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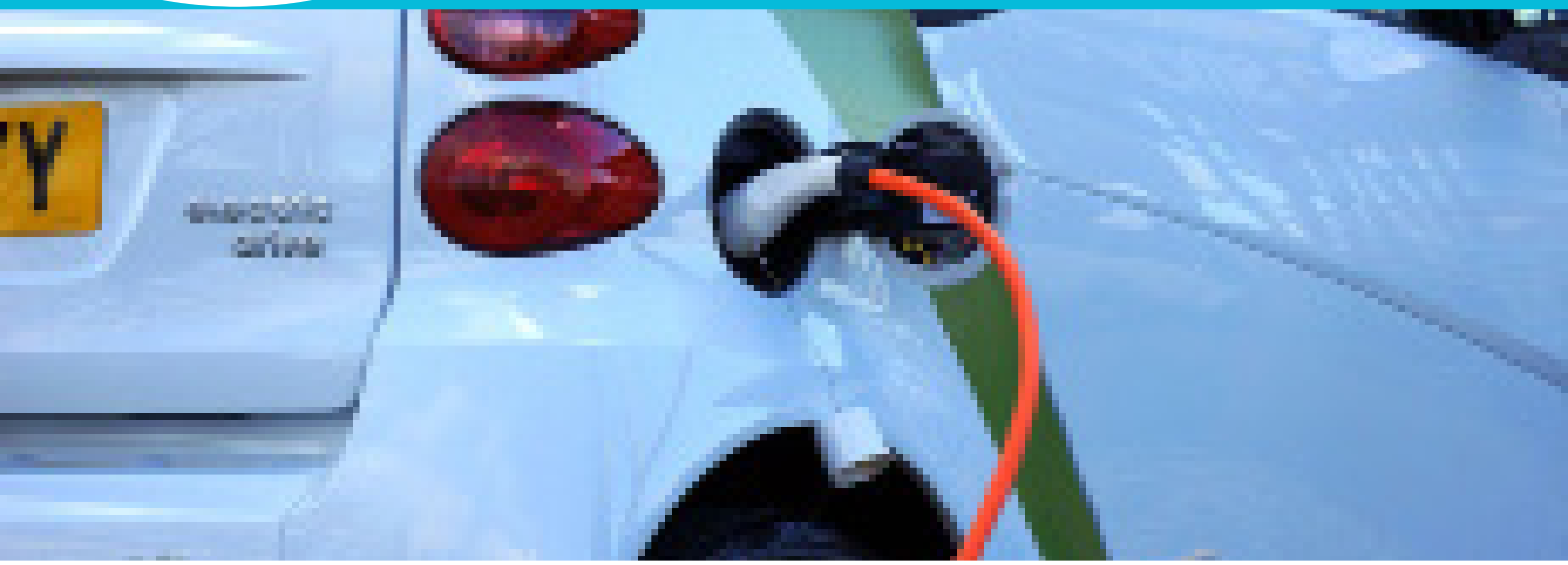
Summary

Battery Technologies



Wuppertal Institut
UN HABITAT FOR A BETTER URBAN FUTURE
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This paper was prepared by:
Future Radar project
This project was funded by the Horizon 2020 framework of the European Commission

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The graphic design was prepared by Barbara Lah (UEMI)

Berlin, 2018

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UEMI SOLUTIONS

Supported by

The project has received funding from the European Union´s Seventh Framework Programme and Horizon 2020 under the grant agreements no 604714 (SOLUTIONS) and no 723970 (FUTURE RADAR)

UEMI

Urban Electric Mobility Initiative (UEMI) was initiated by UN-Habitat and the SOLUTIONS project and launched at the UN Climate Summit in September 2014 in New York.
UEMI aims to help phasing out conventionally fueled vehicles and increase the share of electric vehicles (2-,3- and 4-wheelers) in the total volume of individual motorized transport in cities to at least 30% by 2030. The UEMI is an active partnership that aims to track international action in the area of electric mobility and initiates local actions. The UEMI delivers tools and guidelines, generates synergies between e-mobility programmes and supports local implementation actions in Africa, Asia, Europe and Latin America.

Future Radar

Future Research, Advanced Development and Imple- mentation Activities for Road Transport (FUTURE-RA- DAR) project will support the European Technology Platform ERTRAC (the European Road Transport Re- search Advisory Council) and the European Green Vehicle Initiative PPP to create and implement the needed research and innovation strategies for a sus- tainable and competitive European road transport system. Linking all relevant stakeholders FUTURE-RA- DAR will provide the consensus-based plans and roadmaps addressing the key societal, environmental, economic and technological challenges in areas such as road transport safety, urban mobility, long distance freight transport, automated road transport, global competitiveness and all issues related to energy and environment.

