



Wireless Charging of Electric Vehicles

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DOI : <https://doi.org/10.5281/zenodo.20126360>

ARTICLE DETAILS

Research Paper

Accepted: 25-04-2026

Published: 10-05-2026

Keywords:

wireless charger; wireless power transfer; electric vehicle; safety standard; hazard-based safety engineering (HBSE).

ABSTRACT

Electric Vehicles (EVs), a revolutionary innovation in contemporary transportation systems, provide a green alternative to the existing gasoline-powered internal combustion engine cars. EVs, which use electric motors operated by rechargeable batteries, minimize the production of carbon emissions, noise pollution, and dependence on petroleum resources. Although poised to see widespread use in the very near future, a range of challenges exist for Electric Vehicles pertaining to the efficiency, charging speeds, purchase price, availability of infrastructure, and impact on the environment. The development of Wireless Charging of Electric Vehicles (WCEVs), a technological advancement aimed at mitigating the drawbacks of existing plug-in charging infrastructure, includes risks, wear, user inconvenience, etc. This manuscript provides a thorough literature review of recent advancements concerning the application of Wireless Power Transfer (WPT) principles in electric vehicle charging systems. The manuscript discusses the vital components of a WPT-based electric vehicle charging system, such as power converters, compensation networks, coupling coils, as well as different controls, in a rigorous, in-depth manner. The manuscript also briefly introduces current & latest developments, dynamic charging for moving electric vehicles, etc.

I. INTRODUCTION

- Conceptually, the idea of WPT can be traced back to the late nineteenth century when Nikola Tesla demonstrated the transmission of electrical energy without conducting media. Tesla showed in 1891



the illumination of lamps without wires using high-frequency alternating currents and then described the transmission of energy over long distances through the Earth and atmosphere. Over the past few decades, the public transportation sector has emerged as a significant contributor to harmful emissions that adversely affect human and living organisms. This sector heavily relies on non-renewable fossil fuels, which are expected to diminish over time.

- The technology of inductive charging has been in use for several decades, and has been commonly used for charging toothbrushes, shavers, and other small electrical appliances with lower power. Recently, inductive and resonant inductive chargers have become a hot technology mainly because of the emerging of massive mobile electronic products such as laptops, cellphones, PDAs, and other devices. For example, a laptop fitted with Bluetooth and/or Wi-Fi can be used without cables, except during recharging a battery. Therefore, removing the power charging cord is a natural progression of maximizing the mobility of the product.
- The mobile device must be placed on a charging pad because the majority of inductive chargers have a charging distance of less than one centimeter. Incorporating wireless charging into conference tables or desktop surfaces is one of the new ideas for inductive charging. But such a system would probably need to be implemented widely. Due to a lack of standards, embedded charging has not gained popularity despite the technology's ability to make it happen. The majority of current products on the market, such as the wireless Wii™ remote charger from Fu Da Tong Technology Company [1], have very short charging distances and are primarily useful because they eliminate the need to plug the device in.
- In this paper, the fundamental operation of WCS for EVs, including methods of power transfer, is analyzed. In addition, a variety of wireless transformer structures are explained in order to improve power transfer efficiency. This paper also outlines current developments in the static and dynamic modes of WEVCS in both the commercial and university sectors.. In this application, the goal was to eliminate exposure of the operator to electrical contacts that are at high potential and able to deliver very high currents. Maximum power available from the Magne Charge was 6.6 kW, requiring 208-240 VAC and 32 A services.[2]
- More recent wireless charging technologies for EVs describe charging the vehicle without the need to plug in a charger, through the use of coils or small antennas embedded in the floor of a garage, parking space, or even in the street at intersections or along the roadway [3][4]. This paper describes approaches to wireless power transfer technology with a focus on large-power applications, inductive

and magnetic resonant wireless chargers for electric vehicles, and then discusses key safety concerns and potential areas that may need specialized testing standards development

II. WIRELESS CHARGING TECHNOLOGY

- In this paper, we discuss two wireless charging technologies applicable for EV. One technology uses an inductive coupling method, also known as the inductive power transfer (IPT) system. As shown in Figure 1, such a system is composed by a primary coil, a secondary coil, and a rectifier to convert the AC power into DC power. The secondary coil is placed on and carried by the EV and the primary coil is embedded in the floor of a garage, parking space, or in the street.[5]

