FULLY ELECTRIC BUSES ARE PROMISING TECHNOLOGY IN THE FUTURE

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INTRODUCTION

Fossil fuels remain the dominant sources of primary energy worldwide. Since 2010 more than a third of the primary energy is derived from oil, and around 62% of the final energy consumption is associated to the transportation sector [1]. In Europe, in the European Union member countries (EU-27) in particular, the transport sector represented approximately 33% of the total energy consumption and was responsible for about 24% of CO2 emissions in 2011 [1]. Given that, governments have been introducing a large number of policies and measures across all modes in an effort to improve efficiency of energy use. European decision makers have established political goals in order to address these complex issues. Kyoto protocol, 2003/30/EC European, 20-20-20 targets are some examples of a global trend to diminish emissions from the transportation sector that is under effect [1].

According to a UITP (International Association of Public Transport) report published in 2011, buses account for 50-60% of the total public transport offer in Europe, and 95% use diesel fuels. However, a wide range of alternative fuels and technologies, at different levels of technical and market maturity are now available for bus operators. If CO2 emission and local pollution targets are to be met, it is clear that alternative vehicle solutions must be found [2].

When purchasing buses, public authorities and operators of public transport services are obliged to follow the conditions laid out in the Clean Vehicles Directive (2009/33/EC), by taking into account energy consumption, CO2 emissions, and other harmful emissions (NOx , NMHC and particulates). In addition, all new bus models sold on the market since 1. January 2014 must meet the stringent Euro VI standards for harmful emissions [2].

Within the transport sector three main reduction routes are available that can contribute to meeting the target [3]:

- Improving the energy efficiency of vehicles, specifically of internal combustion engine vehicles by more efficient engines and drive trains, weight reduction, improved aerodynamics and a range of other measures;
- Application of alternative, low CO2 energy carriers, such as electricity, hydrogen or synthetic methane from renewable sources, and gaseous and liquid biofuels;
- Behavioral measures including energy efficient driving styles, improved logistics and curbing the growth of travel demand.

Both electro mobility (pure electric vehicles, fuel cell vehicles, and plug-in hybrid configurations) and advanced internal combustion engines (powered by advanced liquid or gaseous fuels) will play significant roles in achieving this target. The energy carriers for these vehicles will need to be produced increasingly from renewable, low-carbon energy sources [3].

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Long-term decarbonization efforts obviously include electric buses but also second-generation biofuels from biomass and waste valorization. The fragmentation of this 5% share of alternative fuels and technologies today (CNG, LPG, biofuels and biogas, ethanol and electric) or tomorrow (hydrogen, hybrids, full battery electric, fuel cells etc.) places the manufacturing industry in an uncomfortable position when prioritizing R&D investments; which technology will be the 'mainstream successor' of diesel [4]

Bus electrification appears to be a highly promising option in terms of reducing fuel consumption, mitigating the environmental footprint and diversifying energy sources. But it is still hampered by a number of technical hurdles. Electric buses still have a long way to go before they reach maturity. At present, all-electric buses can only be used for short distances due to their low range and the high cost of batteries. Batteries are critical components in hybridized and electrified buses to achieve their potential.

Battery-electric buses are often referred to as "pure" electric buses because the propulsion system is powered only by the electric energy stored in the battery. The battery pack is recharged when the batteries are discharged. The first battery electric bus propulsion systems are primarily targeted to smaller buses, such as those used for shuttle service or other bus routes that are short and low speed. This is due to the limited range and power of current commercial battery technologies. Because of the potential benefits of using zero emission buses in public fleets, there has been much R&D funding devoted to improving the battery technology over the last decade. As a result, today there are some of manufacturers offering battery electric buses, primarily for short distances and relatively small ranges [5].

Electric drive trains are up to three times more energy efficient than conventional drive trains, they have zero tailpipe emissions, and they can transmit the energy originally found in a wide range of renewable and fossil energy resources into vehicle power through the electric energy batteries. Most electrified vehicles under development today obtain electricity from the power grid and store it onboard in batteries [6].

The paper content is processed through several thematic sections:

In section 2, electrification of vehicle drive trains is considered as a possible option to decarbonization of fuel in the transport sector. Depending on the level of electrification, possible alternative drive train solutions are given. On the basis of available analysis, expectations in terms of their development to year 2050 are presented.

In section 3 are given basic information about the full electric vehicles drive train architecture, some characteristics of electric motors, power electronics, and batteries as a power source. Special attention is paid to lithium-ion batteries as the current technologies for vehicles, their costs, performances, and prediction of further development.

In section 4 is shown state of the development of fast charging battery systems and given some typical solutions.

In section 5 is presented the state of development of electric buses, their presence in the market, and expectations regarding further increasing of the fleet. The basic information on some existing solutions of full electric buses, including the latest information about the trials, demonstrations, and projects are presented. E.g. from exploitation of several full electric buses, positive effects compared to diesel buses are shown.

In section 6 are given some information about electric buses that are related to their cost, emissions, LCA analysis, and energy efficiency compared to the diesel buses and other alternative technologies.

ELECTRIFICATION OF VEHICLE PROPULSION SYSTEMS

In order to comply with the established targets, to reduce the energy consumption and CO2 emissions, new fuels, as well as the respective production pathways improvement, and new vehicle technologies become extremely important to study [1]. At present, the energy carriers to power the vehicles are such hydrocarbons as gasoline or diesel fuel. The promising energy carriers capable of replacing these hydrocarbons are new energy sources like natural gas, synthetic fuels, biofuels (e.g. ethanol, biodiesel, biogas, and methanol), electricity and hydrogen, Figure 1. Some solutions regard technology improvements like hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), extended-range electric vehicle (E-REV), battery electric vehicles (BEV), and fuel cell electric vehicles (FCEV). In this framework, with the growing importance of sustainability policies, the vehicle industry is experiencing the gradual penetration of alternative technologies and fuels [1].

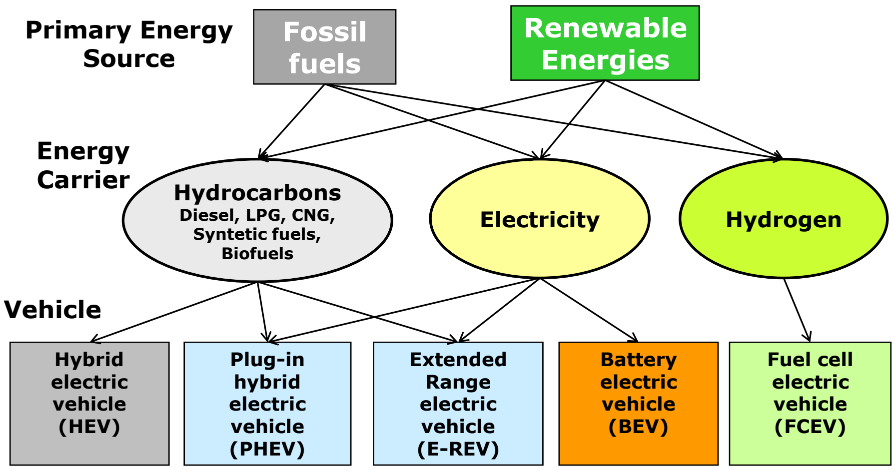


Figure 1 Energy flows to vehicles with various drive trains

The electrification of a vehicle is an option to decarbonize the fuels used in the transport sector. Vehicle electrification enables the improvement of urban air quality (no local emissions), diversification of primary energy sources (electricity can be generated from a wider range of sources, not necessarily with fossil origin), and allows the use of technologies that may improve energy-efficiency (such as regenerative braking and low consumption electric driven components). Hybridization is the first step towards drive train electrification.

Depending on the share of the electric motor to the traction power, most electric vehicles can be classified as a micro hybrid electric vehicle, mild hybrid electric vehicle, full hybrid electric vehicle, plug-in hybrid electric vehicle, extended range electric vehicle, and battery electric vehicle [7]. All electric options are applied in hybrid electric buses except micro and mild hybrid. Electric vehicle with fuel cell power packs can be classified as a fuel cell electric vehicle. These different classifications with respect to the level of electrification can be seen in Figure 2.

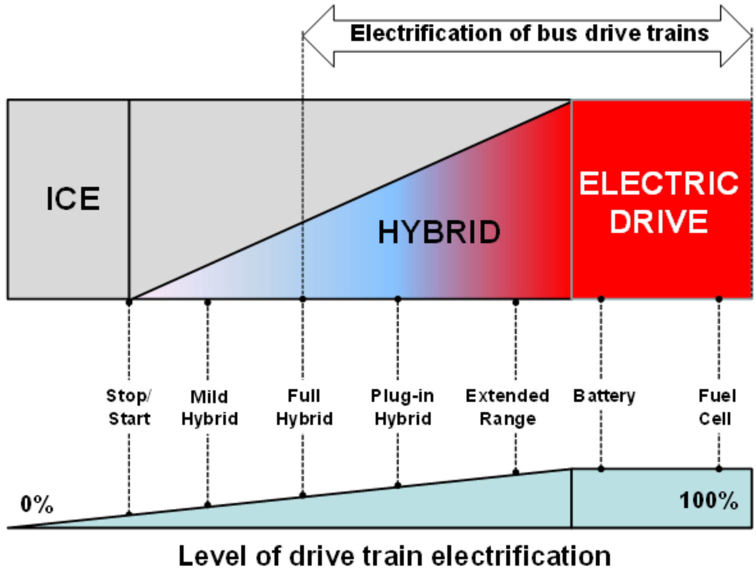


Figure 2 The range of electrification options for vehicles

A micro HEV is a vehicle with an integrated alternator that uses start/stop technology. Start/stop technology is where the vehicle shuts down the IC engine at a complete stop and then restarts when the driver releases the brake pedal. During cruising, the vehicle is propelled only by the IC engine.

A mild hybrid electric vehicle is the least electrified type of HEV. In a mild hybrid, the IC engine must always be on while the vehicle is moving. However, the motor/generator can be used to enable idle stop in which the engine is turned off while the vehicle is at idle. A mild HEV generally has an electric drive system rated at less than 20 kW of power and an IC engine power rating high enough to provide satisfactory vehicle performance when electrical power is exhausted [8].

A full HEV has an electric drive system rated at a relatively high power (usually >50 kW) allowing for the engine to be downsized [8]. The differences between a mild and full HEV are that a full HEV typically uses a smaller engine, has the ability to propel the vehicle solely off the electric motor, and utilizes a more sophisticated control system to optimize efficiency [9].

A Plug-in Hybrid Electric Vehicle (PHEV) or Plug-in Hybrid Vehicle (PHV) is a hybrid vehicle which utilizes rechargeable batteries, or another energy storage device, that can be recharged to full by connecting a plug to an external electric power source. A PHEV shares the characteristics of both a conventional parallel hybrid electric vehicle and of an all-electric vehicle, having a plug to connect to the electrical grid.

Extended-Range Electric Vehicles (E-REV) have a plug-in battery pack and electric motor, as well as an internal combustion engine. The difference with a plug-in hybrid is that the electric motor always drives the wheels, with the IC engine acting as a generator to refill the battery when it is discharge. Range extender is an auxiliary power unit built-in or externally attached to an all-electric (BEV) or plug-in hybrid electric vehicle (PHEV) to increase its all-electric range. The range extender can also be powered by a fuel-cell or other energy sources.

