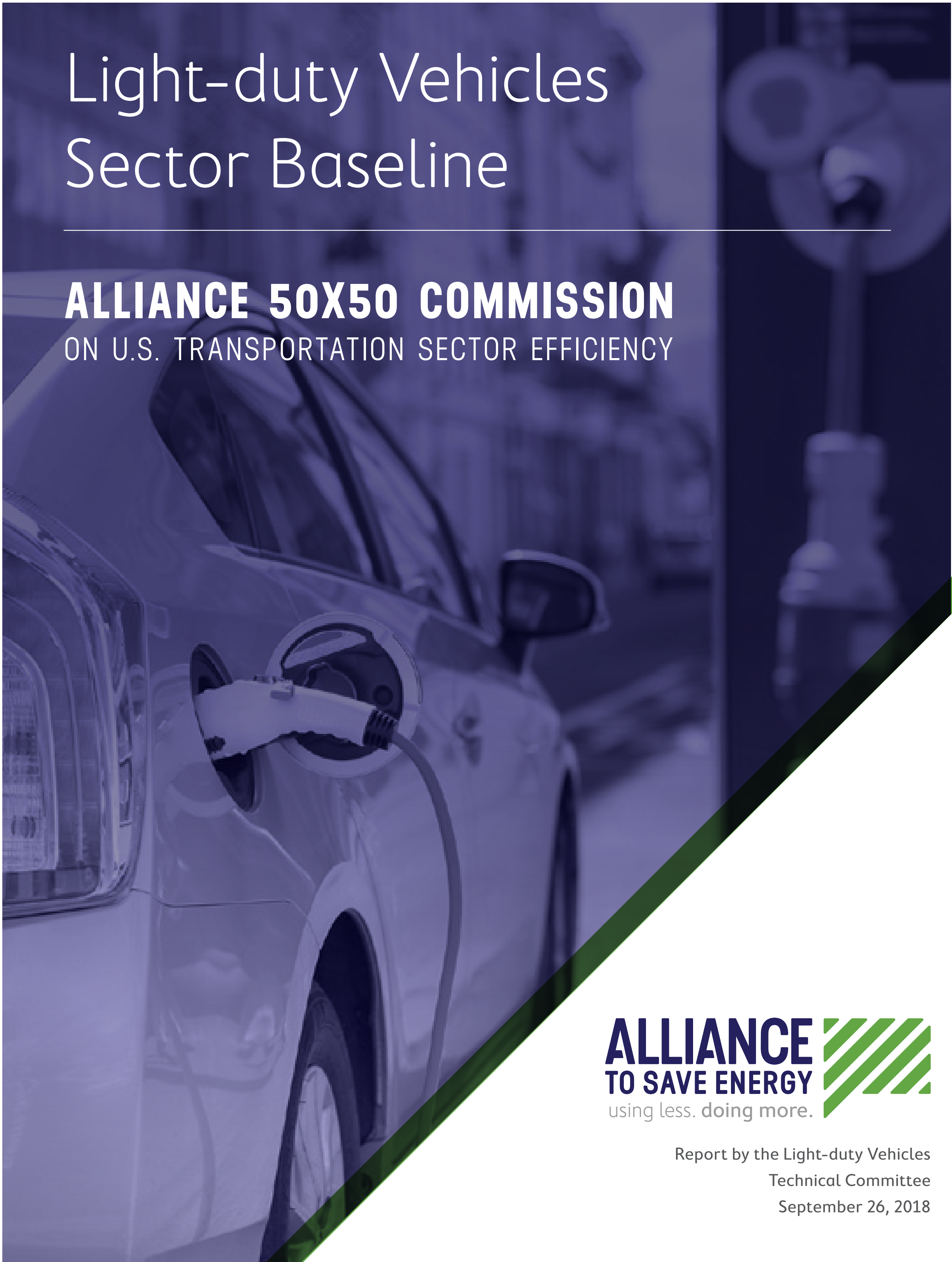
Light-duty Vehicles Sector Baseline



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

ALLIANCE TO SAVE ENERGY
using less. doing more.

Report by the Light-duty Vehicles
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 the 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, Light-duty Vehicles, 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 – Heavy-duty Vehicles & Freight; Non-road Vehicles; ICT, Shared Mobility, and Automation; and Enabling Infrastructure – helped inform the 50x50 Commission's policy recommendations.

Technical Committee

Our sincere thanks and appreciation go to the 50x50 Commission Light-duty Vehicles Technical Committee:

Robert Chapman (Chair), *Electric Power Research Institute*
Brad Stertz, *Audi of America*
Cody Thacker, *Audi of America*
Rebecca Kiernan, *City of Pittsburgh*
Shannon Baker-Branstetter, *Consumers Union*
Nate Goshen, *Covestro LLC*
Richard Skorpenske, *Covestro LLC*
Steve Rosenstock, *Edison Electric Institute*
Rick Tempchin, *Edison Electric Institute*
Genevieve Cullen, *Electric Drive Transportation Association*
Dan Bowermaster, *Electric Power Research Institute*
Wil Smith, *Electric Power Research Institute*
Barbara Tyran, *Electric Power Research Institute*
Britta Gross, *General Motors*
Dan Dykstra, *Ingersoll Rand*
Bill Hilbrunner, *National Grid U.S.*
Simon Mui, *Natural Resources Defense Council*
Luke Tonachel, *Natural Resources Defense Council*
Rajiv Diwan, *New York Power Authority*
Adam Ruder, *New York State Energy Research and Development Authority*
Ronald Graves, *Oak Ridge National Laboratory*
Bill Boyce, *Sacramento Municipal Utility District*
Yann Kulp, *Schneider Electric*
Rich Weiner, *Schneider Electric*
Suzanne Frew, *Snohomish County Public Utility District*
Diane Harris, *Southern Company*
Adam Gromis, *Uber*

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

TABLE OF CONTENTS

INTRODUCTION

Light-duty vehicle (LDV) use currently accounts for approximately 56 percent of total U.S. transportation energy consumption.[1] The 50x50 Commission goal to reduce U.S. transportation-related energy consumption by 50 percent by 2050 will thus require a significant focus on LDVs.

While the 50x50 goal is ambitious, many of the LDV technologies necessary to help achieve the goal—from more efficient powertrains to lighter materials—are already available in today's market. LDV energy consumption has already begun to decline and the Energy Information Administration (EIA)'s Annual Energy Outlook (AEO) 2018 projects that the recent downward trend in LDV energy consumption will continue despite a projected 18 percent increase in vehicle miles traveled (VMT) by 2050.[2] This reflects the strong role that fuel economy and emissions standards have played in the market, along with projected increases in market penetration of higher-efficiency alternative technologies—including electric vehicles, which are projected to reach 19 percent of market sales by 2050 under current policy conditions.[3]

Achieving the 50x50 goal will likely require even greater efficiency gains in internal combustion engine (ICE) vehicles and much greater penetration of alternative fuel vehicles (AFV) combined with consumer shifts to less energy-intensive transportation modes.[4] Reaching the 50x50 goal will require a combination of the following key actions:

- Substantially improved efficiency of ICE vehicles, which currently dominate the LDV market.
- Rapid deployment of alternative fuel and hybrid vehicles. Hybrids, plug-in electric vehicles and fuel cell electric vehicles currently account for about only three percent of new LDV sales.[5]
- Shifts in customer choices toward more efficient cars, right-sized vehicles, and more efficient modes of transport, including public transit and ride-sharing.
- Ensuring that the deployment of autonomous vehicles is accomplished as efficiently as possible, with a focus on keeping VMT low, even as passenger miles traveled (PMT) may increase with population growth.

Assessing future trends in the LDV market requires analysis of consumer demand, technology advancement, public policy and the ever-present impact of fuel prices. The availability and convenience of fueling infrastructure also will play a key role. Fundamentally new transport options, such as ride-sharing and autonomous vehicles, may even change the notion of car ownership in the 2050 timeframe.

OBJECTIVES AND SCOPE

This report describes the current state of the LDV market in the U.S., including recent trends in vehicle efficiency and consumer choice, and opportunities for reducing fuel use. The report does not judge which technologies might have a greater impact on achieving the 50x50 goal. Instead, the report discusses the current key opportunities and challenges related to deploying more energy-efficient LDV technologies and implementing best practices for efficiency in the LDV sector.

This report discusses the following vehicle types:

- Conventional Internal Combustion Engine (ICE) vehicles: conventional vehicles running on gasoline or diesel fuels
- Hybrid Vehicles: conventional gasoline or 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 an ICE and a battery for an electric 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 using 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).
- Flexible-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 PEVs, FCEVs, natural gas, propane, and FFVs.

The following sections of this report include a more detailed discussion on the current technology make-up of the LDV market, on technical and policy strategies for reducing energy use, and on the consumer's perspective.

SUMMARY OF KEY FINDINGS

Fuel Economy Standards Are a Critical Tool

Fuel economy standards will remain a key driver for future transportation efficiency gains, especially for conventional ICE vehicles.

Fleet Turnover Will Influence the Pace of Change

Slow fleet turnover from conventional ICE vehicles to more efficient vehicles, including BEVs, FCEVs and PHEVs, slows the pace of progress, even as new technologies come onto the market. Consumer education on the benefits of more efficient vehicles will play a key role in fleet turnover.

Alternative Fuel Vehicles Have Efficiency Benefits, But Low Market Penetrations

Alternative fuel vehicles – especially electric vehicles (BEVs, PHEVs, FCEVs) – can produce significant energy efficiency gains over conventional vehicles, but their markets are still at early stages of development.

Alternative Vehicles Require Significant Infrastructure Development

Meeting the needs of the national fleet of the future will require significant investments in new fueling infrastructure, including PEV charging infrastructure.

With New Emerging Technologies, Efficiency Should Remain a High Priority

The rise of new vehicle types, ride-sharing business models and autonomous vehicles may result in transformational changes to the transportation sector. While this could enable highly efficient options such as ridesharing in automated and electrified vehicles, these technologies also could result in a "rebound effect" (where users increase vehicle miles traveled (VMT)) and a weakening of public transportation systems. Strategies to address these emerging impacts are critical to reach the 50x50 goal.

LIGHT-DUTY VEHICLE TECHNOLOGY

LIGHT-DUTY VEHICLE TECHNOLOGY

Whether in commercial fleets or personal vehicles, LDVs are the primary – and in many cases only – tool for personal travel in the United States. LDVs, which include personal cars and light trucks such as sport utility vehicles (SUVs), consume the most fuel of all highway transportation vehicle classes (55 percent) and account for the most vehicle miles traveled (VMT) per person per mile (nearly 3 trillion miles, or 94 percent of total miles traveled).[6,7] 91 percent of U.S. families own a personal vehicle, and 24 percent own three or more.[8]

Today's LDV market offers numerous opportunities to reduce energy consumption, which could lead to remarkable benefits given its scale. These opportunities range from improving fuel economy to enhancing markets for highly efficient alternative fuel vehicles. Automation and new business models that enable ridesharing could lead to transformational changes in personal mobility. This report summarizes a number of these opportunities that can help achieve the 50x50 goal.

Internal Combustion Engine Vehicles

ICE vehicles comprised 97 percent of vehicle sales in the U.S. in 2017. [9] In addition, with more than 160,000 gasoline fueling stations, the fueling infrastructure for ICE vehicles is both mature and widely geographically distributed.[10] The U.S. transportation sector thus relies heavily on petroleum, with 89 percent of the sector powered by petroleum-based fuels in 2017.[11] As a result, oil price instability continues to be a major influence on the sector, and is a particularly important determinant of which cars consumers choose to purchase.[12] Among ICE vehicles, the primary opportunities to enhance energy efficiency are through fuel economy standards and the advancement of technologies that enable fuel economy gains.

