The Future of Vehicle Grid Integration

Harnessing the Flexibility of EV Charging

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Introduction

Transportation electrification is happening now. Consumers' preference for electric vehicles (EVs) is growing,[1] the number of available EV models is increasing,[2] and global enterprises have announced plans to go electric.[3] Federal funding[4] and private investments[5] are supporting the transition. Questions about the transition have moved past "if," and "when" has given way to "how." This transition is occurring at the same time with other transformations at the grid edge where buildings, industry, renewables, and storage come together, leading to projections of faster load growth for the first time in more than a decade.[6] Understanding the role of EVs in this coordinated transition is essential. **A shared vision for vehicle grid integration (VGI) can help stakeholders chart the course forward to harness the value EVs offer**.

An electrified transportation system can benefit all Americans. **Seamless VGI is crucial to achieving this goal and maximizing benefits for electricity system users and EV drivers**. VGI refers to the full suite of grid infrastructure, hardware, and software controls, and the corresponding markets and regulations that enable widespread adoption of electric vehicles in a way that supports the needs of both EV drivers and the grid. VGI supports the transition to cost-effective decarbonized transportation while also supporting the decarbonization of other sectors (e.g., buildings, industry, electricity), and further enhancing grid reliability and resilience.

EVs embody many of the changes taking place in the larger evolution of the nation's electric grid to **a system that is more nimble, flexible, resilient, and clean while also more dependent on and responsive to customer decisions**. Unlike traditional utility loads, EVs are flexible, mobile loads. They can shift the time and location of charging and can use the energy stored in their batteries to support electric grid operations and customer resilience while still meeting customer transportation needs. VGI takes the act of plugging in an EV beyond a simple one-way connection and capitalizes on the inherent flexibility of EV charging so vehicles become not just a load to be served but a grid resource. VGI encompasses a broad set of approaches, including deploying chargers at strategic locations to utilize existing grid capacity, managing charging by modifying the charge rate or charge time, or using the energy stored in the vehicle batteries to supply energy back to the grid or a building through approaches such as vehicle-to-buildings (V2B) or vehicle-to-grid (V2G).

EVs disrupt the status quo, raising new questions for decision makers. Capturing the value of EVs and integrating them into how the electricity system is planned, operated, and managed requires incorporating behavioral, market, and social sciences with engineering and economic solutions to create the conditions in which creativity and innovation flourish, **opening the door for inventive, ingenious, and better solutions**. Stakeholders must work together collaboratively to plan and coordinate solutions that match state and community objectives; align with customer values, lifestyles, and preferences; and support businesses' strategies and operating cycles. Such collaboration ensures that **EVs can provide benefits to the grid, customers, utility ratepayers, and society**.

1 In 2023, light-duty EV sales in the US exceeded 1.4 million while achieving 9% market share.
2 https://afdc.energy.gov/vehicles/electric_availability.html and https://www.anl.gov/esia/light-duty-electric-drive-vehicles-monthly-sales-updates.
3 IEA Global EV Outlook 2023, Corporate Strategy. https://www.iea.org/reports/global-ev-outlook-2023/corporate-strategy.
4 For example, programs like the National Electric Vehicle Infrastructure Program, which includes both public and private sector commitments.
5 Edison Electric Institute National Electric Highway Coalition; "Seven Automakers Unite to Create a Leading High-Powered Charging Network Across North America"; Clean Investment Monitor www.cleaninvestmentmonitor.org.
6 Wilson, J., and Z. Zimmerman. "The Era of Flat Power Demand is Over." December 2023.

About this Document

This document lays out a shared vision for a beneficial, EV-integrated future where EVs are safely and securely connected, reliably served, and harmonized with the electric grid. It was developed as part of The Department of Energy's (DOE) *EVGrid Assist* initiative. Stakeholder input was gathered through individual and collective conversations, including eight listening sessions with more than 100 participants representing utilities of different sizes and operating structures, manufacturers of vehicles and chargers, national associations, standards organizations, Tribes, fleet managers, consumer advocates, charging network operators, community-based organizations, utility regulators, consultants, vendors, labor, and environmental justice organizations.

DOE's ***EVGrid Assist: Accelerating the Transition*** initiative is a cross-DOE initiative focused on vehicle grid integration (VGI) that convenes the broad spectrum of stakeholders to demonstrate technologies, facilitate decision making, resolve challenges and barriers, and provide pathways for stronger stakeholder coordination.

