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Electrifying the Vehicle Fleet Within the United States, a Feasibility Analysis of Environmental Impact and Technical Deployment

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Abstract
In November 2021, the Infrastructure Investment and Jobs Act was passed and signed into law, which along with many other funding initiatives, will provide $7.5 billion to begin the infrastructure expansion of electric vehicle charging stations within the United States. This specific funding from the federal government is a crucial step towards the current administration's carbon neutral goals and the building of a national connected network of 500,000 electric vehicle charging stations and having 50% of light duty vehicles sales being electric by 2030. However, achieving these goals is complicated and the beneficial environmental effect of further electric vehicle integration is often debated. This is due to the concerning total carbon footprint produced from the manufacturing of electric vehicles, usage, and growth of power demand from charging station infrastructure. To counter that common viewpoint and through a feasibility analysis of environmental impact and technical deployment, this study has been able to highlight the beneficial and adverse effects of increased usage of electric vehicles and found many solutions and initiatives that are available to alleviate the negative effects. Long term environmental impact comparisons to existing internal combustion engine vehicles do demonstrate the positive environmental advantages of increased electric vehicle usage, although as highlighted, the scale of those advantages vary depending on contributing infrastructure factors. Effective and measurable ways to increase feasibility and mitigate the total carbon footprint from electric vehicle usage and charging station infrastructure include further development and grid inclusion of renewable power sources, utilization of alternative critical material extraction technologies, policy changes to tax benefits or infrastructure construction incentives, and proper societal planning of charging station infrastructure. Committing to more sustainable technologies such as electric vehicles is always promising, however, many factors contribute to the total carbon footprint and utilizing mitigation strategies must be done to make the transition efforts environmentally meaningful. With electric vehicle ownership continually rising in the United States and government funding becoming available for the construction of more electric vehicle charging station infrastructure, assessing the feasibility of increased electric vehicle usage and renewable based solutions is important to efficiently meet the ever-growing demand.

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ELECTRIFYING THE VEHICLE FLEET WITHIN THE UNITED STATES, A FEASIBILITY ANALYSIS OF ENVIRONMENTAL IMPACT AND TECHNICAL DEPLOYMENT

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ABSTRACT

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Bryan Cashman
James Hagan, Ph.D.

In November 2021, the Infrastructure Investment and Jobs Act was passed and signed into law, which along with many other funding initiatives, will provide $7.5 billion to begin the infrastructure expansion of electric vehicle charging stations within the United States. This specific funding from the federal government is a crucial step towards the current administration’s carbon neutral goals and the building of a national connected network of 500,000 electric vehicle charging stations and having 50% of light duty vehicles sales being electric by 2030. However, achieving these goals is complicated and the beneficial environmental effect of further electric vehicle integration is often debated. This is due to the concerning total carbon footprint produced from the manufacturing of electric vehicles, usage, and growth of power demand from charging station infrastructure. To counter that common viewpoint and through a feasibility analysis of environmental impact and technical deployment, this study has been able to highlight the beneficial and adverse effects of increased usage of electric vehicles and found many solutions and initiatives that are available to alleviate the negative effects. Long term environmental impact comparisons to existing internal combustion engine vehicles do demonstrate the positive environmental advantages of increased electric vehicle usage, although as highlighted, the scale of those advantages vary depending on contributing infrastructure factors. Effective and measurable ways to increase feasibility and mitigate the total carbon footprint from electric vehicle usage and charging station infrastructure include further development and grid inclusion of renewable power sources, utilization of alternative critical material extraction technologies, policy changes to tax benefits or infrastructure construction incentives, and proper societal planning of charging station infrastructure. Committing to more sustainable technologies such as electric vehicles is always promising, however, many factors contribute to the total carbon footprint and utilizing mitigation strategies must be done to make the transition efforts environmentally meaningful. With electric vehicle ownership continuously rising in the United States and government funding becoming available for the construction of more electric vehicle charging station infrastructure, assessing the feasibility of increased electric vehicle usage and renewable based solutions is important to efficiently meet the ever-growing demand.
Introduction

