional charging is what this paper advocates as the best possible outcome for fleet electrification. As mentioned above, there are many V2G services that fleet operators can perform, all with varied pros and cons. Peak load shaving and shifting are some of the services with the greatest benefits to society, the grid, and the fleet operator. It is important to note that an EV can be bidirectionally capable without being integrated into the grid.

Cost Comparison

When comparing the different levels of charging in terms of cost, it should be clear that **unmanaged charging** will be the highest, primarily due to time and period-based demand and energy pricing structures. Most utilities vary energy and demand pricing to incentivize the alignment of electric load with generation resource profiles. In some cases, peak energy and demand pricing can be two to three times higher than off-peak prices.[29] Even a slightly higher price for electricity increases exponentially when multiplied by tens, hundreds, or thousands of EVs in a fleet.

Smart charging can reduce these economic burdens by charging during off-peak times in the middle of the day or night, primarily from cheaper renewable sources. Based on the majority of utilities offering TOU pricing, EV fleets would be guaranteed to save money by practicing managed instead of unmanaged charging. At the extreme, EV fleets that strictly charge during off-peak hours compared to a fleet that only charges at peak demand times would decrease charging costs by up to 70%.[30] Typically, charging an EV at times that are optimal for the grid are accompanied by the cheapest electricity rates.

30 Electric Vehicle (EV) Rate Plans, Pacific Gas and Electric Company, 2016. https://www.pge.com/en_US/residential rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page

With **bidirectional charging**, EV owners essentially add another value stream to smart charging by discharging energy back into the grid when it is of value. Because of the many different VGI services described above, it is difficult to compare the costs from a high-level point of view. However, charging when electricity costs 1X and discharging when it rises to 2 or 3X shows the value that can come from practicing energy arbitrage.

Payback Period

When electrifying a fleet, **unmanaged charging** is the current standard practice, and thus has no effect on the payback period of a project. This method of charging provides no savings and no additional revenue services.

Smart charging reduces the cost of ownership for a fleet of EVs by charging when electricity costs are low, decreasing EV charging costs by 22%-81%.[31] This cost reduction can greatly reduce the payback period of a project, as charging is a majority of operating costs for an EV.

Bidirectional charging adds another revenue stream on top of the savings that smart charging provides, further reducing the cost of ownership for fleet managers. If bidirectional charging makes sense for a project, it can greatly reduce the payback period for a fleet electrification project.

When compared to unmanaged or even smart charging, bidirectional charging appears to provide the highest number of value streams. Despite their benefits, bidirectional chargers are rarely chosen as the standard practice for fleet electrification. The primary reasons for this are the lack of industry knowledge and higher upfront costs, including the physical bidirectional charger, permitting expenses, and other infrastructure upgrades. However, when implemented, bidirectional charging provides a multitude of ways to utilize the energy stored in an EV battery in return for financial compensation. These new value streams reduce the lifetime costs of an electrification project when compared to practicing unmanaged charging.

Battery Life Comparison

As stated above, **unmanaged charging** is the business-as-usual case for current electrification projects, and therefore will be used as a base scenario for battery life comparisons. However, even unmanaged charging could have negative effects on battery health, given that high and low state of charge (SOC) extremes degrade the battery.

31 Value to the Grid From Managed Charging Based on California's High Renewables Study, U.S. Department of Energy, 2018. https://www.osti.gov/pages/servlets/purl/1494793

Smart charging will likely result in minimal changes to the battery when compared to unmanaged charging. The differences would arise if the managed charging includes adjustments to the charge rate and depth. However, if the changes are just to the charging time, this would impact the battery in the same way as unmanaged charging,

The greatest potential to change the battery health stem from bidirectional charging practices. If **bidirectional charging** is improperly managed, VGI services could result in reduced battery life for an EV. However, these harms (or benefits) depend almost entirely on what VGI services are being implemented, and how well they are being managed. This makes it extremely difficult to precisely compare the different effects that bidirectional charging will have compared to managed and unmanaged charging. At its worst, research shows properly managed bidirectional charging will affect the battery in the same way as unmanaged charging. Given the constant improvement in BMSs and bidirectional charging algorithms, battery degradation issues are expected to continue decreasing.

Emissions

Similar to overall costs, emissions are drastically higher when practicing **unmanaged charging**. This is due to a majority of generation coming from fossil fuels during peak demand times. Unmanaged charging will have the highest emissions of the three charging methods.

Managed charging would reduce these emissions by actively charging when renewables are available and abundant or more simply operating in response to the real time GHG emission factor on a grid. In locations with abundant renewable generation, managed charging could have the ability to reduce a considerable amount of emissions by increasing the share of renewables on the grid. The specific amounts of reduced carbon emissions vary widely due to different types of electricity generation sources across the country.

Bidirectional charging would allow EVs to charge with renewable energy and then discharge this back to the grid, curtailing the need for peaker fossil fuel generation. This would have the potential to dramatically reduce emissions from the grid. However, more actualized projects are needed that provide better quantification of the reduction of emissions, as most current data is based on theoretical models.

Alternatively, an ideal scenario would be to pair an EV fleet with on-site solar (or wind) to effectively eliminate any emissions, depending on space constraints and fleet size. Thus, on-site DERs could greatly reduce emissions and help renewable energy goals. These reductions in emissions could also generate revenue for the fleet operator, if they reside in areas that compensate for clean fuel standards, renewable energy credits, or other financial incentives.

