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TECHVIEW REPORT ELECTRIC BUSES

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TECHVIEW REPORT

Electric Buses

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TECHVIEW REPORT

Electric Buses

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Abbreviations

AISC	Automotive Industry Standards Committee
BRTS	Bus rapid transit-system
BSES	Bharat Stage Emission Standards
CKD	Completely knocked down
CNG	Compressed natural gas
EES	Electrical energy storage
EV	Electric vehicle
GHG	Greenhouse gas
HEB	Hybrid electric bus
ICE	Internal combustion engine
IEC	International Electrotechnical Commission
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KERS	Kinetic energy recovery-system
LFP	Lithium-ferrous-phosphate
Li-ion	Lithium-ion
Li-s	Lithium-sulfur
NiCd	Nickel-cadmium
NiMH	Nickel-metal hydride
NMC	Nickel-manganese-cobalt
OEM	Original equipment manufacturer
PEB	Pure electric bus
R&D	Research & development
STU	State Transport Undertaking
UC	Ultracapacitors
UNECE	United Nations Economic Commission for Europe

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1 Overview and taxonomy

With a growing number of people living in urban areas, municipal and government officials face a number of challenges like increasing noise emission as well as air pollution. Especially cities in developing economies like India have to consider new means of public transport in order to tackle these pressing issues.

Due to the ongoing development in the field of electric mobility, buses have the ability to benefit from the rapid development in propulsion technology, electrical energy storage-systems (EES) and the charging infrastructure in order to make cities cleaner and more livable.

Even though the development of hybrid electric buses (HEB) and pure electric buses (PEB) is at a stage of infancy, a large number of bus producers have made a commitment in finding suitable substitutes for diesel technology.

The following section focuses on the technological aspects of alternative bus concepts. The taxonomy (See fig. 1) shows the affected technological fields that one has to consider when examining the general development of buses. After that, the analysis examines the already mentioned key technologies that determine the development of alternative buses.

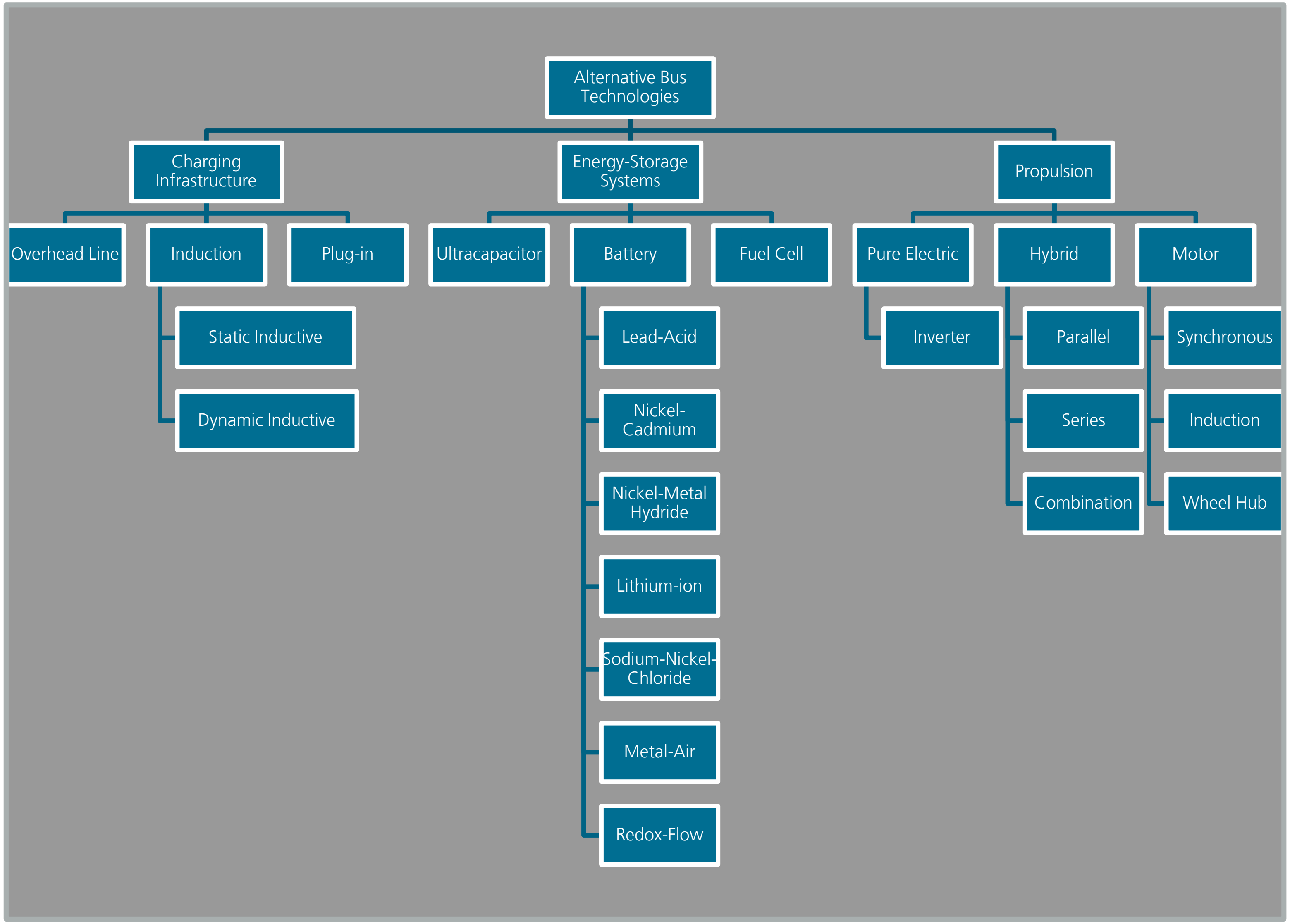


Fig. 1: Taxonomy of alternative bus technologies

Source: Fraunhofer MOEZ

1.1 Propulsion systems

There are mainly two propulsion systems that make use of electric energy - pure electric and hybrid systems.

The electric drive is the connection between the EES-system and the driveline. It includes all components that are necessary to transform the stored electro-chemical energy of the EES-system to mechanical energy. Generally speaking the inverter transforms the direct current from the battery to alternating current used by the driveline. Additionally, the electric drive allows the regeneration of energy. In this process the mechanical energy from breaking is transformed back to electrochemical energy, which in turn can be stored in the EES-system. This energy recycling is generally realized by kinetic energy recovery-systems (KERS). It is especially useful for buses in cities due to stop and go traffic and the regular service at bus stops.[1]

Hybrid drives combine the electric engine with a conventional internal combustion engine (ICE). The vehicle is still primarily running on fuel with an electric powertrain as an additional drive in order to reduce fuel consumption. The first type of hybrid propulsion system is the parallel hybrid, which connects both engines to the power transmission. In this case, the vehicle can be powered by either one of the engines or by both simultaneously. The second type of hybrid drive is the serial hybrid. Thereby the ICE is solely connected to the power converter in order to charge the battery and to propel the electric engine. There is no direct connection to the transmission. The third type is the combination hybrid. It combines both other types of hybrid drives. The ICE is connected to the transmission and helps to recharge the battery as well, which makes its technology more complex.[2]

