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An Analysis of the Challenges Facing the Electric Car Revolution

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An Analysis of the Challenges Facing the Electric Car Revolution

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First and foremost, I would like to thank my wife for her relentless encouragement. She constantly motivated me to complete this paper. I could not have completed my paper without my wife’s willingness to provide feedback and assume all household responsibilities.

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Abstract

The US and other developed countries are working to transition from the internal combustion engine to all electric clean car technology. The electric car does have a long history that is greatly unknown, but it has failed to evolve over time. With the current legislation and increased awareness on global warming, there is a push to go electric that has sparked a revolution. This is an important distinction as it will impact us all.

However, there are serious challenges that face the electric car revolution. Those challenges include, but are not limited to, material procurement, national defense, infrastructure, cost, and adoption. This paper will summarize the history of the electric car, where and how it is already been implemented, and make a comparison of the driving factors behind the production of the electric car in the past to today. The focus of the paper will be to analyze those challenges facing the rapid transition to clean car technology and the resolutions that are being implemented.

In conclusion, the electric car revolution is eminent and will impact us all. The challenges facing it will have to be resolved. This paper will provide an analysis through research of those challenges and provide insight into how they are being addressed.

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An Analysis of the Challenges Facing the Electric Car Revolution

The automotive industry is undergoing a significant shift towards innovative all-electric vehicles, replacing traditional internal combustion engines. This transformation marks a pivotal moment in transportation and its impact on the environment. With advancements in technology and growing environmental concerns, all-electric vehicles are the future. Some hybrids have been developed as an intermediate step between internal combustion and all-electric vehicles. Their existence is a viable option for those seeking to reduce their reliance on fossil fuels but are hesitant about transitioning entirely to an all-electric vehicle. However, hybrid vehicles fall outside the scope of this paper. The current trend is leaning towards all-electric vehicles. This is evident as numerous countries, businesses, and institutions have committed to achieving net-zero emissions as outlined in the 2015 Paris Agreement.

Throughout history, the development of electric vehicles has paralleled that of internal combustion engines. A thorough understanding of this shared history is crucial to fully grasp the rise and decline of electric vehicles which were eventually overshadowed by the dominance of internal combustion engines. However, with growing efforts to reduce the consumption of fossil fuels, electric vehicles have made a comeback and are now undergoing a rapid and transformative revolution.

The resurgence of all-electric vehicles can be attributed to various factors, such as advancements in technology, silent operation, and zero emissions. Moreover, as non-renewable fossil fuels continue to deplete over time, it has become imperative to seek sustainable alternatives. The decreasing reserves of crude oil, coal, and natural gas since the industrial age highlight this pressing need. However, the primary reason for the all-electric vehicle's rise is its ability to decrease carbon dioxide emissions caused by burning fossil fuels. This issue has been recognized on a global scale since the conception of the United Nations Framework Convention on Climate Control's (UNFCCC) Paris Agreement, established in 2015. It is widely accepted that addressing climate change is a global emergency that requires radical measures. For nations committed to the Paris Agreement, transitioning to all-electric vehicles is a crucial step toward achieving the established long-term goals.

Established in 1988, the International Panel on Climate Change (IPCC) supplies scientific information to assist governments in creating climate change policies. The organizations define climate change as, "A change in the state of the climate that can be identified by changes in the mean and/or variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal process or external forces such as modulations of the solar cycle, volcanic eruption, and persistent anthropogenic changes in the composition of the atmosphere OR in land use." (Shukla et al., 2019, p. 808).

In 1992, the UNFCCC was formed as a framework for international cooperation on climate change. The UNFCC defines climate change as, "A change in the climate which is attributed directly or indirectly to human activity that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." (UNFCCC, 2018b). In contrast with the IPCC's definition of climate change, the UNFCC defines climate change because of human activity.

Considering both the UNFCC and the IPCC definition of climate change, climate change is caused by natural processes, and by human activity. Global warming is one of the ways humans contribute to climate change. Global warming is defined by Merriam-Webster as, "an increase in the earth's atmospheric and oceanic temperatures caused primarily by an increase in greenhouse gases caused by pollution" ("Global Warming," 2024).

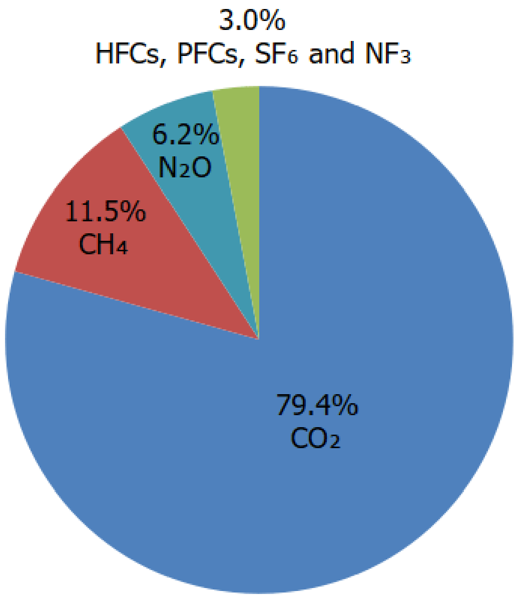
Greenhouse gases envelop our planet and absorb radiant energy wavelengths that are not visible to the human eye, but humans can feel in the form of heat. The more radiant energy or heat trapped in our atmosphere, the higher the surface temperature becomes. Greenhouse gases consists of seven different gases, four of which are synthetic. The seven greenhouse gasses are:

1. Carbon dioxide (CO_2) – some of the ways CO_2 enters the atmosphere are through natural processes, such as an erupting volcano, but mostly through burning of fossil fuels (*Overview of Greenhouse Gases | US EPA*, 2024).
2. Methane (CH_4) – CH_4 enters the atmosphere via a variety of ways, including from livestock, agriculture, decay of organic waste and through the production and transport of coal, oil, and natural gas (*Overview of Greenhouse Gases | US EPA*, 2024).
3. Nitrous oxide (N_2O) – some of the ways N_2O enters the atmosphere are through agriculture, land use, and combustion of fossil fuels (*Overview of Greenhouse Gases | US EPA*, 2024).
4. Fluorinated gases (Synthetic) –synthetic fluorinated gases enter the atmosphere through household, commercial, and industrial processes (*Overview of Greenhouse Gases | US EPA*, 2024). These gases are entirely man-made. The following are examples of fluorinated gases:
    a. Hydrofluorocarbons
    b. Perfluorocarbons
    c. Sulfur Hexafluoride
    d. Nitrogen Trifluoride

According to the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, carbon dioxide is the largest contributing greenhouse gas followed by methane at a significant distance.

Figure 1

Total Gross U.S. Greenhouse Gas Emissions 2021

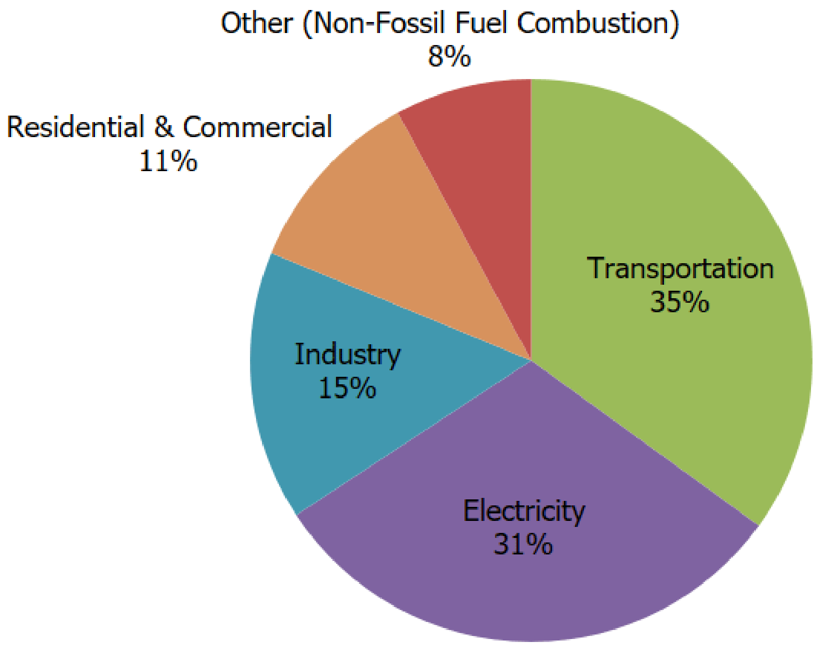


U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Furthermore, the inventory breaks down the carbon dioxide emission by economic sector and shows the largest contributor to be transportation at 35% followed by electricity (heating, ventilation, air conditioning, lighting, and appliances) at 31%.

Figure 2

Total Gross U.S. Greenhouse Gas Emissions 2021 By Economic Sector

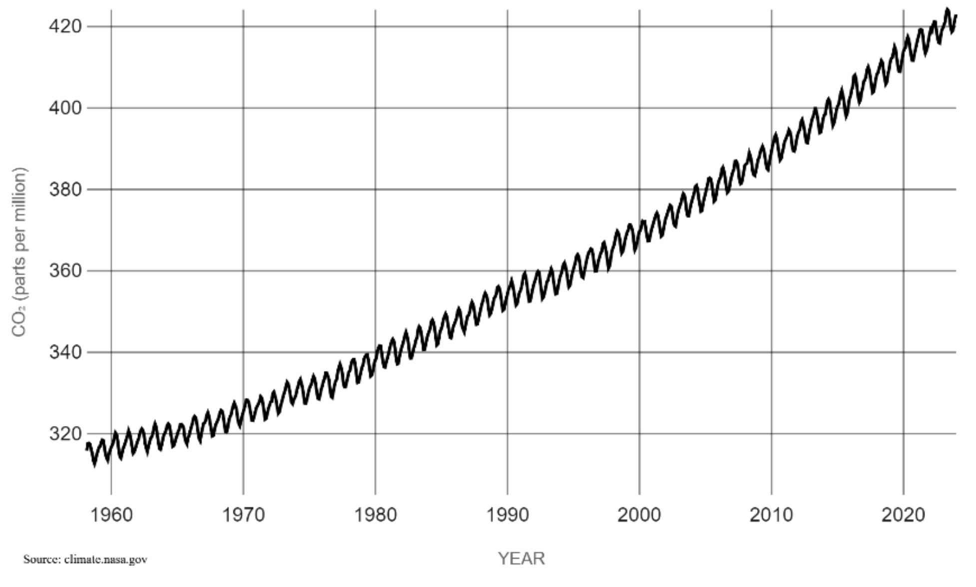


U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

With 66% of all carbon dioxide emissions coming from the transportation and electricity sectors, it makes sense for government policy to focus on those two sectors. This justification supports the need for electric vehicles and the further development of the infrastructure needed to further expedite the integration of electric vehicles into society.

