Enabling Infrastructure Sector Baseline

ALLIANCE 50X50 COMMISSION
ON U.S. TRANSPORTATION SECTOR EFFICIENCY

ALLIANCE TO SAVE ENERGY
using less. doing more.

Report by the
Enabling Infrastructure
Technical Committee
September 26, 2018

PREAMBLE

The Alliance to Save Energy launched the 50x50 Commission on U.S. Transportation Sector Efficiency (the "50x50 Commission") to lay out regulatory, policy, and investment pathways to significantly improve energy efficiency in the U.S. transportation sector. Comprising executives and decision makers from a range of key stakeholder groups—including vehicle manufacturers, utilities, federal and subnational governments, technology developers and providers, environmental advocates and targeted customers—the 50x50 Commission established the goal to reduce energy consumption in the U.S. transportation sector by 50 percent by 2050 on a pump-to-wheel (PTW) basis, relative to a 2016 baseline.

The 50x50 Commission work is complementary to that of the Alliance Commission on National Energy Efficiency Policy, which recommended energy efficiency policies and practices that could lead to a second doubling of energy productivity by 2030. As transportation represents roughly one-third of overall energy consumption in the U.S., the transportation sector offers enormous potential for gains in both energy efficiency and energy productivity.

The outputs of the 50x50 Commission include a foundational white paper that outlines the goals and scope of the Commission's work, a set of five "sector baseline" reports that assess the current state of energy efficiency within the transportation sector, and a suite of policy recommendations outlining the types of government support, at all levels, necessary to achieve the 50x50 goal.

This report, Enabling Infrastructure, is one of the five sector baseline reports that identifies the general market trends for efficient transportation technologies and explores opportunities and challenges related to deploying those technologies. This report and the sector baseline reports covering the other four technology areas—Light-duty Vehicles; Heavy-duty Vehicles & Freight; Non-road Vehicles; and ICT, Shared Mobility and Automation—helped inform the 50x50 Commission's policy recommendations.

Technical Committee

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While many Alliance to Save Energy staff assisted with the development of this document, special recognition is given to Natasha Vidangos and Mikelann Scerbo for their significant contributions to this sector baseline.

EXECUTIVE SUMMARY

Every form of transportation requires supporting infrastructure. In the case of most highway road vehicles, this includes infrastructure for fuel production, for the transport and distribution of the fuels for retail, and for the construction and operation of the fueling stations. While popular discourse around the transformation taking place in the transportation sector often focuses on the vehicles, it is equally critical to consider the infrastructural requirements that accompany each vehicle technology.

Appropriate development of fueling infrastructure—the primary focus of this report—involves enormous long-term and capital-intensive investments, planning, and coordination among many stakeholders, some of whom are being leveraged into new roles. Supporting infrastructure must be affordable and widely available across broad geographies and demographics, to achieve necessary levels of reliability and affordability. Investments can take years, if not decades to plan, develop and finance; and investments made in the near-term can help spur further development and encourage adoption of more efficient vehicles. If significant system-wide efficiency improvements are to be made by 2050, a vision for the necessary accompanying infrastructure must be planned for and committed to now. This work identifies a number of key findings, including:

General points

- **Public policy**
  Clear and supportive public policies are necessary to spur the significant capital investments in enabling infrastructure necessary to support widespread deployment of more efficient vehicles.

- **Coordination and collaboration**
  Coordination and collaboration among key stakeholders aligned around a common and sustainable strategic vision for the future will be critical to break through logistical and administrative barriers.

- **Variable infrastructure development**
  Infrastructure for the fuel production, transport, storage and distribution segments of the value chain is necessary to advance the market for all alternative fuel vehicles, but the infrastructure for each fuel type exists at different levels of development, and not all fuel types require the same level of new investments.

For electric vehicle infrastructure

- **Infrastructure requirements**
  The National Renewable Energy Laboratory (NREL) estimates that 27,500 direct-current (DC) fast chargers and 601,000 Level 2 (L2) chargers would be needed in 2030 to support 15 million light-duty plug-in electric vehicles (PEVs) in the United States. Other estimates suggest future demand may be even higher. Only 13 percent of this capability is currently installed (and not all installations are accessible by all PEV owners) and current private sector efforts are insufficient to meet expected future demand.

- **Robust power system**
  It is anticipated that the nation's electric system is robust enough to serve forecasted levels of PEV adoption in the near- and medium-term with careful planning and coordination of the infrastructure buildout.

- **Promoting access through standardization**
  Standardization of charging infrastructure would enhance the accessibility of electric vehicle (EV) chargers for all customers and is expected to positively affect PEV markets.

- **Equity and affordability**
  Policy development and implementation should ensure that low-income communities receive the benefits of electrification and alternative fuels.

- **New questions related to automation**
  Many industry observers have noted that EVs are natural targets for automation. How such automated vehicles are deployed in the future (e.g., for personal use or fleets of shared vehicles) may present new opportunities—and new uncertainties—related to how charging infrastructure should be designed, sited, and developed..

For alternative fuels infrastructure:

- **Co-benefits of alternative fuels**
  Many alternative fuels have the potential to provide benefits for the overall energy efficiency of the sector as well as a variety of co-benefits, such as improved air quality, greenhouse gas (GHG) and other emissions reductions, local economic development, convenience and fuel flexibility, affordability, and energy security. The potential benefits of the specific infrastructure requirements of these fuels also should be considered in an analysis of the future transportation paradigm.

- **Infrastructure development needs of hydrogen and renewable natural gas**
  Among alternative fuels, hydrogen and renewable natural gas (RNG) have the greatest need for new infrastructure. While RNG can be distributed through the existing extensive natural gas pipeline network, both hydrogen and RNG require infrastructure development for fuel production and fueling.

- **Alternative fuels in Medium and Heavy-duty Vehicles**
  Certain forms of heavier-duty vehicles are expected to delay electrification due to their extensive battery requirements; such vehicles also have seen significant advancements in alternative fuels, including propane and compressed natural gas (including RNG). Such fuels provide benefits in cost reductions and have infrastructure that is generally widely developed and available in the United States.

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STATEMENT OF SCOPE AND FOCUS

This report considers infrastructure for the deployment of more efficient vehicles, and more efficient vehicle usage, with a focus on downstream energy use to 2050. The scope of the report covers electric vehicle supply equipment (EVSE) and other alternative fueling infrastructure (hydrogen, propane, natural gas, and biologically derived fuel distribution infrastructure). The report discusses both the current state of development and potential barriers to widespread and accelerated adoption of more efficient vehicles, but does not judge which technologies would have a greater impact on achieving the 50x50 goal.

The report also briefly addresses stationary infrastructure that reduces vehicle idling, congestion, and other energy waste. Certain elements—such as truck stop and port electrification infrastructure—are not discussed in detail, since they are covered in other sector baseline reports (i.e., the heavy-duty vehicle and non-road vehicles sector baseline reports, respectively). Additionally, while the light-duty vehicle sector baseline report explores the specifications of vehicle charging infrastructure necessary to enhance EV deployment (i.e., "what do drivers need?") as well as the eventual assessment of vehicle demand in 2050, this report focuses on how such infrastructure can be designed, funded, owned, and operated effectively, such that social and environmental objectives are achieved (i.e., "how do we create and run it?").

Finally, this report focuses primarily on the "downstream" aspects of fueling and energy end-use. The infrastructure relating to the upstream aspects (i.e., the extraction, refinement, and production of fuels, and generation), while important for a comprehensive analysis of the transportation sector, is not a focus of this paper. However, an exception is made for fuels that are still in the nascent stages of production (renewable natural gas and hydrogen), since production infrastructure is as much a key barrier as the fuel distribution infrastructure to enable market growth.

DEFINITIONS

This paper discusses infrastructure relating to many different vehicle types as follows:

- **Conventional Internal Combustion Engine (ICE) vehicles:** vehicles operating with an internal combustion engine and conventional fuels (diesel, gasoline)
- **Hybrid Vehicles:** conventional gasoline/diesel vehicles that use hybrid technologies to enhance vehicle efficiency but do not use plug-in charging
- **Battery Electric Vehicles (BEVs):** short- or long-range electric vehicles that require plug-in battery charging as their sole fuel source
- **Plug-in Hybrid Electric Vehicles (PHEVs):** Dual-powertrain hybrid vehicles that include both a battery and an ICE for range extension
- **Plug-in Electric Vehicles (PEVs):** both BEVs and PHEVs
- **Electric Vehicle Supply Equipment (EVSE):** another term for PEV chargers
- **Fuel Cell Electric Vehicles (FCEVs):** fuel cell vehicles utilizing a hydrogen fuel source to drive an electric motor
- **Electric Vehicles (EVs):** all vehicles that use an electric motor, including FCEVs and PEVs (BEVs and PHEVs).
- **Flex Fuel Vehicles (FFVs):** vehicles capable of handling a wider range of biofuel blends than a conventional ICE
- **Alternative Fuel Vehicles:** all vehicles that have the capability to deploy a fuel other than conventional gasoline or diesel (including low-level fungible biofuel blends E10 or B5), including PEVs, FCEVs, natural gas, propane, and FFVs.

INTRODUCTION

Every form of transportation has infrastructure requirements. In the case of most highway road vehicles, this includes infrastructure for fuel production, for the transport and distribution of the fuels to fueling stations for retail, and for the fueling stations themselves. While popular discourse around energy-efficient vehicles often focuses on deploying alternative fuel vehicle types, it is equally critical to consider the infrastructural requirements that accompany each vehicle technology.

Appropriate development of fueling infrastructure—the primary focus of this report—involves enormous long-term and capital-intensive investments, planning, and coordination among many stakeholders. Supporting infrastructure must be affordable and widely available across broad geographies and demographics, to achieve necessary levels of reliability and affordability. Investments can take years, if not decades, to plan, develop and finance. If significant system-wide efficiency improvements are to be made by 2050, a vision for the necessary accompanying infrastructure must be planned for and committed to now.

To support a fast-growing market of alternative vehicles, fueling infrastructure must supply two main features: *access* (users can fuel their vehicles for typical use) and *coverage* (users can fuel their vehicles when traveling longer distances). When access is insufficient, it can stifle the market for specific demographics—for example, the EV market for consumers who live in apartment complexes without home charging options. Lack of access is a strong disincentive to owning an alternative fuel vehicle; and lack of coverage can lead to "range anxiety"—the concern that a consumer will not be able to travel longer distances with the vehicle.[1,2,3]

Range anxiety presents an early market timing challenge. Consumers are reluctant to purchase alternative fuel vehicles until the infrastructure is established, but policy makers and investors are reluctant to develop the necessary infrastructure until the market is stabilized by large-scale adoption, long-term policies, and robust future demand projections.[4] Due to limitations in access and coverage, currently more than two-thirds of alternative fuel passenger car purchasers and leasers do not use these vehicles as the primary household vehicle—a trend that implies the vehicles are disproportionately owned or leased by higher income households with the means to possess multiple vehicles.[5]

In the early stages of alternative vehicle market development, achieving sufficient coverage requires a sufficient number of fueling stations to be spatially distributed, but does not depend significantly on the number of vehicles serviced. As a result, during the early stages of vehicle deployments, fueling stations tend to be lightly utilized, providing poor incentive to build additional stations. The Department of Energy (DOE) refers to this as the "utilization gap." As vehicle penetrations increase, the utilization of existing stations increases and, at a given threshold, the market becomes more attractive and drives investment. Driving the market past the "utilization gap" is key to achieve widescale deployment of alternative fuel vehicles.[6]

Currently, fueling station coverage varies significantly by fuel source—both in total quantity and geographical distribution throughout the United States. Compared to approximately 160,000 gasoline fueling stations, there are an estimated 27,663 alternative fueling stations in the U.S., which is nonetheless a significant increase from approximately 10,000 in 2012.[7,8] The prevalence of alternative fueling station types, ranked from highest to lowest, is: electric vehicle charging ports (primary Level 2), ethanol,[a] compressed natural gas, propane, biodiesel, liquefied natural gas, and hydrogen. Significant numbers of ethanol stations are clustered in the Midwest and hydrogen stations are concentrated in California; other fuel types are distributed more broadly across the country. Figure 1 provides maps of current fueling/charging infrastructure.

a E85 blend. Ethanol blends are discussed in greater detail in the "Biofuels" section.

