U.S. Department of Energy

Strategy for Achieving a Beneficial Vehicle Grid Integration (VGI) Future

Table of Contents

Executive Summary

Electric vehicles (EVs) are hitting the road. Led by electric passenger cars and medium- and heavy-duty trucks, electrification is occurring across all transportation modes, including rail, off-road, and maritime applications. In 2023, more than 1.4 million new EVs were purchased in the United States,[1] representing approximately 10% of U.S. light-duty vehicle sales. To date, there are over 5.8 million light-duty EVs on U.S. roads,[2] and the demand for electricity to power these vehicles is growing rapidly. At the same time, the electric grid is undergoing a significant transformation from centralized control to more decentralized assets. Digital technologies and clean energy are reshaping the way customers interact with the electricity system, enabling more active participation in daily electricity needs.

Beneficially integrating EVs with the grid is essential to ensure EV drivers have timely access to electricity to charge their vehicles while ensuring this new load becomes an asset to the grid, making the grid more affordable, resilient, and reliable. Vehicle grid integration (VGI) exists at the intersection of these transforming sectors and can provide a pathway to more efficient utilization of the grid while capturing savings for EV drivers and electricity customers. EVs and their associated load present a unique opportunity for EVs to become a positive asset for the grid. Successful VGI implementation can enhance electricity affordability and support grid reliability and resilience; enable timely, cost-effective access to electricity for EV charging; and support a positive customer charging experience. Without proactively supporting the implementation of VGI and enabling coordination and planning across the transportation and electricity sectors, these opportunities may not be realized. There is widespread recognition among automakers,[3] utilities, and electric vehicle service equipment (EVSE) providers[4] that the time to act on VGI is now.

The U.S. Department of Energy's (DOE's) **Strategy for Achieving a Beneficial VGI Future** (Strategy) builds on DOE's visioning document, The Future of Vehicle Grid Integration: Harnessing the Flexibility of EV Charging (Vision), describing activities DOE will undertake to support stakeholders in achieving an EV-integrated future in which EVs, including personal vehicles, commercial freight fleets and school buses, are safely and securely connected to, reliably served by, and harmonized with the electric grid. This holistic, department-wide effort was developed recognizing DOE's key role as a convener and partner in the development and deployment of new technologies. It employs three strategies that are focused in areas where DOE can have the most impact and support stakeholders to cement coordination between the electric and transportation sectors.

The three strategies, which work collectively and in coordination, are:

Figure ES 1: DOE's strategies to support decision-making for VGI

1. **Validate Repeatable, Extensible VGI Solutions.** For successful deployment, a bridge must be constructed to move from pilot to scale. Developing opportunities for scaling under this strategy, DOE will support flexible charge management to shift load, engage in work that enhances reliability and resilience by utilizing EVs, and further technology solutions for seamless data and information sharing, while ensuring learnings can be extended across jurisdictions.
2. **Support VGI Institutional Decision-Making.** The work of integrating EVs into the grid will depend on decisions from stakeholders, including regulators, automakers, and customers. Making information and data accessible can facilitate decision-making. DOE will provide resources, convene stakeholders, and provide pathways to measure progress accelerating institutional decision-making for VGI.
3. **Spur VGI Innovation.** Continued innovation is needed to achieve the Vision. This requires continued support of technological advancement and innovation; adapting existing processes, systems, and our workforce to evolving technology; and enabling institutional innovations that create pathways to accelerate deployment.

These strategies are designed to increase stakeholder confidence in VGI technologies, which enables investment in and widespread adoption of VGI approaches. The Strategy describes the portfolio of VGI tools and the value they offer. It emphasizes areas where stakeholders, with DOE's support, can focus their attention and effort and find resources to accelerate VGI implementation. The Strategy highlights ongoing and future ways for stakeholders to get involved in sharing perspectives and developing solutions and describes the programs DOE will develop to provide assistance.

VGI implementation must start now. Consumers and businesses continue to show increasing interest in EVs, and while the growth of EVs will vary throughout the country, by acting now it is possible to purposefully plan investments, establish grid-friendly charging behavior through well-designed rates and programs, and provide EV drivers timely connections to charging for commercial and personal use. Through judicious planning and robust collaboration across stakeholders, including utilities, EV automakers, regulators, EVSE providers, aggregators, and labor, it is possible to achieve the Vision for VGI that provides value for all electricity customers regardless of EV ownership.

DOE is committed to partnering with stakeholders as the electric grid and transportation sectors undergo this significant transition through the development of actionable solutions that meet market needs and enhance affordability for all.

Beneficially Integrating EVs with the Grid

In 2023, more than 1.4 million new electric vehicles (EVs) were purchased in the United States,[5] representing approximately 10% of U.S. light-duty vehicle (LDV) sales. To date, there are over 5.8 million light-duty EVs on U.S. roads.[6] Led by electric passenger cars, electrification is occurring across all transportation modes, including medium- and heavy-duty trucks, rail, off-road, and maritime applications, as the preference for EVs has grown in response to declining battery costs[7] and lower total cost of ownership,[8] positive feedback from drivers,[9] and state and national policies.[10] Industry forecasts suggest accelerated growth of EV adoption for both LDVs and medium- and heavy-duty vehicles by 2035.[11] While EVs used less than 0.2% of total U.S. electricity demand in 2023,[12] the growing adoption of EVs is expected to drive electricity demand to charge those vehicles to reach approximately 6% of 2023 total U.S. electricity consumption in 2030.[13] While 2050 projections are more uncertain, studies project electricity demand for EV charging in 2050 to increase, potentially reaching between 20-50% of total 2023 electricity demand.[a, 14]

As the number of EVs and their electricity load grows, EVs can reduce costs for all utility customers. A study by Synapse found that EV drivers across the United States contributed approximately $2.44 billion in revenue for utilities net of program costs over an 11-year period (2011–2021).[15] Studies show that even non-EV driving customers can benefit—with one analysis indicating a 10% reduction in electricity costs over a year.[16] Beneficially integrating EVs with the grid through vehicle grid integration (VGI) can ensure reliable and affordable charging and transportation for customers as EVs become an asset to the grid, enhancing reliability and resilience and helping to keep electricity costs affordable.

The transition to and growth of EVs is happening at the same time the energy sector is undergoing its own transformation. Power systems are moving from central generation and control to a more decentralized system, renewable energy is becoming a greater proportion of the generation mix, and digital technologies and electrification of other end uses are reshaping the grid edge.[b, 17] These changing grid dynamics are heightening focus on grid affordability, security, reliability, and resilience.

Meeting customers' growing electricity demand affordably will require both investments in electricity infrastructure (distribution, transmission, and generation) and solutions that take advantage of demand and supply flexibility, such as from EVs. It will also require greater interaction and coordination across the transportation and electricity sectors, two sectors that have traditionally operated independently of each other, to mutually strengthen and improve the affordability of both sectors. While the pace and timing of the transition will vary throughout the country, **the time to act is now** so that investments are purposefully planned, EV drivers establish cost-effective grid-friendly charging behavior through well-designed rates and programs, and EV drivers have timely access to electricity for commercial and personal EV charging and other electric modes of transportation.

a Given the uncertainty around total future load, including potentially new load from buildings, industry and data centers, percentages are reported as a function of 2023 U.S. annual electricity generation.

b The grid edge is where buildings, industry, transportation, renewables, storage, and the electric grid meet. See Supercharging the Electric Grid for more information.

Vehicle Grid Integration for Electric Mobility

VGI spans the suite of grid infrastructure—including hardware, software controls, and the corresponding markets, regulations, and processes—and is aligned with customer charging behaviors to provide value to the grid, EV drivers, utility ratepayers, and society.

VGI strategically integrates EVs with the electric grid in a way that meets customers' growing need for electricity to charge their vehicle and allows EVs to be an asset to the grid, ensuring that their integration benefits all electricity customers. **VGI seamlessly aligns the grid's physical infrastructure, operational dynamics, regulatory frameworks, institutional processes, and market design with customer charging behaviors** to create a symbiotic relationship between the vehicle and the grid. By capitalizing on the unique characteristics of EVs to shift the time and location of charging or to discharge energy back to the grid or to other loads, VGI takes the act of plugging in an EV beyond a simple one-way connection and **extends value to all electricity customers, EV drivers, and the community**.

Successful VGI depends on the collective effort of many stakeholders to reimagine and redefine institutional process, business models, markets, policies, and regulations so they are responsive to emerging technological trends and changing consumer and business needs. Effective VGI includes participation from many stakeholders, including automakers, EVSE manufacturers, customers, fleet managers, charging network providers, load aggregators, utility organizations, their respective regulatory entities, and community and local governments. Robust coordination and collaboration between these stakeholders and across sectors can ensure that access to charging is timely and seamless while also supporting a clean, resilient, and secure grid that is affordable for all.

As a trusted partner, the U.S. Department of Energy (DOE) plays a unique and critical role. Leadership and support from DOE can help stakeholders as they work to implement affordable, reliable, cost-effective solutions that benefit their community, the grid, and the nation as a whole.

This document lays out the value of VGI, the challenges and opportunities to capture this value, and DOE's strategies for supporting stakeholders in realizing the vision for VGI. The Strategy was developed as part of DOE's EVGrid Assist initiative and draws upon multiple ongoing DOE efforts[c] that engage stakeholders and leverage industry and national laboratory expertise.[18] Beneficially integrating EVs with the grid requires both near-term actions that respond to today's challenges and long-term strategic activities. DOE's strategies support stakeholders across both areas by identifying synergies, anticipating barriers and obstacles, and developing pathways for progress.

c Such as the Vehicle Technologies Office's Vehicle Grid Integration Assessment Report, the Office of Electricity's Impact of Electric Vehicles on the Grid, and EVGrid Assist's The Future of Vehicle Grid Integration: Harnessing the Flexibility of EV Charging.

Working collaboratively and in partnership with industry stakeholders, DOE will focus on three strategic priorities:

- Validate extensible VGI solutions and approaches.
- Support VGI institutional decision-making.
- Spur VGI innovation.

While the focus of this Strategy is on transportation, including all transportation modes, electrification of other end uses such as buildings and industry have similar needs and opportunities where coordinated solutions can enable efficiencies in cost and time. DOE is committed to coordinating across grid and end-use technology areas to ensure learnings are shared and programs reflect the integrated perspectives of stakeholders across the grid and grid edge.[19]

Through these strategies, DOE will advance innovation, increase confidence in VGI solutions and approaches, and help to resolve challenges and barriers. DOE's objective is to accelerate VGI implementation in a way that meets the growing need for electricity, maintains downward pressure on rates, and enhances value for all utility ratepayers, EV drivers, and the grid—all while cost-effectively serving transportation needs.

