

## **A Review Analysis on Electric Vehicles**

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### **ABSTRACT**

*The purpose of this paper is to describe current uses of battery technology for internal combustion engine vehicles and newer hybrid electric vehicle and battery electric vehicle alternatives. This paper will also discuss the benefits and challenges to alternative vehicle adoption. As battery technology and charging structure carry on to advance, and drivers become more knowledgeable about these technologies, adoption rates for alternate vehicles have the potential to rise dramatically, leading to a dramatic alteration of the auto and petroleum industries.*

**Keywords:** *Automobile, electric vehicles, battery*

### **INTRODUCTION**

Battery-powered electric vehicles have the possibility to be one of the most disruptive technologies of the early 21st century and can potentially alter two of the largest and most influential industries of the world economy: automobile and petroleum. While electric vehicles are not a perfect solution, they do offer some answers to current concerns in society. The greatest challenges for widespread adoption of electric vehicles are twofold. First, the cost and energy density of battery technology prevents electric vehicles from being comparable to internal combustion engine vehicles. Second, driver's perceptions and fears of the limitations of electric vehicles need to be skillfully finessed.

This paper will explore the history and current state of vehicle battery technology and its deployment, the current use of batteries in vehicles, and different battery chemistries currently utilized. The benefits and challenges of current battery technology will be assessed considering performance characteristics and safety concerns. Further, perceptions of electric vehicles preventing widespread electric

vehicle adoption will be appraised. Additionally, charging infrastructure and its benefits and challenges will be explored.

### **BATTERY FUNDAMENTALS AND HISTORY**

Batteries in today's society are so prolific and easy to use that it is easy to dismiss the effect they have on convenience, comfort, and technological advancement. They have enabled the cell phone industry, portable electronics and computing, robotics, and the electric car industry, just to name a few. Without the ability to store energy electrochemically in a battery, many of today's advancements would not be possible. All electrical devices would have to be plugged into a continuous supply of electricity, typically supplied by the electric grid, and would therefore be tethered to their power source eliminating most forms of reasonable portability. Because batteries are so common and easy to use, it is easy to ignore the hidden chemistry that enables our modern conveniences. While varying types of batteries exist their basic process of storing electricity remains the same.[1] Batteries that have a single use, primary cells, are

composed of a negative terminal, anode, positive terminal, cathode, electrolyte and casing or packaging. [1] The electrolyte separates the anode from the cathode while allowing ions, positively charged particles, to pass freely between them. When a load, the source that is using the electricity, is connected between the terminals the battery undergoes an electrochemical reaction that sends electricity, electrons, through the circuit and the connected load. This process occurs when the anode undergoes an oxidation reaction and releases electrons through the terminal. [1] Simultaneously, the cathode undergoes a reduction reaction in which the cathode material reacts with ions in the electrolyte and available electrons released from the anode. [1] To put it more simply, the anode reaction releases electrons, and the cathode absorbs them. [1] In the process, the movement of electrons through the circuit generates work on the connected load. In a rechargeable battery, or secondary cell, the anode and cathode switch while the battery is being recharged. This switch occurs because, by definition, the anode always releases electrons and the cathode always uses them.

Italian physicist Count Alessandro Volta is credited for discovering the process in 1799 when he created a simple battery from metal plates which acted as the electrodes and brine-soaked cardboard which acted as the electrolyte. The resulting Voltaic Pile was able to generate a sustained current. [1] Some archeological evidence suggests that crude batteries may have been developed as early as 200 B.C. [1] In the last two centuries, the basic battery concept has been greatly improved upon. A variety of components and elements for the anode, cathode, and electrolyte have been explored and investigated, yielding a range of batteries with different characteristics and properties and a wide range of applications. This paper will focus primarily on the three

most common forms of batteries currently used in modern vehicles. Those batteries are the lead-acid battery, the nickel-metal hydride battery, or NiMH, and the lithium-ion battery, or Li ion.

