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## Battery Electric Vehicles: Review and Emerging Trends

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**ABSTRACT:** With soaring fossil-fuel prices and shifting focus towards Renewable Energy and Alternate Fuels, the transport industry is inevitably tipping towards the adoption of Battery Electric Vehicles (BEVs). These BEVs are propelled by an electric motor which uses electric energy stored onboard in batteries. The electric motor has very high efficiency on all loads and engine speeds compared to the ICE, along with instant torque delivery from the start and regenerative braking. Yet they have a long way to go to effectively replace conventionally powered vehicles, and seal their place as the more practical option. This paper presents an extensive overview of the 3 branches of the current BEV eco-system along with their components, analyzing their respective current and emerging trends:

- i. Design of BEV
- ii. Electric Vehicle Supply Equipment (EVSE)
- iii. EV Charging Infrastructure

**KEYWORDS:** Battery Electric Vehicle, EV Charging Infrastructure, EV Design, EVSE, EV Batteries

### ABBREVIATIONS:

A/C – Air Conditioning

DC – Direct Current

EV – Electric Vehicle

EVSE – Electric Vehicle Supply Equipment

ICE – Internal Combustion Engine

ICEV – Internal Combustion Engine Vehicle

LIB – Li-Ion Battery

RE – Renewable Energy

US – United States

## I. INTRODUCTION

The EV burst onto the scene in the late 1800s and early 1900s. At the turn of the 20th century, more than one-quarter of all cars in the US were electric, yet the EV had all but vanished by 1935. ICEs had won and would rule the automotive world for decades. This disappearance was largely due to the insufficient range and power of EV batteries compared to ICEs. Furthermore, EVs were significantly more expensive than their gasoline counterparts.

It wasn't until the 1960s and 1970s that interest in EVs began to grow again with two companies leading the way in the US, Sebring-Vanguard with their "CitiCars" and the Elcar Corporation. BMW debuted its first EV at the 1972 Summer Olympics. Many more EVs debuted in the 1970s but not many sold. But by 1990s, emission regulations once again

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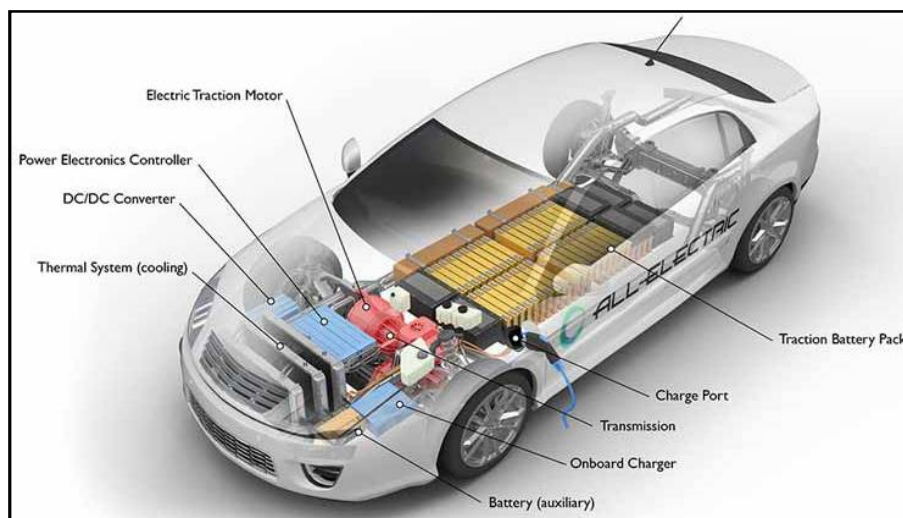
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pushed automakers towards EVs. GM's EV1 and the Toyota Prius helped grow the public's interest in fuel-efficient cars. Finally, the emergence of Tesla in 2006 and the Nissan Leaf in 2010 helped propel EVs to the forefront. Worldwide sales of EVs grew by approximately 45% in 2016. 2017 was the year EVs went from a promising progressive fad to an industry-wide inevitability, owing to 3 major factors: China's aggressive pro-EV stance, Tesla's Model 3 and governments and manufacturers ramping up their EV-plans. Every major automaker has released a fully or partially electric model, and several countries have seen the rise of new players in electricity markets catering to the growing demand of EVs.