Adjusted Fuel Economy

The efficiency with which a vehicle converts fuel to energy is described by the U.S. Environmental Protection Agency (EPA) and automakers in terms of "adjusted fuel economy," a miles-per-gallon (mpg) metric that accounts for the average miles a vehicle can travel per gallon of fuel, and includes additional mpg "credits" (off-cycle credits) for other technologies that improve fuel efficiency and reduce greenhouse gas (GHG) emissions, such as adaptive cruise control or the use of air-conditioning refrigerants with lower global warming potential. Fuel economy gains can be achieved through several different strategies, such as by adjusting horsepower and reducing vehicle weight; many of these strategies can reinforce one another.

Fuel Economy Standards

Historically, fleet-wide improvements in fuel economy have been driven primarily by regulations – specifically corporate average fuel economy (CAFE) standards.[13,14] CAFE standards were introduced in 1978 and 1982 for cars and light trucks, respectively, and strengthened from 1978 to 1985, in response to high petroleum prices and national energy security concerns. Since their inception, CAFE standards have resulted in reductions in vehicle size, weight and horsepower (see Figure 1).[15,16] During 1985 to 2005, when the standards were held constant, the adjusted fuel economy for the overall U.S.LDV market slightly regressed. After 2005, CAFE standards were again strengthened, and adjusted fuel economy has risen alongside horsepower, while vehicle weight has remained constant. This is particularly notable considering the shift in consumer preferences from sedans toward light trucks. Compared to 47 percent of LDV sales in 2012, light trucks—including minivans, SUVs and pickups—made up 67 percent of LDV sales by December 2017.[17]

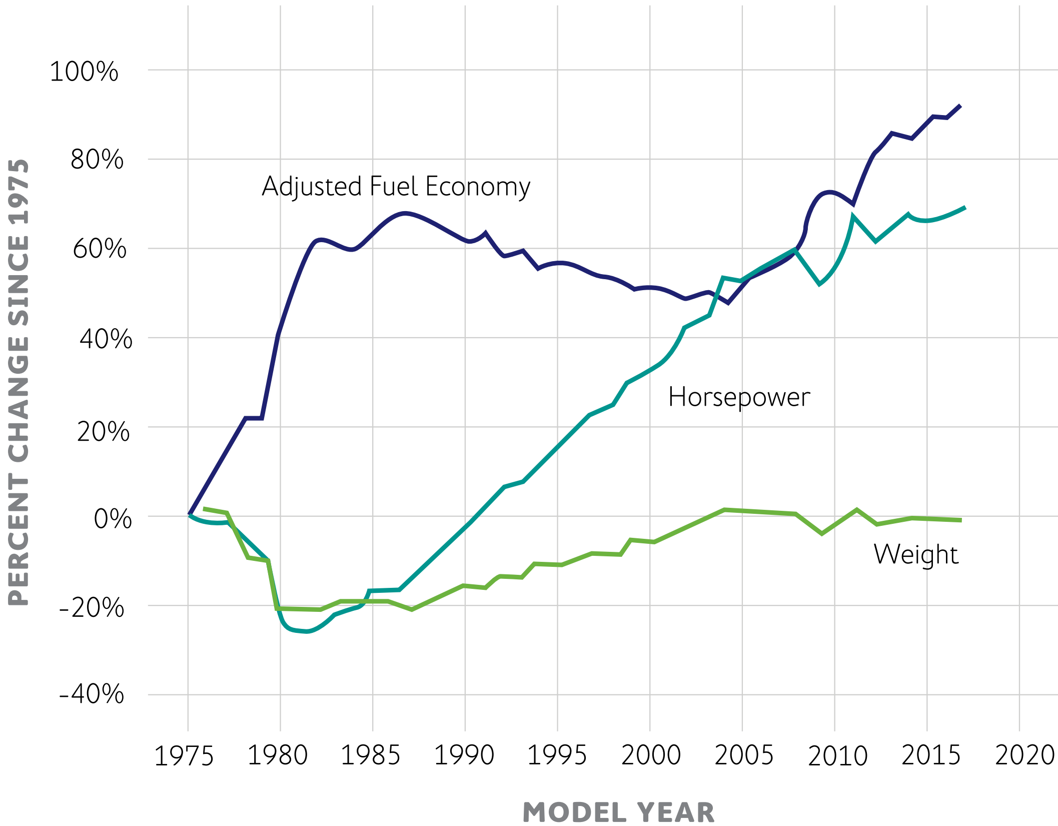


Figure 1. Change in Adjusted Fuel Economy, Weight, and Horsepower for MY 1975-2017

Environmental Protection Agency 2018. Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2017. U.S. EPA-420-R-18-001, Office of Transportation and Air Quality, January 2018.

Fuel economy improvements are a key focus of recent re-designs for popular LDVs of all sizes. Improved transmissions, weight reductions and smaller turbocharged engines have all contributed to fuel economy improvements. Hybrid electric vehicles, introduced to the U.S. market in 1999, also present high-efficiency alternatives. Examples of fuel economy improvements among a variety of vehicle sizes include:[18]

- Honda increased efficiency in its CR-V model (a compact SUV) by deploying a turbocharged engine as well as a continuously variable transmission, while reducing the engine from 2.4 to 1.5 liters.
- Audi's Q5 model increased efficiency by 3 mpg over its predecessor by employing its "ultra" technology, which uses a quick-reacting and electromechanically enabled all-wheel drive system, achieving a combined estimated fuel economy rating of 25 mpg.[19]
- General Motors' turbocharged 1.5 -liter ECOTEC engine enables its 2018 hybrid Chevrolet Malibu to achieve an estimated fuel economy of 27 mpg in the city and 36 mpg on the highway.[20]
- Ford's model F-150 offers a smaller turbocharged engine, in addition to the traditional V8 engine, which helps reduce vehicle weight and improve acceleration time.

One feature of adjusted fuel economy is that energy savings are not linear with respect to mpg improvements. For example, on a 100-mile trip, improving fuel economy from 5 mpg to 10 mpg will save about 10 gallons of fuel; but improving fuel economy from 30 mpg to 35 mpg will save less than one gallon.[21] This comparison highlights the outsized impact of enhancing fuel economy for vehicles that are least efficient. It also demonstrates the importance of consumer preferences: Preferences for larger, less efficient vehicles are likely to define the future of the sector as much as – or even more than – our ability to innovate minor improvements to the fuel economy of top-performing vehicles.

Future Fuel Economy Improvements

- While fuel economy of new vehicles has incrementally increased for decades, there is still space for improvement. In a 2015 report, the National Academy of Sciences identified key technologies for improving fuel economy, including engine improvements, electric powertrains, transmissions and non-powertrain technologies (e.g., aerodynamics, weight reductions, tires, automated/connected vehicles).[22] Many of these technologies are commercially available today, although many are not yet fully adopted. Specific examples of these technologies include:
- Engine improvements
  - Start/stop technology completely shuts the engine off when the vehicle stops.
  - Cylinder deactivation allows some engine cylinders to shut off when the car has a low demand for driving power.
  - In smaller, turbocharged engines, forced air boosts the power of an engine, yielding greater horsepower from a smaller, more efficient engine.
  - A multimode combustion engine can enable highly efficient engine operations by combining low temperature compression ignition with conventional spark ignition. Mazda's spark-controlled compression ignition is an example of a multimode combustion engine.[23]
  - Enabling Atkinson cycle features in an engine can enhance efficiency. Atkinson cycle engines often are paired with hybrids since they provide greater efficiency but typically have a lower power density, for which the electric powertrain can compensate.
- New drivetrain approaches
  - Greater number of vehicles have demonstrated enhanced performance and efficiency over the last two decades. Significant growth in mild hybrid powertrains (i.e., ICEs equipped with an electric machine enabling the engine to be turned off when the car is braking, coasting, or stopped) is expected due to their relatively high benefit-to-cost ratio. Hybrids can achieve up to 80 percent better fuel economy than their ICE vehicle equivalents.[24]
- Transmissions
  - Greater number of gear ratios can increase efficiency by increasing the number of options an engine has to achieve optimal efficiency. Automatic transmissions are available today with as many as ten gears.
  - Continuously variable transmissions offer an almost infinite number of gears.
- Non-powertrain technologies
  - Automakers are reducing weight while using stronger materials in car frames and interiors. They also are eliminating spare tires and downsizing other accessories to reduce weight. The U.S. Department of Energy (DOE) estimates that reducing a vehicle's weight by 10 percent can improve fuel economy by 6 to 8 percent.[25] Using lightweight materials also helps offset the potential increase in weight from new technologies such as connected and autonomous vehicles.
  - Aerodynamic improvements enhance efficiency, aided by improved computer simulation modeling.
  - Low rolling resistance tires can yield significant energy savings.

Applying combinations of these technology improvements will yield the greatest energy savings. For example, the EPA recently projected that a 2016 Honda Civic (an ICE compact car), with an L15B7 turbocharged engine, could increase its fuel economy by about 35 percent by 2025 with a combination of engine improvements, lower rolling resistance, and improved aerodynamics.[26]

While not yet commercially available or fully deployed, other technically feasible technologies can achieve even greater efficiency improvements. For example, higher octane fuels than typically used, including fuels with increased ethanol content, are expected to increase engine efficiency.[27] Also, exhaust energy utilization systems that are typically effective in heavy-duty engines may be adaptable to LDVs. Advanced materials, in conjunction with combustion developments, should lead to reduced heat transfer losses. Finally, alternative configuration engines under development, including opposed piston and compound expansion engines, could yield additional efficiency benefits.

Alternative Fuel Vehicles

While conventional ICE vehicles are still the most common vehicles on U.S. roads and highways, there are several alternative fuel vehicle types on the market, with many demonstrating significant improvements in fuel economy and/or emissions reductions.

For example, electric motors are considerably more efficient than ICEs. According to estimates by Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use (GREET) Well-to-Wheel calculator, a battery-electric car running on the average U.S. electricity mix is estimated to be slightly over twice as efficient as a gasoline vehicle (running on gasoline with 10 percent ethanol, or E10); hydrogen fuel cells using fuel produced from centralized natural gas steam methane reforming, by comparison, are 1.4 times as efficient.[28]

Well-to-wheel GHG emissions from natural gas vehicles are up to 11 percent lower than the emissions from gasoline-powered vehicles.[29] BEVs emit no tailpipe emissions, and well-to-wheel emission rates for PEVs and hybrids are typically about half of the emissions rates from gasoline ICE vehicles.[30] Hydrogen FCEVs, which use hydrogen fuel to power an electric motor, emit only water at the tailpipe; it is important to note, however, that emissions from hydrogen fuel production vary significantly depending on the energy source.

While each type of alternative fuel vehicle faces unique deployment challenges, the recent rapid growth in the number of available models indicates that there is significant potential for increased market penetration of many alternative fuel vehicle types. From 2010 to 2016, the number of LDV alternative fuel models offered in the U.S. grew from one to 29 for PEVs (including PHEVs and BEVs), from one to 12 for natural gas vehicles, and from zero to three for FCEVs.[31]

Plug-in Electric Vehicles

As mentioned above, PEVs – which include both BEVs and PHEVs – use a highly energy-efficient powertrain. While conventional ICE vehicles convert about 20 percent of the supplied fuel energy to power at the wheels, BEVs convert about 60 percent of the supplied electrical energy to power at the wheels.[32] As a result, while conventional passenger cars (including non-plug in hybrids) from model years 2016 to 2018 had a fuel economy range of approximately 10 to 58 mpg, BEVs in the same period had a fuel economy range of about 70 to 120 miles per gallon equivalent (mpge).[33] PHEV adjusted fuel economy ratings reference both fuel economies: one for electric and one for conventional fuel use. For example, the Toyota Prius Prime has a fuel economy of about 133 mpge if running on both electricity and gasoline, while it offers 54 mpg if running on gasoline only.[34] Falling costs coupled with performance improvements mean that PEVs will likely play a critical role in any pathway to a 50 percent reduction in transportation energy use on a PTW basis.