An Electric Vehicle (EV), either full or battery electric vehicle (BEV), is a vehicle that relies 100% on electricity (from either the grid or an off-grid source) for motion power. The wheels are propelled solely by electrical power from the energy storage device. As a result, BEVs usually have a limited driving range [8].

A Fuel Cell Vehicle (FCV) or Fuel Cell Electric Vehicle (FCEV) is a type of vehicle which uses a fuel cell to power its on-board electric motor. Fuel cells in vehicles create electricity to power an electric motor, generally using oxygen from the air and hydrogen. Fuel cell vehicles can be equipped with other advanced technologies to increase efficiency, such as regenerative braking systems, which capture the energy lost during braking and store it in a battery. Fuel-cell electric vehicles (FCEVs) are another type of zero-emission vehicle producing no CO2 or other emissions.

There are some major advantages of electric drive technologies but there are also some disadvantages. Table 1 summarizes the advantages and disadvantages of the hybrid-electric, plug-in hybrid electric, battery electric, and fuel cell drive systems [10].

Table 1 Advantages and disadvantages of electric drive technologies

Technology	Advantages	Disadvantages
Hybrid electric	Lower fuelling costs; Reduced fuel consumption and tailpipe emissions; Recovered energy from regenerative braking	Higher initial cost; Complexity of two drive trains; Component availability
Plug-in Hybrid Electric	Cleaner electric energy thanks advanced technologies or renewable; Reduced fuel consumption and tailpipe emissions; Optimized fuel efficiency and performance; Recovered energy from regenerative braking; Grid connection potential; Pure zero-emission capability	Higher initial cost; Complexity of two drive trains; Component availability-batteries, drive trains, power electronics; Cost of batteries and battery replacement; Added weight
Battery Electric	Use of cleaner electric energy; Zero tailpipe emissions; Overnight battery recharging; Recycled energy from regenerative braking; Lower fuel and operational costs; Quiet operation	Mileage range; Battery technology still to be improved; Possible need for public recharging infrastructure
Fuel cell	Zero tailpipe emissions; Higher energy efficiency than the IC engine; Recovered energy from regenerative braking; Potential of near-zero well-to-wheel emissions when using renewable fuels to produce hydrogen; No dependence on petroleum. Increased reliability and durability;	Higher initial cost; Hydrogen generation and onboard storage; Availability and affordability of hydrogen refueling; Codes and standards development; Scalability for mass manufacture;

The development of alternative fuels and drive trains in vehicles has began several years ago with intensive use of natural gas as a fuel, and more recently the development is characterized by increasing electrification of drive trains. Predictions of further development of propulsion systems to 2030, in which they included the renowned vehicle manufacturers, have resulted in a variety of scenarios. One of such scenarios, which are shown in Figure 3, is given by Daimler [11].

According to this scenario, starting from 2010 the increase of market share of CNG, hybrid, and electric propulsion systems is clearly shown, while commercialization of vehicles with fuel cell technology is expected after the 2020.

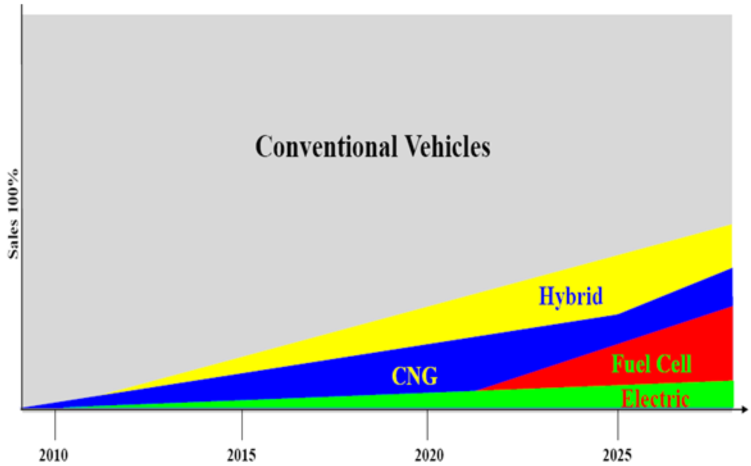


Figure 3 Increasing market share of alternative propulsion systems

BATTERY ELECTRIC VEHICLE DRIVE TRAIN

The drive system for a battery-electric vehicle, Figure 4, consists of:

- an electric motor (EM),
- a control system or power electronics that governs the vehicle operation, and
- a battery pack to provide energy storage.

Electric motors and power electronics

Electric motors offer greater efficiency and less noise than internal combustion engines. They provide their highest torque at low speeds, which results in better acceleration from a stop. Electric motors also increase energy efficiency by enabling regenerative braking: when the vehicle decelerates, the motor becoming an electricity generator that can recharge the battery pack during braking regime.

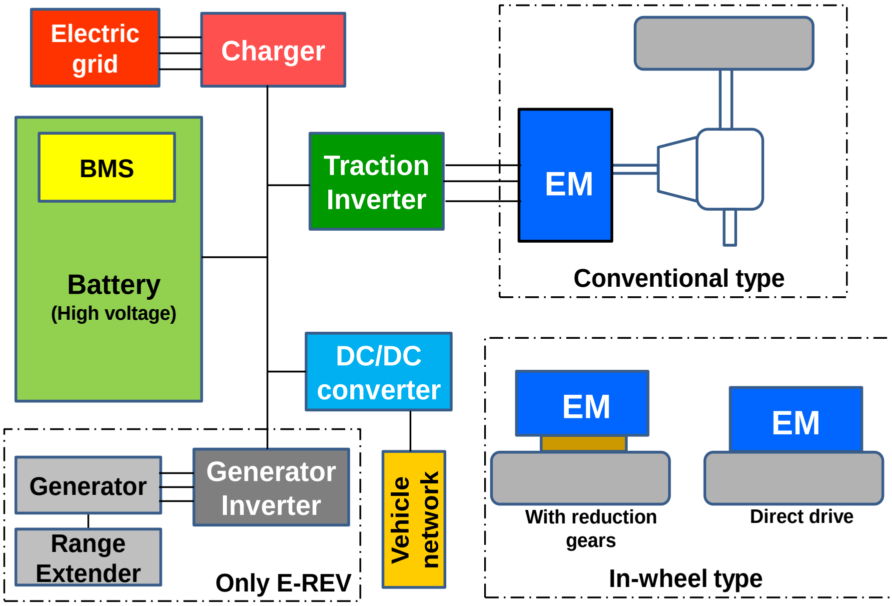


Figure 4 Electric vehicle drive train

Electric motors are already a mass-market product with a wide range of applications. They are produced by well-established manufacturers. However, the requirements for electric motors for vehicles differ from those of regular electric motors. In particular, electric motors for heavy vehicles and buses are subject to greater weight and packaging restrictions, have higher efficiency needs (due to the limited energy supply), superior power requirements, and need a broader speed range [12].

Several types of electric motors can be used to propel the vehicles, Table 2. Essentially, they can be divided in two groups: alternating current motors (AC) and direct current motors (DC). Each category has its disadvantages and benefits. The electric motors used in vehicle applications are mainly AC motors.

There are three types of electric motors that can be used in electric vehicle traction drive systems [13].

- Induction motors (IM) have high starting torque and offer high reliability. Their power density and overall efficiency are lower than that of IPM motors. Induction motors are of simple construction, reliability, ruggedness, low maintenance, low cost, and ability to operate in bad environment conditions.
- Internal permanent magnet (IPM) motors or permanent magnet synchronous motors (PMSM) have high power density and maintain high efficiency over a high percentage of their operating range. Therefore, almost all hybrid and plug-in electric vehicles use rare earth permanent magnets in their traction motors. These motors are relatively expensive due to the cost of the magnets and rotor fabrication.
- Switched reluctance motors (SRM, SM) offer a lower cost option that can be easy to manufacture. Also, switched reluctance motors are less efficient than other motor types, and require additional sensors and complex motor controllers that increase the overall cost of the electric drive system. SRM drives can inherently operate with an extremely long constant-power range.

Table 2 Current status of electric motor technology [12]

Input/stator current	AC			DC
Rotor speed relative to stator field	Asynchronous	Synchronous		Synchronous
Rotor field generation	Induction	Permanent magnet	Current excited	Permanent magnet
Type	IM	IPM, PMSM	SRM, SM	DC motor
Manufacturing cost	Low	High	Medium	Medium
Vehicle application	Yes	Yes	Yes	No
Key reasons	Low cost	Low weight, compact design	No permanent magnet	Low efficiency, heavy motors

DC motors are the only type of motor that is generally ruled out from vehicle application, as their low specific power and efficiency make them very unattractive for application in vehicles. Only innovative, brushless DC motors could potentially make a difference here [12]. Permanent Magnet Brushless DC Motor Drives are specifically known for their high efficiency and high power density. By using permanent magnets, the motors can eliminate the need for energy to produce magnetic poles. So they are capable of achieve higher efficiency than DC motors, induction motors, and SRMs [14].

Electric motors can be mounted in different ways into the vehicle, Figures 4, 5, and 6:

- On conventional type (where the electric motor is mounted instead of an IC engine, the transmission and summarizing differential remaining) and
- In-wheel type (where electric motor is mounted in the wheel with direct drive or with reduction gears).

Both alternative solutions have now found application in battery electric buses and have their own advantages and disadvantages.

Electric motors installed in the wheels contain integrated power electronics and the rims, brakes, sensors for temperature, ABS and tachometers. Along with the in-wheel hub motors driving the wheels, they can also be used as generators for regenerative brakes (recuperation). The installation space and fitting dimensions are usually compatible with common standard portal axles for low-floor buses.

Vehicle power electronics primarily process and control the flow of electrical energy in electric drive vehicles. They also control the speed of the motor, and the torque it produces. Finally, power electronics convert and distribute electrical power to other vehicle systems such as heating, ventilation, and lighting. Power electronics components include inverters, DC/DC converters, and chargers [17]

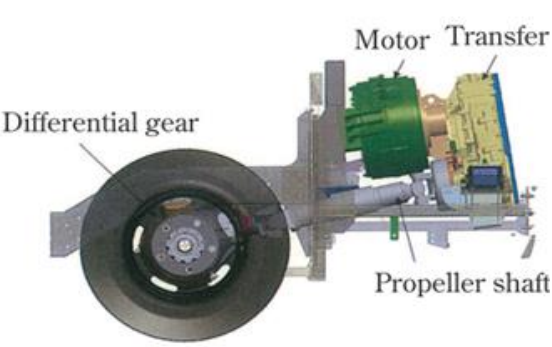


Figure 5 EM mounted on conventional type [15]

Figure 6 In wheel mounted electric motors [16]

An inverter is needed in an electric drive system to convert the DC energy from a battery to AC power to drive the motor. An inverter also acts as a motor controller and as a filter to isolate the battery from potential damage from stray currents. In extended–range electric vehicles that use range extender (a small IC engine with a generator that supplies energy for electric propulsion when the battery is empty) power electronics contain an inverter generator.