This document focuses on the future of electric on-road U.S. transportation, specifically the integration of light-duty vehicles (LDV) and medium- and heavy-duty vehicles (MHDV) and their charging infrastructure with the electric grid. However, many of the insights here may apply to electrifying other transportation modes, as well as other distributed energy resources (DER).

The future illustrated in this document is the goal to work toward. While there is work ahead to develop pathways to success, identify opportunities for standardization, build business models, and ultimately accelerate VGI deployment, technological achievements and completed pilot projects demonstrate that the vision is achievable. This document is intended to ignite creativity, stimulate constructive dialogue, uncover roadblocks, and serve as a foundation for detailed, whole-industry planning and action that will make an electrified future a reality. Reflecting on the ambitious attributes can illuminate gaps and highlight areas that need attention, so that specific, measurable goals can be developed and adopted in the near term.

This document is meant to serve as a guidepost for the transition—helping stakeholders prioritize and target action as they face competing priorities and balance tradeoffs based on the needs of their local communities. In addition to this visioning document, DOE is developing a VGI strategy that will detail activities DOE plans take to support stakeholders' forward momentum in pursuit of the vision by continuing to advance and demonstrate technologies; facilitate stakeholder learnings and discussions; develop data, tools, and analyses that support decision making; and provide technical assistance to support stakeholders as they develop and implement solutions. In all of this work, DOE recognizes that the preferences and values of customers, workers, and business owners—those who will be using and maintaining the technology—will determine final outcomes, but by working together to chart pathways and to develop equitable, affordable, and reliable solutions, the vision will become a reality.

Shared Vision of VGI

Decarbonized | Reliable | Resilient | Cost-effective

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.

Successful VGI will create a decarbonized, reliable, resilient, cost-effective ecosystem that enhances value for the grid, EV drivers, electricity customers, and society. VGI is much more than connecting vehicles to the grid for charging. It seamlessly aligns the grid's physical infrastructure and operational structure, regulatory frameworks, and market design with customer charging behaviors to create a symbiotic relationship that benefits everyone, regardless of EV ownership.

With successful VGI, it is possible to meet customer mobility needs and their expanding relationship with energy while also enabling timely, cost-effective solutions. VGI enables accelerated, widespread adoption of electric vehicles (light-duty, medium, and heavy-duty) and associated charging at various power levels while minimizing impacts and maximizing benefits to the grid, users, and the public. This will be achieved by better utilizing past and future electricity infrastructure investments and aligning vehicle charging during times of available clean energy generation. EVs are one of the largest opportunities for virtual power plants (VPPs)[7] to offset grid infrastructure and generation assets.

Why is VGI Important?

- Ensures vehicles can be connected without delay.
- Puts downward pressure on electricity rates.
- Ensures cost-effective charging, which lowers total cost of EV ownership.
- Supports the integration of clean energy resources.
- Enhances grid reliability and resilience with EVs as a resource.
- Increases use of electricity infrastructure assets to reduce electric system cost.

VGI uses intelligent and flexible coordination to meet consumers' and businesses' transportation needs while providing benefits for all ratepayers that fund electricity infrastructure investments. VGI reduces the urgency for grid upgrades, allowing for more strategic and phased grid investments that optimize the use of available supply chains and existing electricity infrastructure. Ultimately, balancing benefits across stakeholders will require local decision makers to guide implementation and identify solutions that meet local priorities.

7 https://liftoff.energy.gov/wp-content/uploads/2023/09/20230911-Pathways-to-Commercial-Liftoff-Virtual-Power-Plants_update.pdf.

Attributes of a Realized Vision

The shared vision of VGI is built upon the following five pillars. The focus is VGI, but these attributes can also apply to other customer-sited DER such as solar panels and grid interactive, efficient buildings. Achieving these principles is enabled through grid tools[8] and is underpinned by a skilled workforce. These pillars open the door for other DERs, and, likewise, learning from other DER technologies lays a foundation and provides lessons learned for VGI. Each of these pillars is described in detail on the following pages.