## **BATTERY USE IN MODERN VEHICLES**

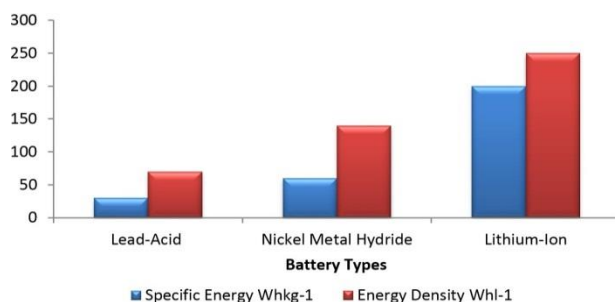
The most common battery in current vehicles is the lead-acid battery. Lead-acid batteries have their benefits, and as a result, have been widely adopted for today's current internal combustion engine (ICE) vehicles, for a specific purpose. Lead-acid batteries have a long shelf life, are inexpensive, reliable, easily recyclable, and are safe when properly handled and maintained. [2] The lead-acid battery provides the functions of starting, lighting, and igniting the vehicles ICE, cabin, and lighting systems. [2] The lead-acid battery, developed in 1859 by the French physicist Gaston Plante, was the first recharge-able battery. [1] It is able to produce a large amount of power for a short period of time to the starter to turn the engine over and begin the combustion process. The deployment of the lead-acid battery allowed vehicle manufactures to forgo the hand crank that was originally used to start ICE vehicles and implement modern computer processing, sensing applications, and lighting. Once the vehicle has started, the engine generates current, via the alternator, and sends electricity back to the battery to be recharged.

The performance requirements of the lead-acid battery are limited, and therefore, it need not possess a high energy density compared to newer battery technologies. One of the greatest limitations of the lead-acid battery is its considerably poor specific energy compared to modern technologies. Specific energy related to energy storage is a measure of the amount of energy (watt-hours per kilogram)  $\text{Whkg}^{-1}$ , the energy source can store. [2] Lead- acid batteries have a specific energy of 30-40  $\text{Whkg}^{-1}$ .

[2] By comparison, gasoline has a specific energy of  $13,000 \text{ Whkg}^{-1}$ . [3] Lead-acid batteries would add a tremendous amount of weight to the vehicle if they were used for other functions such as propulsion. As a result, it is not realistically viable to propel vehicles exclusively with lead-acid batteries.

The nickel-metal hydride (NiMH) battery was the next rechargeable battery widely produced for commercial applications in hybrid electric vehicles (HEV). Toyota released its Prius HEV in 1997 to the Japanese market and to the rest of the world in 2000. [4] The Prius used both an electric motor and a small ICE for propulsion. At low speeds, the electric motor drove the vehicle exclusively, and when more power or speed was needed, a small ICE turned on automatically to provide additional power for propulsion. NiMH batteries were used to supply energy to the electric motor because they offered a higher specific energy than lead-acid batteries, at  $60 \text{ Whkg}^{-1}$  and had a

much better energy density (watt-hours per liter) of  $140 \text{ Whl}^{-1}$  compared to a lead-acid batteries  $70 \text{ Whl}^{-1}$  (see Figure 1). [5] NiMH batteries are also highly reliable and safe similar to lead-acid batteries. In contrast to lead-acid batteries, NiMH batteries are composed of noncorrosive substances resulting in safer handling and recycling. Therefore, NiMH batteries were well suited for the development of hybrid vehicle technology. [5] Although the Prius Battery only provided modest propulsion, it was still able to increase the miles per gallon (mpg) metric, to 42 mpg. By employing a hybrid drive system, Toyota was able to reduce the Prius carbon dioxide ( $\text{CO}_2$ ) emissions by up to 37.4%. The NiMH battery is still being deployed today in HEVs and plug-in hybrid electric vehicles (PHEVs). PHEVs operate in the same manner as HEVs, however, they have the additional ability to plug into the electric grid to charge the battery. The NiMH battery's limited specific energy does constrain the electric-only range of HEVs and PHEVs.



