# CHALLENGES OF EVS AND HVS TO THE U.S. ELECTRICAL POWER GRID

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## Abstract

Environmental concerns, depletion of fossil-fuel resources, and the increase in gas prices boost the demand for Electric Vehicles (EV) and plug-in Hybrid Vehicles (HV) because of their high efficiency and low or no gas emissions. But, despite their advantages, the rapid increase in EVs and HVs has brought challenges including a lack of sufficient electric power, lack of electrical transmission line capacity, dependence on foreign batteries, and other obstacles. Envisaging electrical power need with consideration for the time when everyone may have EVs and HVs and planning the country's energy policy are critical. The high demand for HVs and EVs will bring a high load to the transmission lines. Because of this increased demand for HVs and EVs, there will be a significant shift in use of energy from gasoline to electricity, which brings an important question to mind. Can the U.S. electric energy generation capacity meet the energy demands from HVs and EVs during the next 20 years? This extensive study was conducted regarding potential problems and challenges EV/HV technology will face in the near future.


## Introduction

For more than a century, people have attempted to harness electricity, the clean and versatile fuel, for personal transportation. Ideas for an electric vehicle were first introduced in 1835 by Professor Stratingh, and thus cannot be considered a new idea in our century [1]. The earliest electric cars emerged in the mid 19$^{th}$ century and in the early years of the 20$^{th}$ century, when they competed effectively with gasoline-powered cars. Early in the 19$^{th}$ century, there were more EVs than internal-combustion-engine (ICE) vehicles, but ICE vehicles had advantages such as available gasoline resources and less technology in terms of control of the vehicle and energy storage. EV production dwindled in comparison with ICE vehicles until the mid 1990s. In 1997, The Toyota Prius was introduced to the Japanese market. First-year sales were nearly 18,000 [2]. Today, major automobile companies have their own hybrid car models commercially available [3-11]. Demands for HVs are promising. Considering the depletion of fossil-fuel resources, the higher efficiency of EVs, and environmental concerns, it can be said that demand for HVs and EVs will increase significantly. Increase in demand for HVs and EVs implies a significant shift in usage of energy from gasoline to electricity, which brings an important question to mind. Can the U.S. electric energy generation capacity meet energy requirements in case of a high demand for HVs and EVs in next 20 years? The following sections explain the current condition of power generation capacity, future expectations, and battery technology for EVs and HVs.

Over the years, improvements in internal combustion engine technology, such as reduction in noise, vibration, and other advances, led to the supremacy of cars powered by gasoline, since they have better range and decreased fueling time compared to electric vehicles. Electric vehicle technology continued in the form of electric powered trains and fork lift trucks. There have been various attempts over the years to reintroduce the concept of electric vehicles, with updated improvements. However, issues with battery charging times, slow battery technology improvements, and range concerns (the fear of running out of energy with no locally available charging stations), have contributed to the inability of EVs to penetrate the market. Recently, because of increased gas prices, concerns about the link between carbon-based fuels and climate change (global warming issues), the environmental impact of oil and gas exploration as evidenced by the current oil spill in the Gulf of Mexico [12], improvements in battery technology and charging infrastructure, interest in EV vehicle technology has returned to the market place and is being considering for consumer production by many vehicle companies [13].

After a long term of research and development processes, EV and HV technology is reaching the highways. Environmental concerns, depletion of fossil-fuel resources, and increase in gas prices boost the demand for EVs and plug-in HVs because of their high efficiency and low or no gas emission. But despite their advantages, the rapid increase in EVs and HVs have brought several challenges such as the lack of sufficient electric power, lack of electrical transmission line capacity and dependence on foreign batteries. EV and HV technologies can be a good alternative to conventional combustion-engine car technology as long as the required infrastructure is established. This infrastructure includes sustainable electric power, reliable transmission capacity, a safe and high-capacity battery, domestic production of EVs/HVs and their parts, and waste management. Envisaging the electrical power needed if the majority of automobile owners have EVs and HVs and planning the country's energy policy is critical. A high demand for HVs and EVs will bring a high load to the transmission lines. One of the most important motivations for developed countries to provide large funding for research on HVs and EVs technologies is to avoid dependence on foreign energy resources. This can be accomplished if and only if some critical parts of HVs and EVs, such as batteries, are manufactured domestically. Waste management is also a very important issue in HV/EV technologies. Batteries in HVs and EVs contain huge amount of hazardous materials. Eliminating or lowering the toxic material in batteries and lessening their impact to the environment is imperative. A study by Electrical Engineering Technology and Industrial Technology students and faculty was conducted regarding potential problems and the challenges EV/HV technology will face in the future so that solutions for those challenges might be discovered.