DC/DC converters are used to increase or decrease battery voltages to accommodate the voltage needs of motors and other vehicle systems. If the vehicle electric motor design requires higher voltage, such as an internal permanent magnet motor, it will require a boost DC/DC converter. If a component requires lower voltage, such as most vehicle systems, it will require a buck DC/DC converter that reduces the voltage to the 12V to 42V level 17].

Onboard vehicle chargers convert AC energy from the electrical grid to DC energy required to recharge batteries. Battery chargers for plug-in electric vehicles are currently based on proven, traditional, high-frequency charger circuits and can be located either on the vehicle or off board, as part of a DC fast charger.

A battery management system (BMS) is any electronic system that manages a rechargeable battery, monitoring its state, calculating secondary data, reporting that data, and controlling its environment.

Battery as a power source

Energy storage systems, usually batteries, are essential for electric drive vehicles. Batteries must have a high energy-storage capacity per unit weight and per unit cost. Because the battery is the most expensive component in most electric drive systems, reducing the cost of the battery is crucial to producing affordable electric drive vehicles.

The electrical energy storage units must be sized so that they store sufficient energy (kWh) and provide adequate peak power (kW) for the vehicle to have a specified acceleration performance and the capability to meet appropriate driving cycles. For those vehicle designs intended to have significant all-electric range, the energy storage unit must store sufficient energy to satisfy the range requirement in real-world driving. In addition, the energy storage unit must meet appropriate cycle and lifetime requirements. These requirements will vary significantly depending on the vehicle type (battery or fuel cell powered or hybrid electric).

There are many energy storage technology and battery chemistry and packaging options for electric drive vehicles. A number of different battery technologies exist at present. However, none of these battery technologies provide the energy density required for sufficient driving distance in pure electric mode.

Lithium ion (Li-Ion) battery chemistry represents the technology of choice for electric vehicles today and for the foreseeable future. All Lithium-ion technologies are based on the same principle: Lithium-ions are stored in the anode (or positively charged electrode), and transported during the discharge to the cathode (or negatively charged electrode) in an organic electrolyte. The most popular materials are graphite for the cathode, and a metal oxide for the anode, based on Nickel, Manganese and Cobalt. All of these materials have good Lithium insertion properties, allowing the large amount of energy storage [18]. Research on next generation lithium batteries will continue the development of electrode and electrolyte materials and chemistries in order to increase the life and energy density of the battery while reducing size and weight.

The original Li-Ion chemistries developed for consumer applications have proven too expensive for vehicle uses, given their large share of the total cost of the vehicle. This has spurred the development and deployment of alternative, cheaper Li-Ion chemistries with more suitable thermal characteristics better adapted to vehicle applications. These include lithium-iron-phosphate (LFP), lithium-manganese-oxide spinel (LMO), and nickel-cobalt-aluminium. To date, no dominant chemistry has emerged, but deployment for vehicle applications is still in its infancy and further experience will prove invaluable in improving performance and reducing costs [7].

The iron phosphate based systems are believed to be the safest and to have the lowest cost, but also have lower performance than other chemistries [19].

The relationship between power density and specific energy density is very important for the performance of the vehicle. Figure 7 show the specific power density relative to specific energy density for different electricity storage options [7].

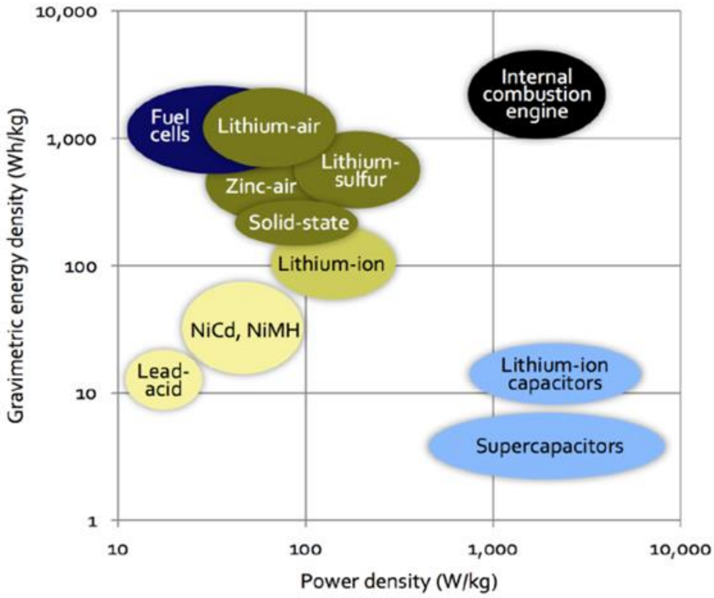


Figure 7 Energy density versus power density of different energy storage systems

The key parameters a vehicle designer must take into account when considering a battery are costs, the specific energy density of the battery, and the relationship with power charge and discharge. The specific energy density can be measured in two ways; either in terms of energy per unit mass (e.g. Wh/kg) or volume (e.g. Wh/litre) [7].

The estimate of battery pack costs for EVs in 2012 varies quite widely depending on the source of data, but is typically USD 500-800/kWh. The average battery cell costs are USD 400/kWh, but they vary widely depending on the scale of production. The build-up into battery packs adds 50-100% to the cell costs [7].

Battery performance degrades over time with the number of cycles (charge/discharge cycles) performed. Maximizing the number of cycles a battery can perform before it deteriorates to a point it needs replacement will significantly enhance the economics of PHEV and EVs. To maximize the life of a battery, the swing in the state-of-charge (SOC) is typically limited to 40-80%. Thus the effective cost of electricity available for driving is higher than the nameplate cost, as only 40-80% of the battery charge is made available. For instance, a battery pack that costs USD 500/kWh, but that charges and discharges over only 60% of its capacity would have an effective cost of USD 833/kWh [7].

The most promising chemistry materials to involve silicon, sulfur and air (oxygen) and another important development is research into nanotechnologies. These trends have been widely recognized and a recent presentation by Limotive researchers showed the following battery technology roadmap, Figure 8 [19].

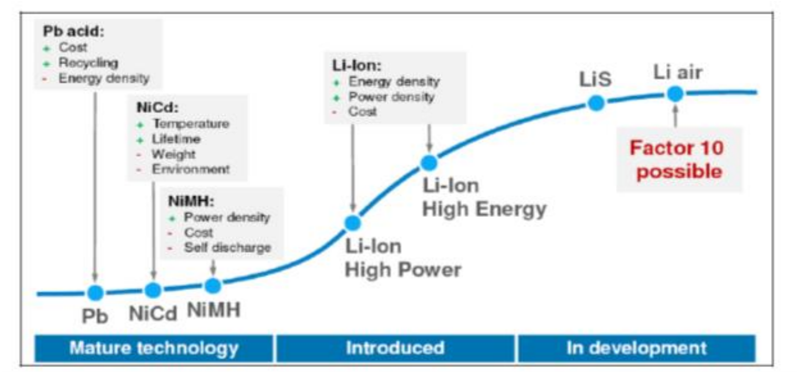


Figure 8 The battery technology roadmap

Silicon is an attractive anode material for lithium-ion batteries because it has about ten times the amount of energy that a conventional graphite-based anode can contain. It also has a specific energy of 1.550 Wh/kg – about four times the energy of a conventional graphite-based anode. Furthermore, silicon is the second most abundant element on the planet and has a well-developed industrial infrastructure, making it a cheap material to commercialize with a cost comparable to graphite per unit of weight [19].

The problem with silicon is that it is very brittle and when lithium-ions are transferred during charge and discharge cycles, the volume expands and contracts by 400% which can pulverize the silicon anodes after just the first cycle.

The lithium-sulfur systems have a theoretical specific energy of 2.600 Wh/kg which exceeds current generation lithium-ion batteries theoretical specific energy by about a factor of 5. Current cathode materials, such as those based on transition metal oxides and phosphates, are limited to an inherent theoretical capacity of 300 Ah/kg while the theoretical capacity of sulfur is 1.600 Ah/kg. Other benefits of sulfur are that it is abundant and low cost [19].

The lithium-air technology uses oxygen as a catalytic air cathode to oxidize a metal anode such as lithium or aluminum. Theoretically, with oxygen as essentially an unlimited cathode reactant source, the capacity of the battery is limited only by the lithium anode. Estimates of energy density vary from 2 to 10 times the energy capacity of current lithium-ion batteries.

Also, it could greatly reduce costs as lithium batteries currently use a cathode which is the most expensive component of lithium batteries. Lithium-air with a theoretical specific energy of 13.000 Wh/kg is one of the few, promising technologies that can potentially approach the energy density of a hydrocarbon fuel [19].

Battery manufacturers also indicated that each battery generation was likely to be in production for 4 to 5 years at least to recoup capital investments and R&D costs, so that 2011/2012 introduction of the first generation of vehicle lithium-ion batteries implies that the second-generation batteries could be commercialized in 2016/17 and third-generation batteries in the early 2020 time frame [19].

BATTERY CHARGING SYSTEMS

The battery electric and plug-in hybrid buses require top-up charging stations, but only at terminals or other locations where sufficient time (at least 5 minutes) is available within duty cycles for recharging. Without super-capacitors the vehicle batteries cannot be charged sufficiently rapidly to make charging during normal bus stop dwell times a practical proposition [20].

Most battery electric buses use “conductive charging”, which is also known as “direct wired contact” or “direct coupling”. This well tried and proven system has traditionally involved plugging a cable into a socket on the vehicle. However other variants are being created which involve physical contact with an overhead power supply - but only whilst the bus is stationary at a dedicated charging point.

In addition to “conductive charging” another way to charge the batteries (whilst they still remain in the bus) is via electromagnetic “inductive charging”. One of the problems with batteries is that they risk being damaged if charged too quickly. Fast charging will also shorten their service life.

The power electronics for charging the energy storage system could be on-board or off-board the vehicle. Improving the efficiency and cost of this component may be critical to the success of electrified transportation. Weight of on-board units is also important. On-board units take AC power from the grid and rectify it to DC power to charge the DC battery pack. Off-board units make this same conversion and deliver DC power to the vehicle [21].

Some buses, known as opportunity electric buses, are charged end route either at charge points throughout the bus circuit or at first and final stops. Others have their batteries recharged overnight and are therefore known as overnight electric buses [21].

With fast charging, it is possible to reduce the weight and size of the battery pack dramatically while simultaneously increasing the operating range. Instead of using a 300 or 400kWh battery pack, a 50 or 100kWh pack can be used instead. This has major benefits in reducing the bus weight, and providing more room inside the bus for passengers [22].

Some interesting systems for battery charging are:

<u>The IPT (Inductive Power Transfer) charging system:</u> The first ever field trials of a 12 - meter electric bus charged wirelessly by induction is currently underway in the Netherlands [23].

The charging technology IPT allows the electric bus to run reliably for 18 hours, covering some 288 kilometers a day, without the need to stop for prolonged periods or return to the depot to recharge. The project, which is currently in the final phase of vehicle testing, has come at just the right time, as stricter emissions standards are due to come into effect in the EU in 2014 [23].

