Charging of Electric Vehicles: Technology and Policy Implications

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Executive Summary: Electric Vehicles (EVs) are rapidly becoming the forerunners in vehicle technology. EVs have the potential to help reduce dependence on fossil fuels and thus reduce the future impact of transportation emissions on climate change. This paper aims to answer the questions of how a moving car can be wirelessly charged and what costs will be incurred in establishing this infrastructure, with corresponding policy suggestions. The EV market is growing at a rapid pace in the US and if the current rates of growth continue it could be a globally dominant market. This paper addresses the following: (i) current practices in EV technology, costs associated with setting up of EV charging stations, and the various kinds of Electric Vehicle Supply Equipment (EVSE) currently being used; (ii) various capital, infrastructural, and operating costs associated with setting up of various types of charging stations; (iii) the concept of wireless charging technology and how it can be utilized in stationary and dynamic conditions; (iv) the various kinds of wireless charging technologies that are currently being investigated with policy recommendations for their implementation.

This paper gives a detailed overview of the public and residential charging infrastructure available in the United States. It also provides a data-based cost-benefit analysis of plug-in charging, wireless charging, and wireless charging in motion of EV's using different scenarios. A variety of factors have been taken into account such as the cost of electricity, the cost of infrastructure, and overall lifetime costs. It also compares the two charging methods (plug-in vs. wireless charging) primarily used for charging of Plug-in Electric Vehicles (PEVs) and reaches a conclusion that the cost of charging in both methods is comparable and thus wireless charging, with its added benefits, can be a beneficial replacement for plug-in charging. This may be accomplished through establishing a targeted subsidy or tax credit program through government action. It also looks into the novel concept of Dynamic Wireless charging of electric vehicles (*i.e.* charging in motion) and reaches a conclusion that the costs for building such an infrastructure would be less than the costs of a public charging station. Recent cases in which wireless electric charging has been put into practice are additionally reviewed. The paper also gives a comparison of the time-of-use (ToU) rates and energy-based rates for public charging and its implications and the policies that can be formulated for best outcomes in the US. Some of the cases where wireless charging has been implemented on a test basis have been discussed briefly. It also discusses some of the common misconceptions people have about electric vehicle infrastructure and how they become a hindrance to the consumer adoption of EVs. The paper gives an overview of how different market-based mechanisms can be applied for a successful and mass adoption of EVs. Federal polices formulated for growth of EV infrastructure and some possible reasons for decrease in federal funding have been stated. It also gives an insight into how lobbying of Congress by major oil companies have had a negative impact on development of EV infrastructure.

1. Current and Future Projections of Electric Vehicle Use

Since 2010, 50,000 new electric vehicles (EVs) have been sold in the US, making it the country with the largest fleet of EVs in the world (Plug In America and Sierra Club 2012). The Energy Improvement and Extension Act of 2008, and later the American Clean Energy and Security Act of 2009 (ACES) granted tax credits for new, qualified plug-in electric vehicles (Internal Revenue Service 2009). The American Recovery and Reinvestment Act of 2009 (ARRA) also authorized federal tax credits for converted plug-ins, though the credit is lower than for new plug-in electric vehicles (PEVs). The total amount of the credit allowed per vehicle for a new PEV is US $7,500[1] (Internal Revenue Service 2009). With a growing fleet of EVs and the encouragement provided by the tax credits, the number of charging stations required and the total amount of electricity required has also gone up. As of November 2014, there are 8844 electric stations and 21,946 charging outlets in the US (EERE 2014). The majority of the charging stations, both public and private, are concentrated in California while the rest are unevenly distributed all across the country (Department of Energy 2014).

A total of 54,731 electric vehicles have been sold in the United States in the first quarter of 2014. These sale figures are a good indicator, considering the fact that there are almost 225,000 electric vehicles on US roads (Energy Policy Information Center 2014).

According to the report titled “Strategic Assessment of the Global Electric Vehicle Service Equipment Market 2012-2016,” the EVSE industry is predicted to grow at a compound rate of 35.3 percent from 2012-2016. Residential charger sales are largely driven by the increase in the sales of electric vehicles, but commercial charging unit sales are largely driven by government support or investment by private entities. The major global markets are projected to be in the US, China, and Japan. According to a report by Navigant research, it has been projected that the global demand for charging equipment would grow from 442,000 units and $567 million in revenue in 2013 to 4.3 million units and $5.8 billion in revenue in 2022, which is a compound annual growth rate of 28.8% (Navigant Research 2012). The same report also suggests that the sales in residential charging station will fall from 63% in 2013 to 47% in 2020 (Morris 2013). One major factor responsible for this projection would be the increase in sales of plug-in hybrid vehicles

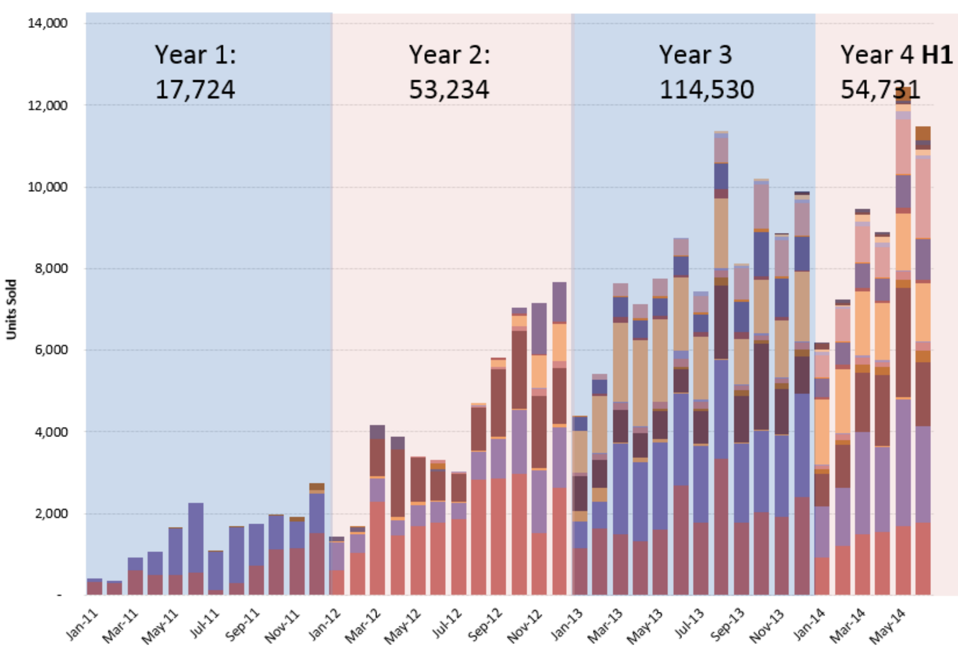

Figure 1: Plug-in Vehicle sales in US. Source: (Energy Policy Info, 2014). Traditional Supply Chain. The dark blocks represent the three chain components – designer, manufacturer, and retailer. The ovals depict the external resource network for the manufacturer component. The orange arrows illustrate the product development flow through the supply chain. The consumer obtains the good outside of the supply chain.

1 The federal tax credit for new PEVs is worth US$2,500 plus US$417 for each kilowatt-hour (kWh) of battery capacity over 655 kWh and the portion of the credit determined by battery capacity cannot exceed US$5,000

(PHEVs). These PHEVs would be equipped with smaller battery packs, which could be fully charged via a standard 110-volt outlet overnight. Additionally, a large number of PEV owners might not necessarily have access to a dedicated parking spot for charging and thus the reliance on workplace or public charging would increase.

2. Electric Vehicle Supply Equipment (EVSE)

The term EVSE in a broader sense defines all the grounding and non-grounding equipment, electric vehicle connectors, attachment plugs and all other kinds of accessories needed for charging of electric vehicles. The most important feature is the two-way communication between the charging unit and the vehicle. The catagories for charging or EVSEs are based on the various charging rates. Charging times range from less than 30 minutes to 20 hours or more, based on the type or level of EVSE, the type of battery, the energy capacity of the battery, how depleted the battery is, and the size of the vehicle's internal charger (US DOE 2012). According to the EV charging station installation guide, these are the following categories (HydroQuebec 2012):

Level 1: 120 Volt AC

These are mostly used for residential charging purposes. The current rating in this case is in the range of 15-20 amperes.

Level 2: 240 Volt AC

These are most commonly used at public charging facilities due to their efficiency in charging as compared to level 1 charging. They use 220-240 voltage range and current is of the order 80- 100 amperes.

Level 3: DC Fast Charging

These kinds of chargers would provide a fast recharge and 50 percent of the total recharge in just 10-15 minutes. They are most suitable for commercial and public applications. In this case the vehicles on-board battery management system controls the off board charger to deliver direct current (DC) to the the battery.