FUTURE-RADAR will also facilitate exchange between cities in Europa, Asia and Latin America on urban electric mobility solutions. The FUTURE-RADAR activities include project monitoring, strategic research agendas, international assessments and recommendations for innovation deployment as well as twinning of international projects and comprehensive dissemination and awareness activities. Overall it can be stated that FUTURE-RADAR provides the best opportunity to maintain, strengthen and widen the activities to further develop the multi-stakeholder road transport research area, for the high-quality research of societal and industrial relevance in Europe.

Table of Content

In brief

In brief
This section provides a summary of the existing battery technologies being used in vehicle applications and provides highlights the relevant issues for such technologies.

Batteries are critical components of EVs, as well as an important determinant of the overall impacts that EV systems may have. They are also key towards determining the advantages (and disadvantages) of EVs against conventional fossil-run vehicles. For example, the total amount of energy stored for an EV can perhaps be a quarter of what a regular ICE vehicle needs to perform the same mileage (Young et al., 2013). On the other hand they need to handle high power and high energy capacity but need to do so within a limited weight and space, at an affordable price.

Nickel Metal Hydride (NiHM)

Nickel Metal Hydride (NiHM)

Most of the available HEVs use this type of battery due to tits mature technology. General Motor chose NiMH as suited for its EV-1 vehicles, as well as HEVs by Toyota and Honda in the early 2000s (Young et al., 2013). Many of the metals used in NiHM, although environmentally-friendlier than previous versions (i.e. NiCd), are rare metals (Berg, 2015).

On the positive side, NiMH cells have low internal resistance, and allows for deep cycling. It can tolerate fast charging, as well as discharge conditions over a wide range of temperatures. Storage and uncontrolled usage may result in gas emissions (O2 or/and H2) and thus vents are incorporated for safety. At high charging rates, large amounts of oxygen can cause pressure. A complete discharge may lead towards the reversal of polarity which may lead to irreversible damage (Berg, 2015).

The charging of NiMH cells is restricted in order to avoid overcharging, as temperature increase causes cell voltage to drop as the fell is fully charge. A constant voltage charging process cannot be used. Voltage control and temperature control methods are used as charging procedures (Berg, 2015).

A charging phenomenon called “memory effect” is observed in NiMH cells, wherein it can “remember” the capacity of the previous charge and will only accept the same amount of capacity in subsequent charging. The NiMH cell, however, can recover if fully discharged (Berg, 2015).

Capacity losses in NiMH cells are related to voltage depression, due to long-term overcharge conditions, as well as repeatedly charging partially. Compared to the Li-ion batteries, NiMH have lower energy storage capacity, as well as a high self-discharge coefficient (Manzetti and Mariasiu, 2015).

Nickel Cadmium (NiCd)

These batteries have been known to have the longest lifespan in terms of number of charge and discharge cycles (approximately 1,500). However, usage of Nickel Cadmium batteries has been limited, particularly in the EU due to the use of Cadmium, which is a heavy metal that has harmful effects on human, environment, and animal health (Manzetti and Mariasiu, 2015).

Nickel Cadmium

Lithium

Lithium is one of the most reactive, and lights of metals, which gives it potential for having high power density, and energy. Its cell potential is in the range of 2.5 V to 4.5 V. Among the different battery chemistries within lithium batteries, lithium-ion has become the most common battery for all-electric vehicle.

For most Li battery concepts, temperature must be controlled due to the instabilities of the electrolyte, as side reactions may take place. To reduce the risks of side reactions, Li batteries usually contain a management unit with a protective circuit to control temperature, currents, and voltage levels. Low temperatures (lower than 10 Celsius), charging cannot be safely charged due to increased internal resistance.
Lithium battery concepts include lithium metal, lithium-ion, lithium-ion polymer, lithium oxygen, and lithium-sulphur.
Table 1: Lithium Battery Concepts
Sources : (Berg, 2015 and Manzetti and Mariasiu, 2015).