To enhance infrastructure development in this environment, the following elements are necessary:

- **Clear and supportive public policy**
  The appropriate regulatory and legislative bodies must make major commitments to support large investments in infrastructure. Furthermore, policies should support ongoing commitments that can lead to widespread deployment of the necessary charging infrastructure, including research and development, public-private partnerships (PPPs), establishment of codes and standards, and education and outreach campaigns.

- **Financing, investment, and ownership of infrastructure**
  With significant up-front capital requirements, some investments have long payback periods that complicate investment. Identifying an effective and financially feasible model for building, maintaining, owning, and operating infrastructure is key.

- **Data availability**
  Both vehicles and fueling/charging stations are a potential source of valuable data that can help define best practices and advance the market.

- **Complementing social and environmental priorities**
  Infrastructure design can have significant social and environmental impacts and should be designed to maximize positive impact for underserved populations and the environment.

- **Education and awareness**
  As for any innovative space with emerging technologies, end-user education and awareness will be critical to advance the use of alternative fuel vehicles.

- **Coordination among key stakeholders**
  Strategies to advance the use of alternative fuel vehicles will require high levels of coordination among stakeholders to help break through logistical and administrative barriers.

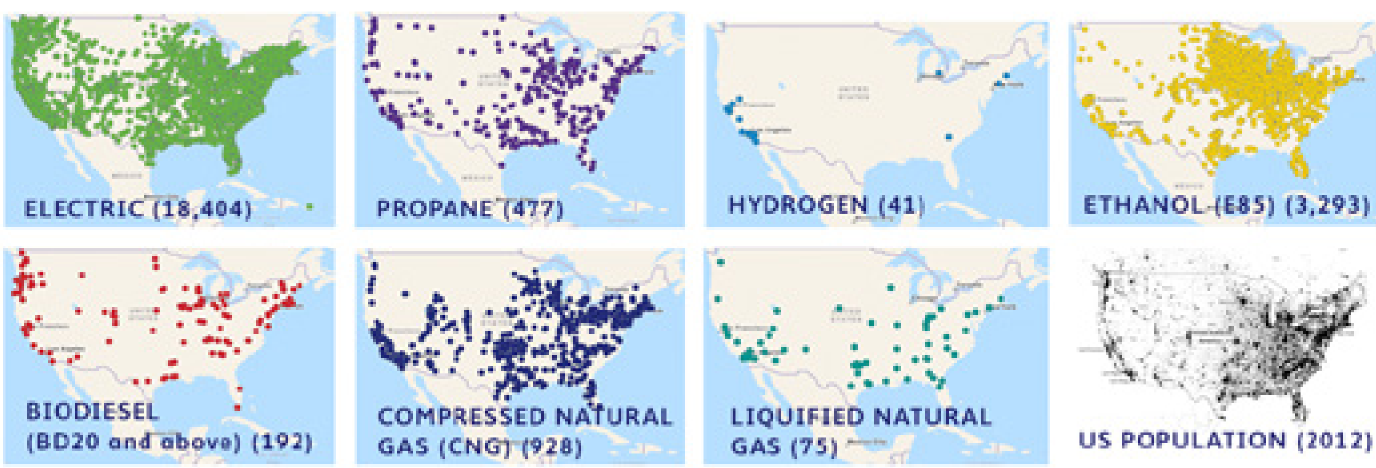
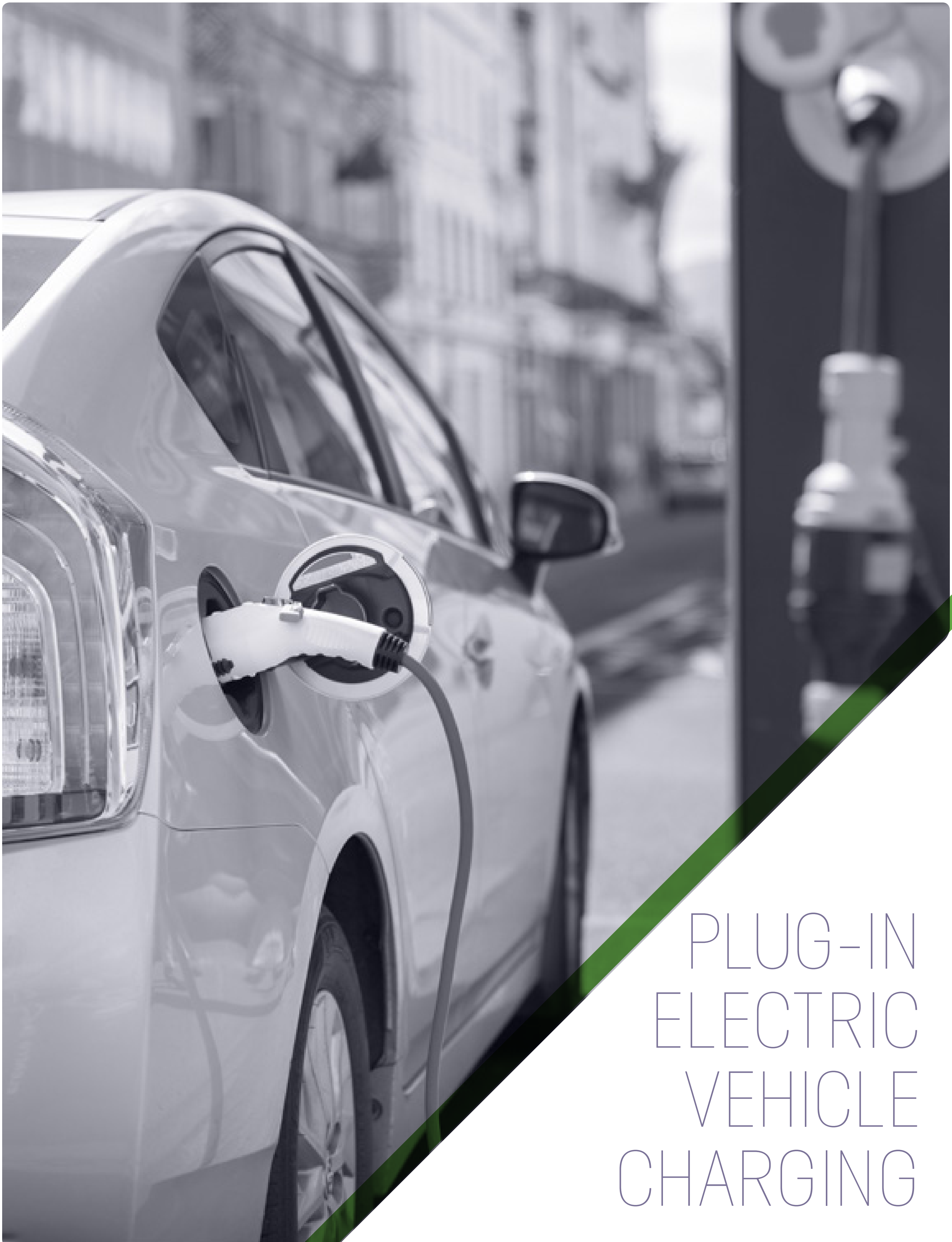


Figure 1: Number of fueling stations in the United States by fuel type (the number of stations referenced on the map are listed in parentheses), and 2012 population density of the United States (lower right).[9, 10] Electric charging stations include L1/L2/DCFC stations. Alternative Fuels Data Center, Department of Energy. Data current as of August 2018.

This report explores the current status of "enabling infrastructure" for different fuel types. Section I focuses on electric vehicle charging infrastructure, including discussions of different types of chargers and their relative costs and benefits; projections for the level of future demand and existing initiatives to expand the network; models for ownership and operation of charging infrastructure; considerations for utility involvement; and features—such as universal payment and station reliability—to ensure a positive customer experience. Additional topics include specific considerations for low-income consumers, the needs of medium- and heavy-duty electrified vehicles, and the tremendous opportunity and uncertainty that relates to infrastructure for automated vehicles (AVs).

Section II focuses on other alternative fuels (hydrogen, propane, natural gas, and biofuels), offering a snapshot of the benefits each can provide to society and users; their current levels of deployment and costs; technological opportunities for advancement; and their infrastructural requirements, opportunities, and challenges.



PLUG-IN ELECTRIC VEHICLE CHARGING

PLUG-IN ELECTRIC VEHICLE CHARGING

Electrification is markedly different from conventional liquid fueling. Unlike fossil fuels, which can be stored in simple storage tanks, electricity must be consumed when generated because wide-scale storage is often cost-prohibitive. The provision of reliable and affordable electric power is a complicated process, and utilities deploy extraordinary tools and operate in regionally specific regulatory environments to ensure power systems run reliably and efficiently. The combination of electricity and transportation leads to a new level of complexity and diversity of policy, regulatory, and private sector stakeholders, leveraging many of them into new roles.

Nevertheless, plug-in electric vehicles are on the rise. From 2015 to 2016 and 2016 to 2017, the U.S. PEV market grew 22 percent and 26 percent, respectively.[11,12] In addition, nearly all major automakers have announced plans for future EV options across most vehicle types and body styles, which will lead to increased options for PEVs in the marketplace.[13,14,15,16,17,18]

A variety of studies have demonstrated that vehicle electrification can bring benefits to society.[19] The potential advantages of electrification are numerous: PEVs can reduce household transportation costs, insulate consumers from gas price fluctuations, reduce or eliminate tailpipe pollutants[b] and improve U.S. energy diversification.[20,21]

To enable wide-scale vehicle electrification, establishing sufficient fuel infrastructure is paramount. Increasing the coverage and access to infrastructure would accelerate PEV consumer acceptance, facilitate long-distance travel (enabling PHEV drivers to increase their all-electric miles driven), and alleviate range anxiety concerns. Currently a majority of PEV charging activity takes place where the vehicles are parked – usually at a residence, workplace, or for commercial vehicles, the fleet yard. Increasing the coverage of charging stations will be important to overcome range anxiety and increase the number of PEVs that serve as the primary household vehicle. Increasing access also will be important to ensure the inclusion of communities, such as low-income communities where residents predominantly live in multi-family housing, and do not have regular access to charging infrastructure at home, work, or elsewhere.

An annual international assessment of the automotive industry, the 18th Automotive Executive Survey, found that while nearly half of 953 executive respondents viewed PEVs as a significant near-term market opportunity, 62 percent absolutely or partially agreed that the infrastructure challenges cause widespread PEV deployment to "fail."[22] Ensuring robust electrification infrastructure through careful design and effective policy will be fundamental to overcome these concerns.

EVSE Charger Types, Uses and Costs

EVSE is currently available at different power levels: Level 1 (L1), Level 2 (L2), and DC Fast Chargers (DCFC).[c] The power level determines how long it takes to charge a vehicle, and the cost of the infrastructure. Table 1 below summarizes the potential installers and specific challenges faced by the various charging infrastructure categories.

b The lifecycle emissions of electric vehicles reflect the upstream emissions from electricity generation. However, electric vehicles generally still result in overall emissions reductions relative to emissions associated with conventional gasoline vehicles. According to the Argonne National Laboratory's GREET "Well-to-Wheel Calculator," the well-to-wheel GHG emissions of a BEV passenger car running on 100 percent coal-fired power (377 gCO2e/mile) are estimated to be less than those of a conventional gasoline vehicle (421 gCO2e/mi) on a per-mile basis. They are, however, greater than those of a diesel vehicle (356 gCO2e/mi). Cleaner power enhances this effect, with BEVs running on the average U.S. mix estimated to produce 190 gCO2e/mi.

c The term "station" generally refers to a location with multiple charging "ports" to allow PEVs to plug in. There are variations of these terms in the current literature: Charging stations also can be referred to as "charging points," "electric recharging points," and electric vehicle supply equipment (EVSE). Ports are sometimes termed "plugs" or "outlets."

L1 Charging

L1 charging, the lowest level, requires a standard 120-volt (V) outlet already present in nearly all U.S. buildings. L1 equipment charges slowly, adding only two to five miles of range per one hour of charging, making it impractical for longer-range vehicles.