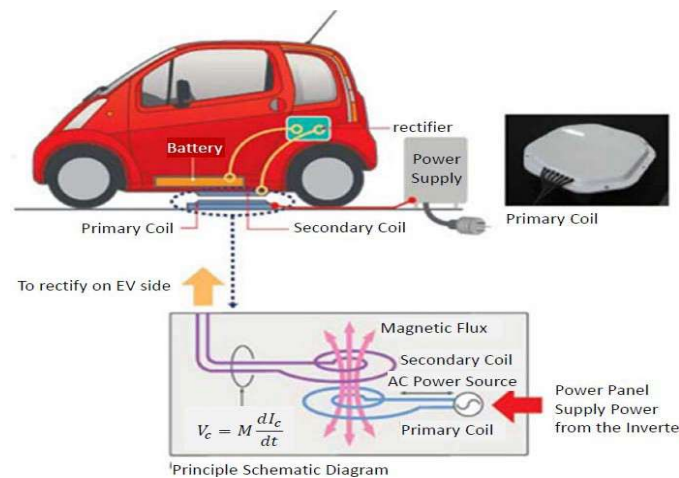


Figure 1. Schematic Diagram of Inductive Power Transfer System for EV(1)

- In Rotorua district of New Zealand, the first inductive power transfer charging technology for electric vehicles was installed in 2002, allowing the first buses to be wirelessly charged while in motion by automating the bus stops in Genoa and Turin. These buses operate on a 60-kW power supply and reach charging capacities of 90% efficiency with a distance of 40mm spacing from each transmitter/receiver pair, on average [6], [7]. The Oak Ridge National Laboratory (ORNL) in the USA has worked on two types of wireless charging systems, both static and dynamic. A single phase 100kW wireless charging system has been developed that has a rated efficiency of 97% with 5 inches of air gap between transmitter/receiver [8], [9]. This system uses one transmitter and one receiver. ORNL also has used this wireless charging system to charge various electric vehicles, providing 6.6kW of power to them and achieving a total-to-total efficiency of 85% [10].
- The WiTricity one of the leading companies in the wireless charger production. They offered static



wireless chargers up to the range of 3.6-11 kW and is further scalable up to 22 kW power transfer. A power converters based on SiC MOSFET showed a grid to battery efficiency of more than 91% and claimed 98% of coil-coil efficiency [11], [12].

- This technique gained significant attention through the work of A. Karalis and colleagues at the Massachusetts Institute of Technology (MIT) [13]-[14]. Inductive Power Transfer (IPT) technology has been used in public transit systems. A 30kW bus system has been developed and the system charges the batteries when it comes to a complete stop at a bus station [15]. A nominal charging distance of 40mm is required with minimal tolerance; hence a mechanical alignment system is needed. More recently systems named On-Line Electric Vehicle (OLEV) have maintained similar power levels, while significantly improving the charging height to 170mm and offering much greater tolerances [16]. As such, the buses can also get power transfer while moving slowly on a short section of electrified roadway. The earlier generations of this system had efficiencies of around 70% from grid to battery and this has recently improved to 80% [17].
- The requirement for an autonomous and long-range electric vehicle motivated to move towards wireless power transfer (WPT). Wireless power transfer makes Electric vehicle free from range issue, and to make it autonomous new concept of dynamic wireless charging is introduced. Dynamic charging is very clean and fast technique. It charges the vehicle going on road enabled with charging coils. It should not to stop for charging purpose. Locating the charging point for the vehicle very difficult task as the current charging infrastructure is very sparse. Through WPT charging wired connection not required.
- Specialty of WPT is that it charges the vehicle under motion or while it is parked. According to Nikola Tesla's experiment conducted in 1899 electrical energy transmission is possible even wirelessly [18]. Nowadays Inductive Power Transfer has its application in electric cars, locomotive or metros. According to Halo IPT report maximum efficiency is up to 95%. Under my review paper, dynamic wireless charging general structure and Coil designs to get near perfect alignment of the EV side have been discussed. We also discuss health and safety standards or issues under my paper[19].
- Wireless power transfer (WPT) technology emerges as one of the most promising innovations in this domain. It transmits electrical energy without the need for physical connections, offering an alternative to traditional plug-in charging method.[20]
- WPT technology transmits energy through the air, eliminating the hassle of wiring. Its notable feature



is the ability to provide users with a seamless charging experience, addressing challenges faced by traditional charging infrastructure, such as the inconvenience of physically accessing charging stations and handling cables [21]. This approach not only streamlines the charging process but also enables the possibility of charging electric vehicles while in motion.