Electrifying and transitioning the United States of America vehicle fleet away from internal combustion engine vehicle (ICE) use has the potential for widespread environmental benefits. The transportation sector, which includes all movement of people and goods by vehicles, trains, ships, and airplanes, produced 27% of the total U.S. greenhouse gas emissions in 2020. This rate of greenhouse gas emission was the largest by any economic sector in the United States, followed by the electricity sector at 25%, industry sector at 24%, commercial and residential sector at 13%, and agriculture sector at 11% (EPA 2022). In 2021, petroleum was 90% of U.S. transportation energy use. There are currently over 279 million registered vehicles in U.S. and at least 253 million of those vehicles are classified as light vehicles or under 10,000 pounds. Specifically for classification of light vehicles, there are estimated 105 million cars and 148 million light trucks. This light vehicle classification accounted for 2.5 trillion of the 2.9 trillion miles driven in the U.S. in 2020 (Davis & Boundy 2022). Also, the average fuel economy of light vehicles was 25.7 mpg. (Vehicle Technologies Office 2021). In 2019, the 253 million light vehicles accounted for 63% of transportation petroleum use (Davis & Boundy 2022). Out of the 253 million light vehicles on the road today, it is estimated that at least 2 million of them are plug-in or fully electric vehicles. Electric vehicles can be categorized into three types, hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery powered electric vehicle (BEV). Understanding the differences of types of electric vehicles and usage capabilities is important to gauge the feasibility analysis of environmental impact, technical deployment, and societal incorporation.
Hybrid electric vehicles (HEVs) are powered by both an internal combustion engine and an electric motor that utilizes battery stored energy. Instead of charging and plugging the battery into an electrical source, HEVs are designed to charge the battery most commonly through regenerative braking. Once charged, the electric motor can assist the energy performance of the internal combustion engine which results in better fuel economy. Due to the limited internal charging ability, battery size and thus shorter usability from purely battery power of HEVs, PHEVs and BEVs have become increasing popular. In contrast to HEVs, plug-in hybrid electric vehicles (PHEVs) offer increased battery size and drivable range since the battery can now be charged through plugging into an electrical source and use regenerative braking which creates less reliance on the co-existing internal combustion engine. Battery electric vehicles (BEVs) are completely battery powered and do not have an internal combustion engine. The associated batteries are quite larger capacity wise since the entire vehicle relies on that power source to operate. BEVs are charged mainly through plugging into an electrical source but some models take advantage of regenerative braking also. This simplistic definition of HEVs, PHEVs, and BEVs, is stated because at times related quantity data of HEVs ownership can be incorrectly included in data sets that concern electric vehicle charging infrastructure, which only PHEVs and BEVs are able to utilize.

In 2021, sales of HEVs, PHEVs, and BEVs vehicles all vastly increased with HEVs increasing from 3.2% to 5.5% of all light vehicles and PHEVs and BEVs nearly doubling in sales of the previous year from 308,000 to 608,000 (Minos 2022) In total, HEVs, PHEVs, BEVs and accounted for 9.9% of total light vehicles sales, which was the highest since 1999 when such data began to be recorded as seen in Figure 1. Specifically, the sales shares were 5.5% for HEVs, 1.2% for PHEVs, and 3.2% for BEVs (Davis & Boundy 2022).
To mitigate the environmental impact of the transportation sector and further support usage and implementation of electric vehicles, the current Biden administration has set ambitious goals of increasing the electric vehicle sales share to 50% for all light vehicles by 2030 and the creation of a 500,000 electric charging station national connected network by 2035. A positive first step in the direction of these goals was made in November 2021, with the passage of the Infrastructure Investment and Jobs Act, which along with many other funding initiatives, will provide $7.5 billion to begin the infrastructure expansion of electric vehicle charging stations within the United States. Also included in the Infrastructure Investment and Jobs Act was the creation of the National Electric Vehicle Infrastructure Formula Program (NEVI), which will control the disbursal of $5 billion of the above funding to States for electric vehicle charging infrastructure developments. The act also provides $2.5 billion for competitive grants that would go towards electric vehicle charging station infrastructure construction initiatives in underserved communities with the goal of improving local air quality and increase electric vehicle charging access. In December 2021, further governmental support of electric vehicle charging infrastructure expansion was confirmed by the Department of Energy and the Department of

Figure 1. HEV, PHEV, BEV sales from 2000-2021. Source: US DOT
Transportation through the creation of the Joint Office of Energy and Transportation. This new joint office will provide states with technical assistance, resources, and availability of existing DOE/DOT expertise to accelerate the planning of construction and deployment of electric vehicle charging station infrastructure (DOE 2021). Through the above stated funding and various program creations, the United States government is making long-term investments and incentives for increased electric vehicle usage and charging station infrastructure developments. However, some important questions persist and that concerns the feasibility of these actions, the environmental impact of new use demands, and whether the transition to an overall higher electric vehicle usage is a truly worthwhile environmental investment.