In 2017, Britain and France said that by 2040 new cars completely reliant on petrol or diesel will be illegal, and China and India have both vowed to scrap ICEs by 2030. An analysis by Morgan Stanley reckons that half the cars on the road globally, a billion in total, will be battery-powered by 2050. Today, the widely used commercial car-models in the global EV market are Nissan Leaf, Chevrolet Volt, Tesla vehicles, and the Reva and Mahindra e2o in India.

## II. DESIGN OF BEV



**Fig. 1: General design layout of a BEV**

A Battery Electric Vehicle (BEV) (also called Battery-only Electric Vehicle (BOEV), Full Electric Vehicle (FEV) or All-Electric Vehicle), is a type of EV that uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers instead of ICEs for propulsion. They derive power from their battery packs and thus have no ICE, fuel cell, or fuel tank. The most significant difference between BEVs and ICEVs is the number of moving parts. The BEV has one major moving part which is the motor whereas the ICEV has hundreds of moving parts. ICEVs require a wide range of maintenance activities like frequent oil-changes, filter replacements, periodic tune-ups, exhaust system repairs, etc., whereas the BEV requires less periodic maintenance making it far more reliable.

However, existing ICEVs are remarkable in that they provide excellent performance in each of these categories. We can drive our cars for more than 500 km, and fill up anywhere in 5 minutes. When treated well, these vehicles can last a decade and travel hundreds of thousands of kilometres before they finally fall apart. This sets quite a high bar for the new BEV market entrants. The major limitations that need to be addressed in today's EVs are energy and power density to cover long distances, battery charging particularly in terms of charging-time, lifetime performance particularly considering battery replacement and overall system costs.

Here, we have reviewed the current trends and emerging technologies in the following six major aspects of a BEV from the design point of view:

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- i. Battery
- ii. Vehicle Structure
- iii. Powertrain
- iv. Electric Motor Drives
- v. Air Conditioning
- vi. Brakes

## 1. Battery

The major bottleneck for BEV penetration in the market is the battery technology. Though battery technology has certainly improved over the last century, much research and development is still needed to improve performance while ensuring that batteries are lightweight, compact, and affordable. Lithium-Ion batteries (LIBs) are currently used in the majority of EVs, and it's likely that they will remain dominant into the next decade. A 24 kW-hr LIB for around 160 km range for a compact vehicle, still may cost around INR 5,00,000 with a weight of around 200 kgs, and the charging time is also quite a bit as compared to the almost instantaneous refuel for a petrol/diesel car.

In 2012, LIBs for EVs had a Power Density of 400 W/kg and Specific Energy of 100W-hr/kg with a cost of about INR 38,000/kW-hr. The objective for 2020 is 2000 W/kg, 250 W-hr/kg and INR 8000/kW-hr. However, these values are still not enough for a significant sales increase of EVs as the range will still be low compared to fossil fuels. The US Department of Energy (DOE) has a goal of reducing the production cost of a BEV battery ultimately to INR 5000/kWh, increase the range of EVs to 500 km, and decrease charge time to 15 minutes or less. In order to achieve this goal, a major effort within the battery research community has been on increasing the energy density of the cell, which refers to the amount of energy stored in a specified weight or volume. Increasing electrode thickness is an effective way of improving the energy density of a cell.

The 3 new promising future technologies are Li-S, Li-Air and Zn-Air chemistries. Their possible estimated power and energy density values are given in Table 1 below.