However, PEV markets are still emerging. Even though PEV purchases and leases are increasing year-on-year, PHEV and BEV sales combined accounted for only about one percent of total LDV sales in 2017. Non-plug-in hybrid vehicles still account for only two percent of LDV sales.[35]

Factors that affect PEV market penetration include cost, infrastructure availability and consumer purchasing decisions; these factors are explored below. Infrastructure issues in this report are discussed primarily in the context of enabling greater deployments of PEVs. The Enabling Infrastructure Sector Baseline report provides greater detail on the opportunities and challenges related to alternative fueling infrastructure deployment.

Total Cost of Ownership

A primary challenge for increasing PEV deployment is the upfront vehicle cost, which tends to be higher for PEVs than for conventional vehicles. LDV consumers remain highly price-sensitive.[36] For example, while about 80 percent of consumers are willing to pay 5 percent more for an environmentally friendly vehicle, only 35 percent of consumers are willing to pay 15 percent more, and fewer than 10 percent of consumers are willing to pay 25 percent more (see the "Consumer Purchase Decisions" section below for more discussion of factors that affect consumer purchases).[37] Many economic analyses thus project that the year when PEVs reach price parity with conventional vehicles will represent a tipping point for PEV markets.[38]

However, cost comparisons based only on upfront vehicle costs are missing a key factor. According to an Applied Energy report, the total cost of vehicle ownership (the cost of the vehicle plus the expenses incurred over its lifetime) for PEVs tends to be on par with or lower than the cost of ownership for conventional vehicles.[39] The report accounted for a number of factors for each vehicle type, including vehicle depreciation, taxes, maintenance costs (which are lower for PEVs due to fewer moving parts), insurance and annual fuel cost. Another recent study from the University of Michigan found the average total cost of ownership of PEVs to be 2.3 times lower than that of conventional gasoline vehicles.[40] It is worth noting, however, that projections for the total cost of ownership for PEVs could change if current tax policies and regulations change. For instance, while the Highway Trust Fund is currently funded through the gasoline tax, changes in its pricing scheme that involved fees for PEVs could add to future total cost of PEV ownership.[41]

Battery Cost

The average manufacturer's suggested retail price (MSRP) of a PHEV or BEV currently exceeds that of a standard gasoline engine vehicle.

The high purchase cost of a PEV is largely due to the cost of the vehicle's battery; for BEVs, batteries can constitute more than 40 percent of the vehicle's cost.[42,43] Nevertheless, increases in vehicle production and rapid decreases in battery costs— with average battery pack prices falling by 79 percent from 2010 to 2017—are driving PEV costs down.[44]

A California Air Resources Board collection of recent reports shows that studies across the board, despite differences in assumptions and approaches, predict that battery prices will continue to decline.[45] Bloomberg New Energy Finance (BNEF) projects that the weighted average price for lithium-ion battery packs, including both stationary energy storage and PEV battery packs, will fall below $100 per kilowatt-hour (kWh) in 2025, a significant drop from $209 per kWh in 2017.[46] Price reductions will largely be driven by production improvements (including economies of scale in manufacturing, process improvements, and vertical integration in battery manufacturing), along with improvements in battery chemistry, energy density and battery pack design. The National Renewable Energy Laboratory estimates that a BEV with 70 miles of range is likely to reach upfront purchase parity with an ICE vehicle by 2025 (see Figure 2 and note that the numbers in the legend listed after "BEV" and "PHEV" indicate the miles of range for each vehicle).[47]

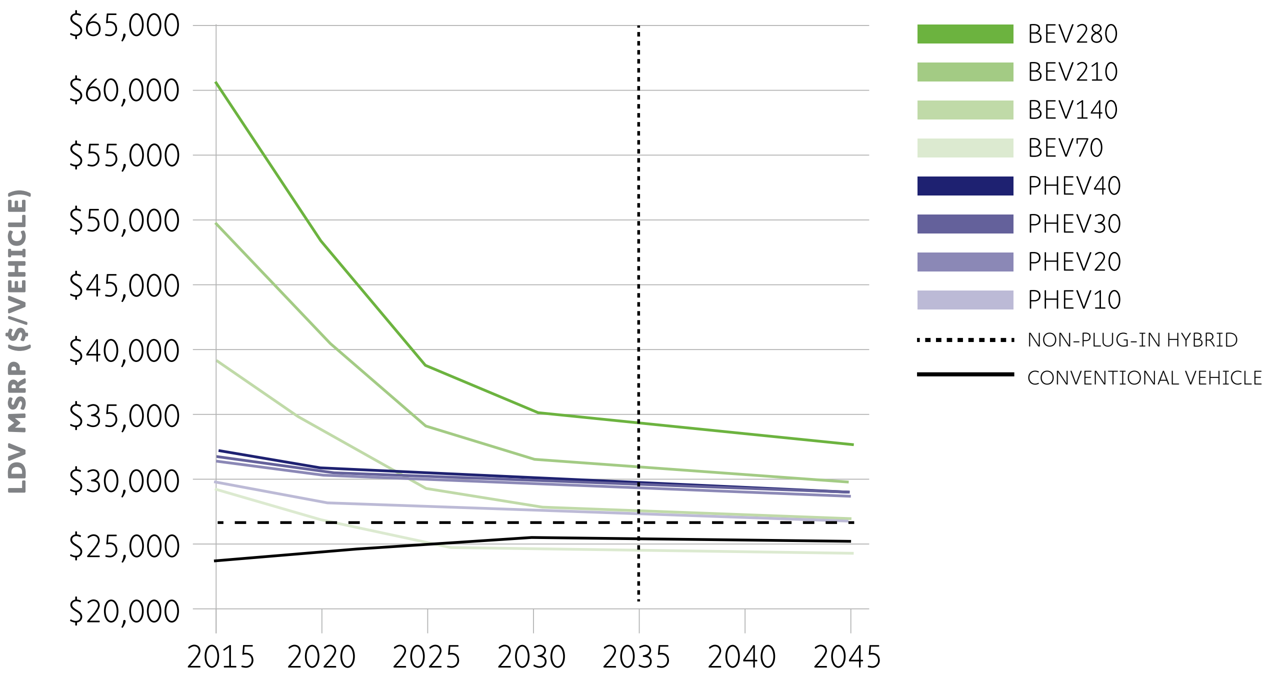


Figure 2. Time series representation of the high-med light-duty vehicle BaSce cost trend results from Moawad et al. (2016), after applying a 1.5 retail markup factor to estimate the manufacturer's suggested retail price (MSRP), shown in units of dollars per vehicle. This figure is from the National Renewable Energy Laboratory's 2016 report titled "National Economic Value Assessment of Plug-In Electric Vehicles."

Rapid drops in battery costs have been accompanied by rapid increases in their capabilities. The combination of lower cost per kWh and higher density battery packs, offering more miles of range, makes both PHEVs and BEVs more appealing. The highest performing BEVs today, with ranges higher than 300 miles, have enough capacity to meet most consumer transportation needs.[48]

While battery price estimates are informative, they do not apply to all PEV scenarios since battery prices depend on a wide variety of dynamic factors, including the following:

- Battery prices will depend on the battery's application. Stationary energy storage likely will have higher prices per kWh, while large volume passenger PEVs, including buses, will have lower prices per kWh.
- Trade policies and supply chain design could lead to different battery prices based on the country of origin.[49]
- Potential fluctuations in raw material prices, especially for cobalt, can significantly impact future battery prices.
- Predictions of battery price trends usually do not include potential breakthrough technologies still undergoing testing, such as lithium-sulfur, lithium-air, and solid-state batteries. Commercialization of these technologies could lead to a significant additional drop in battery prices.

Impact of Government Incentives

Government incentives can help reduce the purchase cost differential and increase the value of PEVs in the near term to help drive demand. Nearly 30 percent of all U.S. PEV buyers cited the 30D federal PEV tax credit as a factor that encouraged their purchase decision.[50] A number of other countries, including China and Norway (see Table 1), also have successfully used government incentives to advance PEV adoption. The Chinese and Norwegian experiences demonstrate that pursuing many avenues simultaneously—and updating incentives regularly—can make PEVs significantly more attractive to consumers. Prioritizing research and development to further reduce cost, increase range and reduce refueling speed of PEVs also can increase their appeal. As technology advances, the costs of PEV ownership fall and markets adopt PEVs at greater levels, such government incentives become less necessary and can be decreased.

Table 1. International Examples of Successful Policy Support for PEV Adoption: China and Norway

China China surpassed the U.S. as the world's largest PEV market in 2015.[51] PEVs represented 2.1 percent of car sales in China in 2017.[52]	**Norway**[53] PEVs represented 39 percent of car sales in Norway in 2017.[54]
• (2009) Electric Vehicle Subsidy Scheme that provides purchase incentives for electric vehicles in two phases.[55] • (2009) Ten Cities, Thousand Vehicles Pilot Program initially selected ten cities to offer electric vehicle purchase incentives; the program quickly expanded to include 25 cities.[56] • In Beijing and Shanghai, where the number of vehicle license plates issued per month is restricted, those who drive PEVs qualify for dedicated and free license plates.[57] • In Changchun, where vehicle use is restricted in some areas for a portion of the day, PEVs are exempt from those restrictions.[58]	• No purchase/import taxes (1990) • Low annual road tax (1996) • No charges on toll roads or ferries (1997 and 2009) • Free municipal parking (1999) • 50 percent reduced company car tax (2000) • Exemption from 25 percent value-added tax (VAT) on purchase (2001) • Access to bus lanes (2005) • Exemption from 25 percent VAT on leasing (2015) • Access to bus lanes in Oslo require carpooling with at least one passenger during rush hour (2015) • Zero annual road tax (2018) • 40 percent reduced company car tax (2018) • 50 percent discount for ferries (2018) • Zero re-registration tax for used zero emission cars (2018)

Range Anxiety and Infrastructure Requirements

Another challenge for the broader adoption of PEVs is range anxiety – the fear that a vehicle has insufficient range to reach its destination or a charging station. Range anxiety is primarily driven by two features: battery performance and the availability of charging stations.

Battery Performance

The average commute of a U.S. driver is 29 miles, or 55 minutes, which is well within the electric range of available PEV models.[59] Many PEV models offer electric ranges above 100 miles and some have ranges of up to 300 miles.[60] Nonetheless, many drivers at least occasionally take longer trips, which raises questions about range limits and availability of charging stations en route. Over 50 percent of consumers report that the range limit on a full charge is a significant concern in purchasing a PEV, and 37 percent report that the location and availability of charging stations is a significant concern.[61]

Two current trends—greater availability of compatible electric charging stations, combined with rapidly increasing battery capacity—will help reduce range anxiety. These trends already are resulting in the availability of more models with higher battery ranges. For example, the 2018 Nissan Leaf has a range of 150 miles, compared to the original Nissan Leaf's 70-mile range.[62,63] Other recent models have even larger ranges – for example, 250 miles for the Chevy Bolt and 300 miles for the Tesla Model 3.[64,65]

Availability of Charging Stations

To stimulate PEV markets, charging stations will need to be geographically available and also provide a positive customer experience in terms of both cost and convenience that is comparable to traditional gas stations. While publicly available gas stations can refuel ICE vehicles in a short period of time, PEV charging times can vary widely based on the power level of the charger: [66]

- AC level 1 (L1) charging uses the standard 120 volt (V) wall port ubiquitous in U.S. residential electric systems. Its low power provides only two to five miles of range per hour of charging. For most daily commutes, a vehicle can be recharged overnight.
- AC level 2 (L2) charging requires a 208 V commercial or 240 V residential AC circuit. Typical L2 charging can provide an estimated 10 to 20 miles of range per hour of charging. It takes about two hours to charge a vehicle for a typical 35-mile commute.
- DC fast-chargers (DCFCs) provide high voltage DC power directly to the battery. They typically can provide an estimated 60 to 80 miles of range per 20 minutes of charging, depending on the power level and the size of the battery pack.