**Feasibility of environmental benefits of electric vehicles**

The analysis of quantifiable benefits of increased electric vehicle usage can be complicated due to many variable differences in models, charging infrastructure access, and use patterns. Since the early 2000s, the market and electric vehicle industry has grown immensely, and major analysis strides have been made in that time to clearly assess the ongoing impact. Two obvious major environmental improvements of electric vehicle usage are the reduction of harmful tailpipe emissions and reliance of petroleum use. These emissions are standard for internal combustion engines, which commonly operate in two forms, spark ignition or compressed ignition. Gasoline powered spark ignition engines (SI) are the most common combustion type in the United States, whereas diesel powered compressed ignition engines (CI) are often found in larger vehicles. In comparison to gasoline SI engines, diesel CI engines are more efficient in terms of power consumption. But the advantage of SI engines is the less complicated reduction of emissions due to the use of three-way catalytic converters which have the ability to reduce emissions of carbon monoxide by 95%, and oxides of nitrogen and
hydrocarbons by 90% (CEP 2022). While electric vehicles do not have tailpipe emissions of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx) from internal combustion engine vehicles, electric vehicles still produced a problematic volume of emissions from the manufacturing stage, usage, and ongoing need for electrical power consumption which most commonly comes from existing electrical grids. From 2010 to 2020, an estimated 1.7 million PHEVs and BEVs were sold and driven approximately 52 billion miles by electrical power. This usage has cumulatively saved 1.9 billion gallons of gasoline. In 2020, those savings were 500 million gallons, however, those vehicles also used 4.4 terawatt-hours of electricity (Gohlke and Zhou 2021). While this offset of gasoline use is environmentally beneficial, the rate of power consumption and support from existing electrical grids still causes concerning amounts of emissions.

Life Cycle Assessment

An efficient way to start to compare and quantify the environmental effects of an internal combustion engine vehicle (ICE) and a battery powered engine vehicle (BEV) can be done through a life cycle assessment. Since the introduction and then emergence of the BEV industry in the 2000s, literature associated to life cycle assessments has grown immensely and while each provides beneficial information, direct comparison or conjunction can be problematic due to differences in the study parameters. Examples of these differences in parameters could include the goal and scope, vehicle models being analyzed, available datasets, region assessed, and variability of inputs and outputs. Thus, one must understand the vast differences in LCA studies to consider them valid or meaningful for comparison purposes. This scope and difference dilemma of LCA studies was evident in survey of related research done in 2012, which analyzed 51 available environmental assessments of electric vehicles and found that not one study
contained a complete cradle-to-grave assessment of electric vehicles (Hawkins et al. 2012). The 51 environmental assessments reviewed were commonly found to focus more on the LCA of the related fuels and electricity rather than a LCA of the vehicle itself (Hawkins et al. 2012). This finding highlights the problematic conclusions that many previous and future LCA studies may have since limiting the inclusion of all process steps can certainly produce misleading results. These variabilities ultimately provide a range of results and an overall comparative review of the literature related to life cycle assessments can be limited unless specificity is applied. To counter this potential variation and apply specificity, choosing to highlight cradle-to-grave life cycle assessments offers the most comprehensive feasibility analysis since it incorporates the complete life cycle impact of the fuel and vehicle. Specifically, a cradle-to-grave life cycle assessment will include the effects of the fuel’s extraction, processing, transmission, and use, along with the vehicle’s raw material extraction, processing, production, use, and end of life disposal or recycling.

After a robust literature survey of differing cradle-to-grave life cycle assessments of BEVs and ICEs, it first became obvious that LCA studies that utilized data from the US government supported GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) program and life cycle modeling system were the most accurate to correctly assess the US-based impacts of increased electric vehicle usage. Additional benefits of LCA studies that utilize data and the GREET life cycle assessment modeling system are consistency of data, transparency, and ability to be reproduced. The GREET life cycle assessment modeling system is also cost-free to use and thus has unlimited availability. Since 1995, the US government has commissioned The Argonne National Laboratory to compile data gathered by the U.S. Energy Information Administration (EIA) and the U.S. Department of Energy (DOE)
and develop a yearly updated life cycle assessment modeling system. This compiled data and GREET life cycle modeling system began as a calculatable Excel spreadsheet. But due to the added detail and complexity over two decades, in 2014, The Argonne National Laboratory developed a new software-based approach, GREET.net, and a graphical toolbox which allowed users to perform life cycle assessment simulations with much more simplicity. This new GREET.net software-based approach combines all the previous years of Excel spreadsheets in a single system and database. However, the yearly GREET Excel model is still available to use and was not discontinued since certain users have legacy experience with that type of format and it is still able to calculate life cycle assessment simulations (Argonne National Laboratory 2022).

To put it simply, the GREET life cycle assessment modeling system is a tool that can calculate cradle-to-grave life cycle assessments for any given type of vehicle, ICE or BEV for example, and include the impacts of all associated energy systems, fuels, production, and disposal.