3. Current Practices in EV Charging

Practices in EV charging are dependent on the location and time of charging. According to a report on EVs by (Accenture 2011), 48% of individuals stated the ability to charge at workplace or public charging as one of the factors to be considered before buying an electric vechicle. Some of the big auto companies, such as Nissan and Tesla, are in the process of installing DC fast charging infrastructure. This fast charging infrastructure helps to charge an EV much more quickly than a regular charger and is a good way of reducing the "range anxiety" of EV owners. Range anxiety in the case of an EV is the constant fear of the battery running out of charge while driving, and thus stranding the vehicle (Blanco 2010).

There are business owners who are installing charging stations with free charging options close to their showrooms or retail outlets in order to draw a larger customer base. Tesla is one of the EV manufacturers which is making remarkable efforts in this direction. This company is making a network of supercharging stations which would deliver power at 120kW, almost twice as fast as a regular charger, and will be able to charge an EV in around 30 minutes (Schwartz 2012). They are also planning to have a network of chargers extending across the entire United States (Tesla Motors 2014). The only shortcoming of this undertaking is that these charging stations could only be used for Tesla vehicles.

Estonia has become the first country in the world where an EV can be driven without range anxiety, as they have a nationwide coverage of EV charging stations. The network consists of 165 fast charging stations installed along highways at a minimum distance of 40-60 km. The cost of a single charge is 2.5 to 5 euros in totoal (Estonian World 2013). A similar experiment called the West Coast Electric Highway has shown promise in the US: public charging stations have been installed at 25-mile intervals on a stretch of Interstate 5 in Oregon extending from Ashland in the south to Cottage Grove. This project has installed level 3 DC fast charging and level 2 chargers (Motavalli 2012).

The opponents of public charging infrastructure argue that it would actually not contribute significantly as the majority of EV owners do not access public charging infrastructure because they drive only short distances in urban areas and for not more than an hour each day. These opponents also cite the argument that under-utilized public charging stations would be a waste of taxpayer's money.

As per K. Parks (2007), there can be four different scenarios for charging of EVs.

Uncontrolled Charging or the end-of-travel charging. This is the typical charging scenario for an EV parked in a residence. It requires no smart control equipment to tell how and when charging occurs. Also, it does not give any data about consumer behavior or incentives such as time of use rates (ToU). The assumption for this case is a constant charging rate of 1.4 kilo Watt (kW) based on a common household 110/120 volt 20 Ampere circuit with a continuous rating of 1.8-2.0 kW. Even with this considerably low charging rate, the usual charge time for a completely discharged battery is around six hours.

Delayed Charging. This is similar to end-of-travel charging except that it initiates charging only after 10pm. In this case, a timer is needed either in the vehicle or in the charger to regulate power use. With a modest increase in infrastructure, use of ToU is accessible. This scenario is more likely preferred by utility companies because of the already existing incentives for off-peak energy use. A large number of utility companies like Xcel Energy offer ToU rates to residential customers. The charging rate here is 1.4 kW, which is similar to the above case of uncontrolled charging.

Off-Peak Charging. In this scenario, all charging occurs in residential areas during overnight hours, and it aims to provide the most optimal, low-cost charging as the vehicle charging can be controlled directly or indirectly by a local utility company. In the case of indirect control, the vehicle would be responding intelligently to a real time price signal. In the case of off-peak charging, the charge rate is increased to 3.2kW for maximum system optimization. This is greater than the continuous charge rate of a common household circuit and assumes that 20 percent of all charging is done using 240 V/40Ampere level 2 chargers. The charge time would be around six hours.

Continuous Charging or Publicly-available electricity charging. This scenario is similar to the end-of-travel charging except that it assumes that the electric vehicle is being charged at a public charging station. Although charging during off-peak hours is encouraged, vehicles are charged whenever they are stationary for more than an hour. This is also a case of uncontrolled charging. This type of charging profile has two peaks of use - generally during the morning and evening hours.

4. Recent Advances

There have been many technological advances in the area of wireless charging. A variety of pilot projects have been undertaken in recent years:

Oakridge National Laboratory and Evatran are working on a project entitled "Wireless Power Transfer (WPT) and Charging of Plug-In Electric Vehicles." The team also includes two major international automobile manufacturers, Clemson University's International Center for Automotive Research (CU-ICAR), Cisco, and Duke Energy. After the first year of the project, the team plans to integrate 6.6kW and 10 kW designs into six different production electric vehicle models during the second year of the project for field trials (Plugless Power 2013).

A New York based startup HEVO Power is developing the concept of Green Parking and Green Loading Zones. In this concept, manholes would be equipped with wireless chargers and electric vehicles would similarly be equipped with a wireless receiver to receive the charge. As a result, commuters would get premium parking, there would be less congestion of roads, and EV owners would benefit from extension of current driving ranges. This pilot project has been tested in New York City.

Figure 2: A view of the HEVO Power pilot project, New York City. Source: (Mearian 2013)

5. Cost of Charging an EV

The components related to the charging of EVs are numerous. The primary costs as detailed in the coming paragraphs include setting up charging station infrastructure, equipment operation and maintenance, and electricity costs. Different states have their own criterion for charging tariffs. Some charge on an hourly basis while others charge on a kWh basis. For example, California has passed a law that allows the charging station owners decide which model to adopt. There are different kinds of costs involved in the case of public charging stations, such as the infrastructure costs to be incurred for setting up of the equipment, construction costs of the charging stations and electricity costs depending on the location of the station. The farther the station is from an electric node, the higher the cost.

Cost Estimates for Setting up Charging Stations. The costs involved in setting up the infrastructure and equipment for the charging stations have been calculated based on a variety of parameters. The National Renewable Energy Laboratory's handbook provides an estimate of $15,000 to $18,000 for a Level 2 station; for a DC fast-charging station, the estimate increases to a range of $65,000 to $70,000 (US Department of Energy 2011). In the United States Department of Energy (US DOE) 2012 handbook for PEVs, costs of $12,000 for setting up a station with one Level 2 EVSE unit (plus $4,000 to $8,000 per additional unit) and $45,000 to $100,000 or more for a station with one DC fast-charging EVSE unit are noted. As more and more stations are built and the associated economies of scale are established, the costs involved in setting them up will surely go down**.**

The EVSE described in Section 1.1 plays a very important role in determining the costs incurred for electricity. Different types of EVSEs have different configurations and thus vary in regards to the amount of electricity needed and the time taken to fully charge. For example, a station at a retail store might charge vehicles for short periods that include peak hours, *i.e.* the hours at which the utility company may charge the highest electricity rate. Most of the utility companies offer a lower rate for electricity obtained in off-peak (evening) hours. Thus, people prefer to charge the cars overnight in reference to home charging systems. For public charging stations, the electricity prices vary from $1 to $2 per hour (Yan 2012). A national level service provider called the CarChargingGroup Inc. has recently announced their plans to move from the ToU model to the per kWh model. In certain states (California, Hawaii, Washington, Maryland, Virginia, Oregon, Florida, Colorado, Minnesota, and Illinois) they will now set a price of $0.49 per kWh for EV charging services, instead of billing according to a time-based pricing model (Yan 2012). According to them, the new pricing policy is much more structured as compared to the ToU policy since different EVs take up different amounts of electricity at different rates.

EV Public Charging Costs: Time vs. Energy. One of the most important factors that are necessary for the success of a public charging infrastructure platform is to have the optimum number of public charging stations to satisfy market demand. As a part of the EV Project by US DoE which started in 2009, (Ecotality 2013), public charging stations were established across cities in the states of AZ, CA, GA, OR, PA, TN, TX, WA and DC . In order to encourage participation, they were initially provided at no cost, though this later proved to be an ineffective decision. To provide a more appropriate balance of costs and to incentivize use, some of the infrastructure can be supported by government subsidies. Free charging could help in initiating the process and forming a customer base but will not be helpful in the long run. To establish a PEV charging infrastructure, a private investment would be necessary, and a return on the investment should be in the form of some payment (access fee) by the customer. The access fee is currently calculated based on one of three options:

a. Time-based fee.
b. Energy-based fee.
c. Monthly subscription for all the charging stations in a particular network.

The first two are the most prevalent kinds of fee collection methods employed in the US and thus discussed in detail.

a. Time-Based Fee

These kinds of fees are applicable to the user of the charging infrastructure for the time the vehicle is connected to the unit. The fee is applicable regardless of the fact whether energy is being delivered to the vehicle or not. Once charging starts, the costs accumulate with the passage of time and continue until the charging is stopped or disconnected. The advantages are:

Cost of Infrastructure. It would be beneficial to recover the initial capital costs and the ongoing costs of EV charging infrastructure. Capital costs would include the parking space, the costs of the charging unit, and installation costs of the charging unit and permits (which vary in different cities). Ongoing costs would include costs to maintain the parking lot (cleaning, lighting, etc.), insurance costs, property taxes, and the cost of electricity consumed.