VGI in Action: Downward Pressure on Rates

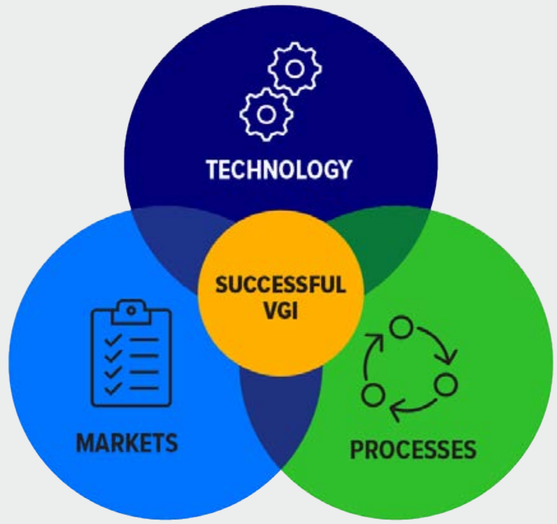
Increasing utilization of existing infrastructure decreases costs and puts downward pressure on electricity rates

Strategic utilization of EVs and their charging can increase the usage of existing utility infrastructure, reducing the need for utility system investments in generation, transmission, and distribution capacity.[20] Beyond efficiently employing EVs as a grid resource, EV charging can increase revenue by spreading the costs across a greater number of electricity sales. A Synapse Energy study assessed real-world utility system revenues and costs associated with EVs purchased between 2011 and 2021. During that time period, EV drivers contributed approximately $2.44 billion in revenue for utilities net of program costs, leading to downward pressure on electricity rates for all customers—both EV owners and non-EV owners alike. While other studies show the future promise of EVs and managed charging, the Synapse data shows that the positive impact of EVs to all ratepayers is happening already.[21]

What is VGI?

VGI includes a broad set of approaches that extends beyond technical considerations to encompass markets and processes. All three categories of VGI work together to create the environment for VGI tools and approaches to take hold.

The table below shows examples of VGI approaches in the categories of technology, markets, and processes. The VGI in Action callouts through this document showcase how VGI is being implemented today across the country and the value it is providing.



Technology	Markets	Processes
• Embedded communication and controls for grid, EV and EVSE • Discharging EV battery for vehicle to-load, -buildings, or -grid (V2L, V2B, V2G) • Building energy management systems and adapters • Automated load management systems that respond to net load to protect grid assets • Reduced net load with battery and on-site photovoltaics • Deeper integration of DERMS capabilities into ADMS	• Mechanisms that value grid services and compensate participation from EVs as a dependable grid resource • Industry-led technical standards and protocols for seamless and secure vehicle-grid communications • Cost-benefit analysis to enable cost-effective resource planning • Rates and incentives to motivate customers • Procurement of certified and interoperable equipment • Increased grid transparency to strategically locate chargers	• Aligning timelines for upgrade plans with charger deployment • Shared utility and developer project pipelines • Utility plans that account for all loads (including EVs) and generation resources • Flexible interconnection agreements • Cross transport-electric sector planning and analysis • Data sharing frameworks that enhance planning and protect privacy • Proactive engagement with fleets

Figure 1: Defining VGI and its categories along with practical examples

The Vision and Value of VGI

Achieving seamless VGI and the associated value for all requires imagining the ideal future where barriers are removed and stakeholders can capitalize on opportunities. **The Future of Vehicle Grid Integration: Harnessing the Flexibility of EV Charging (Vision) lays out the shared vision for a beneficial, EV-integrated future where EVs are safely and securely connected to, reliably served by, and harmonized with the electric grid**. The Vision, a result of extensive engagement with stakeholders, articulates the attributes of a realized vision and is built on five pillars: universal value, right-sized infrastructure, standards-supported innovation, customer-centered options, and secure coordination (see Figure 2).

The Vision provides a foundation for stakeholder discussions, **enabling actions that ensure EVs become an additive resource in supporting the electric grid**, not just a load to be served. This Strategy describes DOE's pathways, resources, and priority areas for assisting the nation in achieving that future.

VGI draws on a portfolio of approaches, giving utilities, regulators, and other stakeholders new tools in their toolkit as they work to realize their local, state, and regional objectives for reliable and affordable electricity and to meet customers' increased electricity demand to charge their EVs. VGI builds on and complements the tools that have historically been employed to meet the nation's growing electricity needs. It also provides approaches that reimagine longstanding business and institutional policies and practices, while holding on to important constructs, so that EVs are a positive force for change. It leverages technological advancements to enable more efficient and more valuable outcomes by aligning and leveraging the unique capabilities and characteristics of EVs and charging infrastructure with grid operations.

VGI Vision: By 2030, millions of electric vehicles, charging at home and work, at charging depots and along the route, are integrated with the electricity system in a way that supports affordable and reliable charging for drivers and enables a reliable, resilient, affordable, and decarbonized electric grid for all electricity customers.

Core Pillars of the VGI Vision

PILLAR 1. UNIVERSAL VALUE

Investments in grid infrastructure to support EV charging, enhance grid resilience, and provide shared benefits to ratepayers regardless of EV ownership.

PILLAR 2. RIGHT-SIZED INFRASTRUCTURE

A responsive, decarbonized electric grid harnesses the flexibility and mobile storage of EVs to minimize peak load impacts and increase the utilization of grid and charging assets.

PILLAR 3. STANDARDS-SUPPORTED INNOVATION

Harmonized grid, vehicle, and charger standards and clearly articulated grid requirements allow innovation to flourish and new products to be integrated into a robust, interoperable system.

PILLAR 4. CUSTOMER-CENTERED OPTIONS

Customers have a wide range of products and services to accomplish their charging needs and are compensated when they provide services to the grid.

PILLAR 5. SECURE COORDINATION

Cyber and physical systems that connect the vehicle, charger, and electric grid are appropriately secure to mitigate manmade or/and natural disruptions.

Figure 2: VGI Vision and pillars

Achieving the shared VGI Vision **is more than installing and deploying technology; it requires parallel innovations in state and local policy, markets, and institutional practices and procedures**. It depends on a healthy innovation system (Figure 3) across these domains that creates an environment in which change is welcome, and innovations become interwoven with institutional processes and customer behavior. As technologies are deployed and used, progress accelerates through iterative learning and by continually adapting to evolving customer and societal needs. Successful implementation of VGI relies on the robust exchange of ideas and information between jurisdictions and within and across sectors. It depends on a skilled workforce and secure supply chain. A healthy innovation cycle creates the environment for positive change to realize the shared vision and the value of VGI, thereby improving the well-being of citizens and enhancing the nation's economic competitiveness.

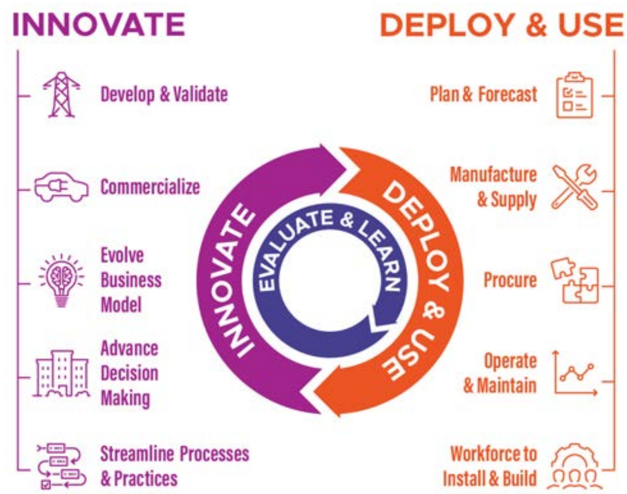


Figure 3: A cycle of iterative learning supports a healthy innovation system, allowing for continuous improvement and value-creation that responds to evolving needs.

Implementation of VGI approaches as part of a healthy innovation cycle creates a positive feedback loop that helps keep electricity rates affordable and lowers transportation costs for everyone (Figure 4). This opportunity for VGI approaches to deliver more cost-effective solutions and thereby cost-savings to ratepayers and EV drivers is a key motivator for utilities, regulators, and other stakeholders that are considering implementing VGI approaches or solutions.

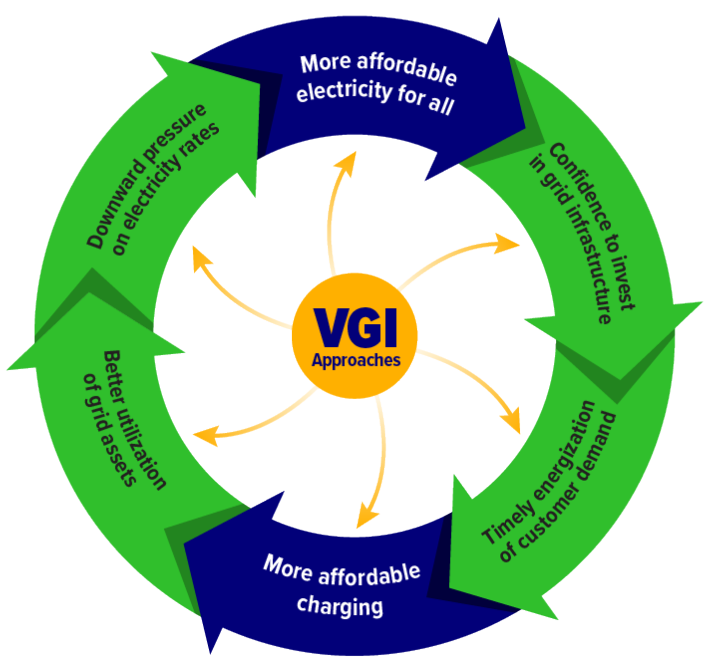


Figure 4: VGI enables a virtuous cycle that puts downward pressure on rates and keeps charging affordable.

VGI can create a positive feedback loop that accelerates the integration of EVs with the grid and the realization of VGI benefits: Affordable electricity for all allows affordable EV charging. Faster energization timelines that better serve customer demand, along with a lower cost of charging, lead to increased adoption of EVs and increased electricity sales. Increased sales of electricity from EVs that are flexible and managed improves the utilization of existing and future grid assets. This, in turn, puts downward pressure on electricity rates and further reduces cost to all utility customers, enabling a positive feedback loop that accelerates the benefits of VGI.

For successful VGI, value must be universal. Value must accrue across multiple stakeholders and ultimately benefit customers and ratepayers by reducing costs and grid impacts and enhancing grid reliability and customer resilience. Keeping customers at the forefront as policies, practices, and solutions are implemented will help to achieve universal value for all Americans regardless of EV ownership. Table 1 describes the value of VGI for different stakeholders.

Stakeholder Type	Stakeholder Value
Grid/utility	• Increased utilization of invested assets • Increased electricity sales • Integration and increased utilization of clean energy resources • Increased grid reliability and resilience • Downward pressure on electricity rates • Seamless shifting of load • Avoidance of supply chain delays
Utility ratepayers	• Affordable electricity rates for all ratepayers • Increased grid reliability • Deferred or avoided utility investments in transmission, distribution, and generation assets
EV drivers	• Affordable and reliable electricity to power vehicles • Lower total cost of EV ownership and opportunity for additional revenue • Avoided cost of panel upgrades • Timely connections and energizations • Increased site or home resilience • Seamless managed charging experience and improved battery life
Charging network providers	• Faster energization timelines • Lower costs to connect
Automakers	• Increased EV sales • Customer resilience (home/site backup)—expanded market opportunity
Society	• Improved local air quality • Integration of clean and renewable energy • Reduction in greenhouse gas emissions
Labor/Workforce	• New career pathways and workforce development programs to install, operate, and maintain the grid and charging infrastructure

Table 1: VGI Value to Different Stakeholder Groups

Managed charging,[d] or the flexibility of EVs to shift the timing and magnitude of energy demand, is one of the largest and most studied value propositions for VGI to date. By shifting when vehicles charge and potentially even providing energy either directly to a customer's home (V2H), building (V2B), or back to the grid (V2G), flexible charging and discharging can provide more cost-effective solutions to integrating EVs into the grid. Managed charging can defer costly grid upgrades by better utilizing the distribution system.[22] It can displace higher-priced generation with lower-priced options to capture the energy value. It can also reduce the need for stationary energy storage deployments if EV charging can be scheduled to occur during times of excess renewable energy production.