Attributes	Li-Ion (Obj.2020)	Li_S	Li_Air	Zn_Air
Power Density (W/kg)	2,000	750	1,000	-
Energy Density (Wh/L)	250	250	250	-
Theoretical Specific Energy (Wh/kg)	600	2500	11,000	1,200

**Table 1: Estimated power and energy density values of different battery technologies**

(Source: References – [4])

As seen from the above Table 1, Li-S batteries offer a higher theoretical energy density and a lower cost than LIBs, but their low cyclability, caused by expansion and harmful reactions with the electrolyte, is the major drawback. Most Metal-Air or Metal-Oxygen prototypes also have problems with cyclability and lifetime currently. Zn-Air batteries are stable towards moisture, whereas most components of Li-Air cells are unstable towards moisture. Thus, the latter must be assembled in an inert atmosphere which is very expensive. Zn-Air batteries also have stronger price competitiveness than Li-Air batteries. However, the reversibility of Li-Air batteries is better than that of Zn-Air batteries, which provides better charging ability. Also, the operating potential and specific capacity of Li-Air batteries is higher than those of Zn-Air batteries, resulting in much higher energy density, an irresistible fascination of Li-Air batteries.

The Metal-Air technology looks very promising for BEV penetration. However, it still has many technical problems to be resolved. Sources analyzing the future of Li-Ion, Li-S and Metal-Air technologies show that LIBs will continue to improve steadily and plateau at around 2035. Li-S and Li-Air technologies will be at a good point at around 2050. Therefore, these results suggest a gradual increase of the BEV market up till 2050, and an accelerated increase of the

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market after 2050. Incremental innovations on Li-Ion battery systems will further change the inclination of the market penetration.

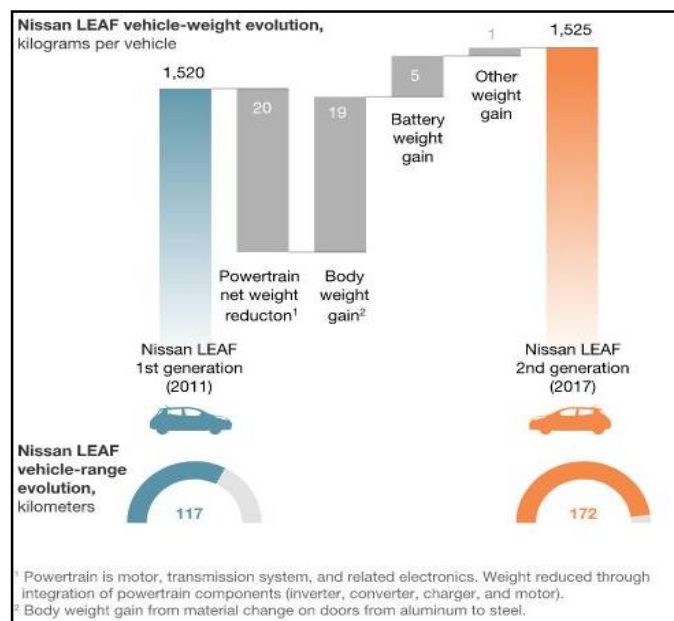
For the BEV market to be successful, it is anticipated that significant improvements in battery performance and range will be needed, along with a dramatic reduction in charge time. The battery management system can control the charge and discharge rates to help extend life. Careful thermal management will help reduce capacity-degradation over time, as high-temperatures are particularly damaging for batteries. Advancements in batteries are likely to not only transform the transportation industry, but also significantly affect global energy markets having electricity-storage needs.

## 2. Vehicle Structure

The use of metal base-structures and reinforced-plastic body-shells is now an established technology for the low-to-medium range of cars in production. However, the Austin Seven car when first introduced in the 1920s was a ‘composite’ of steel chassis and timber-framed aluminium body which scaled well below the half-tonne benchmark. These ‘light-cars’ of early history were considerably lighter than similar-sized cars of the present day, albeit poorly equipped with lower performance and safety.

Today’s conventional small cars do well to scale under 1 tonne; exceptions are the products of small companies such as Reliant whose steel chassis and GRP-bodied cars are still below half-tonne tare weight. The lightweight BEV design concept of composite construction is to use reinforced plastics in more intimate combinations with metals. This permits the most efficient usage of thin-walled sheet-metal structures together with plastic systems to stabilize the entire assembly against buckling. Lately, interest is also being shown in truss-like plastic reinforcements for stabilizing box-beams and a variety of hollow open and closed structural members for future designs.