Manufacturers of electric and hybrid vehicles have produced exciting developments and it is obvious that EVs and HVs may be here to stay if appropriate infrastructure is created. These vehicles currently offer such advantages as lower cost to operate, reduced dependence on oil, ecological advantages to reduce global warming concerns and issues. However, it may become an issue for the electric industry due to required power for battery charging purposes. A major concern for the electric utilities is the impact of the additional current drain that will be required to charge these vehicles. It is assumed that most of the owners of these new technologies will use 240V chargers to provide an assured overnight charge. These battery chargers will draw an amount of electric current from the grid that is equal to or greater than an average home use during the night time. For example, the Nissan Leaf draws 40A at 240V, representing a 9.6KW demand on the electric grid. The grid is usually established with local sub-stations consisting of several transformers for every 6-10 homes on average. One vehicle connected to the grid putting more load on a transformer may not create problems, but the concern is that the number of vehicles will increase in the near future, which will put more of a load on these transformers. If the number of electric vehicles increases in specific locations, there is a very real concern that the additional load will cause transformers to fail, especially if the vehicles are allowed to charge during peak hours. Taking these issues into consideration, precautions should be taken before adapting electric vehicle technologies to our daily lives. For example, a demand response [14] is a key Smart Grid solution that needs to be in place to enable the expected growth in EVs, but there are unique aspects of demand response that come into play [13].

# Transmission Lines

According to the U.S. Department of Energy, the U.S. electric transmission system is under stress. Growth in electricity demand, lack of investment in new transmission facilities, and the incomplete transition to fully efficient and competitive wholesale markets have allowed transmission bottlenecks to emerge. These bottlenecks increase electricity costs to consumers and increase the risks of blackouts [15], [16]. Over the past decade, the cost trends for transmission plants have increased 23% and those for distribution plants have increased 21% [17]. As is shown in Figure 1, the cost of electric utilities increased about 20-30% around the U.S. [18], [19]. Investments in transmission infrastructure dropped by $117 million between 1975 and 2000 [19]. Increases in costs of transmission plants and distribution plants are about the same. Low investments with an increase in cost worsen the situation.

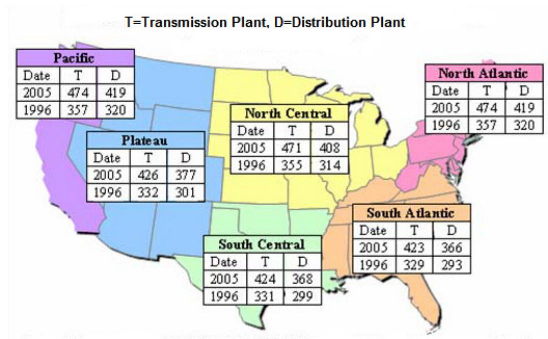


**Figure 1: Cost Trend of Electric Utility Construction by Geographic Division and Type of Plant, 1996-2005 [14]**

Unless substantial amounts of capital are invested over the next several decades in new generation, transmission, and distribution facilities, service quality will degrade and costs will go up [19]. As is shown in Figure 2, investment in new transmission facilities has declined steadily for the last 25 years [20], [21].

Transition from combustion engine vehicle to HVs and EVs will bring a heavy load to U.S. transmission lines in the near future. The current status is not sustainable in terms of electric transmission and distribution. In case of a high demand for EVs and HVs in the next 20 years, the U.S. Electric Transmission and Distribution system will face serious problems such as low efficiency, blackouts, congestion, transmission bottlenecks, and increase in the cost of electric energy [17-21].