Multiple studies have quantified the value of managed charging to reduce peak demand, demonstrating substantial savings. Pacific Gas & Electric (PG&E) estimated a combined value of $300 per EV per year, including savings from bulk power, distribution system operational improvements, energy arbitrage, and emission reductions.[23] WeaveGrid, in collaboration with Boston Consulting Group, reported managed charging has the potential to avoid infrastructure investsment costs for generation, transmission, and distribution by roughly $4,000 per EV over the vehicles' lifetime.[24] A DOE analysis of deferment potential from managed charging across five states demonstrated a peak reduction of between 0.4% and 4.5%, which translates to a savings of $700 million by avoiding investment in four substations, 50 reenforced feeders, and 9,000 service transformers cumulatively for the five U.S. states assessed (CA, IL, NY, OK, and PA).[25] While the actual value, or realized value, from managed charging will vary depending on time and specific operating conditions, these estimates across multiple studies highlight why many stakeholders are pursuing managed charging as a key VGI tool to reduce costs.

Compared to some VGI approaches, like managed charging, that can be more easily quantified today, other VGI approaches have less easily monetized benefits or do not yet have established valuation methodologies. For example, V2G could provide ancillary services to the grid, such as frequency regulation, voltage management and blackstart services, but may require market rules and techno-economic analyses to quantify value. Likewise, V2H or virtual power plant applications can provide resilience improvements, while shortened interconnection timelines for chargers help EVSE providers, site hosts and customers, but these approaches aren't easily

VGI in Action: Working Within Capacity

Avoiding or deferring residential electrical panel upgrades

Most newer homes with 200-amp electrical service have sufficient electrical capacity to accommodate EV charging. However, the panel in some older homes may not be sized to accommodate concurrent additional peak load for the EV charger. VGI approaches, such as a load sharing device or a home energy management system, can optimize electricity demands to work within the capacity of an existing panel, avoiding costly panel upgrades.

Redwood Energy and NeoCharge recently demonstrated whole-home electrification of two homes with 100-amp electrical service in Arcata, California, using smart load splitters and API controllers. PG&E and Itron are partnering on the EV Connect pilot program. It uses grid edge computing to coordinate EV charging with panel and utility grid limits allowing customers to connect a level 2 EV charger at home faster without needing a service panel upgrade.[26]

d See Appendix A: Load Flexibility and Managed Charging.

monetized today. Establishing approaches to quantify VGI benefits and value further increases the total recognized value of VGI and enables accelerated integration of EVs with the grid.

Working alongside stakeholders and supporting them through all phases of a healthy innovation cycle—from imagining new ideas to anticipating challenges and assessing emerging risks to widespread adoption—DOE will provide resources and assistance to ensure that the system evolves and transforms in a manner that remains affordable. This supported transformation will ensure necessary capabilities are in place to create a secure, interoperable system across the vehicle, the charger, and the grid. Keeping customers at the forefront as policies, practices, and solutions are implemented will help to achieve universal value for all Americans regardless of EV ownership. The Department is committed to using the tools at its disposal to help stakeholders understand the value of VGI approaches and solutions and will provide resources so they can understand and evaluate the options available as they work to meet their local, state, and regional objectives while responding to growing electricity demand from EVs.

Figure 5: A representation of tools to enable VGI. With a suite of tools, local considerations—including cost-effectiveness, time to service, and customer experience—guide implementation.

VGI Opportunities to Enhance Value

Meeting new load growth from light-, medium-, and heavy-duty EVs over the coming decades will require significant coordination and planning across the transportation and electricity sectors. Beneficial VGI presents an opportunity to seamlessly integrate EVs while providing stakeholders with a portfolio of approaches for driving positive change and increased value in their communities, states, and regions. Successfully implemented, VGI can reduce the need for grid upgrades and increase grid efficiency by leveraging EV charging flexibility and the storage and energy of the onboard battery. Implementing emerging technological advancements and streamlining processes can provide EV customers with timely, cost-effective access to energy. A proactive planning posture allows for electricity infrastructure investments to be planned and phased in a way that balances opportunities and costs, so electricity remains affordable. Innovative VGI solutions can lead to new customer value streams and a convenient charging experience that helps customers manage their transportation costs.

However, beneficially integrating EVs with the grid requires new approaches. EVs are first and foremost used to meet transportation needs. In addition, many of processes that govern the electricity sector are based on the systems of the past. Harnessing the value and opportunities of VGI will require coordination of multiple stakeholders across jurisdictions and domains. Enhanced collaboration and knowledge-sharing is essential to accelerate learning and ensure efficient use of resources to take advantage of VGI opportunities and benefits. The following section describes key opportunities where VGI can provide value, along with the challenges and barriers that need to be addressed to successfully achieve the benefits of VGI.

Enhance Affordability and Support Grid Reliability and Resilience

EVs embody many of the changes taking place in the larger evolution of the nation's electric grid as customers are generating their own energy and showing a willingness to use their assets to support grid operations in return for compensation. VGI leverages customers' growing relationship with energy and the new and unique capabilities of EVs to bring greater efficiency to grid operations, ultimately helping to maintain affordable electricity rates. Unlike traditional electrical loads, EVs do not require electricity from the grid when being used, and with onboard batteries and significant periods between utilizing power, EVs have the flexibility to shift when they charge. The average personal vehicle is driven 10% of the time and sits unused the remaining hours of the day,[18] meaning that it is possible to shift charging to different time periods or modulate the vehicle's charging power without impeding the driver's transportation needs (Figure 6).

Managing vehicle charging to shape consumption can reduce system peaks, relieve grid congestion, and align with excess generation. This shift can improve grid asset utilization, making it possible to defer infrastructure upgrades and align charging with cost-effective electricity generation, lowering electricity costs to consumers. However, the amount of flexibility and the degree to which load can be shifted are highly dependent on the vehicle's use case and the customer's transportation requirements. Utilities have a spectrum of approaches available to manage load that include time varying rates, direct load control, and incentives to shift charging. Likewise, third party aggregators, as well as site-level and customer controls, have different opportunities for shaping load and require different levels of grid control capabilities. Some emerging approaches need validation and testing to be adopted and accepted, and a few are still under development and require further research Each approach ranges in cost and complexity to implement.

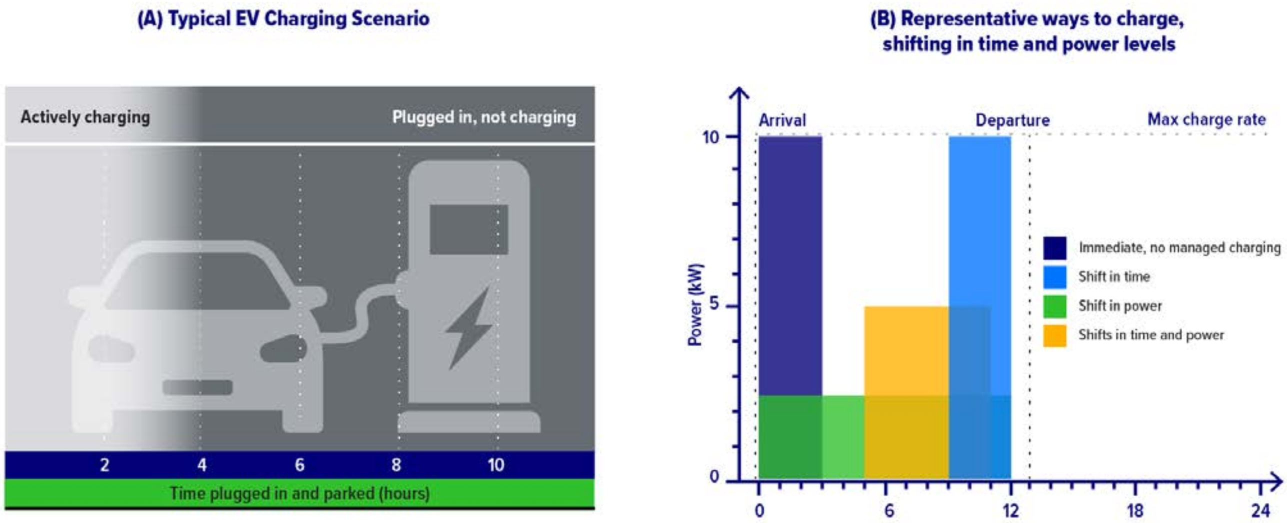


Figure 6: EV charging flexibility. A) Time flexibility in a typical light duty vehicle charging scenario, and B) Representative ways to meet charging demand by shifting power and time. Adapted from SEPA.[27]

The benefits of EV flexibility to the grid go beyond shifting energy. EVs can also provide cost-effective frequency response or other grid services such as reserve, regulation, frequency response, voltage management, and blackstart.[e] If appropriately incentivized or automated, EV charging can be managed or can be used as a mobile battery, potentially even discharging their stored energy to a home or back to the grid, while still meeting the driver's transportation needs. With EVs projected in 2030 to make up approximately 6% of 2023 total U.S. annual electricity demand[28] and growing by 2050 to levels equivalent to 20-50% of 2023 electricity demand,[f,29] this flexible resource offers tremendous potential for supporting grid reliability and resilience through grid services. Whether through automated customer settings or third-party or utility-controlled programs, customers can strategically balance their transportation needs with providing grid services to give them an additional value stream while minimizing the impact on or potentially improve battery lifetime.[30] Unlocking this full potential requires reimagining current institutional processes, business models, policies, and regulations. Developing and implementing signals that communicate grid conditions, along with markets and incentives for services that compensate customers, creates the environment for advanced solutions to take hold.[g, 31]

EV charging will occur at different power levels across locations to meet the various needs of EV drivers. Right-sizing charging infrastructure by using cost-effective charging infrastructure that matches transportation needs[18] and is secure, interoperable, and safe across the charging network can reduce the grid capacity needs while also enabling greater flexibility to serve this charging demand. The National Renewable Energy Laboratory's 2030 National Charging Network study identified a cost-effective charging network that would support 33 million light-duty EVs in 2030 while maximizing the convenience for a variety of passenger trips and minimizing charging infrastructure costs (Figure 7).[h, 32] Compared to a network where drivers rely more

e See Appendix B: Grid Services.
f Given the uncertainty around total future load, including potentially new load from buildings, industry and data centers, percentages are reported as a function of 2023 U.S. annual electricity generation.
g Grid visibility and control technologies such as AMI, ADMS, and DERMS provide the foundation for this sensing and signaling.
h In this network, 99.5% of the total ports are located at Level 1 and Level 2 charging ports located in single-family, multifamily properties and workplaces, with the remaining 0.5% split between publicly accessible Level 2 ports and fast direct current (DC) chargers along highway corridors and local communities.

heavily on fast charging (more similar to today's gas station model), a right-sized network, sized suitable to the dwell time, leveraging where vehicles are already parked, and where the majority of charging comes from lower powered charging (both Level 1 and Level 2), can reduce the grid capacity and associated cost needed to meet the load. In addition, increased reliance on Level 2 charging, where vehicles are often sitting for a duration longer than is needed to charge (Figure 6), also increases the opportunity for managed charging, which can further reduce grid impacts. Deploying a right-sized charging infrastructure network reduces the cost of charging infrastructure while also allowing for the right-sizing of grid infrastructure, thereby reducing costs to EV customers and utility ratepayers alike. Chargers with built-in capabilities to enable managed charging in a simple and customer-friendly way allow these benefits to be fully realized.