These charger types can be deployed in different ways, including:

- Residential Charging. According to DOE's EV Project, more than 80 percent of charging takes place at home.[67] However, the increased availability of workplace charging or cheap public charging could reduce home charging. Alternatively, home charging could expand to include more L2 charging infrastructure. Analysis of the 12 largest utility service territories in the U.S. projected that home charging in 2035 would be 59 percent L1 and 41 percent L2.[68]

  Installation of a single-family home charging station is a simple process and involves a limited set of decision makers. In comparison, charging installations at multi-unit dwellings can be more challenging, since the beneficiaries of the infrastructure may be temporary residents and/or renters, and there are multiple decision makers (i.e., building management, property owners). For those living in buildings without access to residential charging, workplace or public charging is critical.

- Charging at the Workplace and Other Long Dwell-time Locations. Charging stations at workplaces and public locations where cars are parked for long periods (such as park-and-ride lots, stadiums and shopping centers) offer the most flexibility in charging. In addition, workplace charging can benefit employees if the electricity cost is subsidized by the employer.

  Workplaces and other long dwell-time locations typically offer L2 charging. Employers and commercial owners may choose differently powered installations based on costs and typical employee parking periods.

- Public and Centralized Fleet Fast Charging. DCFC is ideal for re-fueling on 200-mile or longer trips, or "corridor charging", and for fleet vehicles in constant service, such as ride-hailing and car-sharing services. DCFCs offer a charging experience that is comparable to refueling at a gas station. New developments include top speed DCFCs, capable of powering at 350 kilowatt (kW), which can fully charge a PEV in about ten minutes.[69,70] The high-power requirements for DCFCs increase infrastructure costs, but high utilization of DCFCs can potentially spread the costs among many drivers to make per-charge pricing attractive.

The need for improved availability and convenience of charging stations as well as the demand for PEVs are key factors driving future infrastructure needs. The National Renewable Energy Laboratory (NREL) predicts that consumers will require 40 L2 charging ports and 1.7 DCFC charging ports per every 1,000 PEVs, requiring a total of 600,000 L2 charging ports and 27,500 DCFC charging ports to support 15 million light-duty PEVs by 2030.[71] As of August 2018, however, only about 6,900 DCFC chargers and 49,000 AC Level 2 chargers had been installed (including both public and private installations).[72] For comparison, there are 160,000 gasoline stations in the U.S.[73,74]

In addition to being accessible, charging stations will need to be responsive to customer preferences and behaviors. Important factors affected by consumer preferences include the following:

- Charging speed: Consumers prefer short charging times, especially in DCFC stations. This may drive the market toward higher power chargers, which require less charging time but may have greater infrastructure costs.
- Standardization: Not all vehicle types can use all charger types, due to a lack of interoperability among some charging providers. This restricts the number of customers that can benefit from a given charging station.
- Car ownership: The rise of ride-sharing and autonomous vehicles could fundamentally change the number of cars purchased and charging infrastructure needs for fleets versus personal vehicles
- VMT: As the rising use of PEVs offers lower-cost options for transportation, there could be a “rebound effect” that may lead consumers to travel more, increasing electric VMT, and leading to greater demand for chargers.

The quantity, convenience, visibility, accessibility and compatibility of chargers are key to assuring PEV adopters that their mobility is not restricted by vehicle range. Please see the Enabling Infrastructure Sector Baseline report for a more detailed discussion.

Consumer Purchase Decisions

In addition to cost of ownership (including fuel costs) and range anxiety, what other factors affect a consumer’s decision to purchase a PEV? Other vehicle attributes—including reliability, style, safety, and infotainment features—often have higher priority in a consumer’s purchase decision.[75,76] High-efficiency vehicles all face this market challenge except where policy supports efficient fuel economy or during spikes in fuel prices. Other factors that influence the consumer decision-making process include energy prices, vehicle functionality and feel, technology risk, and model availability.

Consumer education and expanding model choices are two strategies for addressing some of the consumer adoption challenges to PEVs.

Consumer education. Consumers often benefit from a greater understanding of PEV range, availability of infrastructure, and other aspects of how a PEV may align with their lifestyle. Numerous advocacy groups and municipalities are implementing education initiatives to boost consumer demand. For example, the nonprofit organization Forth, formerly Drive Oregon, provides extensive PEV education and hosts a brand-agnostic PEV showroom in Portland, Oregon. Consumers can visit the showroom to speak with PEV product specialists and to test drive PEVs from multiple manufacturers.[77] State and local governments also have been engaging directly with consumers to promote PEV awareness and education. At the 2018 edition of the New York State Green Commuting Fair, for example, consumers can participate in a PEV ride-and-drive event while speaking with PEV product specialists.[78]

Increasing PEV Models. The ICE vehicle market currently has a much greater diversity of models than does the PEV market. Within the PEV market, sedans dominate, with three—the Chevrolet Volt, Nissan Leaf and Tesla Model S—accounting for over 40 percent of PEV sales in 2015-2016.[79] Enhancing PEV model choices, and especially incorporating PEV technology into light truck model lineups, would provide new options for consumers—especially since the large market share of light trucks continues to be an obstacle to reducing overall energy usage in the LDV sector. U.S. consumers increasingly prefer SUVs and light trucks, which comprised 67 percent of the total LDV sales in 2017.[80]

By contrast, light trucks made up only 16 percent of PEV sales in 2016 (led by the Tesla Model X and the BMW i3).[81] As of August 2018, out of 391 SUV models available, only 11 SUV models are hybrids or PEVs.[82]

However, the diversity of PEV models is rapidly expanding, with many new offerings announced for SUVs and trucks for deployment in the next five years. The Electric Power Research Institute (EPRI) noted that, between 2012 and 2017, the number of available electric vehicle models in the U.S. grew from 9 to 39; EPRI predicts that 90 PEV models will be available by the end of 2022, 40 percent of which could be SUV/crossover vehicles.[83]

Partly due to the complex decision-making process involving so many vehicle characteristics, consumers can exhibit paradoxical vehicle purchase behavior. For example, while one car may be attractive to a consumer because it is more fuel efficient and has a lower total cost of ownership, a different car may be more appealing due to its lower upfront cost, familiar technology, or simply its look and feel. More study of consumer behavior affecting vehicle purchase decisions could provide additional guidance for effective promotion of PEVs. For example, a review of PEV market diffusion models found that attitudes toward PEVs and risk aversion are significantly less important factors than purchase price and energy prices for LDV purchase decisions; however, the review also found that these behavioral perceptions had not been modeled as frequently.[84] While such factors are more difficult to quantify than financial factors, a better understanding of consumer perception of PEVs could provide greater insight into their effects on LDV purchase decisions.

Hydrogen Fuel Cell Electric Vehicles

Hydrogen FCEVs are significantly more efficient than ICEs, using up to 50 percent less fuel than conventional ICE vehicles per mile traveled.[85] In addition, FCEVs offer significant emissions reduction potential on a PTW basis, since they only emit water and air. Nevertheless, the upstream, well-to-pump process of producing hydrogen fuel can be expensive and energy intensive. Hydrogen is generally produced through one of two processes, steam methane reforming or electrolysis, each of which can produce a range of energy and emissions impacts. Renewable electrolysis is generally considered the cleanest pathway on a lifecycle basis, since it relies on renewable electricity to produce hydrogen from water, avoiding the use of fossil fuels as an energy source or as a feedstock.

Hydrogen Fueling

The range and fueling experience of FCEVs is similar to that of ICE vehicles in the LDV sector.[86] FCEVs can typically travel more than 250 miles on a full tank of fuel and refuel in three to five minutes, which is notably faster than most PEV charging.[87] One challenge is the fuel cost: Hydrogen fuel for FCEVs typically costs $0.21 per mile, while the gas for an ICE vehicle costs about $0.13 per mile.[88] However, NREL predicts that hydrogen fuel prices could potentially drop to $8 per kilogram by 2025, which would translate to $0.12 per mile.[89] The DOE, through its Hydrogen Storage Tech Team, continues to set targets to reduce hydrogen fuel costs and increase the usable energy density of hydrogen fuel.[90] In addition, the DOE has pledged $15.8 million for 30 new projects to develop lower cost materials to support hydrogen production and storage for LDVs. Light-duty FCEVs are driven almost exclusively in California, since the 36 existing public retail hydrogen fuel cell stations in the U.S. are all in California.[91] However, FCEV sales are gradually increasing as hydrogen fueling infrastructure expands. For example, Toyota is working with Air Liquide to establish 12 hydrogen fueling stations in the northeast, from New York to Boston.[92]

FCEV Deployments

There are currently four FCEV models available in the U.S. LDV market.[93] More than 3,000 light-duty FCEVs were on the road as of 2016, and the AEO predicts that more than 7,000 light-duty FCEVs will be on the road by the end of 2018.[94] The Toyota Mirai, which achieved cumulative sales of 3,000 vehicles in California as of January 2018, currently accounts for a large portion of light-duty FCEVs on the road.[95]

California, which currently has the highest levels of FCEV deployments, incentivizes FCEVs through its zero-emission vehicle (ZEV) targets and through multi-stakeholder support. In January 2018, California's Governor Brown issued an executive order establishing a target of 5 million ZEVs on the road by 2030, supported by $2.5 billion in funding.[96] The funds will be used in part to build hydrogen fueling stations, with a goal of completing 200 stations in California by 2025.[97] In addition, the California Fuel Cell Partnership is a coalition of stakeholders that collaborates on FCEV education and FCEV-specific issues, such as commissioning stations, to arrive at consensus on best practices in the industry.[98] For example, the partnership created the Station Operational Status System to inform FCEV customers about whether specific hydrogen fueling stations are open and have fuel.

Challenges

Barriers to the adoption of FCEVs include high vehicle and infrastructure costs, the limited availability of fueling stations, and the vehicle's heavy weight – due in part to the weight of the hydrogen storage tank. While the operational cost of refueling a vehicle with hydrogen is comparable to refueling with a conventional fossil fuel, the costs of the vehicle and the installation of fueling infrastructure are higher for FCEVs than for ICE vehicles.[99,100] In addition, upfront costs for FCEVs are compounded by the fact that there is not yet a critical mass of fueling stations, requiring the steepest growth of any alternative fuel infrastructure to reach viability. And finally, because hydrogen fuel is less energy-dense than gasoline on a volumetric basis, a greater volume of hydrogen fuel is required to yield the same amount of energy generated from gasoline.[101] As a result, hydrogen fuel tanks are typically larger and add weight to a vehicle.

MAKING EFFICIENCY A HIGH PRIORITY IN EMERGING TRANSFORMATIONS

MAKING EFFICIENCY A HIGH PRIORITY IN EMERGING TRANSFORMATIONS

Purchasing decisions and vehicle use are essential elements of consumer behavior that will continue to affect LDV energy use, and both will be influenced by increasing transportation mode choices as well as the introduction of autonomous vehicles.

With the potential for such rapid change in the LDV market, it will be critical to ensure efficiency is an integral consideration during every transformation to avoid major energy consumption increases. For example, the introduction of autonomous vehicles may either support or inhibit energy efficiency efforts, depending on whether this transformation is deployed in a holistic manner with efficiency as a connecting thread. Regarding LDVs, there are two structural challenges that will have significant impacts on the fuel consumption of the sector: VMT and fleet turnover.

- Potential growth in VMT. Growth in the number of vehicles on the road as well as their usage, measured in VMT, has the potential to offset gains in fuel efficiency. Since 1985, motor vehicle registrations have risen faster than overall population growth.[102] VMT, which increased steadily from 1985 to 2005, slowed for about five years before resuming its climb.[103]

- Vehicle fleet turnover is another important factor, since the composition of the vehicle market governs overall energy consumption. New vehicle purchases accounted for only 4 to 7 percent of the overall U.S. fleet from 2010 to 2015.[104] In addition, consumers today are holding on to cars longer than they previously did, so the U.S. LDV fleet is rapidly growing older: The average vehicle age was 8.4 years in 1995 and 11.6 years in 2016.[105,106] At 2015 rates of purchase and retirement of vehicles, it would take almost 15 years to turn over the U.S. LDV fleet, compared to 9.6 years in 1970.[107] The fuel usage impacts of the aging of the fleet are somewhat offset by lower utilization of older cars and trucks.