Inductive Power Transfer is an energy transfer system for electric vehicles that works by magnetic resonance coupling. The system consists of two main components: a primary coil in the road, which is connected to the power grid via a converter, and pickup coils fitted in the road and underneath the bus. IPT is based on the principle of short but regular charging during operation. The battery is fully charged over night and then topped up as necessary and as possible over the course of the day at suitably equipped stops, usually by about 10-15%, when the bus stands still for longer at a station or at each end of the route. Conventional electric buses are almost exclusively recharged overnight by cable [23].

<u>The Opbrid Bůsbaar charging system</u>: In April 2014, during recent tests of Hybricon Bus Systems’ new Arctic Whisper (HAW) urban bus in Umeå, Sweden, the Opbrid Bůsbaar achieved ultrafast charging at 625 amps for 6 minutes. This paves the way for charging at 500 - 1000 kW or more to achieve 2-3 minute charges at the end stations of longer bus routes [24].

The Opbrid Bůsbaar is an overhead, pantograph-based fast-charging station for buses, Figure 9.

While fast charging of urban buses has already been shown to be a valuable way to achieve “infinite electric range” in bus systems by Hybricon, Proterra, Volvo, and others, bus operators want ever shorter charging times. If charging times can be reduced to just 2-3 minutes, then the operators do not have to add additional buses-and their associated costs-to a route [24].

The unit cost of a roof mounted pantograph charging station is around € 200,000, while the cost of manual plug-in charging station approximately £ 58,000 (€ 73.000) [20]. Manual equipment can charge the vehicle batteries to full capacity in less than 2 hours.

Bombardier’s PRIMOVE charging system: In February 2013, Bombardier has announced that it will be testing its electric bus technology on buses that are operating in Montréal [25]. Bombardier is currently also working on implementing its PRIMOVE system for electric buses in Mannheim and Berlin, Germany, and in Bruges, Belgium. In addition, tests with a dynamically charged truck were successfully completed in Mannheim in January 2014. Bombardier’s PRIMOVE charging technology is based on inductive energy transfer, Figure 10. It is installed entirely under the road surface and under the floor of the vehicles. The charging process begins as soon as the vehicle completely covers the charging segment.

Figure 9 The Opbrid Bůsbaar fast-charging station

According to information from Bombardier the costs for a PRIMOVE charging point amounts to approx. 125,000 €, but it is unlikely that this sum includes the costs for the installation or the costs for the feeding cables [26].

On the basis of the available information it is assessed that the costs for a complete charging point amounts to approx. 150,000 €. Thus, the inductive charging point would be about 50,000 € more expensive than the conventional charging point (no consideration at all of the feeding cables from the next rectifier substation to the charging point and no consideration of the costs for expansion of the rectifier substation itself).

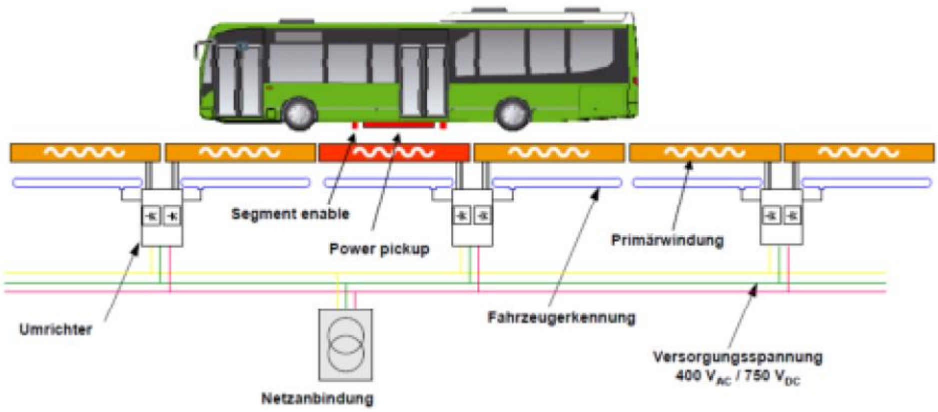


Figure 10 Charging point according to the PRIMOVE principle of Bombardier

The ABB flash charging system: European technology giant ABB (a global leader in power and automation technologies based in Zurich) has developed a new technology that will help power the world's first high-capacity flash charging electric bus system [27].

In 2013, ABB announced at the 60th congress of the International Association of Public Transport (UTIP) in Geneva that it is working together with the city's public transport company (TGP), the Office for the Promotion of Industries and Technologies (OPI), and the Geneva power utility SIG on the TOSA electric bus system pilot project [27].

The new boost charging technology will be deployed for the first time on a large capacity electric bus, carrying as many as 135 passengers. The bus will be charged directly at selected stops with a 15-second energy boost while the passengers enter and leave the bus, based on a new type of automatic flash-charging mechanism [27].

Onboard batteries can be charged in 15 seconds with a 400 kilowatt boost at selected stops. At the end of the bus line a 3 to 4 minute boost enables the full recharge of the batteries. Thanks to an innovative electrical drive system, energy from the roof-mounted charging equipment can be stored in compact batteries, along with the vehicle's braking energy, powering both the bus and its auxiliary services, such as interior lighting [27].

ELECTRIC BUS MARKET AND DEVELOPMENTS

This Section presents the state at the market of full electric buses and gives information on some of the buses already in routine exploitation and on some which are in different phases of development or trial/demonstration stages over the European market.

Electric bus market

Over the past few years governments around the world stimulate development and introduction in use of alternative fuel buses, including buses with electric drive trains, especially, hybrid and battery buses.

Hybrid buses have already captured significant market share in the United States. China has also been strong in this technology. Hybrid buses have begun increasingly to appear in Europe, albeit at a slower rate than in the United States or China [28].

Battery electric buses currently available are rigid vehicles 11 to 12m in length and no production of battery electric articulated bus is running. However, manufacturers published roadmaps for future product development to indicate that such vehicles are likely to become available in the near future and plans have been announced for the operation of 18m battery electric buses in Braunschweig, Germany and Barcelona, Spain commencing during 2014 [20].

China is the world leader in developing battery electric buses. The southern city of Shenzhen has the world's largest zero-carbon fleet of all-electric buses and taxis, and plans to have 6 000 electric buses in service by 2015. Shenzhen is also home to the world's largest manufacturer of electric buses, BYD (Build Your Dreams). The company has started to enter overseas electric bus markets. At the start of 2013 its vehicles received Whole Vehicle Type-Approval from the European Union, giving the company the green light to sell its buses to all EU member countries without further certification. The number of electric buses in countries other than China is limited but growing [29].

Sales of electric drive buses in Western Europe will experience steady growth (around a 20% CAGR- Compound annual growth rate), as the hybrid market begins to take off and there is continued interest in building the electric and fuel cell bus markets [29].

The Latin American market will be driven largely by uptake in Brazil, but other countries will also spur adoption, notably Uruguay which recently indicated it would purchase 500 battery electric buses [28].

The Africa/Middle East countries will see very little uptake due to the high cost of electric buses and infrastructure.

Some investigations [30] indicated that of all alternative technologies the largest growth in the future would have the electric drive systems (about 41,5%), the largest growth being that of the hybrid systems (69,7%) and the fully electric with batteries somewhat lower (45,5%), Figure 11.

The US-based market research and consulting firm Pike Research forecast in August 2012 that the global market for all electric drive buses including hybrid, battery electric, and fuel cell buses will grow steadily over the next six years, with a CAGR of 26,4% from 2012 to 2018 [29].

According to Pike, the largest sales volumes will come in Asia Pacific, with more than 15 000 e-buses being sold in that region in 2018 – 75% of the world total. China will account for the majority of global e-bus sales, Pike predict. They believe that growth in the e-bus market will accelerate strongly in Eastern Europe and Latin America, the latter driven largely by Brazil [29].

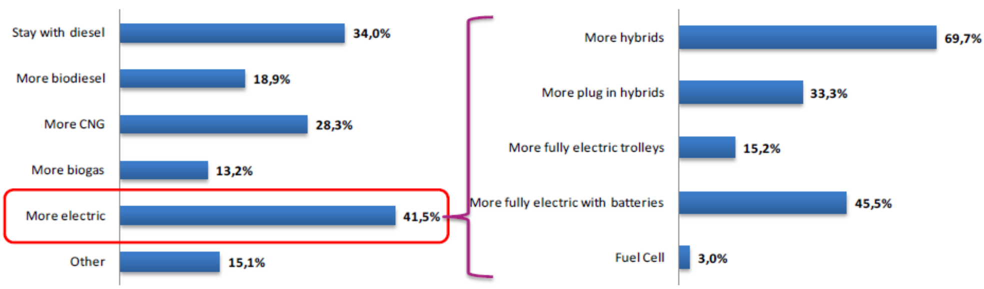


Figure 11 Future plans for propulsion technology change

The report by the research and consultancy firm IDTechEx forecast that the market for electric buses and taxis will rise 8.7 times from 2012 to 2022, of which the largest part will be buses. China will become by far the largest market for both electric buses and electric taxis [29].

Electric buses in regular service

BYD electric bus: BYD Co., Ltd based in Shenzhen, China is a globally leading-edge provider of green energy technologies that specializes in the IT, automotive and new energy fields. Today, BYD is the fastest-growing Chinese auto company and a global pioneer in the field of new energy vehicles including pure electric models. BYD Europe is the marketing and distribution arm of BYD Co., Ltd.

Build Your-Dream (BYD) hybrid buses were showcased during the 2008 Beijing Olympics and have been selected as the sole eBUS provider for the 2011 International Universiade Games held in Shenzhen, China. The 12-meter long BYD electric bus, Figure 12, is made from carbon steel chassis and aluminium bodies. The top speed is 70km/h. At the core of the eBUS technology is BYD's in-wheel motor drive system and the Iron Phosphate battery technology.

Figure 12 BYD electric bus

The wheel-hub permanent magnet synchronous AC motors are water-cooled and installed in the rear drive axle together with regenerative braking technologies. Compared with a normal motor, the rear drive axle system in the BYD eBUS has no gear box, no transmission shaft, and no differential mechanism. The power from the motor is directly transmitted to the wheels, so that significant improvements are achieved in transmission efficiency and reductions in noise and vibration. In addition, the bus weight can be cut by 300kg, and interior space is greatly saved [31].

Each of the wheel-hub motors has a maximum power output of 90kW and produces maximum torque of 350 Nm. Rotation speed is 0~7500 rpm. Power comes from the 600Ah, 324kWh BYD Fe (Lithium Iron Phosphate) batteries. On board the batteries are located in three banks, one each over the two front wheel arches and the third at the rear on the roof.

In theory the batteries give the buses a range of between 200-250km a day. The plan is to keep developing the bus range in every way. One of the targets they have set themselves is to reduce the weight of the e-bus by around 700kg to a figure of 13.100kg. They claim that those on the e-bus are good for over 4.000 cycles from fully charged to discharged and back to fully charged which at one charge a day equates to just under 11 years. Each of the battery packs contains 168 cells, each cell weighing 6kg, giving a total of 1.008kg. The weight of the three traction battery packs together is therefore 3.024kg [31].