Figure 3

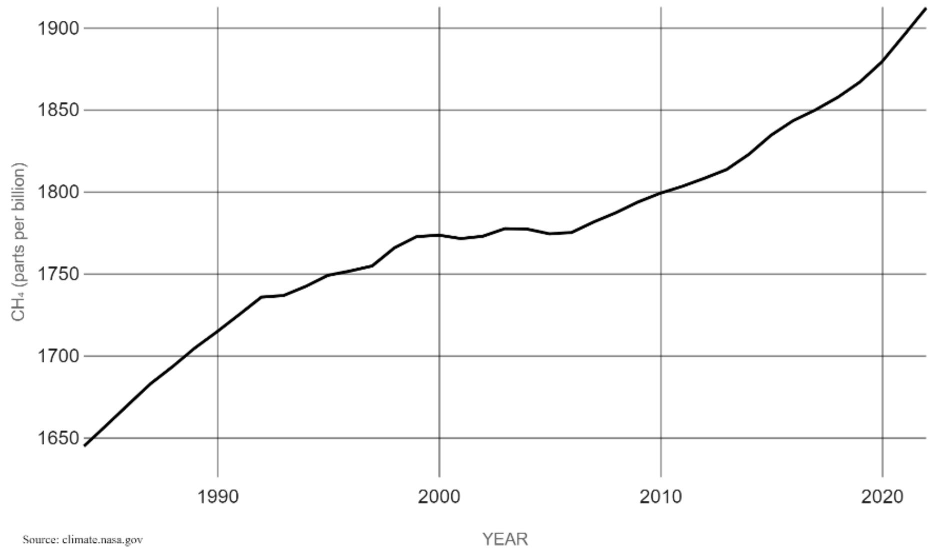
Increase in carbon dioxide parts per million since 1956 to current.



(N. G. C. Change, n.d.)

Figure 4

Increase in methane parts per million since 1956 to current.

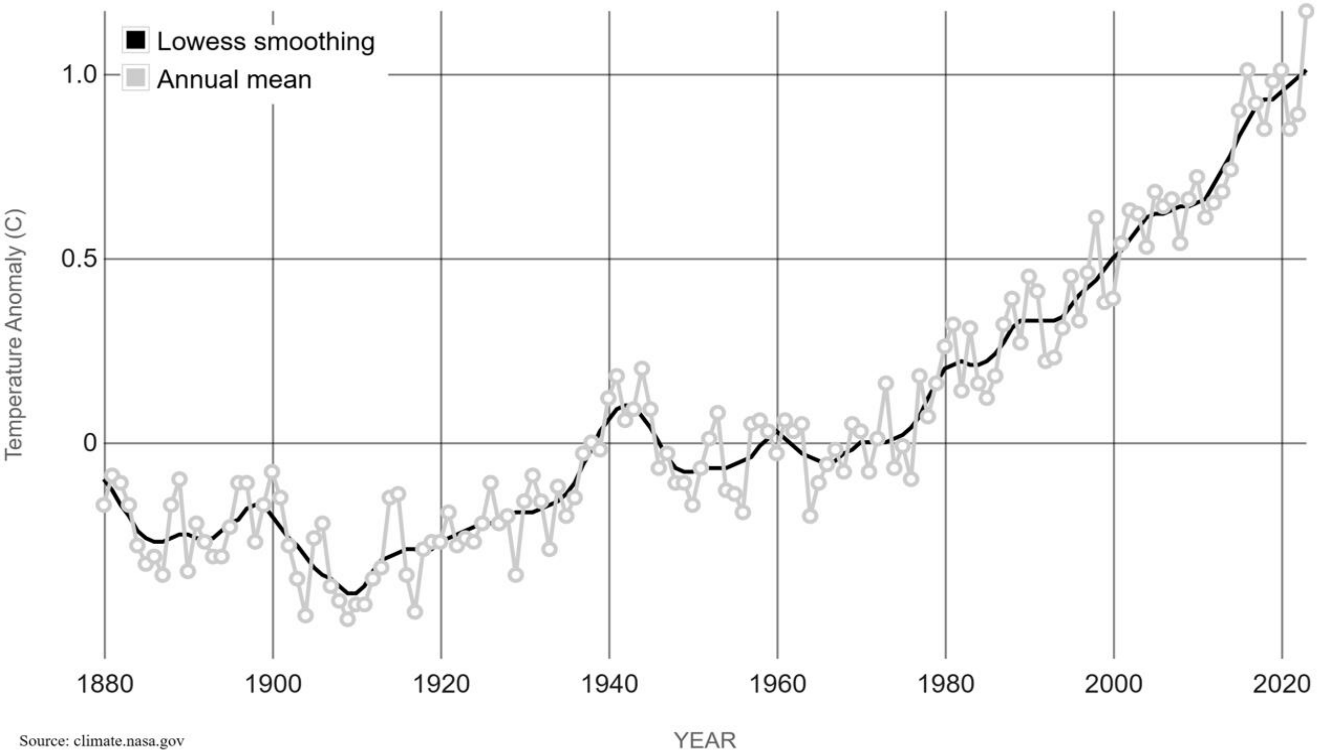


(*Methane | Vital Signs – Climate Change: Vital Signs of the Planet*, n.d.)

Climate change, caused by the increasing amount of greenhouse gases in our atmosphere, has significant consequences including melting glaciers, rising sea levels, heatwaves, wildfires, and extreme weather events such as heavy rainfall or droughts. These impacts vary across different regions. The IPCC Sixth Assessment Report published in 2021 revealed that human-produced greenhouse gas emissions have already led to a 1.1-degree Celsius increase in global temperatures since the start of the industrial era in 1850-1900 and will continue to rise in the future (Change, 2023c).

Figure 5

Global Land-Ocean Temperature Index



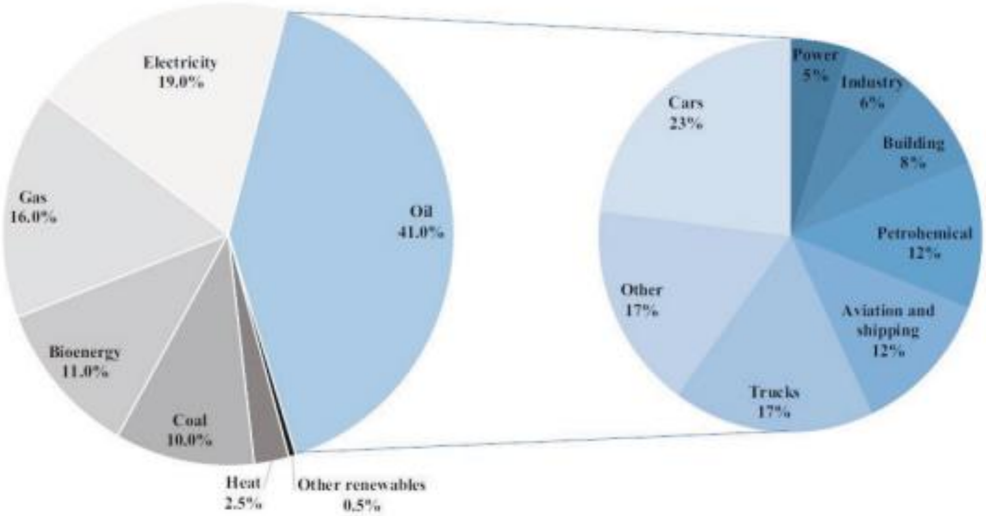
Source: climate.nasa.gov

Data source: NASA's Goddard Institute for Space Studies (GISS). Credit: NASA/GISS

The transportation sector is the greatest contributor to greenhouse gases, followed by electricity. The impact of climate change is already evident and will only become more so over time. According to the IPCC, "The evidence is clear: climate change poses a threat to both human well-being and the health of our planet. Urgent global action is needed to secure a livable future before it's too late." (AR5 Climate Change 2013: The Physical Science Basis – IPCC, n.d.). This highlights the importance of transitioning to all-electric cars and sustainable sources of energy for electricity, not only for our own benefit but for the planet. The figure below illustrates the impact cars have regarding oil consumption which supports the need to transition to all electric vehicles.

Figure 6

Global Energy Consumption by Type and Global Oil Consumption by Sector.



Note: Global energy consumption by type (left) and global oil consumption by sector (right).

Copied from Raja, V B., Raja, I., & Kavvampally, R. (2021, December 1). Advancements in Battery Technologies of Electric Vehicle. IOP Publishing, 2129(1), 012011-012011. https://doi.org/10.1088/1742-6596/2129/1/012011

History

As the 20th century approached, horse and buggy remained the primary mode of transportation. However, alternatives to human or animal power were also available. These alternatives included wind, water, and other forms of propulsion. Despite these options, most people could not afford the still-primitive technology at that time. The main sources of power and propulsion in this era were steam, electricity, and gasoline. Steam engines had already been used for passenger transport since the early 1800s. Gasoline engines were notoriously loud and produced unpleasant exhaust fumes. Electricity, although quiet, was not suitable for transportation until later developments such as electrification and rechargeable batteries. To fully comprehend the evolution and eventual decline of electric vehicles in the 20th century, it is important to understand key inventions involved in their development.

1827

Hungarian engineer and inventor Anyos Jedlik built the first direct-current motor capable of running continuously. The simple design consisted of a stator, rotator, and commutator. What was special about this design and unique to other existing motors of the time was that the commutator, a special kind of switch, allowed the motor to run continuously. This invention laid the groundwork necessary for the development of modern-day direct-current motors. (*Ányos Jedlik - Linda Hall Library*, 2022).

Figure 5

Electromagnet Rotor 1828 Built By Anyos Jedlik

Electromagnetic rotor built by Jedlik in 1828 and subsequently kept in the physical laboratory at Pannonhalma seminary, in *Elektrotechnika*, vol. 24, 1931 (Linda Hall Library)

1834

American inventor Thomas Davenport was an early pioneer in the development of electric motors. He developed a battery-powered electric motor that he used to power a small electric car around a circular track. Davenport's battery-powered electric motor was the first example of an electric railway (The Editors of Encyclopedia Britannica, 2024). Thomas Davenports invention is a very early example of the electric railway and his contributions paved the way for electrification of rail systems.

1834

Dutch chemistry and technology professor Sibrandus Stratingh went on his first test journey of his steam vehicle. While the test was a success, Professor Sibrandus felt the vehicle was too smokey and loud. Given that Professor Sibrandus was a leading advocate of electric power, he decided to change from steam power to electric power and in 1835 he built a small-scale electrical cart powered by non-rechargeable powered cells.

Figure 6

Small Scale Non-Rechargeable Powered Cart

1859

French physicist Gaston Plante is credited with the invention of the first practical version of the rechargeable lead-acid battery. He found that his specially designed, lead-acid cell configuration could hold a charge for a considerable amount of time. His configuration involved rolling two sheets of lead separated by rubber strips and submerging them in sulfuric acid. This invention led to further developments in lead-acid battery technology and led to the eventual development of modern-day lead acid batteries (Kurzweil, 2010). Gaston Plante’s invention of the lead-acid battery and subsequent development was a significant milestone in providing the foundation for the modern battery.