Transformations in LDV applications could have a strong effect on VMT and vehicle fleet turnover. For example, mode shifting, ride-sharing, and autonomous vehicles may inspire changes in consumer behavior that could reshape the landscape of mobility. In a new mobility paradigm, it is possible that LDVs may be used primarily for fleet services rather than personally owned; this could have tremendous impacts that may either increase or decrease overall transportation energy consumption. Therefore, keeping efficiency at the fore during planning for deployment of any disruptive technology is key to avoiding drastic increases in energy consumption.

Changing the LDV Sector's Role

Mode Shifting

LDVs are currently, and have historically been, more energy intensive than other forms of passenger travel, especially relative to rail and other public transportation options that run with high levels of occupancy.[108] As a result, selecting the most efficient mode for a trip, also known as mode shifting, can increase PMT while maintaining or even reducing overall VMT and energy consumption. As buses increasingly shift to alternative fuels and trains are increasingly electrified, mass transit could become an even more efficient alternative.

Vehicle Ownership

Fundamental shifts in vehicle ownership also may have significant implications for vehicle choice and use. Over the last decade, new mobility technology providers, notably car-sharing companies like ZipCar and Transportation Network Companies (TNCs) like Lyft and Uber, have begun to expand consumer access to transportation in cars the users do not own. While the ride-sharing market currently only captures one percent of global VMT, consumers' uptake of ride-sharing services has occurred rapidly over a short period of about five years.[109] While changes in vehicle ownership are still relatively small—since car-sharing, to an extent, has displaced some rental cars and ride-sharing has displaced some of the taxi business—the expansion of car-sharing and ride-sharing has the potential to yield substantial change.

The utilization rate of personal cars already is low since the average car owner drives for less than one hour per day, and personal car ownership could become less appealing if car-sharing and ride-sharing are more cost-effective.[110] Overall, car-sharing and ride-sharing have strong potential to reduce cost-per-mile for travel by relying on fewer cars with much higher utilization, reducing the need for parking, and avoiding the costs associated with frequently idle cars.

PEVs also could increase consumer appeal for the new mobility market by further reducing cost and energy consumption. PEVs are innately attractive for car-sharing and ride-sharing due to their ability to handle high utilization and their lower costs for maintenance and fuel. However, PEV range could become an issue since ride-sharing drivers often cover hundreds of miles per day.

Although the advent of new mobility technologies over the last decade is notable, the effect these technologies will have on car ownership is not yet clear. A McKinsey study from April 2017 estimates that new mobility technologies may decrease previous vehicle sales estimates through 2030 by about one third.[111] In contrast, a 2017 Goldman Sachs report estimates that peak car ownership will take place in 2030 with a global vehicle population of 1.3 billion.[112]

Automation

Autonomous vehicles also could play a significant role in ride-sharing and in fleet electrification. As with ride-sharing applications, PEVs are attractive for autonomous vehicles due to their ability to handle high utilization. Autonomous fleets would be conducive to wireless, inductive charging, making self-refueling more feasible, which would be a distinct advantage over conventional vehicles. In addition, without drivers, fleet charging can be optimized to meet customer and grid needs. Some autonomous vehicle companies already have electrified autonomous vehicles; for example, Waymo has announced that it will procure 20,000 autonomous Jaguar SUV BEVs.[113]

LOCAL, STATE AND FEDERAL POLICY FOR PEVs AND OTHER ALTERNATIVE FUEL VEHICLES

LOCAL, STATE AND FEDERAL POLICY FOR PEVs AND OTHER ALTERNATIVE FUEL VEHICLES

Fuel economy standards, particularly CAFE standards, will continue to remain key drivers for future transportation efficiency gains. However, it is critical to also consider the subnational policy landscape as cities and states begin to invest in PEVs and other alternative fuel vehicles to help meet targets for energy and emissions savings. Many local governments—including the cities of Los Angeles, San Francisco, New York, and Portland, Oregon—have established strategic plans to promote PEV adoption that help focus local resources to grow the PEV market.[114] Many policy options for alternative fuel vehicles are available to be deployed wherever they are best-suited depending on stakeholder interests, geography, market availability, and financial considerations. The following section provides an overview of policies that could influence more widespread adoption of PEVs and other alternative fuel vehicles.

Vehicle Incentives

Federal tax incentives are key to consumer appeal for PEVs and FCEVs. The Internal Revenue Code Section 30D Plug-In Electric Drive Vehicle Credit for PEVs is an effective tool for speeding consumer adoption and promoting a diverse array of manufacturers' investments in production.[115] Currently, consumers can receive up to $7,500 in federal tax credits for high-efficiency electric vehicles for the first 200,000 vehicles per manufacturer. A year-long phaseout period follows after a manufacturer reaches its 200,000-vehicle limit. During the phaseout period, the maximum tax credits decline to $3,750 in the first six months, and to $1,875 in the last six months.

The 30B Fuel Cell Electric Vehicle Credit previously offered up to $4,000 for light-duty FCEVs; however, the credit lapsed at the end of 2017, just as fuel cell vehicles began to enter the commercial market.[116]

State-funded PEV rebates and sales tax exemptions also can spur sales by directly decreasing the vehicle price at the point of sale. Cash-on-the-hood rebates secured by dealers and applied at the dealership are advantageous because they clearly offset the incremental cost of a PEV relative to an ICE vehicle in the showroom. Conversely, a state rebate or tax credit that requires a separate transaction with the state comes with extra effort and occasionally also with uncertainty that the incentive will remain available at the time of purchase. Local communities, such as Sonoma County, CA and Fort Collins, CO, also have undertaken partnerships with auto dealers and automakers to promote PEVs. In these partnerships, local organizations help advertise or structure group buys with auto dealers or automakers at reduced prices.

The primary non-monetary incentive for promoting PEV sales is access to state-controlled high-occupancy vehicle (HOV) lanes for clean vehicles. In California, 59 percent of PEV owners surveyed stated that PEV access to HOV lanes on highways was an "important consideration" in their purchase decision.[117] States also have sought to boost low-emission vehicle adoption through discounts on state tolls.[118] Other non-monetary incentives enabled by local policies include preferential parking locations and free or subsidized parking.[119]

Fleets and Workplaces

States and communities can help spur the PEV market by "walking the talk" with purchases of PEVs for state and local fleets. Many communities are supporting PEV adoption by setting goals to incorporate electric transit vehicles into their operational fleets, as well as to install charging infrastructure for fleet charging and for workplace charging.[120] Aggregating purchase orders among municipalities within a state is another way to increase the impact for PEV adoption and could facilitate negotiations with auto dealers for bulk purchase discounts. Some local governments also encourage local businesses to adopt similar fleet and infrastructure goals.

Infrastructure Incentives and Investments

Investing in alternative fueling infrastructure supports adoption of low-emissions vehicles by increasing charging and alternative-fueling accessibility and reducing range anxiety. Examples of federal support include the federal 30C Alternative Fuel Vehicle Refueling Property Credit that provided a 30 percent credit of up to $1,000 for residential and up to $30,000 for commercial alternative fueling infrastructure installations; the credit expired at the end of 2017.[121] The Congestion Mitigation and Air Quality Improvement (CMAQ) federal program is still active and includes funding for charging infrastructure.[122]

The American Recovery and Reinvestment Act of 2009 also supported many projects through federal and state grants in 2011 to 2013 to develop public charging infrastructure.[123] Most municipal charging infrastructure efforts to date have focused on L2 charging in public locations and municipal parking garages, but some communities are beginning to support higher level DCFC installations.[124]

State programs to deploy infrastructure have included both state-authorized utility infrastructure programs and state-funded deployment. Several states are providing grants for purchasing charging equipment for businesses, local and state government agencies, and universities.[125] In addition, some states' public utility commissions have authorized electric utilities to install charging infrastructure and recover the costs through the utility customer rate base.[126] Widespread and well-managed transportation electrification has the potential to place downward pressure on rates or have no impact on rates if the increased revenue from PEV charging meets or exceeds the cost of supplying PEV charging.[127]

While kick-starter funds cannot substitute for extensive utility or state programs, states can take advantage of infrastructure funding opportunities in the near term through programs such as Electrify America's zero-emission vehicles infrastructure deployment program and the Volkswagen NOx Mitigation Trust Fund.[128,129] Nevertheless, the amount of future PEV charging infrastructure needed across the U.S. will likely exceed the amount that can be deployed through these programs.

Some organizations have developed guiding principles for utility PEV programs to help ensure that infrastructure deployments help promote widespread access to clean, electric transportation, particularly in low-income communities. The Transportation Electrification Accord establishes principles agreed upon by a variety of organizations, including automakers, electric utilities and environmental advocacy groups.[130] The accord encourages implementation of consumer protections and local government support throughout the development and deployment of charging infrastructure. The Natural Resources Defense Council (NRDC) also developed a broader list of guiding principles for utility programs to accelerate transportation electrification.[131]

The construction required for charging infrastructure represents a significant challenge for retail businesses and property owners. Charging infrastructure often involves trenching in combination with disruptions to parking lot access. Major trenching operations are typically required during construction to access electrical service, since most retrofit installations favor siting infrastructure near the building. This is partly to help coincide with Americans with Disabilities Act (ADA) access points, since electrical access points are not often located near ADA-compliant walkways. Policies that support alternative fueling infrastructure must comply with the accessibility requirements set by the ADA.

Regulatory Opportunities and Considerations

A number of policy and regulatory opportunities relate to permitting, building codes, and standards. Examples include:

Charging infrastructure permits. Some local governments have taken steps to expedite PEV-related charging infrastructure permits.[132] California, for example, requires municipal governments to streamline and expedite PEV charging infrastructure permits. Typical methods for expediting permits include the institution of online permitting that can be approved within 24 hours for simple residential charging station installations. Some communities also have reduced permitting fees for charging infrastructure.

Updated building codes. Building code updates often include requirements for charging infrastructure during new construction or major renovations. For example, these updates typically require new residential construction to include electric panel breaker space for a charging circuit and a dedicated electrical conduit run to the garage for future charging installations. Some communities also require a minimum number of charging infrastructure parking spaces for new multi-family developments.[133]

Ordinance adoption. Ordinances to support PEV adoption also have been embraced by some communities.[134] Common types of ordinances include requirements for PEV parking spaces and rules to prevent ICE vehicles from parking in PEV charging spaces. Ordinances also have been adopted that prevent home owner associations or rented/leased facilities from precluding charging infrastructure installation. Under these circumstances, the PEV owner typically is required to pay for the entire charging infrastructure installation.

Standards. Performance-based standards promote and support innovation in the auto industry. Consistency in standards across states throughout the U.S. is critical for the effective widespread deployment of efficient vehicles. California often sets precedents for progressive vehicle standards. For example, California created more stringent GHG and criteria pollutant standards beyond the federal CAFE standards (discussed in more detail in the above section on ICE vehicle technology trends). Also, California's Advanced Clean Car program mandates minimum sales of ZEVs, which include PEVs and FCEVs. The ZEV program, introduced in 1990, has been a critical driver for the development and deployment of electric-drive technology.[135] Under the federal Clean Air Act, other states can adopt the California vehicle standards in lieu of following applicable federal standards, provided that the California standards meet or exceed the level of protections in the federal standards for public health and welfare. To date, 13 states and the District of Columbia have adopted California's standards for GHG and criteria pollutants and nine of those states have adopted the ZEV program.[136,137] While the ZEV program is helping deploy low-emission vehicles, it also had the unintended consequence of enabling automakers to comply with CAFE standards by selling PEVs and FCEVs only in the states participating in the ZEV program.