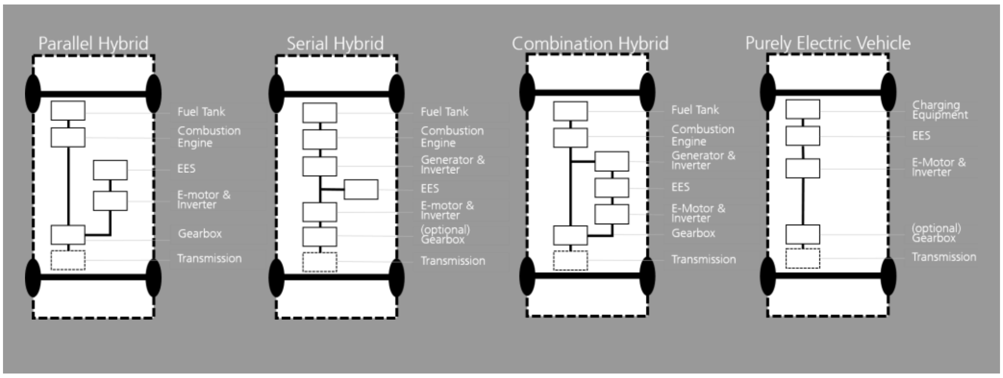


Fig. 2: Overview alternative propulsion systems

Source: Fuel Cells and Hydrogen Joint Undertaking (2014); Shen et al. (2011)

1.2 Electrical energy storage-systems

The feasibility of electric buses depends mainly on the onboard EES-system. Currently, there are three EES-systems available on the market: batteries, ultracapacitors (UC), and fuel cells. They have different technological attributes and economic characteristics. Their commercial viability depends on a number of factors, which tend to work in opposite directions. These factors can be subsumed under safety, durability, costs, environmental sustainability, energy-density, and performance. It is especially necessary to consider all these factors in order to meet demands of public transport. Furthermore,

[1] Kampker 2013
[2] Shen et al. 2011

finding a suitable EES-system is crucial in order for PEB or HEB to become a viable alternative to diesel buses.[3]

1.2.1 Batteries

PEBs and HEBs most commonly use batteries as an EES-system. Batteries are electrically connected galvanic cells. A galvanic cell is a chemical device that consists of two electrodes, an anode and a cathode. Within the electrodes an active material is integrated, which allows the storage of electrical energy. During the charging process the electrolyte transforms electrical energy into chemical energy. Thereby, the anions are transmitted to the anode and the cations to the cathode. The whole process is reversed once the battery discharges.

Lithium-ion (li-ion) batteries have proven to be the most promising EES-system for electric vehicles (EV). Theoretically, li-ion batteries can combine a high specific power (300 Wh/kg), a high energy density (90-140 Wh/kg), and a low self-discharge over time. Additionally, their low weight and endurance of high temperatures make them suitable for the usage in PEBs. Li-ion batteries are able to endure approximately 1,000-1,500 loading cycles. The batteries consist of an oxidized cobalt material on the cathode and a carbon based material on the anode. Lithium salt is used as the electrolyte. However, li-ion batteries are still expensive in production. Also, the electrolyte is highly inflammable and it requires a sufficient battery management system.

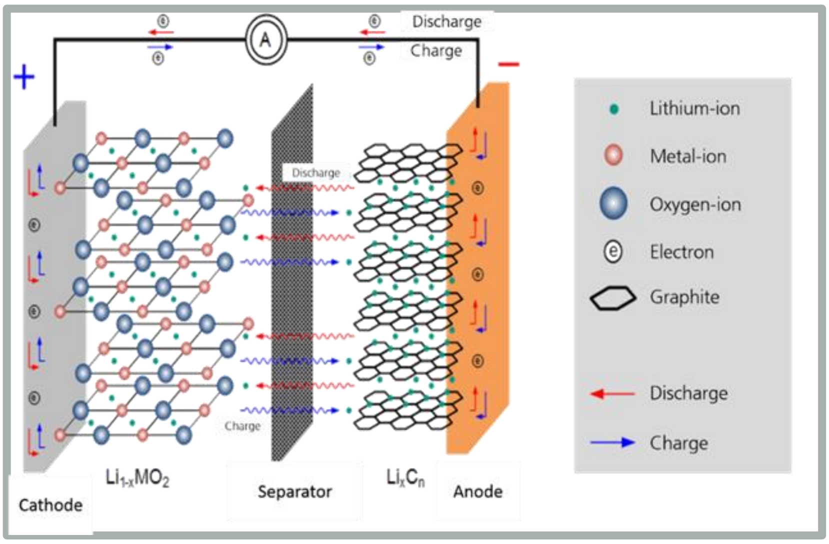


Fig. 3: Li-ion cell

Source: Karlsruhe Institute of Technology

However, other types of batteries have proven to be disadvantageous compared to li-ion batteries. Lead-acid batteries consist of the lead as the negative and lead oxide as the positive active material, as well as diluted sulfuric acid as the electrolyte. It is a mature technology with low manufacturing costs, but very low energy density (20-30 Wh/kg). Nickel-metal hydride (NiMH) batteries are more feasible than lead-acid batteries since they have twice the energy-density (40-55 Wh/kg), are operable at high voltage and have a long life of approximately 2,000 cycles. However, they tend to discharge at high load currents and the battery capacity reduces after 200-300 loading

[3] Deutsches CleanTech Institut 2010

cycles. Compared to li-ion batteries, the battery storage of NiMH batteries is lower and needs more time to charge.[4]

1.2.2 Ultracapacitors

UCs store energy by mechanically separating the negative and the positive charges on two parallel plates, but connects them electrically via an electrolyte. The process allows the physical storage of the charges on the electrodes. If there is voltage applied to the capacitor a Helmholtz double layer is formed at both electrodes. As a result, a layer of anions or cations is deposited on the opposite electrode. Since this process does not contain chemical variations on the electrodes, UC have a longer life cycle than batteries. Furthermore, they have a higher power density than batteries and can be charged and discharged within a shorter period. On the downside, they have a much lower energy density than batteries. They are able to store only 10% of the energy, li-ion batteries can store. UCs are either based on carbon or metal fiber composites, foamed carbon, carbon particulate with a binder, doped conducting polymer films on a carbon cloth or mixed metal-oxide coatings on a metal foil.[5]

1.2.3 Fuel cells

Fuel cells generate electricity by converting a fuel-like hydrogen (anode) with an oxidant (cathode). The anode and cathode are isolated by a membrane (electrolyte), which allows charges like water protons to pass from one side of the cell to the other. The isolated electrons produce energy by moving from the anode to the cathode through an external circuit. In comparison to batteries, fuel cells need a continuous source of fuel and oxygen to sustain the chemical reaction. Hydrogen has the highest energy density available, but hydrocarbons or alcohols are also suitable as fuels. Other oxidants include chlorine and chlorine-dioxide. Fuel cells have a high conversion efficiency of fuel to electrical energy, a low noise emission and almost no greenhouse-gas (GHG) emissions. Nevertheless, they have a low energy density, which makes large fuel tanks necessary. Furthermore, fuel cells have a longer response time than UC or batteries and are still more expensive due to the high cost of components like platinum and palladium.[6]

1.3 Charging infrastructure

The necessary infrastructure and technology to charge the EES-systems in HEBs or PEBs can be categorized in plug-in, inductive and overhead charging. The future success of these charging methods is linked to the development of EES-systems.

Plug-in technology relates to the direct charging of PEBs or HEBs via charging stations, which can either be localized at the bus depot or the end of the bus route. The traditional plug-in charging is standardized in terms of mode (IEC 61851-1) and type of plug (IEC 62196-1) by the International Electrotechnical Commission (IEC). There are four different modes (mode 1-mode 4), which are regulated by the electric current and the level of transferred electricity, whereas mode 3 is the most common and mode 4 the fast-charging method.[7] The advantage of plug-in charging technology is that its expansion can be linked to the expansion of the infrastructure needs of personal EVs. However, in order to be suitable to the needs of public transport, the charging stations

[4] Doetsch et al. 2014; Khaligh et al. 2010; eMobilitätOnline
[5] Fraunhofer 2014; Khaligh et al. 2010
[6] Khaligh et al. 2010
[7] Claude Ricaud et al. 2010

have to be either mode 4 at the end of the bus route or mode 3 when charged overnight. Obviously the latter is intervened with the EES-system, which has to provide a power supply for the whole day. However, the requirements of daily bus routes cannot be managed by current EES-systems.