Energy Equity and Vehicle-Grid Integration

Environmental Justice and Energy Equity

As is the case with any technology, careful consideration should be taken to ensure that the distribution of environmental and economic benefits of VGI are shared equitably. Environmental and social justice are inextricably linked, meaning that every new project affects people in some way. It is the responsibility of fleet electrification project managers to ensure that burdens and benefits of these projects are equitably distributed. Historically, new energy projects have left underserved communities with the negative air quality impacts associated with generation, transmission, and distribution. Fossil fuel generation plants or other industrial facilities are often located in lower income or communities of color, due to inequitable land use policies or displacement of neighborhoods from gentrification. Acknowledging these inequities enables energy project planners to make better decisions moving forward. EVs are often celebrated for their reductions in localized air pollution, but when they are charged on a power grid supplied by fossil fuel generation, the emissions burden is shifted to a new neighborhood rather than eliminated. At scale, dispatchable EV batteries paired with VGI technology have the capacity to greatly reduce the need for fossil fuel power sources, playing an important role in the transition to clean energy.

At scale, dispatchable EV batteries paired with VGI technology have the capacity to greatly reduce the need for fossil fuel power sources, playing an important role in the transition to clean energy.

Lessening Dependence on Fossil Fuel Peaker Plants

Mass electrification of the transportation sector poses an imminent threat to an already fragile grid system, and when unmanaged, plays directly into our dependence on fossil fuel energy resources. The way our electricity system operates, energy must be used simultaneously as it is generated. This poses a challenge as intermittent renewables like solar and wind come online and as we continue to electrify across sectors. EV adoption is expected to rise exponentially in the future as battery technology continues to improve and prices continue to decline.[32] Unmanaged, the influx of EVs connecting to the grid can be detrimental to generation and transmission infrastructure. If EV commuters or fleets all arrive at their depots in the evening to recharge at the same time, this increased energy demand during an already peak demand period threatens grid stability. Meeting this new and unchecked demand will result in the need to further utilize highly polluting fossil fuel powered peaker plants, which are often located in low-income neighborhoods or communities of color.[33] Further, these peaker plants make up some of the most expensive forms of energy in the country.[34] Antiquated peaker plant infrastructure makes them inefficient and highly polluting. To reduce the disproportionately negative impacts of this added demand on underserved communities, charge management practice is recommended to be paired with any major vehicle electrification project. Managing our charging patterns and giving vehicles VGI capabilities will be essential in the future to ensure EV's are an asset to grid resilience, not a hindrance.

Distributed Energy Resources as a Localized Energy Solution

While electrification is an important component of reducing emissions, a large added demand may cause energy supply challenges in the future. Ensuring that there is availability of clean, dispatchable resources will be imperative in order to preserve the health of both people and the planet. Developing robust and resilient grid systems that are supplemented by distributed energy is the most strategic path forward for ensuring access to electricity services. While renewables like solar and wind have taken the lead as the cheapest form of energy, many of the benefits are inaccessible to those who cannot afford them, or who live in communities that depend on fossil fuel generation.[35] Community-based DERs can extend these benefits to more people, and reduce the requirement for additional land use areas (particularly in rural communities) for utility scale renewable projects since energy is utilized closer to the load. These distributed energy resources can also serve to offset some of the costs associated with the transition to renewable energy, reducing the risk for energy insecurity in communities that are vulnerable to spikes in electricity costs. The integration of aggregated vehicle batteries providing a storage solution for the grid would not only amplify these localized benefits, but also provide a larger systems benefit as well.

32 Walton, Robert, Electric vehicle models expected to triple in 4 years as declining battery costs boost adoption, Utility Dive, 2020. https://www.utilitydive.com/news/electric-vehicle-models-expected-to-triple-in-4-years-as-declining-battery/592061/#:~:text=He%20said%20costs%20have%20fallen,prices%20will%20continue%20to%20drop.%22.
33 Spector, Rachel, Yeampierre, Elizabeth, & Rodriguez, Daniella, Peaker Plants Harm Communities of Color; It's Time for New York City to Replace Them, Gotham Gazette, 2020. https://www.gothamgazette.com/opinion/9511-peaker-plants-harm-communities-of-color-it-s-time-for-new-york-city-to-replace-them
34 Ramirez, Rachel, These dirty power plants cost billions and only operate in summer. Can they be replaced?, 2020. https://grist.org/justice/these-dirty-power-plants-cost-billions-and-only-operate-in-summer-can-they-be-replaced/
35 Majority of New Renewables Undercut Cheapest Fossil Fuel on Cost, International Renewable Energy Agency, 2021. https://www.irena.org/newsroom/pressreleases/2021/Jun/Majority-of-New-Renewables-Undercut-Cheapest-Fossil-Fuel-on-Cost
36 Becker, William, Miller, Eric, Mishra, Partha, Jain, Rishabh, Olis, Dan, and Xiangkun, Li, Cost Reduction of School Bus Fleet Electrification With Optimized Charging and Distributed Energy Resources, National Renewable Energy Laboratory, 2020. https://www.nrel.gov/docs/fy20osti/74187.pdf

Vehicle-Grid Integration in Various Communities

VGI has the potential to provide cost reductions and environmental benefits in a variety of places including residential neighborhoods, commercial and industrial zones, or even facilities in rural or natural areas. Pairing smaller maintenance fleets with bidirectional chargers can reduce electricity costs in multi-family housing, making energy more affordable for tenants or building operators. VGI is an opportunity to promote transit-oriented development (TOD) in higher density areas, because there is no longer an air quality issue associated with placing bus depots under or adjacent to housing. There are limited studies surrounding the pairing of VGI and multi-family housing, but research shows there is promise for the potential of V2B projects. In the commercial sector, the connection of fleets to the grid can provide an opportunity for building owners to sell energy back to the grid during peak demand periods and provide stability to the grid, which benefits all energy consumers. VGI technology and software management of EVs can not only optimize charging schedules to reduce the impact on additional electricity demand from vehicles, but also enable EVs to be an asset to utility companies and fleet owners. Similar to a community solar approach, this excess energy could be utilized to benefit energy users who may be unable to afford individual EVs at this time.