To summarize with an example, the Nissan Leaf launched in 2011 weighed around 1520 kgs and had a maximum range of 117 km. Today, its 2017 edition weighs 1525 kgs but with a considerably improved range of 172 km. The design-to-cost efforts focused on a wide range of optimizations in the area of battery, powertrain and body-weight to make this increased range of 55 km achievable. This evolution is clearly illustrated in Fig. 2 below in terms of vehicle-weight.



**Fig. 2: Nissan Leaf evolution from 2011 to 2017**

(Source: McKinsey&Company – A2Mac1; McKinsey Centre for Future Mobility)

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### 3. Powertrain

A BEV is driven by at least one electric drive motor, and can be configured as a four-wheel drive vehicle or with one drive axle. The two main concepts generally implemented are:

- i. Drive with in-wheel motors (Fig. 3)
- ii. Drive with one electric drive motor in the central drive train (Fig. 4)

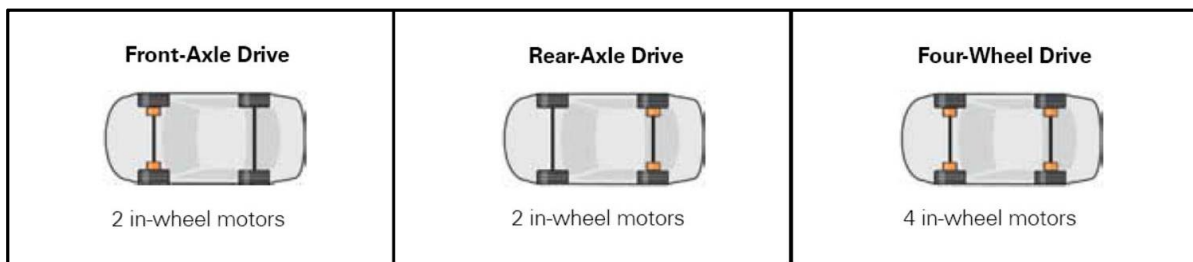


Fig. 3: Drive with in-wheel motors

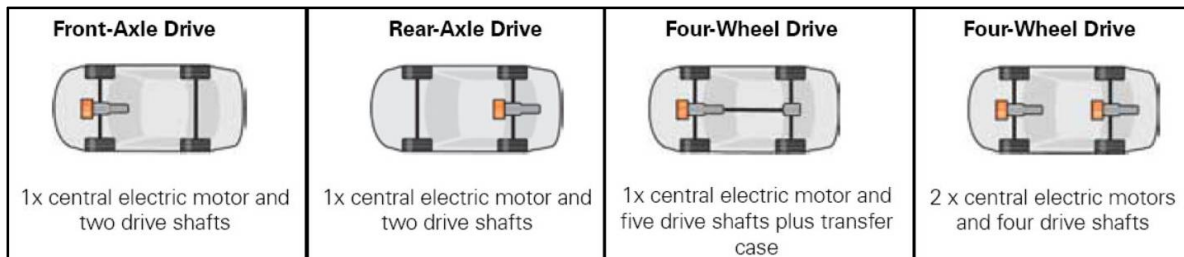


Fig. 4: Drive with just one electric drive motor in the central drivetrain

These powertrain configurations are predicted to be in use for the coming years also, interchanging only as per vehicle design and battery-placement requirements.