Charger Overuse. As the EV owners are aware of the time-based rates, they would promptly disconnect their vehicle once charging is completed so as to not end up paying more. This helps in making the charging unit available to a large number of PEV's and also discourages parking for extended periods once the charging is complete. It provides a simple and uncomplicated metering scheme based on time

The disadvantages are:

1. Although it accurately represents the overall cost of providing charging infrastructure, it is not proportional to the total energy provided. The time-based access fees reflect the fixed capital cost of the charging station and the time-based ongoing operating costs (such as taxes), but it does not take into account the cost of electricity actually transferred during a charge. As a result, the fee assessed per unit of time to connect to the charger must reflect an average energy transfer. This average can precisely reflect energy transfer for low power charging. According to the example in the US DOE's 2013 EV Project, at a 3.3 kW level 2 AC charge rate, PEVs would generally charge at the full 3.3 kW until very near the end of charge. However, at higher power charging, particularly DC fast charge, the charge rate can vary significantly over time.
2. A PEV owner is paying for blocking access to others even if he or she is not getting charge from the unit.

Energy-Based Fee. This kind of fee is based on total energy consumption. It measures the total energy consumed by the EV and the set price of electricity per kWh is multiplied by the total electricity consumed and billed accordingly. Since the user only pays for the energy consumed, a prior authorization to charge and connect to the vehicles is needed.

One of the advantages of this type of charging fee is that the EV owner pays only for the energy consumed and not for the time the EV was connected to the charger. As of September 2014, 12 states including California, New York and Florida along with the District of Columbia, currently allows the energy-based pricing model (Morris 2014).

This system of fee collection has the following disadvantages:

Cost of Infrastructure. There is little return on the capital costs as there is no accurate way to measure fee collection based on energy consumption. This results from the inability to reset the utility meter every time a new charging sequence is started. The rate of charging additionally depends on the condition of the battery. In this case the access fee can very easily recover the ongoing costs of energy (if not the capital costs). Thus, it gives the owner of the charger a consistent value (energy priced in kWh) for the fee paid to access the charger. However, because most of the investment in the charging infrastructure is the initial fixed capital cost of equipment and installation, it does not provide any profitable returns. The access fee can be adjusted to provide a return on this investment but this would be complicated by charge events, during which the vehicle remains connected to the charger even after completing the charging.

Need for a License. Utility companies have huge financial investments and are the exclusive authority when it comes to owning, generation, transmission and distribution infrastructure, and also providing electricity to the customers. Thus, no other companies are permitted to charge for the sale of electricity on kWh basis. If an EVSE manufacturer wants to charge for electricity he or she has to obtain a special license or a permit. As of now, only a few states CA, CO, VA, MD, FL, WA, OR, MN, ILhave amended their laws to allow such permits for the sale of electricity per the US DOE's Alternative Fuel Data Center (Department of Energy 2013).

Accuracy of Measurement. The accuracy of measurement in this kind of system is questionable and there has to be a third part that can certify the total consumption of electricity and the costs incurred.

6. Wireless Charging Technology

Wireless charging is based on the principle of inductive coupling. In this kind of coupling, a circular magnetic field is generated as a result of the movement of current through a wire coil. If another loop of coil is placed close to the first coil, a current will be induced in it.

The concept of inductive charging has been used for charging small elecronic devices like toothbrushes, cellphones, and tablets with power mats acting as the primary coil. Mutual inductance occurs when the change in current in one inductor induces a voltage in another nearby inductor. This is similar to the mechanism by which transformers work, but it can also cause unwanted coupling between conductors in a circuit. In wireless charging technology, an induction coil present in the induction chargers creates an electromagnetic field within a charging base station. Another induction coil in the portable device acquires the energy generated due to the electromagnetic field and converts it into electric current for charging the battery. These coils are regulated to have the same resonant frequency in order to avoid energy leakage and reduce the risk of electrical shock.

The following section will highlight the various kinds of wireless charging technologies employing this methodology being used currently.

Qualcomm HALO WEVC. Qualcomm HALO Wireless Electric Vehicle Charging (WEVC) is a simple and elegant wireless charging technology. HaloIPT was a leading provider of wireless charging technology before it was acquired by Qualcomm in 2011. Qualcomm, along with HALO and Auckland UniServices (the commercialization company of University of Auckland), have been collaborating on this project.

The HALO is a 28mm plate that can transfer 3.3kWh to the vehicle without requiring it to be parked precisely over the charging unit. The vertical range would be sufficient enough to charge a SUV, meaning at least one foot above the ground - though a height has not been specified by the company to date (Cooper 2012). The first commercial models of the technology which can be laid on the floor in the garage would be available in 2014. The technology has currently been demonstrated on a test basis at the Formula E championship: the safety car, a BMW i8 was successfully run on this technology.

The most important features of this technology which will give it an advantage over other technologies is the alignment tolerance (both in lateral and vertical planes) and the high power efficiency of the transfer between the pad and the car. It uses a patented double "D" quadrature design of the power pads that can transfer power even with significant misalignment (Qualcomm 2012). The power transfer efficiency of a HALO system is almost comparable to a conductive (cable) charging system. A conductive charging system could be 1-2% more efficient than the wireless power transfer, but overall the efficiency of this system would be in the range of 90% or above. With an increase in power from 3.3kW to 6.6kW and up to 20kW the charging efficiency can increase as the losses will remain the same. (Harris 2013)

Estimated Charging time. Charging time depends on the power rating of the system. There are different Qualcomm HALO WEVC systems which can be used for a variety of requirements. This can best be explained through an example the Qualcomm HALO WEVC systems at 3.3kW and 7kW can be used for home charging, 7kW is best suited for public charging and 20kW for fast charging. If a 27kW battery was depleted to 6kW then it would need 21kW of charge. Charge time is obtained by dividing the energy required by the amount of power transferred into the system. At 3.3kW the charge time would be around six and a half hours. The charge time would thus be reduced to little over three hours if the power level was 6.6kW (Harris 2013).

Shaped Magnetic Field in Resonance (SMFIR). This type of technology can be used for dynamic as well as stationary charging. It uses 3-phase power at 60 Hz and either 380 or 440 V entering the inverter which converts it into single phase 20 kHz electricity with 200 A (I.-S. Suh 2011). In the case of electric power, a phase can be defined as the exact position of a point in time on a waveform cycle. A waveform cycle has 360 degrees of phase. It can also be used to express the relative displacement between waves at the same frequency.

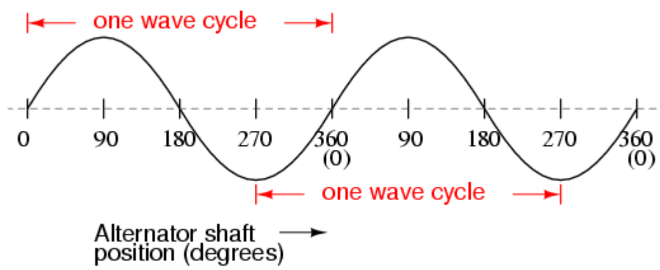

Figure 3: SMFIR wave cycle Source (Kuphaldt 2007)

A 3-phase power supply uses three or more separate conductors to conduct three separate currents at a single frequency, offset in time by one-third of that particular frequency. This power is applied to cables beneath the road surface generating time varying alternating current (AC) magnetic fields. This magnetic flux is exposed to a mutually inductive device installed at the bottom of the EV. This device is composed of a T-shaped iron core with coils wound around the center. The coils are tuned to a natural frequency of 20 kHz in order to ensure a resonance coupling between the power supply and pick-up device. The pick-up device or the receiver is also composed of a T-shaped iron core with coils wound around the center part, installed at the bottom of an EV. Thus, it ensures that resonance coupling between power supply circuit and pick-up devices is engaged.

Pulse Transmission Nanocomposite Magnetic Resonant Coupling (PNMRC). PNMRC is comprised of three major components in conjunction with the EV: a power inverter, power nanocomposite emitting coils, and nanocomposite receiving coils mounted underneath the electric vehicle (Tran 2011). This technology offers two methodologies to solve the issues of energy loss and instability. The first approach is using the pulse transmission mechanism to control the switching frequency and break time on-demand. The second approach is the development of a novel nanocomposite carbon-copper coil. Due to their enhanced signal-to-noise ratio, the nanocomposite coils can result in significant improvements in efficiency of wireless electrical charging for EVs.

Similar technologies include the following examples from Paulus, (2011):

- Evatran uses Plugless Power technology. Here, the PEV has a solution that allows the EV to be modified and refitted. There is 3.3 kW output with a claimed 90 percent transfer capacity. The cost of installing the system comes to around $3000.
- Delphi Wireless Charging System has been developed along similar lines. This technology is comprised of sharply resonant magnetic coupling (non-inductive) across 20 cm air gaps. This product is in development stage, with an early launch in progress.
- ORNL Project: Currently under development at Oak Ridge National Laboratory. It has 90-94% transfer efficiency at a 25 cm air gap. It is greater than 4 kW, which is typical of current technology. It is being targeted to achieve 7 kW.