Improved Local Air Quality and Social Considerations

The transition from diesel to electric can reduce fleet emissions associated with providing transportation, decrease bus maintenance costs, and reduce localized exposure to aerosol pollutants and diesel exhaust particulates.[36] The upfront costs, however, are one of the biggest challenges of the transition to electric. The addition of VGI technology to fleet electrification projects can aid in a reduction in operational costs, which makes the technology more accessible, helps to speed up EV fleet adoption, and contributes to reductions in air pollution. Areas to target with this technology are neighborhoods that do not meet the national primary or secondary ambient air quality standard for the National Ambient Air Quality Standard defined by the EPA as nonattainment zones, because these areas can realize the greatest benefits in improved air quality. It is estimated that by 2030, over 40% of bus fleets will be EVs, and between now and 2040, public transit bus fleets will grow by three times while EV school bus fleets will grow by thirty times. The people impacted by this transformation will range from drivers and mechanics who will require additional safety and workforce training but will benefit from less exhaust exposure, to the transit riders and community members living in areas where the fleet vehicles provide services. When more of these BEVs become bidirectionally capable, communication, outreach, and education of relevant stakeholders will be imperative to bring this technology to scale. Projects that have community impacts should be paired with thorough community engagement.

37 Ozone Designation and Classification Information, U.S. Environmental Protection Agency, 2020. https://www.epa.gov/green-book/ozone-designation-and-classification-information

Equitable Electrification

Ensuring that the costs and benefits of VGI are equitably shared is imperative to the technology's success. New energy technologies should not exacerbate the existing inequities associated with energy generation and emissions. The emission reduction benefits should not be limited for only those who can afford an individual EV, and the power supplied for EVs should not be a burden on communities that live near fossil fuel generation sites. By making EVs bidirectionally capable, there are more opportunities to create grid benefits, and make the technology more financially feasible for a wider range of clients. Communities with vulnerable populations such as school children, the elderly, or those with pre-existing health issues can greatly benefit from electrification. But in order to electrify equitably, projects must take a holistic and future-ready approach, promoting decarbonization of our energy supply systems and supplemental DERs to promote energy-resilient communities.

38 Combining Energy Storage with High-Power Charges to Mitigate Grid Power Availability Issues for Electric Fleet Vehicles, Rhombus Energy Solutions, 2020. https://secureservercdn.net/45.40.145.201/o7j.844.myftpupload.com/wp-content/uploads/2021/04/Combining-High-Power-Chargers-and-Energy-Storage-Ref-Architecture-FINAL-04082095.pdf

VGI As Resiliency Solution

The Value of Resiliency

One of the greatest benefits of VGI technology is the ability to provide additional power when it is needed. In the face of global warming, resiliency (or the ability to bounce back quickly), is something that public and private entities alike are striving for. The value of resiliency cannot be easily quantified, yet the value of regulating indoor temperatures during extreme weather events is immeasurable.

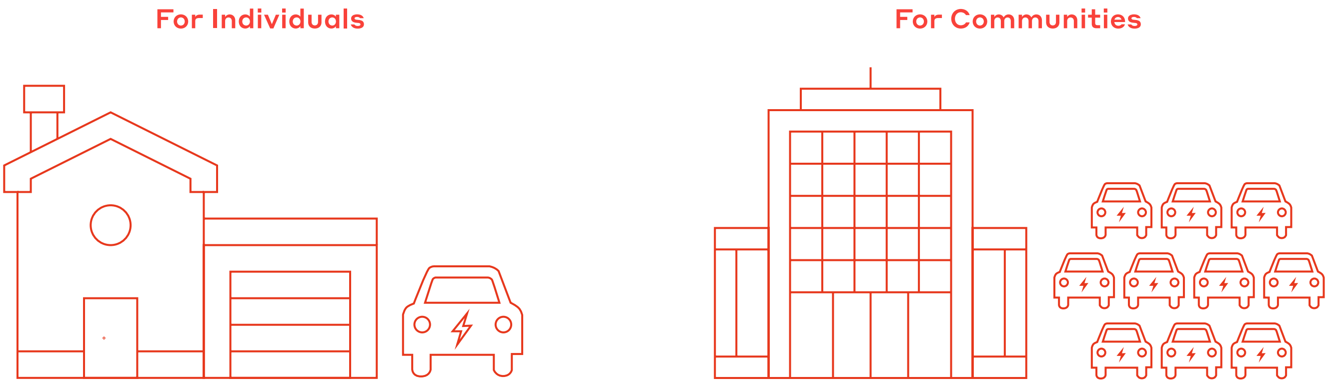
One of the biggest challenges with climate change is the unpredictability of severe weather events, which is why adaptation strategies are so important. Good preparation can save lives. Economists have struggled to place a dollar amount on resiliency, but researchers at the National Renewable Energy Lab (NREL) found a way to accurately place a monetary value on energy resilience. In their report, they compare the costs and "days of survivability" between 2 megawatts (MW) of solar power combined with 500 kilowatt-hours (kWh) of battery storage and a 2.5 MW fossil fuel generator.[39] The results found that the solar and battery combination provided nine days of survivability, while the generator by itself could only provide five. Tapping into the available energy storage in naturally aggregated EV fleets could expand these days of survivability even further.

Among energy professionals, there is often a debate surrounding decentralized vs. centralized energy production, when in reality the best outcome is a combination of both. Decentralizing the current grid system is one of the best ways we can prevent major outages in the future, and ensure communities have a more distributed power system in case the centralized grid fails. Which is not to say that there is not a place for utility scale generation, but rather, that DERs like VGI can be a supplemental asset to local energy systems. By giving communities the power to act independently of the "macrogrid," they are increasing their energy security.

New energy policy is beginning to incentivize distributed energy resources as well. In 2011, as a response to hurricanes Sandy and Irene, Connecticut was the first state to legalize microgrids as an adaptation strategy to promote community resilience.[40] Amending policy to be favorable for DERs is essential for wide scale VGI adoption. Assessing the role that EV batteries can play in local energy systems can help both rural and urban neighborhoods be better prepared for future climate impacts. When it comes to resiliency, the key is for planning for when events occur, not if.