California and Oregon also have adopted low-carbon/clean fuel programs that require the transportation fuel supply to gradually decrease its carbon emissions per unit of fuel energy.[138,139]

Other Considerations. Transportation GHG cap-and-invest programs represent an opportunity for states to set a transportation sector GHG emissions cap along with a GHG emissions allowance market. The GHG emissions allowance market could generate stable revenues for states to fund PEV purchase rebates and other clean transportation programs.

Education and Outreach

Because many consumers are still unaware of the availability and benefits of PEVs, there is opportunity for state-sponsored public education to make PEVs more attractive to customers.[140] A study by the University of California Davis found that fewer Californians could identify the model name of a PEV for sale in 2017 than in 2014.[141] In addition, Californians did not notice a difference in the number of charging stations available from 2014 to 2017, even though the number doubled in that timeframe.[142] Consistent and widespread PEV charging station signage is critical for increasing awareness that public refueling infrastructure is sufficiently available. Ride-and-drive programs also are important for addressing questions and helping consumers commit to a PEV purchase.

Some local governments also are supporting community outreach for PEVs and associated charging infrastructure, sometimes in partnership with local organizations that focus on clean transportation or improved air quality.[143] Types of outreach include static displays at large community events and ride-and-drive events, as well as permanent displays, information kiosks or branded charging infrastructure in high visibility locations.

REFERENCES

REFERENCES

1 Annual Energy Outlook. (2018). Table: transportation Sector Key Indicators and Delivered Energy Consumption. *U.S. Energy Information Administration [EIA].* Retrieved from https://www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2018&cases=ref2018&sourcekey=0

2 Annual Energy Outlook 2018 with Projections to 2050 [PPT Presentation]. (2018 Feb 6). *EIA Office of Energy Analysis.* Retrieved from https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

3 Annual Energy Outlook 2018 with Projections to 2050 [PPT Presentation]. (2018 Feb 6). *EIA Office of Energy Analysis.* Retrieved from https://www.eia.gov/outlooks/aeo/pdf/AEO2018.pdf

4 U.S. National Electrification Assessment. (2018 April 02). *Electric Power Research Institute.* Retrieved from https://www.epri.com/#/pages/product/3002013582/?lang=en

5 Consumers and Auto Sales. (n.d.). *Auto Alliance.* Retrieved from https://autoalliance.org/energy-environment/consumers-and-auto-sales/

6 Use of Energy in the United States Explained, Energy Use for Transportation. (2017). *EIA.* Retrieved from https://www.eia.gov/energyexplained/index.php?page=us_energy_transportation#tab2

7 U.S. Vehicle Miles. (2016). *Bureau of Transportation Statistics, U.S. Department of Transportation [DOT].* Retrieved from https://www.bts.gov/content/us-vehicle-miles

8 Popular Household Statistics, Vehicles Available. (2017). *National Household Travel Survey.* Retrieved frm https://nhts.ornl.gov/households

9 Consumers and Auto Sales. (n.d.). *Auto Alliance.* Retrieved from https://autoalliance.org/energy-environment/consumers-and-auto-sales/

10 Access to Alternative Transportation Fuel Stations Varies Across the Lower 48 States. (2012, April 30). *EIA* Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=6050

11 Use of Energy in the United States Explained. (2017). *EIA*. Retrieved from https://www.eia.gov/energyexplained/?page=us_energy_transportation

12 Davis, C., Williams, S. & Boundy, R. (2018 April). Transportation Energy Data Book: Edition 36.1. *Oak Ridge National Laboratory.* Retrieved from https://cta.ornl.gov/data/tedbfiles/Edition36_Full_Doc.pdf

13 Petroleum & Other Liquids. (2018). "U.S. Crude Oil First Purchase Price." *EIA.* Retrieved from https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=f000000__3&f=m

14 Chapter 1: Extent and Physical Condition of the U.S. Transportation System (n.d.). *Bureau of Transportation Statistics, DOT.* Retrieved from https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/transportation-statistics-annual-reports/215361/2017-tsar-ch1.pdf

15 Chapter 7: Transportation Energy Use and Environmental Impacts. (n.d.). *Bureau of Transportation Statistics, DOT.* Retrieved from https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/transportation-statistics-annual-reports/215391/2017-tsar-ch7.pdf

16 Highlights of CO2 and Fuel Economy Trends. (n.d.). *U.S. Environmental Protection Agency [EPA].* Retrieved from https://www.epa.gov/fuel-economy-trends/highlights-co2-and-fuel-economy-trends

17 Piotrowski, M. & Ruiz, P. (2018, January 12). “Key Charts Highlighting Trends In Automobile Sales & Gasoline Consumption.” *The Fuse.* Retrieved from http://energyfuse.org/key-charts-highlighting-trends-automobile-sales-gasoline-consumption/

18 Plungis, J. (2018, Feb 22). The Race to Improve Fuel Economy. *Consumer Reports.* Retrieved from https://www.consumerreports.org/fuel-economy-efficiency/the-race-to-improve-fuel-economy/

19 “2018 Audi Q5 offers highest EPA-estimated fuel economy in competitive segment.” (2017, March 29). *Audi Newsroom.* Retrieved from https://media.audiusa.com/en-us/releases/151

20 2018 Chevrolet Malibu. (n.d.). *General Motors Fleet.* Retrieved from https://www.gmfleet.com/chevrolet/malibu-sedan.html

21 Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles. *The National Academies of Sciences.* Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog/21744/cost-effectiveness-and-deployment-of-fuel-economy-technologies-for-light-duty-vehicles

22 Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles. *The National Academies of Sciences.* Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog/21744/cost-effectiveness-and-deployment-of-fuel-economy-technologies-for-light-duty-vehicles

23 Chabot, B. (2017, Nov 16). Controlled Compression Ignition: Mazda Leverages Spark and Pressure for Improved Engine Performance. *Motor Magazine*. Retrieved from http://newsletter.motor.com/2017/20171116/!ID_Mazda_SPCCI.html

24 Can a Hybrid Save Me Money? (n.d.). *DOE Office of Energy Efficiency & Renewable Energy.* Retrieved from https://www.fueleconomy.gov/feg/hybridCompare.jsp

25 54.5 MPG and Beyond: Materials Lighten the Load for Fuel Economy. (2012, Dec 04). *DOE.* Retrieved from https://www.energy.gov/articles/545-mpg-and-beyond-materials-lighten-load-fuel-economy

26 Stuhldreher, M., Kargul, J., Barba, D., McDonald, J., Bohac, S., Dekraker, P., & Moskalik, A. (2018, April 03). Benchmarking a 2016 Honda Civic 1.5-liter L15B7 Turbocharged Engine and Evaluating the Future Efficiency Potential of Turbocharged Engines. *SAE International.* Retrieved from https://www.researchgate.net/profile/Joseph_Mcdonald3/publication/324189526_Benchmarking_a_2016_Honda_Civic_15-liter_L15B7_Turbocharged_Engine_and_Evaluating_the_Future_Efficiency_Potential_of_Turbocharged_Engines/links/5b1582530f7e9bda0ffd04a7/Benchmarking-a-2016-Honda-Civic-15-liter-L15B7-Turbocharged-Engine-and-Evaluating-the-Future-Efficiency-Potential-of-Turbocharged-Engines.pdf?origin=publication_list

27 McCormick, R.L. (2016, March 17). High Octane Fuels: Benefits and Challenges [PowerPoint slides]. *National Renewable Energy Laboratory.* Retrieved from https://cleancities.energy.gov/files/u/news_events/document/document_url/158/CC_HOF_Webinar_Combined.pdf

28 GREET WTW Calculator available at https://greet.es.anl.gov/results.

29 Alternative Fuels Data Center, Natural Gas Vehicle Emissions. (n.d.). *DOE.* Retrieved from https://www.afdc.energy.gov/vehicles/natural_gas_emissions.html

30 Alternative Fuels Data Center, Emissions from Hybrid and Plug-In Electric Vehicles. (n.d.). *DOE.* Retrieved from https://www.afdc.energy.gov/vehicles/electric_emissions.php

31 Alternative Fuels Data Center. “Light-Duty AFV, HEV, and Diesel Model Offerings, by Fuel Type.” (2016). *DOE.* Retrieved from https://www.afdc.energy.gov/data/10303

32 All-Electric Vehicles. (n.d.). *DOE.* Retrieved from https://www.fueleconomy.gov/feg/evtech.shtml

33 Fueleconomy.gov, Find a Car. Search Results, Sorting is based on EPA Combined City/Hwy MPG. *DOE & U.S. EPA.* Retrieved from https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&year1=2016&year2=2018&cbmcsmallCars=Small+Cars&cbmcfamilySedans=Family+Sedans&cbmcupscaleSedans=Upscale+Sedans&cbmcluxurySedans=Luxury+Sedans&cbmclargeSedans=Large+Sedans&cbmchatchbacks=Hatchbacks&cbmcCoupes=Coupes&cbmcconvertibles=Convertibles&cbmcSports_Sporty_Cars=Sports%2FSporty+Cars&cbmcstationWagons=Station+Wagons&cbmcpickupTrucks=Pickup+Trucks&cbmcsportUtilityVehicles=Sport+Utility+Vehicles&cbmcminivans=Minivans&cbmcvans=Vans&minmsrpsel=0&maxmsrpsel=0&city=0&hwy=0&comb=0&YearSel=2016-2018&make=&mclass=Small+Cars%2C+Family+Sedans%2C+Upscale+Sedans%2C+Luxury+Sedans%2C+Large+Sedans%2C+Hatchbacks%2C+Coupes%2C+Convertibles%2C+Sports%2FSporty+Cars%2C+Station+Wagons%2C+Pickup+Trucks%2C+Sport+Utility+Vehicles%2C+Minivans%2C+Vans&vfuel=&vtype=&trany=&drive=&cyl=&MpgSel=000&sortBy=Comb&Units=&url=SearchServlet&opt=new&minmsrp=0&maxmsrp=0&minmpg=&maxmpg=&rowLimit=10&pageno=1&tabView=0

34 Fueleconomy.gov, Compare Side-by-Side. (n.d.) *DOE.* Retrieved from https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=39882

35 Consumers and Auto Sales. (n.d.). *Auto Alliance.* Retrieved from https://autoalliance.org/energy-environment/consumers-and-auto-sales/

36 National Research Council. (2013). *Transitions to Alternative Vehicles and Fuels.* Washington, DC: The National Academies Press. https://doi.org/10.17226/18264. https://www.nap.edu/read/18264/chapter/7#78

37 Miremadi, M., Musso C. & Weihe, U. (2012, Oct). "How much will consumers pay to go green?" *McKinsey Quarterly, McKinsey&Company.* Retrieved from https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/how-much-will-consumers-pay-to-go-green

38 Bloomberg New Energy Finance. (2017, June 23). "Electric Cars to Reach Price Parity by 2025." *Bloomberg New Energy Finance.* Retrieved from https://about.bnef.com/blog/electric-cars-reach-price-parity-2025/

39 Palmer, K., Tate, J.E., Wadud, Z., & Nellthorp, J. (2018). Total Cost of Ownership and Market Share for Hybrid and Electric Vehicles in the UK, US and Japan. *Applied Energy, 209,108-119.* Retrieved from https://www.enriquedans.com/wp-content/uploads/2017/12/Total-cost-of-ownership-and-market-share-for-hybrid-and-electric-vehicles-in-the-UK-US-and-Japan.pdf

40 Sivak, M., Schoettle, B. (2018) "Relative Costs of Driving Electric and Gasoline Vehicles in the Individual U.S. States." *University of Michigan, Report No. SWT-2018-1.* Retrieved from http://umich.edu/~umtriswt/PDF/SWT-2018-1.pdf

41 Niquette, M. (2018, March 2) "A Higher Gas Tax Won't Fix America's Highways." *Bloomberg.* Retrieved from https://www.bloomberg.com/news/articles/2018-03-02/a-higher-gas-tax-won-t-fix-america-s-highways