Apart from the standard charging model using a plug, inductive technology charges the bus wirelessly by creating a magnetic field between two inductive plates, which are embedded in the ground. Thus, PEBs as well as HEBs can be recharged while driving (dynamic inductive charging) or standing (static inductive charging) without a physical connection to the charging facilities. This offers the possibility to charge the bus on its normal route or at designated charging points, which could be a number of stations on its route.[8]

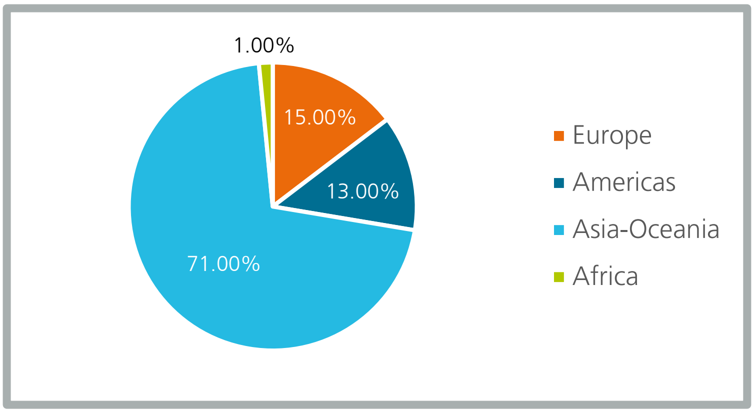
The second alternative is overhead charging. It basically uses the same method that has been applied by trolleybuses and trams since the early 20th century. Thereby trolley poles on top of the bus transfer the current flow either directly to the engine or use it to charge the EES-system. Due to the large necessary infrastructure investments and the aesthetic constrains of visible overhead wires, just a few number of new projects use the constant overhead current flow. Recent approaches include fast-charging-systems that recharge the bus at every third or fourth stop with a short and intense current as well as a longer charge at the end of the route via a retractable pole.[9]

The two latter alternatives are able to bypass the constraints of current EES-systems in order to make PEBs suitable for the daily demands of public transport. The complementary charging possibilities allow the original equipment manufacturers (OEMs) to reduce the amount of EES-systems used. Thereby the reduced weight extends the range of the bus as well as reduces the costs for EES-systems. On the downside, both alternatives make additional infrastructure investment necessary, which is unfavorable for the general acceptance of inductive or overhead charging.

[8] Frost & Sullivan 2014a
[9] ABB 2013

2 European market overview

The European market is one of the leading regions for innovation in the bus sector. However, considering the general output per region, Asia is by far the biggest producer since it compromises over two-third of the worldwide output of buses and coaches. The Asian dominance is mainly led by the increasing output of Chinese OEMs. On the contrast the European continent produces one fourth of the total worldwide output; similar to the level of the Americas (See dia. 1).[10]



Dia. 1: Worldwide bus production by region (2011-2013)

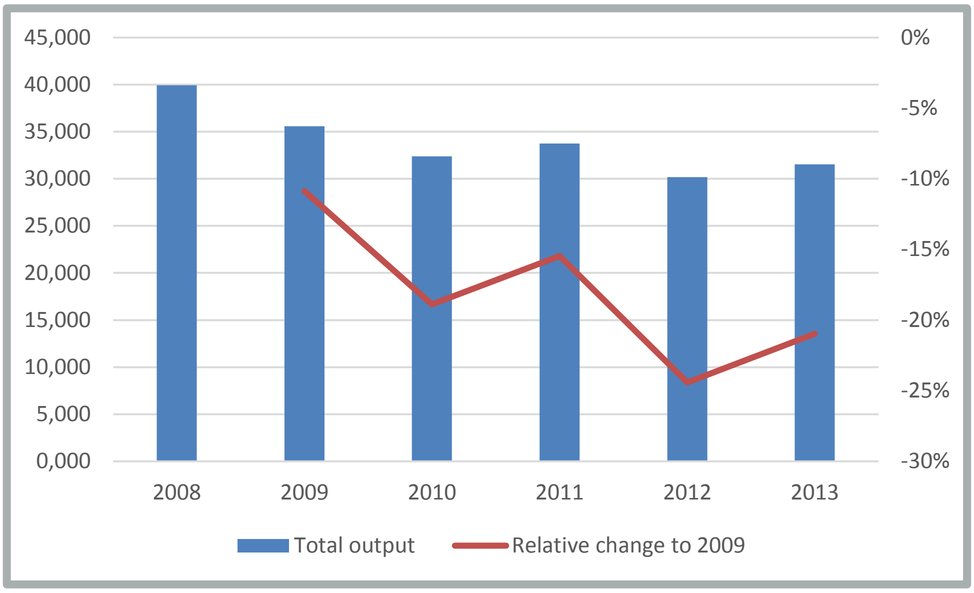
Source: Organisation Internationale des Constructeurs d'Automobiles (OICA)

The following section will give a short overview over the European market for diesel buses as well as HEBs and PEBs. It will take the current market status, value chain, key players and technological development into account.

2.1 Current status of the market

The registration of buses in the EU peaked at 41,997 units in 2008 after it had seen a constant increase in output the prior years. Since then, the EU bus market has suffered from a significant downturn in demand.[11] Due to the Eurozone crisis in the aftermath of the financial crisis in 2009, the European governments set up a number of stimulus packages. They helped limiting the annually decreasing output of OEMs to 10% in 2009 and 18% in 2010, compared to the peak output in 2008. However, after most stimulus packages expired, new registrations of buses and coaches plummeted at 30,181 units in 2012 (-24.40%). Although sales of buses slightly increased in 2013 it is far away from the previous numbers prior before 2009 (See dia. 2).[12]

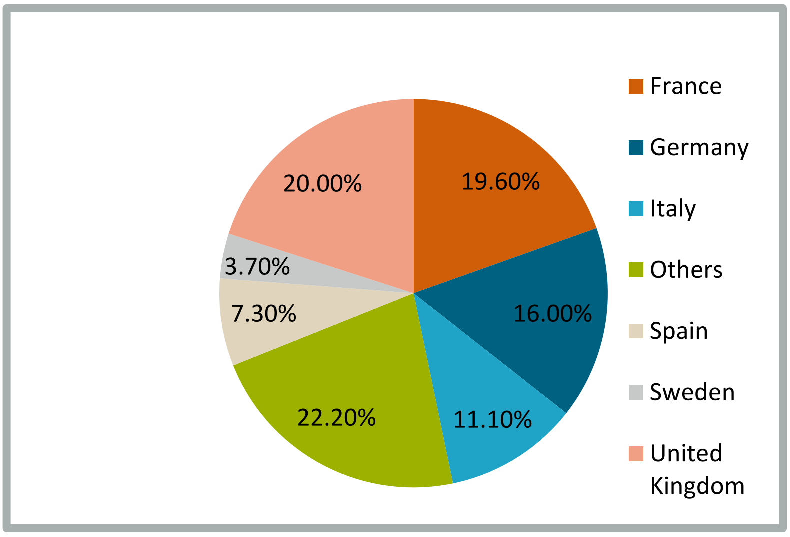
[10] Please note that the OICA defines Europe as the whole European continent including the "Common-wealth of Independent States", the EU and Serbia.
[11] ACEA 2013
[12] Please note that the EAMA defines Europe as the former EU-27 members



Dia. 2: Development of newly registered buses and coaches in the EU-27 (2008-2013)

Source: European Automobile Manufacturer's Association (EAMA)

Two third of the total registrations of buses over 3.5 tons are captured by four of the largest European economies Germany, France, UK, and Italy. Their spending on transport has the biggest impact on bus sales, which could be seen in 2009, when a significant downturn in the Italian registrations had a tremendous impact on the decline in registrations for Europe in total (See dia. 3).