Building buses since 2003, they have tested the e-bus in European cities including: Paris, Bremen, Bonn, Madrid, Barcelona, Salzburg, Warsaw, Amsterdam, Brussels, Budapest, Copenhagen and London. BYD presently has sold and deployed over 1,000 operating electric buses in China and throughout Europe and Latin America [32]. Already BYD has over 4,000 bus orders for 2014, most of them admittedly in China [31]

BYD has gained official permission to sell its electric buses in all European Union member states without the need for individual national approval. A Whole Vehicle Type

Approval (W.V.T.A) has been obtained from the European Commission, which is compulsory for vehicles for sale within the E.U. The W.V.T.A. encompasses 25 tests and sets the standards for vehicle and safety performance. In order to achieve the certification, a bus must conform to European directives for the transportation sector [33].

According to the data from exploitation of 220 BYD electric buses [34] in Shenzhen, China who have achieved 27 million kilometers by the end of May 2014, the significant savings compared to the same diesel bus are as follows:

- BYD e-bus has achieved energy savings valued approximately €7.425.600 and
- Reduced CO2 tailpipe emissions by about 28.390 tons.

Optare's battery-powered Versa: Optare's battery-powered Versa is the UK's first commercial full-size battery bus, Figure 13, which started on 1. April 2011. At 11.1 meters long, the buses seat 38 (23 of them including three tip-ups with step-free access) and have a total carrying capacity of 59. Maximum range is 75-95 miles (120-153km), depending on the terrain, on one overnight charge [35].

Battery-powered Versa buses are planned to be in service at peak times, providing a capacity increase on the 12-minute interval service. The buses can either be rapid charged, using a special charger, or slow charged. A return journey is around 5 miles (8 km).

The fast charging station was made in Holland and is capable of taking the Versa EV's batteries to full capacity in less than 2 hours compared to the standard 6 to 8 hours of a normal charger, thus potentially doubling the vehicle's daily range.

When first ordered, it was envisaged the Versa EVs would utilize a Siemens drive system and summation gearbox with 90kW of power and 320Nm of torque, power being drawn from 48 lithium ion batteries arranged in two banks of 24. However, that was changed to the Enova Systems P120 motor with a summation gearbox, working in conjunction with 56 Valance lithium ion/magnesium phosphate battery packs to deliver a more powerful 120kW with 650Nm of torque [35].

Figure 13 Optare's battery-powered Versa

The 56 batteries are split into two packs of 28, and are covered by a five-year warranty. Equalization and conditioning is managed by on-board computers during recharge. Already the replacement cost of the battery packs has fallen from £75.000 to £56.000 (€94.500 to 70.560), and is likely to come down further.

e-Busz: Netherlands' company e-Traction (European integrator of low-floor fleet buses), delivered in the year 2010 the first of two e-Busz electric drive buses (with extended range) to Rotterdam's public transportation authority [36]. The e-Busz, Figure 14, is a VDL Bus & Coach Citea CLF bus converted with the third generation of the e-Traction system. The RET (Rotterdam Electric Tram) tested two buses in 2012 on its route between Station Zuidplein and Rotterdam Central [37].

e-Traction specializes in development of TheWheel as a direct-drive in-wheel motor system with integrated power electronics and fluid cooling. TheWheel SM500/3 is designed to deliver very high torque at low revolution and 240kW power [38]. The vehicles with TheWheel save up to 40% traction energy and are 50% more fuel efficient compared to the standard diesel equipped bus.

The e-Buzs is a “battery dominant” hybrid bus or E-REV (Extended Range Electric Vehicle). This means that it has the ability to run on battery only 107 kWh (allowing 80km range or about 4 hour zero emission drive) with the diesel generator turned completely off. The diesel unit (30kW) can be replaced and, importantly, the bus returned to revenue service in roughly one hour [38].

Figure 14 e-Busz electric powered bus

After nearly 3 years of operational experience e-Buzs has achieved [39]:

- Consumption reduction by 25% to 50%,
- Engine noise int./ext. below 67dB/73dB,
- Regenerative braking in urban cycles saves about 25% of energy (potential 40%),
- Direct drive of e-Traction/ZA makes 0.9 kWh/km feed to wheel energy use feasible, other tested systems need 10-15% more and
- Total energy cost varies between 0.2 and 0.5 €/km, to earn back batteries as much as possible full electric driving is mandatory.

Electric buses in trials and demonstrations

Trials are usually conducted on a small scale and on less crucial routes and they have the benefit of encouraging innovation and help to mainstream newly developed technologies. They also help manufacturers establish whether improvements need to be made, in order for their vehicles to perform optimally in real life conditions [2].

Demonstrations are used to test whether a technology could take over from a normal ‘in service’ vehicle, after the technology has been successfully trialed. Using demonstration buses before purchasing allows the transport operator to test the passenger acceptance, real world performance and practicalities of the vehicle before any significant investment is made into a fleet, including any infrastructure requirements [2].

Below are given typical examples of electric buses that are in trials and demonstrations across Europe.

Caetano Bus (Cobus 2500 EL): In 2011, the City of Vila Nova de Gaia (Portugal) started commercial testing of a full electric 25 seat (total capacity 67) Caetano Bus (Cobus 2500 EL), Figure 15. The bus can also be adapted for use on urban areas due to its smaller dimensions - 2.55 m width and 9 - 12 m length. It has an aluminum body (CO-BOLT system) assembled on a modular chassis. The front module contains the 150kW UQM

Power Phase 150 permanent magnet synchronous electric motor fed by seven lithium ion batteries with a total capacity of 150 kWh, allowing a range of approximately 120 - 160 km [40].

Recharging the batteries of the bus from 10% to 90% SOC (state of charge) took less than 3 hours. After the positive experience in the testing period in Gaia, as well as in the German cities of Offenbach and Wiesbaden, the Cobus EL 2500 is now certified to run on regular roads and ready for market and series production [2].

Figure 15 Cobus 2500 EL full electric bus

Hybricon Arctic Whisper city bus (HAW 12 LE): In 2011, the City of Umeå in Sweden tested fully electric buses on standard routes, with very good results [2]. A 12-metre Hybricon Arctic Whisper city bus (HAW 12 LE), Figure 16, featuring the in-wheel hub drive ZAwheel, produced by the German electric motor manufacturer Ziehl-Abegg. The operating time is 18 hours a day [41]. Due to the fact that there is a pure wind and hydro plant power in Umea, buses can run fully on clean energy, well-to-wheel.

The bus uses LTO (lithium–titanate battery) batteries that can be charged for 1 hour drive in 6 minutes. Hybricon Bus Systems AB provides the city with the whole system, including charging stations. The City of Umea has a startup plan for up to ten 12m buses and 20 articulated 18m buses [42].

Figure 16 Hybricon Arctic Whisper electric bus

The buses have been ordered in two different sizes: three 18-metre vehicles, each with four drive motors (HAW 18 LE 4WD), and five 12-metre vehicles, each with two drive motors (HAW 12 LE). Delivery is due to start in autumn 2014 with the 12-metre buses. In spring 2015, there will be nine fully electric city buses circulating in Umea. The vehicles will be charged with 650 kW each at three ultra-fast charging stations. The batteries have a power output of at least 50kWh, depending on the route. They will be recharged for three to five minutes per hour, enabling non-stop electrical operation (24/7) [41].

Each city bus will have a small range extender on board, which can run on biodiesel or ethanol and recharge the battery via a generator. This means that each electric bus can still be operated even in the event of a power cut. As the range extenders are part of a modular system, it will be simple to switch to a fuel cell in five years time [41].

Solaris Urbino 12 electric bus: A Solaris battery bus was also chosen by the Swedish city of Västerås, which ordered the Solaris Urbino 12 electric with conventional plug connection. Its 160 kWh battery will be divided into four packs. Two of them, 40 kWh each, will be placed on the roof, while the remaining two will be installed at the rear of the vehicle. Thanks to this solution, axle loads will be evenly distributed and three additional seats will be added on the rear bench. The bus will additionally be equipped with a heater powered by two gas cylinders installed on the roof. The gas heater will extend the range of the bus, since it will not use the energy stored in the battery to heat the interior. It will improve the vehicle's efficiency, especially during Swedish cold winters. The bus will be also equipped with a 25 kW electric heater [43].

In the spring of 2014, Solaris delivered two Solaris Urbino 12 electric with conventional plug connections to Düsseldorf, Figure 17. They are fitted with 210 kWh batteries. Both vehicles can be also equipped with an automatic system for conductive fast charging mounted on the roof at a later date. According to a stimulation prepared by Solaris's engineers, there will be one 200 kW battery charger on the route. Buses will use it during their daily service. The charging time will be adapted to the timetable and will take only a few minutes. The charging cable will be fitted into a special arm allowing easy and comfortable use. Thanks to this solution, the charging process is as simple as fueling a bus. Two additional 32 kW battery chargers located at the depot will be used at night. All parameters were adapted to supply the amount of energy required to complete the service, even in case of unexpected obstacles preventing a bus from arriving at a charging point on time [43].

Figure 17 Solaris Urbino 12 electric bus in Germany

The German city of Braunschweig chose the Solaris Urbino 12 electric with contactless inductive charging. The system allows a bus to be charged automatically at bus stops thanks to induction coils fitted under the road surface. The whole process is fast and efficient. In 2014, Solaris will deliver four more inductively charged electric buses to Braunschweig, this time 18-metre versions. These Solaris Urbino 18 electric will be the first articulated electric buses produced by Solaris. Their purchase is part of the EMIL project for "e-mobility through inductive charging", whose aim is to increase the number of inductively charged electric buses. The first five Solaris buses are only the beginning of this project [43].

Siemens/Rampini electric bus: The first 8m electric bus (eBus) for the Austrian capital city of Vienna, Figure 18, supplied by Siemens and Rampini, has been brought into service by "Wiener Linien", the municipal public transport company. The buses recharge at their end stations by hooking up to the overhead lines of the Viennese tram using an extendable pantograph, an arm on the roof [44].

With this recharging technique, it is possible to install a smaller battery system (nine lithium iron phosphate batteries with a total capacity of 96 kWh instead of the 180 kWh electric buses usually need). Buses have a top speed of 62 km/h and a range of up to 150 km without recharging (the distance decreases to 120 km in winter when the heating system consumes about 7 kW more energy) [45].

Each electric bus cost is €400.000, double the cost of a comparable diesel bus. Prices are likely to drop as production rises, however. In addition, the additional charging infrastructure costs included a charging point at each end stations (each costing €90.000), and charging point at the bus depot (€320.000) [45].

In 2013, Bremen's public transport company (BSAG) tested an 8m electric bus from the manufacturer Siemens/Rampini, which it borrowed from the City of Vienna. The bus does not generate direct or indirect CO2 emissions, because it is charged in Bremen with electricity from renewable sources. Bremen is also undertaking a trial with three small battery electric buses, which are charged overnight from the grid at the depot and a 12m battery electric bus will also soon be trialed [2].

Figure 18 Siemens/Rampini electric bus

EMOSS e-bus: In 2012, the first ever public-service field trials of an electric bus charged wirelessly by induction are currently underway in the Netherlands [47]. EMOSS e-bus 12 meter is unparalleled seating capacity, full low floor, zero emission, and quiet electric bus based on the Volvo 7700 range, Figure 19. Top speed is 85 km/h, occupancy 86 passengers. Available with AC and DC, conductive or inductive fast charge, the versatile configuration gives Public Transport Operators a wide range of deployment possibilities [46].