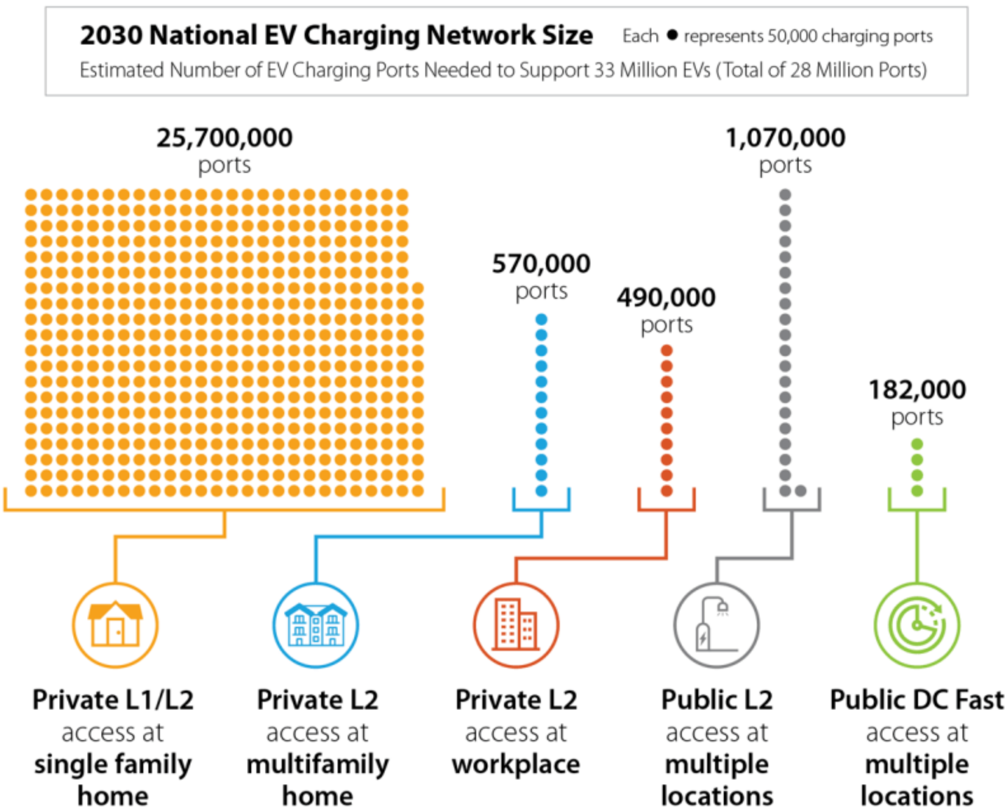


Figure 7: Baseline charging network to serve 33 million light-duty vehicles in 2030.[33]

While there is a large collective opportunity to align charging with grid needs and for EVs to provide other services to grid operations, customers must remain central to program development and incentive design. Serving their transportation needs must be paramount. Capitalizing on this opportunity will require a portfolio of rates and incentives that appeal to differing customer preferences and perceptions of value so that customers are willing to participate or respond. It requires understanding driver needs and behaviors to appropriately design programs that match customer motivations, as well as characterizing behavioral responses across all participant segments and use cases so that utilities have the confidence to integrate them into planning at scale.

From a grid planning perspective, incorporating EVs requires new approaches that allow utilities to manage the uncertainty associated with the timing and location of EV adoption as well as how consumers will charge. While VGI technologies have been tested and shown to be technically sound in demonstration, not all utilities yet have the confidence to apply these technologies at scale, and not all EVs and/or EVSE equipment is designed to fully support VGI, which hinders infrastructure and technology deployment and thus the realization of the benefits of widespread VGI. Clear valuation methodologies and certification test procedures are needed to quantify how VGI approaches will contribute to reliability and mitigate impacts. Scenario analysis and trusted data sets that characterize performance and behavior offer tools for utility planners and other stakeholders to enable integration at scale.

Embracing market-driven evolutions on the grid and leveraging emerging technological advancements can improve grid efficiency. Coupled with phased investments that right-size electricity infrastructure, the implementation of managed charging through rates or programs can economically benefit both ratepayers and investors.[i, 34] **Judiciously planned and managed, EVs can put downward pressure on electricity rates**, keeping rates affordable for all electricity customers, and EVs can serve to support and stabilize the grid during both standard and emergency operations while also increasing asset value to EV owners and all electricity customers.

Enable Timely, Cost-Effective Access to Electricity for EV Charging

While the pace of EV load growth will vary across the country, EV loads can show up much more quickly than other traditional electricity loads. These loads may be invisible to utilities because EV drivers do not always inform utilities when they purchase EVs. Even when known, grid investments can have much longer installation timeframes than that of EV charging infrastructure.[j] This unpredictability and accelerated pace can make planning for and responding to growing EV adoption challenging. **VGI approaches can enable faster grid interconnection timelines and reduce the costs of upgrading the grid.** Traditional electricity planning and operations are built on delivering electricity to immobile structures with relatively predictable usage patterns or deviations

VGI in Action: Strategically Sized Charging

Right-sizing charging infrastructure to reduce cost

Right-sizing charging infrastructure involves aligning the number, type, and placement of EV charging stations with charging demand and use patterns in a way that minimizes system cost. Niagara County, NY, with support from DOE's Clean Energy to Communities[k] technical assistance program, studied local patterns of driving, including how long vehicles park in different locations, and assessed the costs of different pathways of charging infrastructure deployment. This analysis informed Niagara County's subsequent purchase of a set of Level 2 charging stations, placed at five parks around the county. Matching dwell time with charging needs lowered costs for both the county and the EV drivers. Visitors and residents can plug in their EVs before enjoying the parks and come back to a full charge.[35]

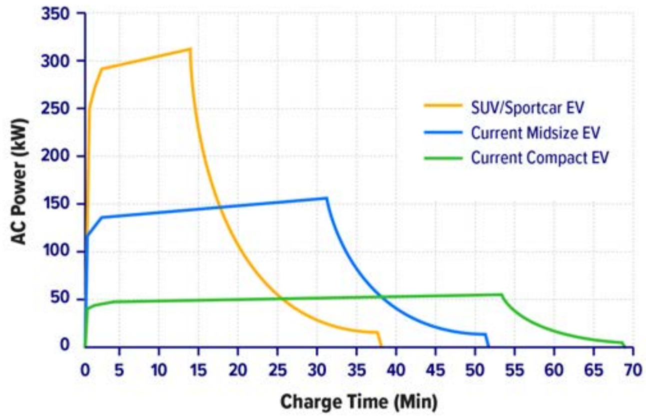
i An economic analysis performed by Lawrence Berkeley National Laboratory (Satchwell, A., et al. 2023) found that if EVs are deployed with Low Peak Impact (i.e., "managed") charging strategies, ratepayers are always better off because of lower cost impacts, suggesting that pricing and programs to encourage noncoincident peak charging are highly beneficial from the ratepayer perspective.

j The timeframe for installing vehicle chargers (months, weeks, or even days) is mismatched with the timeframe required for grid infrastructure (months or years).

k See Energy to Communities Program for more information.

throughout the day and the year. EVs and other distributed energy resources (DERs) are leading to a more dynamic grid environment that poses challenges for grid planners as customer requests for additional electricity to support EV charging and other beneficial electrification efforts test the norms for these practices. The ability to plan for and respond to new EV load will develop as decision makers become more familiar with this new technology. In the interim, increasing confidence in the reliability and performance of VGI approaches by bounding near-term uncertainty can enable faster deployment. Characterizing customer behavioral response can provide insights into how consumers charge holistically in response to rates, incentives, and managed charging programs. Certification of technologies that manage site loads to reduce net demand and establish the operational parameters for performance can provide the certainty needed so that solutions can be integrated into planning, ultimately leading to faster charger energization.

Example Direct Current Fast Charging Charge Profiles for Hypothetical Vehicles



	SUV/ Sportscar EV	Current Midsize EV	Current Compact EV
Max Charge Rate (kW)	300	150	50
Vehicle Charge (Miles)	250	275	150
Vehicle Resembles	Porsche Taycan	Tesla Model 3	Nissan Leaf

Figure 8: Charging profile varies over the charge cycle and for different vehicle makes and models.[36]

Besides EVs' unique charging flexibility, EV power requirements and charging characteristics are different from other traditional loads. The power needed to charge an EV varies throughout the charging cycle depending on the vehicle size, battery and charger capacity, the battery's state of charge when charging is initiated, the charging rate of different vehicle makes/models, and the vehicle charging profile. For example, for fast charging, the maximum charge rate is sustained only for a short duration, after which the charge rate slows (Figure 8).[l] Taking charging patterns into account and developing approaches to mitigate maximum coincident site demand, rather than evaluating charging only based on maximum coincident output for the entire charging cycle across all chargers at a site, can reduce site interconnection costs and allow timelier energization. Other opportunities to speed approval timelines include reevaluating interconnection processes and procedures for charger interconnections to account for EV load characteristics, and the use of certified site load management technologies when onsite battery storage or generation are included to reduce grid impacts.[m]

l The power reduction toward the end of the DC charge cycle (at about 80% State of Charge) is a deliberate design choice to safeguard the battery for overvoltage.

m This along with other opportunities to speed energization timelines are captured in EV Charging Infrastructure Energization: An Overview of Approaches for Simplifying and Accelerating Timelines to Processing EV Charging Load Service Requests.

New EV loads heighten the need for utilities, developers, and regulators to coordinate and share information that allows new operating variables to be incorporated with distribution engineering and align planning timeframes to timely and cost-effectively connect EV chargers. Automating review processes or implementing new approaches, such as flexible interconnection,[n, 37] can serve EV customers' time-sensitive and fast-growing interest in deploying and energizing EV charging infrastructure and increase the utilization of existing grid assets and reduce costs for general ratepayers.

Increased grid transparency, enabled through approaches such as load and hosting capacity maps,[o] offers another opportunity for more timely access to electricity for EV charging. It can provide a foundation for a more robust and constructive dialogue between stakeholders that leads to solutions or approaches that increase grid efficiency and lead to greater customer satisfaction. Automating the process of creating and maintaining a load or capacity map can make it more cost effective and enable more timely updates. With up-to-date data on grid capacity site developers and other stakeholders can strategically locate charging where capacity is available, helping to lower interconnection costs and reduce energization timelines. In addition, increased transparency about available capacity and other grid characteristics can foster innovative third-party solutions that offer value for customers, the utility, and site owners. It can also reduce infrastructure upgrades and costs when appropriately balanced by policies and practices that respect confidentiality, privacy, and proprietary operational concerns.