Dia. 3: Mean market share of newly registered buses in the EU-27 (2008-2013)

Source: EAMA

The European bus market (w/o Russia) is saturated and expected to settle down between 23,000 and 27,000 vehicles per year over the long term. Within this spectrum, city buses have a share of approximately 40% and coaches/ interurban buses of approximately 60%. Sales generally fluctuate based on general market cycles.[13] Currently new vehicles are solely acquired to replace vehicles already withdrawn from service. The biggest customers of city bus manufacturers are municipalities and public transport companies. Currently, they tend to extend the duration of their fleet due to

[13] Based on a recent interview with Richard Averbeck who is currently a consultant. He obtained extensive insight in this market due to a long career in the bus sector.

fiscal restrictions.[14] This trend can be expected to continue considering the European Treaty on Stability, Coordination and Governance that laid the groundwork for national laws, which require stricter fiscal restrictions.[15] Nevertheless, new growth impulses and regulations are expected to occur since the latest government programs in Europe target electric mobility.

2.2 Key Players

Europe is home of a variety of manufacturers for high technology appliances since automotive and electronic industries play an important role in Germany, France and other European countries. The upcoming market for HEBs and PEBs is an opportunity for cross-industry cooperations in the development of engines, batteries and OEMs. The following section will give a short overview over the variety of different industry sectors and their main players which are incorporated in the overall value chain of HEBs and PEBs (See fig. 4).[16]

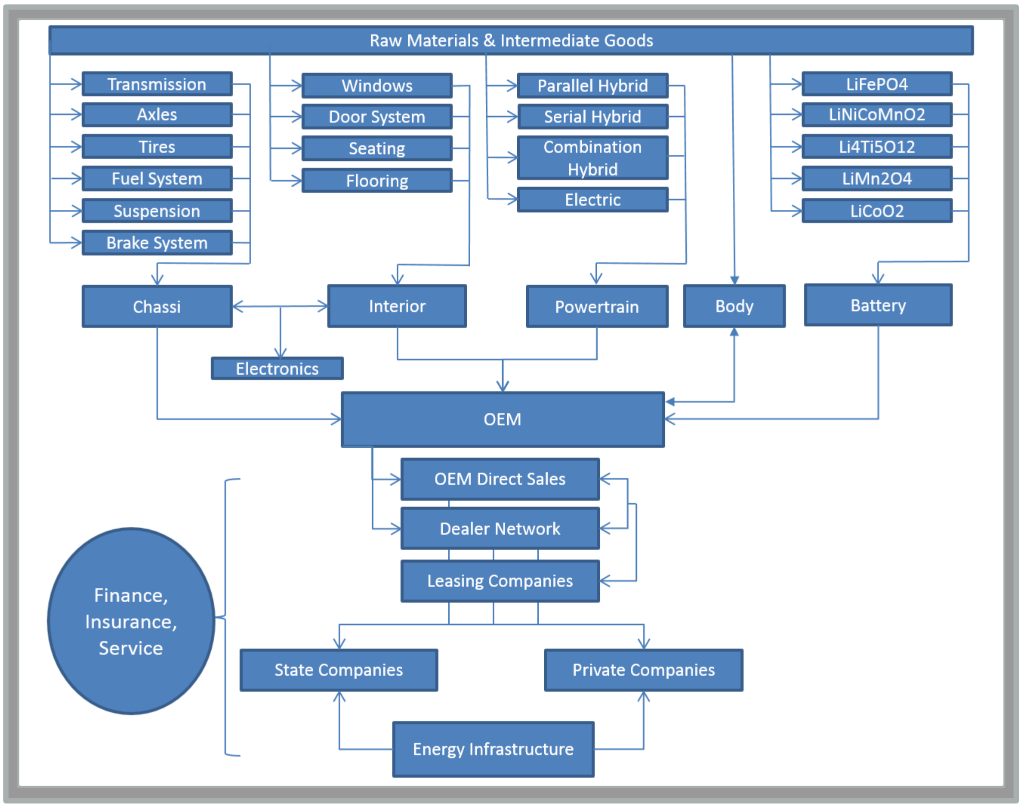


Fig. 4: Value chain of alternative buses

Source: Fraunhofer MOEZ, Frost & Sullivan (2013)

2.2.1 Original equipment manufacturers

There is an extensive number of OEMs for buses and coaches in Europe. They fall in two sectors. The first sector is composed by larger manufacturers (considering total output) like Volvo, Scania, Iveco, MAN and Daimler. These OEMs are all part of multinational corporations, which are usually active in multiple vehicle sectors. The first sector-OEMs have not produced a PEB yet, but offer HEBs and develop other

[14] VDA 2013
[15] European Commission 2012
[16] Please check appendices for an extensive overview of European companies in each technology sector.

alternative propulsion systems based on fuel cells or hydrogen. Due to their extensive financial resources they are able to invest heavily in different new propulsion technologies and to expand to other markets outside of Europe. On the downside, they are usually pressured by the overall company strategy as well as shareholder interest. Thus, they are not able to diversify the propulsion system portfolio as much as the second sector-OEMs do.

OEMs from the second sector are usually family-owned companies that are smaller in size and more specialized concerning their portfolio. They include OEMs like Van Hool, Solaris, Optare and Cobus Industries. In contrast to the first sector, they have been able to develop feasible HEBs as well as PEBs. UK is currently the largest demander of electric buses (78%). Thus, Optare and Wrights Electric from UK added PEBs to their product portfolios.

Concerning the total market share, Daimler as the biggest supplier of diesel buses and coaches in Europe, increased its market share in 2013 to almost one third. It is followed by Iveco (17.2%), Ford (10%), MAN (9.3%) and Volvo (6.5%).[17] Currently, Volvo captures about half of the total market share of hybrid buses in Europe; followed by ADL (17%) and Daimler (10%).[18] However, the European PEB market is still considered at an early stage.

Due to the decreasing demand as well as challenging regulatory standards for buses and coaches in general over the last years, competition has become fiercer and margins smaller. As a result, industry shifted production from high wage central European countries like Germany, France and Italy to countries with comparable low production costs, namely Poland and Turkey.[19]

It is expected that the European bus market in general will consolidate. This is especially unfavorable for OEMs of the second sector, since they do not have the financial backing to outsource their production or withstand a temporary drop in demand.[20]

2.2.2 Battery manufacturers

The market for batteries is mainly determined by the development of alternative fuel technologies in the personal-vehicle sector. At the moment li-ion batteries are the only suitable EES-system for HEBs and PEBs. The main battery manufacturers are located in Asia, especially Japan and Korea. The worldwide li-ion battery market is currently dominated by five companies, which make up for 78.58% of the global supply. The Japanese Panasonic/Sanyo captured the biggest market share with 41.2%, followed by AESC (18.46%), Samsung (7.13%) and LGC (7.11%) from Korea. LiTec (4.68%) was a subsidiary of the Daimler Group and the only noticeable European producer of li-ion batteries with a significant global market share.[21] Nevertheless, Daimler has recently decided that it will terminate its engagement at LiTec and solely focus on its other li-ion battery endeavour Deutsche Accumotive.[22] Other European companies engaging in the battery sector are ABB from Switzerland, Magna Steyr from Austria, Saft from France, Pardo from Italy. Still, these are not the leading companies in this area, but they play a significant role in their home markets. Other European companies that perform research and development (R&D) in this sector are for instance Evonik, BASF or Bosch from Germany.

[17] ACEA 2013
[18] Frost & Sullivan 2013
[19] Newstix 2013; Averbeck 2014
[20] The Market assessment in Chapter 2.2.1 is based on the Solaris case study in chapter 5 of this report.
[21] Springer Professional 2014
[22] Spiegel-Online 2014

2.2.3 Alternative propulsion systems

There are a few automotive suppliers that produce hybrid or solely electric propulsion systems for commercial vehicles like buses and coaches. Due to the engineering tradition in Germany, namely German companies like ZF, Bosch, Heinzmann, Voith and Vossloh Kiepe are engaged in this sector. UK's BAE is one of the few non-German suppliers. Most OEMs buy their propulsions systems from the already mentioned suppliers. Volvo is the only OEM that develops and produces their powertrains in-house (See tab. 1).