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

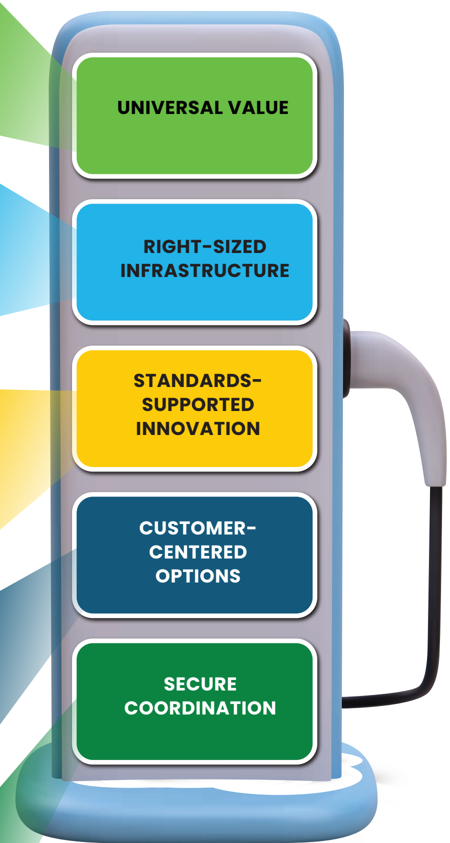
Harmonized grid, vehicle, and charger standards and clearly articulated grid requirements allow innovation to flourish and new products to be integrated into a robust, interoperable system.

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.



Core Pillars of the VGI Vision

8 Grid tools such as Distributed Energy Management Systems (DERMS) that integrate DERs with utility operations.

Pillar 1: UNIVERSAL VALUE

Universal value means that investments in electricity infrastructure to meet the diverse range of EV charging loads—whether at home or work, at fleet depots or parking facilities, or for on-the-go daily life or long-distance travel—offer value for all utility customers. Electrified transportation needs are met while also using EV flexibility and capabilities to support grid operations. Successful VGI enables a wide variety of convenient, accessible, and affordable charging options, and with increased electricity sales and more efficient use of shared electricity infrastructure investments, it extends value to electricity customers and puts downward pressure on rates.

1.1 EV charging and discharging helps maintain electricity rate affordability. Increasing electricity sales from vehicle charging during off-peak hours, lower price times, or during times of excess renewable generation, and discharging during system constraints helps to increase efficient use of the system, reduce costs, and maintain downward pressure on rates. Better use of grid assets reduces the risk of overbuilding.

1.2 Equity is a core tenant of VGI. Community planning related to EVs and charging are incorporated into collaborative grid infrastructure planning processes actively engaging a diverse set of stakeholders. This holistic approach reduces institutional barriers and ensures VGI infrastructure meets the unique needs of a community. This integration helps to ensure that all customers have the opportunity to participate in and benefit from electric transportation.

1.3 Financially viable investment strategies maintain charging infrastructure and include whole-system benefits. Investment approaches between the utility and site host complement ratepayer, private, and public capital so investments for electrified transportation do not create an undue burden on specific communities or ratepayer classes.

1.4 Economic signals reflect locational and temporal grid conditions. Rate signals or other market mechanisms reflect location and time-varying conditions of the grid and compensate for a wide variety of services. This allows customers to align vehicle charging with low-cost, clean energy resources and discourages charging or encourages discharging of stored energy, during times of system constraints.

1.5 Electrified transportation is ready to serve on blue, gray, and black sky days. Regional, local, and cross-sector planning ensure access to vehicle charging in the event of natural disasters. Collaboration and interagency coordination anticipate and addresses resource adequacy requirements, and contingency planning ensures that charging needs can be met during emergency situations or large-scale outages (e.g., wildfires, winter weather, hurricanes, etc.).

1.6 A diverse, high-quality workforce is essential to successful VGI. VGI implementation is underpinned by skilled workers in high-quality jobs. Registered electrical apprenticeships and certifications in relevant industries[9] are utilized and expanded to support the needs of VGI. Employers offer programs to readily recruit and train workers through good wages, training, supportive services, benefits and conditions, strong training programs and partnerships, and clear career pathways.

9 Such as the Electric Vehicle Infrastructure Training Program (EVITP). The National Electric Vehicle Infrastructure (NEVI) Program requires that all electricians installing, operating, or maintaining EV supply equipment have a certification from the EVITP or graduation or a continuing education certificate from a registered apprenticeship program.