Automated processes, such as those that streamline and increase the transparency of load service requests and interconnection review processes, can provide stakeholders with a mechanism for staying up to date on the approval process, thereby increasing customer satisfaction and reducing frustration, while managing the time and resources required.

VGI in Action: Reducing Connection Timelines

Deferring service transformer upgrades through flexible service agreements

While utilities work on multi-year timelines to upgrade grid infrastructure for new EV load, charging infrastructure such as public charging or DC fast charging can be built in a matter of months. Developers looking to build public EV charging stations or fleet charging depots can face significant delays connecting to the grid due to a lack of existing capacity, ranging from several months to two years or beyond. This mismatch in timing is exacerbated by factors outside of utility control, such as supply chain constraints.

Stakeholders are investigating innovative service connection agreements to leverage the flexibility of EVs to more quickly connect to the grid. The SCE LCMS Pilot provides customers with early access to connection under the condition that SCE may reduce charging load during certain hours of the day, managing charging so that it does not exceed the existing electrical service capacity. The LCMS technology requires certification from a third party, providing utilities with the certainty that the technology works reliably. This approach reduces the service connection time from years to months while additional capacity is built out, which benefits both the fleet and the utility.[38]

n With flexible interconnection, software-controlled technology limits load to avoid violating grid constraints. Appropriately utilized, technology solutions could allow for additional interconnection without the need for upgrades.

o For example, U.S. Atlas of Electric Distribution System Hosting Capacity Maps.

Facilitate a Positive Customer Charging Experience

VGI can enable a seamless and reliable customer experience across EVs, EVSE, and utilities. Supporting interoperability between devices can make aligning charging with grid conditions simple to implement and enable scalable solutions that result in a positive charging experience for drivers. Grid responsive actions, such as managed charging or frequency regulation, require coordination across multiple parties. With multiple equipment manufacturers (EV and EVSE), thousands of utility jurisdictions, multiple standards development organizations and numerous other stakeholders (e.g., DER, aggregator, building management reliability coordinator/balancing authority), harmonizing codes, standards, and protocols can reduce fragmentation and lead to more positive outcomes for customers. EVs, and other DERs, increase the data that needs to be transmitted and shared between parties. Simplified interactions—underpinned by established cybersecurity practices between the grid and those devices, and well-defined, open communication protocols that provide the basis for sending and receiving data—can facilitate seamless operations. Standards-supported solutions enable common communication across technologies, including sending signals and verifying responses while avoiding the added cost of proprietary solutions. A single platform for customers at home and on the road can make it simple for customers to respond. Enabling an interoperable and secure system requires agreement among stakeholders, along with continued development of hardware, software, and communication procedures, as well as testing requirements, protocols, and procedures. It will also require appropriate distribution grid control capabilities and communications for data transfer in a standard format that is accessible and scalable to all vehicles and chargers.

Mutually Strengthen Transportation and Electricity Infrastructure

An interoperable system that provides a positive EV charging experience for customers goes beyond technology and standards that allow devices to communicate with each other. It also depends on cohesive relationships and interactions between parties within the system (i.e., how the structures, processes, and parties work together). **VGI can strengthen two fundamental pillars of society: transportation and electricity**. These two sectors of the economy, and the policies that govern them, have typically operated mostly independent from one another. Now with more widespread adoption of EVs, sector-focused policymaking can result in one agency's actions having unforeseen implications for another sector.

Through cross-sector planning and collaboration, grid designers, transportation planners, and other stakeholders can assess the interplay between sectors to identify and mitigate risks and to determine options that enhance citizens' lives and improve the efficiencies of both sectors. Regional and state planning activities can identify strategic opportunities for shared resources and utilize an element of risk science to develop contingency and disaster response plans that ensure resilience and enable effective and efficient restoration efforts. The VGI policies and practices that spur progress and innovation reinforce linkages between the sectors, consider new interdependencies, enhance domestic supply chains, and develop a skilled workforce to operate, install, and maintain VGI solutions.

VGI in Action:
Reducing Regulatory Barriers

EV charging interconnection rules provide direction to utilities

EV batteries with bidirectional charging capabilities have the potential to provide cost-effective energy storage and other grid services to enhance reliability and resilience to the electric grid, while also offering customer benefits, including resilience, backup power, and avoided demand charges. However, a lack of standardized interconnection processes and other barriers are preventing broader adoption.

Recognizing the value for ratepayers, legislatures in Maryland and California have directed their regulators to develop rules and regulations for how bidirectional chargers can interconnect with the grid. Utility experts have highlighted areas where regulatory barriers are preventing vehicle-to-everything (V2X) deployment, highlighting the role of regulations and policy to accelerate beneficial VGI implementation.[39]

As the grid edge becomes more interactive and dependent on customer assets, and as the industry seeks cost-effective and timely solutions, integrated planning processes can account for the combined needs. Integrated planning that takes a holistic view can align actions and create efficiencies across sectors and address supply chain considerations. There will be both short- and long-term solutions that co-evolve to adapt to the changing landscape. As confidence builds around these new technologies, sharing knowledge across jurisdictions and between parties can lead to faster scale-up by incorporating advancements learned from previous pilots and demonstrations. **Sharing successful approaches across sectors and lessons learned will allow stakeholders to develop a robust suite of solutions that work sooner.**

Strategies to Realize VGI Benefits and Value

DOE's Strategy for achieving a beneficial VGI future for all electric transportation represents a holistic, department-wide effort with three specific strategies that comprehensively support stakeholders in achieving the attributes described in the Vision. The three strategies support a healthy innovation cycle and target different aspects to address challenges, remove barriers, and allow stakeholders to capitalize on opportunities. Facilitating learnings and communication across strategies supports iterative learning that advances progress more quickly. Together, the three strategies aim to increase stakeholders' confidence in VGI technologies and the approaches needed to implement those technologies; support decision-making by providing data, tools, and frameworks that help to clarify options; and continue to advance technological innovation that enables progress and supports American competitiveness. Executed in parallel, the three strategies work together to support stakeholders as they evaluate options and take action across the three domains of technology, markets, and processes to meet their goals and objectives to beneficially integrate EVs with the grid (Figure 9).

Strategy 1:
Validate Repeatable, Extensible VGI Solutions

- Flexible charge management approaches to enable load shifting
- Utilizing EVs to enhance reliability and resilience
- Seamless data and information sharing technology solutions

Strategy 2:
Support VGI Institutional Decision-Making

- Build institutional knowledge
- Convene stakeholders to share information and develop resources
- Provide pathways to measure progress

Strategy 3:
Spur VGI Innovation

- Technological advancement and innovation
- Adapting to evolving technology
- Institutional innovation

Figure 9: DOE's strategies to support decision-making for VGI.

Strategy 1: Validate Repeatable, Extensible VGI Solutions

VGI pilots and demonstrations taking place across the country are testing VGI technologies and approaches. However, implementation of VGI to date remains relatively small and is occurring through disparate approaches across the country. Moving from demonstrations into widespread implementation requires identifying the most impactful, scalable, extensible approaches that maximize value to the grid, electricity customers, and EV drivers. For this to occur, it is necessary to characterize responses and certify the performance of new VGI technologies and solutions—building the confidence and certainty necessary for these technologies to be integrated into grid operation and planning. Quantifying and documenting the costs and benefits of these approaches supports evidentiary decision-making for approval of grid-related investments.

Proactive collaboration and sharing across demonstrations help build portfolio-level perspective that can inform future investments, programs, and approaches. Early consultation with stakeholders helps ensure projects are structured so results are extensible and support decision-making.

Working collectively with industry, **DOE will undertake high-impact field validations that provide value for all and that generate the evidentiary information necessary to support stakeholder decisions**. DOE will concentrate demonstrations on non-proprietary, interoperable, scalable solutions and ensure transparency to meet business and regulatory requirements. **Learnings will be actively shared across VGI stakeholders and between efforts underway in the two other strategies, extending the impact of the demonstrations**. Initial field validations will focus on three focus areas, **flexible charge management approaches for load shifting, enhancing reliability and resilience of utilizing EVs, and seamless data and information sharing technology solutions**. Priorities for validations will be responsive to emerging needs and new advancements gained in other DOE VGI strategies.

VGI in Action: Enabling Customer Resilience

Vehicle-to-Home/Load (V2H/L) providing backup power to ride out power outage

During the devastating 2024 hurricane season, bidirectional EV charging became a lifeline for powering homes, and also for supporting community services during an extended power outage. In Asheville, NC, after Hurricane Helene, a bidirectional EV charger powered essential appliances in the household. Trips to town to recharge the EV provided a chance to talk with and support neighbors.[40] Stories continue to emerge of bidirectional EVs powering community buildings and vet clinics, lifesaving medical equipment, and vital internet services during the outages. While bidirectional technology is still nascent, automakers recognize the value bidirectional technology provides both to customers and the grid and are increasingly including this capability in their EVs.[41]

Flexible charge management approaches to enable load shifting

Existing pilots on managed charging have typically been performed with relatively small numbers of vehicles and participants. They have explored a variety of approaches, including scheduled charging via on-board scheduling features or through a smartphone app, with incentives ranging from time-of-use rates to monthly credits for participation or free/discounted charging equipment.[42] While these pilots have provided valuable information and data about the feasibility of charge management approaches, utilities are still evaluating the value of such approaches to their system for deferring grid investments and mitigating grid impacts. In addition, experience in scaling programs across jurisdictions and utilities is limited, and the performance across a broad set of customers is not fully known.

To achieve widespread VGI deployment at scale, **DOE's VGI managed charging field validations have targeted and will continue to target high-impact charge management approaches**[p] and solutions that have the most potential to reduce grid impacts and provide value for customers and utility ratepayers.[q] These include dispersed charging of LDVs where vehicles are sitting for long periods of time, and concentrated, coordinated charging of fleets, such as trucking operations, transit buses, and school buses. Future demonstrations will test and evaluate a portfolio of advanced EV charging technologies, along with grid management and signaling capabilities and approaches, that leverage a variety of participation incentive structures. Demonstrations will assess customer response and categorize how approaches contribute to enhancing system reliability and resilience. Demonstrations will be designed to build confidence in the technology or approach, develop data reporting to support evidentiary decision-making, and be exportable to other jurisdictions or operational structures.

Utilizing EVs to enhance reliability and resilience

In addition to using charge management to shift load, EVs can provide additional grid services[r] and customer resilience benefits. **DOE will demonstrate the value of EVs to maintain grid reliability and both grid and customer resilience** through the provision of non-energy grid services and resilience benefits utilizing both unidirectional and bidirectional power flow, such as V2X. Grid services require two-way communication between the EV/EVSE and the utility or aggregator, along with continuous monitoring of service performance. Interoperability of communication and controls is essential for hundreds of thousands of EVs to provide reliable grid services such as frequency response or regulation services in unidirectional and bidirectional modes.[s] However, providing reliability and resilience benefits may become more possible and more desirable. As with flexible charge management approaches, validating the technologies in a way that demonstrates verifiable and trusted performance is essential to widespread deployment.