	MAN	Daimler	Van Hool	Solaris	ADL	Optare	Wright Bus	Iveco	VDL
BAE					x			x	
Siemens	x					x	x		
Voith			x	x					
Vossloh				x					x
ZF		x	x						x

Tab. 1: Exemplary supplier relationship for hybrid propulsion systems in 2012

Source: Frost & Sullivan (2013)

Due to the increasing restrictions on CO_2 emissions, expected to be imposed by the EU by 2020, most OEMs and as well as their suppliers will switch from diesel propulsion to alternative propulsion systems.[23]

2.2.4 Charging infrastructure

Most PEBs in Europe are still in trial-phase. Only a small number of European OEMs have developed solutions for a charging infrastructure. Most of them try to find a suitable solution for the low range of current batteries. One approach is to develop new charging methods, which make public infrastructure investment necessary.

For instance, the Mitsui-Arup joint venture MBK Arup Sustainable Projects (MASP) tests an inductive system via underground induction coils, positioned at each end of a bus route in Milton Keynes, UK.[24] Furthermore, ABB introduced its flash charging method, in which the bus receives a charge of around fifteen seconds every third or fourth stop via overhead charging. At the terminal, the battery can be fully recharged within three to four minutes.[25] Another approach is to use existing charging infrastructure in cities. A joint venture between Siemens and Rampini Carlo uses the already existing power grid of trams for a partial charge of ten to fifteen minutes at the terminal. During the night the batteries are fully recharged.[26] Assuming that the weight and duration of battery technology improves over time, plugin-charging-systems that charge the vehicle overnight will be the most suitable solution.[27]

From a practical point-of-view, providers of bus fleets will be reluctant to switch to plug-in hybrids (during the daily route) or overhead charging technology since they would have to deal with possible vandalism and safety measures. Considering the current capabilities of the EES-systems, inductive charging systems would in that sense be ideal, but the necessary infrastructure investment is comparatively larger.[28]

[23] Averbeck 2015
[24] Arup 2014
[25] ABB 2013
[26] Siemens 2013
[27] Slavik 2014
[28] Averbeck 2014

2.3 SWOT-analysis

Strengths	Weaknesses
➔ European companies are among the global innovators in most production stages of hybrid and electric buses. ➔ The European common market guarantees free movement of goods, services, capital, and people. ➔ Wage- and competence-disparities across Europe allow OEMs and suppliers to optimize the quality and cost structure of their value chain. ➔ A highly developed infrastructure as well as a plethora of well-educated human capital to maintain just-in-time production and R&D. ➔ High quality- and industry-standards.	➔ European OEMs and suppliers missed out on the early development and introduction of suitable EES-systems for HEBs and PEBs. ➔ The cutting-edge development of the highly important li-ion batteries is mainly located in Asia. ➔ High production costs in Western Europe as well as increasing production costs in Eastern Europe and Turkey. ➔ Development in hybrid propulsion-systems is at the moment mostly based on subsidies rather than commercial feasibility. ➔ European OEMs have not standardized, which EES-system or charging infrastructure to use so far.
Opportunities	**Threats**
➔ Increasing urbanization puts pressure on city development. ➔ New public transport solutions like bus rapid transit-systems (BRTS) as well as city-expansions are necessary to ease congestion, pollution as well as commuting time. ➔ The demanding European emission standards prepare European producers for the emerging economies, where urbanization and pollution are more crucial issues. ➔ Functioning subsidy structure in the single European states and the EU, which could allow efficient support for the development of PEBs, HEBs, EES-systems and the necessary charging infrastructure. ➔ Increasing crude-oil prices over the long term.	➔ The stagnant demand for buses reduces the revenue in the home markets of European OEMs. ➔ Expansion of Chinese manufacturers to Europe, since BYD offers a feasible PEB. ➔ Even though there is a wide range of Europe-wide laws, companies still have to consider numerous national laws as well as cultural differences within Europe. ➔ Restrictive labor laws, which tend to be more restrictive than elsewhere around the world, which puts European OEMs and suppliers into an unfavorable position compared to Asian competitors.

2.4 Technology trends

The major components of an electric vehicle are the battery (EES), the traction motor and the motor controller. However, the general acceptance of electric mobility as well as the market penetration will mainly depend on the further technological development of EES-systems. Maintaining the balance between factors of cost, driving range, safety, energy- and power density will be crucial in that sense.[29]

Battery Technologies

It is expected that li-ion batteries will remain dominant in the short and medium term, at least in the next six to ten years until suitable alternatives are commercially viable.[30] The energy density of current materials can be improved from 140 up to 250 Wh/kg.[31] Regarding the anode materials, graphite as well as amorphous carbons are currently most widely used. Graphite captures the biggest market share due to its balanced profile of characteristics. Lithium-titanates will gain importance in the next years since their recharging period is shorter and they are able to process higher currents.[32] For instance, Solaris and Vossloh Kiepe started using lithium-titanate batteries in a pilot-project in Esslingen, Germany.[33] Over the middle- and long-term carbon silicon-, carbon tin composites, silicon-, non-silicon alloys, and lithium-metal will become more important in order to increase the energy density.[34]

Considering the cathode's active material, it is necessary to improve the performance of the Nickel-manganese-cobalt (NMC) composition, which is the commercially most viable cathode material at the moment. Further improvements are possible by increasing the share of nickel as well as decreasing the share of manganese and cobalt by 25% each, which would allow to increase the specific capacity from 150 to 220 mAh/g.[35] Furthermore, lithium ferrous phosphate (LFP) will gain importance as a cathode material over the next years since the ion supply is higher and it is considered safer than layered oxides like NMC. Assuming researchers are able to increase its electric conductivity by decreasing the size of the LFP-particles as well as using carbon coatings.[36]

However, current li-ion-technology is limited. The next crucial step will be to develop new materials as well as new cell concepts. One promising cell concept, which is already in the development, is the Lithium-Sulphur (li-s) battery. It is superior to current li-ion batteries because of its higher energy density, cheaper materials and lower weight. The current energy density is 350 Wh/kg but is expected to increase up to 400 to 600 Wh/kg. It replaces graphite with a small amount of lithium metal, which functions as electrode as well as lithium source. Furthermore, the layered oxides currently used are replaced by sulphur, which is cheaper and able to use the lithium more efficiently. However, li-s batteries still need at least six to ten years to gain market maturity since they still have a low amount of charging cycles, which are related to degradation processes of the electrolytes.[37]

[29] Meisenzahl et al. 2014
[30] Averbeck 2014
[31] Korthauer 2013
[32] Wurm et al. 2013
[33] Vossloh Kiepe 2014
[34] Wurm et al. 2013
[35] IAS 2014
[36] Graf 2013
[37] Althues 2014

Another promising technology is Lithium-Air (li-air) in which lithium oxides at the anode and oxides at the cathode get reduced. There is extensive research in this field due to its promising characteristics. Theoretically, it is able to increase the energy density up to twenty times. Practically, it is expected that the minimal energy density would be 500 Wh/kg. However, research is still in its infancy considering several technological obstacles.[38]

Despite the development of EES-systems, energy efficiency especially for PEB and HEB gain importance since their unsteady driving style strains the batteries additionally. Therefore, other components of the buses have to use energy more efficient. One crucial feature will be the development of regenerative braking systems, which use the kinetic energy from breaking and reuse them when accelerating the vehicle. These KERS are naturally linked to the development of the powertrain as well as in-wheel UCs. The latter either complement the on-board EES systems or have the potential to replace them completely.[39]