Utilizing the dataset provided by the GREET life cycle assessment modeling system, many cradle-to-grave life cycle assessments have been produced by a variety of authors and organizations. As previously noted, transparency of inputted data, clarity of boundaries or sensitivities, and reproducibility are all essential aspects for the validity of a life cycle assessment. After a performing a literature survey with those aspects in mind, the most up-to-date robust study in terms of data gathered from GREET and publication is the Fuels Institute’s Life Cycle Analysis Comparison report from January 2022. This study was chosen to be highlighted for this feasibility analysis because it provided detailed reasoning and calculations for each life cycle process step and produced an informative baseline environmental impact comparison for US-based ICE vehicles and BEVs. To provide some background, The Fuels Institute was founded in 2013 by the NACS (National Association of Convenience Stores) and is
a non-profit and non-advocacy research organization that analyzes vehicle energy use and industry related issues or proposals in the transportation sector. By their definition, the term fuel is any type of energy being used to power a vehicle. NACS is a global trade association with over 1,300 retailer and 1,600 supplier members from over 50 countries, whose goal is to advance and support convenience and fuel retailing (NACS 2022). Specifically in the United States, this trade association also attempts to communicate the convenience and fuel retailing industry’s objectives or issues to Congress and federal government agencies. Increased usage of electric vehicles and associated charging infrastructure is a dynamic of interest for NACS since their stakeholders could be very involved with developmental support of the industry on convenience or fuel retailing property. NACS and The Fuels Institute commissioned Ricardo Strategic Consulting, which specializes in engineering consultancy and is best known for previous engine and powertrain analysis, to conduct a cradle-to-grave life cycle assessment to analyze the differences of ICE vehicles and BEVs life cycle emissions and total cost of ownership (The Fuels Institute 2022). This LCA focused on three different types of vehicles and powertrain combinations: an average-sized ICE light vehicle, a hybrid electric light vehicle (HEV), and a battery electric light vehicle (BEV) in the crossover/SUV category. These specific types were chosen to align with current U.S. sales rates and thus commonly used vehicles. As previously mentioned, this cradle-to-grave LCA provides current and in-depth analysis of contributing environmental impacts from the vehicle production, operation, and disposal, essentially comparing the vehicles as more of a total system and calculating all the inputted and outputted aspects. The boundary conditions were set as followed, in the manufacturing or vehicle production phase, all emissions were included from the stages of obtainment of materials needed to construct the vehicle, processes to convert the materials into usable manufactured goods, and
the vehicle assembly methods. For the use or operation phase, all emissions were included from the fuel extraction processes and effects of using the related fuel. For example, for BEVs, this use phase included emissions from the electricity production to charge and operate the vehicle which is very important to get holistic view of the environmental impact of electric vehicles. Lastly, the disposal or afterlife treatment of the vehicles considered all emissions from recycling processes if possible and long-term environmental impacts through recycled resource retention (Fuels Institute 2022).

Before analyzing and comparing the resource allocation and vehicle manufacturing phase, the ICEV, HEV and BEV vehicles in this study were normalized in weight to negate any differences in size and specific design attributes from manufacturers. Then using existing GREET models concerning GHG emissions of material gathering, manufacturing and assembly, a comparison could be produced. As seen in Figure 2 below, the vehicle production phase for BEVs is substantially higher compared to ICEVs and HEVs. This is mainly due to the higher energy and carbon intensity needed to process the extracted materials into usable components for the BEVs. As will be noted later in this analysis, the location and usable electricity mix has a significant impact on that rate of carbon intensity. For this example, average U.S. electricity mix was inputted for these results (Fuels Institute 2022).

![Figure 2. GHG emissions from LCA vehicle production phase. Source: Fuels Institute](image)
Next, for the operation phase of the cradle-to-grave LCA, it was obvious that ICEVs and HEVs would be far higher in relation to GHG emissions due to the reliance, usage, and burning of gasoline for power. However, informative data was also seen in this study concerning the comparative environmental impact of BEVs. This study specifically analyzed the relation to carbon intensity of different electrical grids which in turn would be providing electrical power to the BEVs. When this variable was accounted for, the environmental impact of widespread transitioning to BEVs became more complicated but also provided clear indications of what could be done to ensure beneficial feasibility. For a baseline, 200,000 miles of usage was chosen to be a vehicle’s lifespan for all types (Fuels Institute 2022).

As seen in figure 3, when using average U.S. electricity mix, the total GHG emissions after 200,000 miles of usage was 66 tons for ICE vehicles, 47 tons for HEVs, and 39 tons for BEVs. This data clearly shows that the utilization of BEVs is a positive environmental impact over the
estimated total lifespan. However, as the mileage usage begins to decrease, the GHG emission gap becomes much smaller. This is best representative in percentages, at 200,000 miles, there is roughly a 27 ton or 69% reduction, but at 100,000 miles, there is only a 11 ton or 44% difference. This association of mileage use to environmental benefit becomes even more evident has the vehicle mileage drops.