DOE will build on existing efforts[43] and continue to support field validations to demonstrate the interoperable and reliable delivery of grid services and customer resilience by EVs and to quantify the value of services to customers and the grid. Demonstrations will evaluate and demonstrate the value of new VGI business and operational models to identify value streams that reduce costs and enhance reliability and resilience while facilitating market access.

Seamless data and information sharing technology solutions

As decentralized assets, EVs and other DERs are changing the data landscape (see Figure 10). Integrating and synchronizing these numerous decentralized assets requires coordination and introduces new requirements

p Such as SuperTruck Charge and Connected Communities 2.0.
q See Appendix A: Load Flexibility and Managed Charging for more details.
r See Appendix B: Grid Services for more details.
s See Appendix B: Grid Services for more details.

for data exchange across parties. It expands the potential control surface of the grid but adds increasing operational complexity. With EVs and other DERs there is now data that originates outside the utility that can be valuable for utility operations and planning, and grid data can be valuable for other stakeholders as they develop solutions, create site infrastructure, and evaluate program performance. The need to share data heightens the focus on what and how data is shared and on data access requirements that enable data sharing while protecting consumer privacy and commercial confidentiality. Technology solutions that enable secure data exchange—providing the right data to the right stakeholders—can enhance planning, enable seamless operations, accelerate decision-making, and spur innovation.

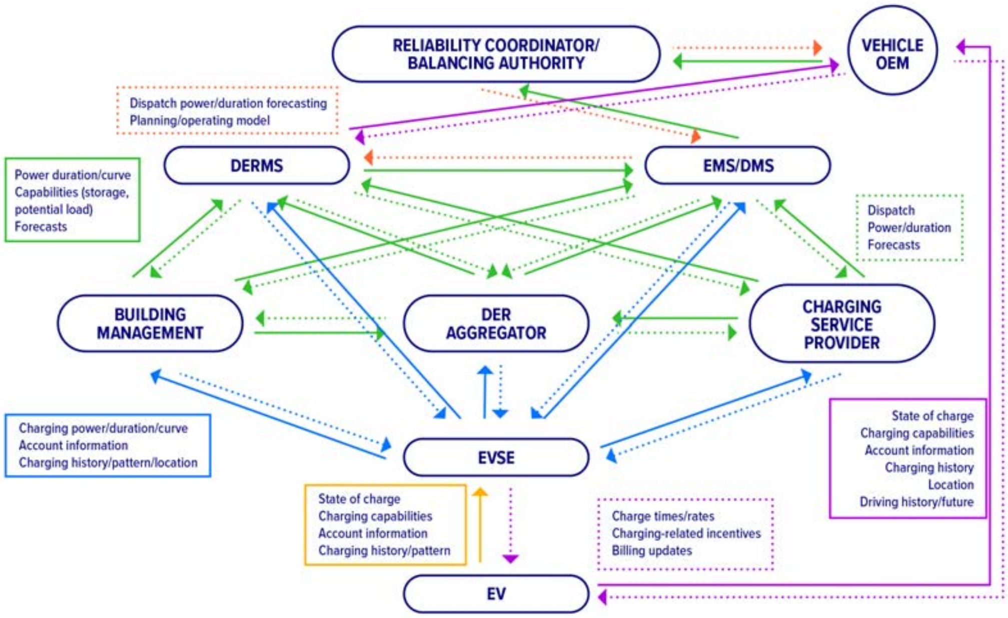


Figure 10: Potential data pathways for information exchange[22]

Automation can ease the time and effort required to perform tasks, increasing productivity and efficiency while providing up-to-date information for decision-making. For example, automating time-intensive processes, such as annual hosting capacity analysis or parts of interconnection studies, allows more current, reliable, accurate, and up-to-date system information across all VGI stakeholders. This can help site developers to understand cost implications and prioritize site selection where capacity is available, while still meeting customer needs. For customers, a smartphone app can automatically execute a response according to customers' preferences (such as "set-it-and-forget-it"[t]), enhancing the customer experience. In addition, innovative regulatory processes with higher levels of digital reporting allow greater exchange of information between regulated utilities and their regulator, fostering transparency and accelerating the overall timeframe of the decision-making process.

DOE will partner with industry to demonstrate innovations that automate and streamline interactions, improve data sharing, and increase worker productivity to accelerate VGI deployment. In partnership with industry, DOE will support the development of shared, scalable, open-source communication methodologies and demonstrate the approach in real-world conditions.

t SEPA coined expression. See endnote 19.

Strategy 2: Support VGI Institutional Decision-Making

Enabling accelerated decision-making across utility regulators, utilities, technology providers, and other stakeholders can accelerate VGI implementation. Increasing access to data, tools, and analysis, the identification of best practices, and development of frameworks are critical for robust decision-making. In addition, peer sharing and stakeholder convenings accelerate learning through collaboration by highlighting lessons learned, emerging gaps, and opportunities. DOE will support institutional decision-making across stakeholders through a coordinated set of activities, collectively referred to here as the VGI Accelerator (Figure 11). Utilizing a variety of mechanisms, the VGI Accelerator will increase decision-making capabilities, help stakeholders navigate options, and provide pathways for measuring progress.

DOE's VGI Accelerator includes programs and efforts specifically designed to draw on lessons learned through Strategy 1 (Validate Repeatable Extensible VGI Solutions) and Strategy 3 (Spur VGI Innovation), providing an integrated approach that enhances institutional knowledge about emerging approaches and solutions. Efforts will convene stakeholders to develop frameworks, identify best practices, and build a community of stakeholders that can work together and advance progress by exchanging ideas and resolving challenges. This, along with data, tools, and analysis, provides stakeholders a portfolio of resources as they work to achieve their local, state, and regional objectives. The VGI Accelerator efforts will help stakeholders prioritize efforts and will identify emerging topics and solutions. Activities will help to reduce uncertainty and provide structured approaches for evaluating options.

Build institutional knowledge

Increased knowledge and capacity at critical institutions is crucial to the successful implementation of VGI. In the face of multiple, fast-paced transformations at the grid edge, keeping pace with technological advancements and emerging solutions can be difficult and add to existing workload priorities. While a myriad of information exists, it is essential that information is actionable, accessible, and relevant so a stakeholder can apply outcomes and results to their circumstances. Vetted resources and direct support help stakeholders filter and prioritize information and address local needs, thereby reducing uncertainty and enabling accelerated progress.

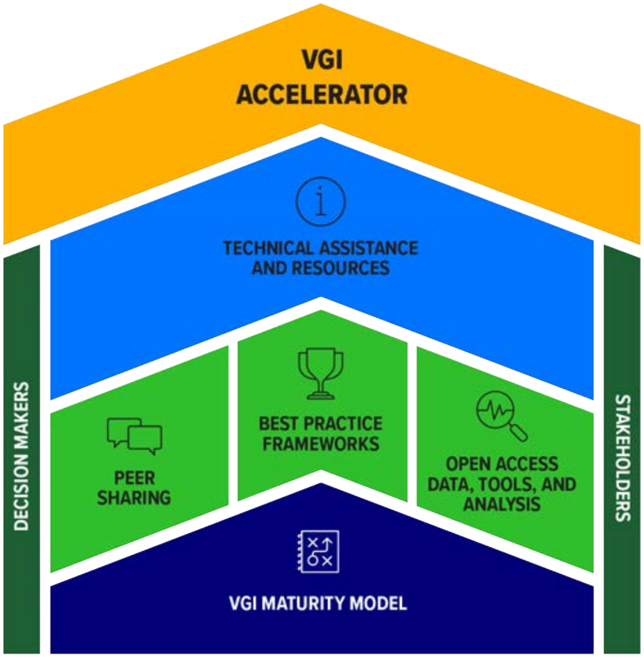


Figure 11: VGI Accelerator combines activities to accelerate institutional decision-making.

Trusted and independent data, tools, and analysis provide stakeholders with neutral, unbiased resources that assist with planning. Drawing on its longstanding and ongoing research, **DOE will support the creation of new or enhanced data, tools, and analysis to assist stakeholders in the evaluation and implementation of VGI. This will**

include EV adoption projection data sets, sample charging profiles, and valuation analyses for managed charging and VGI. DOE will continue working with national labs and industry partners to develop reference data sets and user-friendly tools and analysis that are accessible and publicly available to a wide audience, including regulators, utilities, and charging project developers.

A range of targeted and tailored assistance allows DOE to address stakeholders' specific needs. With technical support, states, utilities, and energy organizations can be more responsive to changing regional or local conditions and the evolving regulatory and policy landscape. **Through high-impact technical assistance, DOE will provide support and resources to regulators, utilities, and other stakeholders at differing levels of depth and duration**.[u]

Convene stakeholders to share information and develop resources

Integrating EVs requires collaboration and coordination across the expanded set of VGI stakeholders. Supporting a healthy exchange of information between stakeholders helps align perspectives and leads to development of structured approaches for decision-making in critical areas. Frameworks help increase confidence and build momentum so that new approaches can be embedded into institutional processes. Bridging diverse stakeholder perspectives leads to holistic, cost-effective solutions that provide value and enhance the customer experience. It also creates the environment where new challenges are identified and resolved so processes and practices can continually be adapted based on learnings and experience.

In its role as a convener, DOE brings the community of stakeholders together to hear different perspectives, identify synergies, and leverage lessons learned, supporting accelerated implementation of VGI. **Through multiple forms of stakeholder engagement, DOE will gather information on challenges, share best practices, and support the robust exchange of ideas and insights.**[v] **DOE will also convene stakeholders to develop frameworks that align stakeholders on approaches for key VGI issues,** such as load forecasting and cost-benefit analysis and data sharing. Sharing information encourages transparency while reducing information asymmetry across regulators, utilities, and other stakeholders.

u Such as the Resources and Assistance for State Energy Offices and Regulators technical assistance, the Utility and Grid Operator Technical Assistance and the Joint Office Technical Assistance.

v See EVGrid Assist COLLAB Forums.

Provide pathways to measure progress

Stakeholders across VGI are working to respond to consumer and business needs for EVs. Providing mechanisms for determining progress gives stakeholders a structured process for evaluating options and is essential for reducing unnecessary or distracting information, enabling stakeholders to prioritize actions and advance progress. While there are unique aspects, sizes, and timeframes of the various transformations taking place, there are also strong linkages and potentially common solution sets. Staged progression models[w] will underpin DOE's VGI Accelerator because the evolution from today's operational paradigm to one in which non-utility, distributed assets contribute to reliable, resilient electricity systems will take place at varying speeds in different areas based on the needs and priorities of those communities. **DOE will provide utilities and regulators with a structured, systematic approach for measuring their programmatic maturity in beneficially integrating EVs with the grid**. It will be a valuable resource for stakeholders as they evaluate strengths and weaknesses during planning processes and identify priority activities to enable progress in all three VGI categories (policy, technology, and processes). The model will also assist DOE in identifying emerging gaps and needs for frameworks and education, along with data, tools, and analysis.

w For example, Pacific Northwest National Laboratory's Cybersecurity Maturity Models.