**Fig. 1:** A Comparison of Electricity Storage Characteristics of Lead-Acid, Nickel-Metal Hydride and Lithium-Ion Batteries.

The next step in the progression of battery technology and its implementation with relation to HEVs, and battery electric vehicles (BEVs or EVs) was the lithium-ion battery. The limiting factor for vehicles is size and weight, and as a result, the automotive industry constantly seeks a battery that has a greater specific energy and energy density to increase the range of electric vehicles, one of consumer's biggest concerns regarding EVs. The Li-ion battery

is a step in that direction. The Li-ion battery has a specific energy of over  $200 \text{ Whkg}^{-1}$ , and an energy density of  $250 \text{ Whl}^{-1}$  (see Figure 1). [6] In evaluating the performance of EVs, range becomes a realistic concern and engineering challenge. This challenge is often referred to as range anxiety. The implementation of the Li-ion batteries and their improved battery-only range has allowed some automobile manufacturers to realistically

produce EVs for the consumer market. The most notable vehicles today are the Nissan Leaf and Tesla Model S. [7] The Nissan Leaf is an all-electric vehicle with an estimated range of 84 miles per charge costing \$29,000 and the Tesla Model S has an estimated range of 265 miles per charge and costs \$71,000. Both vehicles rely on Li-ion batteries. [8]

Similar to NiMH batteries, Li-ion batteries are reliable, require low maintenance, and have a long life-cycle of about 8-10 years or 100,000 miles. The two greatest concerns for Li-ion batteries are safety and cost.<sup>9</sup> While Li-ion batteries are considered safe, there are concerns with the batteries concerning thermal runaway. [9] Thermal runaway can be caused by defects in the internal Cells of the battery that short the cell between the anode and cathode. Such a short results in current flowing freely from one electrode to the other building up heat and eventually starting a fire or exploding. [9] Electronic circuitry and monitoring components are integrated into the battery packs of EVs to prevent such events from occurring. Li-ion batteries have been used for quite some time in portable electronics and laptops with minimal defects. However, when dealing with vehicles safety standards are much higher. Battery manufacturers are constantly working to improve manufacturing processes and safety. It is common, however, for new technologies to be held under greater scrutiny by the public until they are better understood and become more commonplace.

### **Positive and Negative Aspects of HEVs, PHEVs, and EVs**

Electric drive technology is not new. The last decade has seen a dramatic increase in research and implementation of electric powered vehicles as well as HEVs. There are a number of challenges that the widespread implementation of these technologies can help address, such as climate change, air pollution, noise pollution, and dependence on petroleum,

both domestic and foreign. [7] While EVs and HEVs are able to mitigate some of the issues mentioned above, they also provide additional benefits that were not the primary focus of the technologies deployment, including increased energy security and independence, instant torque at low speeds provided by electric motors creating more fun for the driver, the benefit of not having to use refueling stations, reduced maintenance costs, and increased fuel energy savings and price stability for the consumer. [10]

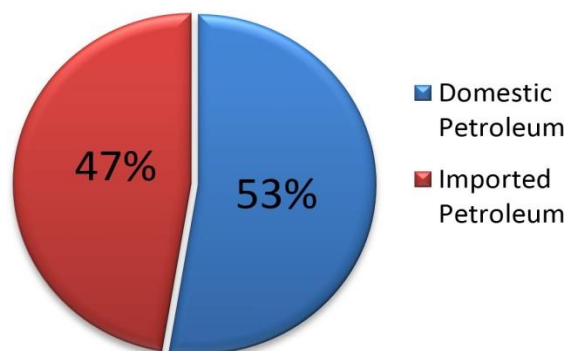
It is widely accepted by the scientific community that the earth is undergoing global warming caused by increased levels of greenhouse gases in the atmosphere, primarily CO<sub>2</sub>, and that humans are the cause. Global warming and the resultant climate change will cause a host of problems for humans and the environment. As a result, governments globally have implemented policies to reduce greenhouse emissions including further implementation of HEVs and EVs. Some studies regarding greenhouse emissions and PHEVs have shown that PHEVs emit as much as 50% fewer greenhouse gas emissions compared to ICE vehicles, even when coal is the primary source of electricity. [7] Furthermore, EVs have zero tailpipe emissions, and can have no emissions at the source of electricity if the electricity is generated with renewable forms of energy. [7]