Figure 7

Gaston Plante’s Lead-Acid Battery

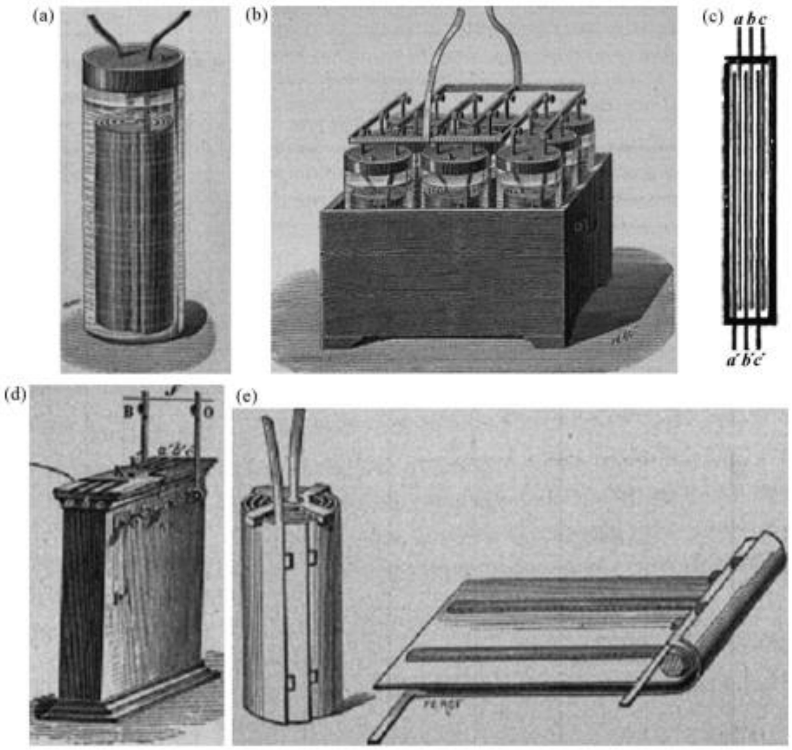


Fig. 3. Drawings from *Recherches sur l'Électricité*. (a) Couple secondaire à lames de plomb en spirale (Secondary cell with coiled lead plates). (b) Batterie secondaire de grande surface (Secondary battery of large surface). (c and d) Secondary cell with parallel lead plates (a, b, c, a', b', c'). (e) Lead plates separated by rubber strips.

1861

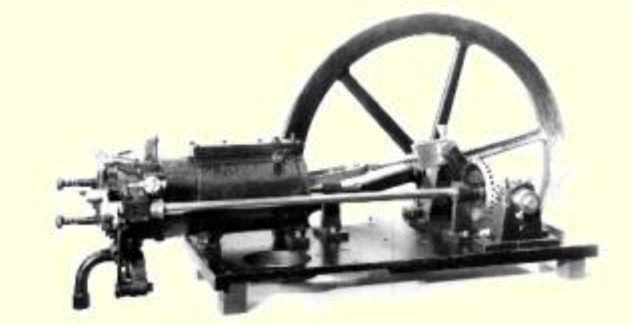
Austrian inventor Franz Kravogl built an electric vehicle prototype and presented a bicycle with an electric motor to the World Exhibition in Paris in 1867. His demonstration was recognized and awarded him the silver medal; however, it was unable to attract investors to bring his prototype to production. His prototype did not present any further promotional success or integration into society (Lucendo, 2019). Even though his prototype did not materialize, it is part of the foundation of which electric vehicles would be developed.

1876

German engineer Nicolaus Otto made a substantial contribution to in his development of the four-stroke compressed-charge internal combustion engine. This engine was coined as the "Silent Otto" as it was significantly more quiet than other engines of the current time. Additionally, Otto's engine was three to four times more efficient than steam power engines, then in use. (Bryant, 1967). Otto's engine utilized a cycle that had four distinct strokes (intake, compression, power, and exhaust). This became the foundation for most automobiles today and was considered a significant advancement in internal combustion engines.

Figure 8

Four-Stroke Otto Engine



1881

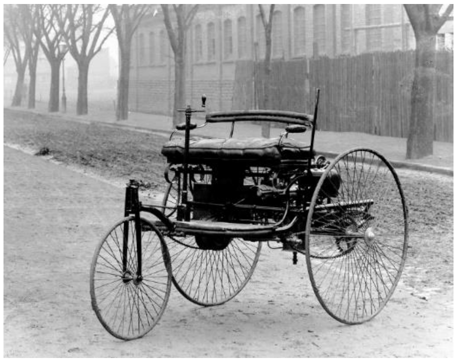
French chemical engineer Camille Faure developed a process for electrode coatings that allowed lead-acid batteries to achieve high capacities (Pavlov, 2011). His improvements involved coating lead plates with a paste of lead oxides, sulfuric acid, and water. This resulted in a porous structure that allowed for a greater surface area that led to the increased capacity to store and supply electrical energy. His work not only significantly enhanced the capacity but made it more practical for widespread use. The work Gaston Plante and Camille Faure solidified the lead-acid batteries position as one of the most common rechargeable batteries in history.

1886

German mechanical engineer Karl Benz built and patented the Benz Patent-Motorwagon. This considered the first practical modern automobile that would also go into production (Parissien, 2014). The Patent-Motorwagon was a three-wheeled vehicle that was powered by an internal combustion engine. This was a practical application of an internal combustion engine. This was an example of emerging technologies in engine and vehicle design and development. This was a pivotal time in history as it marked the transition from experimental vehicles to practical consumer product.

Figure 9

Benz Patent-Motorwagon

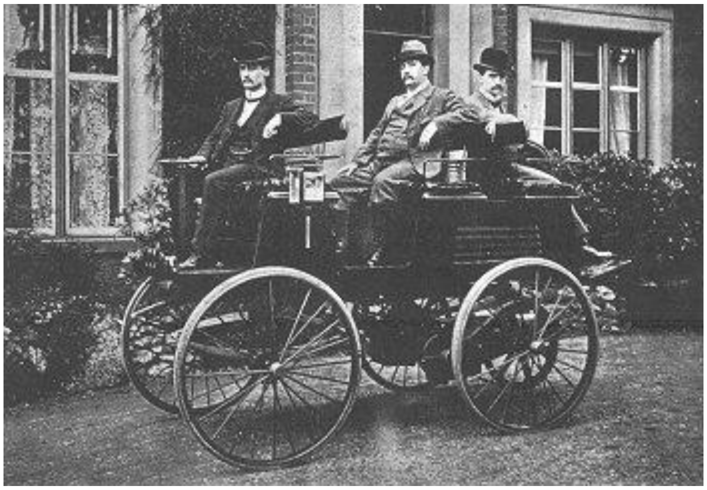


1884

Electrical engineer Thomas Parker is credited with producing one of the first practical electric car (Chan, 2013). Thomas Parkers goal was to provide a cleaner and more efficient alternative than other modes of transportation of the era. His interest was in the application of electricity to transportation as it was clean compared to that of coal and steam. Parker is also credited with contributing to electrifying the London underground. Parker was an inventor of batteries which he used to power his electric car. What made his electric vehicle so practical was the use of rechargeable batteries. This made it more sustainable and efficient. Parker's contributions were critical in the advancement of electric vehicle technology.

Figure 10

Thomas Parker's Electric Car



1893

German inventor and mechanical engineer Rudolf Diesel invented the diesel engine for which he was awarded a patent (Reif, 2014). The diesel engine was more efficient than the steam and internal combustion engines of his era. Diesel set out to create an engine that would convert heat into work more efficiently than the internal combustion engine. His design utilized higher compression ratios which allowed ignition with needing a spark ignition system. The higher compression ratios relied on the heat of compression to ignite the fuel. This resulted in better fuel economy and utilization for heavier duty applications. Diesel engines paved the way for industries such as shipping and transportation.

1894

Mechanical engineer Henry G. Morris and chemist Pedro G. Salom used their own patented technologies to create the first successful commercially available electric vehicle called the Electrobat (Amatucci, 2015). The Electrobat was another example of emerging technologies coming together. The Electrobat utilized an electric motor and battery system that were of their own development. Their advancement clearly demonstrated that the electric vehicle could be practical in its production.

Figure 11

Electrobat

1897

British electrical engineer Walter C. Bersey introduced a fleet of electric taxis to London where the London Electric Cab Company began service and could travel for 50 miles between charges. The electric taxis were referred to as the “Bersey Cabs”. The Bersey Cabs were among the first self-propelled vehicles for hire and were distinguished by their distinctive humming sound. This sound earned the nickname “Hummingbirds”. The fact that the electric taxis could travel approximately 50 miles on a single charge made a significant advancement in the early efforts to electrify public transit.

1900’s

Ultimately the electric vehicle and its advancements were severely impacted with the introduction of the mass-produced gasoline powered vehicles like the Ford Model T. The Model T benefited from Fords invention of the moving assembly line. This revolutionized the automotive industry and dramatically reduced the cost of the automobile and made them accessible to the average consumer.

Additionally, even considering this was the age of electrification, electricity was only extended to urban areas. This led to an inadequate charging infrastructure. This could not compete with the recent discovery of an abundance of fossil fuel reserves. The abundance of fossil fuel reserves led to an increasing number of gasoline stations that dramatically reduced the cost of gasoline.

At the same time, road networks were expanding and there was a need for greater range. Considering the technological limitations of lead acid batteries and their limited range compared with gasoline powered vehicles, these limitations made them impractical for long distance travel. Due to these factors, gasoline powered vehicles reigned supreme and interest in the electric vehicle faded.

Environmental Benefits from Electric Vehicles

Emissions and Environmental

Electric vehicles offer numerous environmental benefits compared to traditional gasoline-powered vehicles. Firstly, since they are not powered by fossil fuels, they do not emit tailpipe pollutants such as carbon dioxide, nitrous oxide, and particulate matter, which contribute to air pollution and climate change (Zhang et al., 2014). This also allows electric vehicles to reduce dependence on domestic and imported fossil fuels. In addition to being environmentally friendly in terms of emissions reduction, electric vehicles also have the potential to be powered by renewable energy sources like wind or solar power. Additionally electric vehicles do not have engine combustion noise or mechanical noise frum components such as valves, camshafts, and pistons like those found in internal combustion engines. Electric motors also operate at lower rotations per minute than that of internal combustion engines and since they do not produce exhaust gases, they do not have exhaust system noises.

Harmful Chemicals

Additionally, due to the complexity of the internal combustion engine, it relies heavily on the use of toxic ethylene glycol for cooling systems. Oil is needed for the internal combustion engine lubrication, and the transmissions require hydraulic fluid to operate. On the other hand, electric vehicles are engineered with less moving parts and a simpler design than gasoline-powered vehicles. They also benefit from modern technological advancements in their operation, and they also do not require hydraulic fluid to operate their transmissions due to their different drivetrain architecture.

Operational Efficiency

Electric vehicles have minimal power loss due to friction since they have a simpler drive train design with fewer moving parts. Electric motors are thermally efficient over a wider range of operating conditions when compared to that of an internal combustion engine. Electric vehicles do not idle like that of an internal combustion engine preventing wasted energy when stationary. These factors allow electric vehicles to convert about 60% of electrical energy into power at the wheels, whereas gasoline-powered cars can only convert around 20% of their energy from gasoline (McCormick, 2013). In addition, the regenerative braking system in electric cars allows them to recapture some of the energy that is normally lost as heat during braking, further increasing their efficiency.