Strategy 3: Spur VGI Innovation

Continued innovation across all VGI categories, technology, markets, and processes can unlock additional value. Research informed by lessons learned from deployed technologies and changing conditions along with foundational advancements that enhance capabilities and functionality leads to creative and novel solutions. This strategy describes three strategic areas of focus: technological advancement and innovation, adapting to evolving technology, and institutional innovation. Support for these elements will foster productive and mutually beneficial integration of EVs and the electricity grid, responding to core innovation needs.

Technological advancement and innovation

DOE conducts high-risk R&D and helps to catalyze technological advancements. Continued support for R&D efforts will build off DOE's long-standing portfolio for EVs, EV charging infrastructure, grid management and control, and cybersecurity.[x] To address technology-specific barriers and develop innovative solutions associated with a safe and secure charging ecosystem, along with grid management and control,[y] a significant level of pre-competitive and vendor-neutral R&D will be needed. As part of a healthy innovation cycle, **DOE will continue its R&D portfolio to advance fundamental research and develop early-stage technologies and approaches for the grid, the EV, and the EVSE** that are interoperable and secure.

Adapting to evolving technology

Technology will evolve as consumers use the technology and businesses implement VGI solutions. Likewise, cybersecurity, standards, the workforce, and an understanding of customer motivations and responses will need to evolve with technology. Addressing considerations from these key areas will ensure that communications are secure and work seamlessly across technologies, that the workforce has the necessary skills and capabilities, and that solutions are responsive to customer needs.

Secure coordination is one of the core pillars of the VGI Vision. If not proactively addressed, cyber-related risks and consequences can increase with growing numbers of EVs connected to the grid. Addressing vulnerabilities in the EV/EVSE ecosystem through Cyber-Informed Engineering[z] can help limit propagation of vulnerabilities. In collaboration with industry and other federal agencies, **DOE will continue efforts to identify and mitigate cybersecurity challenges and ensure integration of cybersecurity through all VGI activities.**

x For example, the Electric Vehicles at Scale Consortium Research.
y See Office of Electricity, Grid Controls and Communications.
z See Office of Cybersecurity, Energy Security, and Emergency Response Cyber-Informed Engineering.

Standards are foundational for safe and seamless operations across different actors and sectors at the VGI interface. There is a need for leadership and a clear vision to identify VGI standards requirements that ensure seamless integration that leverages vehicle and charger functionality while ensuring grid reliability and resilience. **DOE will continue its work with national and international standards bodies to prioritize standards, establish testing and certification requirements, and facilitate consensus building across stakeholders, while supporting harmonization across domains.**

The ability to adapt to evolving technology will be dependent on a skilled workforce who will install, operate, and maintain the infrastructure. A trained workforce that is prepared to respond to innovation is critical for scaling VGI. To meet the workforce needs required for VGI, it will be important to build on existing workforce development initiatives in the sector,[aa] while also utilizing sectoral workforce strategies.[ab] Training and retaining the workforce necessary to support VGI means ensuring that high-quality jobs with competitive wages, comprehensive benefits, health and safety training, and career pathways are available. Curriculum development and support for Registered Apprenticeships[44] and certification programs across VGI industries ensure workers have the necessary skill sets to succeed, while safety standards and training ensure worker safety while installing or maintaining equipment. **DOE will continue to prioritize workforce development and education opportunities, as well as direct training programs and safety standards across VGI activities.**

In addition, supporting career pathways that increase workforce capacity at critical energy organizations such as public utility commissions, grid operators, cooperatives, municipal utilities, and state energy offices helps increase institutional expertise.[ac] **DOE will continue to support career development in ways that promote increased knowledge about VGI solutions**.

As more EVs and other DERs are deployed, customers become active participants in grid operations. Technical approaches that overlay decision science onto behavioral response can illuminate how solutions contribute to reliability and affordability. Enhancing the understanding of human behavioral aspects to bound and characterize how and when customers may respond under blue and gray sky conditions is essential for grid planners to gain confidence so assets can be integrated into utility planning. Understanding customers' motivations for participation can also inform the development of programs and incentives so they appeal to customers and enable sufficient participation at scale. **DOE will investigate how consumers charge and respond to incentives or interventions for EV charging under normal and stress conditions.** This research will help ensure stakeholders provide a wide range of customer-centered options to maximize the benefits and value of VGI.

Institutional innovation

Institutional innovation focuses on developing mechanisms that incorporate learnings and adapt to changing conditions to speed deployment and manage the uncertainty that can accompany technological advances. Novel approaches to risk sharing and mitigation paired with innovative regulatory approaches, business models, and investment mechanisms can support the full integration of VGI.

aa Such as the Electric Vehicle Infrastructure Training Program, as required by the National Electric Vehicle Infrastructure Program.
ab Such as the Battery Workforce Initiative.
ac For example, the Energy Innovator Fellowship.

Meeting customers' accelerated demand for electricity can pose economic risks that make planning for grid infrastructure investments more challenging during initial EV growth. The investments for electricity infrastructure to meet charging demand will have to occur years before the increased revenue from electricity sales is realized due to different timeframes for investment and installation between electricity and charger infrastructure. Innovative approaches and financial mechanisms[ad] can bridge the timing misalignment and share risk, giving utilities and regulators the necessary confidence for more proactive electricity infrastructure investments, while reducing rate impacts in the near term and maintaining affordability in the long term.

Reimagining policies and practices can create an environment that speeds the development and integration of efficient, cost-effective, inventive, scalable solutions that are responsive to customer needs while enabling resilient, safe, and reliable grid operations.[ae] Innovative policies and practices can ensure transparency while maintaining prudent oversight. They can enhance stakeholder collaboration, encourage the development of new ideas, and create a supportive relationship between electric utilities, solution providers, and other stakeholders.

A healthy innovation cycle that embraces iterative learning can accelerate inventive solutions that help balance affordability with the need for greater infrastructure investments. **DOE will continue working with stakeholders to explore innovative approaches that speed implementation of scalable solutions while ensuring judicious investments that provide value to ratepayers.** Working with stakeholders, DOE will help evaluate new business models and compensation mechanisms that help match the needs and pace of changing market and operational dynamics.

VGI in Action: Engaging Fleets

Shortening the energization timeline for an EV charging station through proactive engagement

By actively identifying organizations early on that may electrify their fleets, utilities can project where load will increase and proactively prepare for this coming load, thereby accelerating the energization timeline for EV charging infrastructure.

Duke Energy's Fleet Electrification program engages stakeholders, explores technology options, and supports site and infrastructure investment to meet a fleet's operational needs. In addition, Duke Energy strategically identified fleet load clusters across the service territory where electrification is likely and proposed reconductoring capacity upgrades through their general rate case to support the anticipated load. By proactively increasing the capacity on the grid, the utility can meet this growing need for transportation electrification while avoiding operational disruption.[45]

ad The National Grid Electric Highways Study and Southern California Edison's load forecasting in its 2025 general rate case offer two approaches.

ae For example, the Connecticut Innovative Energy Solutions Program and the Joint Office of Energy and Transportation's iQMS for Clean Energy Interconnection and Energization program.

Indicators of Progress

Progress toward a beneficial EV-integrated future will occur at different speeds in different communities, driven by customer preferences; business needs and objectives; and community, state, regional, and national goals. VGI will also take different pathways to deployment, with jurisdictions, utilities, and others integrating VGI in ways that make the most sense for their needs. A portfolio of short- and long-term indicators can provide a more complete measure of progress toward a beneficial EV-integrated future and will be collected by a combination of DOE and stakeholders.

For example, the number of EV sales and installed chargers are progress indicators for the transition to transportation electrification and are tracked by DOE's Vehicle Technologies Office and the Joint Office of Energy and Transportation. The Grid Modernization Index, developed and tracked by GridWise Alliance, evaluates states' progress in modernizing the electric grid.[af] These are important aspects of a beneficial VGI future; however, demonstrating progress toward the VGI Vision extends beyond these metrics.

A portfolio of VGI metrics can track progress toward intermediate goals and encourage action by capturing both the grid and customer perspectives. The metrics identified in Tables 2 and 3, which focus on the intersection of the electricity and transportation systems, provide an overarching indication of progress. These indicators are not comprehensive, but rather help stakeholders prioritize action and ensure DOE's activities enable progress toward these metrics and the VGI Vision. By identifying metrics now and beginning to capture data during early EV growth, it will provide a baseline for measuring future progress.

Grid Perspective	Indicator	Metric	Connection to VGI Vision Pillar
	Near term		
	Grid signaling capabilities to facilitate time varying rates	Percentage of utilities with visibility and control technologies	3, 5
	VGI resources integrated in grid operations and planning	# of EV-integrated planning processes	1, 2
	Long term		
	Distribution system asset utilization	% grid utilization	1, 2
	Increasing proportion of transportation electricity that is flexible	Effective flexible MWh EV as a percentage of EV electricity sales	1

Table 2: Indicators of VGI Progress from a Grid Perspective (VGI pillars are described on page 7)

af The Grid Modernization Index provides insights on state and utility readiness to accommodate grid impacts in a reliable and affordable manner.

Customer Perspective	Indicator	Metric	Connection to VGI Vision Pillar
	Near term		
	Vehicles and chargers with VGI capability (managed charging, V2H, V2G)	#, % of models certified to smart charge standards	3, 4, 5
	Average reduction in energization time (commercial, residential)	Days, % reduction of energization time	2
	Long term		
	Increasing percentage of residential charging is flexible/ smart	% vehicles with preset configurations for load management	3, 4, 5
	Availability of programs, rates, or incentives for grid services	% of customers enrolled in programs, time varying rates, or incentives; number of utilities offering programs, time varying rates, or incentives	3. 4

Table 3: Indicators of VGI Progress Looking Through the Customer Lens (VGI pillars are described on page 7)

Conclusion

Beneficially integrating EVs and their associated electricity load with the grid presents unique opportunities for EVs to act as a resource for the grid and support customer resilience. VGI approaches and solutions can leverage the unique aspects of EVs to manage the increasing load, keep electricity and charging affordable, and maintain grid reliability and resilience.

DOE's holistic, department-wide Strategy supports stakeholders by validating extensible scalable solutions; accelerating decision-making by providing data, tools, and frameworks that help to clarify options; and continuing to advance innovation that enables VGI progress and supports American competitiveness. These strategies are designed to increase stakeholder confidence in VGI technologies, enabling investment in and widespread adoption of VGI approaches. The Strategy describes the portfolio of VGI tools and the value those tools can offer. It emphasizes areas where stakeholders, with DOE's support, can focus their attention and effort and find resources to accelerate VGI implementation. The Strategy highlights ongoing and future ways for stakeholders to get involved in sharing perspectives and developing solutions and how to get assistance.

VGI implementation must start now. Consumers and business continue to show increasing interest in EVs, and while the growth of EVs will vary throughout the country, by acting now it is possible to purposefully plan investments, establish grid-friendly charging behavior through well-designed rates and programs, and provide EV drivers timely connections to charging for commercial and personal use. Through judicious planning and robust collaboration across stakeholders, including utilities, EV automakers, regulators, EVSE providers, aggregators, and labor, it is possible to achieve the Vision for VGI that provides universal value for all electricity customers regardless of EV ownership.