- Dynamic wireless charging technology allows vehicles to charge while in motion via embedded road charging devices, significantly alleviating range anxiety—a primary barrier to widespread EV adoption [22]. By integrating WPT technology into urban infrastructure, cities can create a more EV-friendly ecosystem, thereby promoting the adoption and use of EVs.
- Plug-in and wireless power transmission methods have been used to charge electric vehicles. In the plug-in technique, the electric vehicle's battery is charged at the charging station via a cord or plug. In contrast, in the wireless charging method, the battery of an electric vehicle (car) is charged utilizing wireless power transmission. The wireless charging technique is superior to wired charging in several ways. First, there is no need to carry and store cords, which could be considered the primary advantage of using wireless charging. Using this method circumvents the possibility of having wires wear out over time [23]

WORKING PRINCIPLE OF WCEV

- Wireless charging of electric vehicles operates on the fundamental concept of **Wireless Power Transfer (WPT)**, wherein electrical energy is transmitted from a power source to an electrical load without direct physical contact. The most widely adopted technique for EV applications is **Inductive Power Transfer (IPT)**, which relies on **electromagnetic induction** between two magnetically coupled coils — a transmitter coil and a receiver coil.
- In this system, the **transmitter coil** (primary) is embedded in a charging pad on the ground and is connected to an alternating current (AC) power supply. When current flows through the transmitter coil, it generates a time-varying magnetic field. The **receiver coil** (secondary), mounted on the underside of the electric vehicle, is positioned such that it lies within the magnetic field generated by the primary coil. According to **Faraday's law of electromagnetic induction**, this changing magnetic field induces an electromotive force (EMF) in the secondary coil, which is then rectified and conditioned to charge the vehicle's battery.

Working principle topology

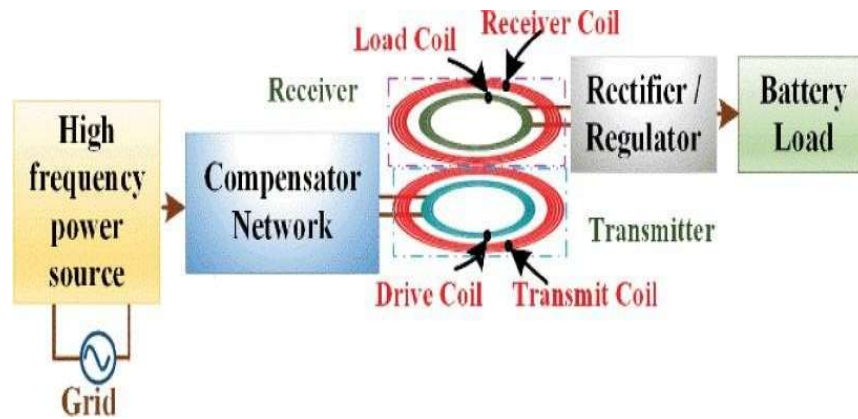


Figure 2. Working principle topology(2)

- There are two types of Wireless Power Transfer (WPT): near field and far field. Unlike far field, which has low power levels for transferring energy over long distances, near field has the capability of transferring higher power levels to an individual wavelength. However, power rapidly decreases proportionally to the distance it is transferred to the load [24]. One of the types of WPT within the near field category is Inductive Power Transfer (IPT), which works by utilizing inductive coupling through two magnetic field coils. With far field WPT, energy is transmitted away from the source; however, energy transmitted via near field WPT is retained close to the source due to the non-radiative nature of the transfer, reducing the safety concerns associated with exposing humans to energy and magnetic fields [25]. In order to provide high power transfer efficiency and range, coupled magnetic resonance is used for electric vehicles (EVs) [26]. WPT technology uses two resonant circuits that resonate at the same frequency, allowing energy to be transferred through resonant coupling of the magnetic fields produced by the resonant circuit coils [27]. The concept of resonant coupling was developed by Nikola Tesla, who performed successful experiments with resonant coupling at low power levels. The growth and advancement of electronic components have contributed to the continued development of resonant inductive power transfer (RIPT) technology.