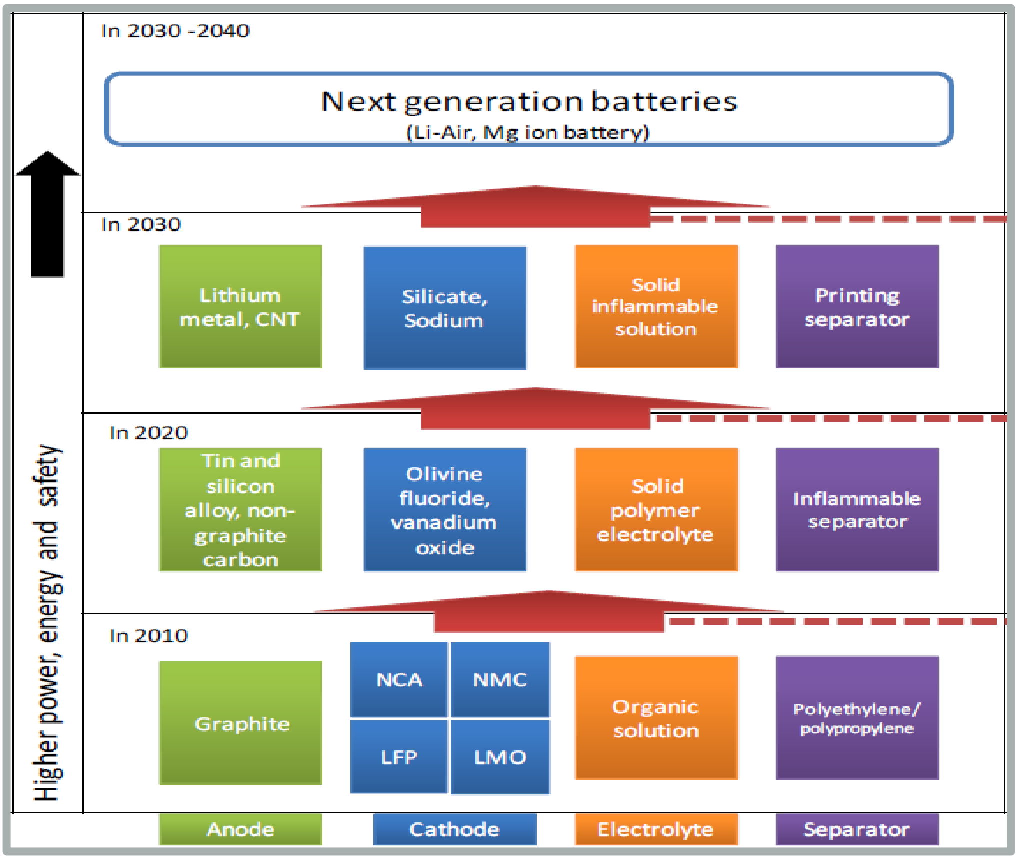


Fig. 5: Roadmap of future development in battery technology

Source: EBTC Cleantech Mapping

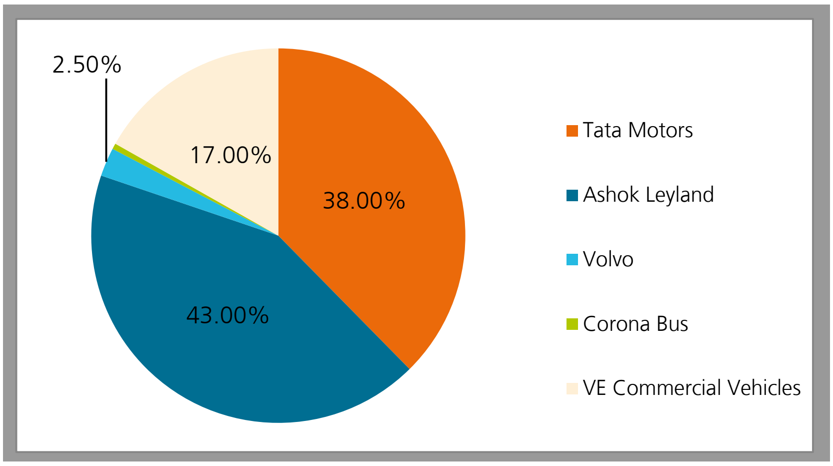
[38] Imanishi et al. 2014
[39] Frost & Sullivan 2013; Siemens 2013

3 Indian market overview

India is a lucrative market for domestic as well as foreign OEMs since it is the second largest bus market in the world with an immense growth potential. The following section will give a short overview over the current market status, gaps and opportunities as well as the level of technology involvement.

3.1 Market overview

India is considered as a growing bus market with an increasing degree of competition led by two domestic OEMs – Tata Motors and Ashok Leyland. Together they own 81% of the city bus market, where Tata Motors holds 38% and Ashok Leyland 43% (See dia. 4). In 2012/2013 74,728 buses were sold in total. Followed by a 10% increase the following year, which is more than twice the amount of the European market. Additionally, an estimated number of 35,000 overaged buses have to be replaced in the near future.[40] However, domestic sales decreased over the last months, but are expected to rise again up to 12% in the next fiscal year.[41] Foreign OEMs like Volvo, Daimler AG or Scania prepare to enter the Indian bus market or to increase their marginal market share.[42] One main reason for that is the possibility to conduct business without any noteworthy governmental restrictions, which is usually the case in China (the biggest bus market in the world).[43]



Dia. 4: Market shares of Indian city bus market 2012/2013

Source: Motorindia/RACE Analysis

In 2005 the Indian government initiated a massive city modernization program, the Jawaharlal Nehru National Urban Renewal Mission (JNNURM). Its main goal was to improve the quality of public transport by enhancing existing bus fleets and infrastructure in Indian metropolitan regions by introducing BRTS. The most advanced and developed Indian BRTS is currently located in Ahmedabad. This positive example led other cities like Chennai, Kolkata, Bangalore or Indore to implement or launch a similar transport system. Eleven BRTS projects have been sanctioned under the JNNURM including Vijayawada, Jaipur, Pune and Kolkata and are at various stages of implementation so far.[44] The main reason for BRTS as a central mean of the JNNURM

[40] Motorindia 2013
[41] The Economic Times 2015
[42] Frost & Sullivan 2012a
[43] Averbeck 2015
[44] EMBARQ India 2014

was the massive daily congestion of most Indian cities. Furthermore, a lot of cities with more than 1 million inhabitants do not have an adequate bus system.

The implementation of BRTS and the funding of purchases of city buses under JNNURM led to the introduction of modern low floor buses which made bus services more attractive. In the first phase of JNNURM over 15,000 buses were purchased.[45] The main goal of the second phase was an implementation of articulated and hybrid buses. Especially Tata Motors and Ashok Leyland benefited from JNNURM since they received the majority of orders. However, over the years the success of JNNURM has been widely criticized, which is the reason why the government decided to let the program expire. Instead the government introduced a new "Smart Cities project", where transport (including public transport) will be one crucial element.[46]

Diesel-powered buses dominate the Indian bus market with approximately 95% of the total city buses. The remaining 5% are mainly caused by compressed natural gas (CNG) buses, which Tata introduced in 2010 and which is solely used in New Delhi.[47] Furthermore, Tata as well as Ashok Leyland try to follow foreign OEMs in adding other alternative buses like HEBs and PEBs to their portfolio. In January 2015 Ashok Leyland announced that it would start producing a PEB in cooperation with Optare. Depending on regulations, Ashok plans to launch the bus in the Indian market as a completely build-up unit in the next two years.[48] However, the Chinese BYD already introduced the first PEB in Bangalore in 2014. The bus was given to Indian government on a free of cost trial basis.[49] Nevertheless, it can be assumed that in short- and mid-term diesel will remain the first choice powertrain in India, but alternate technologies are expected to gain momentum over the next few years.[50]