Smart Grid Technologies

The integration of smart grid technology and vehicle-to-grid (V2G) systems with electric vehicles is comprised of a sophisticated approach to enhance the efficiency and stability of energy systems, particularly in urban areas. Smart grid technology incorporates information and communication technology into the grid. This enhances the transmission and distribution of electricity by enabling two-way communication between the grid and the customer, hence the term “smart”. Realization of V2G technology involves several steps, from an in-depth analysis of car movements and identification of optimal charging station locations to the development of cloud platforms and mobile applications for interaction between EVs, charging stations, and the energy system (Zhukovskiy et al., 2019).

Bidirectional Energy Exchange. Bidirectional is key in the concept of Vehicle-to-grid (V2G) technology. This allows for bidirectional energy exchange between electric vehicles and the power grid with the intent of enhancing the efficiency and stability of the electrical grid, especially in urban areas. This means that vehicles can not only draw power from the grid to charge their batteries but can also feed stored energy back into the grid during periods of high demand (Tan et al., 2016). Feeding stored energy back into the grid can reduce the need for the power plant to produce additional power. This is beneficial in a scenario where peak demand could exceed capacity of renewable energy sources and additional power would need to be generated utilizing fossil fuels. Bidirectional energy exchange also supports the integration of renewable energy sources such as wind or solar. The excess energy can be stored during high production of energy and then released when production is low.

Demand Response. Demand response is an energy management technique that is made possible with smart grids using vehicle-to-grid applications. The goal of demand response is grid reliability and reduction of electricity costs. During peak load hours, electric vehicles can supply stored energy back to the grid, effectively "shaving" peak demand. Consumers can receive incentives if they are willing to reduce their usage during defined peak periods. This is more efficient than producing additional power to meet the higher demand. This is accomplished through smart grid interaction technology that allows consumers to adjust their energy consumption automatically or manually.

Renewable Integration Support. As mentioned earlier, electric vehicles play a critical role in the support and integration of renewable energy sources. This is made possible due to their large energy storage capabilities. By acting as mobile energy storage, vehicle-to-grid applications can help balance intermittent supply from renewable energy sources like solar and wind. By storing excess generation and supplying energy when sunlight or wind is low, electric vehicles can improve the grid's ability to integrate renewables. Electric vehicles can use smart charging technology to schedule their charging during peak periods of renewable energy production.

Smart grid technologies provide various grid services, including frequency regulation, voltage support, reduction in electrical infrastructure strain and an increase in the stability and reliability of the power system (Tan et, al., 2016). The effectiveness of the vehicle-to-grid integration depends on several factors such as the development of adequate communication and control technologies, regulation and policy frameworks, and consumer participation incentives. Furthermore, a robust and widespread charging infrastructure is essential to facilitate the widespread use of vehicle-to-grid applications. Despite the challenges, vehicle-to-grid technology presents a promising avenue to enhance the sustainability and reliability of electricity grids as the adoption of electric vehicles continues to grow.

Considering electric vehicles produce zero tailpipe emissions, contribute less greenhouse gases, especially if charged with renewable sources of energy, and they are far more efficient at converting their energy to power at the wheels. These environmental and ecological advantages over a gasoline-powered vehicle position electric vehicles as an important measure against global warming, climate change, human impact on the environment, and progress towards achieving the net-zero emissions goal set out in the 2015 Paris Agreement.

Environmental Concerns from Electric vehicles

As outlined in the previous section, electric vehicles offer many environmental benefits such as reduced emissions, reduction on fossil fuel dependency, and grid support. However, they do possess their own set of environmental concerns.

Batteries Manufacturing

The production of lithium-ion batteries involves mining for lithium, nickel, cobalt, and copper. The mining process can lead to environmental degradation through the depletion of resources like that of depletion of fossil fuels. Additional environmental degradation can be caused by the destruction of ecosystems and wildlife habitats that could lead to extinction. In addition, soil can be contaminated with heavy metals and other toxic substances from the mining process. Mining also requires large quantities of water that can deplete local sources and lead to water pollution through leakage of toxic substances. (Lundmark et al., 2014) Electric vehicle batteries will continue to evolve, and researchers are looking at alternative chemistries that could address resource scarcity and environmental concerns.

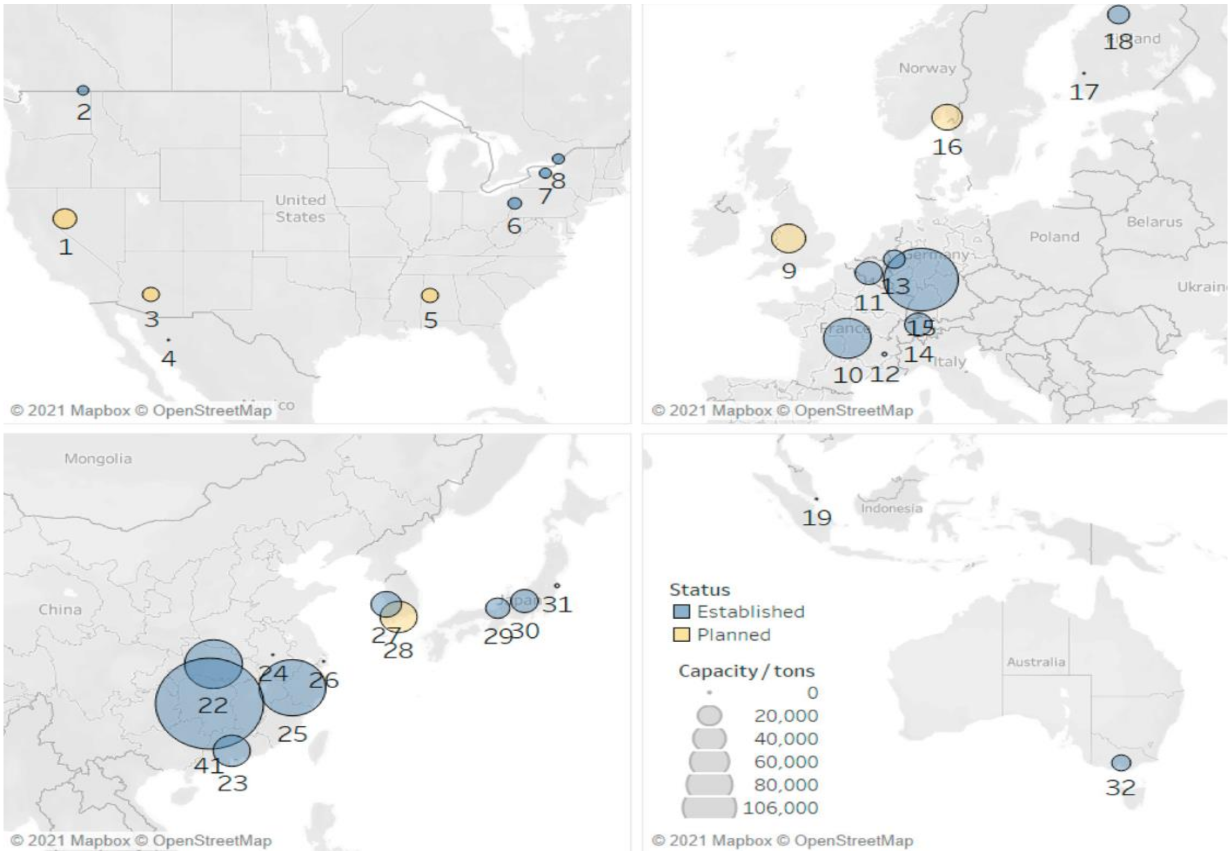
Battery Disposal and Recycling

Lithium-Ion batteries contain valuable and hazardous materials. The batteries need to be recycled in a way that allows recovery of cobalt, nickel, and copper so they may be reused. This will minimize the need for additional mining that could lead to environmental degradation to include depletion of resources needed for battery production. (Ordonez et al., 2016) The recycling process also needs to be able to recover the hazardous materials so they can be disposed of properly. This highlights the need for end-of-life management and recycling technology and infrastructure that can handle the recovery aspects and account for the volume of battery waste. Currently states such as New York and California have legislation that is designed to manage the disposal and treatment of lithium-ion batteries to recover the valuable materials and dispose of the hazardous materials in an environmentally friendly manner. Additionally, they ban disposal of lithium-ion batteries in the landfill and impose fines for noncompliance. (Gaustad, 2018) However, given the volume of waste that will be a byproduct from moving to all electric vehicles, legislation will need to continually evolve to ensure batteries and not discarded, but instead are collected and recycled in an environmentally friendly manner and valuable natural resources are recovered.

Global lithium-ion battery production volume is projected to exceed 1 million tons annually by 2025. Therefore, additional battery recycling facilities will be needed to support this growing demand for batteries. As of 2021, approximately two-thirds of the lithium-ion battery recycling capacity is in China with a total recycling capacity of 207,500 tons. Europe contains nine recycling facilities and has the second largest recycling capacity at 92,000 tons. North America only has four recycling facilities with a total capacity of merely 20,500 tons. The map below shows the global share of lithium-ion battery recycling facilities as of 2021.

Figure 12

Global Share of Lithium-ion Battery Recycling Facilities as of 2021



Note: Established and planned global Li-ion battery recycling facilities as of November 2021.