In figure 4, at 50,000 miles of usage, the BEV only provides roughly a 23% reduction of GHG emissions. The environmentally beneficial tipping point for BEVs is estimated to begin after 27,000 miles of usage when using average US electricity mix. The average U.S. resident drives 11,200 miles per year (Davis & Boundy 2022). Thus, after only three years of driving, the average mileage rate per year would put BEVs into the beneficially environmental impact category and be a feasible option for widespread adoption.

However, not every electrical grid is aligned with the average U.S. electricity mix and grid carbon intensity can vary significantly in different areas of the country, starting with the
lower carbon intensity grids, as seen in states such as Washington, Oregon, New Hampshire, Vermont, Maine, Minnesota, California, South Dakota, Maryland, and New Jersey (EIA 2021).

In figure 5, the total GHG emission gap is much larger at 200,000 miles, roughly a 47 ton or 276% reduction. The environmental benefits also begin earlier after 19,000 miles of usage, effectively making it only two years of on average driving needed. In contrast, there are also electrical grids within the U.S. that are still considered high carbon and one state has what is referred to in this study as an extremely high carbon grid. States that have high carbon grids include Iowa, Tennessee, and Texas (EIA 2021). In such states and associated electrical grids, there is only a 9-ton reduction of GHG emissions after 200,000 miles and BEVs require 82,000 miles of usage before becoming environmentally beneficial as seen in Figure 6 below.
The state with an extremely high carbon electrical grid is West Virginia, where in 2020, coal-fired power plants contributed 88% of the state’s total net power generation (EIA 2021). This electrical grid is realistically an excessive example; however, it truly showcases the potential problematic environmental situation BEV owners may encounter in certain areas. If solely powered by this 88% coal supplied electrical grid, BEVs would not be an environmental benefit and are estimated to contribute 12 more tons of GHG emissions after 200,000 miles as noted in Figure 7 below.
Figure 7. Total GHG emissions from ICE, HEV, and BEV at 200,000 miles and 100,000 miles of usage. Extremely high carbon electricity mix. Source: Fuels Institute

This carbon intensity electrical grid data is showcased and included because it represents the close relationship that more renewable powered electrical grids have with feasibility of electric vehicles being environmentally beneficial. Future commitments to further renewable energy sources being incorporated into existing grids will ultimately increase the environmental benefits of transitioning and utilizing fully electric vehicles. This process of adding and using more renewable power sources can happen on both the macro and micro level. Increased government funding for renewable energy infrastructure could have far-reaching and long-lasting positive effects and in turn provide existing grids with the ability to become more sustainable. Also, on a micro level, localized grids that are controlled on a state, county, or city level could commit to further expansion and inclusion of renewable energy infrastructure to ensure BEV owners and all local users of electrical, a potential more environmentally friendly solution.

Further research by Union of Concerned Scientists (UCS), has also shown the positive impact of more integrated and renewably powered electrical grids in relation to improving the environmental feasibility of using electric vehicles. While it is not a complete cradle-to-grave life
cycle assessment, the UCS still utilized GREET models for estimating and comparing emissions from the extraction, transportation, and refining of gasoline and other electricity fuels used for specific power plants. Using data from regional power plant emissions from 2018 through the eGRID2018 database, they were able to estimate the fuel economy or mpg equivalent for an electric vehicle utilizing those specific regional power plants. The average BEV mpg stated is also based on sales-weighted data from where BEVs were sold from 2011 to 2019 (UCS 2020).

Figure 8. EV emissions as gasoline MPG equivalent. Source: UCS

As seen in figure 8, there are immense differences in terms of equivalent BEV mpg depending on how renewably powered the electrical grid and associated regional power plant are currently operating. While not all-encompassing as seen in the previous cradle-to-grave life cycle assessment, this example does provide valuable insight and a country-wide snapshot with how certain regional power plants and areas are much environmentally beneficial for electric vehicle usage.

Overall, for the environmentally concerned BEV owner or prospective buyer, there are few ways to influence the environmental effect of already established processes of material
extraction, manufacturing, and production of said vehicle. Thus, the focus must be on how and by what power source the BEV is charged to guarantee the utmost environmental benefit. Renewable powered electrical grids and associated charging station infrastructure have been proven to be environmentally feasible and worthwhile if funded, supported, and built for widespread utilization.