3.2 Current status

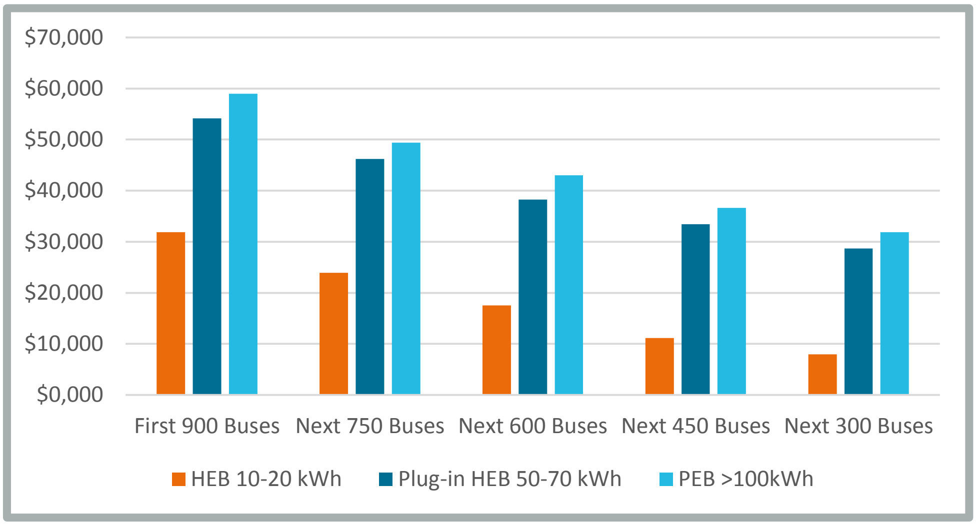
A big advantage of domestic OEMs is the lower market price for conventional diesel and alternative powertrain buses compared to Europe or North America.[51] Furthermore the market is already consolidated. Years of isolation of the Indian market have led to the development of a well-structured dealer and service network for domestic manufacturers. About 90% of the market share is split between few Indian manufacturers, what makes it hard for foreign companies to enter the market with new brands and compete with the low priced products of the domestic OEMs.[52] Additionally, foreign companies have to deal with complex rules and state structures, as well as high import duties and capital investments, which further their competitive disadvantage. Lastly, domestic OEMs have the advantage of strong cooperative partnerships with the State Transport Undertakings (STU). All new BRT-projects initiated by transport agencies will be immediately supported by OEMs like Tata Motors or Ashok Leyland.[53]

The R&D-level of domestic OEMs and component manufacturers concerning all key components is low compared to the level of foreign OEMs. Due to the years of isolation of the Indian market and a low R&D level India technologically lags behind

[45] Ministry of Urban Development 2012
[46] Ministry of Urban Development 2014
[47] Frost & Sullivan 2012b; Tata Motors 2010
[48] The Hindu 2014a
[49] The Hindu 2014b
[50] Frost & Sullivan 2012b
[51] Frost & Sullivan 2013
[52] KPMG 2011
[53] Frost & Sullivan 2012b

other nations. Additionally Indian cities still lack behind in terms of necessary infrastructure investment. However, Infrastructure investment is especially important for the implementation of electric buses since they require charging infrastructure as well as a sufficient road network. At the moment many cities and their transport systems are not able to handle the growing transport demand, which leads to massive congestion on a regular basis. As a result, passengers use inter-mediate public transport, such as rickshaws or mini buses, adding to traffic congestion.

The Indian bus market is still an emerging market where an increasing government support is needed. The government takes a leading role in the adoption of electric mobility by intervening in five main areas: demand creation, supply related interventions, power and charging infrastructure, R&D and the infliction of stringent fuel efficiency measures.[54] Demand could be stimulated through the mandating of electric or hybrid buses in public transport or through subsidies like cash or tax incentives. Also supply related interventions are necessary to spur domestic manufacturing, for example through tax holidays or accelerated depreciation. The proposed incentives (See dia. 5) in the National Electro Mobility Mission Plan have not yet been materialized, but once implemented, they could be an opportunity for OEMs.



Dia. 5: Proposed demand incentives for low floor urban buses

Source: Ministry of Heavy Industries & Public Enterprises

Regarding the infrastructure there is still room for improvement, but India already invested heavily in the road network linking all main centers of the country. From 2012 to 2017 about $ 1 trillion will be invested in infrastructure. Also urbanization trends have paved the way for the development of satellite towns, which are supposed to amount 70 by 2020. In 2025, 38% of the Indian population will live in urban regions, resulting in growing demand for commuter services. This is why bus transport is and will be the most-sought after form of transport and shows the importance of infrastructure investments.[55]

To strengthen the local R&D-base both government and industry investments are required. In order to become globally competitive, Indian companies need to improve their R&D capabilities in research areas like battery cell or power-train technologies. Strategic cooperations and knowledge sharing with foreign manufacturers could help to improve the R&D level. Once electric vehicles accomplish economic viability and are

[54] Ministry of Urban Development 2012
[55] Frost & Sullivan 2014b

more prevalent and accepted than today, stringent fuel efficiency norms can be an important instrument to support the sale of electric vehicles.

In the past bus transport also battled with its negative image among the public, as it was considered unreliable, slow, uncomfortable, noisy and polluting. A solution to this problem will be the greater adoption of HEBs and PEBs in Indian cities, since they enable the reduction of the high pollution levels. Especially air quality has become a pressing issue in the last years since the vehicular density in India is supposed to fivefold until 2030. Together with the implementation of BRTs across the country they could enhance the image of bus transport.[56]

Major threats for domestic OEMs are global players like Daimler or Volvo entering the market. With India being the second biggest market for heavy buses worldwide, global players are keen to participate in this market in order to safeguard their global market share. Chinese bus producers may compete from two ends of the market: on the lower end they have low priced tech products, on the upper end they offer competitively priced hybrid and electric buses due to massive government support.[57] Another problem for both domestic and foreign OEMs are the lack of government incentives as well as the high acquisition costs of PEBs compared to conventional diesel buses, which has made it more difficult to sell PEBs to Indian customers. In addition there is less price pressure to upgrade bus technology due to the current low of the crude oil price. Furthermore, rail based solutions and metro services in big cities represent a threat for bus transport in general, as they are considered the most prestigious form of urban transport.[58]

[56] The Hindustan Times 2014

[57] Frost & Sullivan 2013; Averbeck 2015

[58] Frost & Sullivan 2012b

3.3 SWOT-analysis

Strengths

- Far lower regional market price for conventional diesel and alternative powertrain buses compared to Europe or North America
- Largely consolidated market, about 90% of the market share is split between few Indian manufacturers
- Well-structured dealer and service network for domestic OEMs
- Market barriers for entering OEMs caused by complex rules and state structures as well as high import duties and capital investments
- Domestic OEMs have strong cooperative partnerships with STUs

Weaknesses

- Low R&D level of OEMs and component manufacturers concerning all key components
- Lack of necessary EV-infrastructure
- Insufficient electricity network
- Lack of government support/limited public money for public transport
- Products with a lower construction quality compared to European products

Opportunities

- Demand creation through the mandating of HEBs or PEBs in public transport or through subsidies
- Stringent fuel efficiency norms to support EV-sales
- High investments in the Indian infrastructure and road network over the next years
- High mobility needs due to a high level of urbanization
- Government and industry investments in R&D in order to become globally competitive
- Implementation of BRTs across the country
- India as a production and distribution hub to reach African and Asian markets

Threats

- Global player like Daimler, Volvo or BYD entering the market
- High acquisition costs of HEB and PEB compared to conventional diesel buses
- Less price pressure to upgrade the technology due to the current low of the crude oil price
- Rail-based solutions and metro services

3.4 Technology trends

The current level of technology involvement is limited.[59] The low and uncertain demand for EV in the past led to significant underinvestment for specialized EV components.[60] In India, the Lead-Acid technology holds a major share in electric vehicles battery. Nevertheless, institutes like the Centre for Automotive Energy Materials runs R&D-programs on materials and components for electric and hybrid vehicles. They especially focus on the development of li-ion batteries as the biggest concern related to EVs is the battery technology.[61]