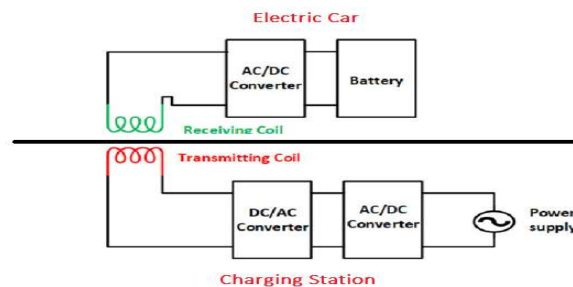


Figure 3 Block diagram(2)

- One of the most important aspects of an efficient magnetic coupling between the transmitter and the receiver is the pad design of the transmitter/receiver coils. The design of the transmitter and receiver coils dictates the shape of the magnetic field which directly affect misalignment tolerance, leakage flux, and magnetic radiation; all three of these parameters are impacted by the design of the coils. A further inductive charging method is the on-line electric vehicle system.
- In the case of static WPT systems, the magnetic structure will be based on a lump pad shape, however for the purposes of economics the DWPT systems will generally incorporate either an OLEV track style system (which has a looped coil design) or a track-based system composed of multiple smaller loops that can be operated independently as separate pads. It is disadvantageous to employ tracks that are significantly longer than necessary because the only part of the track that would be able to energize the receiver coil would be the area covered by the coil, thus reducing overall coupling efficiency whilst at the same time creating an exposed EM field throughout the length of the track as a result.[28]

III. TYPES OF WIRELESS CHARGING SYSTEM FOR ELECTRIC VEHICLES

Wireless electric vehicle (EV) charging systems are categorized into two major instances depending on the functionality with which a power source transfers energy to a battery bank for charging a car.

1) *Static wireless charging system:*

- WEVCS Shuts Another Door, So That the User Has a Friendlier Place to Access and Use Their Electric Vehicle (As Well As Being Able to Keep Them Safe with Regards to Plug-In Chargers). Static WEVCS Takes Place of a Plug-In Charger with Minimal Driver Interaction and Solves Safety Related Issues Including Trip Hazards and Electric Shock. Figure Illustrates a Typical Arrangement of Static WEVCS. A Primary Coil Is Installed Below Ground (Or Road) With Some Power Converter and Other Electronics Adjacent to The Primary Coil.
- The receiver coil, or secondary coil, is EVs can utilize WEVCS to charge their batteries through inductive charging. They are typically located at the front, back or center of the vehicle. The inductive charging technology converts the incoming AC power into DC through a power converter, which then delivers electricity to the vehicle's batteries. To improve safety, wireless communication networks will allow for two-way communication between the charging pad and charging station

(primary side), and the battery management system and power control (secondary side). Charging time varies based on the available source power, area of the charger pad(s), and the distance between the two windings (i.e., the distance between the charger and vehicle). Unfortunately, the operating range of lightweight duty vehicles is only about 150 to 300 mm. Static WEVCS also has potential to be installed in parking lots, car parks, residences, etc. [29]

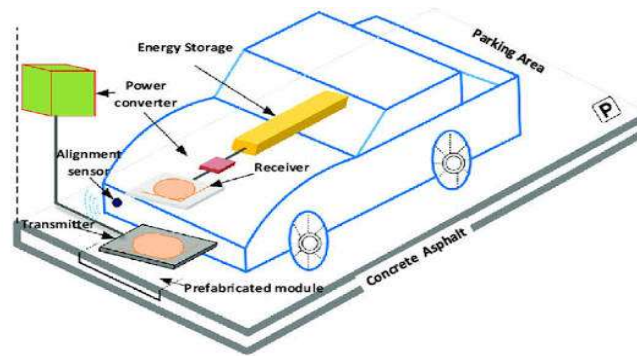


Figure 4. Static wireless charging(3)

