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CACTUS

Models and Methods for the Evaluation and the Optimal Application of Battery Charging and Switching Technologies for Electric Busses

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Partners

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Document: Deliverable 1.2 Technologies for Fully Electric Busses

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Content

Abbreviations

AC	Alternate Current
AEV	All-electric vehicles
AFC	Alkaline electrolyte fuel cells
BEV	Battery electric vehicle
DC	Direct current
DMFC	Direct methanol fuel cells
EDLC	Electric double-layer capacitors
EM	Electric motor
ESS	Energy storage system
EV	Electric vehicle
FC	Fuel cell
FES	Flywheel energy system
HEV	Hybrid electric vehicle
HESS	Hybrid energy storage system
ICEV	Internal combustion engine vehicle
MCFC	Molten carbonate fuel cell
PAFC	Phosphoric acid fuel cells
PEMFC	Proton exchange membrane fuel cells
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaic cell
SOC	State of the charge
SOFC	Solid oxide fuel cells
SPHEV	Series plug-in hybrid electric vehicle
UC	Ultracapacitor
ZEBRA	Zero emissions batteries research activity

1 Introduction

The global trend towards clean and energy-efficient vehicles is driven by concerns regarding the impacts of fossil-fuel-based road transport on energy security, climate change and public health. Electrification in particular is understood as providing a potential multitude of opportunities for the use of energy from renewable sources and for the reduction of local emissions and greenhouse gas emissions like no other. In 2009, the European Commission presented the Green Cars Initiative aimed at encouraging the development and market uptake of clean and energy-efficient vehicles. This strategy will enable the environmental impact of road transport to be reduced and will boost the competitiveness of the automobile industry.

1.1 Problem

The use of public transport is an environmentally friendly way to travel. If more and more passenger cars will be powered by electrical energy in the future, public transport companies will be forced to convert their diesel busses into electric busses in order not to lose this advantage.

The requirements of busses are different to those of passenger cars. A bus covers an average distance of 250 to 300 km each day. The bus itself has a weight of, for example, 14-17.5 t (Solaris Urbino 18), 28 t (MAN NG 313) or 26.6 t (Mercedes O 405 GN). A suitable battery that would enable the bus to run for such a long distance without having to be recharged would be far too big, heavy and expensive. In order to overcome this problem, several approaches are currently being investigated, for example switching the battery and the short inductive charging of super capacitors at bus stops. With these technical solutions, which combine vehicles and infrastructure, fully electric busses should be enabled for use in public transportation.

Assumptions:

1. In the near future, there will be no batteries for fully electric busses which provide the daily output of 300 km without needing to be recharged and which would be acceptable in terms of their size, weight and cost.
2. No technical approach that is currently being investigated will be equally suitable for all public transport companies.
3. In any case, investment costs for vehicles, in-vehicle components and infrastructures (e. g. battery charging or battery switching facilities) will be very high for public transport companies.

The following conclusion is drawn: The available technical approaches and solutions must be considered separately against the prerequisites and requirements of every single public transport company in terms of transportation, technical, economic and environmental aspects. Only on this basis can a decision for a technology that optimally meets the requirements of a public transport company be made.

1.2 Objectives

Technical solutions to enable fully electric busses should be evaluated so that they reflect the prerequisites and requirements of the participating public transport companies. The ultimate goal of the project is to find the best technical solution for the participating public transport companies HVB, MVB, PVGS and PKM depending on their real input data (timetable, vehicle operation plan, etc.), which in most cases may mean minimising the investment and operational costs. Of course, the best solution may vary between the participating public transport companies due to the strongly different prerequisites, assignments and aims. The best solution does not only involve a technology, but also its optimal application.

To achieve this aim, models of all relevant transportation, technical, economic and ecological values will be elaborated. Methods will be developed with which the question as to the most suitable technical solution (depending on the input values) can be answered and which help to apply the technical solution found in an optimal way. A software tool will be developed with which the different solutions can be easily compared. It should be possible to study the gradual integration of fully electric busses into existing fleets of diesel, natural gas and hybrid busses.

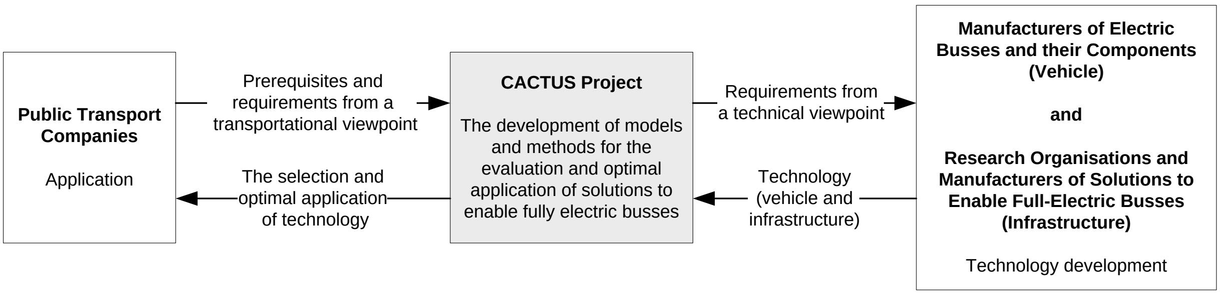

Figure 1: The role of the CACTUS project

The preliminary studies with the participating public transport companies will be lead into recommendations for the actors in the field of technology development, namely the manufactures and researchers of fully electric busses and the corresponding infrastructure. The role of the CACTUS project can be seen in Figure 1.

1.3 Concept

In the CACTUS project, considerations concerning techniques for fully electric busses will be made to decide which best fits a public transport company’s needs. This requires a series of detailed questions to be answered. Some general questions are:

- Is it possible to keep to the timetable with a given configuration (all technical and strategic elements requiring the operation of fully electric busses), a given vehicle fleet (including those with mixed engines) and a given vehicle operation plan?
- How high are the investment and operational costs?

In this context, several optimisation issues arise, some of which are listed here:

- What should the operation plan look like so the timetable can be kept to?
- Where the charging or exchanging facilities have to be located?

In the CACTUS project, methods that can be used to answer these will be developed.

1.4 Scope of this Deliverable

In Deliverable 1.1 the questions have been collected which will be answered within the CACTUS project. The Deliverable 1.1 only mentioned ‘what is the problem’ not ‘how will the problem be solved’ (this is part of Deliverable 2.1 and moreover part of Deliverable 3.1). This Deliverable 1.2 deals with available technologies for all-electric busses.

“Vehicles can be classified into three groups: internal combustion engine vehicles (ICEV), hybrid electric vehicles (HEV) and all- electric vehicles (AEV). Figure 2 shows all available vehicle types. The hybridization factor (HF) was derived to calculate the ratio of hybrid or electric vehicle [98, 97] as expressed in Eq. (1), where power from electric motor (EM) is divided by total power from EM (PEM) and ICE (PICE). Assuming that the vehicle is not assisted by an auxiliary energy source (AES), HEV usually can be divided into mild or medium hybrid electric vehicles (mild-HEV) and full hybrid electric vehicles (full-HEV).

$$HF = P_{EM}/(P_{EM} + P_{ICE}) \quad (1)$$

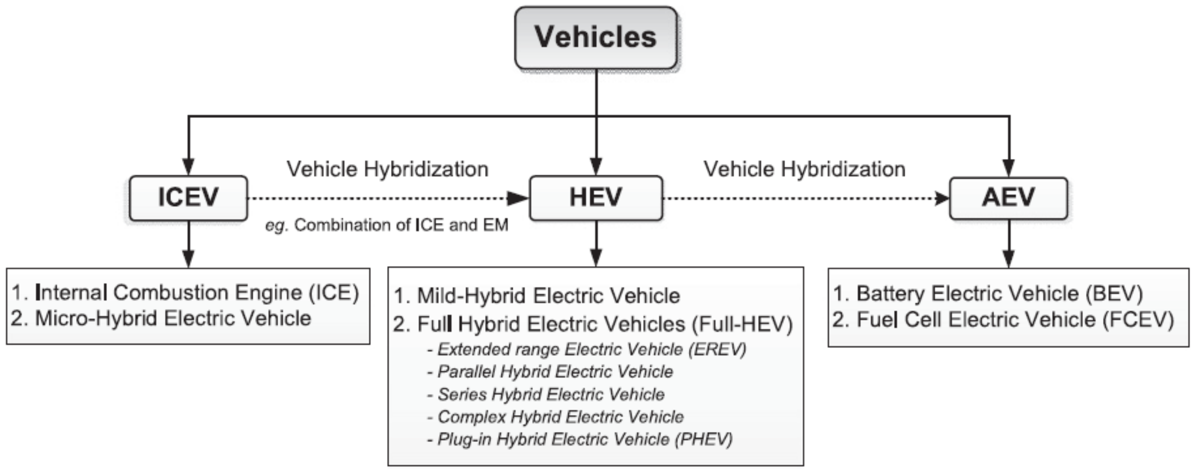

Figure 2: Classification of the vehicle [130]

Currently, there are two ways to cascade the EM to ICE. One is by sharing the same shaft with ICE and EM. The second one is by a power split path. The difference in fuel efficiency calculated by mile per gallon (mpg) can be seen in every stage of vehicle hybridizing. Fuel efficiency is kept increasing from a conventional ICE vehicle to an AEV [...]. A footnote on the Environment Protection Agency (EPA) site explains, ‘MPGe is miles per gallon of gasoline-equivalent and represents the miles per amount of energy of a non-gasoline fuel that is equivalent to the amount of energy in a gallon of gasoline. For an EV or PHEV, 33.7 kWh of electricity represents the same amount of energy as one gallon of gasoline’ [134, 109].” [130]

1.5 Structure of this Deliverable

Electric busses in any case use energy storage technologies for storing the energy for moving (Chapter 2). How the energy is transferred into the bus is a matter of the energy transmission technology (Chapter 3). Chapter 4 deals with different modes for battery charging while Chapter 5 focus on battery exchanging. In Chapter 6, a lot of currently available models of electric busses are collected. Each of them combines an energy storage technology with an energy transmission technology. Trolley busses are addressed in Chapter 7. Finally, Chapter 8 focuses on some alternative propulsion technologies.

2 Energy Storage Technologies

The energy storage must be carried by the bus. It is used for powering the bus when no external energy source is available. It has a mass and a volume. Important values are the energy density [Wh/kg] and the power density [W/kg] of the energy storage.

2.1 Battery

“Battery is a storage device which consists of one or more electrochemical cells that convert the stored chemical energy into electrical energy. There are several characteristics that one should take into account in selecting the most appropriate battery for EV. The most significant characteristic is the battery capacity, which is measured in ampere-hours (Ah). Besides that, the energy stored in battery (capacity × average voltage during discharge) which is measured in watt-hours (Wh) should be carefully calculated. The useable state-of-charge (SOC) of the battery which is represented in percentage is equally important as it indicates the current status of charge available in the battery.

The battery has to be managed well to operate in the window of SOC or SOC swing in order to prolong the life-cycle of the battery. The capacity is proportional to the maximum discharge current. The maximum discharge current is typically represented by the index of C. For example, a discharge rate of 1C indicates that the battery is depleted in 1 h while 2C indicates that the battery is depleted in only half an hour. This maximum current is affected by battery’s chemical reactions itself and heat generated. [...]

Today, five groups of battery are available in the market which is suitable for road transportation application. Table 1 shows all the battery technologies and characteristics. A lead-acid battery is the most common and cheapest battery used by a conventional ICE vehicle. The application of this battery is more preferable when weight is least concern. The lead-acid battery is not an environment-friendly battery. It causes environmental problems either during production or disposal process.

The nickel battery, for example, nickel-zinc is more environment-friendly, comparatively, but has a short life cycle. The major issue of a nickel-iron battery still is its heavy weight, high maintenance cost and high self-discharge rate. The nickel-cadmium (Ni-Cd) battery has a memory effect that is not suitable to use in high charge/discharge rate like automobile application but it performs well under rigorous working conditions. Besides, it contends toxic materials and high maintenance cost. Nickel- metal hydride (Ni–MH) is also one of the environment-friendly batteries. Ni-MH has about 50% higher self-discharge compared to the Ni-Cd. The other drawback of this battery is that it takes longer time to charge than lead-acid and Ni-Cd battery, and it generates a large amount of heat during charging. Consequently, Ni-MH battery requires more complex charge algorithm and expensive chargers despite being most widely used in EV [92].

A zero emissions batteries research activity (ZEBRA) battery is built by sodium nickel chloride (NaNiCl). It has a high temperature characteristic around 300-350 1C. Then high temperature technology has to be used in order to maintain suitable efficient operation. ZEBRA batteries have less life-cycle-cost than those of lead-acid batteries [70]. It has advantages such as higher or equal energy density to lithium battery, lowest cost of any modern EV battery technology, high calendar life, ruggedness, fail-safe to cell failure (overcharging or over discharging), resistant to overcharge and over-discharge. The main drawback of this battery is 90 W energy loss while not in used [129].

A lithium battery is one of the promising energy storage devices due to its light weight, high specific energy, high specific power and high energy density. In addition, lithium batteries have no memory effect and do not have poisonous metals, such as lead, mercury or cadmium. Every lithium battery needs a protection circuit in every pack in order to maintain safe operation. The main disadvantage is that lithium battery requires high production cost than NiCad and Ni-MH battery pack. In a lithium battery, lithium metal is the most expensive among them but less safe than lithium-ion battery. Currently, the lithium-sulfur battery can give a higher energy capacity with low weight among lithium batteries but cycle life is a major drawback. Lithium-ion polymer can adapt to a wide variety of packaging shapes, reliability and ruggedness but it has a poor conductivity and a low power density. For a high power density lithium battery, lithium-iron phosphate is one of selections in other word it has higher discharge current then most of lithium battery. Besides that, lithium-iron phosphate is a superior thermal and chemical stability battery, which provides better safety characteristics than lithium-ion batteries. The lithium-titanate battery has the advantage of being faster to charge than other lithium-ion batteries which are currently used by Mitsubishi’s i-MiEV electric vehicles.