Copied from Zachary J. Baum, Robert E. Bird, Xiang Yu, and Jia Ma

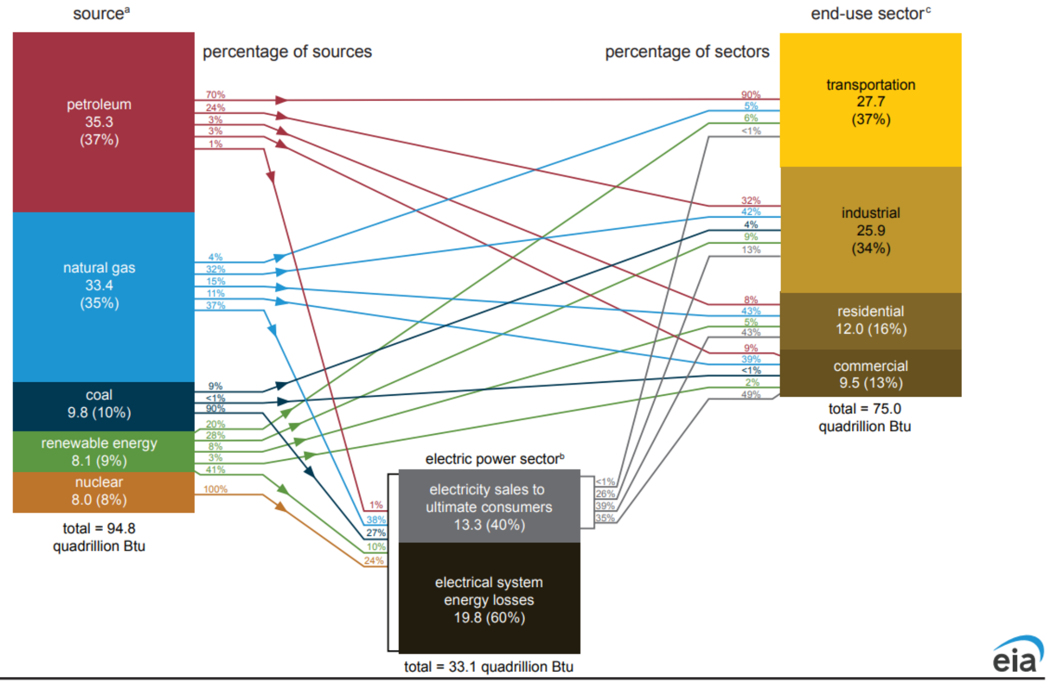
Increased Demand on the Electrical Grid

Along with an increase in the adoption of electric vehicles comes an increase in demand on the electrical grid. As a growing number of electric vehicles are charging simultaneously, especially during peak hours, this can greatly increase the demand and stress on the electrical grid. This could potentially lead to a situation where capacity is exceeded. Advanced communication infrastructures are needed to handle the dynamic changes in load as there is an increase in the number of electric vehicles. (Khan & Khan, 2013) Also, there are environmental impacts of electricity generation. If demand is too high and there is not sufficient power produced through renewable sources such as solar and wind, there will be an increase in fossil fuel-based power generation. This will lead to an increase in greenhouse gas emissions that would nullify the environmental benefits from electric vehicles. The below graphical summary illustrates the United States energy consumption by source and sector in 2022. This highlights the need for additional renewable energy sources such as wind and solar to be integrated into the grid. (Yoder, n.d) (Khan & Khan, 2013)

Figure 13

U.S. energy consumption by source and sector, 2022

quadrillion British thermal units (Btu)



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (September 2023), Tables 1.3. 1.4c, and and 2.1a-2.6.

Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended Chart Notes" on next page.

[a] Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Generation from noncombustible renewable energy sources are converted to Btu using the "Captured Energy Approach." See

[b] The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses are calculated as primary energy consumed by the electric power sector minus the heat content of electricity sales to ultimate consumers. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.

[c] End-use sector consumption of primary energy and electricity sales to ultimate consumers, excluding electrical system energy losses. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants

Electric Vehicle Adoption

As the world shifts towards a greener and more environmentally friendly future, and electric vehicles continue to emerge as solution to reduce carbon emissions and reliance on fossil fuels, they continue to face several challenges that need to be addressed to facilitate widespread adoption and overcome barriers to their success. In this analysis, we will explore the key challenges facing electric car adoption and examine potential strategies for addressing them.

Range Anxiety

One of the biggest challenges facing the widespread adoption of electric cars is range anxiety. Range anxiety is the fear that an electric vehicle does not have sufficient charge to reach its destination, leading to the possibility of the vehicle running out of power before it can reach a charging station. This concern can cause stress and inconvenience for electric vehicle drivers and is seen as one of the barriers to the adoption of electric vehicles (Raja et al., 2021). According to the mentioned sources, range anxiety is a significant psychological factor that affects electric vehicle adoption behavior. Factors contributing to range anxiety include battery capacity, charging infrastructure and cost, as summarized below.

Battery Capacity. . Even though electric vehicles range is getting longer, the typical electric vehicles range on a single charge is around 270 miles (440 kilometers) per charge. There are higher end models that can go upwards of 370 miles (600 kilometers) on a single charge, however this is still less than that of gasoline powered vehicles. Additionally, like that of gasoline powered vehicles, there are factors that can affect range such as speed, acceleration, weather, and terrain. Electric vehicle range is also susceptible to battery age and the number of onboard accessories such as infotainment systems. The below graph conveys a sample of twelve electric vehicle models and their drive ranges on a single charge, given in kilometers.

Figure 14

Example of Electric Vehicle Driving Range

Note: Comparison of drive range of different electric vehicle models.

Copied from Raja, V B., Raja, I., & Kavvampally, R. (2021, December 1). Advancements in Battery Technologies of Electric Vehicle. IOP Publishing, 2129(1), 012011-012011. https://doi.org/10.1088/1742-6596/2129/1/012011

Charging Infrastructure. In addition to concerns about limited driving range, the presence and accessibility of charging infrastructure are crucial factors in encouraging more widespread use of electric vehicles. Charging infrastructure is underdeveloped when compared to gasoline stations. Establishing a reliable network of fast-charging stations and convenient home charging options is essential to address these accessibility and convenience issues. Furthermore, integrating smart grid technology and renewable energy sources into the charging infrastructure can significantly enhance the overall sustainability of electric vehicle charging, making electric vehicles more attractive to consumers. The availability and distribution of charging stations play a pivotal role in supporting practical usage of electric vehicles. Studies have shown that public charging stations have a remarkable impact on the adoption rate of electric vehicles. Studies have shown that a one-unit increase in the number of chargers per capita leads to a percentage increase in electric vehicle adoption. (Brian, 2023)

Charging Time. Electric vehicle charging time adds to range anxiety in the sense that it takes longer to charge an electric vehicle than it does to fill up a gasoline powered vehicle. There are several factors that affect charging times.

Battery Size. The larger the battery pack, in terms of kilowatt-hours (kWh), the longer it will take to charge, all else kept equal. The larger the battery, the more energy it can store, conversely, more energy is required to charge it.

State of Charge. Electric vehicle charging time is heavily influenced by the batteries' current state of charge. There can be up to three phases of charging depending on the batteries state of charge.

Initial Charging Phase. Also called the constant current phase, this is the initial phase of charging. This is the fastest phase of charging that typically takes place when the charge is less than 70%.

Middle Charging Phase. Also called the saturation phase, this phase happens when the state of charge is around 70-80%. During this phase, the charging speed is intentionally reduced to protect the battery from degradation through overheating and overcharging.

Taper Charging Phase. Also called the constant voltage phase, this is the final phase of charging. As the battery approaches a higher state of charge, usually around the 80-100% range, charging tapers off significantly. This is done to protect the battery's health and lifespan.

The transition between charging phases is managed by the vehicles battery management system which monitors the batteries temperature, voltage, and state of charge to optimize the charging process and protect the battery.

Charger Output. Charger output, measured in kilowatts (kW), greatly affects charging time. The higher the kilowatt output of the charger, the faster it can charge the electric vehicles battery in a given amount of time.

Level One Charging. Level one chargers that utilize standard household power of 110/120 volts typically only provide about 5 miles of range per hour of charging. Level one chargers are rated anywhere between 1.4 and 2.4 kilowatts output. This is the slowest type of charger and is mostly suited for overnight charging.

Level Two Charging. Level two chargers use 220/240-volt power supply and increase the miles per hour of charging to 12-80 miles depending on the electric vehicle. Level two chargers are rated anywhere between 307 and 22 kilowatts of output. These are common in public charging stations and in home charging stations.

Level Three Charging. Also known as DC fast chargers, this type of charger is much more powerful and can deliver 3-to-20-mile range per minute of charging. Level three chargers are rated anywhere between 50 and 350 kilowatts of output. This allows electric vehicles to charge their batteries to 80% in as little as 20-40 minutes depending on the maximum charge rate of the vehicle and the output of the fast charger.

Charging at home overnight with a Level one or two charger is generally sufficient for daily use, while DC fast chargers are typically used to enable long-distance travel with shorter charging stops. Even with DC fast chargers, the actual time to charge will depend on the vehicle, battery condition, and other factors. Higher end vehicles will have a faster charging rate than more economical models and are still lower than filling up of a gasoline powered vehicle.

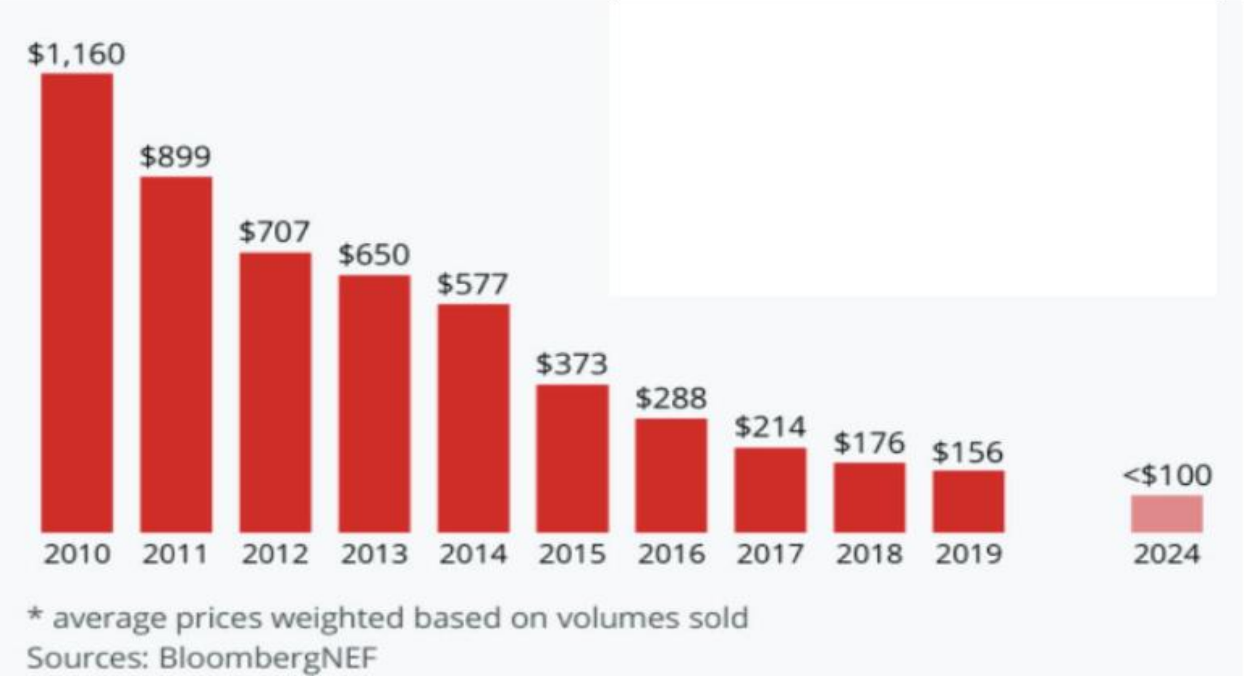
Initial Cost

One of the primary obstacles to the widespread adoption of electric vehicles is the higher initial purchasing price in comparison to the traditional gasoline powered vehicle. I higher initial price can deter potential buyers who are primarily focused on the price point. These higher costs can be attributed to the following.

Batteries. The battery is the most expensive component of an EV. Advances in battery technology and increased production scales have led to a decrease in battery costs over time, but they still comprise a significant portion of the vehicle's cost. The image below shows the decrease in battery cost over time.