Construction of Power Pads. Power Pads are the charging units, which are placed underneath an electric vehicle for transfer of power to the vehicle's battery. They are connected to an electric supply and produce an alternating electromagnetic field. The vehicle has a receiver underneath it to receive this and thus the battery is charged. The power pads can be placed on a garage floor. There are a variety of power pads based on different technologies, which can be used in this manner.

Pulse nanocomposite Magnetic Resonant Coupling (PNMRC). The important underlying concept of the PNMRC is the capability to reduce energy loss by minimizing the leakage field with pulse transmission signals and by carefully selecting the design variables of the cables, coils, and resonant frequency. Wireless charging is a type of non-radiative power transfer that uses a magnetic near field with no harmful effects to human beings or animals. Thus, it is safe and simple to operate.

A PNMRC System embedded on the roadway enables dynamic charging to an EV in motion travelling non-stop over a long distance. This is a unique feature that will solve a major obstacle of range limitation and will expedite the deployment of electric vehicles in a new frontier of freedom for electrified transportation.

Delphi Wireless Charging System. Delphi has rights under a patented MIT-developed wireless energy transfer technology based on the following principle: two properly designed devices with closely matched resonant frequencies can strongly couple into a single continuous magnetic field. The wireless charging system is comprised of the vehicle mounted capture resonator and interface electronics — fitted to the bottom of the vehicle, EV power and signal distribution systems, and stationary source resonator pad — mounted on the ground and stationary charging controller.

Compared to inductive systems, this highly resonant magnetic coupling technology will efficiently transfer power over significantly larger distances and will allow more parking-related vehicle misalignment. The Delphi system developed in cooperation with WiTricity Corporation can supply power up to 3.3 kW to a load over a distance of 20 cm (Aldhaher 2014). The system can fully charge an electric vehicle at a rate comparable to most residential plug-in chargers, which can be as fast as four hours.

7. Wireless Charging Systems vs Plug-in-Charging Systems

The use of wireless EV charging is strongly recommended because of the following shortcomings associated with the current EVSE systems (Electric Transportation Engineering Corporation 2010):

a) The current standards for EVs by Society of Automotive Engineers (SAE) make use of J1772, a North American standard for electric connectors used in EVs. It is efficient but must be engineered to prevent inadvertent disconnections, it must have a grounded pole that is the first to make contact and the last to break contact, and it must contain an interlock device that prevents vehicle startup while connected. No such hassle is necessary in the case of a wireless system.
b) The EV inlet must be de-energized until it is attached to the EVSE and also must be de-energized prior to removal of the connector. No EV inlet is present in the wireless system.
c) The EVSE must have a charge current interrupting device that will shut off the electric supply if it senses any risk of shock to the user. The wireless pad will detect the presence of any ferrous or magnetic material near it and stop the charging process. This will be very useful to prevent any kind of fire or a short-circuit hazard. The positioning of the EVSE equipment has to be such that it is closest to the nearest electric supply breaker for cost optimization.
d) The approximate cost for EV charging station for personal use on a garage along with EVSE ranges from \$3000- \$15000. This cost depends on factors that include distance from the nearest circuit breaker and the cost of fitting into the existing infrastructure (Yan 2012).
e) Depending on the output of public charging stations may at times be quite inconvenient. Unlike a couple of minutes at the gas station, electric charging via EVSEs may require plugging in for three-four hours to get a full charge.
f) The need for multiple charging standards and plug standards would be reduced.
g) The power pads would only operate when the vehicle is parked above it and thus cuts down on the costs of charging.

Keeping in mind the above facts, it can be seen that use of inductive charging by a charging pad would be a far more cost effective and less energy intensive process. Efficiency of wireless power transfer is very good. Especially in high power applications, end-to-end efficiencies (AC input to DC output) greater than 90% have been demonstrated. Such success is only possible if each stage in the system has an efficiency of 97-98% or greater (Kessler 2013)

Since vehicles are parked majority of the time, the batteries of EVs can be used for vehicle to grid (V2G) supply. This is a cost effective means of providing regular services by giving spinning reserves, peak shaving capacity, and handling sudden and brief surges in load. Peak shaving capacity means to compensate for the excess demand (load) on a load curve by using buffer generation, which can be from a natural gas plants or any other form of generation. The basic idea is to reduce the sudden surge in demand. However this will not be possible in the case of stationary wireless chargers since the technology to harness bidirectional transfer of wireless power is still under development.

8. Stationary Wireless Charging: How to Cut the Cord on Electric Vehicle Charging?

Stationary wireless charging can be broadly classified into two categories of both residential or personal charging and public wireless charging systems. The details about both these categories are explained below.

Residential/Personal Charging. This type of wireless charging could replace the existing plug-in charging system in the future. The primary requirements and components needed for this are as follows:

Vehicle adapter. This is the receiving part of the coil for the inductive charging process and is fixed permanently beneath the car. It is customized according to the battery size and the type of car (Plugless Power 2014).

Parking pad. This is the floor-mounted enclosure for the transmitting-side coil of the wireless charging system, and is connected to a level-2 charger. It operates at 208/240 V and 3.3 kW of continuous power. It also detects if there is a ferrous or magnetic object present on or near the pad and stops the charging process so as to prevent a fire or any kind of short-circuit hazard. There is also a 3 coil automatic X and Y alignment offset detection and user indication (Chopra 2013).

Power control module. This is the wall-mounted enclosure that houses all control and power supply components for the system. The commercial model includes an integrated indicator panel (Chopra 2013).

Indicator panel. This is a wall-mounted panel which guides EV drivers to properly align the car with the parking pad, displays charging status, and shows diagnostic information to the EV owner (Chopra 2013).

Public Wireless Charging Systems. A Light Duty Vehicle (LDV) like a personal car spends most of its time in a parking lot. In order to avoid congestion at public charging stations, parking lots in offices or public garages can be equipped with wireless charging systems. This relies on all the wireless systems being level-2 systems and thus rated for 80-100 A current range and 240 V. The total power consumption for a three-phase system can be calculated using the following formula:

$$P = \sqrt{3} * V * I * Powerfactor$$

In this formula, V represents the applied voltage and I represent the current. Assuming a power factor of 0.8 and 80 A and 240 V, around 26kW of power will be required to charge depending on the size of the battery.

Paulus et al (2011) suggests the use of solar panels in the roof of the shade at the parking location to save space and provide clean power. The appropriate number of solar panels required can be calculated using the radiation received at the location per day. This would help to dramatically reduce CO_2 emissions.

9. Scenario Analysis

The per-mile driving costs for stationary charging of a plug-in EV are compared by creating three different scenarios:

- Plug-in charging vs. Wireless charging at home
- Stationary wireless charging vs. Plug-in charging at home
- Wireless charging vs. Plug-in charging at a public charging station

Scenario 1: Plug in Charging vs. Wireless Charging at Home. In this scenario, a conventional home plug-in system is compared with a home wireless charging system (see Table 7-1). The initial cost of installing the pads in the car as well as the base unit may come to $3000 (primary information from Evatran Group, Inc.). The other assumptions considered in order to arrive at the costs are as listed below. Electricity costs are estimated at 11 cents per kWh.

- Discount rate: 10 percent
- Vehicle ownership: 5 years
- Daily miles driven per day: 40
- Vehicle cost: $39000
- Cost of charging at Charging Station: $1 per kWh
- Cost of home plug-in station: $2200 (Kanellos 2010)
- Cost of home wireless station: $3000

Vehicle	EV – long range with plug-in (Home charging stations)	EV – long range with wireless charging (At home)
All-electric range	32	32
Efficiency on electric drive (miles / kWh)	3.6	3.6
Miles/day (total)	40	40
Miles/day (electricity)	115.2	115.2
No. of years	5	5
Electricity cost ($/kWh)	0.11	0.11
Discount rate	10%	10%
Purchase Price*	41,200	42,000
CRF	0.264	0.264
VMT / year (total)	14600	14600
VMT / year (electricity)	14600	14600
$ / year (electricity)	446.11	446.11
$ / year (capital)	8240	8400
VMT (total)	73000	73000
$ / mile (total)	0.179	0.182

* includes the costs of setting up battery charging station at home for both plug-in and wireless

Table 0-1: Cost Comparison for home plug-in charging systems vs. the wireless charging systems

Conclusion. It can be concluded from this table that the total cost of plug-in and wireless charging in the home is comparable. Thus, wireless charging systems cannot be assumed to bring in the economic advantages based on this crude analysis but may prove to be a relatively hassle-free option. A wireless charging system could rest on the garage floor and an EV can be charged even with a slight misalignment of the wireless charging pad and the vehicle.

Scenario 2: Stationary Wireless Charging (at public stations) vs. Plug-in Charging at Home.

Similarly, the second scenario was worked out using the matching assumptions for stationary plug-in charging at home versus wireless charging at public stations with the results of 0.18 and 0.42 $/mile as described in Table 7-2.