Pillar 2: RIGHT-SIZED INFRASTRUCTURE

Investments in infrastructure are the right size, in the right place, and occur in the right timeframe to minimize system costs. Economic drivers along with institutional and regulatory mechanisms support right-sized charging and grid infrastructure investments. Integration with buildings and across DERs helps optimize energy usage to reduce capacity needs.

2.1 Right-sized charging infrastructure serves charging needs while minimizing future grid infrastructure investments. The charging network holistically serves customers' transportation needs in ways that are convenient, accessible, and affordable with an emphasis on lower power charging options, where possible. Using charging flexibility to shift charging to times of excess capacity or renewable generation increases utilization of electricity infrastructure.

2.2 EV load forecasting approaches are integrated into utility planning processes. Utilities anticipate additional charging load informed by exchanging relevant planning information with policy makers and commercial entities to facilitate proactive, timely infrastructure build-out. Appropriate utility compensation and third-party procurement mechanisms value EV flexibility and other non-wires alternatives[10] alongside traditional capital investments.

2.3 Planning and operational techniques that fully leverage demand and supply flexibility are widely implemented. Behavioral and decision science have characterized customers' willingness to participate and respond to programs, prices, and load management signals[11] sufficiently to incorporate EV flexibility into utility planning and operations. Established rules for participation—and accountability for that participation—define boundary conditions for performance, giving utilities confidence about how EV demand and supply flexibility can be used to enhance reliability.

2.4 Transparent grid data facilitates siting of charging infrastructure. Clear information about upgrade costs, capacity availability[12], and load service request processes helps developers and site owners identify cost-effective charging locations where capacity is available. Data availability fosters development of third-party products to enhance analysis for siting chargers, which increases speed, reduces costs, and improves the customer experience.

2.5 Flexible interconnection and active network management increase grid asset utilization. Flexible interconnection agreements ensure that charging does not violate grid constraints. This allows a greater number of electric vehicles to be connected to the grid on a faster timeline while increasing the use of existing grid infrastructure. Certified and tested software-controlled devices provide utilities with the necessary operational confidence to inform investment decisions.

2.6 Electricity and charger infrastructure is safely built, installed, operated, and maintained. Safety standards, practices, and training programs incorporate the interaction of EV charging with the grid. Workers have appropriate skills, training, and certification for routine tasks and emergency response situations. Standards and operating procedures are aligned across utility, third-party, and equipment providers to maintain worker safety.

10 Non-wires alternatives are investments or practices that allow a utility to avoid or defer infrastructure upgrades to traditional transmission and distribution equipment (i.e., poles and wires). Examples include use of DER, energy storage, energy efficiency, grid software, and controls.

11 With unidirectional charging, electricity from the utility charges the EV's battery. Bidirectional charging allows electricity to flow from the utility to the battery and from the battery back to the grid.

12 DOE's U.S. Atlas of Electric Distribution System Hosting Capacity Maps.

Pillar 3: STANDARDS-SUPPORTED INNOVATION

Integrating millions of EVs to provide grid services will require synchronization of these numerous decentralized resources. Codes, standards, and protocols create the conditions for increased innovation that unlock value for the customer and the grid.[13]

3.1 Comprehensive, appropriately harmonized codes and standards facilitate interoperability between chargers, vehicles, and the grid. Standards are open by default, non-proprietary and sufficiently defined to enable interoperability, yet provide enough flexibility to enable innovation. Testing and certification procedures ensure adherence across technology domains and applicable interfaces. Vehicles and chargers have interoperable, cost-effective control and management capabilities that allow customers to meet their charging needs while also providing grid services. Energy building codes and permitting processes include requirements for new or expanded charging capabilities.

Codes, standards, and protocols govern performance and lay the foundation for interoperability.

Standards: specifications to increase certainty that varied manufacturers' products are able to interconnect and operate with other products.

Protocols: rules for interaction between multiple parties, including rules on data exchange and commands for sending and receiving signals.

Codes: mandatory technical specifications required for product implementation, as defined and adopted by authorities.