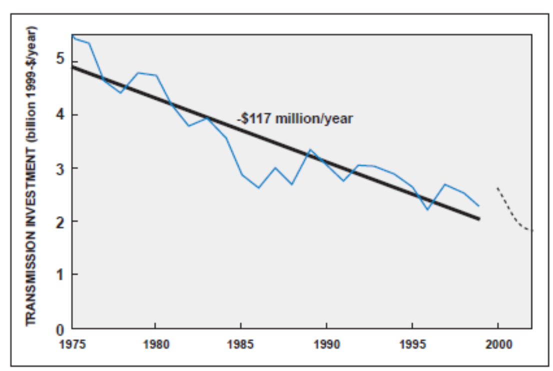


**Figure 2: Transmission System Investment Over Time [21]**

Smart-grid systems are currently available and under research for improvements. Smart grid may be a viable solution to link the charging of electric vehicles with available renewable energy systems such as solar and wind technologies. For instance, as wind capacity increases, EVs would be allowed to charge faster but when the renewable power on the grid drops, the EVs charge would decrease. This concept can be used to integrate charging stations with residential or commercial generation capacity from wind, solar or other alternative energy sources [13]. Utility companies are building infrastructure and involving research for charging stations to address all of the aforementioned issues and concerns. Companies such as Batter Place, AeroVironment, and Coulomb Technologies are offering vehicle charging services to their customers using advanced networking technologies.

## Energy Consumption by the Transportation Sector

Transportation sectors strictly depend on energy and are one of the major consumers of energy. Figure 3 shows the energy consumption of sectors in the U.S., according to 2005 year data. Energy is primarily consumed by the industrial and transportation sectors, followed by the residential and commercial sectors [22]. According to the Energy Information Administration revisions, total energy use was 99.6 quadrillion BTUs in 2008 with transportation using 28.2% [23]. The transportation sector consumes 28% of the total energy consumption in the U.S., which includes all types of vehicle whether commercial or noncommercial. Light-duty vehicles (LDV), such as cars, pickup trucks, sport utility vehicles, and vans, consume 48% of the total energy (Table 1). As shown in Figures 3 and 4, 84% of the energy consumed today for transportation in the U.S. comes from fossil fuels [24].

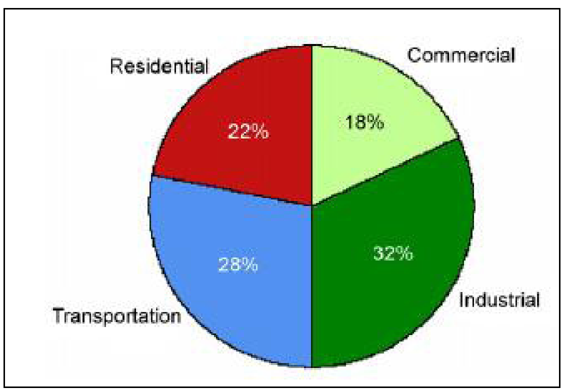


**Figure 3: End-use Sector Shares of Total Energy Use in the U.S., 2005 [25]**

**Table 1: Energy Use by Type of Vehicle [22]**

| Type of Vehicle | Energy Use |
|---|---|
| Automobiles | 32% |
| Light Trucks | 16% |
| Aircraft | 9% |
| Water | 5% |
| Construction & Agriculture | 4% |
| Pipelines | 3% |
| Trains & Buses | 2% |

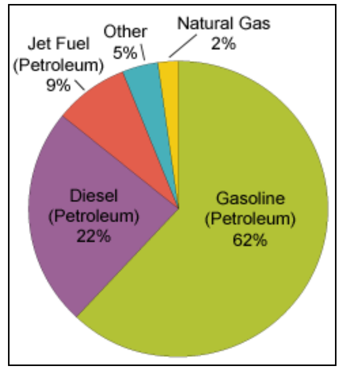


**Figure 4: Fuel Used for Transportation [24]**

An increase in demand for HVs and EVs implies a significant shift in usage of energy from gasoline to electricity, which brings an important question to mind. Is the U.S. electric energy generation capacity able to meet the energy requirements in case of high demand for HVs and EVs in next 20 years? We need to look at emerging technologies and different prospects about the future of HVs and EVs to answer these questions.