The other type of battery such as zinc-air battery is another promising battery. This battery has high specific energy and high energy density than a lithium battery. However, the main drawback is its low specific power, limited cycle life and bulky [92]. Currently, the lithium air battery is still in the research state and has not been commercialized yet. Since the lithium-air battery has a higher energy density than the zinc air battery, it will become the target to all EV.” [130]

Table 1: The comparison of energy storage specifications based on type of energy storage device [139, 102, 99]. [130]

Energy storage Type	Specific energy (Wh/kg)	Energy density (Wh/L)	Specific power (W/kg)	Life cycle	Energy efficiency (%)	Production cost ($/kWh)
Lead acid battery						
Lead acid	35	100	180	1000	> 80	60
Advance lead acid	45	–	250	1500	–	200
Valve regulated lead acid (VRLA)	50	–	150+	700+	–	150
Metal foil lead acid	30	–	900	500+	–	–
Nickel battery						
Nickel–iron	50–60	60	100–150	2000	75	150–200
Nickel–zinc	75	140	170–260	300	76	100–200
Nickel–cadmium (Ni–Cd)	50–80	300	200	2000	75	250–300
Nickel–metal hydride (Ni–MH)	70–95	180–220	200–300	< 3000	70	200–250
ZEBRA battery						
Sodium–sulfur	150–240	-	150–230	800+	80	250–450
Sodium–nickel chloride	90–120	160	155	1200+	80	230–345
Lithium battery						
Lithium–iron sulphide (FeS)	150	–	300	1000+	80	110
Lithium–iron phosphate ($LiFePO_4$)	120	220	2000–4500	> 2000	–	350
Lithium-ion polymer (LiPo)	130–225	200–250	260–450	> 1200	–	150
Lithium-ion	118–250	200–400	200–430	2000	> 95	150
Lithium–titanate ($LiTiO/NiMnO_2$)	80–100	-	4000	18000	–	2000
Metal-air battery						
Aluminum-air	220	–	60	–	–	–
Zinc-air	460	1400	80–140	200	60	90–120
Zink-refuelable	460	–	–	–	–	–
Lithium-air	1,800	–	–	–	–	–
Ultracapacitor						
Electric double-layer capacitor (EDLC)	5–7	–	1–2M	40 years	> 95	–
Pseudo-capacitors	10–15	–	1–2M	40 years	> 95	–
Hybrid capacitors	10–15	–	1–2M	40 years	> 95	–
Flywheel	10–150	–	2-10k	15 years	80	–
Hydrocarbon						
Hydrocarbon fuel (gasoline/propane)	12,890	9500	–	–	< 30	–
Hydrogen	39,720	1600* 2800**	–	–	ICE: < 25 FC: 50	4**
Natural gas (250bar)	14,890	101	–	–	–	–

***Hydrogen storage cost
* In pressure 700 bar.
** In liquid.

Additionally, [138] provides in Table 2 properties of different lithium batteries.

Table 2: Properties of different lithium batteries [138]

Property	$LiMnCoO_2$	$LiFePO_4$	LiTi
Voltage [V]	3.7	3.3	2.3
Discharging Rate [C]	5	30	10
Charging Rate [C]	3	4	10
Full Charging Cycles	> 1000	> 1000	> 10 000
Temperature Range [°C]	0 to 40	-30 to +60	-40 to +55
Safety	–	+	+
Power Density [kW/kg] (Efficiency 90%)	≈ 0.6	≈ 0.9	≈ 0.5
Energy Density [Wh/kg]	≈ 150	≈ 110	≈ 70

[138] assesses the safety of the different lithium cells as follows:

- $LiFePO_4$ (Lithium Ferrum Phosphat): Due to the stability of the chemical compound this cell is safe.
- LiTi (Lithium Titanat): Due to the stability of the chemical compound this cell is safe.

- $LiMnCoO_2$ (Lithium Mangan Cobaltoxyd): From a certain temperature, a self-reinforcing heating up is started. This may lead to ignition or explosion.

Regarding the lifetime of lithium batteries [138] assesses: Depending on technology 1000 to 10000 full charging cycles are possible. Lifetime is given with 20 years, but practical experience says 4-10 years.

2.2 Ultracapacitor

"Ultracapacitor (UC) or supercapacitor has a similar structure with a normal capacitor, but the difference is that UC have high capacitance (high energy capacity with factor of 20 times) than capacitor. The ultracapacitor characteristic includes maintenance-free operation, longer operation cycle life and insensitive to environment temperature variation. Currently, there are three types UC technologies used in HEV and AEV, that is, electric double-layer capacitors (EDLC)—carbon/carbon, pseudo- capacitors and hybrid capacitors. The difference between those UC is in their energy storage mechanisms and their electrode materials used. The specific power density for these three types UC is almost similar around 1000–2000 kW/kg for 95% efficient pulse but EDLC has a more power density than other types of UC. Specific energy density of EDLC is the lowest (5–7 Wh/kg). However, the other two have almost similar energy density (10–15 Wh/kg). The UC lifetime can reach 40 years, which is the longest among all ESS." [130]

[138] talks of more than 1 million full charging cycles.

2.3 Flywheel

"Flywheel energy storage or FES is a storage device which stores/ maintains kinetic energy through a rotor/flywheel rotation. Flywheel technology has two approaches, i.e. kinetic energy (rotational energy) as output and electric energy as output energy. Chris Brockbank, the Business Manager from Torotrak mentioned that the efficiency of energy from braking to FES is 70% which is the double of the efficiency of energy transformed from braking to electric energy and then to FES in [131]. The overall FES mechanical efficiency can hike up to 97% and round-trip efficiency up to 85% if magnetic bearings and vacuum are used. Currently, research agencies (such as Lawrence Livermore National Laboratory (LLNL) in US, Ashman Technology, AVCON, Northrop Grumman, Power R&D, Rocketdyne/Rockwell Trinity Flywheel US Flywheel Systems, Power Center at UT Austin and so on) have developed an ultra-high-speed flywheel system for EV. Typically, the system can achieve 10–150 Wh/kg energy and 2–10 kW/kg power. For instance, LLNL built a prototype which can achieve 60,000 rpm, 1 kWh and 100 kW in a 20 cm diameter and a 30 cm height. Compared to UC, FES has a higher energy density and power density. Unfortunately, the safety issues and gyroscopic force are their disadvantages, if FES fails to manage well in transportation usage [142, 100]. However, FES still can be used in transportation due to some characteristic such as long lifetime more than 15 years with less maintenance compared to other energy storage devices. FES has a fast power response time short recharge time which electric vehicles required. Besides, it operates in a wide temperature range which causes less damage to the environment [33, 34].” [130]

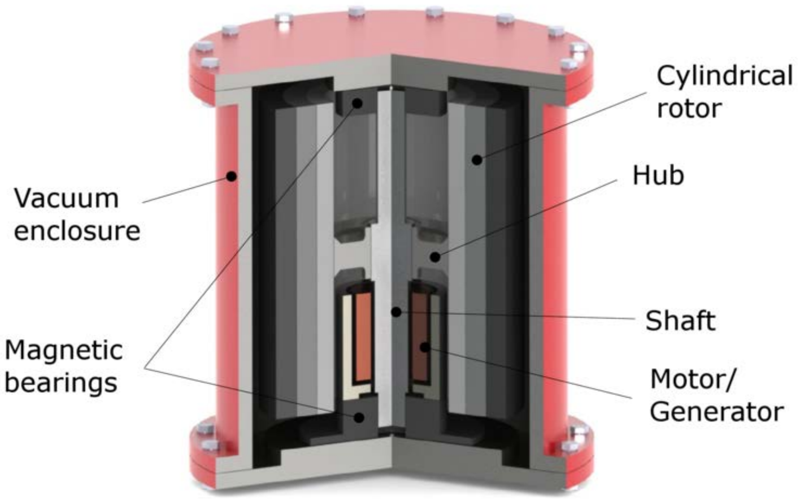

Figure 3: The main components of a typical flywheel [41]

The main components of a typical flywheel are depicted in Figure 3.

2.4 Regenerative Braking

“When a vehicle is in coasting and braking modes, the kinetic energy from a moving car generates electricity back to the supply side which is known as regenerative braking. Currently, there are four ways to capture the energy generated by regenerative braking. First, the electricity generated is stored directly into ESS. Second, hydraulic motors could store energy in a small canister through compressed air. Besides that, energy can also be stored in FES as rotating energy. The last way is to store the regenerative braking energy as gravitational energy (potential energy) through spring. Table 8 shows different methods to recover the braking energy [68, 32]. Regenerative braking operates together with the friction brake in some ratio when the vehicle starts to slow down. This is because the regenerative braking system has not generated enough energy to physically stop the vehicle. It also serves as a safety purpose of the vehicle. In order to improve the regenerative braking operation, there are some constrains that need to be considered. The consideration factors include the ability or size of electric generator, state-of-charge of battery and UC, electrical circuit design and drive cycles [50].

Today the energy, produced through regenerative braking, is only suitable for vehicles with high ESS capacity, which include HEV and AEV. This is due to the fact that electric generators generate very high power which could be in the range of 15-60 kW during braking. For instance, even though the Mazda's i-ELOOP is for conventional ICE vehicles yet it has the regenerative braking system. This model of vehicles can store the electric energy in capacitor and charges the battery to reduce the use of alternator which is claimed to improve the fuel economy up to 10% [35]. Study shows the conventional ICE vehicles only use less than 20% of total fuel energy to propel [48, 106]. Nearly half of the regenerative energy can be recovered back and directly increase the driving range about 10% to 25%; for example, in GM Impact 4 up to 25% [89, 59]. Most conventional ICE vehicles use compressed gas energy storage and FES. Compressed gas energy storage converts the kinetic energy into elastic energy in gas. Then the gas comes out through the pump when the vehicle reaccelerates. FES or kinetic energy recovery system (KERS) is currently used only by Formula One [23]. Both compressed gas storage and FES are of promising methods to handle regenerative braking due to the advantage of large power density and being small in physical size [32]." [130]

2.5 Summary

A good summary of this chapter is provided in Figure 4 which shows a ragone diagram of the energy density of different energy storage technologies [138]. On the x-axis the energy density is plotted while the power density is plotted on the y-axis. The time for complete discharging

$$t = \frac{Energy}{Power} \tag{2}$$

can be depicted in diagonal isochrones (ragone diagram). The diagram says nothing to the efficiency. So sometimes the maximum efficiency is given, but this is only possible for some seconds. A longer load damages the battery. Therefore, the efficiency is 90%, which is a continuous power.

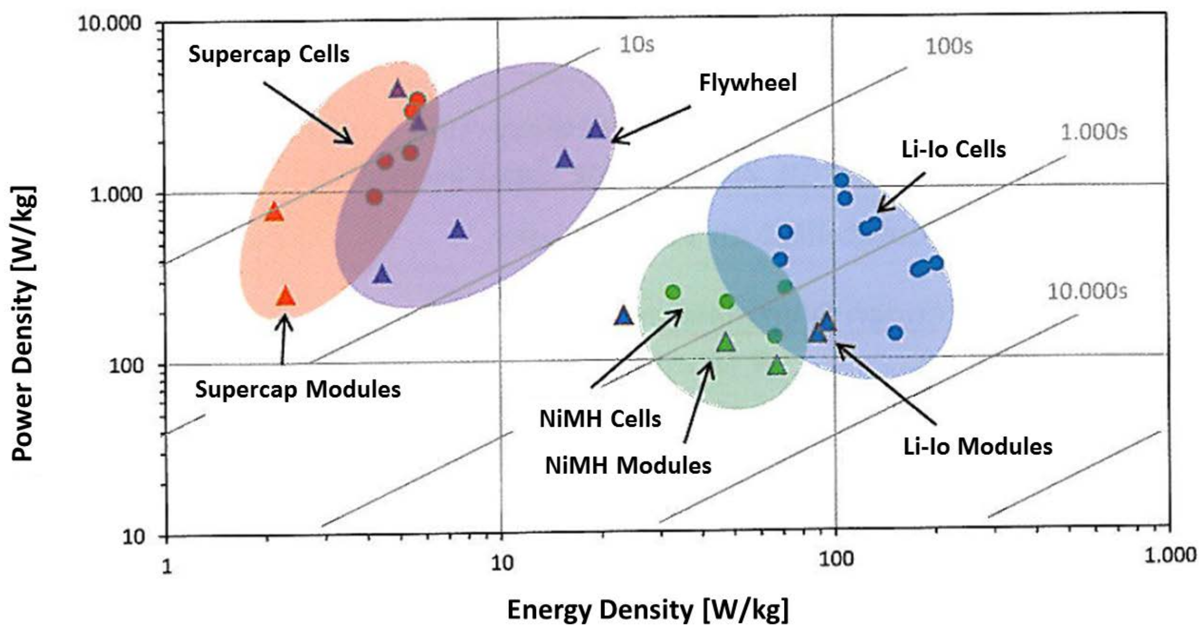

Figure 4: Ragone diagram [138]

[138] differs between (a) commercially available **modules** (triangles) and (b) **single cells** (circles). The values of single cells are theoretically only, because cell connectors, electronic, cool channel and case are additionally needed for practical use. The Flywheel is excluded from this distinction. From Figure 4 is clear, that flywheel storage (violet color) has a higher power and energy density than super cap modules (red color). The energy density of a flywheel is not as high as NiMH batteries. Li-Ion batteries have a 5-10 times higher energy density to flywheels, but the power density is invers.

Besides of [130] and [138], a good overview to batteries and ultracapacitors for electric, hybrid and fuel cell vehicles is given in [54].

3 Energy Transmission Technologies

"Besides the capacity of battery, charging is another challenge in EV, especially PHEV and BEV. The charge duration remains an issue where the large capacity of ESS takes a long time to be fully-charged. Moreover, the charging facility (charging station) has not yet been commonly available and accessible. However, the advancement in power electronic technology has improved the battery charging technology. There are two types of charger, namely inductive coupling and conductive coupling." [130]

3.1 Conductive

"Conductive charging is a conventional charging method which transfers the power through contacting metal to metal between charger and vehicle. In the design of conductive charger, concern has to be stressed on the safety issues and its circuit interface configurations. Currently, the conductive charging method is most widely used and it has two charging methods, namely on-board and off-board methods." [130]

3.1.1 AC

The German National Platform Electromobility tells in its "Technical Guideline Charging Infrastructure" [72] about charging with alternate current (AC): At the (wired) AC charging method the charging unit is located in the vehicle. The charging unit is connected to the single or three phase AC power grid. The charging unit converts the AC power to the DC power required for charging.