Figure 19 EMOSS e-bus

Hybrid and Electric drive train supplier EMOSS provided the electric drive train and integrated wireless charging system to the vehicle system. Benefits of this full electric “charging on route” concept is a downsized battery pack, resulting in lower weight- and cost balance and ability to operate on regular bus routes.

In addition to overnight plug - in charging (7 hours), 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 (4-7 min) while at a bus stop. The battery is Lithium-Ion Polymer, 128 - 300 kWh energy. Electric motor has power 240 kW, torque 960 Nm, direct drive transmission, and operating voltage 700V [47].

SOR BN 12 electric bus: SOR BN 10.5, a low-floor city electric bus, is a double-axle three-door electric bus of 10.370 mm in length designed for public transport for shorter distances (120 km) in city traffic and maximum speed 80 km/h [48] is in service since 11th February 2014, Figure 20. The SOR-Cegelec, which is now being tested in Prague, has already been in full operational use in Ostrava for several years. The city has four vehicles of an older design [49].

The body of the bus comes from the SOR BN 12 city bus, the rear overhang was shortened and the low-floor section remained unchanged. The bus seating capacity is 85 passengers, out of which 19 seats, with other 6 folding seats. A brand new six-terminal electric motor, TAM 1049 Pragoimex, of the nominal output of 120 kW, was developed to drive this electric bus.

The traction battery is composed of 180 cells, 300 Ah, 1.700 kg. Each cell is monitored independently as for overcharging, undercharging, and temperature. In case of a temperature increase, the whole box is cooled. By contrast, for extreme frosts, there is an option to install a heating system into the battery box [48].

The traction battery may be charged in 8 hours by means of "slow" charging (32A), including balancing of cells (necessary once a day). While charging, it is possible to set preheating of the bus interior so that it can be heated at the moment of the departure. Moreover, it is possible to charge by means of "fast-charging" of up to 250A - the charging time is reduced proportionally to the current to about 1 hour [49].

Figure 20 SOR BN 12 electric bus

Skoda Perun electric bus: In 2013, Skoda has begun developments of two basic types of battery-powered electric bus Skoda Perun (Pure Electric RUNner), Figure 21. Both are twelve-meter low-floor buses with a power output of 160kW and battery of 221 kWh, whose design makes use of the latest technological trends and modern solutions. The first type of Skoda electric bus will have a range of about 150 kilometers and its charging will take place at the depot during the night, when the vehicle is not in operation. The production of the second type of bus, with an average range of about 30 km, is planned for 2014. The vehicle will be designed so that the battery can be recharged quickly - in a matter of minutes - at the terminals and bus stops [50].

The battery is charged by a roof-mounted pantograph charging station during the daytime and by a portable charger with COMBO CCS standard during the night time. The vehicle batteries can be recharged up to 100 % of their capacity in 50 minutes during the day, while the night-time charging up, inclusive of balancing of the cells, takes several hours. The vehicle has a capacity of more than 80 passengers and its maximum speed is 70 km/h [50].

Figure 21 Skoda Perun electric bus

VDL Citea Electric bus: The first electric bus of VDL Bus & Coach, the VDL Citea Electric, is introduced during the UITP Mobility & City Transport in Geneva (May 2013). This is a fully electric bus is the Citea SLF Low Floor with a length of 12 meters, Figure 22 [51]. The ability to choose from various electric drives and battery packages ensures that the most ideal and optimal combination can be selected for every deployment area, without consequences for accessibility, interior layout, or comfort.

When selecting options for the Citea Electric, one can choose from various electric drive systems: a large battery charged via a plug-in connection; a relatively small battery charged with various quick-charging methods, such as induction, trolley, or plug-in; and a medium battery charged with a diesel generator (Range-extender vehicle (REV)).

In late May 2014, the first Finnish VDL Citea Electric will be delivered to Veolia Transport Finland. The bus is equipped with Ziehl-Abegg wheel hub motors. These motors are located in the rear wheels of the Citea. A Valence battery pack is installed as energy storage medium [52].

Figure 22 VDL Citea Electric bus

BYD electric bus: In 2012, Movia, the largest public transport company in Denmark, and BYD Europe B.V., have announced the introduction of the first full-size pure electric city buses to enter service in Copenhagen, Figure 23, which has set itself an ambitious goal, in terms of sustainable mobility, to become the world's first zero-emission capital by 2025 [53].

Figure 23 BYD electric bus in Copenhagen

The two electric buses provided by BYD will operate on trial service on different passenger-carrying routes with different loads in Copenhagen for two years. The project is being carried out in cooperation with the Municipality of Copenhagen, DONG Energy, City-Trafik, and Arriva. The company objective is that by 2015, 85% of the municipality's own vehicles should be electric, hydrogen or hybrid powered [41].

In 2013, London has begun trials of two BYD pure electric buses operating on two central London routes, the first in the UK capital to be serviced by fully electric, emissions free buses, Figure 24, [41].

Six further electric buses are set to be introduced into the TfL fleet in early 2014. In addition to the electric buses, London will be running 1.700 hybrid buses by 2016 - covering a fifth of its fleet [54].

Figure 24 BYD electric bus in London

The trial in Ankara is only the latest in a series of European trials of the BYD electric city bus. More than 25 major cities have evaluated the bus in revenue service. Results have been impressive across many different duty cycles showing that the bus is capable of up to 24-hour route-service on a single battery charge (usually completed in 3-5 hours off-peak), unlike the competition that requires in route charging every couple of hours. When compared to a conventional diesel or natural gas fueled buses, the BYD electric bus has demonstrated a dramatic reduction (from 80 - 90%) in operating and maintenance costs [55].

At the beginning of April 2014 the city of Belgrade took a BYD electric bus E-12, Figure 25, to its streets to test whether it lived up to its 'silent and efficient reputation'. This is the first time the model has been tested in the region and this initial trial - run proved it to be a real contender [56].

Figure 25 BYD electric bus in Belgrade

Over a three day period, the E-12 was tested on bus-routes No.26 and No.41, which run through the city of Belgrade, in addition to a suburban route. City Line No26 is known to have the most difficult exploitation conditions in Belgrade (low speeds, multiple traffic lights, large passenger – flow, and steep topography).

On the last Bus Committee, which was held in Copenhagen on 22 May 2014, under the patronage of UITP, some data on the BYD buses involved in several European trial tests were presented [57]. The results are summarized in Table 3.

Table 3 Some results on trials of BYD electric buses

No.	City	Units	Period	Average Range (km)	Energy (kWh/km)
1	LONDON[1)]	2	January 2014	257	1,07
2	MILAN	2	March 2014	237	1,16
3	COPENHAGEN[2)]	2	January 2014	197	1,40
4	BARCELONA	1	November 2013	190	1,44
5	BELGRADE	1	April 2014	212	1,30

[1)] Potential saving of up to 75% in fuel cost, 50% reduction in CO_2 per passenger journey;
[2)] Noise problem – Insulation needed to reduce from 74 to 69 dB.

ZeEUS project: On January 23 the Zero Emission Urban Bus System (ZeEUS) project has been launched in Brussels [58]. The project, with a 42-month duration, involving 40 European partners coordinated by the UITP will focus on showing the economic, operational, environmental, and social viability of electric buses as a real alternative for mobility in urban environments based on various innovative technological solutions in eight European cities: Barcelona, London, Glasgow, Stockholm, Münster, Rome, Pilsen, Bonn, and one city in Italy [59].

Leading manufacturers in bus electrification (ALEXANDER DENNIS; IRIZAR; SKODA; SOLARIS; VDL; VOLVO), Figure 26, will participate with plug-in hybrids or full electric buses using different charging infrastructure and strategies [30].

Figure 26 Leading manufacturers will participate in ZeEUS project

ELECTRIC BUS COSTS, EMISSIONS, AND ENERGY EFFICIENCY

Electric bus costs and tailpipe emissions

Battery electric buses are still not widely commercially available so precise figures for procurement cannot be given. However, there are literature data on prices of these buses. These data are of informative character and they are usually presented concurrently with prices of other busses having different drive trains.

E.g., Table 4 presents data on prices of buses 12m long [61], whereas Table 5 contains data on prices of buses 18m long (articulated buses) [20]. The source data on articulated buses in British pounds have been converted to Euros (1£ = 1.26 €). At the same time, the tables contain information concerning maturity of each technology for its application to the buses, based on the level of its present day development.

Table 4 Capital cost of 12m buses

Bus Type (12m length)	**Capital cost (€)**	**Technology maturity**
Diesel EV	225.000	Mature
Diesel Euro VI	240.000	Mature
Diesel-Hybrid EEV	300.000	Mature
Battery bus (opportunity charging)	**500.000**	**Mature**
Battery bus (overnight charging)	**400.000**	**Mature**

Table 5 *Capital cost of 18m buses*

Bus Type (18m length)	**Capital cost (£)**	**Capital cost (€)**	**Technology maturity**
Diesel	280.000	350.500	Mature

Diesel hybrid	420.000	525.800	Mature
Plug-in Hybrid	470.000	588.400	Incremental development
Battery electric	**500.000-550.000**	**625.900- 688.500**	**No 18m vehicle**
Fuel Cell Hybrid	600.000/	751.100	Unproven

Some reports [2] estimate cost of €5000 more than that of traditional diesel buses for maintenance plus around €100,000 extra for infrastructure. The City of Vila Nova de Gaia, for example, paid around €500,000 to purchase the Cobus 2500EL.

Prices of battery buses are influenced not only by the high cost of the batteries, but also by the need for their replacement during the lifetime of the bus. The batteries may need to be replaced at some point, probably after 8-12 years of use. Costs and risks related to batteries could be spread and/or minimized by leasing the batteries separately. Although initial investments will be high, BEVs provide the benefit of savings in fuel costs and potentially less maintenance requirements, as there are fewer moving parts [2].

E.g. the current cost of a complete replacement battery pack for the Optare Versa EV battery electric bus is £56,000 (€70,560); it is therefore considered that the additional cost of a larger battery for plug-in hybrid will be no more than £15,000 to £20,000 (€ 18,900 to € 25,200) [20].

Full electric buses produce no tailpipe emission, which means no local pollutants. Embedded emissions including carbon, nitrogen and sulphur oxides, depend on the proportion and type of fossil fuels used to generate electricity for the national grid [2].

Emissions savings from battery electric buses are dependent on how the electricity is generated. The grid mix across Europe varies and the emissions savings will be almost 100% if renewable sources of electricity are used. It has been estimated that even with CO2 eq intensive electricity generation the savings will be at least 30% [2].

Full electric buses are less flexible as they will be designed to run on a specific route according to recharging regime. With some systems, delays on busy lines could cause problems due to the charging regime. Recharging could be an issue for smaller fleets or longer bus lines, but there are many other parameters that may influence this. Battery electric buses are suitable for operating in urban areas with stop/start operation [2].

LCA (LIFE CYCLE ANALYSIS) FOR DIFFERENT BUS TECHNOLOGIES

The implementation of alternative technologies in the transport sector is aimed at increasing the efficiency of the vehicle itself but also the vehicle environmental impact. One important tool to evaluate a vehicle utilization impact, including the energy used, is the life cycle analysis (LCA) methodology.