Air pollution is also a concern for governments. Air pollution consist of airborne particles from vehicle exhaust and industrial smokestacks which contribute to smog, mercury that contributes to cancer and brain deficiencies, as well as nitrous oxides and sulfur dioxides that contribute to acid rain and ocean acidification. In addition to global warming, governments and automobile manufacturers are trying to reduce these noxious pollutants from vehicle emissions. One action some governments have taken in this direction is increasing the mandated corporate average

fuel economy standards (CAFE). The CAFE standard requires manufacturers to design and manufacture more fuel-efficient vehicles over time, and creates incentives for low emission or zero emission vehicles to be produced to offset the lower fuel economies of heavier duty vehicles. When vehicles use less fuel they also produce fewer emissions. In addition to CAFE standards, regulations also exist to specifically limit individual pollutants from tailpipe emissions. Some argue that using battery powered vehicles only transfers greenhouse gas emissions from gasoline to dirtier coal generated electricity. This statement should be considered when assessing the effects of EVs and HEVs as they gain market share. The overall percentage of coal generated electricity in America is declining. Furthermore, large, stationary power plants are able to deploy more enhanced pollution reducing technologies than vehicles realistically can. As a result, even though power plants produce a tremendous amount of emissions, EVs powered exclusively from coal generated electricity are ultimately responsible for fewer emissions than the average ICE vehicle of a comparable size. [11] EVs will be responsible for even fewer emissions as more renewable resources generate electricity, and older, notoriously dirty power plants are decommissioned. Noise pollution seems like a mild inconvenience. However, it can contribute to hearing loss, increased blood pressure,

higher rates of coronary heart disease, higher levels of stress and a lower quality of life. [12] Additionally, it can harm animals by disrupting their reproductive capabilities, disrupting their navigation abilities, contributing to their hearing loss, and interfering with their prey detection or predatory abilities. [12] EVs and HEVs are exceptionally quiet. They are so quiet that regulators are considering requiring such vehicles to produce an artificial noise at low speeds for the safety of pedestrians. Greater deployment of EVs and HEVs will dramatically reduce the noise levels in cities in particular, and contribute to a higher quality of life.

Regarding America's dependence on petroleum, America uses approximately 19 million barrels a day of petroleum mostly for vehicle, boat, and plane fuel. [13] Of the 19 million barrels of petroleum used each day, America imports approximately 9 million barrels (see Figure 2). [13] A portion of these imports come from nations that are hostile to the U.S., or from nations that do not share Americas values, some of which are political allies. While this paper will not go into depth about the geopolitical challenges associated with fossil fuel extraction and its use, it can be said that it is in the interest of national security, and the economy to be more energy independent. Achieving that goal requires generating energy from a higher percentage of domestic resources.



*Fig. 2: A Representation of the Proportion of Petroleum Used Each Day in America that is Produced Domestically or Imported.*

EVs are able to Eliminate reliance on petroleum, particularly imported petroleum by using domestic energy from the grid. Even if that energy is generated from coal or gas, America is able to extract those fossil fuel resources domestically. Similarly, HEVs reduce dependence on petroleum, and petroleum imports by requiring less gasoline as fuel and, therefore, reducing overall demand.