[130] talks of "on-board charging method", which means the "charging activity is done inside the vehicle where the vehicle has its own build-in charger. This is suitable for night-time charging at residential area and daytime charging at a work place."

3.1.2 DC

The German National Platform Electromobility tells in its "Technical Guideline Charging Infrastructure" [72] about charging with direct current (DC): The charging unit is outside from the vehicle. The vehicle is directly supplied with DC from a DC charger.

[130] talks of "the off-board method where an external charger is used to charge the vehicle's ESS."

3.1.3 Connection Types

There are the following opportunities for wired energy transfer:

- Plug-In Cable: A plug with a cable is put into a suitable socket. At this, the vehicle cannot move.
- Pantograph: This is a device which maintains electrical contact with the contact wire (overhead contact line or power rail in the ground) and transfers

power from the wire to the traction unit. With a pantograph, the energy transfer is possible on the run.

Figure 5 shows a sample of a power rail in the ground in Bordeaux, France. However, this is used here by a tram (not a bus) in order to cover a part of the route in a sensitive urban building area without the otherwise used overhead contact line. The system here is called APS (Alimentation par le Sol) by ALSTOM. The power rail consists of alternating 8 m energised and 3m non-energised parts. The power rail is located in the center of the track. The tram connects to the power rail via two pantographs. The energised parts are only active, if they are totally covered by the tram. In 2014 the Al Sufouh tram in Dubai is going to used APS on the whole track. [82]

Figure 5: Power rail in the middle of the track in Bordeaux, France [82]

3.2 Inductive

Inductive power transfer does not have “a contacting medium but the power is transferred magnetically. It has the advantage of connection robustness, safer than conductive coupling, power compatibility and durability to the drivers [85]. Although inductive coupling brings convenience to drivers but this method is yet to achieve high efficient level. This technology requires careful considerations which include the range of frequency used, magnetizing inductance, leakage inductance and significant discrete parallel capacitance [57, 122].” [130]

[101] describes the inductive energy transmission system in general as follows: Between the primary coil and the secondary coil is an air gap of max. 200 mm. The transformer is operated with a frequency of 100 kHz. The system achieves an efficiency of 95%. A rectifier in the vehicle converts the transmitted alternating current (AC) into direct current (DC). There is no mechanical wear.

Charging points can be integrated into the ground. Energy transmission is possible while driving. A well-documented example of inductive power transfer is the PRIMOVE technology by Bombardier [51] (see Figure 5, Figure 6, Figure 7):

“PRIMOVE wireless charging technology comprises two sets of components – wayside components that are buried underground and onboard components that are fitted onto the vehicle frame.

Wayside components

- Fully buried underground and can be covered with different materials like asphalt or concrete
- Primary cable segments provide the actual power transfer to the vehicle and are installed just under the road surface
- Magnetic shielding under the primary winding (magnetic layer) prevents electromagnetic interference
- The Vehicle Detection and PRIMOVE Segment Control (VDSC) cable senses when a PRIMOVE-equipped vehicle is above the segment and switches the segment on. Segments otherwise remain inactive to comply with electromagnetic interference protection requirements
- The Supervisory Control and Data Acquisition (SCADA) interface provides information for system control and diagnostics
- Inverters convert the DC supply voltage to the AC voltage used in the system.
- DC feed cables supply power to the inverters

Onboard components

- The PRIMOVE Power Receiver System consists of the pick-up together with a compensation condenser, which are both installed underneath the vehicle. They convert the magnetic field from the primary winding into alternating current
- Inverters convert the alternating current from the pick-up into direct current that powers and charges the vehicle
- Energy storage device (e.g. battery)

- The Vehicle Detection and PRIMOVE Segment Control (VDSC) antenna detects cable segments and coordinates the on/off switching"

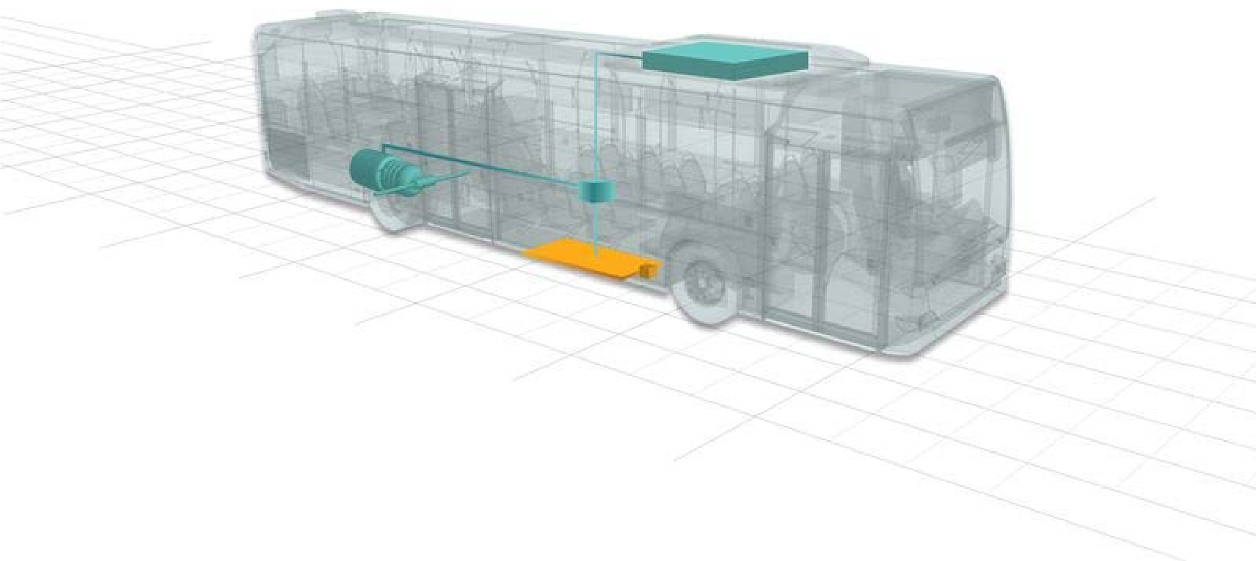

Figure 6: primove bus [51]

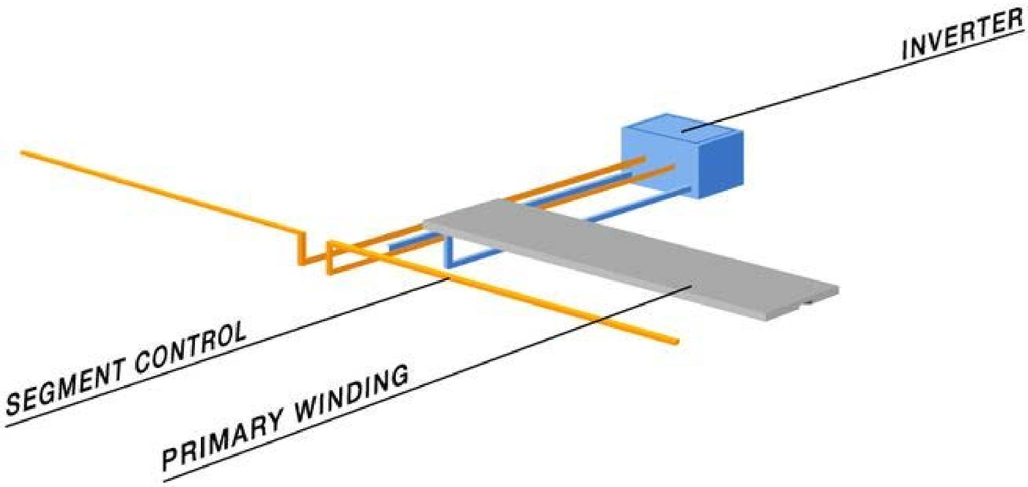

Figure 7: primove bus [51]

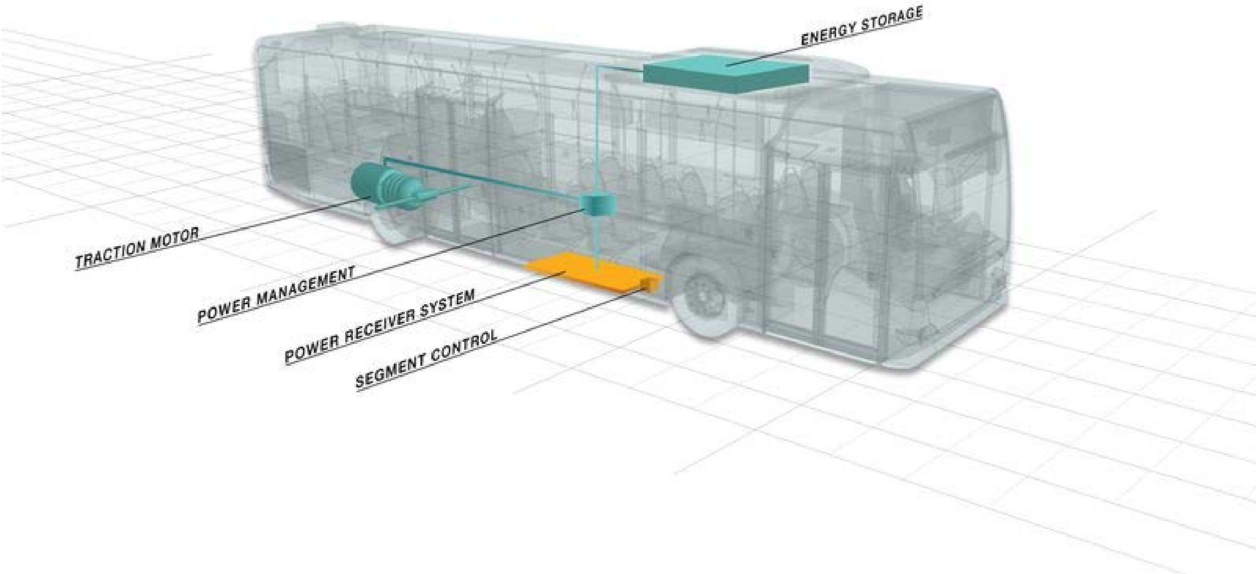

Figure 8: primove bus [51]

Bombardier tests a Van Hool bus on a public road in Lommel, Belgium applying the inductive PRIMOVE technology in order to wireless recharge electric vehicles [101] (see Figure 8).

Figure 9: Bombardier tests a Van Hool bus on a public road in Lommel, Belgium applying the inductive PRIMOVE technology in order to wireless recharge electric vehicles [101]

A test track of the PRIMOVE system has launched in Braunschweig, Germany (see Figure 9). The test track has a length of 11 km. It starts at the main station and comes back to it via the city ring. The first charging point is at the main station. The charged energy enables the bus to reach the 2nd station. At the 2nd station a 30 seconds charging is performed to reach the 3rd station and finally the main station. [101]

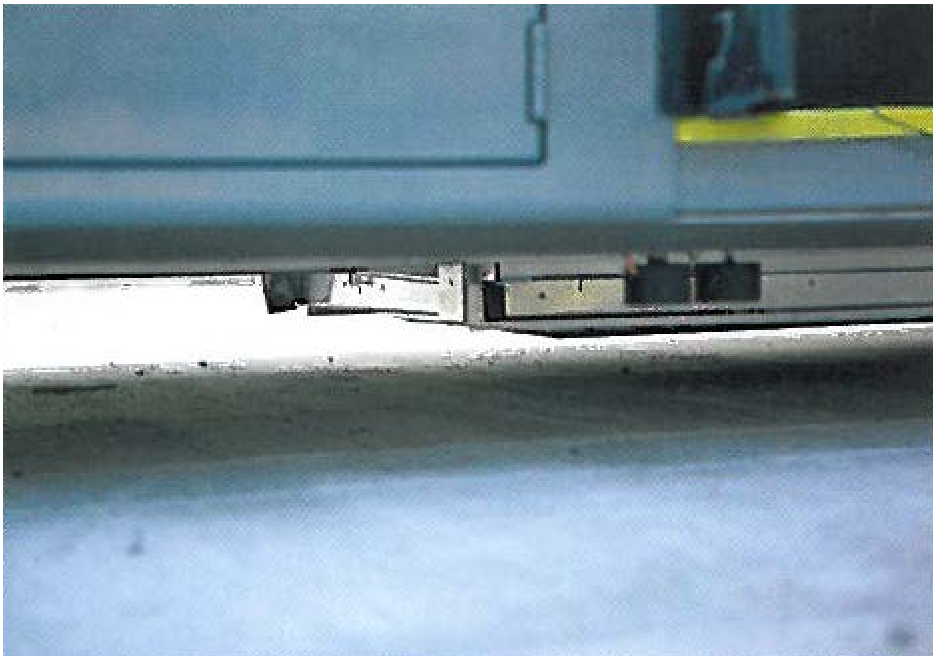

Figure 10: Vehicle components (secondary coil and antenna for segment activation) for energy transfer are mounted below the bus [101]

Another application example of the PRIMOVE system is planned in Mannheim, Germany starting from 2014 [69]. Here, electric busses of the Hess Company from Switzerland are used.

4 Battery Charging

Charging of electric vehicles is not unified so far. During this chapter, the different charging modes in the U.S.A., Europe (including connectors) and Korea are described.

4.1 Charging in the U.S.A.

“Figure 5 summarizes the classifications and technologies of available EV charging stations [46, 37].” [130]

Classification	On-board method Residential/Level 1				Public/Level 2	Off-board method Fast or ultra-fast/Level 3
	Mode 1		Mode 2		Mode 3	Mode 4
Electrical characteristic	1-Phase 120/240 V_{ac} 16 A 3.3 kW	3-Phase 400 V_{ac} 16 A 10 kW	1-Phase 240 V_{ac} 32 A 7 kW	3-phase 400 V_{ac} 32 A 24 kW	3-Phase 400 V_{ac} 63 A 43 kW	Direct current 50–700 V_{dc}, 100–125 A, 50–300 kW
Charging period	6-8 h	2-3 hours	3-4 h	1-2 hours	20-30 min	$<$ 20 min
Safety	Circuit breaker to protect against overload		Basic protection * with In-cable protection device		Basic protection* with control system	Basic protection with control system
Standard	local NF-C-15100		IEC 61851-1 IEC 60309		IEC 61851-1	IEC 62196 IEC 61851-1
Socket	Household socket		Domestic socket		Dedicated circuit-socket	DC connection socket

* Such as earthling system, circuit breaker to protect against overload and an earth leakage protection.