3.2 Proper incentives, valuation, and market protocols along with interoperable technology facilitate bidirectional charging. Compelling business and value propositions for vehicles to import and export energy[14] are clear for utilities, businesses, and customers. Proper incentives for vehicle and charger manufacturers, EV drivers, fleets, and aggregators motivate participation, and appropriate grid management systems establish and maintain coordination. EV policies align with policies for other DERs so that value can be stacked and optimized across technologies.

3.3 Data access frameworks and open data enhance innovation. Well-defined roles, rights, and responsibilities of parties that share data across interface boundaries reduce tension and protect commercial interests by providing structure and clarity. Open data shared by stakeholders stimulates economic innovation.

3.4 Grid capabilities facilitate integration of third-party solutions. Utilities have the operational capabilities for integrating EVs and chargers and using them for grid services, either directly or through third-party solutions, to support grid resilience and reliability while maintaining grid security and mobility needs. Interoperable systems and technologies, along with appropriate grid controls and spatially and temporally varying signals, foster innovative products that automate load management and grid services to improve ease of use and value to the customer.

3.4 Converged accuracy standards for measuring EV charging minimizes costs. Interoperable technology capabilities between the grid, chargers, and vehicles to measure and verify energy usage, along with supporting regulatory policies, allow for reliable measurement and implementation of dynamic rates and incentive signals while minimizing customer costs.

13 The American National Standards Institute Electric Vehicle Standards Panel published a roadmap to help facilitate a more coordinated standards development approach across vehicle systems, charging infrastructure, grid integration, and cybersecurity.

14 Such as for vehicle-to-grid or vehicle-to-everything.

Pillar 4: CUSTOMER-CENTERED OPTIONS

VGI programs incorporate core consumer values of options, choice, and access. Fundamental to this premise is that customers have a wide range of products and services that are understandable and simple to use, and customers can select the options that best fit their needs or preferences. Customers have multiple pathways to use their vehicle to provide services to the grid and receive fair value for the services they provide.

4.1 Customers have different options for EV charging. Customers are not limited to a single solution or provider and have a range of rate and program options to charge the vehicle. Signing up or switching programs is convenient and simple. Programs developed by utilities, vehicle manufactures, network operators, or other entities cater to different customer preferences and varying appetites for complexity and involvement.

4.2 EV owners have multiple opportunities to use the vehicle to realize value both for resilience and by providing grid services. Whether they come from utilities, third parties, or direct market participation, programs enable solutions that stack value and meet the customers' unique needs and circumstances. In addition, value can be realized directly by the consumer through a range of options such as home resilience or backup power.

4.3 Simplicity is paramount. Implementation complexity is invisible to customers and reduces the participation burden. Technology eases the customer's ability to respond to dynamic rates or signals that optimize charging or discharging based on grid or market conditions. Customer set preferences ensure that EV drivers do not need to continually manage and respond to signals themselves.

Great technology is only as good as the end customer deems it.

Technology—whether for the vehicle, the charger, or the grid—must be used to have value. Customers want technology to improve reliability, lower their costs or expenses, benefit the environment, or serve some other metric important to them.

If the customer fails to see value or if using it is inconvenient or overly burdensome, they are unlikely to use it regardless of its importance to the grid. Tailoring VGI products and services to match customer's values and lifestyles is essential to maximizing VGI benefits.

4.4 Rates are transparent and accessible digitally. Easily accessed digital rates allow customers and businesses to plan, budget, and operate efficiently. Digitization of rates facilitates day-to-day charging, energy export transactions, and analysis of long-term EV purchase and operational decisions.

4.5 Compensation for the use of a vehicle's flexibility or service commensurate with the value rendered to the grid. Compensation mechanisms are tailored and proportionate to different customer segment values and preferences. Compensation is sufficient to warrant participation and adjusts as conditions change in the short- and long-term.

Pillar 5: SECURE COORDINATION

VGI systems are safe, secure, and protected from physical and cyber threats. Synchronizing numerous decentralized EVs is enabled by secure, seamless coordination and data sharing between various parties so that signals are sent and received between the charger, grid, vehicle, and buildings.[15],[16] Appropriate cybersecurity and data sharing practices enhance coordination, minimize risk, leave room for innovation, and maintain a positive customer experience.

5.1 Data transfer mechanisms create secure sharing between parties and across infrastructure boundaries. Secure data transfer between vehicles, utilities, and charging equipment facilitates reliable operations and improves interoperability and implementation of smart charge management, along with other advanced VGI tools that deliver the full value of a vehicle as a resource to consumers and the utility.