DOE is committed to partnering with stakeholders as the electric grid and transportation sectors undergo this significant transition through the development of actionable solutions that meet the market needs and enhance affordability for all.

Appendix A: Load Flexibility and Managed Charging

Managing charging is a series of actions designed to modulate vehicle charging based on site, distribution, or transmission grid conditions, while ensuring that the vehicle is charged when the customer needs it. Implementing managed charging requires both technology solutions and programmatic implementation.

Shifting load or utilizing EVs for grid services (see Appendix B: Grid Services) can be accomplished through unidirectional charging or bidirectional charging and require communication and exchange of data across parties and platforms. Managed charging approaches can either be implemented through utility-controlled programs, like a demand response program, third-party aggregation of grid edge assets (e.g., rooftop solar batteries, EVs), or approaches on the customer side of the meter, such as automated load management.

To implement managed charging, three elements are needed: a signal to communicate the system conditions and consumer needs, an incentive to motivate participation, and a means of determining and implementing a response based on those inputs (Figure 12). Managed charging can take different forms, for instance, with a single entity such as a utility implementing all three elements or separate entities implementing each element. In addition, approaches can be layered together to provide the desired outcomes (i.e., a utility controlled program and a price signal to capture different market participants).

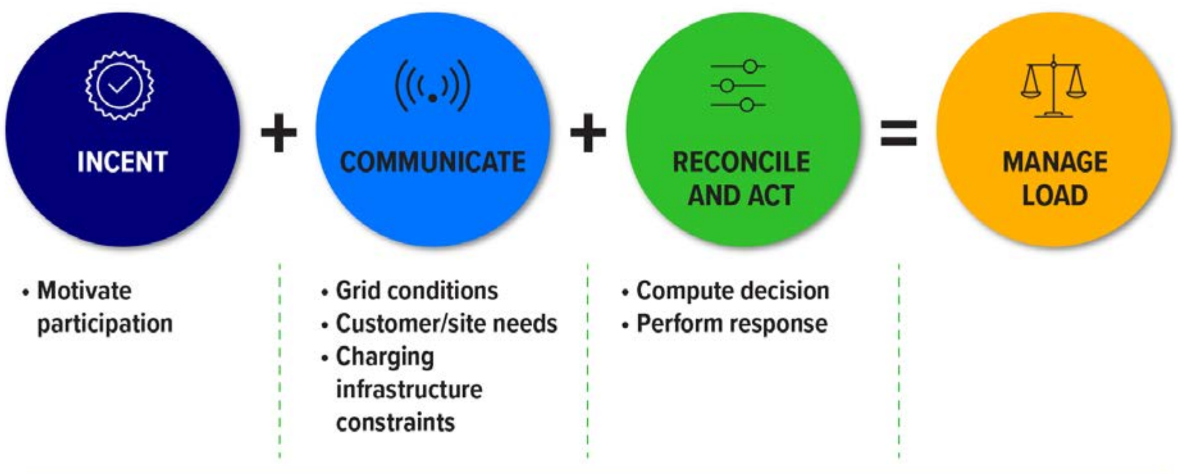


Figure 12: Components necessary for smart charge management

EVs will show up on the grid in different ways, either through larger concentrated loads or smaller dispersed loads (Figure 13). Both configurations will have implications for grid controls, as well as the ability to shift load and the value achieved. Large, concentrated loads have higher power needs and may have larger potential for voltage fluctuations than smaller dispersed loads, but likely fewer actors to coordinate. Managing the charging of many small, dispersed loads and leveraging them for grid services through third-party aggregation will require standards that enable consistent, interoperable implementation across jurisdictions and may require additional participating entities. Demonstrating the approach and validating the value of managed charging across multiple approaches and identifying those that scale and maximize value is instrumental for widespread implementation that limits grid impacts and provides value to utility ratepayers, EV drivers, and the grid.

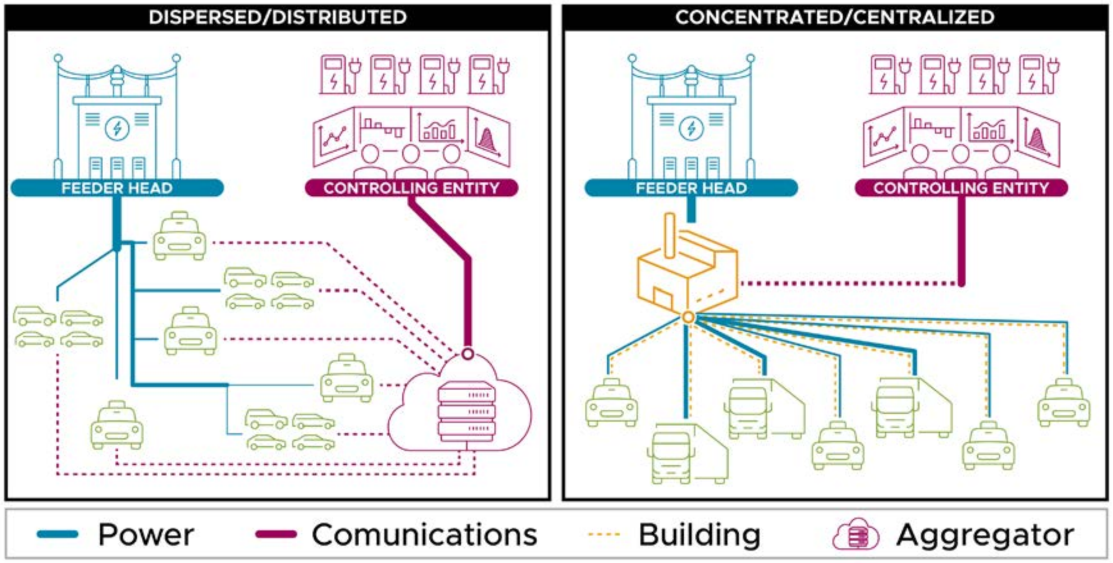


Figure 13: Representation of large, concentrated loads versus smaller, dispersed loads.

Currently there are fragmented approaches in how EV load is managed across installation type, in response to system constraints and the type of grid control (indirect or direct)[ag] (Figure 14). However, by validating and demonstrating a modular approach that pairs EVs, EVSE, and buildings in the context of the grid using open interoperability standards, DOE and the industry can simplify the number of variations that must be tested to build confidence for investment and scaling. A select number of demonstrations and validations all using a common control technology that spans the installation locations, grid controls, and system constraints can identify approaches that scale, thereby enabling economies of scale for manufacturers, easing utility implementation efforts, and simplifying participation for customers.

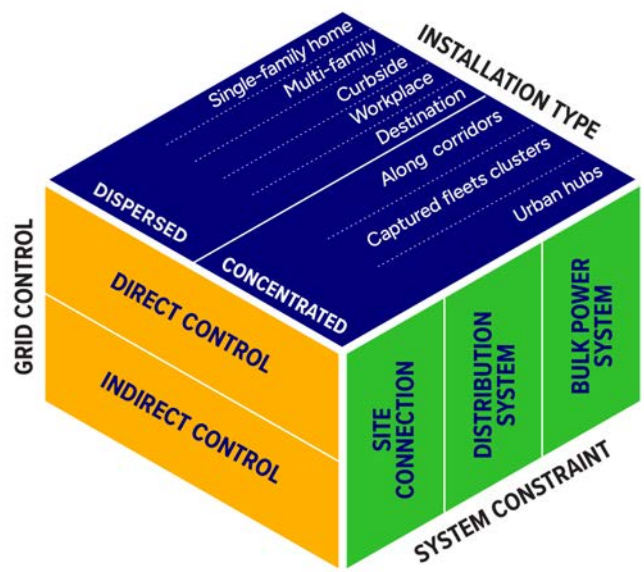


Figure 14: Dimensionality of EV charging installation types, system constraints, and grid controls.

ag Indirect control occurs through the communication of pricing incentives or signals that the vehicle or driver responds to based on charging needs and preferences. Direct control refers to an approach where a system administrator, such as a utility or a third party, operates the charging based upon system needs.

Appendix B: Grid Services

When connected to the electric grid through a charger, EVs can provide a range of grid services; however, the connection must have the ability to do more than simply charging, such as varying the charging rate, modifying the charging schedule, or even discharging energy back into the grid (i.e., V2G). These capabilities enable EVs to contribute toward "grid services." Grid services are defined as the ability of a device to help meet power system operational directives.[46] Operational directives have a variety of names but can be categorized in the six fundamental grid services as shown in Figure 15 below. These include:

1. Energy schedule service: a scheduled production of energy at an electrical location over a committed period.
2. Reserve service: reserves a specified capacity to produce or consume energy at an electrical location when called upon over a committed period.
3. Regulation service: continuously provides an increase or decrease in real power from an electrical location over a specified scheduled period against a predefined real-power basepoint.
4. Frequency response service: responds to a change in system frequency nearly instantaneously by consuming or producing power over a committed period.
5. Voltage management service: provides voltage support (raising or lowering) within a specified upper and lower voltage range at an electrical location over a committed period.
6. Blackstart service: energize or remain available without grid electrical supply to energize part of the electric system over a committed period.

Utility Objectives - Common Grid Service Definitions

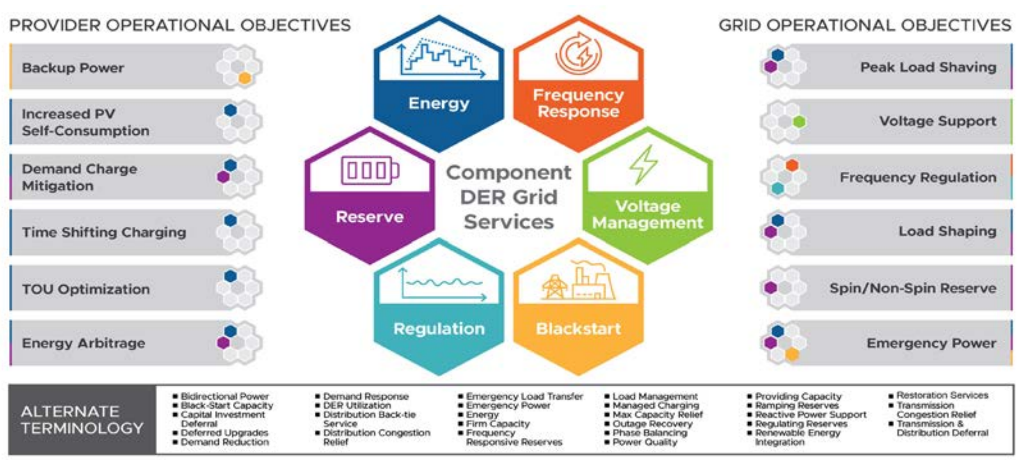


Figure 15: Grid services and alternative terminology[47]

Grid services are tightly monitored by the grid operator for accurate service delivery and performance using fast communication lines.

EVs are electrically capable of contributing to all components of grid services, though they require some method of controlling the active and/or reactive power output (watts and volt-amps reactive). For blackstart grid service, the vehicle must have V2G capability.[48] Other grid services are available with V1G capabilities. However, V2G capable vehicles enable more flexibility and often provide longer duration for the grid service.[49]

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