Figure 11: Classification and technologies of available EV charging stations [130]

“Charging infrastructures can be divided into three levels [85]. The first level is the residential charging infrastructure, which is installed at household area. It allows the vehicle to be charged over night time that uses low cost night time energy tariff as well as to avoid the peak hour demand. The residential charging has two modes (Mode 1 and Mode 2), in which the difference is only the protection standard. In the U.S., Mode 1 charging is prohibited due to the national codes and standard. Therefore, the Mode 2 is introduced for safety protection. The second level of charging infrastructure is the public charging infrastructure. This can be found at everyday activity places such as shopping malls, company parking and workplaces throughout city. This charging infrastructure is normally integrated with authentication and payment system. The third charging level is the ultra-fast charging station which is similar to the petrol station that we have now, but this charging station is typically placed at highway/express way [46].

In near future, more charging stations will be installed to stimulate and encourage the use of EV. This will lead to the increase of energy demand, and the power producer has to figure out new supply option to cope with it. For that reason, smart grids with renewable energy sources become the main source for charging station [95]. The development of smart grid control integrated with demand management helps to reduce peak power usage on power distribution system.” [130]

4.2 Charging in Europe

The German National Platform Electromobility deals in its “Technical Guideline Charging Infrastructure” [72] with the topic of electric vehicle charging. All content of this section is taken from there.

Table 3: Standard charging values at electric vehicles [72]
1) values to be assumed, which can depending on the vehicle concept; values are rather smaller at plug-in hybrid vehicles
2) For the first generation of electric vehicles a DC charging power of maximal 80 kW (400 V/200 A) is recommended. This can be realized by a 3 x 125 A standard AC connection (86 kVA). The connection power of the DC station is higher than the provided charging power

Vehicles	Charging Technology	Charging Power [kW]	Charging Current [A]	Battery Capacity [kWh]	Grid Connection
Pedelecs, E-Bikes, E-Scooter	AC or DC	up to 2	up to 8	0.1-2.0	AC 1 phase
Electric motorcycles	AC 1 phase	up to 3	up to 13	1-5	AC 1 phase
Electric vehicles including Plug-In-Hybrid	AC 1 phase	up to 3.7	up to 16	4-85[1]	AC 1 phase
	AC 3 phases	up to 43	up to 63		AC 3 phases
	DC	up to 170[2]	up to 200		AC 3 phases

The different types of AC charging are termed in the relevant system standard DIN EN 61851-1 (VDE 0122-1): 2012-01 as "charging mode".

4.2.1 Mode 1 (AC Charging)

Charging with alternating current (AC) at a customary household outlet (socket with earthing contact) or a one-or three-phase CEE socket is called charging mode 1. At this charge mode, no communication between the energy discharge point (socket) and the vehicle takes place. This charging mode is possible for charging of vehicles, if it is allowed by the vehicle manufacturer, and if it is ensured that the power supply is equipped with an RCD.

4.2.2 Mode 2 (AC Charging)

The difference to charging mode 1 consists essentially in the fact that in the charging cable here, a control and protection device is integrated ("In Cable Control and Protection Device" IC-CPD). The IC CPD protects against electric shock in case of insulation faults. Through a pilot signal information between the infrastructure and the vehicle are exchanged and the protective conductor is monitored. This charging mode is provided for cases where no specific charging station with charging modes 3 and 4 is available.

4.2.3 Mode 3 (AC Charging)

In this charge mode charging with alternating current (AC) to a dedicated socket takes place. The charging station (or wall box) is permanently installed on the grid here. Alternatively, a fixed connection charging cable can be present at the charging station. The charging process is controlled by a data transfer between the charging station and the vehicle. The charging mode 3 is based on a special infrastructure for electric vehicles, which offers a high degree of electrical safety and protection of the installation against overload (fire protection). In general, current and future passenger cars and light commercial vehicles support the charging mode 3. Due to the above reasons, [72] recommends this charging mode.

4.2.4 Mode 4 (DC Charging)

The conductive DC charging is called charging mode 4 and how the charging mode 3 it is recommended for charging electric vehicles. The charging with direct current (DC) is commonly used for higher charging power. In charging mode 4, the cable on the charging station or a wallbox is firmly attached. At DC charging, there are currently two different systems: "CHAdeMO" and the "Combined Charging System". The European Automobile Association ACEA recommends to use the Combined Charging System for future charging of all electric vehicles no later than 2017, since this system allows both the rapid DC charging as well as the AC charging with only one interface to the vehicle.

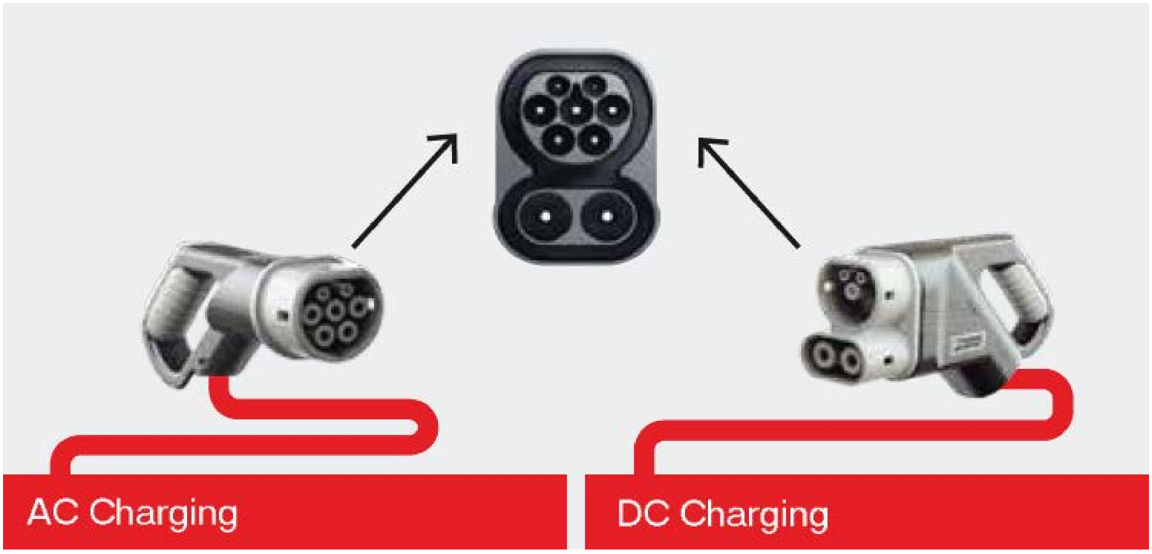

Figure 12: Combined Charging System with European Type 2 electrical connectors and Combined Interface 2 for AC and DC Charging [Source: Phoenix Contact cited in [72]]

4.2.5 Charging Connectors

The use of standardized connections for electric vehicles is of great importance in view of the required interoperability. Each charging technology is assigned to a connector type. Electric vehicles benefit from the use of specially developed and standardized charging plugs and sockets (DIN EN 62196 series), because all relevant power ranges for electric mobility are covered with them. This is especially true for the three-phase charging connectors used for the European market. For charging stations (and wall boxes) with integrated sockets (charging mode 3) a broad support for the type 2 exists in Europe. Electric vehicles are therefore usually offered with a charging cable with a connector of the type 2. Therefore, charging stations can be used with sockets of type 2 by almost all vehicles. For charging stations having a permanently fixed charging cable – optional for charging mode 3, prescribed in charging mode 4 – it is important to regard, that currently some electric vehicles are equipped with a vehicle connector (charging port on the vehicle) of the type 1.

Medium term, all vehicles will be equipped with a vehicle plug of the type 2 / Combined Interface 2. Therefore, charging stations with a fixed cable can only be recommended at this time, if only vehicles with a specific type (either type 2 or 1) should be charged by charging connector plugs.

In January 2013, the European Commission has launched a strategy for environmentally friendly fuels. In this context, the Commission has proposed the use of the plug type 2 / Combined Interface 2 for the common standard for all of Europe.

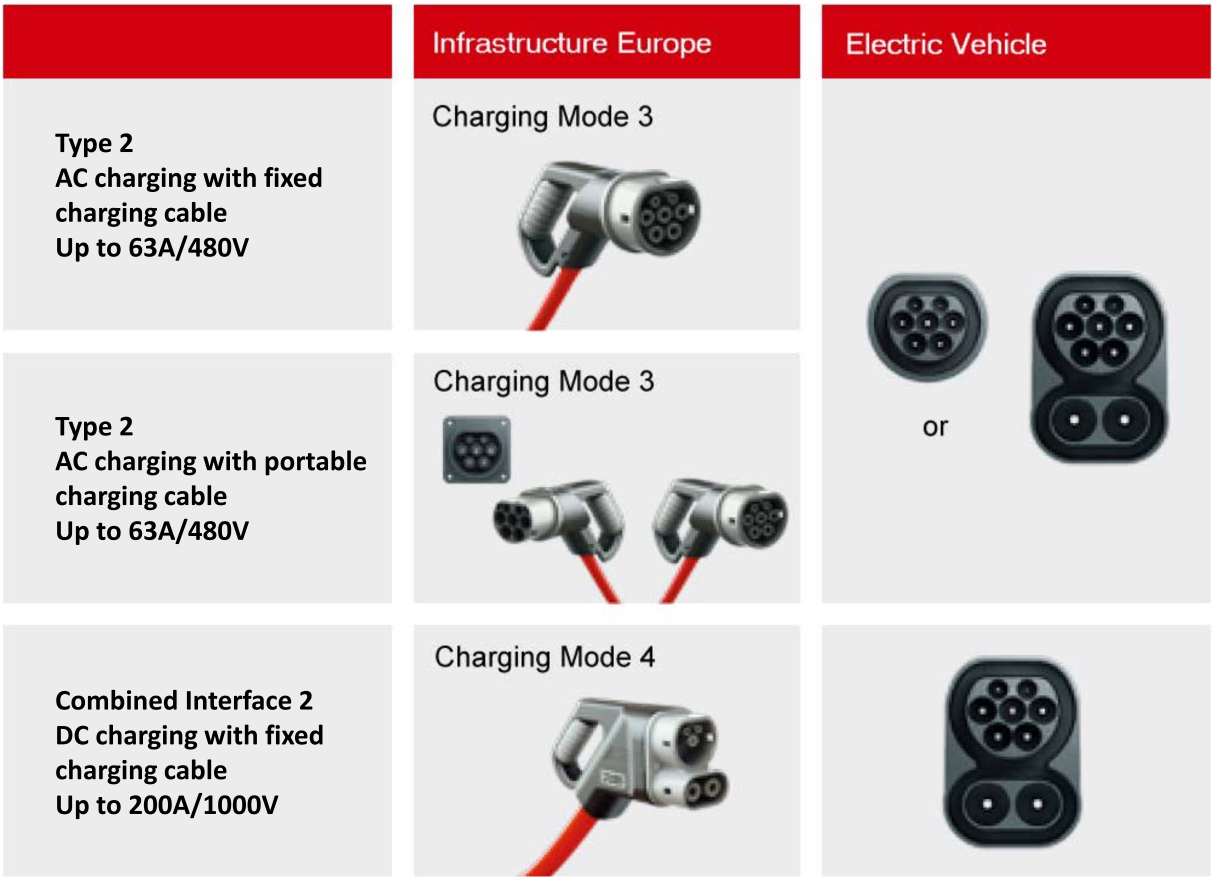

Figure 13: Connectors of the Combined Charging Systems Type 2 and of the Combined Interface 2 [Source: Phoenix Contact cited in [72]]

4.3 Charging Modes in Korea

[133] provides a well overview to electric vehicle charging types in Korea (see Figure 5).

FINPRO **EV Charging Type in Korea**

There are four EV Charging types in Korea, which includes ; 1) Rapid Charging, 2) Slow Charging, 3) Replacing batteries, and 4) Contactless Charging. However, Replacing batteries is not taken by Korean companies.

EV Charging Type

Type	Use	Place	Pros	Cons	Power	Real time fee	Voltage	Charging hour	Major Players
Slow Charging	Household Charging	· Residential Building, company parking lot	· Low effort · Cheaper (midnight) · Low installation cost · No Lithium battery degradation[1)]	· Long time · Electric shock risk · Difficult in public housing	· 1~2 kW (2~7 kW Charging only)	· Unnecce ssary (Avoid progress ive fee, monthly charging fee sum-up)	· AC 220V	· 4-8 Hr	· GS Park24, Samsung C&T (Constructio n sector)
	Public Charging Stand	· Public parking lot, shopping mall, etc · Long-time parking lot	· Low worry about low remaining energy · Lower installation cost	· More expensive EC (daytime) · Charging congestion	· 2-15 kW	· Possible	· AC 220V	· 2-5 Hr	· LS Cable, SK Energy, Signet System, Kodi-s, Soosung, PSTek, Nexcon Technology
Rapid Charging	Public	· Accessible place (Gas station, Highways …)	· Short time · Low worry about low remaining energy	· More expensive EC (daytime) · Charging congestion · LIB degradation · High installation cost · Electric shock risk	· 20-200 kW	· Possible	· DC 500V (Less)	· ~0.5 Hr	
Battery Replacement	Public	· Only Battery change station	· Very short time · No need for Battery maintenance	· Hard to visit battery station	· N/A	· Possible	· N/A	· N/A	· N/A
Contactless Charging	Public	· On the Road	· No battery (Cheaper and lighter without expensive battery) · No charging congestion	· Only in installed areas · Highest installation cost & More expensive EC (daytime) · Power overload risk in daytime	· 62 kW	· N/A	· AC 440V	· N/A	· KAIST Consortium (Hyundai Heavy Industries, SK Energy, Hyundai, LG Chem, Samsung SDI)

1) degradation: Bad for its performance and quality

Source: LG Economic Research Institute, International Electric Standard Board, KEPCO, WesleyQuest Analysis

Figure 14: Overview to EV charging types in Korea [133]

5 Battery Exchanging

Battery exchanging (also called battery replacement, battery swapping, battery switching) means that a battery with a low charging level is taken out of the vehicle automatically at certain exchange stations and is replaced by a fully charged battery from the exchanging station. The empty battery taken out of the vehicle then is recharged within the exchanging station. The battery exchange act can be performed from all thinkable sides (e.g. overhead, from side, from bottom) depending on the specific system.