### 4. Electric Motor Drives

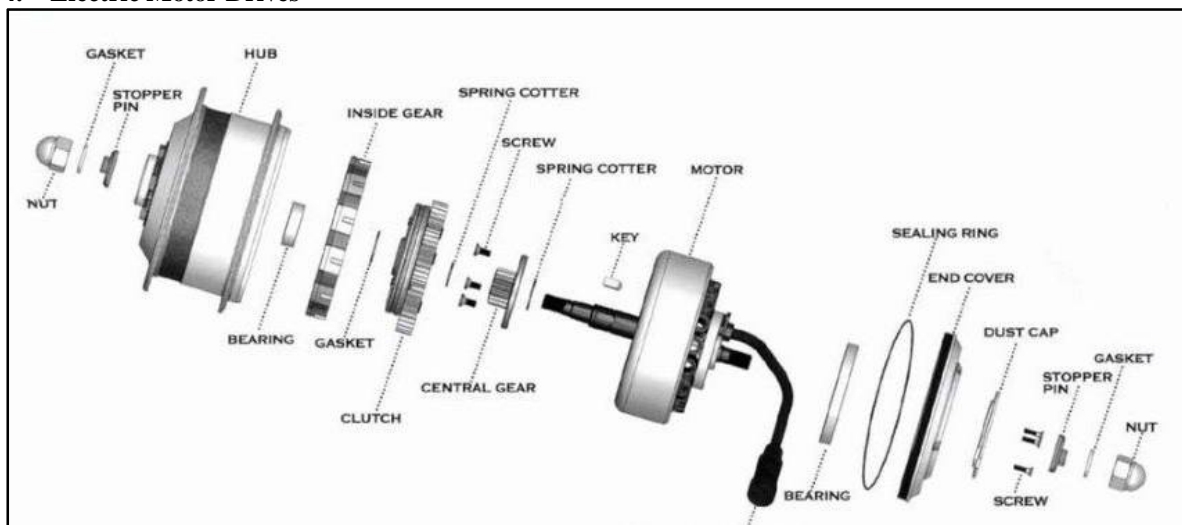


Fig. 5: Wheel-hub motor assembly in a BEV



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DC drives have been used prominently in EVs because they provide simple speed control and ideal torque-speed requirements. These are mainly of two types: Brushed and Brushless. There is little difference between the two in terms of design. If we replace the field winding and poles of a Brushed DC Motor with high energy permanent magnets, then we get BLDC Motors which permit a considerable reduction in the stator diameter. Owing to its low permeability, the commutation can be considerably improved by a small reduction in the size or diameter of the armature.

Sr. No.	Aspect	BDC Motor	BLDC Motor
1	Maintenance Required	Periodic maintenance needed	Less maintenance needed
2	Speed/Torque	Moderately flat. At higher speeds, brush friction increases, thus reducing useful torque	Flat, enables operation at all speeds with rated load
3	Noise Generation	High	Low

**Table 2: Brushed DC Motor vs. Brushless DC Motor**

The Induction Motor drive is another widely-used technology amongst the various commutator-less motor drives. There are two types of Induction Machines (IMs): the wound-rotor and squirrel-cage. When a BEV adopts the single-motor configuration, the induction motor is generally designed for high-speed operation while using a planetary gear to step down the motor speed, so as to match with the wheel speed. The Ford-Siemens EV motor was one of the most well-developed induction motors for EVs.

Based on the various parameters and characteristics of different Electric Motor drives used in EVs, an attempt has been made to classify them according to their characteristics and mode of application. Conclusions that can be drawn are:

- i. The Induction Motor drive is the most cost-effective motor drive.
- ii. The Permanent Magnet Brushless Motor drive is the most energy-efficient motor drive.
- iii. The DC Motor drive is the most mature technology as a lot of research work and development has been done on them over the past.
- iv. The Induction Motor drive is the most reliable motor drive.

The most widely accepted and used Electric Motor drive is the Induction Motor drive and Permanent Magnet Brushless Motor drive, and they are predicted to remain so for the coming years. Also, asynchronous traction motors with longer life, less maintenance, low cost and freedom from magnet price hikes and heating problems are now being tested in a few cars and are expected to contribute to future developments

## 5. Air Conditioning

The move to EVs poses several challenges when it comes to climate control within the vehicle. Gone is the hugely inefficient ICE whose coolant system can easily be tapped for cabin heating, and powering a 3-5 kW A/C compressor takes on a whole new meaning when the typical BEV consumes only 125 W-hr/km to drive at highway speeds. The US DoE has been funding development projects for Thermoelectric Vehicular Heating, Ventilation and Air Conditioning (HVAC) and waste heat recovery, and listed several viable approaches to this problem.