## Future Prospect of Hybrid Vehicle Sales

HV sales are increasing rapidly. Figure 5 shows actual HVs sales from 2000 to 2006 and projected sales from 2007 to 2013. According to the U.S. Energy Information Administration's (EIA) Annual Energy Outlook 2009 report, unconventional vehicles (vehicles that can use alternative fuels, electric motors and advanced electricity storage, advanced engine controls, or other new technologies) account for 63% of total new LDV (cars, pickup trucks, sport utility vehicles, and vans) sales in 2030 in the AEO2009 case study [26].

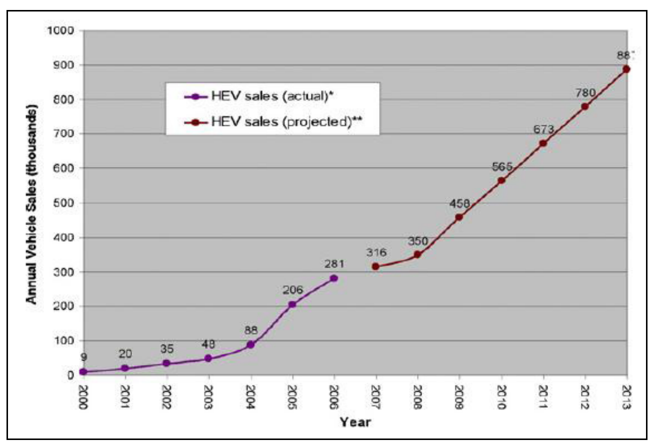


**Figure 5: Annual Hybrid Vehicle Sales [22]**

Hybrid vehicles, including both standard hybrids and plug-in hybrid electric vehicles (PHEV), will represent the largest share of the unconventional LDV market in 2030, with 63% of all new unconventional LDV sales and 40% of all new LDV sales. As shown in Table 2, EIA projects that total hybrid sales will increase from 2.3% of new LDV sales in 2007, to 20.6% in 2015 and 39.6% (7.9 million vehicles) by 2030. Hybrid vehicles include micro hybrid, plug-in hybrid (PHEV), series hybrid, parallel hybrid, etc.

**Table 2: Sales of Unconventional Light-Duty Vehicles by Fuel Type, 2007, 2015, and 2030 (thousand vehicles sold) [27]**

| Year | Total | Electric Hybrid | Micros | Flex Fuel | Diesel | Other |
|---|---|---|---|---|---|---|
| 2007 | 1515 | 346 | 13 | 873 | 271 | 283 |
| 2015 | 6801 | 1247 | 2114 | 2895 | 529 | 543 |
| 2030 | 12631 | 4763 | 3169 | 2664 | 2014 | 2035 |

# Battery Technology

There are major concerns about the battery systems used in EV technology. If the EV is going to take more than 10 minutes to charge, there is the challenge of who will purchase it unless it is used for local commuting and charged overnight. For instance, if EV technology is applied to utility trucks and school buses, it may be viable due to their short-distance ranges. While these vehicles are waiting afternoon pickups, this will be a time for the batteries to be charged for the next trip. Batteries also have disadvantages such as creating harmonics due to charging and discharging the electric grid. Most batteries have limited life cycles, different charging conditions, and the total number of times they can be charged and discharged. A quicker charging solution may be three phase, 480V charging technology, which may significantly cut charging time by using a three-phase power supply. Even this technology will not be able to cut charging time significantly due to battery charging requirements specified by battery manufacturers. In some of the battery types, factors such as heat generated while charging the batteries and the outdoor temperature will affect battery life. These two important issues should be addressed to increase battery charging and storage efficiencies. An intelligent charging station may be a good solution to avoid overcharges that create heat in the batteries. In cold weather, battery storage capability and charging station efficiency should be addressed as well [13]. Moreover, a sound strategy needs to focus on what can be done today to bring battery costs down and make electric vehicles attractive to consumers other than wealthy environmental advocates. A central part of that strategy must be to promote secondary commercial markets for advanced automotive batteries [28].

Although we agree with EIA's 2030 prospect about percentage of HVs, we differ with EIA in several respects. Development in super-capacitor and battery technology is quite promising. Battery technology was a barrier for HVs for decades because of their low range, long charging time, and safety. With new developments in the last several years, battery technologies can overcome almost all of these imperfections. Today, battery range is up to 69 miles depending on type and brand of HV [29]. For electric vehicles, the battery range is up to 240 miles [30].