5.2 Cybersecurity requirements match the needs of specific use cases. Cybersecurity is intertwined with codes, standards, and protocols that are essential for communications, connectivity, and safety. Cybersecurity requirements are appropriate for different charging types and use cases.

5.3 Physical security and cybersecurity are an inherent part of the design process for EVs, charging stations, and the grid. Cyber-Informed Engineering[17] integrates mitigation measures that help limit vulnerabilities from propagating through the electric system. Requirements for cybersecure EV charging systems aid developers and manufacturers in product design and implementation.[18]

5.4 Security is strengthened by use of domestic content, especially for sensitive and strategic components, materials, and software. Key products are domestically manufactured, and critical services including software design and coding and customer service are carried out by U.S. workers. This better secures systems from supply chain disruptions and economic or cyber attacks, further enhancing quality, stability, and safety, and mitigating risks of disruption.

5.5 Data transfer boundaries and interfaces between entities are clearly defined. Established protocols enable actors in the ecosystem to transfer appropriate data across secure interfaces while maintaining privacy and network integrity. Boundaries between networks are well established and respect both the specific responsibilities and the ownership domains of each party.

5.6 Software change control protocols allow operators to respond to emerging threats. Operators have the means to identify, respond to, and mitigate cybersecurity threats. Appropriately implemented best practices and control mechanisms for threat response ensure continued reliability and enhance the customer experience.

15 Securing EVs and electric vehicle charging infrastructure is a strategic priority in the National Cyber Strategy, National-Cybersecurity-Strategy-2023.pdf (whitehouse.gov).
16 Securing EV Charging Infrastructure, https://www.energy.gov/ceser/articles/securing-ev-charging-infrastructure-part-3-working-together-impact.
17 https://www.energy.gov/ceser/cyber-informed-engineering.
18 Sample procurement language from the Joint Office of Energy and Transportation, https://driveelectric.gov/cybersecurity-clauses.

Working Together

DOE is one actor in the national transition to electrified transportation. Achieving the vision laid out in this document requires a collective effort between the public and private sectors, with all stakeholders having distinct roles. Collaboration among stakeholders is essential for achieving the full value of VGI. The community of stakeholders and their respective roles related to VGI include the list below:

Utilities and Grid Operators plan for electricity infrastructure upgrades to meet growing EV charging demand, enable vehicle connections, develop markets and programs to compensate participation, propose electricity rates, and collaboratively develop standards.

Utility Regulators implement legislative direction to meet individual state EV goals, determine utility compensation mechanisms, and assess utility infrastructure investment plans and proposed electricity rate tariffs. Regulators establish program requirements and set objectives.

Ratepayer Advocates, Community Groups, and Intervenors intercede in regulatory proceedings to promote the interest of consumers to maintain affordability for all customers; highlight opportunities to use advanced technologies; and highlight opportunities for policy action to drive equitable solutions.

State and Local Governments set energy, transportation, and building goals or targets; develop state transportation electrification plans and implementation programs; establish local zoning codes; and determine community development decisions that affect the load demand utilities must plan to meet.

Aggregators develop mechanisms for aggregating EV loads alongside other DERs to provide grid services in response to system constraints or to help mitigate peak demand, interact with customers, participate in standards setting processes, and develop solutions that appeal to different customers preferences.

Vehicle Original Equipment Manufacturers (OEMs) determine EV charging control capabilities, set default settings, and integrate protocols and standards that enable vehicle interoperability with chargers and the grid so that vehicles can provide grid services. They engage with customers to understand vehicle and charging preferences.

Charger Manufacturers develop charging equipment, its capabilities, and related consumer products and services. With vehicle OEMs, they are co-creators and implementers of codes and standards for charging and communication standards.

Charging Network Providers own and operate infrastructure that provides charging capability, making them key investors in charging infrastructure. They develop new business models that match consumer preferences and provide value-added services (e.g., smart charging, bidirectional charging).

Retailers, Site Hosts, Building Owners, and Charging Station Operators provide a location for vehicle charging and options for providing grid services as investors in infrastructure. They account for charging in site design and construction. They manage and optimize energy across all site loads.

Standards Development Organizations convene multiple stakeholders in consensus-driven processes to develop codes and standards.