Lithium

Chemistry	Description
Lithium metal	First functional rechargeable lithium battery concept that uses metallic lithium as negative electrode, a lithium insertion as the positive electrode, and a polymer-based electrolyte. Metallic lithium has been implicated in abuse accidents, but research has since found ways to stabilize the material making such batteries operating in temperatures between 80 to 120 Celsius attractive solutions for EVs
Li-ion	Li-ion concepts utilizes graphite or hard carbon as the negative electrode, with lithium salt solvated in an organic liquid solvent as the electrolyte. Li-ion polymer concepts utilizes a polymer matrix as the electrolyte. Li-ion batteries are characterized by a large power storage capacity coupled with very good energy density to weight ratio. Limitations associated with li-ion batteries are high costs, a potential for overheating and a limited life cycle. Another issue is that it needs to be overdesigned to overcome short life.
Li-ion polymer	Li-ion polymer provides longer life cycle than Li-ion but is limited by the functional instability if it overloads or if discharges at a certain value (Manzetti & Mariasiu, 2015).
Lithium-oxygen	Li-air has a very high possible theoretical energy density, and its practical energy is 2 to 3 times higher than Li-ion cells. While the concept is attractive due to higher energy density, it has disadvantages in terms of voltage hysteresis, as well as side reactions brought about by gases aside from oxygen entering the system.
Lithium-sulphur	This uses elemental sulphur as the positive electrode and has a theoretical capacity 10 times higher than lithium-ion, but cell voltage is lower than lithium ion (2V)

Lithium

The potential of Li-ion batteries to obtain higher specific energy and energy density, it is expected that the adoption of such batteries will grow rapidly in the future. The specific energy of typical Li-ion batteries is around 120 Wh/kg, as compared to 13,000 Wh/kg gasoline. The TESLA Roadster utilized 6,831 small cylindrical Li-ion batteries (2008). The Nissan Leaf used 192 prismatic Li-ion batteries (Young et al., 2013).

Young et al. (2013) provides a comparative analysis of battery performances for an NiMH (by Primearth EV Energy CO), and Li-ion (Hitachi Vehicle Energy) batteries and suggested that while the Li-ion provides advantages in terms of higher specific energy and output power, its superiority is limited at the development stage during the time of study (2013). Li-ion batteries require a powerful liquid-cooling structure which leads to heavier system weight.

The battery management system for the NiMH is simpler, and lighter than the Li-ion system. Li-ion and NiMH batteries have the same impedance during charging and discharging, as compared to lead-acid batteries whose impedance during charging is three times higher than the discharge impedance. The maximum input power for Li-ion is limited to 1,000 W/kg at the cell level. Based on the data, there is not so much difference in terms of power and energy performance (Young et al., 2013).

Lead Acid

Most widely used technology in the automotive industry (power supply for starter motors, voltage regulators). Lead acid batteries are primarily designed for purposes of starting, lighting and ignition (SLI) It has over 140 years of development and is regarded as a reliable battery technology. It can deliver high currents at low internal impedance. Lead itself is a heavy metal (11.3 kg/dm3), and thus battery packs are heavy and bulky. The environmental impacts of such batteries also limit its applications.
The production of lead acid cells requires alloying which requires materials such as antimony (as well as sulphur, copper, arsenic, selenium, tellurium). Antinomy, however, is dissolved during the discharging and charging phases, and thus results in loss of capacity. Usage at low state of charge levels, and insufficient charge acceptance are the main drawbacks of lead-acid batteries. Optimized benefits are within high SOC levels, but such would lead to oversized batteries. Deep discharge cycles in a lead acid battery usually result in increased temperature due to high internal resistance. Thicker electrodes are primarily used to counter this, but results in lower charging capacity, and thus requires oversized batteries if fast charging is needed.

Lead Acid

Table 2. Side Reactions of Lead Acid Batteries
Source: Berg (2015)

Side reactions	Description
self-discharge	Self-discharge rates are dependent on storage temperatures (e.g. low antimony, or antimony free alloys have slower self-discharge rates)
sulphation	Battery cell loses ability to be charged under normal charging conditions during sulphation process, which is the crystallisation of the PbSO4 which blocks redox reactions and leads to the decrease in cell capacity (due to minimised contact area between the electrode and electrolyte which increases internal resistance.
stratification	Stratification of the electrolyte is due to the differences in conditions such as temperature and results in uneven utilisation of the electrode.
shedding	Shedding is the exfoliation of lead from the electrodes and can occur due to the electrode construction and design and can lead to electrode damage and capacity loss.

Other Battery Technologies

Berg (2015) discusses other battery technologies that may be viable for future applications in electric vehicles.