Vehicle	EV – long range with plug-in (Charging stations at home)	EV – long range with wireless charging (at parking lot)
All-electric range	32	32
Efficiency on electric drive (miles / kWh)	3.6	3.6
Miles/day (total)	40	40
Miles/day (electricity)	115.2	115.2
No. of years	5	5
Electricity cost ($/kWh)	1	0.11
Discount rate	10%	10%
Purchase Price	39,000	42,000
CRF	0.264	0.264
VMT / year (total)	14600	14600
VMT / year (electricity)	14600	14600
$ / year (electricity)	4055.56	446.11
$ / year (capital)	7800	8400
VMT (total)	73000	73000
$ / mile (total)	0.419	0.182

Table 0-2: Cost Comparison for home plug-in charging systems at home vs. the wireless charging systems

Conclusion. It can be concluded from the above table that wireless charging of EVs at public charging stations may prove to be more economic as compared to plug-in charging at home (not taking into consideration the ToU rate and kWh usage at a public charging station versus the tariff plan for EV charging by a utility).

The wireless charging at a public charging station would also save considerable space as EV's can be parked over the charging pad, which can easily be put inside on the floor. Thus it will eliminate clutter of wires, providing more available parking space. The most important advantage will be that the need for different adaptors will be eliminated. Thus, a Nissan could be charged on a Tesla charging station.

Scenario 3: Wireless Charging vs. Plug-in Charging at a Public Charging Station. For the third scenario, calculations were conducted for plug-in charging versus wireless charging at public charging stations with results as 0.42 and 0.43 $/mile respectively as shown in Table 7-3.

Vehicle	EV – long range with plug-in (public charging stations)	EV – long range with wireless charging (public charging Station)
All-electric range	32	32
Efficiency on electric drive (miles / kWh)	3.6	3.6
Miles/day (total)	40	40
Miles/day (electricity)	115.2	115.2
No. of years	5	5
Electricity cost ($/kWh)	1	1
Discount rate	10%	10%
Purchase Price	39,000	42,000
CRF	0.264	0.264
VMT / year (total)	14600	14600
VMT / year (electricity)	14600	14600
$ / year (electricity)	4055.56	4055.56
$ / year (capital)	7800	8400
VMT (total)	73000	73000
$ / mile (total)	0.419	0.430

Table 0-3: Cost Comparison for Public charging stations on plug-in charging systems and the wireless charging systems

Conclusion. From the above comparison it can be concluded that the costs of plug-in charging and wireless charging at a public charging station are nearly the same. Thus, a large number of public charging stations could be converted from plug-in charging to wireless charging stations which will allow for the charging of a wide range of EV's irrespective of their make at a single charging station. One drawback is that the EV's would have to be fitted with a wireless charge-receiving unit. Another drawback could be that the public charging stations would have to be fitted with wireless charging systems using any of the technologies discussed above. The infrastructural cost would thus increase. However, with the increase in demand of wireless charging technology and advent of new and cheaper technology, the infrastructural cost would decrease. Also, the wireless charging could be slowed by a small fraction as the losses in transfer of power would be there as compared to plug-in charging.

10. Dynamic Wireless Charging

Dynamic wireless charging refers to the charging of the EVs while they are in motion. It is a new concept and is still in the experimental stages because of the restrictions in power transfer in motion. As per the case study, there can be two possible scenarios with respect to dynamic charging (Chopra 2013). One is for urban areas where the wireless charging units (power mats) can be installed at traffic signals and the other one is for highways where they suggest installation of charging equipment at specific distance intervals.

Closed Route Electric Vehicles Charging. In this kind of arrangement it is assumed that only the public transport, such as short range buses, will be using the wireless charging system. The wireless charging units that will be placed at traffic signals would enhance the range of PEVs in urban driving conditions (Chopra 2013). However, private transportation like small cars can also benefit from such a system.

Similar to a smartcard (used for sub-way and other public transportation systems), a Radio Frequency Identification (RFID) fob can be programmed with user information in order to keep a log of the number of users and the amount of use. The RFID reader collects the information from the fob to activate the EVSE station. A monthly subscription for the user keeps the fob active; the monthly fee can be based on either number of actual uses or a set monthly fee. The reader is programmed for the accepted RFID. The costs in this scenario turn out to be $0.18/mile. However, the information provided in Brooker, Wu, Earlywine, & Gonder (2012) indicated a price of $0.27/mile as described in Tables 8.1.

Table 8-1: Cost Comparison for Wireless Public Charging Stations and Dynamic Charging Systems

Vehicle	**EV – long range with plug-in Charging (Charging stations)**	**EV – Closed route wireless charging (dynamic) on at traffic signals. E.g. Utah and South Korea bus**	**EV – long range with wireless charging (dynamic) on highways**
All-electric range	32	32	32
Efficiency on electric drive (miles / kWh)	3.6	3.6	3.6
Miles/day (total)	40	40	40
Miles/day (electricity)	115.2	115.2	115.2
No. of years	5	5	5
Electricity cost ($/kWh)	1	0.17	0.17
Discount rate	10%	10%	10%
Purchase Price	39,000	39,000	39,000
CRF	0.264	0.264	0.264
VMT / year (total)	14600	14600	14600
VMT / year (electricity)	14600	14600	14600
$ / year (electricity)	4055.56	689.44	689.44
$ / year (capital)	7800	7800	7800
VMT (total)	73000	73000	73000
$ / mile (total)	0.419	0.188	0.188

Conclusion. It can be concluded on the basis of the above table that cost of charging per mile is less in the case of a dynamic wireless charging system if employed on a highway or a traffic signal.

Advantages/Disadvantages of a dynamic wireless charging systems over stationary wireless system. With a dynamic wireless charging system in place, a vehicle could be charged while moving. As a result, the capacity of the battery needed would be less, thus resulting in an overall decrease in the size of the battery. This would also result in a decrease in overall weight of the vehicle and in turn contributing to a decrease in cost.

The most important advantage from the perspective of an EV would be the range being increased many fold. There would be no range anxiety as experienced by current EV owners in the contemporary infrastructure. One of the major problems that has recently been realized is the rapid growth in the sale of electric vehicles in the US (from 52,835 in 2012 to 96,702 in 2013) which is placing tremendous pressure on the electric-vehicle charging infrastructure. Most public charging stations are severely congested. Wireless charging would cut down on the need for charging stations and the capital can be used for a dynamic wireless system that would be able to charge more cars simultaneously.

Some of the disadvantages of this technology that are still being researched are the harmful effects that induction charging may have on the body tissue. According to a latest IEEE paper (Ding 2013), the electric vehicles that make use of Inductive Power Transfer also induce an Electro Motive Force (EMF) in the human body. This EMF could be very dangerous to the human tissues. A study to determine the safety of EM radiation from wireless charging was conducted in France, and the effects on a human body were modeled and published in P.-P. Ding (2013). The main purpose of the study was to provide design guidelines so as to minimize the impact of EM radiations on human body. It also concluded that the compliance with safety guidelines is a must. Another study conducted in the US, concluded that a standard test should be made mandatory (Jiang, Brazis and Tabaddor 2014). It should cover electrical shock, electromagnetic field exposure level and fire hazard. The safety standards must also take into account the requirements for implants such as inner ear implants or a pacemaker in the heart. Thus, EV manufacturers should consider the safety guidelines for induced EMF and develop standardization process to make it safe.

Latest Developments in the Wireless Dynamic Electric Charging. There have been some very promising developments in the field of Wireless Dynamic Charging, which have been successfully demonstrated and are in the process of implementation. Some of them are noted in the following sub-headings:

The Aggie Bus- Utah State University. A start-up at Utah State University named WAVE Technologies, Inc has introduced new public transit technology. These vehicles, called WAVEs (Wireless Advanced Electric Vehicles) have made a remarkable breakthrough cutting down emissions, reducing the battery size of electric vehicles, and also providing effective public transit. It is a joint initiative where the Utah State University's Wireless Power Transfer team has been working with the Utah Science Technology and Research Initiative's (USTAR) Advanced Transport Institute. The prototype has been named as the Aggie Bus, and it has been undergoing trials from almost one year. This is the first use of Wireless Power Transfer by a North American entity.

The electric bus at the University of Utah campus will transfer students and faculty to the center of the campus which is a one-mile route. The bus will be able to recharge its batteries every time it returns to the base station while waiting for the commuters at the bus stop, simply by stopping above a magnetic pad buried in the pavement. This would be done by aligning the charging device on the bottom of the bus to the power transfer pad in the road. It can even be done in the case when the bus and the pad are misaligned by up to six inches (Heyborne 2013). This bus will charge for five minutes out of every fifteen minutes of its commute, thus amounting to a charging of approximately 40 times a day and provide enough power for 12 hours of operation.
This technology leads to a reduction in the size of EV batteries and thus an overall decrease in the weight and cost of the vehicle. This would have the added benefit of less noise pollution on campus as compared to fossil-fuel powered buses and also decrease in overall emissions.