Figure 15

Decrease in Battery Cost Over Time



* average prices weighted based on volumes sold
Sources: BloombergNEF

Copied from Raja, V B., Raja, I., & Kavvampally, R. (2021, December 1). Advancements in Battery Technologies of Electric Vehicle. IOP Publishing, 2129(1), 012011-012011. https://doi.org/10.1088/1742-6596/2129/1/012011

Advanced Electronics and Electric Motors. Electric vehicles require advanced electronics and electric motors that can be expensive to produce.

Research and Development. The research and development costs for electric vehicle technologies, along with specialized manufacturing add to the initial cost of the vehicle.

Economies of Scale. As the adoption of electric vehicles is still growing, economies of scale have not yet reached the level of the more mature gasoline powered vehicle market.

Battery Replacement. Although electric vehicle batteries are designed to last many years, they may eventually need replacement. Electric vehicle battery replacement is a consideration for electric vehicle owners as the battery's performance will degrade over time and the cost for replacement has been estimated around $5000 to $15000 depending on the electric vehicle.

Political Divide

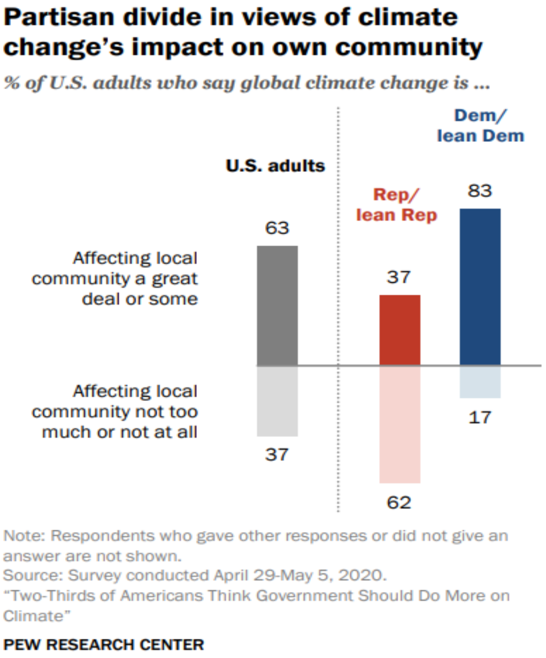
Political ideologies and party lines can influence the adoption of electric vehicles. Research has shown that there is a correlation between political alignment and views on electric vehicles. Democrats are twice as likely to be willing to purchase an electric vehicle compared to that of Republicans (Strawhecker, n.d). Policy approaches also vary by state, with some states like California setting ambitious goals for all new cars to be electric or plug-in hybrid by 2035, while others have less stringent measures (Strawhecker, n.d).

Federal-level policies have included financial incentives to boost the electric vehicle market, such as the proposed $7,500 tax credits for electric vehicle purchases and large investments for charging infrastructure and battery materials through the Bipartisan Infrastructure Law (Strawhecker, n.d). Even with these incentives the electric vehicle market share remains low compared to that of gasoline powered vehicles indicating factors other than monetary.

Global Warming Acceptance

Acceptance of global warming and the science surrounding climate change can differ significantly across political, cultural, and national divides. Generally, political liberals and left-leaning individuals are often more likely to accept the consensus on anthropogenic global warming and support strong climate action, while political conservatives or right-leaning individuals may be more skeptical.

Figure 16



Partisan divide in views of climate change's impact on own community

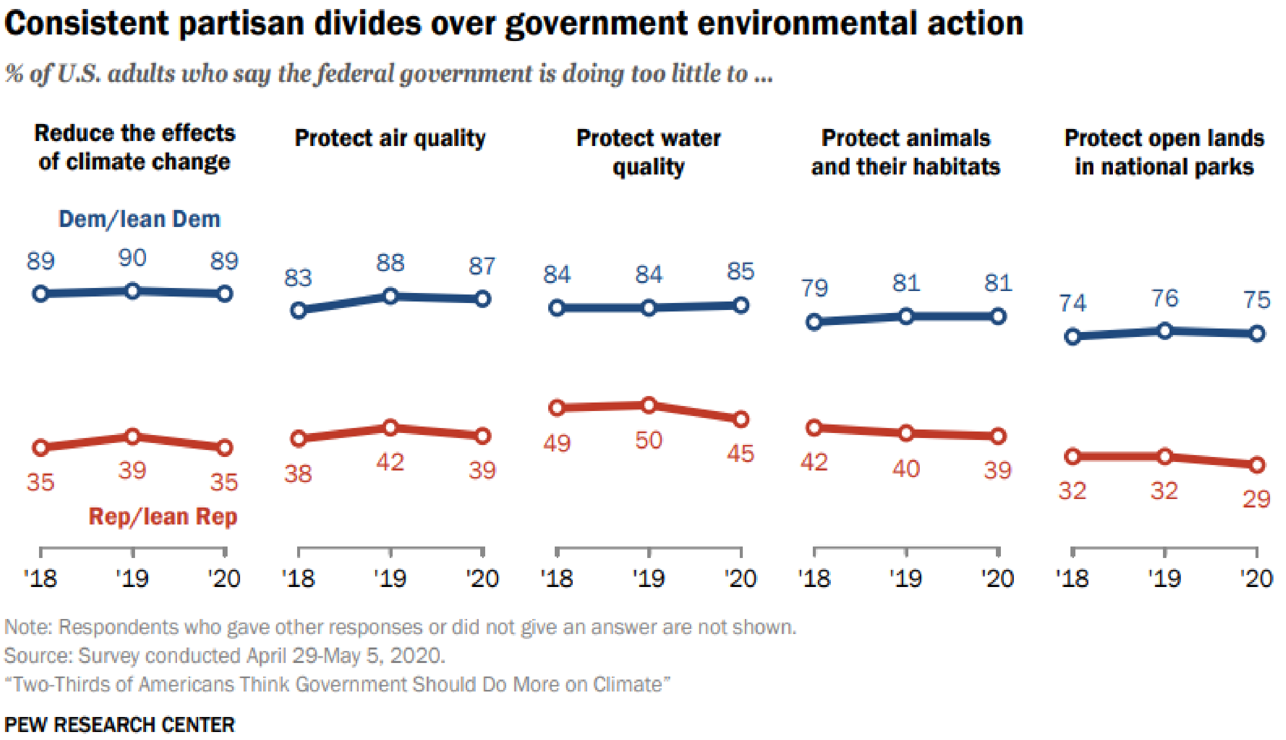
% of U.S. adults who say global climate change is ...

Note: Respondents who gave other responses or did not give an answer are not shown.
Source: Survey conducted April 29-May 5, 2020.
"Two-Thirds of Americans Think Government Should Do More on Climate"
PEW RESEARCH CENTER

Globally, acceptance can also vary with Europe and some other parts of the world showing high levels of acceptance and support for policy measures addressing global warming. Meanwhile, in countries where economic reliance on fossil fuels is significant or where political leadership expresses skepticism, there might be lower levels of acceptance. For example, in the United States there is a wide political divide between Republicans and Democrats on opinions of government environmental action.

Figure 17

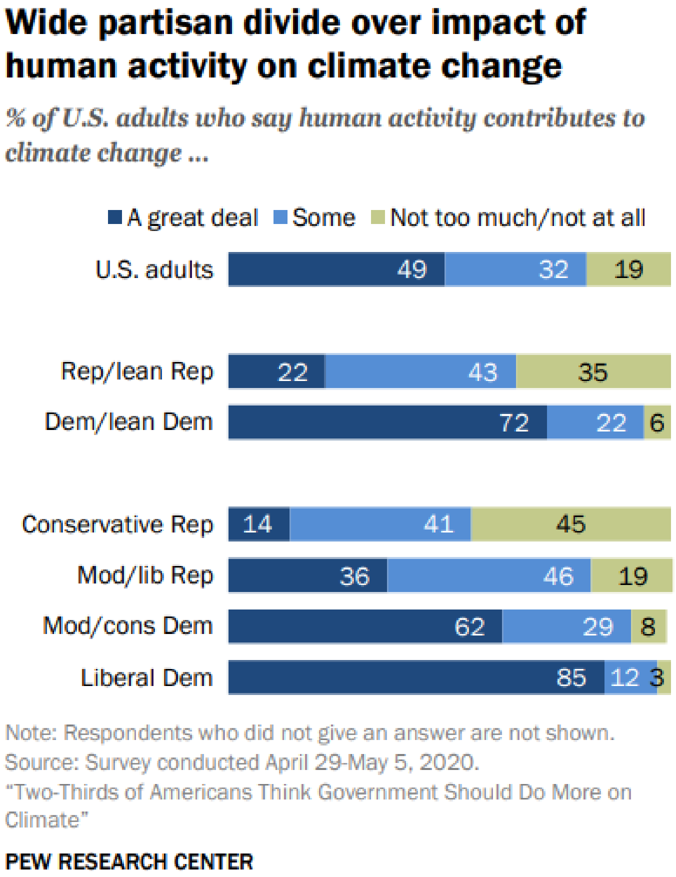
Partisan Divide Over Government Environmental Action



The scientific community, such as the Intergovernmental Panel on Climate Change, asserts that global warming is unequivocal and primarily due to human activities such as the burning of fossil fuels and deforestation (Panel, 2008). However, many United States citizens do not accept this fact. There is a wide partisan divide between the political left and right regarding the acceptance that human activity has caused climate change. This political divide is a roadblock to enacting impactful legislation which may combat the effects of climate change.

Figure 18

Partisan Divide Over Impact of Human Activity on Climate Change



Wide partisan divide over impact of human activity on climate change

% of U.S. adults who say human activity contributes to climate change ...

Note: Respondents who did not give an answer are not shown.
Source: Survey conducted April 29-May 5, 2020.
"Two-Thirds of Americans Think Government Should Do More on Climate"

PEW RESEARCH CENTER

The adoption of electric vehicles is not only influenced by technological advancements and environmental concerns but also by various psychological and practical factors. Range anxiety, limited charging infrastructure, long charging times, and higher initial costs are some of the primary barriers to the widespread adoption of electric vehicles. To address these challenges, it is crucial to continue technological advancements in battery capacity and charging infrastructure. Additionally, efforts to reduce the initial purchasing price of electric vehicles through economies of scale and advancements in battery technology will be essential in making electric vehicles more accessible to a broader consumer base.

Furthermore, public, and private sectors need to work together to educate and incentivize potential buyers, showcase the long-term cost savings of electric vehicles, and assure them of the infrastructure and support available for electric vehicle ownership.

By overcoming these barriers, we can create an environment that promotes the widespread adoption of electric vehicles, contributing to a cleaner and more sustainable transportation system for the future.

Dangers Related to Electric Vehicle Batteries

As the widespread adoption and demand for electric vehicles continues to rise, there is awareness towards the potential dangers related to electric vehicle batteries. Although electric vehicles offer a cleaner and more sustainable mode of transportation, their batteries come with their own set of safety concerns. Electric vehicle batteries, specifically lithium-ion batteries, are generally safe, but they can pose certain risks if not properly managed. Some of the dangers associated with electric vehicle batteries include:

Thermal Runaway

Thermal runaway is a critical danger related to electric vehicle batteries, especially lithium-ion batteries. This happens when the temperature in a cell becomes uncontrollably high leading to a violent reaction, often causing a fire or explosion (Cui et al., 2022). When electric vehicles catch fire, it is intense and difficult to extinguish due to the chemical composition and density of the battery itself. Battery fires also release toxic gases that are hazardous to the environment. Unique to electric vehicles, the toxic gases contained within the smoke of battery fires, are flammable. Therefore, when the smoke is exposed to a spark it may explode.