- High temperature molten-salt batteries utilize molten salts (sodium/sulphur, sodium/nickel) as electrolytes and enables high-power densities. They operate in 200-700 Celsius temperature ranges and require different safety managements systems.
- Nickel Zinc batteries are similar to NiMH but have enhanced energy density.
- Zinc-air batteries are electrically rechargeable batteries that are similar to nickel-based technologies.
- Metal-ion concepts that are similar to Li-ion but utilize other types of metal-ion.
- Zinc-bromide can provide advanced energy storage for vehicular applications (80-90 Wh/kg power density, and 300-600 W/kg energy density) (Hannan, et al., 2014).

Fuel Cells

Fuel cells are technically different from batteries, as they don't store energy in cells, but are rather electrochemical energy converters which converts a fuel's chemical energy into electricity when in reaction with an oxidant. They do not store energy, but similarly with battery cells, these consist of negative and positive electrodes separated by an electrolyte (or membrane). The polymer electrolyte membrane (PEMFC) is regarded as one fuel cell concept that maybe suitable for vehicle applications as it features high power density, fast start-up, and an operating temperature range between 70-200 degrees Celsius.

Super Capacitors

Electrochemical capacitors contain an electrical double layer - made of Nano-porous materials (e.g. activated carbon) that improve energy density- and a separator which hold charges. They have long life cycles (500,000), very high rates of charge/discharge, low internal resistance, offer minimal heat loss and good reversibility, 90% efficiency cycle (as compared to 80% of batteries, but have lower energy densities than batteries (Hannan, et al. 2014).

Other Battery Technologies

Fuel Cells

Super Capacitors

Box 1
Contemporary Issues: Charging

Fast Charging

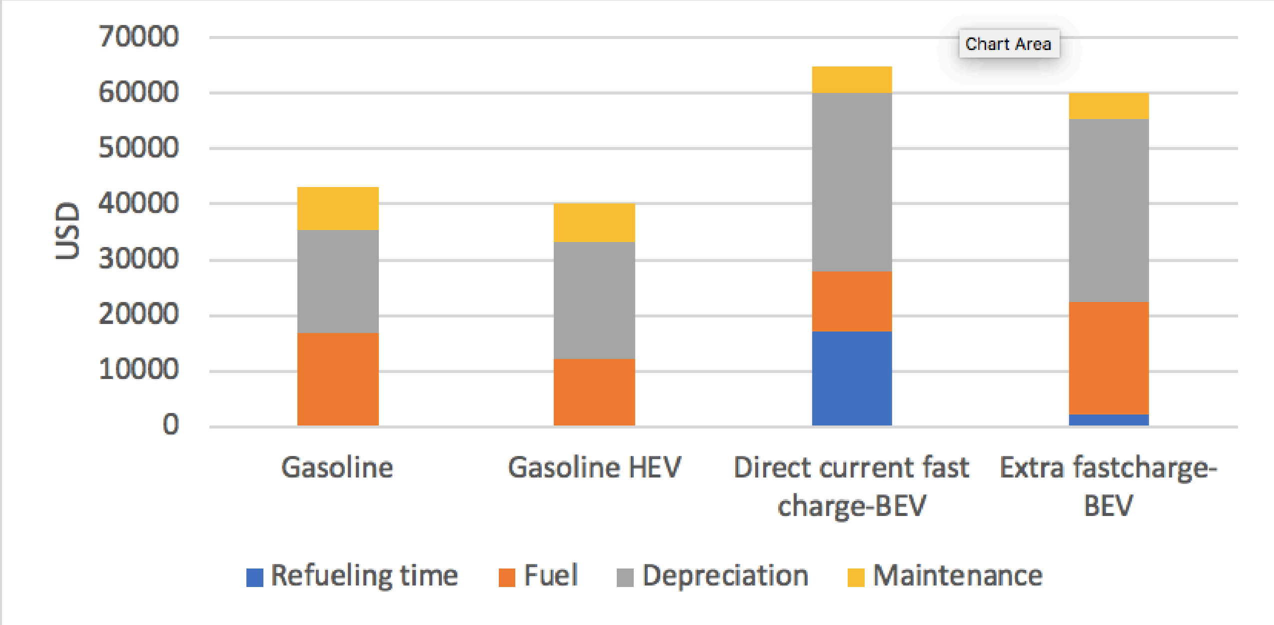
Faster charging speeds may be needed in facilitating the acceptance of EVs by the public. Long charging times led to low turnover rates, and downsize effective distance coverage, which are particularly important for public fleets (Xue and Gwee, 2017). The DCFC (direct current fast charge) technology is capable of charging several times faster than AC level 2 chargers but is limited by the acceptance rate of the EV (depending on the vehicle rating). Also, the rate of charge diminishes over time (Motoaki and Shirk, 2017).