L2 Charging

L2 charging requires a 240V outlet (or 208V commercial electricity), which is a straightforward upgrade that can be made at a residential level; it is equivalent to the outlet used by a clothes dryer. L2 charging is significantly faster than L1 charging, supplying 10-20 miles of range per one hour of charging, and is commonly used for home or workplace charging stations.[23]

DCFC Stations

DCFC stations are much higher power (typically 480V), and provide the fastest charging experience, providing 60-80 miles of range per 20 minutes of charging, depending on the charger rating (20 kilowatt (kW)-400kW). DCFC charging is thus more comparable than L1/L2 charging to refueling a conventional vehicle. However, DCFC infrastructure also requires a larger investment, typically including upgrades to hardware, construction and grid assets, as well as sophisticated power electronics and switchgear, to meet the high power requirements. In the U.S., DCFC utilization rates are often 15 percent or less, due to the lower number of BEVs currently on the road;[24] this stands in contrast to a 34 percent utilization rate of the 160,000 U.S. gasoline stations.[25] This combination of high infrastructure costs and low near-term utilization makes DCFC investments challenging.

Station Costs

The cost to deploy charging stations varies significantly by location, utility territory, power level, and station size. Data from several studies suggest that residential L2 charging in retrofit situations typically costs $1,000–$1,200 per port for a single-family home.[26] DCFC stations cost considerably more given the sophisticated equipment and power electronics involved and the typical 480V electrical supply needed, typically varying from $100,000 to $300,000—with informal reports as low as $30,000—per charger. The largest cost component is typically hardware (i.e., transformers, switchgear, chargers, charging cables, storage), especially if new electrical service was required to service the site; other cost drivers include property negotiations, electrical power access, architectural design requirements, permitting, Americans with Disability Act accessibility, electrical service trenching, lighting and security design, project management, and labor. EVSE installations that have been designed in new construction projects have shown significantly lower costs, on the order of a tenfold reduction. Electrical conduit and breaker spaces in new single-family homes to accommodate charging are in the $150 to $300 range.[27]

Current Deployments of Charging Types

As of January 2018, there were approximately 17,000 public charging stations in the U.S., including 47,000 ports. Approximately 5 percent of these chargers are L1; 82 percent are L2; and 13 percent are DCFC.[28] There are approximately 10 companies that manage PEV charging stations as part of a network. Some of these firms own and operate their charging network (e.g., Tesla and EVgo), while others manage chargers owned by site hosts. The largest three are ChargePoint (21,728 ports), the Tesla Superchargers (7,481 ports), and Blink (3,582).

Table 1: Charging Infrastructure Categories, Potential Installers, and Specific Challenges (adapted from National Academy of Sciences, 2015)

Location	Type	Who has the incentive to install?	Challenges relating to this infrastructure
Interstate, intercity	DCFC	Vehicle manufacturer, government, utility	• Costly to build, depending on the power levels of the hardware and number of chargers involved, whether property requires purchase/lease, distance to higher voltage supply lines; and whether upgrades, trenching/conduit, or repaving of parking area is required. • High transfer rates can cause spikes in electricity demand. • Depending on utility rate structures (i.e., demand charges), electricity could be expensive, increasing operating cost for DCFC developers. • Utilization can be low, especially along rural, less traveled or seasonally important highway corridors.
Intracity	DCFC	Vehicle manufacturer, government, charging provider, utility	
Intracity	L1, L2	Utility, retailer, charging provider, vehicle manufacturer	• Cost of build varies; demand charges could raise electricity costs. • Utilization can be extremely low. • Incompatible with the charging speed needs and expectations of long range BEV owners.
Workplace	L1, L2	Business owner, utility	• Cost of build varies; demand charges could raise electricity costs; lack of clarity regarding whether to classify free workplace charging as imputed income or a de minimus benefit raises administrative barriers (which can be avoided by outsourcing installation, operation, and electricity costs to external charging providers).
Single-family Home	L1, L2	Vehicle owner, utility, tenant	• Straightforward; incentives and costs are generally aligned.
Multi-family home	L1, L2	Complex owner, municipalities, vehicle owners, tenant	• Condominium and homeowners association (HOA) bylaws frequently lack rules to govern deployment and use of EVSE equipment in shared parking lots or at assigned spaces; tenants may lack incentives to build, given that such areas are also historically low-utilization areas.

What Level of EVSE is Necessary?

Selecting sites for EVSE requires careful planning to ensure an appropriate distribution of charging stations—whether it be at home, in the workplace, or on trips (intracity, intercity, or interstate)—to support different kinds of travel. Planning EVSE sites, however, is complicated by a number of uncertainties, including:

- The share of PEVs (and the proportion of BEVs vs. PHEVs) in vehicle stocks in future years;
- The extent to which public EVSE infrastructure will mitigate range anxiety and drive PEV sales;
- The extent to which the user relies on home charging versus public, commercial, workplace;
- The optimal power levels for future charging, e.g., future readiness for ultrafast charging;
- The extent to which states and localities will rely on transportation electrification to meet climate and energy policy goals;
- Costs of charging for various charging levels; (DCFC costs considerably more than residential charging)
- Changes in vehicle miles traveled (VMT) resulting from a shift to autonomous vehicles.

A number of studies and policy proposals—including a 2017 report by NREL—have considered the levels of EVSE infrastructure that may be required in the future.[29] Based on a number of assumptions about 2030—including that the United States will host 15 million PEVs and that drivers generally will need to be within three miles of a charging station—NREL's central scenario estimates that the United States will require 27,500 new DCFC ports (grouped into 8,500 DCFC stations) and 601,000 new L2 ports by 2030. The authors comment that coverage in cities and towns will likely be more challenging than coverage in the interstate system. They further estimate that today's established charging infrastructure constitutes only 13 percent of the port count demand projected in 2030, and note that not all of the existing stations are accessible to all PEV owners due to incompatibility of charger types. However, some cities are more advanced than the national average, with San Jose, San Francisco, and Seattle reaching EVSE development levels of 73 percent, 43 percent, and 41 percent of their expected 2030 demand, respectively.[30]

EVSE charging requirement estimates performed by other parties, such as Tesla[31] and the State of California, suggest that EVSE needs may be even higher.

Existing Initiatives to Expand Charging Infrastructure

There are extensive developments underway to enhance the availability of charging infrastructure, as evidenced by the investments made by charging providers (e.g., ChargePoint, Greenlots, EVgo, eMotorWerks, and SemaConnect) and utilities (e.g., Kansas City Power and Light, Austin Energy, Georgia Power, Avista, and the Sacramento Municipal Utility District), and initiatives such as the Alliance for Transportation Electrification.[32,33,34] Additional examples of the growing marketplace for EVSE development include:

- As of August 2018, **Tesla** had established a network of 429 DCFC stations across the U.S. and Canada.[35] As of June 2017, the average distance between intracity Tesla supercharger stations was approximately 67 miles.[36]
- Established in 2017 as a subsidiary of the Volkswagen Group of America, **Electrify America** LLC plans to invest $2 billion in zero-emission vehicle (ZEV) infrastructure and educational programs over the next ten years—$800 million in California alone, and $1.2 billion in the rest of the U.S. Through mid-2019, Electrify America plans to develop 650+ community-based DCFC and L2 charging stations in retail locations, workplaces and multiunit dwellings across 17 metropolitan areas nationwide. It also plans to invest in nearly 300 DCFC stations along high-traffic corridors connecting 17 metropolitan areas, with an average of five chargers per station. Stations will be spaced an average of 70 miles apart, and no further than 120 miles apart. With charging power levels of 350 kW, this will be the first deployment in the U.S. of ultrafast charging at scale. The Rocky Mountain Institute (RMI) notes that this plan could deliver a 50 percent increase in DCFC charging ports across the country, doubling the existing charging capacity.[37] Nevertheless, the company's cumulative investment in infrastructure is expected to only address 4–15 percent of the charging needs in the 17 markets it has entered by 2020.[38,39]
- In addition to the Electrify America effort, Volkswagen Group of America will place $2.9 billion over four years into an **Environmental Mitigation Trust Fund.** Up to 15 percent of each state's allotment may fund EVSE deployment, and some states (e.g., Virginia) have initiated processes to invest this allotment in DCFC along highly traveled corridors.
- **Nissan and BMW** are also partnering to double the EVgo network of DCFC stations. As of January 2017, 174 EVgo 50kW fast charging stations across 33 states were installed, with an additional 50 stations planned for 2017.[40]
- **The U.S. Department of Transportation (DOT)** recently designated several highways as "alternative fuel corridors," with the aim of establishing a comprehensive national network of refueling stations. This effort includes 48 PEV charging corridors; most of these, however, are not yet corridor-ready.[41]

Other Features to Create a Positive Customer Experience with EVSEs

In addition to the location and prevalence of EVSE charging stations, there are also a number of other features that can help create a positive experience for customers when charging their vehicles.

Cheaper refueling than conventional fuels

Given the higher up-front cost of PEVs, it is widely understood that drivers should realize significant fuel cost savings relative to gasoline or diesel over the life of their vehicle, especially if they charge in a manner consistent with grid conditions (e.g. charging at low-peak periods).

Interoperability in DCFC

DCFC stations also face a specific challenge related to interoperability: While U.S. ports for L1 and L2 chargers are standardized, there exist three unique charging port configurations and communications protocols for DCFC charging stations. These include the non-proprietary DC Combined Charging System (CCS), CHAdeMO, and Tesla's proprietary Supercharger connector. As a result, PEV owners can only charge at stations that support their specific connector. This has been identified as a key barrier to greater accessibility of DCFC stations, and their business model.[42] This barrier could be addressed in a number of ways, including a policy mandating that all charging stations use a specific connector, or a requirement that all DCFC stations deploy multiple connectors. It also has been suggested that this challenge will be naturally resolved by the market: Once a specific connector predominates, all parties will be incentivized to adopt that connector type. In any case, greater coherence among connector types will expand the impact of DCFC stations for all consumers.

Readily available information to find and access stations

While public charging has not yet become ubiquitous, a proliferation of user applications ("apps") has facilitated user experiences with a variety of services, ranging from identifying parking spaces, shared mobility services, and EVSE (e.g., Plugshare, Alternative Fueling Station Locator). Such services—and their data quality and precision—are critical to ensure best usage of EVSE infrastructure. Currently, some EVSE-location apps lack the precision necessary to find a station in, for example, a large multistory parking structure, or are not updated frequently enough for users to trust their accuracy.

Universal payment mechanisms

The existing network of public charging stations has evolved through a bottom-up process that has led to a variety of payment methods and lack of interoperability. The RMI notes consumer complaints that drivers have to "carry a wallet full of radio-frequency identification (RFID) payment cards" for various charging station networks in order to travel long distances. Normal gasoline credit card readers have been shunned by current equipment network providers citing maintenance cost and excessive transaction fees.[43] To address this matter, California's legislation SB 454 prohibits EVSE providers from requiring customers to "obtain membership in any club, association, or organization as a condition of using the station," and requires stations to "allow a person desiring to use the station to pay via credit card or mobile technology, or both."

Consumer protection and accurate billing for public charging

Commonly, charging stations charge for electricity based on either the total plug-in time or the kilowatt-hours (kWh) drawn. However, due to limitations in metering technology, some inaccuracies have been identified in measuring electricity draws. As a result, some states prohibit kWh sales, while other states are developing best practices to create consistency in how electricity delivery is measured. As states, the federal government, and industry work to create consistency that will help guarantee that consumers receive the quantity of electricity for which they are billed, all parties must address practical and technical limitations.

Resilience

Approximately 36.7 million (out of approximately 325 million) people in the United States were affected by power outages in 2017,[44] and power system resilience has been a topic of robust discussion in policy and regulatory circles.[45] A greater penetration of electric vehicles could present both opportunities and challenges during future blackouts. On the positive side, if EV batteries are able to discharge electricity back to the grid, EVs could present a powerful backup battery for stranded communities and families. Where off-grid energy is available (e.g., from rooftop solar panels or distributed batteries), EVs may deliver greater energy-secure mobility access when other resources are unavailable. On the negative side, the greater reliance on the grid could result in unintended challenges if power is interrupted, limiting victims' ability to evacuate, or first-responders ability to reach victims in their electric vehicles. This topic should be considered carefully as PEV market penetrations increase.

Ensuring Longevity and Relevance of Investments ('Future Proofing')

One key challenge for developing electrification infrastructure is the fast pace of innovation. Will charging infrastructure deployed today be viable in 2050? The immediate priority is the development of EVSE in locations, and at increasingly high power levels, that will have high utilization in the near-, medium- and long-term future. Poor long-term siting decisions have the potential to waste investment dollars.