Electric motors are notorious for having a great amount of torque especially at low speeds, meaning electric cars have tremendous acceleration and a sense of power and control while driving. One reporter stated that the quick and powerful yet quiet acceleration is simply awesome and believes the fun of driving an EV is its greatest selling point.[14]

Furthermore, because EVs use electricity as the fuel, the bulk of refueling can be done while the driver is asleep at home. [10] In the convenience culture of America, this ability to recharge at home could be a very attractive feature. One GM salesperson stated that he regretted trading in his Volt, (a PHEV), the first time he had to go back to the gas station. [10]

One study stated that 87% of respondents traveled fewer than 40 miles per day. [7] Driving that limited distance means that EVs can obtain all the energy needed for each day for most drivers from their own electricity while he or she is at home.

Additionally, electric drive systems are much simpler than ICE drive systems for a comparable car. EVs do not have a transmission, alternator, starter, large engine or lead-acid battery, all gasoline or diesel ICE components stated require maintenance. The most common maintenance costs related to EVs are changing tires, brakes, shocks, and windshield wiper fluid. EVs also have the potential to save approximately two thirds

in fuel expenses or more, while at the same time, maintaining lower price volatility in the electricity market than gasoline. [15]

Electricity prices have been consistently in the dollar- a-gallon-equivalent mark for comparable energy to gasoline over the last 15 years. During that same time period Gasoline prices have fluctuated between approximately \$1.30 per gallon to \$4.20 per gallon. [15] This price constancy better allows consumers to budget their expenses without unexpected and dramatic price swings affecting spending habits.

### **Challenges of HEVs, PHEVs, EVs**

The greatest challenges facing widespread adoption of EVs and HEVs are related to the limitations of current battery technology and consumers negative or uninformed perceptions. The restrictions of current batteries include the high upfront cost of the battery packs, the low energy densities of these batteries, and the long amount of time required to charge them.

One of the challenges EVs are currently facing is their higher retail price compared to equivalent gasoline powered vehicles. Vehicle battery packs are expensive. The approximate costs of such batteries are between \$750 per kWh to \$1,500 per kWh for EVs, PHEVs, and HEVs. [16] As a result, battery packs can add \$3,000 to \$30,000 dollars to the cost of electric vehicles, depending on the size of the battery. [16] Even after accounting for fuel savings and maintenance savings, these high additional battery costs sometimes do not result in cheaper ownership of the vehicle when factoring in a fixed, projected gasoline equivalent cost.

Because the battery packs currently have a low specific energy and energy density relative to gasoline, the batteries used in EVs have to be very large to get an acceptable range. Such battery packs can weigh over 600 lbs. for the Nissan leaf and

1300 lbs. for the Tesla Model S. [17,18]. Therefore, adding additional battery cells would have a diminishing return as they would also increase the weight of the vehicles and decrease their performance.

Additionally, the time required to charge the massive battery packs is another engineering challenge. Currently, to charge a dead Leafs battery on a standard 120 V wall outlet would require up to 20 hrs, or 8 hrs on a 240 V circuit.<sup>18</sup> However, an 80% charge could be achieved in about 30 minutes with a fast charger. [19] Consumers are used to being able to refill there gasoline vehicles in about 5-10 minutes and get another 300 miles of range. As a result, consumers would have to dramatically alter their expectations, and habits to accommodate this technical hurdle. However, reducing the impact on the drivers in- convenience can be achieved by the drivers if they plan for their needs. In particular, charging at night while the driver is home would save additional time and effort for most drivers. One concern that arises from EVs charging at night is their effect on the electric grid and its ability to satisfy the increased load. One study tracking 484 Atlanta, GA commuters driving and parking habits found over 10 minute intervals, the greatest average increase in cars parked at the same time was 1% at 7:00 p.m. local time. [20] As such, the current grid would be able to handle modest increases in EV and PHEV deployment without any modification to the existing grid. [20] The concept that all drivers leave work at the same time and would, there- fore, arrive at home and begin charging their vehicles at the same time is not true. As EVs and PHEVs capture greater portions of the auto market utilities may need to improve their distribution capabilities, however, this paper will not further explore the topic.