The South Korea Bus- OLEV. The Korea Advanced Institute of Science and Technology (KAIST) have recently developed the Online Electric Vehicle (OLEV) platform. The buses which operate on this technology are being used in the city of Gumi in South Korea as shuttles on school campuses for short passenger routes. They currently run on a very short distance ranging fifteen miles (Thornton 2014) and use Shaped Magnetic Field in Resonance Transfer (SMFIR) technology. The electricity generated by underground power cables is transferred via a magnetic field to the pickup units which are located underneath the buses. But only one percent of the bus's route has been laid with underground power cable, because an on-board battery supplies power. This battery is less than one-fifth the size of the battery used in battery-powered buses and one-third the size of the battery used in electric cars. The technology used is different from inductive coupling. The length of the road strip takes up only 5-15% of the entire road, thus requiring only a few sections of the road to be rebuilt with the embedded cables (Suh 2011).

It also makes sense to use these technologies for public transport, as such vehicles require halts at regular intervals and thus the charging strips (inside the roads) can be built at the bus stops rather than the entire route.

Developments in Pipeline: FIA Formula E Championship. A new Formula E class, officially the FIA Formula E Championship, has recently been announced. It is a class of auto racing, sanctioned by the Fédération Internationale de l'Automobile (FIA) in France (FIA 2013). It will be a racing championship restricted to electric vehicles. Qualcomm and Renault are the official partners of Formula E.

The "formula," specified in the name, refers to a fixed set of rules that must be complied by all the participant cars. The rules are on the weight, engines, power train, brakes, batteries, and a variety of other parameters. This championship is designed to be the highest class of competition for single-seat, electrically-powered racing cars. Another interesting aspect is that due to lower noise pollution as compared to the traditional Formula 1 championships, the vehicles can run through the heart of the cities. The series was planned in 2012, with the inaugural championship to be held in 2014–15. The first season will be running from September 2014 to June 2015 with a maximum of 10 races (FIA 2013). The new series has attracted a host of big sponsors like Qualcomm and DHL. According to a Formula E projection, the total television viewership is assumed to be around 205 million viewers across the world for the debut season in Sep 2014 (Sylt 2014). In the inaugural race of Formula E in Beijing, a peak audience of 713,000 watched the live broadcast on ITV4, which is remarkable. Around 40 million are assumed to have watched the race worldwide (David 2014). In the first season, Qualcomm plans to bring its HALO wireless charging technology using an electric pad only to the safety cars (which runs alongside racing vehicles) but it hopes to bring the dynamic wireless charging in the second season of Formula E.

Figure 4: Spark-Renault SRT_01E; Debut in Formula E championship Source: (Gtspirit.com 2014)

Electric Vehicles: Why or Why Not? Electric Vehicles still do not have a mass appeal as strong as conventional gasoline vehicles. The market for EV's also does not attract a large number of customers. One of the major causes for this is the number of myths which exist for use of EVs and people need to be made aware that they are baseless. Some of the myths can be enlisted as follows:

Switching to an EV does not reduce carbon emissions.
A lot of the people have a notion that switching to an electric vehicle would not actually reduce the pollution. The CO2 would eventually come from the coal plants used for generating the electricity to charge the EV's. This notion can be proved wrong in terms of the following arguments. According to the report State of Charge by Union of Concerned Scientists (UCS), EV's charged from electricity grid produces less emissions than an average compact gasoline powered vehicle (with a fuel economy of 27 miles per gallon). This is true even in case of "dirtiest" electricity grids where most of the electricity production is by coal. EV's charged entirely from electricity produced by wind or solar does not produce any emissions (Anair 2012).

Recycling of EV batteries is an environmental hazard.
Some people argue that batteries of gasoline powered vehicles have a recycle rate of 98% in the US, but EV batteries do not have the same recycle rate (Sierra Club 2013). But the new batteries will be made of many other metals except Lithium Ion. According to a report by Sandia National Laboratories, a secondary market is being developed for spent nickel/metal hydride batteries, which could be used in stationary applications.

Increase in Electricity Bill of consumers. The use of EVs might lead to a rise in the electricity bill of the consumer but it would be offset by the decrease in use of gasoline. According to an estimate, if an EV is driven for 15,000 miles in one year, at an average electricity rate of $0.12 per kilowatt hour a consumer would end up paying around $500 per year for charging the battery. If a similar, gasoline vehicle with an efficiency of 28 miles per gallon is used, it would cost $1900 (assuming $3.54 per gallon as the cost of gasoline). As a result the savings are $1400, a 74% reduction in fuel costs (Sierra Club 2013).

Range of an EV. A majority of people suffer from range anxiety that the battery would run out of charge. But on an average a person in US, does not drive more than 35 miles a day. A fully charged EV can go from 70 to 130 miles on one charge. There are regular and fast charging stations being installed in most of the states on highways.

Cost of an EV. The initial price of an EV is more expensive than a regular gasoline vehicle, but a lot of other factors like the price of gasoline, maintenance etc. should be taken in to account. Also, a federal tax credit of up to $7,500 for the initial purchase and a partial tax credit for the charging are being offered for EV's. The maintenance costs are approximately 46% less than of a gasoline vehicle according to federal government study.

11. Policy Recommendation

As per the crude analyses provided in this analysis, there is not much difference in the cost of having a home plug-in system versus a home wireless system for EV charging. However, the other benefits of a wireless system are many. The government should encourage the wireless systems by providing extra tax credits to consumers. The price of setting up a home wireless system would be much less than a broader public wireless charging system, and thus can be incorporated as a part of regular home electronics. In order to encourage the installations of home charging systems a tax credit from the government could prove to be very helpful.
As per the cost calculations for dynamic charging options above, it can be estimated that the cost of infrastructure is not as high as the costs for charging at the public charging stations. In addition, the costs of maintain a public charging structure and the ongoing costs would be greater than the costs for setting up of a Dynamic Wireless Charging

Infrastructure. Thus, establishing this infrastructure could turn out to be beneficial, but would require government implementation. There could be a separate, dedicated lane for EVs in case of LDV and in the case of buses or other forms of public transport (which can be charged at every stop by use of level-2 charging). In order to implement this infrastructure, local governments, as well as the federal government, should consider this option in their long-term plans. Assuming that the charging that happens through such an infrastructure will be very frequent, the need for level 3 charging would be eliminated. It can also be seen that financial costs would be reduced per mile in comparison to an at-home system and will thus be beneficial to car owners and in turn encourage increased adoption of wireless EVs.

A market-based mechanism can be put in place for electricity saved, and tax credits can be traded in accordingly. The use of solar panels to supply 3 kW of energy could be another option that the government can look into, though the amount of solar cells for 3 kW cannot fit into a typical pad. Thus, rooftop solar options for public charging spaces should be explored. RFID technology can be employed by fitting both the car and pad on the road with a fob. This will give a more accurate value of the electricity used for charging and the amount of time the car is in contact with the pad, and thus will help in the formulation of a business model. One way of establishing such an infrastructure could be through the utilization of manholes that already exist on roads for drainage systems.

A crucial factor which must be considered while exploring any kind of public charging mechanism is the cost of electricity. The difference in the time-of-use rates and the charging rates based on electricity consumption can a significant difference in the financing of a public charging infrastructure, but the relevant factors vary by individual state. Additional incentives for Wireless EV owners may be given as a congestion allowance in the form of tax rebate because of less charging congestion at a public charging station. The use of continuous available electricity will lead to use of smaller batteries and thus the cost of PEVs will tend to decrease, making it a more viable and popular option.

A large number of polices which support the vehicle electrification have been or are in the process of implementation by the government. With the decreasing conventional oil reserves, it is getting even more difficult to meet the US demand of 8.5 million barrels of oil a day (Gordon 2012). Market forces alone cannot contribute to a major shift towards low-carbon fuels but a concrete policy framework would be imperative. The Obama administration has been working meticulously to develop federal policies to support its goal of 1 million electric vehicles by 2015. Some of the noteworthy policies include: 2012 Through 2016 Greenhouse Gas Emission Regulations, Beyond 2017 Greenhouse Gas Emission Regulations, Advanced Technology Vehicle Manufacturing (ATVM) loan program, EV charging station tax credit, Federal PEV tax credits and PEV community readiness projects.

In spite of all the federal programs, the road ahead for EV’s will not be smooth. There has been a pushback against federal funding mainly because of a few incidents of failure.

Missouri-based Smith Electric Vehicles had to recently close its Kansas plant. The US DOE provided \$32 million as a Stimulus grant to Smith Electric Vehicles for the manufacture of 510 plug-in electric delivery trucks. It was projected by the White House that the company would create 220 direct and indirect jobs but the company could create the hourly equivalent of only 70.35 jobs. The DOE spent an average of \$414,000 for each job created. After sometime, there was a backlash among the employees as the company had been struggling with its finances due to losses suffered (Institute for Energy Research 2014).