The advantage of battery exchanging over battery charging is the much lower amount of time for "refueling" the vehicle. Battery exchanging can be performed in a period of time which is comparable to conventional refueling petrol or diesel. The drawback is a much more effort for construction and maintenance of the battery exchanging stations.

There are a lot of patents for battery exchanging. For example, patent [83] with the name "Battery exchange system for electric vehicles" is described as followed (patent abstract): "An integrated electric vehicle service station system for managing the exchange of heavy and bulky battery assemblies in electric vehicles. The battery exchange system includes a battery platform for supporting an assembly of batteries for the vehicle, a vehicle platform support structure within an electric vehicle for receiving and supporting the battery platform, and a mechanized vehicle service station facility for exchanging recharged battery platforms with spent platforms mounted on-board electric vehicles. The battery platform is of a simple modular shape that may be used with the large variety of sizes and shapes of electric vehicles that may be expected in the future. The battery platform support structure is a correspondingly simple structure that may readily be included in electric vehicles of widely differing designs. The service station facility includes two general service substations – an exchange substation where the spent battery platform is removes from the vehicles and replaced with a fully charged platform, and a staging substation where the battery platforms are stored, re-charged, serviced and staged for insertion into a waiting vehicle at the exchanging substation. The exchange substation is such that the exchange of a battery platform for an electric vehicle positioned at the exchange substation is able to proceed automatically and rapidly with minimum of operator assistance so as to minimize the inconvenience to the vehicle operator."

Further related patents are described in [84, 45, 91, 60, 62, 61].

In [125] a vision based battery exchange robots for electric vehicle is presented.

[107] describes Tesla Motor's battery exchanging robotic system very impressive: "In less time than it took an employee to fill the tank of his Audi A8 at a nearby filling station, Tesla's robotic system completely swapped the batteries in two Model S sedans. While the Audi driver had to stand outside, monitoring the filling process and

breathing the volatile fumes, the two Tesla drivers sat in the comfort of their luxury sedans. By the time the Audi driver had replaced the gas nozzle, screwed on the gas tank cap, closed the filler door, got back in the car and then drove off, the two Tesla cars would have been long gone."

On the other hand, the German National Platform Electromobility estimates in its "Technical Guideline Charging Infrastructure" [72]: Currently (June 2013) it is not foreseeable, that battery exchanging for passenger cars will prevail. Therefore, [72] does not address this topic.

6 Models of All-Electric Busses

Gordon Mackley, The Electric Tbus Group, writes on the internet why he wants to encourage motorists in London to use electric buses [1]:

“Buses are much more efficient in terms of road space and energy per passenger than cars. Zero emission electric buses take this advantage to the ultimate. For example, 1 vehicle in 20 travelling round Parliament Square is a bus and yet they carry 50% of the people. To encourage motorists to use buses more and drive less, new designs of buses need to provide the facilities people have got used to in their cars and avoid the pollution cars create. State-of-the-art electric buses will be a fundamental step in achieving a smooth, clean and quiet traveling experience.”

In this section, a lot of manufacturers of all-electric busses and their bus models are presented. Of course, this section does not claim to be exhaustive.

6.1 Solaris Bus & Coach S.A. (Poland)

The polish company Solaris Bus & Coach S.A. is situated in the greater Poznań region. It sells two different sized electric buses. Solaris Bus & Coach S.A. writes on his website [119]:

“Solaris Bus & Coach is a family company founded and owned by Solange and Krzysztof Olszewski. The company is a major European producer of city, intercity and special-purpose buses as well as low-floor trams. Since the start of production in 1996, nearly 10,000 vehicles have already left the factory in Bolechowo near Poznań. They are running in 26 countries. [...] Despite its young age, Solaris has become one of the trendsetting companies in its industry. For many years, it has been the indisputable leader among the suppliers of city buses in Poland, where it has a more than 50 percent share of the market. In Germany, with a 10 percent market share, it is number three, making it the largest non-German supplier of buses.”

Figure 15: Solaris Urbino 8.9 LE electric [121] (left) and Urbino 12 LE electric [120] (right)

6.1.1 Urbino 8.9 LE electric

The smaller model of an all-electric bus is the Solaris Urbino 8.9 LE electric [121]. It allows a maximum speed of 50 km/h and has a range of 100 to 120 km. It has a length of 8.95 m and offers seats for 21-29 passengers depending on the equipment. The two lithium ion traction batteries have a total capacity of 120 kWh at 600 V operation. Each of them weighs 700 kg. There are two charging modes: (a) when rapid charging is applied, it takes 1.5 hours to refill the fully depleted batteries, (b) when normal charging is applied, it takes 4 hours at 3*400 V, 63 A. The charging power is 100 kW. The traction power is 120 kW. The braking energy is recovered and stored in the batteries.

Application examples of the Solaris Urbino 8.9 LE electric are among others:

- One Solaris bus ran in the host city of Poznań during the Euro 2012 football championship. It is based on the Solaris Alpino LE midibus. The electric equipment was supplied by German specialist Vossloh Kiepe. [64]
- The Bremer Straßenbahn AG (BSAG) has been tested one electric bus Solaris Urbino 8.9 LE electric since the middle of January 2013. [15]
- “The first orders for Solaris’s battery buses come from cities in Austria and Germany. By the end of 2013, a Solaris Urbino 8.9 LE electric will have been delivered to Klagenfurt.” [42]

6.1.2 Urbino 12 LE electric

The 12 m model Urbino 12 LE electric [120] has 23-34 seats (depending on the equipment). The lithium ion traction batteries have a total capacity of 210 kWh at an operational voltage of 600 V. The traction power is 160 kW. The braking energy is recovered and stored in the batteries. The range of the Urbino 12 LE electric is about 150 km (SORT-2 measuring cycle program).

Application examples of the Solaris Urbino 12 LE electric are among others:

- “The first orders for Solaris’s battery buses come from cities in Austria and Germany. By the end of 2013, a Solaris Urbino 8.9 LE electric will have been delivered to Klagenfurt, while its standard-length counterpart will start services in Braunschweig. Further orders came from Düsseldorf and again Braunschweig which bought two Solaris Urbino 12 electric each.” [42]
- Two twelve-metre Solaris Urbino electric buses have been ordered by Rheinbahn AG of Düsseldorf for delivery next year. [116]

6.2 BYD Co. Ltd. (China)

BYD [25] is the leading manufacturer of advanced, environmentally-friendly battery technologies like the BYD’s iron phosphate battery $LiFePo_4$ used in BYD electric vehicles and electric buses. BYD is the fastest-growing Chinese automotive and green energy technology enterprise.

BYD, in which Warren Buffett is an investor, has manufactured 1,000 electric buses, most of which operate in China. A small number operate in Europe and South America. [74]

6.2.1 BYD K9 electric (eBUS-12)

The BYD K9 electric bus has a length of 12 m. It offers space to 60-70 passengers. The lithium iron phosphate battery ($LiFePo_4$) has a capacity of 324 kWh. Charging is done at night at a charging terminal in 4-5 hours. The traction power is 160 kW. The braking energy will be recovered and stored in the batteries. The K9 electric bus has a range of 250 km (155 miles) on a single charge under urban conditions (without solar contribution). The energy consumption is 100 kWh/100 km (100 kWh/60 miles). A solar panel on the roof (see Figure 5) is used to supply the air-conditioning system with energy.

Figure 16: Solar panel on the roof used for the air-conditioning system [25]

References of BYD’s electric busses are:

- In 2011 BYD delivered 300 electric buses of the type BYD K9 (eBUS-12) to run during the Universade in **Shenzhen and Changsha** in China. The company has the most experience in the field of electric buses. [93]
- BYD officially delivered 6 electric buses today in a ceremony at the island home of city of **Schiermonnikoog**, and the Netherlands’ first National Park in the province of Friesland, Netherlands (see Figure 5). [25]
- BYD completes electric bus test in **Warsaw**: An all-electric BYD ebus is now carrying passengers in the Polish Capital. The ebus built by BYD, is the first

pure-electric bus powered by iron-phosphate battery in the world. More than 250 BYD e-buses are now in passenger carrying operations - by far the largest number from any bus brand. [40]

- The U.S. producers of electric buses felt shocked when the transit authority of **Long Beach**, California awarded a contract to buy 10 electric buses made by China – but financed by U.S. taxpayers in April 2013. [74]
- “Europe’s largest, ZERO emissions, all-electric bus fleet will be used to transfer passengers between airport terminals and aircraft at one of Europe’s leading airports at the **Amsterdam** Schiphol Airport. The 35 BYD buses will enter service in July of 2014 and will replace an ageing fleet of conventionally powered buses. The SUBSS Project (Sustainable Bus System of Schiphol) aims to provide a new generation of emissions-free, plane-side, transfer-vehicles to enhance the airport’s image with both the customers and the airline brands. These high-technology buses will reduce maintenance and management costs and improve the overall airport air quality by reducing the emissions of green-house gases (GHGs like CO_2 and NO_x).” [55, 29]

Figure 17: BYD’s ebus in Schiermonnikoog, Netherlands [25]

6.3 Euracom GmbH (Germany)

The Berlin entrepreneur Thomas-Christian Seitz bought a BYD standard electric bus [25], modified it in China and imported it to **Berlin** (see Figure 7**)** [127].

[21] tells about Euracom: The Euracom GmbH is acting in the field of vehicle construction since about 20 years. Euracom provides special vehicles, passenger cars and busses to the world. It has a more than 20-year-old worldwide expertise in vehicle construction.

The following reasons for choosing a Chinese partner are given [21]:

- China exported 2010 high technology products with a value of 110 Billion € which therefore is the second most important national field of export.
- China is a high technology country: the funding of research in the field of e-mobility and battery technology has been massively increased (each year by 20-30%)
- Today, more than 1000 all electric busses and about 80 millions of e-bikes are in use in China.
- China is the pioneer worldwide in electrification of public transport busses. All electric busses are used since 2008 in regular public transport operation.

6.3.1 Euracom 600

The Euracom 600 bus has a length of 11.48 m. Depending on the equipment, the bus offers space for 86 passengers (46 seated, 1 driver) at maximum.

Figure 18: The Euracom 600 bus at the Kreisverkehrsgesellschaft in Pinneberg mbH (Copyright of the left image: manager magazin online; copyright of the right image: KViP Kreisverkehrsgesellschaft in Pinneberg mbH)

The lithium iron phosphate battery (LiFePo4) contains 12 battery containers with 108 cells each. It is produced by Tewoo in Tianjin (China). The total capacity of the battery amounts 630 Ah at a voltage of 346 V (about 218 kWh). The motor has a power of 130 kW. The bus reaches a maximum speed of 80 km/h. The range amounts 250 km at a consumption of 100 kWh / 100 km. The energy recovered while braking is stored into the batteries. The weight of the battery amounts 1,872 kg (each container 156 kg). The total weight of the bus is 17,500 kg. There is a price of about 380,000 Euros given.

Figure 19: Charging connector [21]

Charging is performed by a charging connector as shown in Figure 8. There are two charging modes available [21]:

- Rapid charging uses a charging current of 300 A. After 1.5 hours a charging level of 80% is reached. After 2.5 hours the charging level amounts 90%, after 3.0 hours it amounts 95%.
- Normal charging uses a charging current of 100 A. After 6.0 hours a charging level of 90% is reached. After 7.0 hours the charging level amounts 96%, after 8.0 hours the charging level amounts 99%.

The public transportation company “Kreisverkehrsgesellschaft Pinneberg” tested the Euracom 600 bus on different routes in **Pinneberg** near Hamburg for half a year since May 2012 [86].

6.4 Jiangsu Alfa Bus Co., Ltd. (China)

[24] writes about Jiangsu Alfa Bus:

“Jiangsu Alfa Bus Co., Ltd is a modern bus manufacturer, with full operations of brand management, product research and development, manufacturing, sales and marketing and after sale service. Alfa Bus has a strong background, with the total assets of over RMB 50 million, and an annual production capability of 5000 vehicles. Alfa Bus is an assigned bus manufacturer of large and medium-sized luxurious buses by Ministry of Communications. It also has membership in China Tourism Automobile and Cruise Association, China Highway and Transportation Society, China Bus Association and City Bus Expert Committee of Committee of Science and Technology of China Ministry of Construction. At present, Alfa Bus has over 450 employees, among which 50 are engineers and technicians. In 2002, Alfa Bus was ISO 9001 certified. In 2003, Alfa Bus passed national compulsory 3C authentication. These products cover 6-18 meters medium and top class inter city bus, tourist coach and city bus. [...]

The essence of Alfa Bus is to upgrade technology and produce excellent products. Alfa Bus strives for innovation while assimilating domestic and international cutting edge technology and experience. It co-operates in the field of technique and products with world famous bus manufacturers such as Spanish Indcar, Italian Iveco and Japanese Hino etc. In 2006, Alfa and Swedish Scania, which is reputed as“ King of

Road", partnered to design and develop a domestically top-ranking and internationally advanced large luxury bus. Again in 2007, Alfa cooperated with Scania and signed a technical cooperation agreement for BRT bus. Chinese President Hu Jintao and Swedish Prime Minister Fredrik Reinfeldt were present at the signing ceremony and it was the first time Chinese President Hu Jintao attended a signing ceremony between a Chinese automotive enterprise and a foreign corporation. Alfa Bus has broken through the most up-to-date technology of the Chinese bus industry."

At the time (July 2013), Jiangsu Alfa Bus offers two different models of all electric busses, which are described in the next two sections.

6.4.1 YS6120DGCity Bus (Electric)

Figure 10 provides an image of Alfa's YS6120DGCity electric bus. It has a seating capacity of 95 persons at maximum. The maximal speed amounts 85 km/h at a power of 247 kW and a curb weight of 12,630 kg. During braking the power can be transformed into electricity immediately, which is then stored in the battery. In this way, it could be saved up to 40% of energy. The cutting edge technology (high capacitance and powerful lithium batteries) is applied [27].