42 Chase, N. & Maples, J. (2014, July 22). Fuel Economy and Average Vehicle Cost Vary Significantly Across Vehicle Types. *EIA.* Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=17211

43 Voelcker, J. (2017, June 9). "How Much is a Replacement Chevy Bolt EV Electric-Car Battery?" *Green Car Reports.* Retrieved from https://www.greencarreports.com/news/1110881_how-much-is-a-replacement-chevy-bolt-ev-electric-car-battery

44 "Electric Vehicle Outlook: 2018." (2018) *Bloomberg New Energy Finance.* Retrieved from https://bnef.turtl.co/story/evo2018?teaser=true

45 Advanced Clean Transit Battery Cost for Heavy-Duty Electric Vehicles (Discussion Draft) [PDF]. (2016, Aug 22). *California Air Resources Board.* Retrieved from https://www.arb.ca.gov/msprog/bus/battery_cost.pdf

46 Chediak, M. (2017, Dec 06). "The Latest Bull Case for Electric Cars: The Cheapest Batteries Ever." *Bloomberg New Energy Finance.* Retrieved from https://about.bnef.com/blog/latest-bull-case-electric-cars-cheapest-batteries-ever/

47 Melaina, M., Bush, B., Eichman, J., Wood, E., Stright, D., Krishnan, V., Keyser, D., Mai, T., & McLaren, J. (2016, December). National Economic Value Assessment of Plug-in Electric Vehicles, Volume 1. Figure ES-2. *National Renewable Energy Laboratory*. Retrieved from https://www.nrel.gov/docs/fy17osti/66980.pdf

48 Compare Side-by-Side: 2018 Chevrolet Bolt EV and 2018 Tesla Model 3 Long Range. (n.d.). *DOE.* Retrieved from https://www.fueleconomy.gov/feg/Find.do?action=sbs&id=39786&id=39836

49 Chung, D., Elgqvist, E. & Santhanagopalan, S. (2015, June). "Automotive Lithium-ion Battery (LIB) Supply Chain and U.S. Competitiveness Considerations." *Clean Energy Manufacturing Analysis Center.* Retrieved from https://www.nrel.gov/docs/fy15osti/63354.pdf

50 Tal, G. & Brown, A. (n.d.). Credits and Rebates Play a Key Role in Building Consumer Market for Cleaner Electric Vehicles. *UC Davis Institute of Transportation Studies.* Retrieved from https://its.ucdavis.edu/blog-post/credits-rebates-play-key-role-building-consumer-market-cleaner-electric-vehicles/

51 Chen, S. & Zhang, Y. (2018, Feb 13). "China Raises Subsidies to Reward Longer Range Electric Cars." *Bloomberg.* Retrieved from https://www.bloomberg.com/news/articles/2018-02-13/china-raises-subsidies-to-reward-longer-traveling-electric-cars

52 Pontes, J. (2018, June 29). "China Electric Car Sales Up 77% In June — #CleanTechnica Report." *Clean Technica.* Retrieved from https://cleantechnica.com/2018/07/29/china-electric-car-sales-up-77-in-june-cleantechnica-report/

53 Norweign EV Policy. (n.d.). *Norsk Elbil Forening.* Retrieved from https://elbil.no/english/norwegian-ev-policy/

54 Knudsen, C. & Doyle, A. (2018, Jan 03). "Norway powers ahead (electrically): over half new car sales now electric or hybrid." *Reuters.* Retrieved from https://www.reuters.com/article/us-environment-norway-autos/norway-powers-ahead-over-half-new-car-sales-now-electric-or-hybrid-idUSKBN1ES0WC

55 Hao, H., Ou, X., Du, J., Wang, H., & Ouyang, M. (2014). China's Electric Vehicle Subsidy Scheme: Rationale and Impacts. *Energy Policy.* Retrieved from http://www.tsinghua.edu.cn/publish/dae/4364/20101220102833065470806/4)%20China's%20electric%20vehicle%20subsidy%20scheme-%20Rationale%20and%20impacts.pdf

56 Economy, Elizabeth. (2014, April 18). "China's Round Two On Electric Cars: Will It Work?" *Forbes.* Retrieved from https://www.forbes.com/sites/elizabetheconomy/2014/04/18/chinas-round-two-on-electric-cars-will-it-work/#53bcabd75573

57 Hao, H., Ou, X., Du, J., Wang, H., & Ouyang, M. (2014). China's Electric Vehicle Subsidy Scheme: Rationale and Impacts. *Energy Policy.* Retrieved from http://www.tsinghua.edu.cn/publish/dae/4364/20101220102833065470806/4)%20China's%20electric%20vehicle%20subsidy%20scheme-%20Rationale%20and%20impacts.pdf

58 Hao, H., Ou, X., Du, J., Wang, H., & Ouyang, M. (2014). China's Electric Vehicle Subsidy Scheme: Rationale and Impacts. *Energy Policy.* Retrieved from http://www.tsinghua.edu.cn/publish/dae/4364/20101220102833065470806/4)%20China's%20electric%20vehicle%20subsidy%20scheme-%20Rationale%20and%20impacts.pdf

59 National Household Travel Survey, Daily Travel Quick Facts. (2017). *Bureau of Transportation Statistics, DOT.* Retrieved from https://www.bts.gov/statistical-products/surveys/national-household-travel-survey-daily-travel-quick-facts

60 Compare Electric Cars and Plug-in Hybrids By Features, Price, Range. (n.d.). *Plugincars.* Retrieved from http://www.plugincars.com/cars?sort_by=field_epa_range_value&sort_order=DESC

61 Evarts, E. (2013, Dec 11). Many Americans are just a plug away from owning an electric car. *ConsumerReports.org.* Retrieved from https://www.yahoo.com/news/many-americans-just-plug-away-owning-electric-car-160000286.html

62 Stewart, B. (2018, May 17). Long-term 2018 Nissan Leaf: Discovering the Possibilities and Limitations of the Leaf's EV Range. *Autoweek.* Retrieved from https://autoweek.com/article/car-reviews/long-term-2018-nissan-leaf-discovering-possibilities-and-limitations-leafs-ev

63 Bullis, K. (2012, Sept 24). Don't Drive Your Nissan Leaf Too Much. *Technology Review.* Retrieved from https://www.technologyreview.com/s/429330/dont-drive-your-nissan-leaf-too-much/

64 Olsen, P. (2017, Aug 03). Chevrolet Bolt Sets Consumer Reports' Electric-Vehicle Range Record. *Consumer Reports.* Retrieved from https://www.consumerreports.org/2017-chevrolet-bolt/chevrolet-bolt-sets-electric-vehicle-range-record/

65 "Tesla's Model 3 Breaks 300-mile Range Barrier." (2017, July 19). *Bloomberg.* Retrieved from http://fortune.com/2017/07/29/teslas-model-3-breaks-300-mile-range-barrier/

66 Alternative Fuels Data Center, Developing Infrastructure to Charge Plug-In Electric Vehicles. (n.d.). *U.S. Department of Energy.* Retrieved from https://www.afdc.energy.gov/fuels/electricity_infrastructure.html

67 Smart, J. (2015, June 09). Lessons Learned About Workplace Charging in The EV Project [PDF]. Presentation at the 2015 Annual Merit Review, Washington DC. *Idaho National Laboratory.* Retrieved from https://www.energy.gov/sites/prod/files/2015/07/f24/vss170_smart_2015_p.pdf

68 Lowell, D., Jones, B., & Seamonds, D. (2018, March). Accelerating Investment in Electric Vehicle Charging Infrastructure: Estimated Needs in Selected Utility Service Territories in Seven States [PDF]. *M.J. Bradley & Associates LLC and Ceres.* Retrieved from https://www.ceres.org/sites/default/files/reports/2018-03/Ceres_PEVinfraAnalysis_032718_rev1.pdf

69 Briggs, J. (2018, May 03). Electrify America Switches On The First 350 kW Fast Charging Station in Chicopee, Mass. *Green Car Reports.* Retrieved from https://www.greencarreports.com/news/1116550_electrify-america-switches-on-the-first-350-kw-fast-charging-station-in-chicopee-mass

70 Lambert, F. (2017, Feb 27). The First 'High-Power Fast-Charging Station' (150-350 kW) is Installed by Evgo and ABB Right in Tesla's Backyard. *Electrek.* Retrieved from https://electrek.co/2017/02/27/high-power-fast-charging-station-150-350-kw-evgo-abb-tesla/

71 Wood, E., Rames, C., Muratori, M., Raghavan, S., & Melaina, M. (2017, Sept). National Plug-In Electric Vehicle Infrastructure Analysis [PDF]. *National Renewable Energy Laboratory.* Retrieved from https://www.nrel.gov/docs/fy17osti/69031.pdf

72 Alternative Fueling Station Locator. (n.d.). *DOE Alternative Fuels Data Center.* Retrieved from https://www.afdc.energy.gov/stations/#/analyze?fuel=ELEC&country=US

73 Alternative Fueling Station Locator. (n.d.). *DOE Alternative Fuels Data Center.* Retrieved from https://www.afdc.energy.gov/stations/#/analyze?fuel=ELEC&country=US

74 Access to Alternative Transportation Fuel Stations Varies Across the Lower 48 States. (2012, April 30). *EIA.* Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=6050

75 Wardlaw, C. (2016, March 04). "10 Top Reasons Why People Buy Specific Cars." *New York Daily News.* Retrieved from http://www.nydailynews.com/autos/buyers-guide/10-top-reasons-people-buy-specific-cars-article-1.2552707

76 Lin, Z. & Greene, D. (2013, Jan 25). The MA3T Model: Market Adoption of Advanced Automotive Technologies [PDF]. Presented at EIA Consumer Choice Models and Markets Technical Workshop, Southfield, MI. *Oak Ridge National Laboratory.* Retrieved from https://www.eia.gov/outlooks/aeo/workinggroup/transportation/evworkshop/pdf/lin_greene.pdf

77 Go Forth Electric Showcase. (n.d.). *Forth.* Retrieved from https://forthmobility.org/showcase

78 Green Your Commute Fair. (n.d.). *Downtown Albany Business Improvement District.* Retrieved from https://downtownalbany.org/events/green-your-commute-fair

79 Fact Sheet – Plug-in Electric Vehicles (2017). (2017, Aug 08). *Environmental and Energy Study Institute.* Retrieved from https://www.eesi.org/papers/view/fact-sheet-plug-in-electric-vehicles-2017

80 Piotrowski, M. & Ruiz, P. (2018, Jan 12). "Key Charts Highlighting Trends In Automobile Sales & Gasoline Consumption." *The Fuse.* Retrieved from http://energyfuse.org/key-charts-highlighting-trends-automobile-sales-gasoline-consumption/

81 Fact Sheet – Plug-in Electric Vehicles (2017). (2017, Aug 08). *Environmental and Energy Study Institute.* Retrieved from https://www.eesi.org/papers/view/fact-sheet-plug-in-electric-vehicles-2017

82 2018 Sport Utility Vehicles. (2018). *DOE.* Retrieved from https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year=2018&mclass=Sport%20Utility%20Vehicles&srchtyp=marClassMpg&pageno=1&sortBy=Comb&tabView=0&tabView=0&rowLimit=200

83 A U.S. Consumer's Guide to Electric Vehicles [PDF]. (2018, Feb). *Electric Power Research Institute.* Retrieved from https://www.epri.com/#/pages/product/3002012521/

84 Gnann, T., Stephens, T.S., Lin, Z., Plotz, P., Liu, C., & Brokate, J. (2018). "What Drives the Market for Plug-In Electric Vehicles? A Review of International PEV Market Diffusion Models." *Renewable and Sustainable Energy Reviews.* Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032118301497?_rdoc=1&_fmt=high&_origin=gateway&_docanchor=&md5=b8429449ccfc9c30159a5f9aeaa92ffb

85 Fuel Cells [PDF]. (n.d.). *DOE.* Retrieved from https://www.energy.gov/sites/prod/files/2015/11/f27/fcto_fuel_cells_fact_sheet.pdf