Battery charging time is lower. MIT announced that their engineers have created a kind of beltway that allows for rapid transit of electrical energy using a well-known battery material, an advance that could usher in smaller, lighter batteries [31]. They are considerably smaller and lighter. Although there remain concerns about safety, much progress has been made during the last decade.

The battery is one of the most important parts of the HV or EV. There are many types of batteries that can be used by HVs such as Nickel Metal Hydride (NiMH), Nickel Cadmium (NiCd), Lithium Ion (Li-ion), etc. All contain very toxic materials for the environment and raise health concerns. Currently, 98% of batteries are recycled in the U.S. [33]. With an increase in the use of hybrid cars, battery use will also increase, as indicated in Figure 6. This will bring challenges with it such as recycling costs, transportation of used batteries, etc.

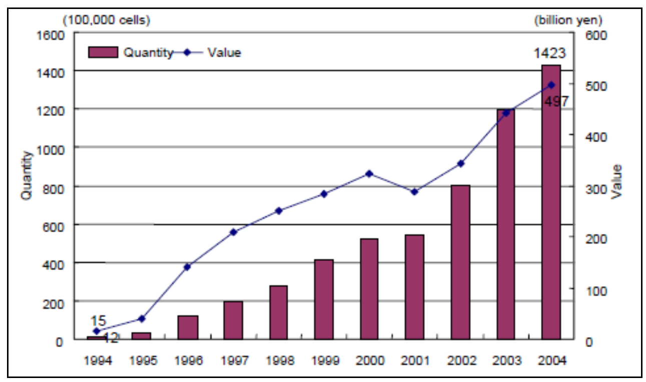


**Figure 6: Growth of Lithium-Ion Battery Industry in the Past 10 Years [32]**

The flat cost to recycle batteries is about $1,000 to $2,000 per ton [34]. The estimated number of HVs and EVs in 2030 is conservatively 30 million. Today, the lifetime of the battery is around 70,000 miles. Each car needs 2-3 battery packs in its lifetime. Depending on type and brand of the car, battery packs weigh 70 to 150 pounds. Taking all of these numbers into consideration, and with the scenario of having 30 million HVs and EVs on our highways, the total cost of recycling batteries will be $4 billion per year.

# Electric Vehicles

Emerging battery technologies and a rapid decrease in the cost of HV components can increase the percentage of hybrid vehicles in the total LDV market and percentage of PHEVs in the hybrid car market beyond the predictions of the Energy Information Administration. Also, there will be pure electric vehicles available on the market. Tesla offers a pure electric vehicle, the Tesla Roadster, which has a 244-mile range. Its battery life is seven years or 100,000 miles. Tesla offers the Roadster starting at $49,900 [30]. It takes about 3.5 hours to charge a battery. Nissan will soon unveil its pure electric car, the Nissan Leaf. The Leaf will have a range of 100 miles per charge under average, everyday driving conditions. Nissan claims to target a price in the range of other typical family sedans [35]. Toyota announced its launch of an urban-commuter battery electric vehicle (BEV) called FT-EV coming to market in 2012 [36].

EIA's case study does not include pure electric vehicles in its projection. Considering all emerging developments, it can be said that there will be a significant increase in sales of hybrid and pure electric vehicles in next twenty years. In this current study, the authors estimate the gross electric energy consumption with respect to 1-15% electric energy share in transportation based on EIA's electric energy consumption data. The total electric energy consumption in 2007 was 4.6 billion kWh per year. Figure 7 shows how the increase in share of electric energy in transportation affects gross electric energy consumption in the U.S. According to the table [25-27], a percent increase in share of electric energy in transportation elevates gross electric energy consumption 2.7% on average. That means that if 15% of energy consumption in transportation is provided by electric energy, gross electric energy consumption will increase about 40%.