Another very famous incident is of the failed DOE investment in the solar company Solyndra which declared bankruptcy in 2011, even after receiving \$535 billion in federal grants (Stephens and D.Leonnig 2014). The US DOE loans have virtually stopped due to scrutiny by Congress over the government to act as a venture capitalist. This would achieve only a part of the goal necessary to curb emissions from the transportation sector as a whole. The transportation sector is a major contributor and responsible for more than 1.8 billion Metric Tons of emissions or 27.1% of total US GHG emissions (Davis 2013). Heavy-duty vehicle (Class-8 trucks) and freight carrier’s account for about 26% of all petroleum-based fuels consumed in the US transportation sector (Grenzeback 2013). If the policy framework to support the research and move towards electric trucks can be manifested, then savings in fuel consumption and decrease in carbon emissions would be evident. One such example is of

Siemens, which has come up with the state-of-art trucks, which can be charged through overhead power lines while in motion.

Another major hindrance to the clean energy programs is the strong lobbying in congress by the oil companies. In the year 2013, the oil and gas industry spent $144.7 million, or more than $396,000 per day, lobbying the U.S. Congress and federal agencies. More than $15 million has been spent by the oil companies in the form of contribution to political campaigns (Taxpayers For Common Sense 2014). Conversely, the total lobbying expenditure by renewable energy group "Miscellaneous Energy" was just $385,000 in the year 2013 (Politics 2014). In spite of the huge financial disadvantage, the renewable energy groups are trying their best to make the lawmakers to act in favor of clean energy.

A hidden threat to the renewable energy industry is the surge in natural gas production in the US, resulting in low natural gas prices. A mandate by the Congress to pull the plug on federal Production Tax Credit (PTC) for wind energy by the end of 2013 also has affected sale of EVs in an indirect manner. Wind energy is among the most viable options for powering a charging station The PTC provides a 2.2-cent per kilowatt-hour benefit for electricity generated from a utility-scale turbine during the first 10 years of its operation (Doering 2012).

US Environmental Protection Agency's approval for the use of E15 (Ethanol 15), gasoline with a 15% by volume blend of ethanol would also impact the EV market negatively. E 15 is still in the early stages and the companies selling E15 is less as compared to the regular gasoline, but it might adversely affect the sale of EVs in the future.

The efficiency of an EV is almost 90 percent as compared to 20 percent of a gasoline powered vehicle (Burgelman and Grove 2010) It is also a known fact, that an EV charged with renewable energy With the advent of technology to increase the range of EVs, it may completely replace the gasoline-powered cars in the near future. The electrification of entire freight transportation would lead to great savings in energy. It will also help to curb the rising oil imports and reduce dependence on foreign oil. The manufacturing of EVs and their batteries would also lead to an increase in GDP by creating new jobs. The EVs can also be helpful in stabilizing the power grid and research is underway on the same. Federal funding to advance research and development for EV and battery technology is one of the key issues that need to be addressed.

A concrete and strategic policy roadmap must be formulated for widespread acceptance and deployment of EVs. This would lead to market-based solutions for deployment of EV charging stations and reduction in the cost of their usage. An increment in tax credits for buying electric vehicles with a replacement warranty of the battery would also facilitate increase in sale of EVs. Collaboration at various levels between auto companies, utilities and the policy-makers is the key to success. In order to harness the benefits for protecting the environment and leap frogging to a better tomorrow; it is quintessential to spread awareness about the EVs.

In lieu of all the above facts, it can be concluded that future holds a great potential for electric vehicles and it can be harnessed only if right efforts are made for consumer adoption.

References

Accenture. "Plug-in electric vehicles: Changing perceptions hedging bets." *Accenture.com.* 2011. http://www.accenture.com/SiteCollectionDocuments/PDF/Resources/Accenture_Plug-in_Electric_Vehicle_Consumer_Perceptions.pdf (accessed 11 24, 2014).

Aldhaher, Samer. "Design and Optimization of Switched-Mode Circuits for Inductive Links." 2014. (accessed 11 24, 2014).

Anair, Mahmassani. "State of Charge." *ucusa.com.* June 2012. http://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_vehicles/electric-car-global-warming-emissions-report.pdf (accessed 11 26, 2014).

Blanco, Sebastian. *Auto blog green.* Sep 1, 2010. http://green.autoblog.com/2010/09/01/gm-trying-to-trademark-range-anxiety-to-tell-you-about-electr/ (accessed Nov 24, 2014).

Brooker, A, H Wu, M Earlywine, and J Gonder. "Evaluation of the Costs, Benefits, and Feasibility of Electric Roadway Technologies and Travel Scenarios." 2012. (accessed 11 24, 2014).

Burgelman, Robert A., and Andrew S. Grove. "Toward Electric Cars and Clean Coal: A Comparative Analysis of Strategies and Strategy-Making in the U.S. and China." 2010. http://web.stanford.edu/class/me302/PreviousTerms/2011-03-01%20Strategic%20Thinking%20around%20EVs.pdf (accessed 12 14, 2014).

Chopra, Swagat, Bauer, Pavol. "Driving Range Extension of EV With On-Road Contactless PowerTransfer—A Case Study." *IEEE transactions on industrial electronics* 60, no. 1 (2013): 329-338.

cleantechnica. n.d. http://cleantechnica.com/2012/11/16/-state-university-introduces-wireless-electric-bus/#4sgEbkxptVfYkoj2.99 (accessed November 10, 2012).

Cooper, Daniel. *Qualcomm Halo wireless charging concept eyes-on.* Jan 12, 2012. http://www.engadget.com/2012/01/12/qualcomm-helo-wireless-charging/ (accessed 04 17, 2014).

David. *Formula E debut peaks with 0.7m in UK.* Sep 14, 2014. https://f1broadcasting.wordpress.com/2014/09/14/formula-e-debut-peaks-with-0-7m-in-uk/ (accessed 11 24, 2014).

Davis, Diegel. *Transportation Energy Data Book 32 Edition.* ORNL, 2013.

Department of Energy. *Alternative Fuels Data Center.* 11 12, 2013. http://www.afdc.energy.gov/laws/state (accessed 04 18, 2014).

Department of Energy, US. *Alternative Fuels Data Center.* 11 25, 2014. http://www.afdc.energy.gov/data/10366 (accessed 11 27, 2014).

Doering, Christopher. *usastoday.com.* 2012. http://usatoday30.usatoday.com/news/washington/story/2012-07-02/renewable-fuels-oil-congress/55987052/1 (accessed 2014).

Ecotality. 2013. http://www.theevproject.com/overview.php (accessed 12 14, 2014).

EERE, US DOE. *Alternative Fuels Data Center.* November 25, 2014. http://www.afdc.energy.gov/locator/stations/ (accessed November 24, 2014).

Electric Transportation Engineering Corporation. "Electric Vehicle Charging Infrastructure Deployment Guidelines Ver. 3.1." April 2010. http://www.oregon.gov/ODOT/HWY/OIPP/docs/evdeployguidelines3-1.pdf (accessed November 24, 2014).

Electric Vehicle News. 12 2012. http://www.electric-vehiclenews.com/2012/12/raleigh-nc-first-city-to-test-wireless.html (accessed 11 24, 2014).

Energy Policy Info. June 2014. http://energypolicyinfo.com/wp-content/uploads/2014/07/pev-sales-june-2.png (accessed Nov 24, 2014).

Energy Policy Information Center. July 04, 2014. http://energypolicyinfo.com/2014/07/two-record-months-of-electric-vehicle-sales/ (accessed 11 27, 2014).

Estonian World. *Estonia becomes the first in the world to open a nationwide electric vehicle fast-charging network.* Feb 20, 2013. http://estonianworld.com/technology/estonia-becomes-the-first-in-the-world-to-open-a-nationwide-electric-vehicle-fast-charging-network/ (accessed 11 28, 2014).

EV Project, US Department of Enerrgy. "Electric Vehicle Public Charging – Time vs. Energy." *www.theevproject.com.* March 2013. http://www.theevproject.com/cms-assets/documents/106078-254667.tvse.pdf (accessed 04 17, 2014).

FIA. *fia.com/news.* 06 28, 2013. http://www.fia.com/news/world-motor-sport-council-1 (accessed 04 18, 2014).

fiaformulae.com. *Formula E Updates.* 04 14, 2014. http://www.fiaformulae.com/news/WMSC-confirms-teams (accessed 04 18, 2014).

Gordon, Sperling, Livingston. "Policy Priorities for Advancing the US Electric Vehicle Market." 2012. Policy Priorities for Advancing the US Electric Vehicle Market (accessed 12 11, 2014).

Grenzeback, Lance R. *Freight Transportation Demand:Energy-Efficient Scenarios for a Low-Carbon Future.* Golden: DoE, 2013.

Gtspirit.com. "Formula E Racecar Spark-Renault SRT_01E Completes Test Debut." Sep 2014. http://www.gtspirit.com/2013/11/23/formula-e-racecar-spark-renault-srt_01e-completes-test-debut/ (accessed 11 24, 2014).

Harris, Stephen. "Your questions answered: inductive charging for road vehicles." *Engineer (Online Edition).* Centaur Communications, 2013. p10-10.

Heyborne, Elenor. *Driving transportation to a cleaner future.* Nov 11, 2013. http://www.ksl.com/?sid=27588541 (accessed April 17, 2014).