Physical Damage

Physical damage to electric vehicle batteries from car crashes can cause short circuits or leakage of hazardous materials. Physical damage can also cause overheating and thermal runaway resulting in a fire. Additionally, it can also present a risk of electrical shock to passengers and first responders after an accident (Liu et al., 2023). Fires can start unexpectedly, for example from a short circuit, and can escalate quickly as shown in the timelapse below.

Figure 19

Time lapse Showing Electric Vehicle Fire Following Short Circuit

A 63 min 28 s **B** 63 min 30 s **C** 64 min 58 s **D** 66 min 2 s

E 66 min 28 s **F** 68 min 11 s **G** 70 min 34 s **H** 72 min 41 s

Note: Timelapse photos showing electric vehicle fire following an experimental battery short circuit. Photo (A) conveys the first appearance of smoke at 63 min 28s after the short circuit was initiated.

Reprinted from Cui, Y., Cong, B., Liu, J., Qiu, M., & Han, X. (2022, April 13). Characteristics and Hazards of Plug-In Hybrid Electric Vehicle Fires Caused by Lithium-Ion Battery Packs with Thermal Runaway. Frontiers Media, 10. https://doi.org/10.3389/fenrg.2022.878035

Figure 20

Combustion Wave

Note: Photos showing electric vehicle explosion and resulting combustion wave following an experimental battery short circuit.

Reprinted from Cui, Y., Cong, B., Liu, J., Qiu, M., & Han, X. (2022, April 13). Characteristics and Hazards of Plug-In Hybrid Electric Vehicle Fires Caused by Lithium-Ion Battery Packs With Thermal Runaway. Frontiers Media, 10. https://doi.org/10.3389/fenrg.2022.878035

Vehicle manufacturers recognize these risks and design battery packs and vehicles to achieve a balance between crashworthiness and battery integrity. For example, the kinematics of how a vehicle's structure deforms in a crash are assessed to determine how it will affect the ESS, and where necessary, the vehicle's crash performance may be tuned by adding or optimizing structural components to modify deformation near the battery (Guerin & Leutheuser, 2009).

Manufacturers and researchers are focused on improving battery safety through advancements in battery chemistry, enhanced battery management systems, robust design to protect against impacts, and the development of materials and technologies to prevent or rapidly address thermal runaway incidents. Despite the risks, EVs remain an essential step toward reducing greenhouse gas emissions and reliance on fossil fuels, and battery safety continues to improve with ongoing research and development.

Federal and Environmental Policy Supporting Electric Vehicles

Electric vehicles have been gaining momentum as a promising sustainable transportation option, offering a cleaner and more efficient alternative to traditional vehicles powered by fossil fuels. In recent years, federal and environmental policies have played a significant role in promoting the growth and adoption of electric vehicles. These policies encompass a range of measures aimed at accelerating the development and deployment of EVs, incentivizing consumers and businesses to embrace this transformative technology, and addressing environmental concerns associated with traditional transportation. Some of the federal and environmental policies aimed at accelerating the transition from gasoline powered vehicles to electric vehicles are summarized below.

Financial Incentives

Financial incentives are critical in lowering the upfront cost of electric vehicles that are often barriers to adoption. Financial incentives are crucial in accelerating adoption among consumers who are highly focused on the initial price point. Financial incentives not only benefit consumers, but they encourage manufacturers to produce more electric vehicles. Some examples of financial incentives include tax incentives, grants and subsidies, or other financial solutions imposed on businesses to incentivize electric vehicle manufacturing and/or infrastructure. Below is a summary of each of these examples of financial incentives.

Tax Incentives. Federal tax credits are offered to consumers purchasing electric vehicles which can range from $2,500 to $7,500, depending on the battery capacity and other factors (Karanam, n.d). The federal electric vehicle tax credit in the United States phases out once a manufacturer sells 200,000 qualifying vehicles. However, federal tax credits are a key financial incentive in promoting widespread adoption of electric vehicles and change with new policies. Federal tax credits address the cost barrier by reducing the initial cost.

Grants and Subsidies. Grants and subsidies are a powerful tool for the government to kickstart the growth of electric vehicle infrastructure such as the installation of public charging stations. Various levels of government offer grants and subsidies that typically come in the form of funding, aimed at both consumers and manufacturers to support infrastructure development (Karanam, n.d) (Rapson & Muehlegger, n.d). Grants can be awarded to businesses, non-profits, and local governments. Unlike grants, subsidies typically come on the form of financing to reduce the cost of infrastructure development (i.e. tax credits, rebates, or other monetary incentives). Grants and subsidies support the electric vehicle charging infrastructure by:

1. Providing a direct financial incentive to reduce the initial investment.
2. Encourage private companies to build charging networks.
3. Leverage public funds to attract additional investments.
4. Reduce the financial.

Incentivized Solutions. Incentivized solutions are another innovative approach in encouraging the shift toward electric vehicles. These could include taxing manufacturers of traditional internal combustion engine vehicles (Karanam, n.d). The revenue received from the taxation would then be used for other incentives to fund and finance electric vehicle infrastructure. Additional incentives could be requiring manufacturers, through a fixed percentage of a vehicle sold, to contribute to the expansion of the electric vehicle infrastructure. This responsibility would ensure that the infrastructure grows in tandem with electric vehicle sales.

State Level Incentives

State level electric vehicle incentives combined with federal incentives can help lower the barrier for consumers and be tailored to specific local goals. State incentives vary by state but could include:

1. Purchase rebates and tax credits. Like federal tax credits, the goal is to lower the upfront cost of electric vehicles. Rebates could be applied at the point of sale reducing the purchase price directly. They could also come in the form of an income tax credit.
2. High-occupancy vehicle lane access regardless of the number of passengers. Several states allow electric vehicles to use high occupancy vehicles or carpool lanes as an incentive. This allows electric vehicles drivers to save time during commutes, especially in areas of heavy traffic.
3. Reduced registration fees. Some states that offer reduced registration fees for electric vehicle owners make owning an electric vehicle more affordable over the lifespan of the vehicle.
4. Reduced electricity rates. Some states utilities offer special rates for electric vehicle charging. They may also provide rebates for charging equipment and discounts for charging during off-peak periods.
5. Incentives or funding for businesses to install public electric vehicle charging stations.
6. Sales tax exemption. Some states exempt electric vehicles from sales tax. This directly supports electric vehicle adoption by addressing the upfront cost barriers of an electric vehicle.

Regulatory Policies

Federal and state-level regulatory policies are an important mechanism and play a significant role in fostering the adoption of electric vehicles through compliance. This is accomplished by setting standards and requirements for both manufacturers and consumers.

Zero-Emissions Vehicle Mandate. Implemented in states like California, the zero-emissions vehicle mandate requires vehicle manufacturers to produce and sell a certain number of zero-emission vehicles, which include electric vehicles as a percentage of their total vehicle sales. Furthermore, President Biden signed an Executive Order in 2021 which dictated that half of all newly sold vehicles in 2030 shall be zero-emission vehicles (Karanam, n.d).

Corporate Average Fuel Economy Standards. Through policies such as the Corporate Average Fuel Economy standards, the government dictate and regulate the fuel efficiency of new vehicles sold in the United States. The standards were revised to include favorable credits for electric vehicles encouraging manufacturers to produce more electric and fuel-efficient vehicles (Rapson & Muehlegger, n.d).

Emissions Regulations. Emission regulations, both federal and state levels, may mandate reductions in vehicle emissions by limiting the amount of pollutants a vehicle can emit. These regulations often incentivize the adoption of cleaner technologies, including electric vehicles, to meet stricter emission standards.

Fuel Economy Labels. Regulations may require labels indicating the fuel economy of vehicles, enabling consumers to make more informed decisions, and tilting their choices toward more energy-efficient vehicles, including electric vehicles.

Urban Low-Emission Zones. Some cities restrict or charge extra for entering certain areas with vehicles that exceed their tail pipe emission requirements.

Public Vehicle Procurement. Some governments require a percentage of newly procured public service vehicles to be electric. This includes public transport such as electric buses.

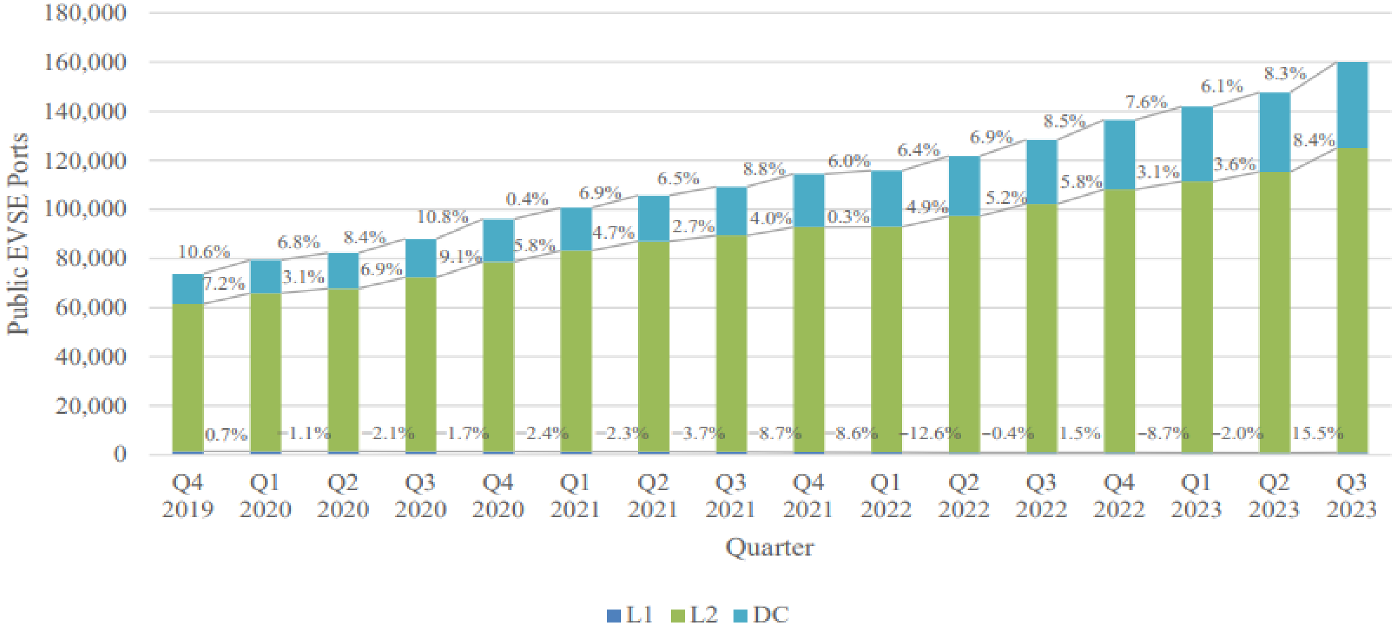
Charging Infrastructure

The federal government acknowledges the criticality of building a comprehensive electric vehicle charging network to facilitate adoption and reduce range anxiety among consumers. Supporting the electric vehicle charging infrastructure is necessary to underscore the commitment to move towards sustainable transportation. This is accomplished through:

Investment in Charging Stations. Governments and private entities are investing in the expansion of electric vehicle charging infrastructure, since the availability of charging stations is a key factor for electric vehicle adoption. There are two types of charging stations that apply to public charging stations, Level two, and Level three. Level two charging stations supply 220V and cost on the order of several thousand dollars. These are commonplace and are commonly found in parking lots. Level three charging stations are considered fast charging, as they can provide a full charge in nearly 30 minutes of charging. These charging stations cost in the ballpark range of $100,000, are less commonplace and are found along highways and interstates. Prioritizing fast charging station investments may provide the highest benefit to consumers provided the higher efficiency of charging and convenience to consumers (Rapson & Muehlegger, n.d).