Higher power charging systems of up to 400 kW are seen to address limitations posed by charging BEVs particularly in terms of length of time to charge, and overall vehicle range (Burnham et al., 2017). Extremely fast charging (XFC) can enable significant driving range for a charging period of 10-25 minutes, which makes the "refuelling experience" comparable to those driving ICE vehicles. Infrastructure costs for XFC would entail upgrades to the electricity distribution network which needs to be able to handle irregular loads and mitigate the effects of intermittency, as well as the addition of stationary storage for minimizing demand charges during charging events (Burnham et al., 2017).

The types of vehicle chargers for such fast charging systems, and their compatibility with existing BEVs need also be considered. The cost of XFC installation and equipment to be 245,000 USD (Francfort et al., quoted in Burnham, 2017). Cyber and physical security are needed due to the high energy transfer rates. The implications of extra fast charging on the battery packs are not yet clear, particularly in terms of degradation. Burnham et al. (2017) analysed the total costs of ownership between a conventional gasoline, hybrid gasoline, direct current fast charge electric vehicle, and an electric vehicle using a fast charging module. The modelling exercise shows that the electric vehicles would have lower fuel costs than the gasoline dependent ones, but the depreciation for the electric vehicles are higher. The time savings from the reduced charging time lowers the total costs of the XFC BEV compared to the direct current fast charge one.

Box 1
Contemporary Issues: Charging

Figure 1: Passenger Car - 15 Year Cost of Ownership
Source: Burnham et al. (2016)



Meintz et al. (2017) highlights the vehicle-related challenges for pursuing the XFC model:

- Battery charging power density must be increased while energy-dense cells are maintained in order to avoid excessive recharging requirements
- The desired use cases for XFC should be well understood due to the implications for trade-offs for vehicle design
- Increased voltage will impact the design of electrical, and power electronics designs, and can increase the mass, volume and the costs of the components
- Interoperability of the charging systems will be required.

Box 1
Contemporary Issues: Charging

Charging Infrastructure Standards

Madian et al. (2016) suggests that instead of subsidies for purchasing EVs, regulatory bodies should contemplate on offering tax rebates related to electricity used for charging such EVs, as well as those policies that would enhance the economics of service provision by the charging service operators (CSO).

Public charging infrastructure are currently dominated by two charging types under IEC 621196 (Xue and Gwee, 2017):
Source: Xue and Gwee (2017)

Standard	Description
Type 1: IEC 62196 / SAE J1772	single-phase vehicle coupler – reflecting the SAE J1772 plug specifications. SAE (Society of Automotive Engineers). SAE J1772 is a standard originated from North America for electrical connectors designed for electric vehicles. It is compatible with single phase electrical systems and is popular in North America and Japan due to their available single-phase power system.
Type 2: IEC 62196-2	single- and three-phase vehicle coupler – reflecting the VDE-AR-E 2623-2-2 plug specifications. Type 2 connector was originally proposed by Mennekes1 in 2009. The system was later tested and standardised by the German Association of the Automotive Industry (VDA) as VDE-AR-E 2623-2-2, and subsequently recommended by the European Automobile Manufacturers Association (ACEA) as the optimal option for charging infrastructure in Europe in 2011, prior to which Type 1 was recognised as the common implementation.

The adoption of a national standard is important for ensuring the interoperability of EV charging. As shown in the experience of Singapore, the industry expressed no preference between the two options, but they encouraged the government to adopt a single standard in order to harvest the benefits of standardisation. Xue and Gwee (2017) provides comparison between the specifications between the two standards in their study. The highlight of which is the charging time, wherein Type 2 led to significantly shorter charging times. Type 2 charging has higher installation costs than type 1 (Cost per unit per annum : Type 1 = 3,663 SGD, Type 2 = 3,924 SGD), but have shorter payback periods due to the shorter charging times. Type 2 charging is also regarded as more efficient, as charging at a higher power at a higher voltage tend to be more efficient (i.e. up to 13%).