Figure 20: YS6120DGCity Bus [27]

6.4.2 YS6120DG New Energy Vehicle (Electric)

The YS6120DG New Energy Vehicle (see Figure 11) offers space to maximal 110 passengers (66 seats and 24-44 standing places). It has a curb weight of 14,500 kg. The range of the bus amounts 150 km (with a 500 Ah battery). The maximum speed is 80 km/h. The lithium iron phosphate battery has a total capacity of 500 Ah (optional 300 Ah and 400 Ah) at a voltage of 600 V. [26]

Figure 21: YS6120DG New Energy Vehicle [26]

6.5 AB Volvo (Sweden)

"The Volvo Group, in cooperation with the Swedish Energy Agency, the City of Gothenburg, Västtrafik, Lindholmen Science Park and Johanneberg Science Park launch a new bus service in Gothenburg which will become a reality in 2015. The buses, powered entirely by electricity from renewable sources will become a part of the Gothenburg's public-transport system. They will be extremely fuel-efficient, silent and completely emissions-free. One of the bus stops will be located indoors.

In addition to the electric buses, the cooperation also includes the creation and trial runs of new bus-stop solutions, traffic-routing systems, safety concepts, energy supply and business models. The hope is that the project, known as ElectriCity, will attract more commuters to use public transport." [135, 43]

An image of the Volvo all-electric bus provides Figure 12.

Figure 22: Volvo all-electric bus (Copyright Volvo, Press release, June 17, 2013)

6.6 Bluekens Truck & Bus B.V. (Netherlands)

“Bluekens Bus is a full service Volvo Busdealer with offices in Breda, Oosterhout and Roosendaal. The Blue Care concept offers a full range of services for the entrepreneur.

Bluekens Bus is a global partner in passenger transport. Volvo Buses is one of the largest bus manufacturers in the world and is Bluekens Level One service dealer for the Benelux. Bluekens Bus has long been also involved in the development of electric vehicles. The first three full electric city buses transport company Arriva have recently officially inaugurated in s’Hertogenbosch.” [2]

“Bluekens Truck and Bus has its expertise in the field of e-mobility bundled in a separate workshop in Oosterhout. The rise of the hybrid or electric car is unstoppable in the Netherlands and that has implications for workplaces, for electric vehicles require special attention. Electric vehicles are equipped with a drive system that works with high voltage.

The how and what is laid down in regulations: NEN3140 is developed for working on electrical installations and is still the standard for working on electric vehicles. [...] Several large companies outsource the maintenance on Bluekens Truck and Bus, this applies to both hybrid trucks and the all-electric vehicles, trucks, buses and cars.” [3]

6.6.1 Volvo 7700 Zero Emission

Bluekens Truck & Bus B.V. in Oosterhout (Netherlands) converted a Volvo 7700 diesel bus to an electric bus.

“The first ever public-service field trials of a 12-meter electric bus charged wirelessly by induction are currently underway in s’Hertogenbosch (Den Bosch) in the Netherlands. Green power makes the electric bus, a converted Volvo diesel bus, completely climate-neutral. In addition to overnight plug-in charging, opportunity charging will allow the electric bus to run reliably for 18 hours, covering some 288 kilometers a day, without the need to stop for prolonged periods. Opportunity charging means that the electric bus invisibly receives a top-up charge by a 120 kW wireless inductive charging system within the space of a few minutes while at a bus stop.” [66, 30]

Figure 23: Bluekens-Volvo all-electric bus (Copyright: Bluekens Truck en Bus B.V.)

The converted Volvo 7700 diesel bus has a length of 12 m. It offers space for 86 passengers at maximum including standing places. The empty weight of the vehicle is 12.0 t. The daily range in Den Bosch, Netherlands amounts 289 km at a flat course in the city center. The electrical energy is stored in a lithium iron phosphate battery (LiFePo4) which has a capacity of 120 kWh. Rapid charging can be performed at special charging points. There, the energy is transmitted inductively with the IPT®Charge (Inductive Power Transfer) system. The distance between the charging points in Den Bosch is 5.232 m. The charging power per charging point is 120 kW (2 modules of 60 kW). Normal charging is performed via a plug-in connector overnight. [136, 65]

6.6.2 BlueCoach First Electric (Low Entry)

The electric bus BlueCoach First Electric (Low Entry) (see Figure 14) has a length of 8.04 m. It offers space for 32 passengers (21 seats) including standing places.

Figure 24: BlueCoach First Electric (Low Entry) (Copyright: Bluekens Truck en Bus B.V.)

The vehicle weight amounts 7.2 t. The daily range is about 125 km. It reaches a maximum speed of 90 km/h. The electrical energy is stored in a battery with a capacity of 84 kWh. The motor has a power of 150 kW. [4]

An example of the electric bus BlueCoach First Electric with low entry is running in Nord-Brabant, Netherlands.

6.6.3 BlueCoach First Electric

The BlueCoach First Electric bus has the same properties as the bus BlueCoach First Electric (Low Entry) except a low entry [5] (see Figure 14).

Figure 25: BlueCoach First Electric (Copyright: Bluekens Truck en Bus B.V.)

6.7 Rampini (Italy)

Rampini in Passignano in the province of Perugia produces electric buses which can be charged at the terminus with a pantograph on the bus roof.

6.7.1 Rampini ALÉ Electric Bus

The Rampini ALÉ Electric Bus (see Figure 16) has a length of 7.72 m and offers space for 43 passengers (10 seats). The empty bus weight is 8.250 kg while the complete bus weight is 12.000 kg. It totally has 9 lithium ion ferrite batteries with a total capacity of 180 kWh: 3 on the roof, 5 in the rear area and 1 at the place of the former fuel tank. Rapid charging (charging duration 15 minutes) can be performed at the terminus after 8 to 15 km. Normal charging is performed at night with a charging power of 15 kW. The power of the Siemens motor is 85 kW with a peak of 150 kW. The braking energy is recovered and stored in the batteries. The maximum speed is 62 km/h. The range amounts 130 to 150 km. [11]

Figure 26: Rampini’s ALÉ Electric bus (Copyright: Siemens Rail Systems)

Application samples of Rampini’s ALÉ Electric bus are:

- The first ALÉ Electric Bus is running in Vienna, Austria. The public transportation company “Wiener Linien” plans to run two city lines in Vienna with 12 electric buses until summer 2013. [123, 20]
- Another ALÈ Electric Bus is running in Finland for test and demo with passengers on board until the 19th of July, 2013. [12]

6.8 BredaMenarinibus (Italy)

“BredaMenarinibus is one of the main Italian companies in the bus industry for tradition and history. During about 90 years of activity, more than 30.000 buses have trespassed the gates of the plant.” [52] BredaMenarinibus is settled in Bologna.

6.8.1 ZEUS

BredaMenarinibus produces the electric minibus ZEUS (see Figure 17) with a length of 5.890 m. It has capacity for 23 passengers (9 seated). The nominal maximum power is 30 kW with a peak of 60 kW. The maximum speed amounts 45 km/h. The traction batteries are constructed of 78 lithium polymer cells with a total capacity of

57.6 kWh. It has a range of 120 km in a typical urban duty cycle. A complete charging cycle takes less than 10 hours at 20 A and 380 V. [31]

Figure 27: The ZEUS all-electric bus (Copyright: BredaMarinibus)

One of the ZEUS all-electric bus model is operating in Osnabrück, Germany, since 18th August 2011. [19]

6.9 Hankuk Fiber (South Korea)

6.9.1 e-Primus

In cooperation with Hyundai Heavy Industries the all-electric bus e-Primus has been developed [103] (see Figure 16).

Figure 28: e-Primus [96]

The e-Primus has 49 seats. The lithium ion polymer battery has a capacity of 102 kWh. The maximum speed amounts 100 km/h. The range of the e-Primus is about 120 km with a single charge. [103, 133]

6.10 Hyundai-Kia Motors (South Korea)

Hyundai was established in 1976. [103] mentions the following business highlights: Hyundai is the largest car manufacturer in Korea but 48.5% of the total production is outside from Korea. The motor group had been focusing more on FCEV than on EV until 2009. Hyundai produced Korea's first pure electric vehicle (Blue On) in September 2010. Around 2,500 units will be produced by 2012 and start mass production in 2013. Kia also introduced the Vega EV in 2010 on the Geneva Motor Show. Hyundai introduced Korea's first electric bus "Elec-City" in June 2010.

6.10.1 Elec-City

Hyundai Motor launched the nation's first 100% electric bus "Elec-City" (see Figure 17) in June 2010 and started test drives. It is a low floor bus. The Elec-City can transport up to 51 passengers. It has a maximum speed of 100 km/h and can drive up to 120 km per charge. The cost of operating Elec-City is only 29% of the cost of operating a CNG bus. The lithium ion polymer battery has a capacity of 95 kWh [103, 133].

Figure 29: Hyundai Elec-City [6]

6.11 CT&T (South Korea)

[103] told in December 2010:

"CT&T plans to roll out its first battery-powered buses next year (see Figure 18). Two 20-seat models with a maximum speed of 80 km/h, driving ranges of 80-120 km per charge, and a six-hour recharge time. The estimated cost is 80 million KRW ($66,528). It is powered by a 120 kW motor from Higen Motors and uses batteries from SK Energy and LG Chem. It features a power control from LS Industrial Systems. The lightweight materials from Hanwha L&C and POSCO and a special chassis jointly developed with the Korea Automotive Technology Institute."

Figure 30: CT&T's electric bus [87]

6.12 Proterra (USA)

Proterra writes about its own on its website [112]:

"Proterra was founded by Dale Hill in 2004 with a vision to design and manufacture world-leading, advanced technology heavy-duty vehicles powered solely by clean domestic fuels. After launching the first and most successful fleet of alternative fuel buses in the 1990s (the 16th Street Mall buses in Denver, CO, that are still running today), Hill formed Proterra to develop and deliver the "bus of tomorrow" to meet a need expressed by the Federal Transit Administration. With the launch of our fast charge EcoRide™ BE35 battery electric bus, Proterra has become the leading innovator of zero-emission commercial vehicle solutions. Proterra's products help transit agencies deliver clean, quiet running, rider and neighborhood-friendly vehicles that also meet government regulations and local mandates. In fact, we are currently recognized by the California Air Resources Board as the first company that is currently delivering a full-size transit vehicle that meets California's Zero Emission Bus Rules.

Early in 2010, we announced our plans to move Proterra's manufacturing plant to Greenville, SC. Its close proximity to Clemson University's International Center for Automotive Research (CU-ICAR), gives Proterra access to tremendous research and development resources while we build our EcoRide™ BE35, next generation zero-emission vehicles and FastFill™ Charging Stations. Our current manufacturing facility has the capacity to produce up to 400 buses per year with room for expansion. Completing the relocation of our headquarters to Greenville, SC from Golden, CO in early 2012, Proterra employs 120 Associates (as of June 2012) and hopes to see continued growth over the next several years. Proterra plans to hire at least 400 associates in Greenville SC. In addition, our indirect impact is expected to be 2,000 jobs in America.

Proterra has assembled a world-class management and engineering team with deep experience in heavy-duty vehicles, state-of-the-art manufacturing, and advanced technology energy storage, charging and drive system advancement."

Proterra was a competitor of BYD in Los Angeles and lost. Los Angeles County Metropolitan Transportation Authority (Metro) signed the contract with BYD [94, 90]. Proterra was one of four losing bidders when Long Beach Transit's board of directors, California City, signed a contract to buy 10 electric buses made by the Chinese BYD [74].

6.12.1 EcoRide™ BE35

„[..] (The, A/N) EcoRide™ 35-foot, low-floor composite body transit bus is built upon a battery-electric vehicle architecture including the key enabling technologies:

[..] (The, A/N) proprietary composite body reduces weight approximately 20-40% over a conventional steel or aluminum bus, is crash and element resistant and is designed specifically to accommodate the battery-electric drive technology.

[..] (The, A/N) proprietary TerraVolt™ Energy Storage System can be charged in under 10 minutes. The cells are packaged in proprietary 23-volt modules along with our proprietary battery management system (8 modules per box) in a package that fits neatly within the composite floor structure in order to maintain a lower center of gravity and even weight distribution.

[..] (The, A/N) ProDrive system is powered by a single UQM PowerPhase® 150 permanent magnet (PM) motor with custom engineering for Proterra and is rated at 150 kW peak (100 kW continuous) power and generates 650 Nm of torque. The drive motor is coupled to a three-speed transmission designed to meet requirements of Proterra's heavy-duty transit applications. The transmission allows the traction motor to operate within the 92% to 95% efficiency range for both driven and regenerative braking modes. While [..] (the, A/N) EcoRide™ BE35 is a pure battery electric bus, its design allows for addition of auxiliary power units (APU) for recharging the energy storage system where vehicle routes or lack of electrical infrastructure does not make charging stations possible or desirable." [<proterra2013b>]

Figure 16 provides an image of the EcoRide™ BE35.

Figure 31: Proterra EcoRide™ BE35 [113]

6.12.2 FastFill™ Charging Station

"Proterra's on-route charging station technology offers the most rapid and convenient method for charging heavy-duty vehicles. Proterra's system allows a battery electric bus to pull into a transit center terminal or on-route stop and automatically connect to an overhead system that links the bus to a high-capacity charger without driver involvement. The bus is then rapidly charged in 5-10 minutes while passengers load and unload. The charging station technology includes advanced wireless controls that facilitate the docking process and eliminate any intervention from the driver. The driver merely pulls into the transit terminal as they normally would, the wireless controls identify that this is the right type of bus and automatically guides and connects the bus with the charging station.

[..] (The, A/N) advantage to the dedicated duty cycle of a fleet vehicle is that the vehicle returns every hour or two to a fixed location (often known as a “layover”) for the operator to take a break, and to realign the schedule with the fixed route times. These layovers are typically 10-20 minutes long and are the perfect “opportunity charge” locations for Proterra’s fast charge system.

Proterra’s FastFill™ charge system is comprised of the software and hardware to rapidly charge the TerraVolt™ Energy Storage System from 0% to 95% with >92% energy charge efficiency in as little as 6 minutes. While such power transfer normally might require a substantial grid connection to feed the fast charge rate, Proterra’s proprietary architecture allows for lower cost and lower impact grid connections while maintaining high charge rates.” [114]

Figure 16 provides an image of the EcoRide™ BE35 at a FastFill™ Charging Station.