Figure 21

Number of Public U.S. Charging Stations and Their Growth by Quarter



Note: Graph showing the number of public U.S. charging stations and their growth by quarter—Level 1 (L1), Level 2 (L2) and fast charging (DC). The percentages in this figure indicate the percent growth between each quarter.

Copied from Brown, Abby, Cappellucci, Jeff, Heinrich, Alexia, & Cost, Emma. Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator (Third Quarter 2023). United States. https://doi.org/10.2172/2293493

Federal Tax Credit for Electric Vehicle Infrastructure. There has been a federal tax credit, known as the Alternative Fuel Infrastructure Tax Credit, which provides a credit for up to 30% of the cost, up to $30,000, for installing EV charging stations (Karanam, n.d).

National Electric Vehicle Infrastructure Formula Program (NEVI). As part of the Bipartisan Infrastructure Law, an allocation of $7.5 billion has been made, which includes the NEVI Formula Program aimed at creating a nationwide network of EV charging stations, particularly along designated Alternative Fuel Corridors (Electric car switch on for health benefits, 2019).

Building Codes and Regulations. Some governments have updated their building codes to include electric vehicles charging readiness into new construction.

The Build Back Better Agenda and Bipartisan Infrastructure Deal. This initiative sets the target for half of all new vehicles sold in 2030 to zero-emissions and invests in the electric vehicle charging infrastructure.

Public-Private Partnerships. Public-Private partnership policies encourage collaboration between private sectors and government to build charging infrastructure. This includes auto manufacturers, technology sectors, and local governments (Karanam, n.d).

Fleet Conversion Initiatives. The adoption of electric vehicles is strategically intended to serve both environmental goals and to demonstrate the government's commitment to sustainable practices. By transitioning government fleets to electric vehicles, the federal administration not only reduces its own operational carbon footprint but also sets an example for private fleet operators and encourages broader electric vehicle adoption.

Fleet conversion policies may include stipulations for replacing aging vehicles with electric models, acquiring new electric vehicles for expanded service needs, and providing adequate charging infrastructure to support these vehicles. As large fleet conversions can lead to increased demand, they can drive down costs through economies of scale and help spur advancements in electric vehicle technologies and infrastructure.

Fleet conversion initiatives also help to foster partnerships between government entities and automobile manufacturers, infrastructure developers, and energy providers. These partnerships can lead to innovative solutions for fleet management and support the growth of the electric vehicle ecosystem (Rapson & Muehlegger, n.d).

Research and Development Funding

Government funding and support for research and development is not only central to advancing the efficiency and performance of electric vehicles, but also in advancing the widespread adoption of electric vehicles. Federal funding programs aim to stimulate innovation in areas such as battery technology, electric powertrains, and thermal management systems, which are critical for improving the reliability, range, and affordability of electric vehicles (Moreno, 2014). The following are examples of government funding research and development in electric vehicles and electric vehicle charging infrastructure.

Research Grants. Research grants provide universities, private companies, and research institutions with the funding necessary to investigate new technologies in advancing electric vehicles and charging systems. The focus of research grants is typically on battery and charging technologies.

Demonstration Projects. Demonstration projects aim to validate research and showcase the practical application of new electric vehicle and charging technologies in real world applications.

National Laboratories. The United States has government run national laboratories conducting research in advanced electric vehicle technologies. These laboratories often collaborate with industry and academic institutions to advance research.

Federal investment in research and development is vital not only for moving closer to environmental goals, but also for maintaining technical leadership.

International Collaboration

Through international agreements and forums, such as the Paris Agreement and initiatives under the International Energy Agency, countries coordinate policies, set shared targets, and support global research and development efforts. Collaboration can lead to unified technical standards for electric vehicles and charging equipment, which can accelerate the adoption of electric vehicles by making them more user-friendly and internationally compatible.

Additionally, by working together, countries can leverage each other's strengths in technology, policy innovation, and market experience. This could include sharing insights from successful national policies or pilot projects, investing jointly in key technologies like battery storage, and developing transnational charging infrastructure to ease long-distance electric vehicle travel.

Such coordinated efforts aim to advance the collective capabilities for electric vehicle technology development, enhance market dynamics, and ensure that diverse regions can benefit from advancements in electric mobility, thereby promoting a significant reduction in global transport emissions. International collaboration is also essential in addressing global supply chain issues, ensuring that critical raw materials like lithium for batteries are sourced and recycled sustainably (Accelerating research in smart electricity grids – Analysis - IEA, 2020).

National defense

Electric vehicles incorporate sophisticated computer systems that manage everything from battery charging to in-vehicle entertainment. They also use advanced batteries that require scarce resources such as Lithium, Cobalt, Nickel, and Copper. As the transition to all electric vehicles continues, risk mitigation must be applied to the factors summarized below.

Cybersecurity

The more connected and autonomous vehicles become, the greater the risk for cyber-attacks. As electric vehicles are equipped with more complex computers and other vehicle-to-grid or vehicle-to-infrastructure, they present more opportunities for cyber-attacks.

Remote Hacking Risks. Electric vehicles are typically connected to the internet, GPS, and other infrastructures that provide multiple entry points for hackers. Since some electric vehicles can be controlled through apps and other connected systems, hackers could potentially take control of the vehicle (Takahashi, 2018) (Mihet-Popa & Saponara, 2018). Security researchers have demonstrated the ability to hack and remotely control a vehicle which was under operation (Sha et al., 2018). This is the most concerning as the hackers could take control of critical functions such as steering and breaking (Rose, 2017)

Data Privacy. Electric vehicles collect and transmit large amounts of data to include information about location and other personal information. For example, information regarding the consumer address or bank account information could be obtained from malicious hacking attempts.

Autonomous Vehicle Manipulation. Autonomous vehicles rely on sensors and artificial intelligence to navigate and make decisions. This is another function that is vulnerable to cyber-attack.

Ransomware. Like that of other types of networks, electric vehicle systems could be susceptible to ransomware.

Disruption of Transportation Systems. Like that of the electric vehicle, this is on a larger scale that could lead to a complete disruption in a transportation system (Song et. al., 2021)

Firmware and Software Updates. Electric vehicles require updates to their firmware and software regularly. These updates are over the air and can be exploited to install malicious software that could compromise critical control systems.

Charging Infrastructure

The charging stations and the networks they connect can be vulnerable to cyber-attack. Many electric vehicle charging stations require payment for charging. Cybercriminals could target this and steal financial information. They could also disrupt charging services to disrupt local transportation. Strong cybersecurity methods that are applied to electric vehicles must also be applied to the charging infrastructure.

Energy Grid

As electric vehicles can interact with the power grid during charging, there is a concern that a compromised vehicle could be used as an entry point to attack the grid itself (Zhukovskiy et al., 2019). As electric vehicles and vehicle-to-grid technology grows, so does the risk of potential cyber attacks on the energy grid. Compromised vehicles could be used as an entry point for cybercriminals to gain access to the grid through malware. This presents the same set of issues as those for electric vehicles and charging infrastructure. This can be used to control, manipulate the grid or to gain access to sensitive data.

Material Procurement

Material procurement for scarce and valuable resources such as lithium, nickel, cobalt, and copper used in the production in electric vehicle batteries can present additional challenges to national security. National security concerns related to the procurement of materials such as lithium for electric vehicle batteries include:

Supply Chain Vulnerability. Lithium and other critical minerals for EV batteries often come from a limited number of countries, which can create vulnerability due to geopolitical risks, trade disputes, or supply interruptions (Elkind, 2020) (Strawhecker, n.d).

Concentration of Resources. Some materials like cobalt are concentrated in countries with unstable governments or regions, leading to concerns about the reliability of supplies and the potential for supply disruption due to political or social unrest (Holmes, 2020).

Environmental and Ethical Issues. Extracting materials such as lithium and cobalt can have severe environmental impacts and, in some cases, is linked to human rights abuses (Ali, 2014). National security must align with ethical procurement practices to avoid contributing to or being associated with these issues (Strawhecker, n.d).

Foreign Dependence. Relying on foreign sources for critical materials could compromise national security if these countries become adversaries or if they decide to limit exports. This might force a reliance on less desirable contingency plans (Strawhecker, n.d).

Strategic Stockpiling. Some countries may engage in stockpiling critical materials to mitigate supply risks, which can increase demand and prices in the short term and lead to further national security implications (Holmes, 2020).

Addressing these concerns involves implementing rigorous cybersecurity measures throughout the design, production, operation, and maintenance stages of electric vehicles and their associated infrastructure. This includes applying encryption, secure software practices, regular security audits, intrusion detection systems, and developing the ability for rapid response to any detected vulnerabilities.

Additionally, it is imperative for national defense strategies to consider diversifying supply chains, developing domestic sources of critical minerals, investing in alternative technology that may reduce the reliance on specific raw materials, promoting recycling to recover critical materials from used batteries, and establishing international agreements that ensure sustainable and stable supplies of essential materials for electric batteries.

Conclusion

In conclusion, the electric car revolution presents an opportunity for individuals, businesses, and nations to transition towards sustainable transportation. The rise of all-electric vehicles is a result of the growing need to address environmental concerns, reduce carbon dioxide emissions, and move towards net-zero emissions. The development of electric vehicles has been a shared history with internal combustion engines, and the resurgence of all-electric vehicles is a transformative revolution that has the potential to positively impact the environment.

As electric vehicle technology advances and becomes increasingly integrated into the global market, it stands to offer numerous environmental benefits. These include the reduction of greenhouse gas emissions, improvements in air quality, and less noise pollution compared to internal combustion engine vehicles.

Governments around the world are taking the initiative in accelerating the transition by implementing policies and investing in infrastructure such as charging stations and providing incentives. Government policies supporting the transition to electric vehicles are critical in the widespread adoption of electric vehicles. It is also a proactive approach towards sustainable transportation and fulfilling the commitment to achieving the long-term goals outlined in the Paris Agreement.

The all-electric vehicle revolution is a step towards a greener future, and we must embrace this change to ensure a sustainable planet for future generations.

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