Backward Compatibility

As PEVs deploy larger battery packs with longer ranges, it is likely that consumers will prefer higher-power charging stations that deliver a faster charging experience. Automakers and charging equipment suppliers are working to ensure that chargers and vehicles remain compatible even as this trend develops, by allowing vehicles to "step down" the power they receive from charging stations. For example, many PEV batteries today can accept power from a DCFC of up to only 50kW. However, a "backwards compatible" 50kW DCFC capable vehicle can use a 350kW charger, since the car controls the level of power delivered. Backwards compatibility at the vehicle will help long-term planning for infrastructure, since a DCFC facility will not require multiple types of chargers to support all the different DCFC levels and types of vehicles. And in the meantime, newer vehicles are being developed that can charge at higher levels, such as the Hyundai Ioniq (100kW) and Tesla vehicles (120kW).

Make DCFC equipment upgrade-ready

Designing DCFC equipment for easy upgrade is another tool to "future proof" investments. For example, kiosk stations can be designed to allow upgrades to power electronics without a full "rip out and replace," and transformers in most cases can be rightsized to allow for station growth.

Who Does It? Investment, Ownership and Operation Considerations for Public Charging Infrastructure

Most parties agree that—in addition to stimulating electric vehicle markets and ensuring appropriate levels of EVSE coverage and access—the EVSE market should allow for healthy competition among providers. Given the inherent challenges of the EVSE market (e.g., the "chicken-and-egg" problem of electric vehicle and charging; the DCFC utilization gap; and the need to provide access in low-income communities), many institutions are interested in playing a role.

Although utilities are almost exclusively responsible for delivering electricity from the distribution system, different parties can serve as the developers, owners, and/or operators of charging station infrastructure. Governments, retailers, real estate companies, utilities, fleet owners and commercial third-party charging companies all may have incentives to finance, construct, own, and/or operate public EVSE (Table 1). For automakers, EVSE can be a market enabler; for example, it is generally understood that Tesla's investments in its "Supercharger" network are primarily intended to encourage would-be Tesla customers to purchase their battery electric vehicles. Some public-facing private businesses (e.g., Whole Foods, Cracker Barrel restaurants) establish charging infrastructure at their retail sites to attract customers. Third-party operators, such as Charge Point, Blink, and EVgo, view EVSE development and operation as a standalone business opportunity. Many utilities also may have interest in EVSE development, as they stand to benefit not only from authorized returns on electrical infrastructure assets, but from the increased revenue that will result from greater electricity demand.[d] In many cases, higher electricity sales can outweigh the costs of the additional infrastructure and put downward pressure on utility rates to the benefit of all utility customers.[46]

In some cases, a single entity develops, owns, and operates EVSE charging infrastructure. In other cases, multiple parties collaborate and/or subcontract different parts of the infrastructure and operation. In some states, multiple arrangements can coexist in one jurisdiction; in others, the business model for a charging network can evolve to include different players over time.

Given the relative newness of high-penetration EVSE infrastructure in the United States, this is a dynamic topic. Many different successful arrangements are emerging, and there appears to be no "right answer" for which business model is best. This diversity provides a panoply of options that can be customized to suit each community's needs, utilize blends of investor resources, and operate within specific regulatory frameworks. A more detailed discussion of different business models is included in Appendix A.

Utility-Specific Considerations

System Requirements for Future Scenarios of PEV Charging

The electric power industry is unlike any other. Due to the difficulty of storing electricity, utilities have a fundamental challenge in ensuring electricity supply perfectly matches demand on a near-instantaneous basis. Failing this balancing act (known as "load balancing" or "maintaining system frequency") can lead to exorbitant costs, damage to infrastructure, and blackouts. Load balancing also carries different challenges at different times of day: High-demand electricity periods, known as peak periods, require special attention and resources, and are responsible for significant costs to utilities and ratepayers. Given the natural complexities of managing the grid, a common question has been raised: Are we ready to provide enough electricity for widespread PEVs?

The answer appears to be yes. The nation's electric system is considered robust enough to serve forecasted levels of PEV adoption in the near- and medium-term. The National Academy of Sciences (NAS), in its 2015 Report on Overcoming Barriers to Deployment of PEVs, notes that PEV charging requirements would consume only 5 percent of electricity production if PEVs constituted 20 percent of vehicle stocks. Others estimate that if 100 percent of light- duty vehicles in the U.S. were replaced with PEVs, they would require 25 percent additional energy (1000 Terrawatt-hour) over today's levels.[47] Although most scenarios of PEV deployments require system upgrades—especially to distribution networks with a high density of PEVs—the NAS concluded that PEV deployment is not constrained by the transmission or generation system capacity, and is more likely to be impeded by electricity costs.[48]

While infrastructure upgrades for PEV charging become more necessary over the long term, the upgrades are expected to be manageable. The expected pace of near-term investment is on par with ongoing utility investment due to "normal" observed load growth. The expected long-term impacts, including reduction in transformer life expectancy, accelerated degradation of feeder networks, and substation capacity upgrades, may take years to materialize.[49]

PEV growth also could yield system benefits, for example, by smoothing demand between peak and non-peak periods. Unlike time-sensitive functions like air conditioning and lighting, most vehicle owners have the flexibility to charge their vehicles over a range of times, from late at night through mid-morning. Utilities can send users price signals that incentivize them to charge at non-peak times of day; these include special tariffs such as "time of use" (TOU) rates and

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d While this is true for many utilities, the motivations are slightly different for those that operate under decoupling policies, which dissociate the utility's profits from its electricity sales. In such cases, utilities are motivated not by increased revenue from electrification, but by the potential to lower customer rates.

demand response programs. Such programs allow utilities to help accommodate PEV charging growth at the lowest possible cost to all utility customers, maximizing the environmental and social benefits of PEV technology. (Utility Rate Design is a critical aspect of demand management with implications for electric system reliability and benefits, and is discussed in greater detail in Appendix B.) Some of these options also can be automated: PEVs can be programmed to delay charging to occur during beneficial times, consistent with utility rates. Many utilities, in collaboration with automakers organized by the Electric Power Research Institute, are supporting the development of a centralized, standardized software platform that can communicate utility dispatches or price signals directly to automakers' vehicles. This development will be grid-friendly, and cost-saving for vehicle owners.[50]

Current experiences from PEV-heavy states are informative. In California, which has the highest penetration of PEVs of any U.S. state, the need for system upgrades due to PEV charging have been rare, and utilities have primarily managed load impacts by encouraging PEV owners to charge their vehicles at low-cost times of day, through options like time-of-day tariffs with off-peak charging rates.[51] However, impacts have materialized more quickly in the Pacific Northwest, where most utilities do not have TOU rates, and larger capacity chargers have required infrastructure upgrades, such as upsizing transformers.

Managed Charging

As referenced above, incenting users to adjust the timing of their electric vehicle charging can provide grid benefits. Taking this concept further, "managed charging" allows utilities to dynamically control or influence vehicle charging for grid needs. Types of managed charging range from "smart charging" (V1G) to "vehicle to grid" (V2G).

V1G is a straightforward process that involves two-way communications with utilities or third parties (e.g., EVSE network companies, automaker on-board telematics or cloud platforms) to allow for a more exact modulation of when the user charges the vehicle. Since V1G can be controlled either up or down, use delayed start times, or be turned off, it can emulate most energy storage systems today. As it provides only minor adjustments to typical user charging behavior, V1G also has the least impact on the PEV battery. To date, the most successful financial mechanism has been TOU rates where the customer either has manual control or utilizes a third-party algorithm to optimize the cost savings.

In contrast, V2G capability allows for two-way communication between utilities and users to enable two-way flows of electricity between the grid and the vehicle battery. In this case, the PEV battery is being treated as distributed electricity storage. While the idea of extensive distributed electricity storage is an exciting prospect for an industry perennially challenged by the difficulty of storing power, V2G is still in early stages of development in the U.S. due to several factors: the low penetration of PEVs, the fact that commercially available PEVs do not have V2G capabilities, the largely undetermined market and regulatory framework, the fact that increased modulation of PEV batteries speeds their depletion, and the prohibitively expensive communication systems required by many performance requirements. The value of V2G has typically been postulated to support wholesale energy markets controlled by large free market balancing authorities, with PJM as the leader in the nation. However, in this scenario, vehicle owners may have reduced driving ranges as more of the battery electricity is sent to the grid. V2G is discussed in additional detail in Appendix C.

While managed charging could provide significant benefits, it is important to note that there are costs to develop all forms of managed charging capabilities. The network companies that provide the communication capabilities for managed charging typically invoke network access fees to help recover their investment in creating the network.[e]

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e The technologies used to create the command and control capabilities originally were cell phone-based, resulting in a high cost. Lower-cost wi-fi internet-based communication systems now coming into the marketplace can use existing customer communication platforms that are already paid for, resulting in new, lower-cost solutions. However, the current wi-fi infrastructure is less reliable than cellular communication.

Special Considerations for DCFC Development

While DCFC stations are likely to have a disproportionate effect on enabling the PEV market, financing DCFC stations is a key challenge, especially in low-utilization areas. While some companies are making independent DCFC investments, investments in the current public charging network are largely due to public policy and public-private partnerships—sometimes as part of legal settlements such as the EVgo/NRG settlement with the state of California and the Volkswagen settlement with the state of California and the U.S. Environmental Protection Agency (EPA).

Rebates and other utility incentives, which can be highly effective for L1 and L2 charging, are likely insufficient for DCFC installations. RMI notes that these installations will need more "patient capital" until PEVs are sufficiently pervasive to drive the market.[52]

Most DCFC stations have combined private investments with some form of public support. Public sector interventions can include low-interest loans, grants, consumer education programs, mandates, building codes, and specific programs and credits – such as California's Low Carbon Fuel standard credits. However, public funding for fast installation of public infrastructure has led to some poor siting decisions, reinforcing the importance of appropriate planning as part of any EVSE development.

A recent Center for Climate and Energy Solutions (C2ES) report explored options to leverage additional private sector capital for charging infrastructure in Washington state. The report found that no owner-operator-only business model produced a payback period of less than nine years, implying that such business models were not likely viable unless the initial charging station utilization was significantly higher than expected.[53] However, if such business models were combined with public incentives, the DCFC investments could become profitable within five years, and the public incentives could be scaled back as the station utilization rose.[54]

There are also other financing options. Municipal bonds and green bonds, long-duration purchase agreements, and green bank investments could support DCFC development; however, these options will likely only become widely available when the financing community becomes more bullish about the prospects of electrification.[55]

The RMI suggests tariffs that shift costs away from private DCFC installers and owners to the general utility rate base would make DCFC installation more profitable. The RMI also recommends that tax relief for the installation and operation of DCFC stations could stimulate investment.[56] However, rate-basing EVSE assets always should be approached with caution to ensure rate increases do not unfairly impact low-income communities, as discussed in the next section.

Positive Social Outcomes for Low-Income Consumers

There is a common criticism that electric vehicles are merely "toys for the rich."[57] However, they could also provide significant benefits for low-income consumers, through PEV ownership (especially used vehicles, which have lower up-front costs), shared mobility options, public transportation, freight, or stationary applications. PEVs produce less noise and air pollutants, both of which tend to concentrate in low-income communities and cause adverse health impacts.[f,58]Electric vehicles also are typically less costly to operate and recharge than conventional gasoline vehicles.[3]

However, ensuring low-income communities receive the benefits of electrification requires careful planning. Two challenges deserve special attention: 1) How to ensure infrastructure development serves the needs of low-income communities, and 2) how to fairly allocate the costs of infrastructure investment.

To ensure low-income communities reap the benefits of electrification, infrastructure must serve their needs. Many low-income consumers live in multi-unit dwellings where the installation of home chargers (either L1 or L2) is at the

f For instance, the California Clean Vehicle Rebate Project offers increased EV purchase or lease rebates for low and moderate-income households with incomes at or below 300 percent of the federal poverty level.

discretion of the property owner, not the residents. For such communities, identifying home charging alternatives—such as a local DCFC charging station that can function similar to a local gas station, or an L2 charging station that could be shared by multiple buildings—could make a difference. In some cases, focusing on workplace charging could be more impactful. Community engagement will be critical to ensure the system design responds to the specific needs of the community.