39 Asmus, Peter, Unpacking the Value of Resiliency That Microgrids Offer, Guidehouse Insights, 2019. https://www.google.com/url?q=https://guidehouseinsights.com/news-and-views/unpacking-the-value-of-resiliency-that-microgrids-offer&sa=D&source=editors&ust=1627084016718000&usg=AOvVaw3kL2w0l2OpVuz754MyHiOp

40 Wood, Elisa, Microgrid Policy: What Really Needs to be Done?, Microgrid Knowledge, 2019. https://microgridknowledge.com/microgrid-policy-really-needs-done/



VGI resiliency applications for individuals and communities

Wildfires

Wildfires have become increasingly devastating in recent years. Australia's wildfires in early 2020 were devastating for both people and the planet. Even in less common areas across Europe, record high temperatures ignited destructive wildfires that threatened historic and cultural areas.[41]

In the Western United States, an area of the country that is more naturally prone to drought and fire, these risks have been exacerbated by warming temperatures and fire suppression forest management practices. According to reports from the BBC, the 2020 wildfire season was worse than it had been in 18 years.[42] In 2021, fires are starting earlier and spreading faster than previous seasons, a trend that will likely continue as our climate changes.

Utility companies like PG&E, the IOU for Northern California, have made efforts to mitigate wildfire risks by scheduling regular Public Safety Power Shut Offs leaving millions to rely on fossil generators for extended periods of time. Implementation of distributed energy resources, including VGI, can provide a more permanent solution for localized, resilient grid systems that can keep people connected to power in the event of an emergency.

Extreme Weather Events

Distributed energy resources such as VGI technology provide an opportunity for improving energy resiliency in communities that are at greater risk for extreme weather events. The impacts of climate change will be felt across the globe, especially impactful to those with aging or ineffective infrastructure. As evidenced by the February 2021 weekend storm that impacted the Electric Reliability Council of Texas (ERCOT) grid, major temperature events can have detrimental impacts to electricity generation and transmission, and when large-scale power systems fail, it poses a dangerous health and safety problem. According to a report from the Oak Ridge National Laboratory, "increased severity of extreme weather events was the principal contributor to an observed increase in the duration of U.S. power outages between 2000 and 2012".

41 CNN, Europe battles wildfires amid scorching heat waves, CNN, 2021. https://www.cnn.com/2021/08/06/world/gallery/europe-extreme-summer-weather-2021/index.html
42 California and Oregon 2020 wildfires in maps, graphics and images, BBC News, 2020. https://www.bbc.com/news/world-us-canada-54180049

There are obvious dangers to having large portions of the population connected to one centralized grid, as many can be left without power when systems fail. In addition to integrating decentralized energy sources, communities should conduct thorough risk assessments to identify vulnerable infrastructure and have plans in place to keep power on in critical facilities. Enabling public facilities to serve as evacuation areas during these severe weather events will require their ability to function outside of traditional grid services, which VGI can play a part in. DERs provide a long-term solution, rather than a temporary, fossil fuel-powered one. When vehicle batteries can provide services aside from mobility alone, their value is increased.

Beyond providing energy storage in the event of an outage, aggregated EV fleets may provide enough grid services to help prevent unplanned outages altogether. When buildings have the ability to "island" outside the centralized grid, utilities can prioritize "flexibility in restoring generation stations, responding to critical outages, and shutting down systems before a major event to prevent damage."[43]

Wide-scale adoption of VGI is where the technology can provide the most benefits, and provide the most cost savings. The natural aggregation of fleet vehicles makes a valuable asset to any client looking to boost their sustainable energy efforts. Bidirectionally capable EV fleets can currently serve both individual buildings and the grid at large, and thereby reduce the need for expensive long-range transmission infrastructure. It is in the interest of both private and public fleet owners to consider VGI if they are considering a transition to electric to meet sustainability goals and ensure critical facilities are more prepared for severe weather events.

Ideal Applications for VGI Technology

As fleet vehicles continue to electrify, there are different characteristics that alter their ability to engage in VGI services. However, most fleets can practice smart charging if bidirectional charging is not an option due to the higher upfront costs. If a fleet can continue performing its duty cycle while strictly charging overnight, this would fit the description of smart charging. Even more so, if the vehicles do not need to rely on their entire battery capacity for their duty cycle, other VGI services would be a great addition to fleet operations. There are some instances of fleets with long duty-cycles not being able to practice smart charging as they need the entire off duty cycle period devoted to charging. This section will break down what types of fleets are best suited to engage in VGI services based on their size, routes, and other characteristics.

Predictable Schedules and Routes

One of the most important characteristics of a fleet that has the ability to provide VGI services is having predictable time schedules. This helps fleet owners better understand the time and duration that the fleet can provide VGI services, given the battery state of charge when returning to the depot. Fleets with sporadic use and charging schedules will have a much more difficult time planning for a VGI project. Some energy markets require hour or even day ahead agreements for participation, and some fleets do not have that kind of flexibility in their duty cycle.

Example Fleet: Public Transportation

Given the increased interest in electrifying public transit fleets, these agencies are a natural VGI candidate. The precise knowledge of their schedules and route distance makes VGI services easier to implement, however, their long duty cycles and limited excess battery capacity could reduce VGI incentives. For transit fleets that require multiple battery-electric buses (BEBs) to replace a single ICE bus, fleet managers could potentially use the excess capacity of the two BEBs to provide VGI services and ideally recoup the extra initial capital costs.