Labor and Workforce Education and Training Organizations develop and offer industry-recognized training and certification that provides workers with necessary technical skills, career pathways, and access to upward mobility opportunities that support recruitment, diversity, and retention.

Trade Associations support industry collaborations and coalition-building, and provide services and tools that meet member needs, convene members to develop solutions to common challenges, and represent member positions.

Customers, including residential consumers, commercial businesses, and fleets, make the ultimate decision of the value of charging options, products, and services through their participation, which will hinge on their perceived value and convenience. They fund electricity infrastructure, and their preferences will drive new options.

Navigating the Path

The transition to electric transportation—and the way customers and businesses use and charge their vehicles—will go beyond simply changing "fuel" types. Achieving the vision outlined in this report will require near-term pragmatic actions, as well as long-term strategies that imaginatively consider, "what if?" Steps taken today must consider changing conditions while also looking to the future, so today's decisions do not close off future opportunities.

Creating a symbiotic relationship between vehicle, charger, and the grid will require keeping customers and their transportation needs at the forefront of policy and planning decisions, while aligning the grid's operational structure and physical infrastructure, regulatory frameworks, and market design. There are ways to translate the understanding of where we are and the vision of where we want to be into useful tools that can provide actionable information to decision makers. Those tools can take the form of best practices, processes, frameworks, or computer simulations to make progress easier to understand and achieve.

Creating a symbiotic relationship between vehicle, charger, and the grid will require keeping customers and their transportation needs at the forefront of policy and planning decisions.

Communities can drive the transition at different speeds based on their needs and priorities, as stakeholders and customers become more familiar with the technology and the opportunities for shared value. At a macro-level, VGI will seem to occur in distinct stages as programs are implemented throughout the country; however, VGI maturity in each community or at each utility may advance more quickly by leveraging best practices developed by those who have already implemented programs and integrated innovative solutions.

The pathway to a future with meaningful and durable VGI involves a process of iterative learning and refinement to unlock dynamic innovation and bring more value to customers, society, and the grid. Given the rapid pace of change, the number of options to consider, and the need for accelerated action, it is vitally important that there is a well-understood framework by which progress toward the long-term vision can be measured. This is especially important in the early phases when change is occurring most rapidly. The need for action will continue as the nation's transportation system continues to decarbonize.

Stages of VGI as Programs are Implemented Across the Country

Achieving the vision laid out here will not happen overnight, and it is not just a matter of flipping the right switches and agreeing on certain principles and practices among stakeholders. Progress will come in stages. By assessing successes and reflecting on lessons learned through each cycle of research and development, planning, deployment, and use, we can facilitate an accelerated transition that ensures cost-effective rapid adoption while reducing delays and costs.

During the **Early VGI stage**, investigations take place as stakeholders use their knowledge of the current system to explore new options and solutions, understand customer behaviors and motivations, test novel technological approaches, define new standards, and develop initial programs.

Progressing to **Expansion** builds on knowledge and expertise acquired during Early VGI. This stage may challenge existing regulatory and institutional paradigms to discover more cost-effective, efficient solutions and implement approaches that will support the rapid scaling of deployment.

Stakeholders will work to align technology and physical grid infrastructure needs with regulatory and market forces and will expand the understanding of factors that may motivate or influence a broader set of customer charging behavior or willingness to provide grid services. Institutional systems and processes begin to transform, laying the groundwork for greater customer participation and creating the conditions for market and product innovations.

Evolving from Expansion to **Widespread VGI** will require iterative learning and development of a body of experience characterizing customer behavior and technology responses that give utilities and their regulators confidence that EVs can be used as a grid resource without sacrificing customer transportation needs. With widespread VGI, innovation flourishes, and new approaches and technologies have gained momentum and become mainstream, making them the new norm.

Early VGI
Investigation to begin to understand benefits

Expansion of VGI
Program implementation for increasing value

Widespread VGI
Seamless integration of the grid's physical and operational infrastructure, regulatory frameworks, market design, and customer behavior

Achieving the Vision
- Universal Value
- Right-sized Infrastructure
- Standards-Supported Innovation
- Customer-Centered Options
- Secure Coordination
  - Creating a symbiotic relationship between Evs and the Grid

Advancing Capabilities to Enable Expanded Benefits

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