Customer's perceptions of battery powered vehicles are the greatest hurdle from a

marketing and sales perspective. EVs and HEVs are still a relatively new technology and people have a hard time adapting to such new technologies. [7] Consumers primary concerns regarding EVs are range, cost, charging infrastructure, reliability, and safety. [7] Because EVs are not perfect substitutes for ICE vehicles they require some changes to the driver's normal habits such as the added hassle of charging and planning trips. Some populations, like apartment or dormitory residents, would have the additional challenge of charging their EVs exclusively at public charging stations. In the face of these substantial changes in habits, consumers have to take time to better understand and learn more about the technology, its applications, and its possible effects and benefits on their lives. Furthermore, when many people think of EVs they do not have a familiar perspective from which to evaluate the technology. As a result of misperceptions, some people underestimate the performance of such vehicles.<sup>10</sup>

Worry about the vehicles actual range is a real concern. When an ICE vehicle runs out of fuel, the driver has to get a can of gas, bring it back to his or her car, dump it in, and the problem is solved. While it is inconvenient to run out of gas, it is not a major problem. However, if an EV ran out of energy the driver could not easily top off the battery with more electricity. He or she could find an outlet and start charging, but the more realistic solution would be to get towed home, or to a charging station. Such a situation would be highly inconvenient and troublesome contributing to range anxiety for EV drivers.

Charging infrastructure is another concern. As mentioned earlier, most drivers, for a majority of driving trips, would be able to satisfy range requirements by charging the EV at home. If the driver needed to charge the EV while on the go, options are continually increasing as infrastructure

continues to develop. Many public parking lots or garages offer free charging. Furthermore, chargers are frequently being installed both by EV manufactures and by third-party companies entering the infrastructure market. [21] In particular, Tesla, the innovator behind the supercharger, has vowed to install superchargers every 80 to 100 miles on major routes throughout the U.S. and Canada. [21] The company also plans to build 200 stations over the next two years and place 98% of the American and Canadian populations within range of a Tesla supercharger. [21] While the infrastructure is developing, it is still far behind the 160,000 gas stations that are currently available across the U.S. for ICE vehicles. Therefore, EV drivers will need to continue to plan and better anticipate their driving needs.

Concerning reliability and safety, while EVs and HEVs are a relatively new technology, they still have to adhere to the same safety regulations as ICE vehicles. There have been very few incidents where the technology specifically related to EVs or HEVs has failed in a manner as to cause harm or injury. Furthermore, most companies producing EVs and HEVs are established automobile manufacturers with proven safety and reliability records, and they offer the same warranties to their alternative vehicles as they do to their ICE vehicles. Tesla would be one of the exceptions. Even though Tesla is a start-up automobile manufacturer, it has proven itself to be a leader in EV innovation, development, and quality with many accomplishments established car companies have yet to achieve. Tesla also warrants its products.

## CONCLUSION

In summary, advancements in battery development, in particular over the past few decades, has enabled the implementation of modern EV, HEV, and

PHEV technology to augment the existing auto market. While these technologies still have a ways to go before they are on par with ICE vehicles, they are beginning to impact the market and consumers perceptions. As EVs, HEVs, and PHEVs become more widely accepted, consumers will be able to save money, be energy independent, have a lower impact on the environment, pollution, and greenhouse gases and have an enjoyable driving experience. Future research and development is needed to continue improving the specific energy and energy density of batteries being used by vehicles, while at the same time reducing the cost of the technology. Infrastructure to support widespread adoption of electric vehicles will also need further development and implementation. Efforts, such as those noted above, can add to alleviating range anxiety for consumers and potentially change overall perceptions of electric vehicles, and as a result, HEVs, PHEVs and EVs will have better market penetration leading to a dramatic change in the automobile and petroleum industries.

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