44 Gimon, Eric, How Market Rules Are Holding Back Energy Storage, Greentech Media, 2019. https://www.greentechmedia.com/articles/read/energy-storage-wholesale-market-rules

45 The Parker Project Final Report - Appendices, The Parker Project, 2016. https://parker-project.com/wp-content/uploads/2019/03/Parker_Final-report_2019_Appendices.pdf

Sufficient Battery Capacity

Along with a known time schedule, another positive characteristic of a VGI enabled fleet is the known distance and energy required to complete a duty-cycle. In an ideal scenario, a fleet would return to depot after daily operations and have extra battery capacity to provide services to the grid. This would be the most profitable during peak demand times, but that is not a requirement for a successful VGI project. If a vehicle comes back to the depot with a low state of charge, it must charge before providing grid services. This could hinder the economics of a VGI project, especially if that vehicle is ending its duty cycle during peak demand times. The vehicles must also have enough down time to provide services to the grid, even if they do have sufficient battery capacity. There is the potential to purchase more battery capacity than necessary and recoup those additional costs by utilizing VGI services, but this needs to be analyzed more before any recommendations are made.

Example Fleet: Corporate, Delivery, and Service Vehicles

Although the specific characteristics of these fleets vary widely, most do not drive long distances throughout the day, and would be able to provide extra capacity to the grid when they return from their duty cycles. Even if the entire fleet does not operate this way, devoting some vehicles to VGI services after their duty-cycle could help reduce the payback period of a fleet electrification project.

46 Duran, Adam, and Walkowicz, Kevin, A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems, National Renewable Energy Laboratory, 2013. https://www.nrel.gov/docs/fy14osti/60068.pdf
47 BYD To Revolutionize Electric School Buses, BYD Auto, 2021. https://en.byd.com/news-posts/byd-to-revolutionize-electric-school-buses/
48 Today in Energy, U.S. Energy Information Administration, 2020. https://www.eia.gov/todayinenergy/detail.php?id=42915
49 Maps and Data - Average Annual Vehicle Miles Traveled by Major Vehicle Category, U.S. Department of Energy, 2020. https://afdc.energy.gov/data/10309

Available During Peak Energy Demand

Another important characteristic for operators that want to participate in energy arbitrage/grid stability/load shaving is if the fleet is not in use during peak demand times. If a fleet is in use during these times, or if their utility does not offer TOU rates, the economics of VGI projects are less advantageous. However, these services would still greatly benefit the allocation of renewable energy on the grid, even if the economics are not as enticing. If this form of VGI service is not an option for a fleet operator, they can still participate in frequency regulation services, which are becoming very lucrative in Europe.[44,45]

Example Fleet: School Buses

School Buses are arguably the best possible candidates for vehicle-grid integration because of their predictable (and short) schedules, OEMs allowing bidirectional charging, and their availability during peak demand times. Besides special events for school and extracurriculars, school buses drive the same schedule and route every day during the school year. In a study by the National Renewable Energy Lab that statistically characterized school bus duty cycles in Washington, Colorado and New York, school buses were found to travel 74 miles per day on average. Today, electric school bus manufacturers offer V2G-capable school buses with ranges up to 155 miles, more than twice the average daily driving distance from the NREL study. With school buses available during the day to charge with solar, and available during peak demand times, school buses meet all of WSP's criteria for Ideal Applications of VGI. Also, most school buses sit idle for most of the summer months, coinciding with the yearly maximum in electricity demand for the United States. Utilizing these dormant batteries during periods of low use could result in elongated battery life, while also helping to relieve stress on the grid.

Although grid services can be provided at all times of the day, they are much more lucrative during peak demand, making school buses an ideal candidate. VGI services can be very helpful for school districts that are typically operating on very strict budgets by reducing the operating costs of electrifying buses.

OEMs and Bidirectional Charging

The most important characteristic for VGI applicability is the manufacturer that makes the vehicle. This is critical, as many OEMs do not allow the use of bidirectional charging by deeming the battery warranty void upon adoption. The only light-duty vehicle that currently allows bidirectional charging in the United States is the Nissan Leaf, with several others advertised to come online over the next five years. There are currently a handful of bus companies that allow VGI services.

Example Fleet: Waste and Recycling

Like school buses, waste and recycling fleets typically do not have long distance routes and are not in use during peak demand times. An average refuse truck drives under 70 miles per day, typically operating in the morning and early afternoon.[49] However, these fleet types are just beginning to electrify, and there are currently no OEMs that allow bidirectional charging.

As stated earlier, many current EV OEMs state battery degradation as the reason for a voided battery warranty when bidirectional charging is in use. However, it seems that this will be changing with the announcements of Ford, Hyundai, and Volkswagen, which have committed to allowing bidirectional charging for users in the future. Furthermore, as VGI projects continue to push the market in this direction, other light, medium, and heavy-duty OEMs will presumably follow suit.

Other Potential Fleets

Fleets that are owned/operated by an entity with their own storage/microgrid could provide great benefits. These would include hospitals, airports, and college campuses. More research needs to be done to understand the feasibility of these endeavors.

Other fleets that could use more examination are private shuttle buses that are typical to tech/large companies in Silicon Valley (and other areas). Also, shipyards with drayage trucks would be an interesting case study.

Recommendations

There are many roles to be played in the wide scale adoption of VGI technology. Due to its infancy, there is a gap in knowledge in the industry. Transmission organizations, system operators, state regulators and utility companies that have experience with VGI projects can help transfer learnings and experience to new projects. As these projects become more common, there will be additional challenges to overcome, and WSP is committing to helping fleets navigate through these challenges to realize all the benefits VGI has to offer. The vision for integrating EVs with the grid to generate value for fleets and for society requires not only the engineering and project management expertise offered by WSP, it requires collaboration between public and private stakeholders, from utility companies and market operators, EV and EV charging infrastructure manufacturers, to all levels of government.

Recommendations for Fleet Owners

Assess the feasibility of VGI in all new fleet electrification projects. **By making initial bidirectional charging investments, fleets can be better prepared for a future where vehicles play a role in providing essential grid services.** Communication and engagement is important to make relevant stakeholders more amenable to VGI. Education, awareness and VGI project experience can make the planning, permitting and interconnection processes go without unnecessary delays. VGI pilot project collaborations are also encouraged between EV OEMs, VGI software and EVSE companies, utilities, and fleet owners. Retrofitting existing projects to become VGI-capable can be costly and time-consuming, so ensuring that the vehicle batteries are covered under warranty and that chargers have the capacity for bidirectional flows is essential for project success.