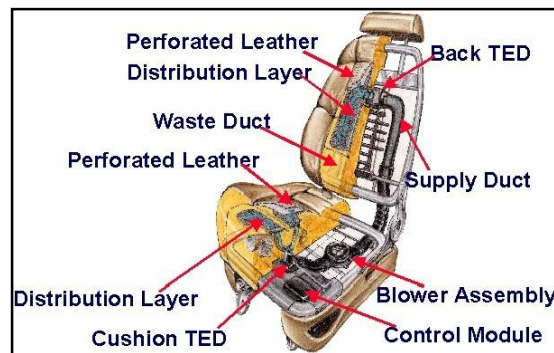
Localized or zonal heating and cooling is an excellent method. Current vehicular HVAC technology heats and cools the thermal loads of the surrounding structures such as the headliner, windows, flooring, and seat backs in addition to the occupants, consuming 3-5 kW of energy. To reduce this load, heating or cooling can be plumbed directly into the seats. These seats are called Climate Controlled Seats (CCS) and usually feature internal ducting, their own blower and a perforated leather surface. Using Reverse Cycle Air Conditioning is another method, wherein like residential A/Cs, with the addition of a simple valve, these systems can be run in reverse cycles to provide heating as well as cooling.

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**Fig. 6: General working of Climate Controlled Seating**

In a BEV, the A/C compressor has to be driven electrically much the same way as a residential air conditioner. The 12V electrical system in most cars isn't powerful enough to drive a 5 kW compressor, but most EVs have a 350V main battery with more than enough power to drive a compressor. The challenge is to reduce the load so that running the A/C doesn't overly drain the battery and dramatically reduce range.

As with residential A/Cs, variable-speed compressors driven by inverters operate more efficiently, mostly because they avoid the high current drain require by repeatedly starting the electric motor driving the compressor. Compared to existing systems, the combination of Climate Controlled Seats and variable-speed compressors will reduce battery loads significantly in the future.

### 6. BRAKE SYSTEM

A BEV has two independent brake systems. One system is the traditional mechanical or hydraulic brake system. The second brake system is formed by the electric drive motor, known as an "Engine Brake". The advantage of this brake compared with ICE is that the energy released by the electric motor/generator during braking and deceleration is recovered and fed into the BEV battery. This is also popularly called "Regenerative Braking".

In a traditional braking system, brake pads produce friction with the brake rotors to slow or stop the vehicle. Additional friction is produced between the slowed wheels and the surface of the road. This friction is what turns the car's kinetic energy into heat. With regenerative brakes, the system that drives the vehicle does the majority of the braking. When the driver steps on the brake pedal of a BEV, these brakes put the vehicle's electric motor into reverse mode, slowing the car's wheels. With the polarity reversed, the motor acts as an electric generator, producing electricity which is then fed into the EV's batteries.

Providing EVs with regenerative brakes along with traditional brakes as backup will help reduce wear in mechanical components, and provide energy to the batteries which can help increase the range efficiency particularly in city traffic. This can also mean higher overall efficiency of the EV. Further advancements in regenerative braking, along with improving battery-reversibility (switching between charging and discharging), will fuel the progress of EVs.

### III. ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

EVSE is a protocol to help keep the EV and its passengers safe while charging. Earlier EV owners would manually need to adjust their charger parameters to ensure that it did not pull more power than the circuit capacity, while ensuring optimum connectivity and charging. EVSE eliminates all user interaction beyond plugging the J1772 connector in. Using two-way communication between the charger and car, the correct charging current is set based on the maximum current the charger can provide as well as the maximum current the car can receive, also taking into consideration battery health. As part of the protocol, a safety lock-out exists, preventing current from flowing when the

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charger is not connected to the car. It also ensures that if a cable is not correctly inserted, power will not flow through it. EVSE can also detect hardware faults and disconnect the power to prevent battery damage, electrical shorts or fire. Over the next few years, expect some enterprising individuals to develop charger conversion boxes which enable an EV to make use of any power outlet by spoofing the EVSE chargers to enable the user to charge from locations where EV chargers are not yet in use. Expect the opposite too, as EVs without J1772 receptacles seek to charge at any available Level 2, EVSE compliant charging stations.

While some EV owners may view EVSE equipped chargers as expensive and unnecessary, they represent a much simpler way for the majority of consumers to charge their EV. The safety features alone also prevent unauthorised access to EV charging stations to non-EV uses, ensuring EV charging points are quick, easy and safe to use for everyone.