**Technical Feasibility and Electric Vehicle Charging Station Deployment**

A critical aspect of the feasibility of increased electric vehicle usage is the technological capabilities and effective compatibility with existing or planned charging infrastructure. To begin on a macro level, it is often debated whether the further implementation of electric vehicles, charging stations, and in turn a higher electrical demand on the grid can be viably supported in the future. The U.S. electrical grid design is multi-faceted in how it is constructed and maintained with specific importance towards a decentralized system that has many inputs of generation capacity. Throughout much of the 20th century, the U.S. electric power system and associated electrical grids were able to meet the electrical demand required while also continuously adding generation capacity. In particular, the decades of 1970 and 1990 saw the highest energy generation growth due to expansions and additions of more nuclear and fossil fuel sources. This needed increase during those decades was directly related to population and land use growth but surprisingly, while the annual U.S. energy consumption rose over that time, energy consumption per capita or per person peaked in 1970s and then proceeded to have few increases and eventually began to steadily decrease after 2000 (EIA 2022). This reduction of energy consumption per capita (per person) has many contributing factors but some of the most influential include electrical efficiency increases of household appliances, advancements in required building insulation, improvements to energy efficiency standards, and overall increase
of population growth in warmer climate regions compared to colder climate regions which in turn has lowered heating energy consumption (EIA 2022). Due to the periodic decline and then relative leveling off of electrical demand, new energy generation growth has also been slowed over the last decade. Past investments in energy generation have allowed the U.S. electrical power system to still add dispatchable generation capacity to exceed any yearly electrical demand. It is estimated that an average of 12 GW of generation capacity is added yearly, and with a maximum of 25 GW seen in specific past years. To equate this generation capacity to potential estimated electrical vehicle power demand, 12 GW can be equivalent to usage of 6 million new electric vehicles (US Drive 2019) As mentioned earlier, electric vehicle sales in the U.S. were 308,000 in 2020 and 608,000 in 2021. This stark doubling of sales is not expected to reoccur, however, consistent increases in sales are projected for future years. In 2021, there were 14.9 million light vehicle sales, 3.3 million being conventional passenger sized vehicles and 11.6 million being light trucks (DOT 2022). The current administration has set a goal through investments for 50% of light vehicle sales to be electric by 2030 or a twelve time increase of sales seen in 2021. That rate of new electric vehicle usage and demand could exceed the capabilities of the average 12 GW of yearly added generation capacity, although much higher capacity years have been seen and could be planned for accordingly. Sales and percentages of types of light vehicles can be complicated to predict, especially due to the high quantity of new electric vehicle models becoming available on marketplace in the coming years. Using the International Council of Clean Transportation’s sales projection scenarios of incremental, moderate, and accelerated, offers some usable representative insight into the potential future electrical demand of new electric vehicles. The incremental sales scenario is based on current electric vehicle production rates and availability from U.S. based manufacturers, which would in
turn see U.S. vehicle sales increase to 3.2 million by 2030 or estimated 20% of 2030 U.S. light vehicles sales. Moderate sales scenario is by far the most realistic since it is based on stated production goals from electric vehicle manufacturers, future investment, market trends, and previous ICCT briefings. This scenario would project that 5.5 million electric vehicles would be sold every year in the U.S. and account for 30% of light vehicle sales by 2030. Lastly, the accelerated sales scenario assumes higher than projected production rates, widespread adoption, and achieving the current administration’s goal of 50% of light vehicles sales by 2030 or roughly 8.7 million electric vehicles based on 2015 to 2019 total average light vehicle sales (ICCT 2022).

Through further funding of electric vehicle charging stations like seen in the Infrastructure Jobs Act and other purchasing incentives, this 50% electric vehicle sales goal could be possible. If so, yearly generation capacity would have to increase to meet the electrical demand and usage which existing electrical generation processes have shown to be able to supply well above that during years of 25 GW additions. However, as addressed in the environmental impact feasibility, where that electrical generation is sourced from is vital and important to the beneficial usability and support of electric vehicles. Overall, the more realistic moderate sales scenario of 5.5 million electric vehicles and 30% of light vehicle sales could be supported by the yearly 12 GW generation capacity increase average. It can be concluded that current average dispatchable generation capacity additions can effectively meet the future electric vehicle usage demand without becoming limited or at risk of distribution failure.

**Electric vehicle charging station infrastructure construction and deployment**

A major component of assessing the feasibility of increased usage of electric vehicles is the planning, construction, and deployment of related electric vehicle charging infrastructure that is needed for operation. Understanding the different levels of power that electric vehicle charging
stations and the benefits or limitations of each type is the first step to assessing usable widespread feasibility. According to the Alternative Fuels Data Center which was created by the Department of Energy in 1991, there are currently 49,633 public charging stations in the United States. Specifically, there are 287 level 1 charging stations, 44,217 level 2 charging stations, and 6,447 DC fast charging stations as seen in Figure 9 below (Alternative Fuels Data Center 2022).