HydroQuebec. " Electric vehicle charging station technical installation guide." 2012. http://www.hydroquebec.com/transportation-electrification/pdf/technical-installation-guide.pdf (accessed November 12, 2012).

Institute for Energy Research. *Another DOE Flop: Smith Electric Vehicles Closes Kansas Plant.* April 16, 2014. http://instituteforenergyresearch.org/analysis/another-doe-flop-smith-electric-vehicles-closes-kansas-plant/ (accessed 11 24, 2014).

Internal Revenue Service. "New Qualified Plug-in Electric Drive Motor Vehicle Credit." *Internal Revenue Bulletin: 2009-48.* November 30, 2009. http://www.irs.gov/irb/2009-48_IRB/ar09.html (accessed November 28, 2012).

Jiang, Hai, Paul Brazis Jr., and Mahmood Tabaddor. "Safety Considerations of Wireless Charger for Electric Vehicles – A Review Paper." *Underwriters Laboratories LLC.* 30 04, 2014. http://newscience.ul.com/wp-content/uploads/sites/30/2014/04/Safety_Considerations_of_Wireless_Charger_for_Electric_Vehicles.pdf (accessed 11 24, 2014).

K. Parks, P. Denholm, and T. Markel. "Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel

Energy Colorado Service Territory." May 2007. http://www.nrel.gov/docs/fy07osti/41410.pdf (accessed 11 24, 2014).

Kanellos, Michael. *Greentech Grid: Will EV Charging Stations Be Free?* Dec 14, 2010. http://www.greentechmedia.com/articles/read/will-ev-charging-stations-be-free (accessed Apr 17, 2014).

Kessler, Morris. "Highly Resonant Wireless Power Transfer:Safe,Efficient and over Distance." *http://www.witricity.com/.* 2013. http://www.witricity.com/assets/highly-resonant-power-transfer-kesler-witricity-2013.pdf (accessed 11 24, 2014).

Kuphaldt, Tony R. 2007. http://www.allaboutcircuits.com/vol_2/chpt_1/2.html (accessed 11 24, 2014).

Mearian, Lucas. *Auto industry cuts the cord on electric car charging.* October 2013. http://www.computerworld.com/s/article/9243346/Auto_industry_cuts_the_cord_on_electric_car_charging (accessed Nov 24, 2014).

Morris, Charles. Sep 2014. http://chargedevs.com/newswire/blink-network-introduces-kwh-based-pricing/ (accessed 11 24, 2014).

—. Oct 2013. http://chargedevs.com/newswire/navigant-evse-market-will-see-huge-growth-more-shakeups/ (accessed 04 17, 2014).

Motavalli, Jim. *Wheels: The Nuts and Bolts of Whatever Moves You.* March 19, 2012. http://wheels.blogs.nytimes.com/2012/03/19/for-e-v-drivers-a-stretch-of-oregon-interstate-to-relieve-range-anxiety/ (accessed 04 16, 2014).

Navigant Research. *Electric Vehicle Charging Equipment.* 2012. http://www.navigantresearch.com/research/electric-vehicle-charging-equipment (accessed 04 18, 2014).

P.-P. Ding, L. Pichon, L. Bernard and A. Razek. "Electromagnetic Field Computation in Human Body Exposed to Wireless Inductive Charging System." 2013. http://www.mht.bme.hu/~bilicz/compumag2013/files/pc1-9.pdf (accessed 11 24, 2014).

Paulus, Mike. "Wireless Charging System for Electric Vehicles." *ORNL.* 2011. http://www.ornl.gov/adm/partnerships/events/Dec_Spark/Paulus_Wireless%20Power%20Transmission%20Presentation%20-%20Paulus%20v2.pdf (accessed November 24, 2014).

Ping-Ping Ding, Laurent Bernard, Lionel Pichon, and Adel Razek. "Evaluation of Electromagnetic Fields in Human Body Exposed to Wireless Inductive Charging System." *IEEE Transactions on Magnetics*, 2014.

"Plug In America and Sierra Club." *60 US Cities to Celebrate 2012 National Plug In Day.* September 2012. http://evworld.com/news.cfm?newsid=28763, accessed on Nov 28, 2012. (accessed November 28, 2012).

Plugin Cars. *The Ultimate Guide to Electric Car Charging Networks.* November 2014. http://www.plugincars.com/ultimate-guide-electric-car-charging-networks-126530.html (accessed Nov 24, 2014).

Plugless Power. 2014. https://pluglesspower.com/plugless-questions/ (accessed November 24, 2014).

—. *Plugless leads the way.* 2014. https://pluglesspower.com/learn-v2/ (accessed November 24, 2014).

—. *Press Release.* March 18, 2013. https://pluglesspower.com/pgls_press_release/evatran-awarded-department-of-energy-sub-contract-to-integrate-high-power-wireless-charging-technology-into-production-electric-vehicles/ (accessed 11 24, 2014).

Politics, Center for Responsive. 2014. https://www.opensecrets.org/lobby/clientsum.php?id=D000056025&year=2013 (accessed 2014).

Qualcomm. *Qualcomm HALO Technology.* 2012. http://www.qualcommhalo.com/index.php/technology.html?id=35#technology (accessed 04 16, 2014).

Ridley-Gal, Sarah. *CarCharging Implements New Pricing Policy at Per Kilowatt Hour Rates.* August 8, 2012. http://www.carcharging.com/about/news/all/carcharging-implements-new-pricing-policy-at-per-kilowatt-hour-rates/ (accessed November 28, 2012).

Schwartz, Ariel. *Why Tesla's Free Electric Vehicle Superchargers Are A Big Deal (And Why They Aren't).* Sep 27, 2012. http://www.fastcoexist.com/1680627/why-teslas-free-electric-vehicle-superchargers-are-a-big-deal-and-why-they-arent (accessed 04 16, 2014).

Sierra Club. "Electric Vehicles: Myths VS reality." 2013. http://content.sierraclub.org/evguide/myths-vs-reality (accessed 11 24, 2014).

Smart, and Schey. "Q3 2012 Report The EV Project - Ecotality North America, Idaho National Laboratory." *www.theevproject.com.* Sep 2012. http://www.theevproject.com/downloads/documents/Q3%202012%20EVP%20Report.pdf (accessed 11 22, 2014).

Social Electric Car Co. *Will my electricity bill go up ?* n.d. http://www.socalelectriccars.com/faq/ (accessed 11 24, 2014).

Stephens, Joe, and Carol D.Leonnig. *The Washington Post.* 24 11, 2014. http://www.washingtonpost.com/politics/specialreports/solyndra-scandal/ (accessed 12 25, 2011).

Suh. *Application of Shaped Magnetic Field in Resonance (SMFIR) Technology to Future.* 2011. http://www.greencarcongress.com/2013/08/kaist-20130808.html (accessed 12 14, 2014).

Suh, In-Soo. "Intelligent Wireless EV Fast Charging with SMFIR Technology ." *Journal of Integrated Design & Process Science* 15, no. 3 (2011): 3-12.

Sylt, Christian. *Formula E Forecasts Television Audience Of 205 Million.* May 27, 2014. http://www.forbes.com/sites/csylt/2014/05/27/formula-e-forecasts-television-audience-of-205-million/ (accessed Nov 24, 2014).

Taxpayers For Common Sense. 2014. http://www.taxpayer.net/library/article/political-footprint-of-the-oil-and-gas-industry-lobby (accessed 12 11, 2014).

Tesla Motors. *Supercharger: The Fastest Charging Station on the Planet.* 2014. http://www.teslamotors.com/supercharger (accessed 11 24, 2014).

Thornton, Jack. "Pulling Power from the Road." *Mechanical Engineering (American Society of Mechanical Engineers)*, 2014: 44-59.

Tran, Lloyd L. *evwireless.net.* 2011. http://www.evwireless.net/ (accessed 11 24, 2014).

U.S. Department of Energy. "Consumer Energy Tax Incentives: Plug-In Hybrid Conversion Kits." n.d. (accessed November 28, 2012).

US Department of Energy. *Clean cities.* Sep 2011. www.cleancities.energy.gov. (accessed November 12, 2012).

US DOE. "Plug-in Electric Vehicle Handbook for Public Charging Station hosts." National Renewable Energy , 2012.

Utah Governor's Office of Economic Development. 2013. Utah Science Technology and Research Initiative (accessed 11 24, 2014).

Wireless, EV. *evwireless.net.* 2011. http://www.evwireless.net/ (accessed November 24, 2014).

Yan. "Public Charging Stations Fuel Desire for Electric Cars, CNN." *CNN.* October 24, 2012. http://edition.cnn.com/2012/10/24/us/public-car-chargers/index.html (accessed November 28, 2012).

—. "Public charging stations fuel desire for electric cars." *CNN.* October 24, 2012. http://edition.cnn.com/2012/10/24/us/public-car-chargers/index.html (accessed November 12, 2012).

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