It has been observed that low-income communities often lack robust market demand for PEVs; as a result, infrastructure in these areas tends to have low utilization. To date, utility investments in these areas have been more successful at EVSE development in these areas than third-party service providers.[59] However, where utilities take the lead in developing EVSE infrastructure, the allocation of costs must be approached with care. Low-income electricity ratepayers often struggle to pay utility bills along with other necessities, even with help from bill payment assistance programs such as the Low-Income Home Energy Assistance Program (LIHEAP).[60] Due to difficulties in paying utility bills, low-income communities, especially low-income people of color, are more likely to experience utility disconnections.[61] This underscores the need for access to low-cost public charging.

Currently some regulatory bodies allow utilities to rate-base infrastructure based on analyses that show an increase in electricity sales caused by transportation electrification. An increase in electricity sales should reduce electricity rates for all consumers – a win-win for all parties involved, including low-income communities. Utilities, regulators and other stakeholders should monitor how the combination of infrastructure investments and increased electric loads impacts customer rates over time as charger utilization increases. Additionally, in light of the ambitious environmental policy objectives many states have set, stakeholders should consider the appropriate balance between state policy objectives, societal costs, and potential affordability impacts.

Where rate-basing results in an increase of electricity rates, even temporarily, program design should include strong protections for low-income consumers. For example, discount electricity rates are offered in California, Massachusetts, and Indiana. Additional assistance programs could include percentage of income payment programs (PIPP), arrears management programs (AMP), and shut-off protections for vulnerable populations.[62] These programs could complement, and not impede, utility investment in infrastructure.

Special Infrastructure Considerations for Specific Sectors

While most reports focus on electric vehicle charging for the light-duty sector, there are also implications for the heavy-duty and non-road sectors, as well as implications for automation. These topics are covered in detail in other 50x50 Transportation Initiative sector baselines, but special infrastructure considerations are referenced below.

Considerations for Medium/Heavy-duty PEV Charging

Electrifying the transportation sector requires inclusion of medium-duty vehicle (MDV) and heavy-duty vehicle (HDV) classes of electric vehicles. The hurdles to enabling wide-scale vehicle electrification in this sector are challenging and slightly different from those in the light-duty sector.

Barriers to Broader Medium and Heavy PEV (MDV and HDV) Adoption

There are three main infrastructure-related barriers to broader adoption of medium- and heavy-duty PEVs:

1. **Ensuring affordable power in the MDV/HDV charging context**
   The power requirements of MDVs/HDVs are higher than those for LDVs, requiring sizable investments to meet load requirements, and intensifying concerns regarding grid integration, rate designs, and infrastructure costs and maintenance. A battery electric bus can carry a battery four to ten times the size of a battery in an LDV and the charging requirements for a large fleet—even off-peak—can easily reach 10MW or more at a multi-bus charging station. Current utility tariffs, especially those including commercial and industrial demand charges (as described in Appendix B), can lead to extremely high electricity costs for MDV/HDV charging sites, creating a significant barrier

to adoption. While this challenge will likely be reduced with higher levels of utilization, it has presented a barrier for early-stage pilot projects.

2. **Availability of funding for vehicles and infrastructure**
   Both infrastructure and vehicle investments are costly, and while maintenance will be lower for PEV versus ICE vehicles, MDV/HDV PEVs will require incentives for deployment. Costs for major charging infrastructure, such as for transit and fleet deployment, could run into the millions of dollars.

3. **Interoperability and standardization of connectors**
   As in the light-duty sector, the lack of standardization of DCFC connectors will inhibit MDV/HDV deployment, leading to range anxiety and limiting the vehicle market. While most HDVs will have dedicated charging either in vehicle depots or en route deployments, more infrastructure will be necessary to travel beyond these charging points. There also may be pressure to equip HDV-dedicated locations to charge more types of vehicles.

New innovations in stationary, electrified infrastructure also can increase the efficiency of the transportation system and can have outsized benefits for the freight sector. Key opportunities include reducing vehicle idling and converting shore power from diesel to electric. By providing electric ports for freight vehicles, e.g., long-haul trucking or ships to "port in" on parking or reaching berth, these vehicles can continue to run "hotel" functions (e.g., air conditioning, heating, lighting, powering electronics) with electricity instead of diesel. This topic is explored more fully in the Heavy-duty Vehicle & Freight and Non-Road Sector Baselines.

Considerations for Electric, Automated Vehicles

Another challenge for infrastructure planning is the significant level of uncertainty in the potential for automation and shared mobility.[63,g] Shared and automated vehicles will begin to appear in some cities in the U.S. and globally by 2019[h] and rapidly will become more prevalent by 2030. By 2050, the very nature of mobility may shift dramatically away from the dominant owner-operator vehicle model. It is widely assumed by automotive original equipment manufacturers (OEMs), technology companies and government officials that this emerging form of mobility makes the most societal and economic sense when it is also electric. The University of California (UC) Davis estimates that the emergence of these electric shared vehicles in driverless transportation network company fleets, or Transportation Network Companies (TNCs), could trim urban light-duty vehicle fleets and urban transportation energy use by 70 percent even as urban travel demand increases.

The combination of automation and electric vehicles has practical implications. The longer drive train lifetimes typical of electric vehicles figure prominently in fleet replacement calculations: Where internal combustion vehicles would need replacement approximately every year, an AV with an electric drive train might reach five to seven years before replacement. Assuming business-as-usual practices for mobility, AVs are also projected to generate significantly more VMTs per year compared to single-passenger, personally-owned LDVs: Whereas the typical LDV is driven by a solo commuter for an average of 30 miles per day, most AVs are projected to travel 150 to 200 miles per day. These additional VMTs could be offset by increased ridesharing, which would remove vehicles from the road. This topic is explored in detail in the ICT, Shared Mobility and Automation Sector Baseline report.

As automation unfolds, it is essential for local authorities to know where and how these electric, driverless TNC vehicles will charge, especially since the normal mileage driven is likely to be four to five times higher than the mileage for the average passenger car today. Some parties have also suggested that the most efficient and beneficial deployment of AVs would be as fleets of automated, shared and electric vehicles for ride-hailing.[64] Whether for personal use or commercial fleets, AVs may require large charging facilities (either centralized or distributed), high-power DCFC, or a combination of both. Currently, few "urban charging hubs" exist, and the lack of charging infrastructure and

g The ISMAT Sector Baseline is exploring other aspects of automation and shared mobility in greater detail.

h Based on GM's application of Bolts

lower range has been a limiting factor for electric ride hailing services. However, Washington, DC recently installed a charging hub exclusively for ride hailing providers,[65] and Electrify America's Green City Initiative in Sacramento, CA will deploy a high density of charging hubs to support electric car share and ride hailing programs.

The key challenges for charging electric AVs, as with the medium- and heavy-duty sector, include the high power requirements and the need for electricity price certainty. As BEVs evolve with larger battery packs and greater ranges, as evidenced by Tesla's latest model and the Chevrolet Bolt PEV, charging stations will be required to provide more power in concentrated areas. Level 2 charging for large batteries require upwards of four to five hours of charge time for a 7kW charger. Some experts have postulated that the cellphone-based financial platforms used by TNCs also could be leveraged to schedule AV charging at existing under-utilized charging assets, including residential home locations. This could dramatically reduce the capital investment associated with charging AVs in more centralized or hub type locations and could take advantage of lower-cost residential electricity rates.

As described above, enabling flexibility in when these automated electric vehicles charge is critical. Most charging is expected to occur at night, since it will likely be most profitable to operate AVs during the daytime; in jurisdictions with significant wind power, the charging time can thus correspond to evening wind resource peak periods. Spikes in transportation in the morning and evening commute hours also will create opportunities for mid-day charging, which can allow for pairing with solar generation peak periods. AVs' higher utilization rates also could enable greater flexibility in demand charges and provide enough energy throughput to make DCFC stations cost effective.

This is an emerging area of great uncertainty. Little data currently exists on charging AVs, and pilot programs will be needed. Electric transportation network and car-share companies also will provide early insight into long-range PEV use.

INFRASTRUCTURE FOR ALTERNATIVE FUELS

INFRASTRUCTURE FOR ALTERNATIVE FUELS

Beyond electricity, there are a variety of alternative fuels that can be deployed in the transportation sector—primarily hydrogen, propane, natural gas, and biofuels. Lifecycle analysis of the energy consumption involved in the extraction, production, transport, and use of these fuels suggests that most of them fall within a similar range of energy use as conventional fuels.[i]

These fuels, however, provide a variety of co-benefits, including reducing GHG emissions and tailpipe emissions relative to gasoline or diesel vehicles (with potentially significant impacts in disadvantaged communities), local economic development, fuel diversity, and energy security. For example, hydrogen qualifies as a zero-emission fuel in many states; and renewable natural gas produced from biological waste streams has the greatest carbon emission offset potential of any fuel, since the use of the resource directly reduces the upstream venting of methane to the environment. Natural gas is one of the least expensive and abundant resources in the U.S. and many natural gas MDVs and HDVs are available on the market.[66,67] The biofuels sector has brought extensive economic development benefits, especially to the Midwest. A recent report estimated that the ethanol sector (including production, co-product output, exports, and research and development) contributed $45 billion to the U.S. economy in 2017.[68] Biofuels, when blended with conventional fuels, also help meet octane performance standards for vehicle operation.

Alternative fuels also may present the best solutions for specific vehicle usages, such as some segments in the medium- and heavy-duty sector, where some widely available alternative liquid fuels have emission, functionality, local economic, and energy security advantages over conventional fuels.

Alternative fuels are likely to be a part of the transportation sector through the medium- and potentially long-term future, due to their convenience, affordability, co-benefits, and potential future innovations. Additionally, some alternative fuels, like compressed natural gas (fossil and renewable) and potentially hydrogen, can be transported via existing natural gas pipelines to reduce the needed investment in fuel distribution infrastructure. Many alternative fuels also can be produced through a variety of pathways that continue to evolve. For example, most hydrogen gas is currently produced from natural gas, but advances in renewable electrolysis could allow affordable hydrogen to be produced entirely from renewable sources.[69,70] Power-to-gas and synthetic gasoline technologies in development also have the potential to provide new fuel sources in the future.[71,72]

Every fuel type has its own infrastructure opportunities and challenges. This section provides a summary analysis of each fuel type's opportunities and benefits, and highlights infrastructural barriers that affect their deployment. A summary of pump-to-wheel and well-to-wheel energy consumption and GHG emissions associated with each vehicle type is presented in Figure 2.

i Estimated using the Argonne National Laboratory GREET well-to-wheel calculator for light-duty vehicles. The effect can be observed in higher-duty vehicles as well.

NORMALIZED PTW/WTW ENERGY CONSUMPTION AND GHG EMISSIONS (PER MILE) BY VEHICLE TYPE (PASSENGER CARS)

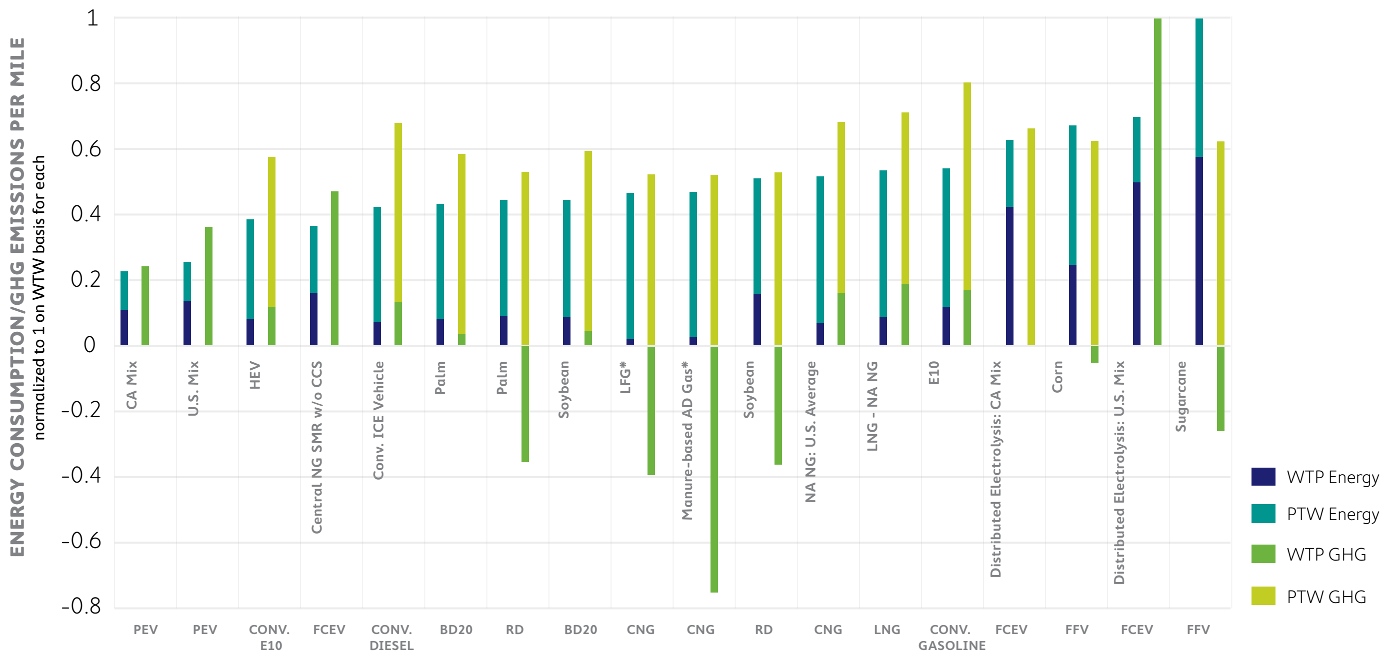

Figure 2: Pump-to-wheel and well-to-wheel energy consumption and greenhouse gas emissions values per mile by vehicle type for passenger cars. Both energy and GHG emissions axes normalized to 100. Vertical text describes the feedstock for fuel types. (GREET 2017 WTW Calculator Tool, based on 2015 fuel data and 2010 vehicle models).