![Figure 9. US public electric vehicle locations. Source: Alternative Fuels Data Center](image)

Level 1 charging stations provide 1.4 kW of power and are simply a conventional wall socket. These level 1 charging systems are ideal for households since no new installations of circuitry is needed and the average household has outlet availability throughout the residence. The downside of level 1 charging is the extremely slow charging rate in relation to the large capacity batteries found in many HEVs and especially BEVs. It would be expected that a full charge from Level 1 charging would take many days for a large BEV battery and depending on the size, 24 hours for an HEV battery. It is often estimated that Level 1 charging stations provide 2 to 5 miles of range.
per hour of charging (DOT 2022). As seen in the data from the Alternative Fuels Data Center, Level 2 charging stations are by far the most popular and available for consumers. At home, level 2 charging stations typically operate on higher powered 220-volt outlets, which are commonly used for appliances such as washing machines, dishwashers, and clothes dryers. These types of outlets are also very common in U.S. households but could be limited in certain older households or not properly planned residential designs. Level 2 charging stations are so popular, at a rate of 44,217 publicly available stations, because of their ability to be provided at workplaces, hotels, gas stations, parking lots, and other related high traffic buildings or areas. Typically, a level 2 charging station at household is limited to 6.6 kW due to safety and limitations of on-board electric vehicles power controllers. However, it is common to see Level 2 chargers being able to reach 19.2 kW of power supply if designed accordingly and existing circuitry can support that electrical current. Since the potential power supply varies so much for Level 2 charging, estimated charging time to full varies also and it should be expected that it will take at a minimum 2 hours to 10 hours depending on the battery size and on-board electric vehicle power controller and 10 to 20 miles of range per hour (DOT 2022). Both of the previously described levels of charging stations are suitable for at-home use and long periods of inactive electric vehicle use, however, societal movement trends often require something that is ultimately much faster charging and can provide immediate usable range increases. Commonly referred to as Level 3 or Direct Current Fast Charging stations, these types of chargers can provide much higher electrical power delivery to electric vehicles. Due to the direct current style of electrical current compared to alternating electrical current, DC fast charging stations can output 50kw to 350kw of electrical power. This rate of current allows large capacity BEVs to be fully charged in 20 minutes to 1 hour and provide range increases of 180 to 240 miles per hour
This level and type of charging station is the most ideal for widespread usage. Unfortunately, not every HEV and BEV can support such fast power delivery of 350kw due to limitations of on-board charging controllers and overall safety concerns. Lack of widespread availability and electric vehicle compatibility in turn limits growth of ownership and ultimately for many people, 20 minutes to 1 hour of waiting for a full charge is still not practical or desirable. For example, a standard size gasoline powered ICE vehicle can add an estimated 250 miles of range in about 90 seconds at the fuel pump. It is certainly technically feasible to use all levels of electric vehicles charging stations, however, certain types may require lifestyle or usage rate changes to ensure the electric vehicle can operate properly and provide the same range abilities of ICE vehicles.

To promote further adoption and feasibility of usage of electric vehicles and associated charging stations, the current administration specifically included $7.5 billion for electric vehicle charging infrastructure expansion in the Infrastructure and Jobs Act signed in November 2021. The National Electric Vehicle Infrastructure (NEVI) program will provide $5 billion in funding to States to help plan, build, and support new electric vehicle charging station charging infrastructure. The act also provides $2.5 billion for competitive grants that would go towards electric vehicle charging station infrastructure construction initiatives in underserved communities with the goal of improving local air quality and increase electric vehicle charging access (White House Fact Sheet 2022). Referring to the NEVI program, the $5 billion disbursed to the States would specifically be focused on expanding electric vehicle charging infrastructure along highways and the approved alternative fuel highway corridors. The overarching goal of the funding is to support the construction of 500,000 new electric vehicle charging stations by 2035. The already existing government program, the National Alternative Fuel Corridors Initiative
could fulfill this goal. This initiative was created in the passage of the “FAST Act” in 2015. The Fixing America’s Surface Transportation Act (FAST) was signed into law in December 2015 and provided the Department of Transportation with $305 billion from 2016 to 2020 for many of its programs including highway and motor vehicle safety, public transportation, motor carrier safety, hazardous materials safety, rail, research, and technology (USDOT 2020). One required use of those funds was to create the National Alternative Fuel Corridors Initiative which falls under jurisdiction of the Federal Highway Administration. The goal of the National Alternative Fuel Corridors initiative is to create and expand a national network of alternative fueling and charging infrastructure through designation of alternative fuel corridors across the United States. These alternative fuels include electric, hydrogen, propane, and natural gas fueling. While there are other options for alternative fuel usage on these corridors, electric vehicle charging is the most practical due to the already established usable technology and a growing industry of electric vehicles. This program allows states to nominate and designate highways within their borders that are equipped with alternative fuel options which are most commonly electric vehicle charging stations (USDOE 2021). After five separate rounds of submissions and approvals since 2016, this program has been successful with establishing many alternative fuel corridor designations. Over the course of five years, 125 nominations have been received from state and local officials from 49 states and the approved alternative fuel corridors cover approximately 58,980 miles of the 165,722 miles of the National Highway System and seen in Figure 10 below (USDOT 2021).
The FHWA designates alternative fuel corridors in two types, corridor ready and corridor pending. Corridor ready, is a highway that has electric vehicle charging stations located within a distance of 50 miles apart and no greater than 5 miles off the highway. Corridor pending, is a highway that has some electric vehicle charging stations but doesn’t meet the distance requirements of corridor ready. Once the FHWA designated a road or highway to be corridor ready or pending, the states are allowed to install Alternative Fuel Corridor signage along those highways. Ultimately, with so many corridors pending or already approved, this could realistically fast track the installation of electric vehicle charging stations once suitable land is deemed available. With the large increase of electric vehicles sales seen in 2021, expedited installation certainly is needed to properly support the existing HEVs and BEVs owners but also
could provide confidence to potential new buyers. But as stated previously, proper planning of which level and type of electric vehicles charging stations is vital to the feasibility and long-term success of more electric vehicle ownership.