86 Fuel Cell Electric Vehicles. (n.d.). *DOE Alternative Fuels Data Center.* Retrieved from https://www.afdc.energy.gov/vehicles/fuel_cell.html

87 Fuel Cell Electric Vehicles & Hydrogen Fuel. (n.d.). *California Fuel Cell Partnership.* Retrieved from https://cafcp.org/

88 Cost to Refill. (n.d.). *California Fuel Cell Partnership.* Retrieved from https://cafcp.org/content/cost-refill

89 Cost to Refill. (n.d.). *California Fuel Cell Partnership.* Retrieved from https://cafcp.org/content/cost-refill

90 Target Explanation Document: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles. (2017). *U.S. DRIVE Partnership.* Retrieved from https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_targets_onboard_hydro_storage_explanation.pdf

91 Hydrogen Fueling Station Locations [interactive graphic]. (n.d.). *DOE Alternative Fuels Data Center.* Retrieved from https://www.afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY

92 Boudette, N. (2017, May 18). First Came the Hydrogen Cars. Now, the Refilling Stations. *The New York Times.* Retrieved from https://www.nytimes.com/2017/05/18/automobiles/wheels/first-came-the-hydrogen-cars-now-the-refilling-stations.html

93 Alternative Fuel and Advanced Vehicles Search. (n.d.). *DOE.* Retrieved from https://www.afdc.energy.gov/vehicles/search/results/?view_mode=grid&search_field=vehicle&search_dir=desc&per_page=8&current=true&display_length=25&fuel_id=9,-1&category_id=27,29,-1&manufacturer_id=365,377,211,410,235,231,215,223,225,409,379,219,213,209,351,359,385,275,424,361,387,243,227,239,425,263,217,391,349,381,237,221,347,395,67,394,117,201,139,0,426,415,113,205,408,71,5,51,9,13,11,57,81,416,195,141,197,417,121,53,397,418,85,414,21,17,143,23,398,27,399,31,207,396,107,35,193,125,419,115,147,405,199,-1

94 Annual Energy Outlook 2018. (2018). Table: Light-Duty Vehicle Stock by Technology Type. *EIA.* Retrieved from https://www.eia.gov/outlooks/aeo/data/browser/#/?id=49-AEO2018&cases=ref2018&sourcekey=0

95 Edelstein, S. (2018, Jan 24). Toyota Mirai Hydrogen Fuel-Cell Car Tops 3,000 California Sales. *The Drive.* Retrieved from http://www.thedrive.com/tech/17924/toyota-mirai-hydrogen-fuel-cell-car-tops-3000-california-sales

96 "Governor Brown Takes Action to Increase Zero-Emission Vehicles, Fund New Climate Investments." (2018, Jan 26). *Office of Governor Edmund G. Brown Jr.* Retrieved from https://www.gov.ca.gov/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/

97 "Governor Brown Takes Action to Increase Zero-Emission Vehicles, Fund New Climate Investments." (2018, Jan 26). *Office of Governor Edmund G. Brown Jr.* Retrieved from https://www.gov.ca.gov/2018/01/26/governor-brown-takes-action-to-increase-zero-emission-vehicles-fund-new-climate-investments/

98 About Us. (n.d.). *California Fuel Cell Partnership.* Retrieved from https://cafcp.org/about_us

99 Cost to refill. (n.d.). *California Fuel Cell Partnership.* Retrieved from https://cafcp.org/content/cost-refill

100 Lee, K. (2017, Oct 26). Toyota Wants to Make Its Hydrogen Cars Cost the Same as Hybrids By 2025: Report. *Jalopnik.* Retrieved from https://jalopnik.com/toyota-wants-to-make-its-hydrogen-cars-cost-the-same-as-1819873773

101 Hydrogen Storage. (n.d.). *DOE.* Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-storage

102 Chapter 1: Extent and Physical Condition of the U.S. Transportation System (n.d.). *Bureau of Transportation Statistics, DOT.* Retrieved from https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/transportation-statistics-annual-reports/215361/2017-tsar-ch1.pdf

103 Chapter 1: Extent and Physical Condition of the U.S. Transportation System (n.d.). *Bureau of Transportation Statistics, DOT.* Retrieved from https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/transportation-statistics-annual-reports/215361/2017-tsar-ch1.pdf

104 Schwartz, H. (2018, Jan 23). America's Aging Vehicles Delay Rate of Fleet Turnover. *The Fuse.* Retrieved from http://energyfuse.org/americas-aging-vehicles-delay-rate-fleet-turnover/

105 Average Age of Automobiles and Trucks in Use, 1970-1999. (n.d.). *Federal Highway Administration, DOT.* Retrieved from https://www.fhwa.dot.gov/ohim/onh00/line3.htm

106 Vehicles Getting Older: Average Age of Light Cars and Trucks in U.S. Rises Again in 2016 to 11.6 Yars, IHS Markit Says. (2016, Nov 22). *IHS Markit.* Retrieved from https://news.ihsmarkit.com/press-release/automotive/vehicles-getting-older-average-age-light-cars-and-trucks-us-rises-again-201

107 Schwartz, H. (2018, Jan 23). America's Aging Vehicles Delay Rate of Fleet Turnover. *The Fuse.* Retrieved from http://energyfuse.org/americas-aging-vehicles-delay-rate-fleet-turnover/

108 Chapter 7: Transportation Energy Use and Environmental Impacts. (n.d.). *Bureau of Transportation Statistics, DOT*. Retrieved from https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/transportation-statistics-annual-reports/215391/2017-tsar-ch7.pdf

109 Khosrowshai, D. (2018, Jan 17). “Dara Khosrowshahi on the Power of Shared Mobility.” *The Wall Street Journal.* Retrieved from https://www.wsj.com/articles/dara-khosrowshahi-on-the-power-of-shared-mobility-1516200983

110 Johnson, T. (2015, April 16). New Study Reveals When, Where and How Much Motorists Drive. *AAA Newsroom.* Retrieved from https://newsroom.aaa.com/2015/04/new-study-reveals-much-motorists-drive/

111 Grosse-Ophoff, A., Hausler, S., Heineke, K., & Moller, T. (2017, April). *McKinsey & Company.* Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-shared-mobility-will-change-the-automotive-industry

112 Burgstaller, S., Flowers, D., Tamberrino, D., Terry, H.P., & Yang, Y. (2017, May 23). Rethinking Mobility. *Goldman Sachs.* Retrieved from https://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/Rethinking%20Mobility_GoldmanSachsMay2017.pdf

113 Meet Our Newest Self-Driving Vehicle: The All-Electric Jaguar I-Pace. (2018, March 27). *Medium.* Retrieved from https://medium.com/waymo/meet-our-newest-self-driving-vehicle-the-all-electric-jaguar-i-pace-375cecc70eb8

114 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

115 Plug-In Electric Drive Vehicle Credit (IRC 30D). (n.d.). *Internal Revenue Service.* Retrieved from https://www.irs.gov/businesses/plug-in-electric-vehicle-credit-irc-30-and-irc-30d

116 About Form 8910, Alternative Motor Vehicle Credit. (n.d.). *Internal Revenue Service.* Retrieved from https://www.irs.gov/credits-deductions/individuals/qualified-fuel-cell-motor-vehicle-credit-at-a-glance

117 California Plug-in Electric Vehicle Driver Survey Results - May 2013. (2013, May). *California Air Resources Board and California Center for Sustainable Energy.* Retrieved from https://energycenter.org/sites/default/files/docs/nav/transportation/cvrp/survey-results/California_Plug-in_Electric_Vehicle_Driver_Survey_Results-May_2013.pdf

118 Thruway Authority, Green Pass Discount Plan. (n.d.). *New York State.* Retrieved from http://www.thruway.ny.gov/ezpass/greentag.html

119 Garfield, L. (2018, June 1). 13 cities that are starting to ban cars. *Business Insider.* Retrieved from https://www.businessinsider.com/cities-going-car-free-ban-2017-8#paris-will-ban-diesel-cars-and-double-the-number-of-bike-lanes-6

120 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

121 About Form 8911, Alternative Fuel Vehicle Refueling Property Credit. (n.d.). *Internal Revenue Service.* Retrieved from https://www.irs.gov/credits-deductions/individuals/alternative-fuel-vehicle-refueling-property-credit

122 Congestion Mitigation and Air Quality Improvement (CMAQ) Program. (n.d.). *Federal Highway Administration, DOT.* Retrieved from https://www.fhwa.dot.gov/environment/air_quality/cmaq/

123 AVTA: ARRA EV Project Charging Infrastructure Data Summary Reports. (n.d.). *DOE.* Retrieved from https://www.energy.gov/eere/vehicles/downloads/avta-arra-ev-project-charging-infrastructure-data-summary-reports

124 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

125 Guinn, S. (2017, July 25). "EVSE Rebates and Tax Credits, by State." *ClipperCreek.* Retrieved from https://www.clippercreek.com/evse-rebates-and-tax-credits-by-state/

126 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

127 Baumhefner, M., Hwang, R., & Bull, P. (2016, June). Driving Out Pollution: How Utilities Can Accelerate The Market for Electric Vehicles. *National Resources Defense Council.* Retrieved from https://www.nrdc.org/sites/default/files/driving-out-pollution-report.pdf

128 Our Plan. (n.d.). *Electrify America.* Retrieved from https://www.electrifyamerica.com/our-plan

129 Frequently Asked Questions (FAQ) On the Zero Emission Vehicle Investment [PDF]. (2016, Nov). *EPA.* Retrieved from https://www.epa.gov/sites/production/files/2016-11/documents/vw-faqs-app-c-final-11-18-16.pdf

130 The Transportation Electrification Accord. (n.d.). *The EV Accord.* Retrieved from https://www.theevaccord.com/

131 Guiding Principles For Utility Programs to Accelerate Transportation Electrification. (2017, August). *Natural Resources Defense Council.* Retrieved from https://www.nrdc.org/sites/default/files/utility-transportation-electrification-ib.pdf

132 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

133 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

134 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

135 The Zero Emission Vehicle (ZEV) Regulation. (n.d.). *California Environmental Protection Agency Air Resources Board.* Retrieved from https://www.arb.ca.gov/msprog/zevprog/factsheets/general_zev_2_2012.pdf

136 States Adopting California's Clean Cars Standards. (n.d.). *Maryland Department of the Environment.* Retrieved from http://mde.maryland.gov/programs/Air/MobileSources/Pages/states.aspx

137 What is ZEV? (n.d.). *Union of Concerned Scientists.* Retrieved from https://www.ucsusa.org/clean-vehicles/california-and-western-states/what-is-zev#.WxgP5u4vy70

138 Low Carbon Fuel Standard. (2018). *California Air Resources Board.* Retrieved from https://www.arb.ca.gov/fuels/lcfs/lcfs.htm

139 Oregon Clean Fuels Program. (n.d.). *Oregon.gov.* Retrieved from http://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels.aspx

140 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. T*he International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

141 Kurani, K. & Hardman, S. (n.d.). Automakers and Policymakers May Be on a Path to Electric Vehicles; Consumers Aren't. *UC Davis Institute of Transportation Studies.* Retrieved from https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/

142 Kurani, K. & Hardman, S. (n.d.). Automakers and Policymakers May Be on a Path to Electric Vehicles; Consumers Aren't. *UC Davis Institute of Transportation Studies.* Retrieved from https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/

143 Slowik, P. & Lutsey, N. (2017, July). Expanding The Electric Vehicle Market in U.S. Cities. *The International Council on Clean Transportation.* Retrieved from https://www.theicct.org/sites/default/files/publications/US-Cities-EVs_ICCT-White-Paper_25072017_vF.pdf

1850 M Street NW, Suite 610, Washington, DC 20036
PHONE 202.857.0666 FAX 202.331.9588
info@ASE.ORG ASE.ORG AllianceToSaveEnergy ToSaveEnergy