** Modeling performed by the GREET.net full lifecycle analysis tool suggests the upstream energy consumption of renewable natural gas, such as Landfill Gas (LFG) and gas derived from manure-based anaerobic digestion (AD) may be even more favorable -- i.e., negative -- by offsetting energy consumption in other sectors, such as fertilizer production.*

Alternative Fuels, Use and Infrastructure

Although the fuels discussed below derive from different sources and have different regulatory frameworks, advantages, and challenges, there are several common themes that affect the development of their infrastructure, which usually requires investments recovered over the medium- or long-term:

- **Regulatory certainty**
  The complex national, state, and local regulatory frameworks that govern the deployment of these fuels—whether through building, storage, and fuel transport codes or direct mandates like the Renewable Fuel Standard (RFS)—are complex, regionally diverse, and at times shifting, complicating long-term investment decisions.

- **Market prospects**
  Because a variety of alternative fuels is available, the uncertainty of which fuel types will capture future market share, especially in a period of fluctuating energy prices, can increase the risk of stifling long-term investments in fueling infrastructure.

- **Coordination**
  While the conventional fuel sector has a network of fuel distributor stakeholders, many alternative fuel stakeholders lack such a network. For example, new hydrogen producers may lack contacts and experience collaborating with retailers, government authorities, other fuel distributors, automakers and community organizations, creating an organizational barrier to infrastructure development.

- **Production infrastructure**
  Unlike electricity and natural gas, fuels with a smaller market share, like hydrogen and renewable natural gas, will require new fuel production infrastructure.

Table 2 provides a snapshot of the current state of the market for a variety of alternative fuels based on the most recent available data.

Table 2: Summary of Market Aspects for Alternative Fuel Types in the United States

Fuel Type	Hydrogen	Propane	Natural Gas	Biofuels
Number of Vehicles (Total highway vehicles registered 2015: 264 million)	~3,800	200,000	165,000 (CNG and LNG)	20 million (FFVs)[j]
Gasoline gallon equivalent (GGE) or Diesel gallon equivalent (DGE) fuel cost (October 2017 prices: Gasoline $2.49/gallon; Diesel $2.76/gallon)	$5.60/GGE[73]	$3.87/GGE $4.35/DGE[74]	$2.18/GGE (CNG) $2.46/DGE[75]	Ethanol: E85 is $2.87/GGE Biodiesel: BD20 $2.93/DGE; B99/B100 $3.80/DGE[76]
Vehicle types	Dedicated	Dedicated, bi-fuel	Dedicated, bi-fuel, dual fuel (uses diesel for ignition); CNG or LNG	Dedicated for high-level (BD20 and above; E85 and above) blends; conventional vehicles can handle lower-level blends
Fuel source	Natural gas or electricity/ water	Fossil Fuels	Conventional natural gas or renewable (biomethane)	Ethanol: primarily corn, barley, sorghum, wheat,[77] (also cellulosic, food and beverage waste), sugarcane Biodiesel: vegetable oils, animal fats, waste greases
Fueling stations (There are about 120,000-150,000 gasoline stations)	39	438	1,017 (942 CNG; 75 LNG)	Biodiesel (BD20 and above): 201 Ethanol (E85 and above): 3,122

Hydrogen

Of the four fuel categories covered in this section, hydrogen fuel cell electric vehicles (FCEVs) are the most recent to hit U.S. markets. The low level of existing hydrogen fueling infrastructure constitutes one of the most significant market barriers to the deployment of FCEVs.

Benefits and Uses of FCEVs

Hydrogen FCEVs have zero tailpipe emissions (making them zero emission vehicles, or "ZEVs"), operate with highly efficient electric motors, and can be refueled in three to five minutes to a travel range of 360 miles or more. Fuel cells operate by combining hydrogen and oxygen to form water, and then converting the energy released by the reaction to generate electricity and run an electric motor.

A primary challenge is the cost-effective production of the fuel. Hydrogen can be produced through different pathways, with varying impacts on energy consumption and emissions. In the U.S., 95 percent of hydrogen is currently produced

j For "flex-fuel vehicles" that can run up to 83 percent ethanol. Most conventional vehicles can use lower biofuel blends. E10 is standard across US; BD20 (6-20 percent biodiesel/diesel blend) is viable in most diesel engines. 2001 and newer vehicles are approved by EPA for use with E15.

from natural gas through a process called steam reforming, a method that reacts natural gas with steam to produce hydrogen, carbon monoxide and carbon dioxide.[78] According to the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model by Argonne National Laboratory, centralized steam methane reforming with North American natural gas uses 30 percent less energy compared with gasoline and produces a little over half the GHG emissions on a WTW basis in passenger cars. FCEVs' electric motors are nearly twice as efficient as conventional ICE vehicles.[79]

Hydrogen fuel also can be low- or zero-carbon if steam methane reformation is powered by renewable natural gas. Hydrogen also can be produced through electrolysis, which uses electricity to catalyze the splitting of water into its components, hydrogen and oxygen. Electrolysis can be driven by solar or wind power, providing even more favorable energy and environmental impacts, with WTW energy consumption estimated at 40 percent less than a conventional ICE engine, and GHG emissions near zero. However, both steam reforming and electrolysis are currently not cost competitive. Another alternative—the large-scale electrolytic generation of hydrogen using electricity from the grid—generally requires a high-power connection, which can be comparable to the requirements for a DCFC electric charging station. Nevertheless, should renewable electrolysis become commercially competitive, hydrogen could become a 100 percent renewable fuel source for long-distance travel with water serving as both the input and the waste product.[80]

FCEVs also can be scaled easily from passenger vehicles to heavy-duty trucks, avoiding the difficulties of battery range requirements common to PEVs. Anheuser Busch has placed an order with Nikola for up to 800 heavy-duty FCEV trucks, and fuel cells are being tested in public buses in Michigan, California, and Ohio.[81,82] Few buses are on the roads currently, but their successful integration into public fleets could provide additional demand and support for hydrogen fueling infrastructure. Hydrogen fuel cell technology also is being employed for materials handling applications, most notably in forklifts at warehouses and manufacturing plants, where indoor air quality requirements can preclude the use of fossil fuels. Both Amazon and Walmart recently committed to utilizing fuel cell-powered forklifts. About 3 percent of forklifts in all U.S. warehouses are hydrogen-powered.[83,84]

In addition, DOE's Fuel Cell Technologies Office and the U.S. Maritime Administration have partnered to test the viability of using fuel cell generators at shipping ports to power refrigeration units, eliminating the need for ships to keep their diesel engines running while docked (also known as "shore power").

Infrastructure Considerations

More than 4,900 hydrogen FCEVs have been sold or leased across the U.S.[85] The primary support for FCEVs has been in California, where the vehicles first went on sale in the fall of 2015; and in 2013, Governor Jerry Brown announced an eight-year plan (AB 8) to support FCEV deployment and hydrogen fueling infrastructure.[86] Outside of California, FCEVs also qualify for ZEV mandates in Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

As of January 2018, there were only 39 hydrogen fueling stations in the U.S.[87] Nearly all of these are in California: There are 31 public stations, with funding available for another 60 and a state government plan to bring the total to 200 within the next eight years.[88] Toyota and Air Liquide also have announced plans to build 12 hydrogen fuel stations in the Northeast corridor.[89,90]

As with most compressed gases and flammable or explosive fuels, hydrogen stations also face safety concerns related to transport, storage, and fueling. The gas is highly flammable and difficult to detect in leaks, so fueling stations must follow safety protocols and procedures developed for its industrial use. In part due to the extensive permitting required for the stations, the cost of new stations is very high: A 2013 NREL report estimated that new "early commercial" fueling stations from 2014 to 2016 would have capital costs on the order of $2.8 million per station.[91]

With such high infrastructure costs, intensifying FCEV adoption faces the same "chicken-and-egg" problem as do long-range PEVs: Consumers are hesitant to purchase FCEVs in the absence of widely available fueling infrastructure, but stations are slow to come online without substantial consumer FCEV adoption.[92] A 2017 study by H2USA, in partnership with NREL, has identified three possible scenarios to achieve greater FCEV market adoption based on infrastructure development, each deploying different levels of policies. The report concluded that 320-570 new stations were required nationwide by 2025 to enable FCEV market growth, with the potential to achieve a national network of 1,500-3,300 stations by 2035, with a hydrogen capacity of 1.3-3.4 million kg/day, serving 1.8-4.5 million vehicles. In all cases, the greatest deployment was expected to take place in urban areas.[93]

A recent NREL study performed stakeholder interviews to identify primary barriers to investment in alternative fuels infrastructure. For hydrogen, the key barriers included:[94]

- **High-risk, long-term market**
  Many investors view the sector as a long-term solution to mitigate GHG emissions, as well as one that is high-risk due to the many uncertainties relating to vehicle production, consumer uptake, permitting, environmental compliance, and codes and standards. Supply uncertainty and costs are another concern.
- **Demand uncertainty**
  As with other emerging alternative fuels, uncertainty in future demand (due to higher vehicle prices and higher infrastructure costs compared to other products) can lower incentives for hydrogen producers to invest in fueling stations.
- **Length of time to develop infrastructure and lack of information for retail station owners**
  As of 2017, it took about two years or more to construct one hydrogen fueling station.[95] Hydrogen fueling infrastructure can be installed at existing gasoline retail sites, but coordination between existing retail station owners and hydrogen providers will be critical, especially given the long installation timeline. Additionally, many retail station owners lack familiarity with hydrogen fuel and lack incentives to learn about the opportunity.
- **Lack of networks between hydrogen producers and retail stations**
  Many hydrogen producers are unfamiliar with consumer-oriented fuel retailing, in contrast with traditional fuel marketers that have networks of up to thousands of retail distributors.[k]
- **Permitting, codes, and standards**
  There is a lack of uniform codes and standards across the U.S. and even within California for hydrogen fueling stations. This is partly due to the fact that there is a wide variety of stakeholders involved at varying levels, including city councils, planning departments, fire marshals, and environmental protection authorities. California has addressed this issue by created an Ombudsman in the California Governor's Office of Business and Economic Development Office to help developers more efficiently complete the permitting process; however, such mechanisms currently are not present outside of California.

Propane

Benefits and Uses

Propane, also known as liquefied petroleum gas (LPG) or propane autogas, is widely available in the U.S., and has been used and refined for decades. The fuel has a high energy density (although still 27 percent less than gasoline), relatively low cost, and low emissions. Propane is the world's third most common transportation fuel, and it qualifies as an alternative fuel under the Energy Policy Act of 1992 alternative fuel vehicle acquisition requirements. Propane vehicles often have lower maintenance costs relative to gasoline and diesel, making them more popular in a variety of fleets, from taxis and police vehicles to school buses; there are an estimated 200,000 on-road propane vehicles in the U.S.[96] Propane's gaseous properties help it perform well in cold climates, avoiding many of the cold-start issues associated with conventional fuels, and its lower carbon content leads to longer engine life.[97] Propane use is also flexible:

k This may be changing, as conventional gas retailers are beginning to enter the hydrogen space. Shell Oil, for example, is opening hydrogen stations in California.