- Efficiency of power transfer is more effective on SWC, since alignment is enhanced. The figure explains stages of conversion, the efficiency distributions, and total efficiency. To get maximum efficiency, each conversion steps are also to be improved. Several prototype charging stations were tested at different locations on the car (i.e., at the front, rear, and center of the receiver pads), but ORNL's primary goal is improving power transfer efficiency through coil design while the University of Auckland has proposed some additional hardware/software (including development of charging pads) to improve plug-in efficiency.
- A vehicle can be equipped with a system that automatically assists the driver with positioning the vehicle over the main charging pad. The vehicle and charging station communicate via inductive coupling and/or other short-range communication technologies to share information such as the state of the battery and any driver preference information required for adaptable charge processes.
- Overall, prototypes or lab experiments of stationary wireless charging systems (WCS) for electric vehicles (EV) have been created that are rated between 1 kW and 20 kW; with air gap distances between 100 mm and 300 mm; with efficiencies ranging between 71% and 95%.

2) Dynamic wireless charging system:

- The dynamic wireless electric vehicle charging system (D-WEVCS) is a promising technology, which can reduce the problems associated with range and cost of EVs. It is the only solution for future automation EV. It is also known as a “roadway powered” [30], “on-line” or “in motion” [31] WEVCS. As shown in., the primary coils are embedded into the road concrete at a certain distance with high voltage, high frequency AC source and compensation circuits to the micro grid and/or RES.
- While static wireless power transfer (static WPT) technology provides a wireless method for charging electric vehicles (EVs), it only helps with the issue of the EV being stationary while being charged. Therefore, dynamic WPT provides a theoretical unlimited range for an EV depending on the supporting infrastructure for charging. Dynamic WPT is a process similar to a static transfer but will require several modifications both to the EV and the supporting infrastructure.

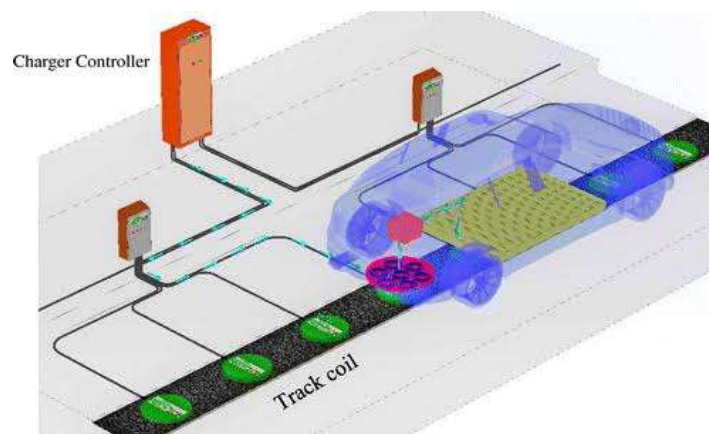


Figure 5.Dynamic Wireless Charging(4)

- The secondary coil, however, is located underneath the vehicle, just like the static-WEVCS. The transmitter receives a magnetic field from the receiver coil of an EV that is travelling over it and converts this to DC to supply a battery via the power converter and BMS. Charging EVs with charging stations reduces the total number of batteries needed for all EVs by approximately 20% compared to EVs without charging stations [33]. In order to charge EVs dynamically, transmitter pads and power supply segments must be installed on predetermined locations along a route [34]. Most of the power supply segments will have either a essential power frequency configuration.
- In a DWPT setup the magnetic field is produced across additional coils consecutively rather than just one coil. These coils become active as the auto passes above the coil so their length and frequency will vary based on what they're used for Since a vehicle's speed typically results in a very short time period during which the coils are interacting, an effective high-power method of transferring power will be needed [32]. Furthermore, as the vehicle moves around there is a high probability of having



misalignment, making it wise to ensure that the DWPT systems can accommodate misalignment. This can be accomplished by having automated vehicle alignment systems, driver training, driver assistance aids/devices, road markings, coil design (size/magnetic character); different methods will suit different conditions and budgets.

- To enhance the effectiveness of dynamic wireless power transfer (DWPT) so that it is as efficient as static systems, the energy from the electric grid needs to be transferred directly to the vehicles' powertrain using ultra or super capacitors (as opposed to charging the vehicle's battery). This eliminates the losses from charging and discharging the battery and allows the vehicle to enter and exit the charging zone with the same state of charge while simultaneously extending its range because the traction battery will have had no usage during travel on DWPT. Therefore, DWPT avoids battery losses and is a more effective method than static charging.
- In general, implementing the initial infrastructure requirements for this technology would be very expensive, however, with the assistance of a self-driving vehicle in the future, it will aid in aligning the transmitter and receiver coils perfectly, thus enhancing the overall power transfer efficiency significantly. Dynamic-WEVCS can easily be adapted into a variety of EV transportation applications including light-duty vehicles, buses, railways, and rapid transit systems.