One main reason why level 2 charging stations are widespread is their relative low cost of installation compared to DC fast charging stations. Estimates range depending on location but conservatively, building a new level 2 charging station on a highway corridor is achievable for under $25,000, whereas DC fast charging stations can easily range from $50,000 to even $100,000. To meet the consumer demand for electric vehicle charging stations, it has been projected those costs will be $28 billion, which would provide 1.3 million level 2 workplace chargers, 900,000 level 2 public chargers, and 180,000 DC fast chargers by 2031 as seen in Figure 11 below.

![Chart showing estimated needed charging infrastructure and investment](chart.png)

Figure 11. Estimated needed charging infrastructure (left), estimated needed investment (right).

Source: Bauer, Gordon, et al 2021

In June 2022, the U.S. Department of Transportation’s Federal Highway Administration announced specific regulations that NEVI-supported projects would have to follow and included in those regulations was a financial and planned commitment to installing the more expensive but also more long-term viable DC fast charging stations. In particular, the FHWA proposed that
if charging infrastructure is funded by the NEVI program, DC fast charging stations would be required for approval at certain traveling waypoint locations. The FHWA continues to specifically state “By servicing this waypoint need, FHWA recognizes that charging stations should be built to prioritize convenience over price in order to be effective and determines this is the best option for those EV charging stations located along Interstates. Convenience is also the goal in the proposed requirement for the number of charging ports at each charging station; §680.106(b) would require a minimum of four charging ports capable of simultaneously charging four EVs” (DOT/FWHA 2022). This statement highlights the feasibility of further electric vehicle ownership and transition away from ICE vehicle usage, which is heavily dependent on the prioritization of infrastructure buildup of DC fast charging stations on highways. While costs may be quite higher, choosing this type of charging station will ensure long-term feasibility and viability of increased electric vehicle ownership.

**Conclusion**

Successfully transitioning the American vehicle fleet from ICE vehicle usage to purchasing and using more electric vehicles is certainly complicated. However, due to the large increase of sales seen in 2021, there’s absolutely a growing population that is willing to endure those complications for the goal of utilizing a more environmentally friendly vehicle. This feasibility analysis has shown that increased electric vehicle usage can be both a long-term positive environmental impact and the needed technical deployment of related infrastructure is already in motion to support the expansion of more widespread usage. If specific commitments are made, including making our electrical grids more renewably powered, increases tax and funding incentives, and proper planning and distribution of DC fast charging stations, the beneficial feasibility of electric vehicle ownership only increases and becomes visibly effective
and obtainable for an even larger population. Countless car manufacturers have documented plans to enter and begin to supply more electric vehicles that are lower priced and tailored to specific use patterns such as city or long-distance driving. There are practical, feasible, and immense opportunities for the U.S. to lead in the development of a robust, efficiently planned, and supported electric vehicle ownership ecosystem. Comparisons are often made to the planning of the U.S. highway system and while it has shown some faults over the decades, the continuous effort to achieve the vision of an interconnected society absolutely spurred growth for the country. Increased electric vehicle usage can now help alleviate an impending environmental emissions and petroleum reliance issue that we all will face. With proper planning and execution of important connected industries, feasibility of environmental impact and technical deployment will only improve and the ICE to BEV transition will provide the needed positive output.
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