Conventional fuel vehicles can be converted to either dedicated propane vehicles or "bi-fuel" vehicles (which can use propane or gasoline as needed). Bi-fuel vehicles can eliminate "range anxiety" for propane users.

Infrastructure Implications

Relative to other fuels discussed in this report, the limitations in fueling infrastructure do not appear to be an outsized barrier for propane vehicle usage and development. According to the DOE's Alternative Fuels Data Center, propane fueling infrastructure is well-established across the U.S., with production, storage, and bulk distribution capabilities for more than 3,900 stations covering intracity, interstate, and rural access.[98] To install propane fueling infrastructure, station managers often need only the dispensing equipment: storage tank, pump, dispenser, and card reader. The total costs of building a propane refueling station are estimated to range from $45,000 to $300,000 depending on the size of the station.[99] A standard private fueling station—appropriate for small fleets up to 50 vehicles—is estimated to cost only $1,500-$15,000 if the propane provider retains ownership of the infrastructure; and $21,500-$75,000 if the fleet company owns the infrastructure.[100]

Natural Gas

Benefits and Uses

Natural gas—a mixture of hydrocarbon gases primarily consisting of methane—can be extracted as a traditional fossil fuel or produced through biological processes (termed "renewable natural gas (RNG)" or biogas). It also can be stored as compressed natural gas (CNG) or condensed by refrigeration into liquefied natural gas (LNG), which raises its energy density but also the costs of its transport and storage. Like propane, the tailpipe emissions for natural gas (including nitrous oxide and particulate emissions) are less than conventional diesel fuels, and natural gas can lengthen engine life.[101,102]

For conventional natural gas, the fuel production, refinement, and distribution infrastructure is already widely available since the fuel is used for electricity production, heating, and cooking. Natural gas is also experiencing prolonged low prices due to the boom in U.S. domestic production, a trend that has been credited with a wide array of positive impacts on the U.S. economy.[103,104] Natural gas is currently cheaper than gasoline.[105] The low prices have led to a notable uptick in the popularity of the fuel for transportation, especially in the heavy-duty freight sector: Natural gas freight vehicles have been adopted by many corporate fleets including Cisco, Pepsi, and Walmart.[106] Like propane vehicles, natural gas vehicles can be converted from conventional vehicles or used as bi-fuel vehicles. In the heavy-duty sector, the use of LNG is growing, especially for trucks requiring a greater range.[107] Transit buses and refuse trucks are currently the most common users of natural gas; in 2014, one-fifth of all transit buses were run by CNG or LNG.[108]

Since methane is a typical waste product in biological processes (anaerobic digestion), renewable natural gas (RNG or biogas) can be harvested through a variety of pathways, including recapture from manure storage, municipal solid waste, wastewater treatment plants, and landfills.[109] Few CNG/LNG vehicles use RNG in the U.S. However, if appropriately purified, RNG is interchangeable with conventional natural gas without any adjustment to the vehicle, storage, or fueling units, in both CNG and LNG forms.

Capturing and using RNG also has the greatest per-unit climate benefits of any fuel. Methane is approximately 84-87 times as potent as carbon dioxide in terms of its global warming potential over 20 years, according to the EPA.[110] As a result, the capture and use of RNG in vehicles reduces emissions for both the downstream and upstream fuel lifecycle: The lower carbon content (and lower NOx, SOx, and particulate emissions) of the fuel produces lower tailpipe emissions, and the recapture of methane from waste removes methane from the environment. The GREET tool estimates that a manure-based natural gas vehicle produces 93 percent less emissions than a traditional gasoline vehicle, and 91 percent less than a natural gas vehicle.[l] A reflection of its aggressive climate goals, California sourced

l The GREET tool finds that a conventional gasoline vehicle produces 422 grams of GHGs (grams CO2 equivalents) per mile; a natural gas vehicle produces 322 grams per mile; and manure-based natural gas results in 28 grams per mile.

60 percent of its natural gas for vehicles from RNG in 2017, and Southern California Gas Co. predicts this number will rise to 90 percent in 2018.[111] It is also worth noting that renewable natural gas can be used to produce electricity, which, if used to fuel electric vehicles, produces compounded positive environmental impacts.

While not currently available in quantities equivalent to conventional fuels, the resource potential for RNG is significant: The American Biogas Council estimates that if the RNG resources currently available across the U.S. were harvested for vehicle use, they could displace 16 percent of all diesel fuel consumed in the U.S., a number that could rise to 45 percent if new conversion technologies are considered.[112]

Infrastructure Implications

There are 300,000 miles of transmission pipelines and another 1.9 million distribution pipelines for conventional CNG within utility service areas in the U.S., creating significant coverage for all forms of travel.[113,114] Existing transmission and distribution natural gas pipelines can transport RNG without any additional investments or modifications. Although LNG provides advantages in long-haul trucking, CNG remains the more popular fuel, partly because of the high costs of LNG infrastructure development.[115] CNG can be transported by pipelines and compressed at fueling stations; in contrast, LNG has more logistical and infrastructure requirements since it is produced at liquefaction facilities and trucked to fueling stations.[116] Reflecting the heavy fleet interest in natural gas vehicles, as of January 2018, there were 942 CNG fueling stations and 75 LNG stations across the U.S. and Canada.[117]

The primary barrier to natural gas infrastructure is the need for additional fueling stations with compression, gas storage, electricity access and sufficient pipeline pressure. However, there is less of an infrastructure gap than there is with DCFC or hydrogen fueling stations. Corporations are investing billions of dollars in CNG and LNG infrastructure development, and in some cases, companies have demonstrated a willingness to cover infrastructure costs in exchange for natural gas purchase contracts.[118,119]

Biofuels

Benefits and Uses

Biofuels constitute one of the most diverse classes of fuels, with forms derived from different biological feedstocks that produce different final products (e.g., gasoline equivalents, diesel equivalents, biomass for power generation). Highway vehicle biofuels are divided into two main categories: ethanol and biodiesel. Both are derived from biological sources: ethanol from corn, grains, cellulosic matter, and food/beverage waste; and biodiesel from vegetable oils (the most common being soybean oil), animal fats, or waste grease. Both also can be produced by specific strains of algae.

Different biofuel pathways present different environmental and economic opportunities and challenges. The EPA distinguishes between first-generation biofuels (largely conventional ethanol and biodiesel) and second-generation or advanced biofuels, which are biofuels produced from qualifying renewable biomass sources that produce 50 percent less GHG emissions relative to conventional fuels.[120] Cellulosic ethanol, for example, can be produced from agricultural and forest wastes, lowering GHG emissions and mitigating some of the concerns relating to biofuels' water and land usage requirements. It also avoids the "food or fuel" debate, which contends that biofuel production can compete with food production and drive up the price of food products. However, advanced biofuels remain in the early stages of commercial deployment in the U.S.: in 2017, 18 billion gallons of renewable biofuels were produced, of which 84 percent was conventional renewable fuel (primarily corn ethanol), 14 percent was biomass-based diesel, and only 2 percent was advanced and cellulosic biofuel.[121,122]

Unlike the other alternative fuels discussed above,[m] biofuels are largely miscible and fungible with existing fuels (ethanol with gasoline and biodiesel with diesel) and can be used interchangeably in conventional vehicles up to certain

m Renewable natural gas is also a biofuel, and qualifies as a cellulosic biofuel through the Renewable Fuel Standard. For the purpose of this report, it is grouped with natural gas given those fuels' shared use and infrastructure. While this section will primarily focus on liquid biofuels, this discussion also applies to RNG.

blend levels.[n] Some biofuel variants can be "dropped in" to existing vehicles and used in all conventional vehicles without alteration to the vehicle. While there are no dedicated biofuel vehicles (i.e., vehicles that can run only on 100 percent biofuel) sold in the U.S., the adjustment of a conventional vehicle to a "flex fuel vehicle" (FFV) that can handle high-level biofuel blends is straightforward and often not costly.[o, 123] Many of today's conventional vehicles already qualify as FFVs. However, many FFV owners still primarily fuel their vehicles with conventional gasoline; many do not even realize their vehicle is an FFV.[124]

Biofuel production and use in the U.S. has been driven largely by the RFS and previous incentives that included fuel tax exemptions and credits as well as state-issued incentives for fuel production. The RFS is a national mandate implemented in 2005 to increase the volume of renewable fuel that is blended into transportation fuels to 36 billion gallons, with over half mandated to be advanced or cellulosic biofuels, by 2022. Since the RFS was established by the Energy Policy Act of 2005[p], and expanded and extended by the Energy Independence and Security Act of 2007, ethanol production alone has increased more than three-fold.[125] However, cellulosic fuels have not reached commercial viability, and therefore have not kept pace with the mandates, requiring regular waivers from the EPA. Nevertheless, due to the RFS, conventional gasoline in the U.S. is mainly available as an ethanol blend.[126,127,128] Biodiesel is less pervasive than ethanol, but biodiesel blends are commonly available at fueling stations, especially where they are produced in the American Midwest.[129]

Infrastructure Considerations

While there is near-complete permeation of low ethanol blends into the transportation fuels market, the future adoption of higher ethanol blends and expansion of advanced biofuels remains uncertain. In 2012, few conventional fueling stations were equipped for higher biofuel blends, and they are largely located in the midwestern U.S. Ethanol is more corrosive than gasoline, and therefore cannot rely on existing pipelines, storage tanks, and pumps without infrastructural adjustments. Most ethanol transport takes place by rail, and the development of new biofuels production facilities and fueling station upgrades—as required to meet increasing RFS mandates—will require financial investment.[130] New pumps and tanks at gas stations, which are needed to accommodate higher ethanol blends, can cost between $22,000 and $100,000.[131] Government support for this transition includes the 2015 Biofuel Infrastructure Partnership, a program that allocated $100 million in U.S. Department of Agriculture (USDA) grants to fund infrastructure to promote utilization of higher ethanol blends, in collaboration with state and industry partners that supplied an additional $110 million.[132]

Primarily owing to uncertainty surrounding future levels of biofuel demand and deployment, several challenges stand out for the development of higher-blend biofuel infrastructure:

- **The future of the RFS volumetric requirements**
  Until the EPA Administrator establishes RFS volumetric mandates for biofuels beyond 2022, there is uncertainty regarding future markets, especially given the required investment in new refining and storage facilities.[133] Furthermore, enhanced ICE vehicle efficiency and the further adoption of alternative fuel vehicles, such as BEVs and FCEVs, may drive a decline in gasoline consumption and create less opportunity for biofuel utilization. This

n E15 has been approved for use in all LDVs model 2001 and newer, and most diesel vehicles accept up to B20. All diesel vehicles accept B5.

o Estimates from 2010 suggest the cost of converting a conventional vehicle to an E85 flex-fuel capable vehicle was approximately $70.

p While the regulatory framework varies for most alternative fuels, one policy is relevant for nearly all of them: the Energy Policy Act of 1992, which defines alternative fuels as methanol, denatured ethanol, and other alcohols; mixtures containing 85 percent or more by volume of methanol, denatured ethanol, and other alcohols with gasoline or other fuels; natural gas; liquefied petroleum gas; hydrogen; coal-derived liquid fuels; fuels (other than alcohol) derived from biological materials; and electricity. The act establishes minimum alternative fuel vehicle purchase requirements for federal, state, and alternative fuel provider light-duty fleets. (The overall purpose of the act is to reduce U.S. petroleum consumption and improve air quality.)

may decrease investment in biofuels infrastructure.

- **Uncertainty regarding advanced biofuel development**
  The RFS's emphasis on cellulosic fuels was intended to stimulate biofuel development and to overcome concerns about its environmental, social, and economic impacts, but the required volumes for cellulosic fuels have not materialized. It is unclear when these fuels will become commercially viable, and whether technological breakthroughs are on the horizon to enhance their feasibility, reduce their GHG emissions, and facilitate their commercialization. These developments also may be overtaken by other competing fuel technologies.

CONCLUSION

CONCLUSION

The infrastructure for fuel production, transport, storage, and distribution is a necessary element to advance the market for all vehicle types. The infrastructure that supports different fueling types is diverse and at different stages of maturity and development based on the specific fuel.