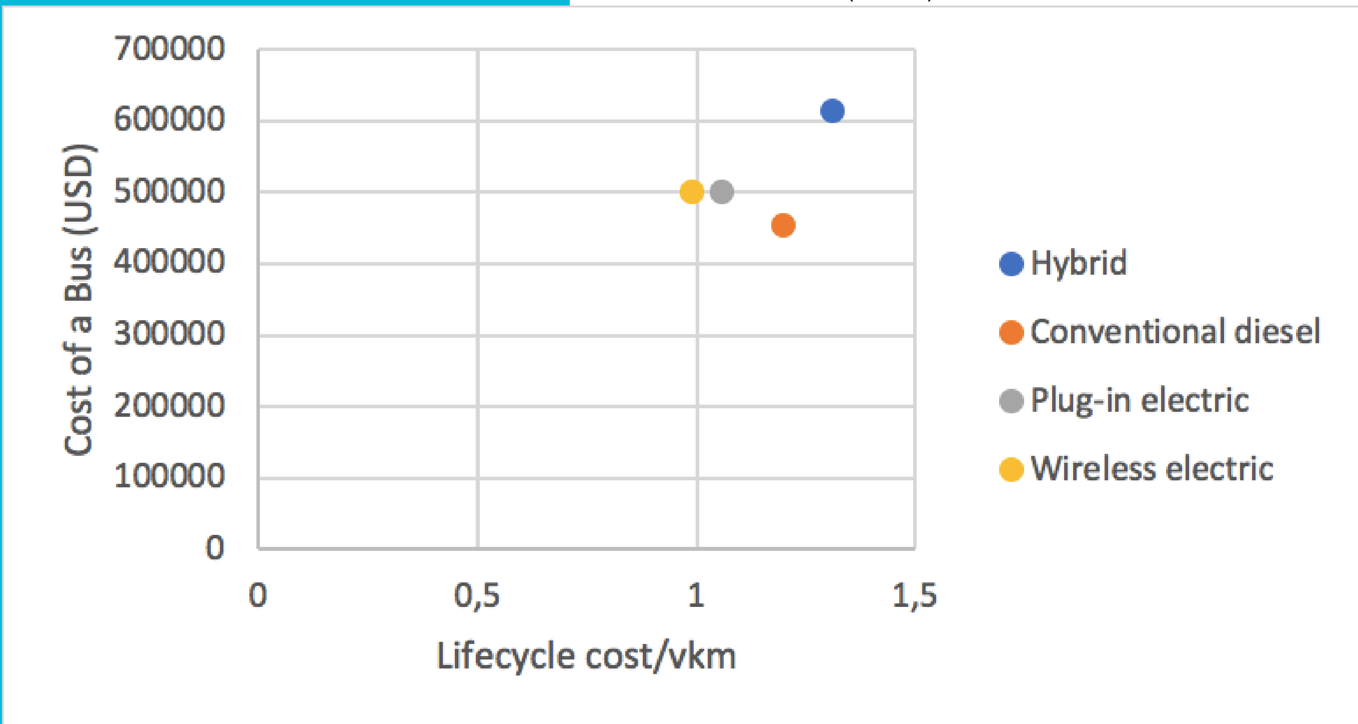
Type 2 charging is also more suited for V2G applications.V2G or Vehicle-to-grid functions are also ideal features of an EV charging system. Such a scheme enables the electricity stored in EVs which are not needed for immediate use to supply back to the grid during peak hours, particularly if peaking options are unavailable or expensive (Xue and Gwee, 2017).

Box 1
Contemporary Issues: Charging

Wireless Charging Technology

Wireless charging technologies have emerged and are addressing primary limitations associated with battery electric vehicles (BEVs) in relation to heavy and expensive on-board battery packs, as well as the required waiting time for recharging. Wireless charging is achieved when there is electromagnetic resonance between two contactless coil plates (e.g. located at the bottom of the vehicle, and the roadway). The reduction in vehicle weight results in savings in energy consumption, as well as GHG emissions and costs associated with the vehicles (Bi et al., 2017). It is seen to be suitable for transport applications where fixed routes are followed (e.g. transit buses). Wireless technologies are categorized into stationary or dynamic (vehicles are in motion). In contrast with conventional plug-in charging infrastructure, wireless charging infrastructure need to be deployed along the routes (stationary). Bi (2017) uses a lifecycle cost analysis methodology to assess plug-in and wireless charging lifecycle costs. The modelling exercise estimates that at the end of the 24-year assessment horizon, wireless systems cost less than 8% compared to the plug-in alternatives. However, the author recognizes that there is considerable uncertainty associated with the finding, as wireless charging has not been scaled.

Figure 2 Lifecycle Costs and Purchase Costs of Buses
Source: Bi et al. (2017)



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