In the literature there are data on concurrent emissions of buses driven by different alternative fuels and drive trains obtained on the basis of numerous studies. One such study, the results are presented in [20], has been carried out in 2013 includes data on emissions of CO2 of buses including battery electric buses.

The study [20] considers CO2 benefits in terms of both well-to-wheel and tank-to-wheel emissions.

- The well-to-wheel (WTW) CO2 emissions of a particular activity captures the CO2 emitted during fuel/electricity production, distribution, and vehicle use;

• Tank-to-wheel (TTW), or tailpipe, CO2 emissions refer to CO2 emissions directly from the vehicle as a result of combustion of fuel.

The report includes a comparison of potential WTW and TTW CO2 emissions relative to the diesel bus baseline for all of the drive train technologies and alternative fuels relevant to the buses under consideration. This is summarized in Figure 27.

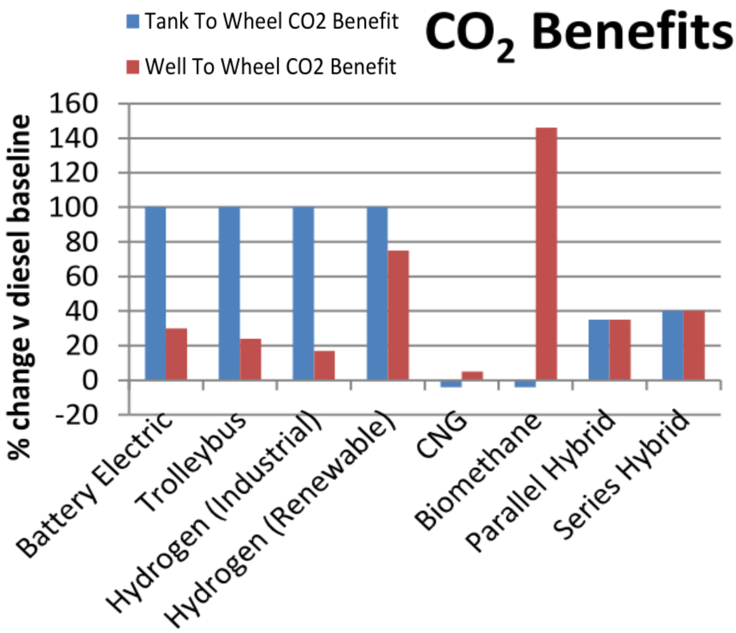


Figure 27 Comparison of alternative fuels vs. diesel baseline

The key points from this comparison are [20]:

- Battery electric, trolleybus, and fuel cell buses can deliver a 100% reduction in TTW CO2 relative to the diesel baseline, but WTW benefits vary significantly with the fuel type and energy pathway.
- The potential WTW CO2 benefits for the battery electric and trolleybus depend on electricity production methods. The reductions of 24% for trolleybus and 30% for battery electric are based on the UK grid mix (164 g CO2 eq/MJ).
- The higher potential reduction in WTW CO2 for battery electric relative to trolleybus is not explained, but is presumed to derive from assumed higher energy efficiency for the battery electric vehicle.
- The WTW CO2 benefits for a hydrogen powered fuel cell bus are lower than the electrically powered buses unless the hydrogen fuel is formed through the electrolysis of water powered by renewable electricity.
- The use of fossil CNG offers only marginal reductions in WTW CO2 emissions relative to a diesel bus and may generate an increase in TTW CO2 emissions.
- The use of biomethane has the greatest potential to deliver a reduction in WTW CO2 emissions relative to diesel bus. The 146% reduction assumes the use of biomethane produced by anaerobic digestion in a dedicated plant, using animal/agricultural waste as a feedstock.

- The potential CO2 benefits of hybrid buses are derived from a reduction in diesel fuel consumption and thus the WTW and TTW reductions are the same?
- Series hybrid technology is considered to offer greater potential for regenerative braking than parallel hybrid technology.

Energy Efficiency of different buses

Table 6 presents the results of the desk research undertaken into the relative energy conversion efficiency of different buses. In order to present data for all vehicles, the figures presented come from a range of sources and thus may not represent directly comparable vehicles or operating conditions [20].

The energy consumption of vehicle heating, ventilation and air conditioning (HVAC) systems can represent a significant proportion of the total vehicle energy consumption and thus data for vehicles operating in warm or cold climates will not be comparable with that for vehicles operating in more temperate conditions requiring less use of HVAC systems.

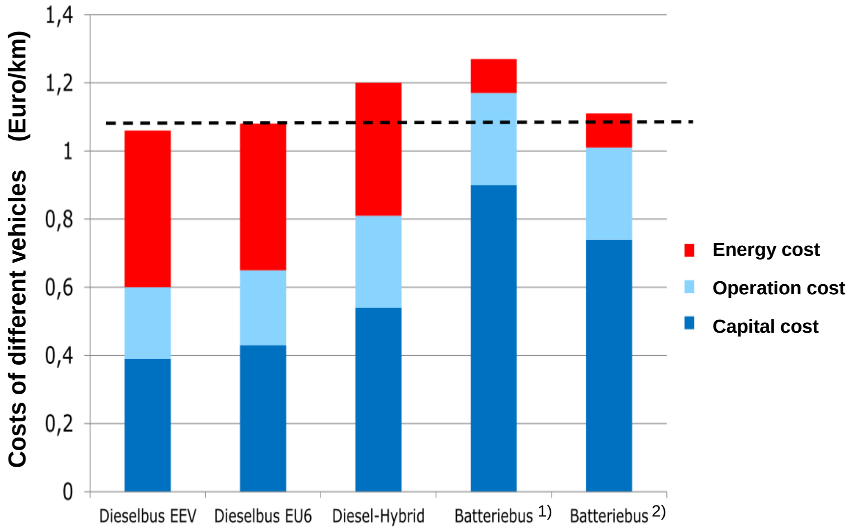
For comparison purposes data have been presented in a common unit of kWh per 100km distance travelled. Table 6 compares the energy efficiency of 12m rigid buses and 18m articulated buses. Battery electric buses are significantly more energy efficient than the hybrid electric buses, which are in turn almost twice as efficient as the buses powered by internal combustion engines. CNG buses are the least energy efficient of all the vehicles and less efficient than a conventional diesel bus which is included for comparison.

Table 6 Energy Efficiency Comparison for 12m and 18 m buses

Bus	**Energy Efficiency (kWh/100km)**	
	12 m bus	**18 m bus**
Fuel Cell Hybrid	269	504
Diesel Hybrid	283-380	523
Plug-in Hybrid	260	No data
Battery Electric	**119-140**	**No data**
Compressed Natural Gas (CNG)	655	735
Diesel	500	624

The general picture of 18m buses is similar to that for the 12m buses, battery electric buses being the most efficient, followed by the hybrids with the fuel cell hybrid performing marginally better than the diesel hybrid, and CNG again being the least energy efficient compared to the electric buses and less efficient than a conventional diesel articulated bus. There are no data for the plug-in hybrid and battery electric buses in this table as there is no production 18m articulated buses. In summary, the best performing buses in terms of energy efficiency are the battery electric powered buses.

Certain analyses of bus costs per 1km of the road, which have taken into account their capital cost, operation cost, and energy cost, are shown in Fig. 28 [60]. The major noticeable differences between compared buses are in the capital cost and energy cost. Despite high capital costs of battery electric buses, their total costs per unit of covered road are acceptable compared to other buses. The current expansion of their development is increasingly motivated by their good energy and ecologic characteristics compared to other drive train technologies.



1) **The batteries are recharged overnight, including replacement of batteries**

2) **The batteries are recharged overnight**

Figure 28 Costs of buses with different technologies

CONCLUSIONS

A significant part in the future reduction of consumption of fossil fuels and of the corresponding reduction of emissions of harmful gases will be played by the electric propulsion systems and alternative fuels.

Electrification of buses is considered as major strategy for reducing dependence on oil and greenhouse gases, and meeting the aggressive fuel economy standards. However, there are many barriers to electric buses market expansion. The limitations that relate to battery technology include: limited electric drive range and long recharge time.

Energy storage systems, usually batteries, are essential for electric drive buses. Batteries must have a high energy-storage capacity per unit weight and per unit cost. Because the battery is the most expensive component in most electric drive systems, reducing the cost of the battery is crucial to producing affordable electric drive buses.

Despite the significant number of barriers, some factors could facilitate the transition of EVs to the mass market. These factors include the effect of zero tailpipe emissions, incentives and low running costs, as well as innovations in the supporting infrastructure.

Current development of the battery technologies and other electric drive system components resulted in some solutions of buses that are in use at regular exploitation.

The analysed state of the development and market of full electric buses, including presentation of the current projects, trials, and demonstrations, show that their growth has been intensified over the past several years and that, irrespective of the existing barriers, their greater commercialization should be expected in the immediate future.

The presented solutions of full electric buses are aimed at confirming the application of electrical energy as an alternative fuel of vehicles in general, specifically of buses, in order to stimulate operators to innovate the exiting fleets by the solutions of this type.

In the future, electric buses will continue further development through the improvement of battery technology, increasing their life and capacity, optimizing electric drive components, and improve the system for recharging the battery.

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REFERENCES

[1] João P. Ribau, Carla M. Silva, João M.C. Sousa: Efficiency, cost and life cycle CO2 optimization of fuel cell hybrid and plug-in hybrid urban buses, Applied Energy 129 (2014) 320–335.

[2] Clean Buses – Experiences with Fuel and Technology Options, Clean fleets, February 2014, http://www.clean-fleets.eu/fileadmin/files/Clean_Buses_ _Experiences_ with_Fuel_and_Technology_Options.pdf

[3] Energy Carriers for Powertrains - for a clean and efficient mobility - ERTRAC Working Group: Energy and Environment, NGVA Europe, Final for publication, 2014.

[4] http://www.ertrac.org/uploads/documentsearch/id32/2014-03-12_Roadmap_Energy_Carriers_for_Powertrains.pdf

[5] Towards low/zero-carbon urban mobility in Europe, A UITP position paper, 2011,

[6] http://www.uitp.org/sites/default/files/cck-focus-papers-files/FPNov2011.pdf

[7] Hybrid electric bus, 2010, http://azhar-paperpresentation.blogspot.com/2010/04/hybrid-electric-bus.html

[8] James S. Cannon, NATURAL GAS: AN ESSENTIAL BRIDGE TO HYDROGEN FUEL CELL VEHICLES, VNG. Co, 2012, http://www.energy.ca.gov/contracts/notices/2012-07-10_workshop/comments/2012-09-18_VNG_Comments_TN-67175.pdf

[9] ROAD TRANSPORT: THE COST OF RENEWABLE SOLUTIONS; IRENA, International Renewable Energy Agency, IRENA REPORT, Preliminary Findings, 2013.