PEVs and hydrogen FCEVs are at the earliest stages of development and face the steepest fuel distribution infrastructure barriers to achieve greater competitiveness in vehicle markets today. Hydrogen and RNG also require significant new fuel production infrastructure. However, these challenges are not insurmountable if there is policy support for progress: All vehicle types discussed have infrastructure requirements that are technically viable and can be deployed through a variety of frameworks to fit the relevant needs and priorities of specific communities. If developed with full consideration of the economic, environmental, and social priorities as highlighted above, the enabling infrastructure for alternative fuels will serve as the foundation of a new transportation paradigm for the coming decades.


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APPENDICES

Appendix A: Business Models for Infrastructure Development, Operation, and Ownership of EVSE

The development, operation and ownership of EVSE infrastructure can be pursued through a variety of different business models. Several are listed here for illustration: [134]

- Automaker supplied: Some automakers, such as Tesla and Nissan, are installing, owning, and operating infrastructure to encourage adoption of their vehicles.
- Owner-Operators: Third party institutions install, own and operate stations intended to provide a service to retail customers. Some of the largest third-party developers/network providers currently operating in the U.S. are ChargePoint, Blink, EVgo and SemaConnect, Greenlots.[135] Electrify America is also a main provider of EVSE infrastructure. This model allows for robust competition among providers to provide affordable, convenient and efficient service.
- Site Host Owned/Operated: A government entity or private property owner desires to install EVSE units on property that they own. These entities typically contract out to independent PEV charging companies (such as those listed above) to develop and operate the sites but the entity typically retains ownership of the EVSE. Under typical line extension policies, utilities will support such private investments by providing allowances to defray the costs associated with providing new electrical service to the site. These allowances are determined by formulas approved by regulators to account for the new service's contributions to the system.

Different models can also be combined with different levels of utility involvement. For example:

- Utility make-ready investments: In this case, utility involvement in infrastructure development goes a bit further than exclusive "line extension", by supporting some of the additional underlying infrastructure necessary to support EVSE infrastructure, known as the "make-ready" infrastructure. Make-ready infrastructure includes the wires and conduits to establish a specific site capable of hosting an EVSE, power panel, and conductor to the actual charging site. These installations occur on both the utility and customer sides of the service meter, but do not include the actual EVSE. Such infrastructure can constitute an enormous cost for EVSE investment; therefore, utility support for make-ready infrastructure can stimulate the market, and utilities can own and earn a rate-of-return on this infrastructure. The actual EVSE installation, maintenance, and operation of the EVSE is typically performed by third-party operators for the property owner or "site-host."
- Utility as owner-operator: This model involves the greatest utility role, as the utility installs, operates, and maintains the EVSE (although specific aspects of the work are generally contracted through third-party EVSE providers). Utilities often have access to low-cost capital, strong balance sheets, and extensive experience with activities necessary for EVSE construction and operation, such as permitting, siting, land purchase/leasing, coordination with stakeholders, and customer outreach. The California Public Utilities Commission relied on such design features when determining that San Diego Gas & Electric's ownership of up to 3,500 EVSE at multi-unit dwellings and workplaces would foster competition and not suppress independent investments (Decision 16-01-045, January 28, 2016).
- Utility incentive model: Utilities provide rebates for make-ready infrastructure and EVSE procurement and installation, but they do not own or operate either the supporting make-ready infrastructure or the EVSE itself. Such rebate programs could potentially stimulate investment in high-priority locations and allow the utility to exercise some strategic influence over EVSE placements, while allowing competitive processes to dictate the developments. Treating rebates as regulatory assets upon which a utility earns an authorized rate of return has been proposed to attract utility shareholders with investments in utility-owned EVSE or make-ready infrastructure. The receipt of rebates also could depend on participation in programs that encourage charging that supports the electrical grid and that maximize fuel cost savings.[136]

There has been significant discussion regarding the appropriate level of utility involvement in this area. Generally, greater utility involvement could bring benefits: Increasing PEV charging load could reduce all customer rates by spreading the distribution costs over larger demand, reducing GHG emissions and local air pollutants (especially around low-income communities, which disproportionately experience poor air quality), enhancing equitable access to mobility options, providing grid management services, and reducing the cost of integrating variable renewable energy resources.[137] Utilities are also well-positioned to perform transparent data collection, and explore opportunities for vehicle-grid integration.

However, utility involvement also raises important policy considerations. Some states (Missouri, Michigan and Kansas) have prohibited regulated utilities from owning/operating EVSE infrastructure out of concern that such ownership could undermine a competitive market.[138] However, this stance appears to be softening in many places. A classic example is the California Public Utilities Commission (CPUC), which largely prohibited California's investor-owned utilities (IOUs) from investing in EVSE in 2011 but lifted the sweeping prohibition and invited utility proposals to be considered on their individual merits in 2014. In 2016, the CPUC approved $197 million in light-duty vehicle charging infrastructure by the state's three largest IOUs targeting multi-unit dwellings and workplaces, including both make-ready and utility owner-operator models, which were supported by a diverse set of stakeholders, including all the major PEV charging companies. In May 2018, the commission approved over $750 million worth of EVSE infrastructure buildout proposals, which include charging for light-duty vehicles, but also emphasize medium- and heavy-duty vehicles.[139,140]

There are insufficient data to conclusively determine whether one specific model is "best," or whether blends of all models are possible.[141] Early data imply that the relative strengths of each model can be best used by matching them to the right needs. For example, there are some early data suggesting that a rebate or make-ready model may not provide the turn-key solution needed to increase access to EVSE at multi-unit dwellings.

Appendix B: Utility Rate Design

Utility rate design, which determines how utility costs are recovered from ratepayers, has two important implications for electrification: ensuring the affordability of PEV charging, and mitigating increased cost for the power system. Drivers can save money for ongoing operating costs through converting to a PEV if their average cost for charging energy is lower than their cost of conventional fueling. As of August 2018, the U.S. average price of gasoline was $2.87 per gallon, compared to an average residential electric rate equivalent of $1.17, providing greater than 50 percent fuel cost savings on average.[142] However, drivers charging at multiple locations outside the home, including high-powered DCFC stations, encounter different pricing levels that may not always result in lower cost-per-mile than conventional gasoline.

Ensuring long-term affordable access to electricity requires managing the costs of supplying that electricity, through both providing affordable energy at public charging infrastructure and through maintaining affordable electric rates. One way to make electric rates more affordable is by managing charging to avoid significant peak demand growth. A 2013 study for the Vermont Energy Investment Corporation noted that if 25 percent of light-duty vehicles were PEVs and charged randomly, peak demand could increase by 19 percent; if the same load were concentrated in the evening hours (when Vermont has its off-peak period), the increased demand would be 0-6 percent.[143] The flexibility of charging during off-peak hours allows drivers to take advantage of attractive rates during those hours.

Rate design can steer users to a more efficient use of the grid through price signals. Electricity tariffs are usually structured using a combination of volumetric, fixed, and demand charges in the case of commercial and industrial tariffs. Volumetric charges can be assessed via a flat rate per kilowatt-hour, a "time of use" (TOU) rate that charges by the time of day, and dynamic rates, which are based on utility costs at a given point in time. Critical peak pricing is another variant that allows utilities to raise electricity prices during specific times of system stress, such as record-heat days. Yet another alternative could be an off-peak "rebate" that pays customers to charge during the off-peak, as currently demonstrated by ConEdison.[144]

It has been well-documented that TOU rates are an effective tool to shift loads to off-peak periods. A research project between the EV Project and San Diego Gas & Electric (SDG&E) found that 78 percent of charging shifted to the super off-period with a 2:1 peak/non-peak price ratio.[145] Dynamic rates, which provide rates that reflect that utility's cost of providing power at that instant, have the potential to be even more effective, although they can prove confusing to customers. SDG&E's "Power your Drive" pilot program is exploring dynamic rates, including a feature in which the utility publishes hourly dynamic prices one day in advance. Customers will be able to use the website or app to be matched to a charging station based on their preferred charging durations, times, and willingness to pay.[146] In a Deloitte survey of executives from investor-owned, cooperative, and municipal electric utilities involved in PEV initiatives, 47 percent of the executives reported that their companies already offer TOU or special PEV rate plans, while 26 percent said they were waiting for regulatory approval or studying the topic.[147] For public charging installations, TOU rates also can be collected from the site host (rate-to-host programs), allowing the host to collect revenue from customers through other means; or to pass the TOU rate directly on to drivers (rate-to-drivers).[148] A list of utility programs implemented to date is included in Jones, et al., 2017.[149] Note that TOU rates may not be appropriate for all residential customers, including vulnerable consumers. For instance, some older consumers or people with disabilities rely on medical equipment that runs on electricity.[150]

Another important tariff element is demand charges, which are widely used in the commercial and industrial sectors, and are assessed based on the highest level of power demand over a given period of time, such as during the monthly billing cycle. Although demand charges help utilities recover their costs adequately and encourage more efficient use of grid assets, for some commercial EVSE hosts, especially those with low utilization rates, demand charges can lead to higher average electricity costs per kWh delivered – sometimes over 90 percent of the total bill due to the demand charge. As an example, changes in demand charges and rate structure in San Diego Gas and Electric territory transitioned a charging station from incurring $3,114 to just under $138 per month.[151] While eliminating demand charges may not be a long-term option for some utilities since cost recovery is necessary to reduce cost shifts between customer classes, some utilities are exploring innovative solutions to lower the impact of demand charges on the business case for EVSE. Southern California Edison received approval to suspend demand charges during an introductory period of five years, relying more heavily on volumetric charges during this period, then gradually phasing the demand charges back in over the subsequent five years as the utilization of stations increases. SDG&E is exploring a tariff that replaces demand charge-like elements with "dynamic adders" that derive from usage during top system hours for a given circuit.[152] Others, such as Hawaiian Electric Co, are considering how the application of distributed energy storage may be able to minimize the cost of grid upgrades.[153] Customer-sided energy storage or other charging-management technologies also may be beneficial long-term solutions to reduce the impact of charging demand on the grid and customer costs. Such creative thinking will likely become increasingly necessary, especially with the higher-rate DCFC deployments.

Appendix C: Vehicle-to-Grid

As cited in the main text, vehicle-to-grid (V2G) capabilities have enormous potential, but also face a number of challenges and costs for deployment.

V2G doesn't only implicate utilities and single customers; it also could create an opportunity for TNC, network operators or other businesses with large PEV fleets, allowing for close coordination between PEV charging equipment providers and utilities to set optimal infrastructural locations, interoperability, and rate plans. This model is being successfully deployed in Denmark, where PEV fleet owners can earn €1,300 (about $1,530) per vehicle annually for participating in a Nissan/Enel SpA V2G program.[154] Very little data of V1G and V2G are available, but it is likely that value could range widely depending on the local characteristics of the energy markets and the grid. Deloitte expects that the emergence of large fleets of PEVs in urban areas will accelerate the value calculation for V1G and V2G, as passenger vehicles and medium- and heavy-duty vehicles electrify, bringing larger battery options to the grid.[155]

As a distributed storage tool, V2G could provide market services for the power sector. Currently, however, the primary market products that could be provided by V2G include the ancillary regulation services that constitute some of the most available power at any given balancing authority. Maximizing the value to all services that the utility or balancing authority can derive from PEV resources and ensuring that participants are compensated across regulated and wholesale electricity markets is a significant challenge.[q] Another challenge is determining the methods and messaging protocols through which charging infrastructure will communicate with utilities.[156]

The business models that could support V2G are diverse. For example, utilities could consider owning and leasing PEV batteries to fleet owners, or fleet owners could sell 80 percent depleted batteries back to utilities for stationary use. Extensive work is still necessary to establish the market structures, policies, and regulations that would allow for the assessment, delivery, and payment of demand response, ancillary services, and other benefits to the grid. In the Smart Electric Power Alliance's 2017 Utility Demand Response Survey, 69 percent of respondents indicated an interest in planning, researching, or considering demand response programs that included V1G; only 20 percent indicated no interest.[157] Value derived from these concepts will also vary greatly by location and access to wholesale markets. For instance, regulation service power at PJM is typically in the $30 to $35 per MWh range whereas in the California Independent System Operator (CAISO) territory the regulation service markets are at $5 to $8 per MWh. As utilities around the world prioritize resiliency of their grid, V1G and V2G become distributed resource tools to help grid operations.

q Much of the control requirements in these markets require modulation in less than four-second time increments which requires a robust communication system including identification of resource availability.

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