Figure 32: Proterra EcoRide™ BE35 at a FastFill™ Charging Station [114]

6.13 Ebus (USA)

The US company Ebus, based in Downey, California, pioneered the 22-foot electric bus and trolley platform in the US that continues being manufactured in all-electric. The buses are capable of being re-charged periodically during daily use and have been upgraded for fast-charging. [16]

6.13.1 Ebus Electric 22-foot

Ebus Fuel Cell buses (see Figure 23) are plug-in electric buses, with the fuel cell and batteries configured electrically in series. The bus can operate on “battery only” part of the day, potentially extending the life of the fuel cell stack.

The Ebus Electric has a length of 6.7 m (22 foot). It has 22 seats and 10 standing places. The “driving range for the Ebus Electric Bus is approximately 45 miles between charges, which can be accomplished in about 30 minutes with the Ebus-built 90 kW Fast-Charger.” [16]

“Low maintenance SAFT Nickel Cadmium batteries can store 60 kilo-Watt hours of energy. Properly cared for, the batteries will last up to 2,000 charge/discharge cycles. This equates to about seven (7) years in typical service.” [16]

“The Electric Bus is ideal on urban circulator routes, university campuses, or in residential neighborhoods where the very low noise level is appreciated. [...] Regenerative braking also increases the energy efficiency of each bus by returning energy to the battery system whenever the vehicle is decelerating. [...]

The Ebus 22 foot Fast-Charge Electric Bus is starts at $295,000, plus taxes and shipping. The 90 kW Fast-Charger is priced at $58,000 and can support multiple buses or trolleys.” [16]

Figure 33: Ebus 22FC Plug-In Electric Fuel Cell Bus [18]

Ebus was one of four losing bidders when Long Beach Transit's board of directors, California City, signed a contract to buy 10 electric buses made by the Chinese BYD. [74]

6.13.2 Ebus Electric 40-foot

[16] and [17] tells of an electric bus with a length of 12 m (40 foot). It is not clear which type of battery is used: [16] names a 120 kWh lithium iron phosphate battery and [17] names a lithium titanate battery. The charging is performed overhead.

6.14 Cobus Industries (Germany)

Cobus Industries tells about itself [77]:

“In 1978 the first COBUS started its service at Zurich Airport.

Although at the time it was not known by this name, it still bore all of the brand‘s most important hallmarks. Today it is still reliably plying its trade. Since CONTRAC GmbH, now COBUS INDUSTRIES GmbH, took over production, the COBUS has been the world‘s market leader since 1990. Today it is to be found at almost every modern airport.”

6.14.1 e.Cobus/Cobus 2500e

“Based on the concept of the aluminum airport bus CONTRAC GmbH now presents the Generation COBUS 2500 (see Figure 24). This new bus can be equipped either with conventional Diesel engine or as fully electric drive. As the new COBUS 2500 has a width of only 2,55 m it is now possible to have the reputable COBUS brand also with permission for public urban transportation. Thus, the COBUS 2500 is both in demand of airports as well as municipalities. Besides the Diesel buses which are successfully operating since almost three decades the ecobus now is the first pure (100 %) electrically operated COBUS. [...]

Some strong technical data: The permanent magnet drive of the ecobus is powered by 7 Lithium ion batteries (lithium iron phosphate [36], A/N) with a total capacity of 150 kWh. Depending on the drive profile and mode of operation the on board energy density is sufficient for a drive of approx. 120 to 160 km. Recharge of batteries is done at steady-state charging stations. In only 3 hours time the bus is 100 % recharged. In addition, the – ecobus – is equipped with an on-board-charging system.

The combination of a complete recharge (for example time-fill) and the possibility of rapid recharge during dead times enables a smooth and efficient full-time operation in a bus line.” [78]

Figure 34: E.COBUS [78]

The bus has a length of 12 m. It has 24 seats and 42 standing places.

[140] tells about the first application of the Cobus 2500e: From 31/10/2011 a Cobus 2500e drove the 17 km long route 103 of the Offenbacher Verkehrs-Betriebe between Mühlheim am Main, Offenbach am Main und Frankfurt-Bornheim in trial operation. Originally, the trial run was planned to 15/12/2011 [13]. On 23 November 2011 it was announced that the trial was shut down in mid-November. The pilot project was interrupted because the installed heating system was insufficient from the perspective of the operator. The vehicle itself went smoothly. On 7 February 2012, the trial operation was resumed with a modified heating system. [14, 28]

6.15 Other

Further manufacturers and models of all-electric busses are mentioned in [141]:

- “Thunder Sky (based in Hong Kong) builds lithium-ion batteries used in submarines and has three models of electric buses, the 10/21 passenger EV-6700 with a range of 280 km (170 mi) under 20 mins quick-charge, the EV-2009 city buses, and the 43 passenger EV-2008 highway bus, which has a range of 300 km (190 mi) under quick-charge (20 mins to 80%), and 350 km (220 mi) under full charge (25 mins). The buses will also be built in the United States and Finland.”
- “Tindo is an all-electric bus from Adelaide, Australia. The Tindo (aboriginal word for sun) is made by Designline International in New Zealand and gets its electricity from a solar PV system on Adelaide's central bus station. Rides are zero-fare as part of Adelaide's public transport system.”

6.16 Summary

Table 3 provides an overview to all models of all-electric busses explained in the sections above.

Table 4: Summary of all-electric bus models

Manufacturer, Country	Model	Passengers	Battery Type	Capacity	Range	Max. Speed	Specifics
Solaris, Poland	Urbino 8.9	21-29 seats	LiIo	120 kWh	120 km	50 km/h	
Solaris, Poland	Urbino 12	23-34 seats	LiIo	210 kWh	150 km	N/A	
BYD, China	K9	60-70	$LiFePo_4$	324 kWh	250 km	N/A	Solar panel on the roof
Euracom, Germany	Euracom 600	86 (46 seats)	$LiFePo_4$	218 kWh	250 km	80 km/h	Modified BYD standard electric bus
Jiangsu Alfa, China	YS6120DH City	95 seats	N/A	N/A	N/A	85 km/h	
Jiangsu Alfa, China	YS6120DH New Energy	110 (66 seats)	$LiFePo_4$	500 Ah	150 km	80 km/h	
AB Volvo	N/A	N/A	N/A	N/A	N/A	N/A	
Bluekens, Netherlands	Volvo 7700	86	$LiFePo_4$	120 kWh	288 km	N/A	Modified Volvo 7700, top-up inductive charging at stops
Bluekens, Netherlands	BlueCoach	32 (21 seats)	N/A	85 kWh	125 km	90 km/h	
Rampini, Italy	ALÉ	43 (10 seats)	LiIoFe	180 kWh	150 km	62 km/h	9 Batteries
BredaMenarinibus, Italy	ZEUS	23 (9 seats)	LiPoly	58 kWh	120 km	45 km/h	
Hankuk Fiber, South Korea	e-Primus	49 seats	LiIoPoly	102 kWh	120 km	100 km/h	
Hyundai-Kia, South Korea	Elec-City	51	LiIoPoly	95 kWh	120 km	100 km/h	
CT&T, South Korea	N/A	20 seats	N/A	N/A	120 km	80 km/h	
Proterra, USA	EcoRide BE35	N/A	N/A	N/A	N/A	N/A	Ultrafast charging
Ebus, USA	Electric 22-foot	32 (22 seats)	NiCd	60 kWh	72 km	N/A	
Ebus, USA	Electric-40 foot	N/A	$LiFePo_4$/ LiTi	120 kWh	N/A	N/A	
Cobus, Germany	e.Cobus	N/A	$LiFePo_4$	150 kWh	160 km	N/A	

7 Trolleybuses

Trolleybuses are known since more than 80 years. Buses which get their energy from a pantograph like a tram are called trolleybuses. But they don't need a track on the street. In Wuppertal (Germany) the line 16 started in 1949 from the railway station Oberbarmen to Beyenburg. The picture in Figure 25 was taken in the year 1960.

Figure 35: Trolleybus in Wuppertal, Germany (Copyright: Sig. Bernhard Terjung)

Today fully electric trolleybuses are running in a lot of cities all over the world, f. e. in Salzburg (Austria) (70 years of experience with trolley buses), Brno (Czech Republic), Parma (Italy), City of Gdynia (Poland), Szeged (Hungary), São Paulo (Brazil), Córdoba (Argentina), Kiev (Ukraine) and many more [7]. [8] talks of 350 places around the world where trolley buses are used and names the cities of Athens (Greece), Moscow (Russia), Bejing (China), Vancouver (Canada), Lyon (France), San Franciso (US), Seattle (US), Boston (US) and Rome (Italy).

The buses have a small battery on board to drive without the pantograph for a special distance or for an emergency case. [7]

"Part of the worldwide attraction of trolleybuses is cost. For superb passenger comfort, a new system can be installed in a fifth of the time and a fifth of the expense of a tramway. Trolleybuses are actually cheaper over the long-term than diesel buses. Virtually all new trolleybuses can be expected to last for 30 years.

New trolleybus systems can be powered by renewable energy sources, are easily installed, are flexible and can mix with other road traffic. They can be given precedence to ensure they are the preferred mode of travel.

They can

- dock at stops within a few centimetres of the kerb and give level boarding
- are renowned for their smooth riding qualities
- have extremely low noise levels, no vibration or jerking and very smooth, powerful acceleration.

The very latest Swiss designs can carry 200 people. In France, trolleybuses are called rubber tyred trams. They have very many similarities to the steel tyred variety

- same propulsion method
- same environmental benefits
- same passenger comfort levels
- same ability to attract car drivers and so reduce congestion, reduce pollution and create a much improved urban way of life.

They have one fundamental difference; they don't need a massive tram track infrastructure that rigidly imposes constraints on other traffic. Route changes, temporary adjustments and operational flexibility are all much easier with trolleybuses." [8]

Table 4 provides an overview to current orders of trolley buses.

Table 5: Current trolleybuses on order [9]

Town	Country	Number of ordered Trolleybuses	Date	Bus manufacturers, Bus models
Salzburg	Austria	26	2017	Solaruis Trollino 18 Metrostyle
Sao Paulo	Brazil	20	2014	CAIO/Mercedes Benz artic
Luzern	Switzerland	9	2014	Hess Lightram 25m
La Spezia	Italy	7	2013-15	Solaris Trollino 12
Seattle	USA	159	2014	(tender)
Bologna	Italy	55	2013-15	Irisbus Crealis Neo
Sao Paulo	Brazil	50	2014	Scania CAIO Eletra
Lublin	Poland	20	2013-14	Solaris Trollino
Zlin	Czech Republic	15	2013	Skoda 26Tr, 27Tr
Szeged	Hungary	13	2013-14	ARC Skoda T187

Tychy	Poland	15	2013	Solaris Trollino 12
Verona	Italy	37	2013	(tender)
Geneva	Switzerland	33	2013	Van Hool ExquiCity 18
Zilina	Slovakia	20	2013	Skoda 30Tr, 31Tr
Arnhem	Netherlands	31	2013	Hess Swisstrolley4
Zlin	Czech Republic	10	2013	Skoda 24Tr, 25Tr
Lublin	Poland	20	2013	Solaris Trollino
Zurich	Switzerland	21	2013	Hess Swisstrolley4
Sofia	Bulgaria	50	2013	Skoda 26Tr Solaris
Bishkek	Kyrgystan	35	2013	Trans-Alfa 5298.01 Avangard
Baia Mare	Romania	8	2013	Solaris Trollino 12
Lausanne	Switzerland	27	2012-13	Hess Swisstrolley4
Rostov-na-Donu	Russia	5	2012-13	MTRZ 6223

During the following sections, some vehicle models of trolley buses are described.

7.1 Van Hool NV (Belgium)

Van Hool NV produces two different sized electric trolleybuses:

- A300T: 30 passengers and length of 11.995 m (see Figure 26)
- AG300T: 45 passengers and length of 17.550 m (see Figure 26)

Figure 36: Van Hool Trolley Bus A300T ([10])

Figure 37: Van Hool Trolley Bus AG300T ([10])

Van Hool trolleybuses run in Ghent in Belgium (among others) [10].

7.2 VISEON Bus GmbH (Germany)

"VISEON Bus GmbH was newly founded by the former head of NEOPLAN, Joachim Reinmuth, who took over the plant in Pilsting founded by NEOPLAN more than 30 years ago with more than 200 staff members in the spring of 2009. Since that time, VISEON has grown very fast. In the summer of 2012, the Chinese Youngman Group joined VISEON as majority shareholder. Since 2009, VISEON has invested several million Euros in new production facilities and the development and design of new vehicles. [...] Also the apron buses, which VISEON manufactures and globally distributes under the NEOPLAN brand, have been technically further developed." [39]

"On 26 April 2013, the VISEON Bus GmbH has filed for the initiation of insolvency proceedings. The reason is that promised financial means have failed to arrive. It is, however, planned to continue business operation." [39]

On end of June 2013 all employees had to be terminated [44].

7.2.1 VISEON LT20

The VISEON LT20 (see Figure 28) is a trolley bus with a length of 19.50 m and a gross weight of 33.200 kg. It has 45 seats and 84 standees. The maximum velocity is 70 km/h at an acceleration of 1.4 m/s². The VISEON LT20 is an extremely quiet passenger transit system.

Figure 38: VISEON LT20 trolley bus (Copyright by Vossloh Kiepe GmbH)

"VISEON Bus GmbH sold twelve innovative trolleybuses LT20 to put in operation in May 2013 on the university campus of the King Saud University of **Riyadh** in Saudi Arabia. The buses are equipped with state-of-the-art traction equipment from the Düsseldorf specialist Vossloh Kiepe. In the months to come the temperatures are going to rise to about 50 °C in Riyadh, which means that the air conditioning system has to be very powerful and will have a high demand for energy. Therefore, the requirements for cooling of the electronic equipment fitted on the roof of the vehicles are very high and, therefore, e.g. energy recuperated during braking is mainly made available to the air conditioning system." [81]

7.3 Carrosserie Hess AG (Switzerland)

Carrosserie Hess AG produces a wide variety of models of trolleybuses from 32 seats and 82 passengers up to 68 seats and 200 passengers and from a length of 12 m up to 24.7 m. The company writes on the internet site that there is **a renaissance in trolleybuses these days**:

"Trolley buses provide an optimum solution when urban centers start to push up against their capacity limits and need rapid access to new transport options, especially if cities adopt stricter environmental standards to be met. For evidence of a true renaissance in trolleys these days, just look at Rome, Lyon, Athens, San Francisco, Seattle and many other cities. With its outstanding energy usage, the trolleybus is an attractive transport choice that is both quiet and emissions free." [22]

7.3.1 Swiss Trolley 4

The Swiss Trolley 4 has a length of 18.7m and a kerb weight of 18.920 kg. It has 48 seats and 75 standees. The maximum velocity amounts 65 km/h at an acceleration of 1.3 m/s^2. A 75 kW Li-ion battery functions as an auxiliary power unit.