Recommendations for Utilities

States, electric utilities and grid operators that explicitly design policies and programs to facilitate EV integration onto the grid offer the biggest incentive for fleets to pursue VGI. **By enabling fleet owners to easily integrate into bidirectional charging into new projects, utilities can ensure these projects can be mutually beneficial.** Companies should continue to evolve TOU rates and schedules or introduce them if they are not currently available. By providing financial incentives, project payback periods can be shortened, and more fleet managers can consider VGI in the future. Technologies that have the potential for load shifting or shaping should be rewarded under current and future utility rate structures. Because one of the largest hurdles to VGI is interconnection with the utility, any policies that specifically call out EVs in interconnection rulings will have the biggest impact on a project's economic analysis and feasibility. Additionally, utilities with goals of adding clean energy should consider the value of VGI and integrate creative storage solutions into renewable procurement projects.

Additionally, policy support and value propositions for EVs and DERs to participate in wholesale and demand response markets greatly benefit fleets interested in pursuing VGI opportunities. Although the availability of these programs varies with utilities and states, these programs offer fleet managers very accessible low-risk opportunities to use their EVs to support the grid and earn compensation.

Recommendations for Local Governments, Public Agencies, and Policy-Makers

Analyze current policy for ability to successfully implement VGI projects. **Ensure that frameworks incentivize VGI development, whether financially or by creating streamlined permitting processes.** Identify vulnerable infrastructure and conduct risk assessments to ensure EV fleets can be integrated into emergency plans. Work directly with community members and stakeholders to inform and encourage all new EV charging infrastructure to be bidirectionally capable. Evaluate current parking requirements, zoning laws, or building codes to be favorable to VGI projects on a case-by-case basis. Reach out to entities engaging in pilot projects and identify practices that best fit individual community needs. Encourage renewable energy development coupled with storage solutions to increase energy security.

Recommendations for Transit Managers

Although transit fleets are a more challenging use case for VGI than other fleets under current regulations, transit managers should still consider bidirectional charging when converting from diesel to electric. Enroll in training programs on how to budget, schedule, and identify potential revenue streams for VGI capable fleets. Learn to understand barriers to ridership in your community, and work to alleviate those route challenges or other issues when you consider transitioning to an electric fleet. Ensure that the technology is implemented equitably throughout cities, so that the emissions benefits and burdens are shared among community members. Reduced air pollution should be prioritized in areas that have existing air quality issues.

Conclusion

Research shows that vehicle-grid integration embodies the concept of "future-ready" design, by taking a complex problem like added strain on the grid from EV adoption and turning it around to enable the EVs to serve as energy storage. VGI is often misconceptualized as something that is years or decades from being feasible, but V2G and V2B technology is evolving rapidly around the globe, today.

There are a number of reasons to invest in bidirectional charging when converting to electric fleets, especially if the fleet has qualities that are favorable for providing grid services. Studies show that under current regulations, school bus electrification projects likely have the greatest potential for VGI due to their compatible duty cycles and natural ability to aggregate. Addressing this sector's attractive potential in a report from Automotive News, the bidirectional charging company Nuvve is quoted saying "electrifying school buses without allowing for the two-way flow of energy would be akin to investing in pagers when cellphones were on the horizon."[50]

VGI can give private and public fleet owners the power to provide their own facilities with electricity in a way that is clean, dispatchable, and beneficial to the grid. It can help communities bolster their resiliency and provide backup power in emergency situations. When coupled with distributed solar, the clean energy benefits of VGI are multiplied. By allowing the vehicles to participate in TOU markets, there are ways to speed up payback periods, reduce ownership costs, and create new revenue streams. The technology's capacity for load shaving, frequency regulation and net load shaping make it a strategic component for demand management as the world continues to electrify across all sectors.

It will take time for VGI technology to grow to scale, but there are leaders in the fleet electrification space paving the way for a clean energy future. If a community or company values innovation leadership, progressive technology solutions and meeting rapidly evolving climate goals, VGI might just fit the bill.

Acknowledgements

Paul Yeric
Boulder, Colorado
Paul.Yeric@wsp.com

Willow Urquidi
Boulder, Colorado
Willow.Urquidi@colorado.edu

Nicholas Garza
Denver, Colorado
Nicholas.Garza@colorado.edu

Shantelle Dreamer
Boulder, Colorado
Shantelle.Dreamer@wsp.com

Cliff Henke
Arcadia, California
Cliff.Henke@wsp.com

Michael Huisenga
Boulder, Colorado
michael.huisenga@wsp.com

Our research team would first like to thank The University of Colorado at Boulder's Masters of the Environment program for allowing this capstone project to come to fruition. Second, we must thank our project partners Shantelle Dreamer, John Heaton, and Cliff Henke. Additionally, we would like to thank the entire team at WSP, including the Zero Emission, Energy Electrification, and Built Ecology teams. Finally, our team would like to express our gratitude to all interviewees for their time and interest in our project.

Masters of the Environment
University of Colorado **Boulder**

50 School Buses Could Someday Help Fortify the Electric Grid, Automotive News, 2021. https://www.autonews.com/mobility-report/school-buses-could-provide-mobile-power

Works Cited

Asad, Harun, Are We Pivoting From Net Zero To True Zero?, Environment Leader, 2021. https://www.environmentalleader.com/2021/06/are-we-pivoting-from-net-zero-to-true-zero/

Asmus, Peter, Unpacking the Value of Resiliency That Microgrids Offer, Guidehouse Insights, 2019. https://www.google.com/url?q=https://guidehouseinsights.com/news-and-views/unpacking-the-value-of-resiliency-that-microgrids-offer&sa=D&source=editors&ust=1627084016718000&usg=AOvVaw3kL2wol2OpVuz754MyHiOp