AC Level 1 Charging	AC Level 2 Charging	DC Fast Charging
2 to 5 miles of range per 1 hour of charging	10 to 20 miles of range per 1 hour of charging	60 to 80 miles of range per 20 minutes of charging
 J1772 charge port	 J1772 charge port	 J1772 combo    CHAdeMO    Tesla combo
<p>AC Level 1 EVSE (often referred to simply as Level 1) provides charging through a 120 volt (V) AC plug. Most, if not all, plug-in electric vehicles (PEVs) will come with an AC Level 1 EVSE cordset, so no additional charging equipment is required. On one end of the cord is a standard <b>NEMA</b> connector, (for example, a NEMA 5-15, which is a common three-prong household plug) and on the other end is an SAE J1772 standard connector. The SAE J1772 connector plugs into the car's J1772 charge port and the NEMA connector plugs into a standard <b>NEMA</b> wall outlet.</p> <p>AC Level 1 is typically used for charging when there is only a 120V outlet available, but can easily provide charging for all of a driver's needs. For example, 8 hours of charging at 120V can replenish about 40 miles of electric range for a mid-size PEV.</p>	<p>AC Level 2 equipment (often referred to simply as Level 2) offers charging through 240V (typical in residential applications) or 208V (typical in commercial applications) electrical service. Most homes have 240V service available, and because AC Level 2 EVSE can charge a typical EV battery overnight, they will commonly be installed at EV owners' homes for <b>home charging</b> or are used for <b>public charging</b> equipment. This charging option can operate at up to 80 amperes and 19.2 kW. However, most residential AC Level 2 EVSE will operate at lower power. Many of these units operate at up to 30 amperes, delivering 7.2 kW of power. These units require a dedicated 40 amp circuit.</p> <p>AC Level 2 equipment uses the same SAE J1772 connector and charge port that Level 1 equipment uses. All commercially available PEVs have the ability to charge using AC Level 1 and AC Level 2 charging equipment. Although Tesla vehicles do not have a J1772 charge port, they do sell an adapter.</p>	<p>Direct-current (DC) fast charging equipment, sometimes called DC Level 2 (typically 208/480V AC three-phase input), enables rapid charging along heavy traffic corridors at installed stations. There are three types of DC fast charging systems, depending on the type of charge port on the vehicle: a J1772 combo, CHAdeMO, or Tesla.</p> <p>The <b>J1772 combo</b> is used by Chevrolet and BMW and is unique because a driver can use the same charge port when charging with Level 1, 2, or DC Fast equipment. The only difference is that the DC Fast Charge connector has two bottom pins.</p> <p>The <b>CHAdeMO</b> is the most common of the three connector types and is used by Nissan, Mitsubishi, and Toyota.</p> <p><b>Tesla</b> vehicles have a unique charge port and connector that works for all their charging options including their fast charging option, called a supercharger.</p>

**Table 3: Different levels of EVSE**  
(Source: Alternative Fuels Data Centre, US DoE)

An additional standard (SAE J3068) is under development for higher rates of AC charging using three-phase power, which is common at commercial and industrial locations in the US. Some components of the standard will be adapted from the European three-phase charging standards and specified for North American AC grid voltages and requirements. In the US, the common three-phase voltages are typically 208/120 V, 480/277 V. The standard will target



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power levels between 6kW and 130kW. In addition, the US DoE's Vehicle Technologies Office is pursuing research that will bridge the technology gaps associated with implementing an extreme fast-charging network in the future. Inductive charging equipment, which uses an electromagnetic field to transfer electricity to an EV without a cord, has been recently introduced commercially for installation as an aftermarket add-on. Currently available wireless charging stations operate at power levels comparable to AC Level 2, though this technology has been used in other countries at higher power levels for mass transit operations.