[10] Robert Jesse Alley, VTool: A Method for Predicting and Understanding the Energy Flow and Losses in Advanced Vehicle Powertrains, Master of Science in Mechanical Engineering, Blacksburg, VA, 2012,

[11] http://scholar.lib.vt.edu/theses/available/etd-06222012-195225/unrestricted/Alley_RJ_T_2012_f2.pdf

[12] Hybrid and Battery Electric Vehicles, HEV Levels, Center for Advanced Automotive Technology (CAAT),http://autocaat.org/Technologies/Hybrid_and_Battery_Electric_Vehicles/HEV_Levels/

[13] Zlatomir Živanović, Zoran Nikolić: The Application of Electric Drive Technologies in City Buses (Book chapter). In: Stevic Z. (ed) NEW GENERATION OF ELECTRIC VEHICLES, InTech, Rijeka 2012, p. 165-203, ISBN 978-953-51-0893-1, http://dx.doi.org/10.5772/51770

[14] Nick Blake, Alternative fuels and Drive trains, Mercedes-Benz, 28 June 2011,

[15] http://www.apse-archive.org.uk/presentations/2011/05/fleet-waste-grounds-seminar/Nick%20Blake%20-%20Session%203.pdf

[16] Michael Valentine-Urbschat, Dr.Wolfgang Bernhart, Powertrain 2020 –The Future Drives Electric, Study, Roland Berger Strategy Consultants, 09/2009,

[17] http://www.rolandberger.at/media/pdf/Roland_Berger_Powertrain_2020_20110215.pdf

[18] Vehicle Technologies Office: Electrical Machines, U.S. Department of Energy's http://energy.gov/eere/vehicles/vehicle-technologies-office-electrical-machines

[19] X. D. Xue, K. W. E. Cheng, and N. C. Cheung, Selection of Electric Motor Drivesfor Electric Vehicles, Australasian Universities Power Engineering Conference (AUPEC'08) Paper P-170, 2008

[20] Yukio Wada, Buses, Society of Automotive Engineers of Japan, 2013.

[21] http://www.jsae.or.jp/e07pub/yearbook_e/docu/07_buses.pdf

[22] F. G. Rieck, NEMS: Electric buses at Rotterdam, Clean fleets, Bremen, 12 December 2014. http://www.clean-fleets.eu/fileadmin/files/e-Busz_Rotterdam_final_Ecomobiel-Bremen_-_Rieck_small_.pdf

[23] Vehicle Technologies Office: Power Electronics, U.S. Department of Energy's http://energy.gov/eere/vehicles/vehicle-technologies-office-power-electronics

[24] E-mobility Roadmap for the EU battery industry, The European Association for Advanced Rechargeable Batteries, 2013

[25] Gopalakrishnan Duleep (ICF), Huib van Essen (CE Delft), Bettina Kampman (CE Delft),

[26] Max Grünig (Ecologic), Impacts of Electric Vehicles - Deliverable 2, Assessment of electric vehicle and battery technology, Delft, CE Delft, April 2011

[27] New Generation Transport, Sub Mode Options Investigation, Mott MacDonald, United Kingdom, 2014.

[28] Tony Markel, Plug-in Electric Vehicle Infrastructure: A Foundation for Electrified Transportation,

[29] MIT Energy Initiative Plug-in Electric Vehicle Infrastructure: A Foundation Transportation Electrification Symposium for Electrified Transportation Cambridge, Massachusetts. April 8, 2010. https://mitei.mit.edu/system/files/trans-infrastructure-markel.pdf

[30] Ultrafast Electric Bus Charging, Revolution-Green, Break Through Energy News http://revolution-green.com/ultrafast-electric-bus-charging/

[31] 12-meter Electric Bus in Regular Service with Inductive Opportunity Charging, Press Release, Conductix-Wampfler GmbH, Weil am Rhein, http://www.conductix.com/sites/default/files/downloads/PR_12-10-01_12-meter_Electric_Bus_in_Regular_Service_with_Inductive_Opportunity_Charging.pdf

[32] OPBRID BŮSBAAR DEMONSTRATES ULTRA-FAST CHARGING AT 625 AMPS, Busworld, Kortrijk, 2014, http://www.busworld.org/articles/detail/2085

[33] [25] Bombardier to Trial Wireless Electric Bus Charging, ElectricCarsReport, 2013, http://electriccarsreport.com/2013/02/bombardier-to-trial-wireless-electric-bus-charging/

[34] Reference Guide on Trolleybus- Tram Network Use, Output 3.3.6: TROLLEY project, Study for Leipziger Verkehrsbetriebe GmbH (LVB), Leipzig, 2013, http://www.trolley-

project.eu/fileadmin/user_upload/download/TROLLEY_PR6_Core_Output_Reference_Guide_Trolleybus_Tram_PP05_LVB.pdf

[35] Blagojce Krivevski, ABB Technology Charges Electric Bus in 15 Seconds, ElectricCarsReport, 2013, http://electriccarsreport.com/2013/06/abb-technology-charges-electric-bus-in-15-seconds-video/

[36] Electric Drive Bus Sales to Growth with CAGR of 26% from 2012 to 2018, ElectricCarsReport, 2012, http://electriccarsreport.com/2012/08/electric-drive-bus-sales-to-growth-with-cagr-of-26-from-2012-to-2018/

[37] Peter Feuilherade, Electric urban transport, A revival after a long decline, E-tech, IEC, 2013, http://www.iec.ch/etech/2013/etech_0413/tech-2.htm

[38] Umberto Guida, Zero Emission Urban Bus Systems (ZeEUS), Project Description, AMTU Event – 8th April 2014, http://www.amtu.cat/portal/infoweb/jornades/10aJornada/10J-02-01-FG.pdf

[39] BYD, 2014 BYD EUROPE, http://www.bydeurope.com/vehicles/ebus/index.php

[40] Lanny Davis, BYD Announces Agreement with Long Beach Transit to Mutually Terminate Electric Bus Contract, Business Wire, March 27, 2014, http://www.businesswire.com/news/home/20140327005966/en/BYD-Announces-Agreement-Long-Beach-Transit-Mutually

[41] BYD electric buses certified for European market , Ecoseed.org , 2013, http://www.ecoseed.org/business/europe/15976-byd-electric-buses-certified-for-european-market

[42] BYD, Green City Solution, 2014 BYD EUROPE, http://www.bydeurope.com/innovations/gcs/index.php

[43] TEST DRIVE: OPTARE VERSA EV, March 2013, http://www.optare.com/images/pdf/routeONE%20Versa%20EV%20article.pdf

[44] E-Traction - Company Profile, E-Traction Europe B.V, http://www.e-traction.eu/about-e-traction/our-company (accessed 12 June 2012).

[45] Electric buses in Rotterdam, http://energyexplorers.nl/en/case/now/electric-buses-rotterdam

[46] Lode Messemaker, RET update, Hybrid User Forum, 2013, http://wp1173759.server-he.de/www/wordpress/wp-content/uploads/2013/06/RET-Rotterdam-update.pdf

[47] F.G.Rieck: NEMS: Electric Busses at Roterdam, Bremen, 12 December 2014 http://www.clean-fleets.eu/fileadmin/files/e-Busz_Rotterdam_final_Ecomobiel-Bremen_-_Rieck_small_.pdf

[48] Paulo Santos, CaetanoBus – COBUS 2500 EL, 2011, http://itsonlybuses.blogspot.com/2011/12/caetanobus-cobus-2500-el.html#!/2011/12/caetanobus-cobus-2500-el.html

[49] Bus services in Swedish city of Umeå rely on electrical mobility, ZIEHL-ABEGG, Press information, 2014, http://www.ziehl-abegg.com/ww/press-release-279.html

[50] Electric power in cold climate - a hot development, HYBRICON, http://www.umea.se/mer/tema/miljo/technicalvisitsstart/inenglish/members/hybricon.4.503585431324ae27add8000822.html

[51] Solaris Urbino electric - the customer’s choice, Transportweekly, 17.04.2014, http://www.transportweekly.com/pages/en/news/articles/108034/

[52] Environmentally Friendly Electric Buses in Vienna, SIEMENS, Reference Number: IN 2013.03.4e, http://www.siemens.com/innovation/en/news/2013/e_inno_1308_2.htm

[53] Peter Wiesinger, Innovative Electric Buses in Vienna, Clean Fleets case study, 2013, http://www.clean-fleets.eu/fileadmin/files/Clean_Fleets_case_study__Vienna_-_Final.pdf

[54] EMOSS e-Bus 12 meter, EMOSS B.V. The Netherlands, http://www.emoss.biz/nl/elektrische-bus/emoss-e-bus-12-meter

[55] First 12 meter electric bus with wireless inductive charging, EMOSS B.V. The Netherlands, 2012, http://www.emoss.biz/nl/nieuws-nl/first-12-meter-electric-bus-with-wireless-inductive-charging

[56] Electric buses, SOR Libchavy Ltd, http://www.sor.cz/site/electric-bus-sor-ebn-105

[57] Oskar Exner, Prague tries out new electric bus – this time SOR, 13. Praha EU, February 2014, http://www.praha.eu/jnp/en/transport/getting_around/prague_tries_out_new_electric_bus_this.html

[58] Škoda Perun, ŠKODA TRANSPORTATION a.s., http://www.skoda.cz/en/products/electric-and-hybrid-buses/batterybus-skoda-26bb-he/

[59] Citea Low Floor Electric, VDL Bus & Coach bv, 2014, http://www.vdlbuscoach.com/Producten/Openbaar-vervoer/Citea/Citea-range/Citea-Low-Floor-Electric.aspx

[60] VDL Citea Electric for Veolia Transport Finland, VDL Bus & Coach bv, 2014, http://www.vdlbuscoach.com/News/News-Library/2014/VDL-Citea-Electric-voor-Veolia-Transport-Finland.aspx?lang=sr-Latn-CS

[61] Copenhagen is introducing the first full-size pure electric buses from, BYD Company Limited, 2012, http://www.byd.com/news/news-114.html

[62] Sami Grover, London gets its first electric-only buses, Transportation / Public Transportation, 2013,

[63] http://www.treehugger.com/public-transportation/london-gets-its-first-electric-only-buses.html

[64] First Pure-Electric Bus Pilots in Turkish Market, BYD Company Limited, 2014, http://www.byd.com/news/news-226.html

[65] Electric bus BYD E-12 put to the test in Belgrade, Clean fleets, 2 May 2014, http://www.clean-fleets.eu/news/news-archive/may-2014/

[66] Francisco González: ELECTRIC BUS BYD, European Trial Tests, UITP, 96 th Bus Committee, 22 May 2014, COPENHAGEN

[67] The ZEUS project for greener urban transport, Exhibition News, 2014, http://www.bustruckexpo.com/spa/newsbrwose.asp?id=8009

[68] Ana Eceiza, Irizar participates in the ZeEUS project to implement electric busesin the main European cities, PRESS RELEASE, Irizar S. Coop.2014,

[69] http://www.irizar.com/en/wp-content/uploads/sites/9/2014/01/NP_ZeEUS_en.pdf

[70] Ralph Pütz: Auf dem Weg zum Elektrobus–Analyse der Lebenszykluskosten verschiedener Busantriebskonzepte, Hochschule Landshut – Institut für Nutzfahrzeugtechnik, Clean Fleets – Stadtbusse in der Beschaffung, Bremen, 11. Dezember 2013, http://www.clean-fleets.eu/fileadmin/files/P%C3%BCtz_Clean_Fleets_11_12_2013.pdf