HEALTH AND SAFETY CONCERNS

- WEVCS has many benefits compared to the plug-in charging systems for electric vehicles (EV), WEVCS presents three significant potential health and safety hazards: electrical, magnetic, and fire. WEVCS uses high levels of current and voltage which may constitute a risk of electrical shock if the equipment malfunctions or sustains damage due to environmental conditions (i.e., extreme temperature) or if the equipment is bumped into, knocked over or otherwise disturbed. A large majority of the level 1 (3.7 kW) and level 2 (7.7 kW) WEVCS charging stations are found in residences, dormitories and general parking lots where the transmitter charging pads are embedded into concrete or other solid surfaces. Additional safety regulations must be in place for these types of installations to protect against electrical shock and to prevent serious injury or death. Electric companies are required by law to meet established safety standards and regulations; however, the magnetic fields produced at high power levels by WEVCS charging stations may exceed established safety standards and regulations as established by regulatory agencies. Therefore, WEVCS charging stations could adversely affect the general public.



- To protect people from the dangers of this new technology, increased safety should be established through the development and enforcement of new standards and new safety regulations. For example, electromagnetic fluxes generated by high power are likely to exceed the minimum level or standard that is typically imposed by regulatory authorities and will pose a risk to the general public. Also, improvements to the surrounding vegetation and animal life must be made by utilizing electromagnetic compatibility and electromagnetic interference tests to assist in resolving the safety needs of this technology (the intent of this point is unclear). In specific regard to primary high level energy transfer from the charging pads of the charger to the charging pads of the mobile device, this is occurring at considerable distances ranging from approximately 150 mm to 300 mm and from a few kilohertz to a few megahertz (30 Hz-3000 Hz) and this is generating energy loss in the form of electromagnetic waves at frequencies much higher than the frequencies of the operating equipment. Therefore, there is a need to establish a maximum amount of exposure of electromagnetic energy to the human body as per what are known as the present exposure guidelines established by, including but not limited to, IEEE C.95.1 2005 [66], ICNIRP 1998 (0 Hz-300 GHz), and ICNIRP 2010 (0 Hz-100 kHz) [33].
- The necessity of defining a set of standards for efficiency, power level, operating frequency, EMI, EMC, safety, and testing in order to establish a user-friendly environment (UFE) for the WEVCS is fundamental to the research and commercialization of these technologies. Numerous global organizations (SAE, IEC, IEEE, UL) have created task forces that include a cross-section of organizations (i.e., research institutes, government entities, universities, and the automotive EV industry) to facilitate their commercialization efforts.

CONCLUSIONS

- Electric vehicle wireless charging technology will be important to the transport of the future, both for those using smart/efficient transportation systems (for example: cars, buses, trains), and for the organizations wishing to offer eco-friendly solutions to delivering products to customers. And because there are no physical connectors required, charging will be simpler for all involved, be safer, provide little maintenance, and importantly, not affect the world around us adversely. The use of inductive and resonant magnetic coupling allows for wireless power transfer, or the transfer of energy between two or more objects without any contact with each other. Wireless Power Transfer (WPT) allows energy to move from the EV charging pad to the EV, with very little human intervention required. The report says that currently static wireless charging offers the most established and



feasible applications. It is also possible to charge EVs dynamically while they are in motion, such as along roadways, though there are still unresolved issues associated with dynamic wireless charging (i.e.: poor alignment between charging equipment and vehicle's WPT receiver, poor efficiency and loss of energy through conversion in the charging equipment, high costs of supplying standalone charging equipment, high costs related to installing WPT equipment, thermal limitations, etc.) before large-scale implementation of WPT will happen. As well as advancements in controlling systems, power electronics, and magnetic materials, the evolution towards practical/sustainable WPT, will greatly enhance WPT's impact on the international electric mobility ecosystem by integrating WPT into renewable energy, smart grid systems, and autonomous vehicles. In conclusion, WPT can completely change the way we travel and transport items in a cleaner, safer, and more convenient way than other forms of transportation..

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