## IV. EV CHARGING INFRASTRUCTURE

BEV sales will increase rapidly in the next 30 years. BNEF's latest report suggests that "EVs are on track to accelerate to 54% of new car sales by 2040". The resulting growth of electricity demand from EVs could overwhelm the grid and pass on higher electricity costs to consumers. Better BEV batteries with greater capacity are helping, but the challenge to the electricity infrastructure is twofold: making sure the system can supply enough energy to quickly charge a great number of new vehicles, and making sure the distribution system is in place to transport those electrons to the right cars at the right time. To this effect, automakers, governments and commercial charging firms are all investing.

Tesla plans to expand its global network of 145KW "supercharger" stations, to 10,000. These public facilities can replenish the firm's larger batteries to 80% in 40 minutes (for technical reasons, fast chargers cannot top up batteries completely). Several other automakers are also rolling out their own fast-charging networks, which need expensive kits but bring charging speeds down to the time it takes to use a conventional fuel pump. Nissan now has a global network of 4,000 fast chargers. Last year Daimler, BMW, Volkswagen and Ford also said they would together install a total of 400 public charging-points in Europe delivering 350KW, which will charge a small car to three-quarters full in 4 minutes and a big vehicle in 12 minutes.

London recently announced plans for 1,500 new charging-points by 2020. France, Germany, the Netherlands and Norway are among the countries that have launched initiatives to improve access to public charging. The EU is also mulling regulations that will require all new dwellings to have access to an EV charging-point. The Chinese government, which is set on remaining the largest market for electric cars, has far bigger plans. This year alone it is installing 800,000 public charging-points, including 100,000 semi-public ones at workplaces and for taxis and commercial vehicles.

'Chargeit', an app that allows owners of home chargers to rent them to the public, launched recently in Britain. Wireless inductive charging from road to car is already technically feasible, if expensive; it would make sense at taxi ranks when vehicles sit idle, for example. Qualcomm, a chipmaker, has demonstrated technology for recharging a moving vehicle on any road surface, although this way of providing limitless range is still some way off. Commercial firms such as 'Chargepoint' may well come to dominate charging away from the home, if only because they are more focused on it than either carmakers or governments. City and national governments are working on roadside charging for drivers who cannot plug in at home. Local authorities there are experimenting with providing low-cost kerbside charging by enabling streetlights to double up as charging-points.

A few basic points related to charging infrastructure that are likely to play a pivotal role in the growth of EVs are:

- i. Free EV charging points
- ii. Focus on implementation of fast-charging points
- iii. Community charging stations
- iv. Reassessment of EV charging networks
- v. Regulated rates for charging
- vi. Investments by large fleet owners
- vii. Battery swapping
- viii. Public awareness regarding charging ethics

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The Renewable Energy (RE) infrastructure of any country will also have an enormous impact on EV emergence. For example, a study suggests that a BEV owner in India could save close to INR 37,000 annually if India meets its Renewable Energy targets by 2030. With the difference in the capital costs of both vehicles expected to be in the range of INR 1,00,000, a BEV owner would be able to recover the incremental cost of his vehicle within just a year. In case the entire electricity consumption for EVs was to be sourced from RE sources, fuel cost savings could increase by another 8% (INR 40,000).

## V. CONCLUSION

As demand rises, BEV technology and design will continue to evolve, and strategic challenges will follow. Ultra-capacitors (or super-capacitors) are being intensely researched on, which permit very fast charging by both the new Level 3 charging stations and regenerative braking, and can release huge surges of power under high-torque requirements. Gas turbine range extenders, which have been on some buses for 12 years, are now being planned for cars. Fuel cells will be viable in fleets where the expensive hydrogen distribution is manageable. Energy harvesting shock absorbers slated to hit the market soon will also help propel the BEV further.

For BEVs, the main barriers today are battery performance, cost, and access to charging infrastructures. We believe that battery performance and cost will be more critical and charging infrastructure will follow the development and trend on the market. As new BEVs enter automotive markets in a big way, companies will learn much more about warranty costs, lifetime, vehicle performance over time, and user satisfaction. The growing market for BEVs will continue to spur innovation in various fields, and we can already see where some of the major obstacles lie. Yet, perhaps the biggest challenge that remains for the acceptance of EVs is non-technical, which is simply spreading awareness amongst the driving public.

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