Figure 39: Trolley 4 (left image: Copyright by Vossloh Kiepe GmbH; right image: [79])

Examples of the Trolley 4 operate at:

- The transport operator Société des Transports en Commune de Limoges métropole (TCL) has put four new trolleybuses from Swiss manufacturer Hess and Vossloh Kiepe into passenger operation. The Trolley4 trolleybuses carry the core load of passengers in the town, on route 4. Irisbus Cristalis trolleybuses are working on all other routes. [80]
- "Arnheim, the only Dutch city with trolleybus operation, can continue to breathe easily: Altogether 11 non-emission trolleybuses from the vehicle manufacturer Hess and the electric drive technology specialist Vossloh Kiepe have been delivered to the transport operator Connexxion." [79]

8 Other Alternative Propulsion Technologies

8.1 Hybrid Electric Vehicle

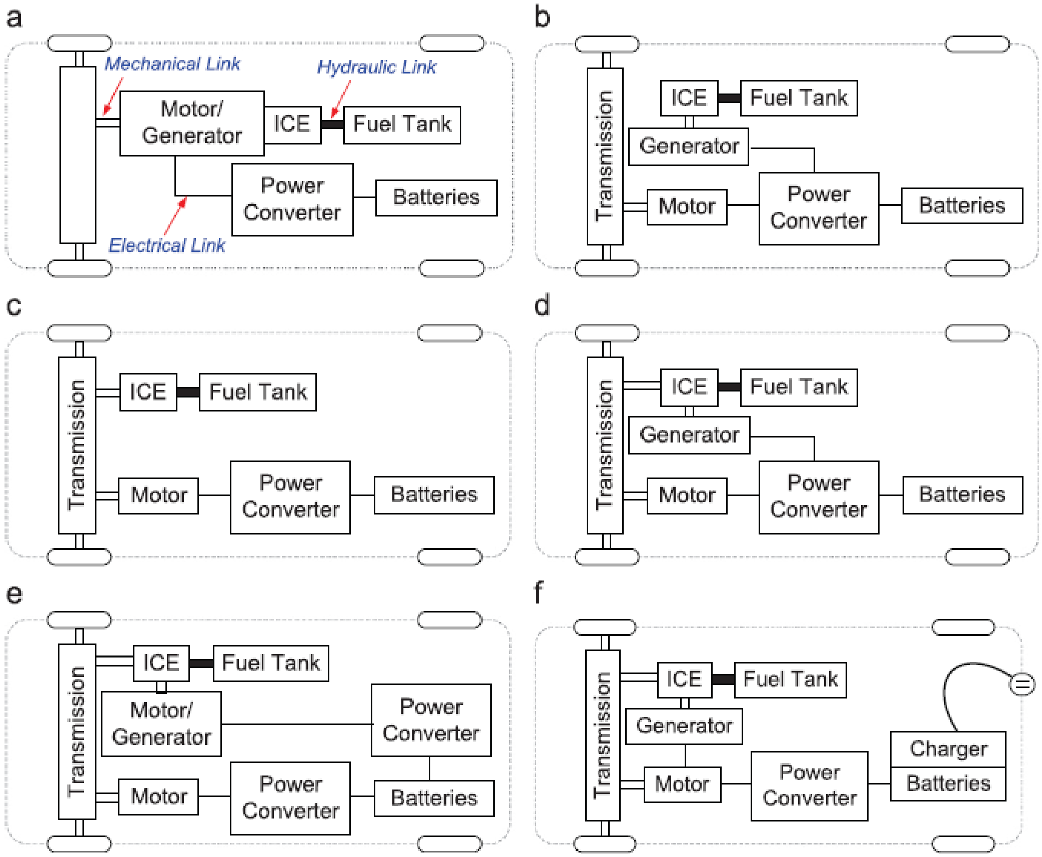

Figure 40: The drive trains architectures on HEV: (a) mild-HEV, (b) series full-HEV, (c) parallel full-HEV, (d) series-parallel full-HEV, (e) complex full-HEV, (f) series-parallel PHEV [130]

“The hybrid electric vehicle or HEV is a vehicle using both ICE and electric motor as power sources to move the vehicle. Nowadays, there are six types of drive trains architectures for HEV which are shown in Figure 40. Mild-HEV has the same advantage with micro-HEV but electric motor in mild-HEV has an electric power of 7-12 kW with 150 V (140 V) operating voltage and can run the car together with ICE. It cannot, however, run without ICE (primary power) because they share the same shaft as shown in Figure 40(a). This type of configuration normally gains fuel efficiency up to 30% and can reduce the size of ICE [47]. The GMC Sierra pickup, Honda Civic/Accord and Saturn Vue are examples for mild-HEV. Today, most of the car makers have the same pace to produce full-HEV due to its use of split power path either running on just ICE or the EM, or both. Without compromising the driving performance, full-HEV can save as much as 40% of fuel. Normally, this type of HEV has high capacity energy storage system (ESS) with operating voltage 330 V (288 V). Full-HEV can be divided into extended range electric vehicle (EREV) or series full-

HEV as shown in Figure 40(b), hybrid electric vehicle (HEV) or parallel full-HEV, series-parallel full-HEV, complex full-HEV as shown in Figure 40(c)-(e), respectively, and plug-in hybrid electric vehicle (PHEV) as shown in Figure 40(f). EREV uses EM as the sole propulsion power as a battery electric vehicle (BEV) but the difference is that they still have a high efficiency (ICE) generator built-in to recharge when the batteries are low. Chevrolet volt is one of the EREVs currently available in the market. Such a vehicle is recognized as series full-HEV or series plug-in HEV. The advantage of this configuration is vehicle's battery that can be reduced depending on the generator power and fuel capacity. This reduces the overall vehicle efficiency to around 25.7% which is the lowest among all other full-HEVs. But it is suitable in stop-and-run driving pattern, i.e. city driving pattern. It reserves and stores most of the energy from regenerative braking to the ESS [142, 73, 58]. Referring to typical configuration in Figure 40(c)-(e), parallel full-HEV has two propulsion powers (ICE and EM) in mechanical coupler, and is capable of improving the overall HEV efficiency to 43.4%. Parallel full-HEV, on the other hand, has a weaker battery capacity. One of the advantages of parallel full-HEV is that the EM and ICE complement each other during driving. This makes the parallel full-HEV a more desirable vehicle under both highway-driving and city-driving conditions. As compared to series full-HEV, parallel full-HEV has higher efficiency due to smaller EM and battery size. The series-parallel full-HEV drive train employs two power couplers that are mechanically powered and electrically powered. Although it possesses the advantage of series full-HEV and parallel full-HEV, it is relatively more complicated and costly. Complex hybrid seems to be a similar configuration with series-parallel hybrid. However, the key difference is that the power converter is added to the motor/generator and motor. This makes complex full-HEV more controllable and reliable than series-parallel full-HEV. For series-parallel full-HEV and complex full-HEV, they are more flexible on their control strategies than the other two configurations. Nonetheless, the major challenge is that they need precise control strategy. Furthermore, full-HEV configuration offers the lowest cost and the option of using existing manufacturer methods for engine, batteries and motors [142, 73, 58]. Toyota Prius, Toyota Auris, Lexus LS 600h, Lexus CT 200h and Nissan Tino are commercially available series–parallel full-HEV while Honda Insight, Honda Civic Hybrid and Ford Escape are commercially available parallel full-HEV.

However, the plug-in hybrid electric vehicle (PHEV) is similar to full-HEV but the battery can be plugged-in to grid. Actually, PHEV is directly transformed from any type of HEV. For instance, Figure 40(f) shows series-parallel HEV transforming into PHEV by adding charger beside the battery. So during running, the driver can set the power draw from battery pack more instead of ICE where it is one of the strategies to further improve the vehicle performance. For instance, in urban drive or a short distance drive, the driver could select the electric motor mode in order to achieve fuel efficiency as compared to the use of ICE engine. This strategy makes PHEV suitable both in city driving and highway driving pattern." [130]

8.2 Fuel Cell

"A fuel cell or FC is an energy conversion device where chemical energy is converted into electric energy via an electrolysis process. The byproduct of an FC is heat and water. Therefore, FC technology was proved to reduce the dependence of oil resources and hazardous CO2 emissions, which are stated in [70, 129]. There are several types of FC, which are direct methanol fuel cells (DMFC), proton exchange membrane fuel cells (PEMFC), alkaline electrolyte fuel cells (AFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cells (SOFC). [...]. Currently, DMFC is used in portable electronic such as mobile phones, PDAs, tablet, laptop and others due to its low temperature operation, fast recharge and more energy capacity. Energy density of methanol is 4390 Wh/L compared with a Li-ion battery with a density of 620 Wh/L. Among the fuel cells, DMFC, PEMFC, AFC and PAFC are categorized in low operating temperature FC. These FCs are currently used in transportation such as Citaro fuel-cell bus and Honda FCX Clarity (passenger vehicle). The MCFC and SOFC are high operating temperature FC, which are normally used in electric utility and distributed generation due to its high power output. The main advantage of the FC in transportation application is the capability of operating in high efficiency, low emissions, silence, and the FC system is simple [53, 88]." [130]

Figure 41 shows a Phileas Fuel Cell Hybrid Bus from the Regionalverkehr Köln GmbH (RVK) [126].

Figure 41: Phileas Fuel Cell Hybrid Bus from the Regionalverkehr Köln GmbH (RVK) [126]

8.3 Photovoltaic cell (PV)

“Solar energy or photovoltaic (PV) as the AES for vehicles has been around since 20 years ago [49, 76, 67]. During that time, using a solar panel was not applicable and necessary for an idea to be used in a conventional ICE vehicle [143]. However, nowadays the solar panel is drawing attention again and becoming the goal of some automakers for the purpose of increasing passenger’s comfort. Vehicles such as the 2010 Prius, Aptera 2, Audi A8 and Mazda 929 have had solar sunroof options for ventilation purposes. There are seven photovoltaic technologies which are shown in Table 6 [118, 75, 128, 56, 71, 104, 132, 111, 117]. Currently, the price of solar panel decreases to 40% due to Chinese manufacturers [63].

Currently, the leading manufacturing PV technologies in market are from crystalline silicon PV and thin-film PV. The crystalline silicon PV can be divided into three types: mono-crystalline, polycrystalline and ribbon silicon. Crystalline silicon PV has an overall efficiency around 15–20 % and can achieve maximum of 30% in rare condition. This PV is very costly in manufacturing, a relatively poor absorber of light and its wafers are thick and bulk if compared to thin-film PV. However, the thin-firm PV has an overall efficiency around 6–11 % and can achieve maximum of 21% in rare condition. This PV technology can have multiple surface options (glass, plastic and steel) with lowest cost per watt (Wp). But the thin-film PV utilizes rare earth elements which is finite quantities globally. Other PV technologies such as shown in Table 6 are the new PV technologies with a small scale in global power production when compared with the crystalline PV.

Table 6: The efficiency of existing PV modules based on different PV technologies [130]

Class of PV	Methods/technologies	Cell efficiency (%)
Mono-crystalline Silicon	Thinner Silicon Wafer Technology	–
	Back-Contact SunPower Technology	22.4-23.4
	Sanyo HIT Technology	22.3
	Suntech Pluto Technology (PERL Technology)	20.3
Polycrystalline	Benchmark Silicon Sawn Wafer Technology	14-17
	Edge-defined Film-fed Growth Process (EFG)	15.7-18.2
	String Ribbon (SR)	16-18
	Back-Contact Emitter Wrap Through (EWT) Technology	15
	Light Capturing Ribbon	19.5
Thin film	Amorphous silicon (a-Si)	9.5-13.2
	Copper indium diSulphide (CIS or CIGS)	16.7-19.9
	Cadmium telluride (CdTe)	15.0-16.5
	Crystalline silicon on glass (CSG)	8.0-10.4
Very high performance PV cells	Single and double junction (GaAs)	21.0-28.3
	Multi-junction	25.0-41.1
	Indium, gallium, nitrogen (full spectrum)	37.6
	Gallium nitride/silicon tandem solar sell	21-33.8
Concentrator PV technology	Low concentrator PV (LCPV) under five suns	25-30
	High concentrator PV (HCPV) typically 500 suns	40
	Combined CPV electricity and direct heating systems	42.4
Third generation	Dye sensitised cell (DSC)—polycrystalline	8.0-12.3
	Organic polymer	2.0-5.0
	Quantum dot	18.7
	Multi-junction nanowire PV cells	–
	Thermophotovoltaic (TPV)	13.0-22.0
Innovative panel designs	Transparent solar cell	1.7-10%

A solar powered vehicle remains as a challenge due to the limitation of space for PV and moreover the amount of power generated is not high. However, when an airplane took more than 24-h solar-powered flight and landed safely [105], it makes every- one fired up again. Many researchers start to install a solar panel on the vehicle and hope, in the near future, the power is fully generated from PV. They maximize the surface of the vehicle to accommodate the PV panel [137]. Ref. [124] derives control algorithms to increase the power produced by PV. The results indicate that the overall efficiency has improved up to 60%. Literature [108] studies the converter used for PV on rooftop of EV and proves that there are fuel economy improvements. Some automakers also start to include PV on rooftop of vehicle, such as Chevrolet Volt and Prius. These manufactures shave integrated PV on rooftop that gives the power up to 130 W. Toyota Prius uses PV energy to cool the interior of a vehicle. During 2007 to 2008, Palmer Louis had built its own 6 m^2 solar powered vehicle (solar taxi) that traveled a distance of 53,451 km in 534 days [110]. However, these are still incomparable with solar powered vehicle with mass 150 kg, ESS capacity of 5 kWh, power produced at 1.8 kW, surface area covered by PV nearly 12 m^2 and better efficiency as compared to current EVs [115, 38].” [130]

At BYD's K9 electric bus a solar panel on the roof (see Figure 5) is used to supply the air-conditioning system with energy.

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