Battery Health and V2G, Nuvve, 2021. https://nuvve.com/battery-health/

Becker, William, Miller, Eric, Mishra, Partha, Jain, Rishabh, Olis, Dan, and Xiangkun, Li, Cost Reduction of School Bus Fleet Electrification With Optimized Charging and Distributed Energy Resources, National Renewable Energy Laboratory, 2020. https://www.nrel.gov/docs/fy20osti/74187.pdf

Behind the Meter: Distributed Energy Resources Capabilities Guide, Smart Electric Power Alliance, 2016. https://sepapower.org/resource/distributed-energy-resources-capabilities-guide/

Briones, Adrene, Francfort, James, Heitmann, Paul, Schey, Michael, Schey, Steven and Smart, John, Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes Review by the AVTA, Idaho National Laboratory, 2012. https://www.energy.gov/sites/default/files/2014/02/f8/v2g_power_flow_rpt.pdf

BYD To Revolutionize Electric School Buses, BYD Auto, 2021. https://en.byd.com/news-posts/byd-to-revolutionize-electric-school-buses/

California and Oregon 2020 wildfires in maps, graphics and images, BBC News, 2020. https://www.bbc.com/news/world-us-canada-54180049

California Heavy-Duty Fleet Electrification Summary Report, Environmental Defense Fund, 2021. http://blogs.edf.org/energyexchange/files/2021/03/EDF-GNA-Final-March-2021.pdf

Casale, Matt, and Mahoney, Brendan, Paying for Electric Buses: Financing Tools for Cities and Agencies to Ditch Diesel, United States Public Interest Research Group, 2018. https://calpirg.org/reports/caf/paying-electric-buses-financing-tools-cities-and-agencies-ditch-diesel

Clack, Christopher T M, Choukulkar, Aditya, Coté, Brianna, and McKee, Sarah A., Why Local Solar for All Costs Less: A New Roadmap for the Lowest Cost Grid, Vibrant Clean Energy, LLC, 2020. https://www.vibrantcleanenergy.com/wp-content/uploads/2020/12/WhyDERs_TR_Final.pdf

Combining Energy Storage with High-Power Charges to Mitigate Grid Power Availability Issues for Electric Fleet Vehicles, Rhombus Energy Solutions, 2020. https://secureservercdn.net/45.40.145.201/07j.844.myftpupload.com/wp-content/uploads/2021/04/Combining-High-Power-Chargers-and-Energy-Storage-Ref-Architecture-FINAL-04082095.pdf

Daniels, Lynn, and Nelder, Chris, Steep Climb Ahead, Rocky Mountain Institute, 2021. https://rmi.org/steep- climb-ahead

Demand Charges Explained, DemandQ, 2021. https://www.demandq.com/demand-charges-explained

Duran, Adam, and Walkowicz, Kevin, A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems, National Renewable Energy Laboratory, 2013. https://www.nrel.gov/docs/fy14osti/60068.pdf

Electric Vehicle (EV) Rate Plans, Pacific Gas and Electric Company, 2016. https://www.pge.com/en_US/residential/rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page

Final Report of the California Joint Agencies Vehicle-Grid Integration Working Group, California Public Utilities Commission DRIVE OIR Rulemaking (R. 18-12-006), 2020. https://gridworks.org/wp-content/uploads/2020/09/GW_VehicleGrid-Integration-Working-Group.pdf

Fink, Larry, A Fundamental Reshaping of Finance, 2020. https://www.blackrock.com/ca/investors/en/larry-fink-ceo-letter

Fitzgerald, Garrett, Mandel, James, Morris, Jesse, and Touati, Hervé, The Economics of Battery Energy Storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid. Rocky Mountain Institute, 2015. http://www.rmi.org/electricity_battery_value

Gimon, Eric, How Market Rules Are Holding Back Energy Storage, Greentech Media, 2019. https://www.greentechmedia.com/articles/read/energy-storage-wholesale-market-rules

Global EV Outlook 2021: Accelerating ambitions despite the pandemic, International Energy Agency, 2021. https://www.iea.org/reports/global-ev-outlook-2021

GreenPrint Survey Finds Consumers Want to Buy Eco-Friendly Products, but Don't Know How to Identify Them, Business Wire, 2021. https://www.businesswire.com/news/home/20210322005061/en/GreenPrint-Survey-Finds-Consumers-Want-to-Buy-Eco-Friendly-Products-but-Don%E2%80%99t-Know-How-to-Identify-Them

Guille, Christophe, and Gross, George, A conceptual framework for the vehicle-to-grid (V2G) implementation, Energy Policy, 2009. https://doi.org/10.1016/j.enpol.2009.05.053

Interview with Christopher Bowyer, Alliance Center Director of Building Operations, 2021.

Interview with Danny O'Connor, City of Boulder Transit Manager, 2021.

ISO 15118-1:2019 Road vehicles — Vehicle to grid communication interface — Part 1: General information and use-case definition, International Organization for Standardization, 2019. https://www.iso.org/standard/69113.html

Lund, Jessie, and Roeth, Mike, High-Potential Regions for Electric Truck Deployments, Rocky Mountain Institute, 2020, https://rmi.org/insight/high-potential- regions-for-electric-truck-deployments

Majority of New Renewables Undercut Cheapest Fossil Fuel on Cost, International Renewable Energy Agency, 2021. https://www.irena.org/newsroom/pressreleases/2021/Jun/Majority-of-New-Renewables-Undercut-Cheapest-Fossil-Fuel-on-Cost

Maps and Data - Average Annual Vehicle Miles Traveled by Major Vehicle Category, U.S. Department of Energy, 2020. https://afdc.energy.gov/data/10309

Nelder, Chris, Newcomb, James, and Fitzgerald, Garrett, Electric Vehicles as Distributed Energy Resources, Rocky Mountain Institute, 2016. http://www.rmi.org/pdf_evs_as_DERs