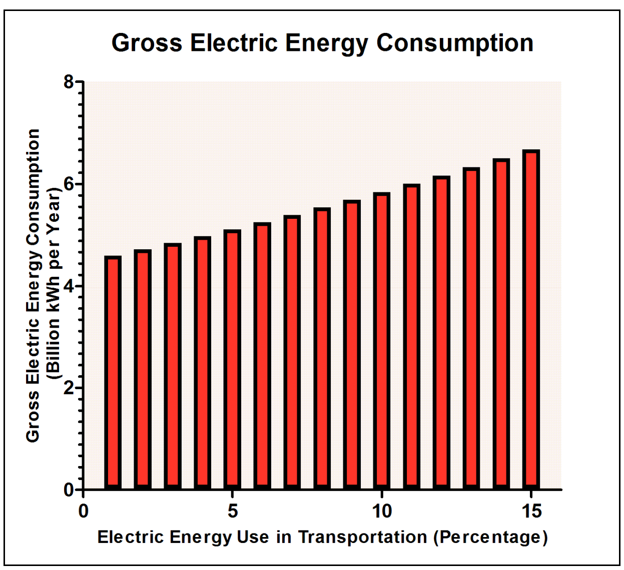


**Figure 7: Projected Electric Energy Needs Depending on the Percentage of Electric Vehicles on the Road**

## Manufacturing of HVs, EVs and Batteries

As shown in Figure 8, major producers of batteries for HVs are Japan, South Korea and China. The U.S. does not have any significant battery production.

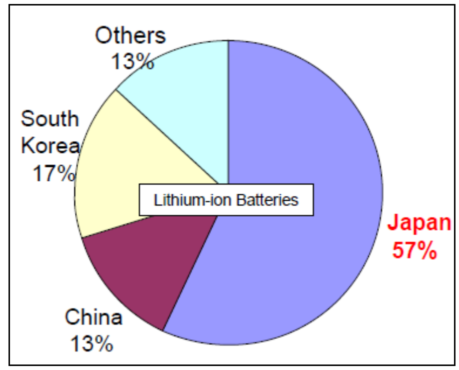


**Figure 8: Global Market Share of Batteries, 2005 [29]**

Today, the U.S. has the biggest ICE vehicle industry in the world, which constitutes both American companies and foreign companies, such as Japan and Germany. The automotive industry plays a major role in the American economy. It provides hundreds of thousands of jobs to American citizens. The growth of the HV and EV markets implies a decline in the ICE vehicle market. The U.S. is the biggest market for hybrid car sales. Japanese automotive companies produce about 80% of the total HVs (Figure 9). Although there are many American companies producing hybrid cars, they constitute less than 10% of total production. This current picture is not sustainable for the U.S. automotive industry. Without proper precautions, the American automotive industry can lose its market share, which implies a higher unemployment rate and economical downturn.

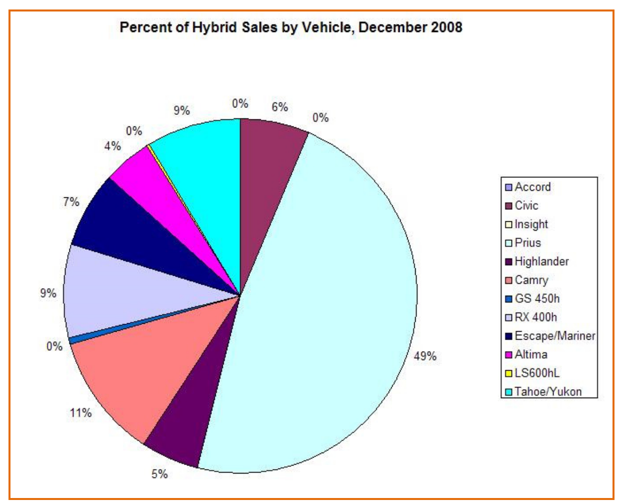


**Figure 9: Original Data Supplied by the Battery Association of Japan [29]**

## Discussion and Conclusions

Although HVs and EVs offer alternatives to traditional energy resources with many advantages, they also bring challenges. The U.S. demand for HVs and EVs is increasing dramatically, which means electric energy consumption will increase in the future. Estimates show that 15% of our transportation needs will be filled by HVs and EVs in 2030. Data in this study show that planned energy production is less than required for such a scenario. Battery recycling costs will increase about $4 billion per year over the next twenty years. Transmissions lines are not capable of transmitting the electric energy needed in the future and require comprehensive inspection, maintenance and updating. Production of HVs and EVs domestically is strategic if we are to avoid dependence on foreign countries. The U.S. is far behind in the production of HVs and EVs compared to other developed countries such as Japan and Germany.

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