Oldfield, Frank, Kumpavat, Krunal, Corbett, Rebecca, Price, Andrew, Aunedi, Marko, Strbac, Goran, O'Malley, Cormac, Gardner, Darren, Pfeiffer, Dominik, and Kamphus, Jan-Torben, The Drive Towards a Low Carbon Grid: Unlocking the value of vehicle-to-grid fleets in Great Britain, Nissan Motor GB, E.ON Drive and Imperial College London, 2021. https://www.eonenergy.com/content/dam/eon-energy-com/Files/vehicle-to-grid/The%20Drive%20Towards%20A%20Low-Carbon%20Grid%20Whitepaper.pdf

Olson, Arne, Hull, Sanderson, Ming, Zach, Schlag, Nick, and Duff, Charlie, Scalable Markets for the Energy Transition: A Blueprint for Wholesale Electricity Market Reform, Energy and Environmental Economics, Inc., 2021. https://www.ethree.com/wp-content/uploads/2021/05/E3-Scalable-Clean-Energy-Market-Design-2021.05.25.pdf

Operating on 24/7 Carbon-Free Energy by 2030., Google, 2021. https://sustainability.google/progress/energy/

Order Instituting Rulemaking to Consider Streamlining Interconnection of Distributed Energy Resources and Improvements to Rule 21, California Public Utilities Commission, 2020. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M345/K380/345380320.PDF

Ozone Designation and Classification Information, U.S. Environmental Protection Agency, 2020. https://www.epa.gov/green-book/ozone-designation-and-classification-information

The Parker Project Final Report - Appendices, The Parker Project, 2016. https://parker-project.com/wp-content/uploads/2019/03/Parker_Final-report_2019_Appendices.pdf

Phadke, Amol, Khandekar, Aditya, Abhyankar, Nikit, Wooley, David and Rajagopal, Deepak, Why Regional and Long-Haul Trucks are Primed for Electrification Now, Lawrence Berkeley National Laboratory, 2021. https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf

Race to 100% Clean, National Resource Defense, Council, 2020. https://www.nrdc.org/resources/race-100-clean#:~:text=More%20than%20150%20cities%20and,that%20target%20through%20varying%20methods

Ramirez, Rachel, These dirty power plants cost billions and only operate in summer. Can they be replaced?, 2020. https://grist.org/justice/these-dirty-power-plants-cost-billions-and-only-operate-in-summer-can-they-be-replaced/

Residential Electric Vehicle Rates That Work: Attributes That Increase Enrollment, Smart Electric Power Alliance, 2019. https://sepapower.org/resource/residential-electric-vehicle-time-varying-rates-that-work-attributes-that-increase-enrollment/

The Role of DERs in Today's Grid Transition, Gridworks and Gridlab, 2018. https://gridlab.org/works/role-of-distributed-energy-todays-grid/

School Buses Could Someday Help Fortify the Electric Grid, Automotive News, 2021. https://www.autonews.com/mobility-report/school-buses-could-provide-mobile-power

Spector, Rachel, Yeampierre, Elizabeth, & Rodriguez, Daniella, Peaker Plants Harm Communities of Color; It's Time for New York City to Replace Them, Gotham Gazette, 2020. https://www.gothamgazette.com/opinion/9511-peaker-plants-harm-communities-of-color-it-s-time-for-new-york-city-to-replace-them

Stout, Sherry, Hotchkiss, Eliza, Lee, Nathan, Holm, Alison, & Day, Megan, Distributed Energy Planning for Climate Resilience, National Renewable Energy Lab, 2018. https://www.nrel.gov/docs/fy18osti/71310.pdf

Today in Energy, U.S. Energy Information Administration, 2020. https://www.eia.gov/todayinenergy/detail.php?id=42915

Trabish, Herman K., Rate Design Roundup: Demand Charges vs. Time-Based Rates, Utility Drive, 2016. https://www.utilitydive.com/news/rate-design-demand-charges-time-based-rates/419997/

Transitioning to Zero Emission Technology: A guide to ensuring a smooth transition towards future-ready vehicles, WSP, 2021. https://www.wsp.com/-/media/Insights/Global/Documents/WSP--Zero-Emission-White-Paper.pdf

Uddin, Kotub, Dubarry, Matthieu, and Glick, Mark B., The viability of vehicle-to-grid operations from a battery technology and policy perspective, Energy Policy, 2018. https://doi.org/10.1016/j.enpol.2017.11.015

Value to the Grid From Managed Charging Based on California's High Renewables Study, U.S. Department of Energy, 2018. https://www.osti.gov/pages/servlets/purl/1494793

Walton, Robert, Electric vehicle models expected to triple in 4 years as declining battery costs boost adoption, Utility Dive, 2020. https://www.utilitydive.com/news/electric-vehicle-models-expected-to-triple-in-4-years-as-declining-battery/592061/#:~:text=He%20said%20costs%20have%20fallen,prices%20will%20continue%20to%20drop.%22

Wang, Dai, Coignard, Jonathan, Zeng,Teng, Zhang, Cong, and Saxena, Samveg, Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services, Journal of Power Sources, 2016. https://doi.org/10.1016/j.jpowsour.2016.09.116

Wood, Elisa, Microgrid Policy: What Really Needs to be Done?, Microgrid Knowledge, 2019. https://microgridknowledge.com/microgrid-policy-really-needs-done/

WSP is one of the world's leading professional services consulting firms. We are dedicated to our local communities and propelled by international brainpower. We are technical experts and strategic advisors including engineers, technicians, scientists, architects, planners, surveyors and environmental specialists, as well as other design, program and construction management professionals. We design lasting solutions in the Transportation & Infrastructure, Property & Buildings, Earth & Environment, Power & Energy, Resources and Industry sectors, as well as offering strategic advisory services. Our talented people around the globe engineer projects that will help societies grow for lifetimes to come.

WSP Global Inc.
1600 René-Lévesque Blvd. West
11th floor, Montreal, Quebec
H3H 1P9

wsp.com

GL-MK-WP-RT-001-EN-202001