OEMs like Ashok Leyland or Tata Motors already manufacture HEB or PEB and undertake research on the development of powertrains and EES-systems. They especially benefit from the technological expertise and R&D-level of their acquired subsidiaries (Optare or Jaguar Land Rover Automotive). Other automotive manufacturers like Mahindra Reva, composed of the former electric vehicle manufacturer Reva and Mahindra & Mahindra, are also investing in alternative technologies for the long term. However, a majority of the EV-technologies and products still needs to be imported. Therefore, at the time of writing, mainly assembly activities are taking place in India.[62]

The collaboration of Indian companies with foreign, technologically more sophisticated products and the resulting higher expectations of quality, safety and reliability at reasonable total cost of ownership will lead to technological advances of domestic products.[63] Additionally, stricter emission standards will necessitate more efficient and cleaner technologies. Besides, the petrol and diesel prices have more than doubled in India since 2000 and together with the raise of taxes on petrol and diesel (by the incumbent Modi government), a shift to alternate technologies is becoming increasingly important.[64]

[59] Frost & Sullivan 2012b
[60] Ministry of Urban Development 2012
[61] International Advanced Research Centre for Powder Metallurgy & New Materials 2015
[62] Ministry of Urban Development 2012
[63] KPMG 2011
[64] Mypetrolprice.com 2015

4 EU-India comparison & strategic recommendation

4.1 EU-India industry comparison

European companies are among the most innovative developers and producers of HEBs and PEBs in the world. This is related to the steady improvement of key components of the diesel or hybrid propulsion systems. Nevertheless, European OEMs as well as suppliers lack behind in the development of suitable EES-solutions in order to catch-up globally in the PEB-sector. However, OEMs of the first sector are under pressure by the saturated European market and low-cost competition from Eastern Europe and Turkey to globalize their sales as well as their production facilities in order to compete on a global scale.

The Indian bus market is the second largest in the world and mainly divided between the two domestic producers Tata and Ashok Leyland. Even though both companies have introduced HEBs, both have been known for affordable products with basic technological, comfort and security standards. Hence, the price difference between Indian and European buses reflects the technological differences (See tab.2). Nevertheless, Tata as well as Ashok Leyland are catching up in the PEB- and HEB-market. For instance, Ashok Leyland plans to introduce a PEB in 2017.[65] Since the Indian and other Asian markets offer massive growth potential, Indian OEMs see no reason to expand to other markets than these emerging ones in Asia, South America or Africa.

	Diesel Bus	**Hybrid Bus**	**Electric Bus**
Europe	\$300,000 – \$410,000	\$450,000 – \$540,000	\$595,000 – \$680,000
India	\$75,000 - \$110,000	\$175,000 – \$255,000	\$325,000 – \$400,000
Difference	approx. 25%	approx. 39-47%	approx. 55-58%

Tab. 2: Assumed price differences between European and Indian OEMs

Source: Frost & Sullivan (2013)

As in other areas of vehicles, OEMs and suppliers have the chance to expand their operations in the value chain in the electric bus segment. Utilities and 3rd parties can position themselves as mobility providers, undermining OEMs' positioning with respect to the customers.

Major opportunity for the EU exists in the areas where only partial solutions exists like in the case of batteries & technology to extend the range of EV's, reducing the charging time etc. (CTM)

[65] Indian Autos Blog 2015

4.2 Market drivers and challenges

Since the European market is considered saturated, this chapter will solely focus on the drivers and challenges of the Indian bus market.

Even though the Indian bus market is largely consolidated, it still offers growth potential (also for foreign OEMs) due to its enormous size of at least 80,000 units produced per year.[66]

The following reasons underline this assumption:

India's prolonged growth has led to an uncontrollable urbanization as economic wealth is mainly located in urban areas. Additionally, the urbanization is fueled by the migration of the rural population and the general population growth. As a result, the growing numbers of commuters are taking a toll on local transport and infrastructure leading to massive congestion. Furthermore, noise- as well as GHG-emissions are threatening the health and life quality of people in these regions.[67]

PEBs as well as HEBs are promising solutions to tackle most of these issues since buses are already used for 55% of total trips in Indian metropolitan regions. The national as well as local governments have therefore implemented several policies. For instance, a number of subsidies are focusing on alternative propulsion systems as well as new infrastructure solutions like BRTS.[68] Since the existing BRTS in Ahmedabad is considered as a success story, a number of new BRTS are being built or are already implemented.[69] Furthermore, the market entry of Volvo has triggered a paradigm shift in terms of lower total lifetime costs and comfort. Indian bus companies have begun to realize that it pays off to invest in high quality buses. This proves that there is a potential market for high-quality buses from European OEMs.

Nevertheless, domestic and foreign OEMs are facing obstacles that might hinder market growth. The JNNURM purchase program is not likely to be repeated in the near future due to its long duration and extent. Because of this cities, municipalities, and transport companies have little incentive to purchase PEBs or HEBs at the moment. Additionally, the general rise of household income leads to a growing number of car owners, who will be reluctant to travel by bus.[70] Another reason is that especially BRTS face competition by rail and metro services, which are avoiding traffic altogether and are considered more prestigious for a city.[71] Even though BRTS cost a fraction of rail services, municipalities and cities have to invest in charging infrastructure in order to electrify public bus services. Furthermore, the Indian infrastructure tends to be partly unreliable, namely the insufficient electricity network which causes heavy blackouts. Also the inadequate road infrastructure could make the purchase of expensive PEBs or HEBs questionable.[72]

[66] Motorindia 2013
[67] World Bank 2013
[68] Frost & Sullivan 2012b
[69] Frost & Sullivan 2013
[70] Verband der Automobilindustrie 2015
[71] Business Standard 2015
[72] Deutsche Presse-Agentur 2014

4.3 Policies and regulatory framework in EU and India

The United Nations Economic Commission for Europe (UNECE) provides an international framework with the World Forum for Harmonization of Vehicle Regulations. It enacts internationally coordinated recommendations concerning technological as well as safety standards, which are translated into national law by almost all developed and developing countries. Therefore, they are the groundwork for vehicle regulations in India, Europe and the single European states.[73]

Regarding electric vehicles, the UNECE passed the ECE 100 as well as the ECE-R 85, which specify the required standards for electric vehicles including their components.[74] Other important international standards in this sector are enacted by the IEC, which regulates charging technology as well as its safety standards. It has standardized plug-in charging stations in terms of mode (IEC 61851-1) and type of plug (IEC 62196-1) used.[75] Additionally, the section 38 of the UN Manual of Tests and Criteria specifies the quality validation of li-metal and li-ion batteries before being transported.[76]

4.3.1 Policies and regulatory framework in the EU

The standards and rules adapted by the EU are legally binding for the single European states and do not need further implementation into national laws.[77] The general framework for motor vehicles is enacted by the directive 2007/46/EC.[78] It is specified by single regulations and directives which in turn adapt the standards set by the UNECE. For instance directive 2009/40/EC is concerned with the technological supervision of vehicles and their parts.[79] Additionally to the regulations by the UNECE, the EU has one of the world's most restrictive GHG emission standards for commercial vehicles as part of the Euro-6 norm, which reduces the nitrogen oxides additionally by 80% compared to Euro-5.[80] Other emission standards include the restriction of noise level in urban areas regulated by directive 2002/49/EC.[81]

The policies enacted by the EU are aligned with the white paper "Roadmap to a Single European Transport Area". It defines certain goals for the development of Europe's transport sector in order to reduce GHG-emissions by 60% until 2050. Public transport means including buses would be upgraded with alternative propulsion system to test their practicability and market readiness. This should lead to CO_2-free transport in cities until 2050.[82] Based on those targets, the EU has launched a number of subsidized public projects under the FP7-framework as well as the Horizon 2020-program. Currently running under the FP7-framework is the ZeEUS-project, which aims to test the viability of electric and PHE buses with different charging solutions in six different European cities. [83] The following framework Horizon 2020 is still in its start-up phase but aims to boost the competitiveness of the European transport industry by providing € 6 billion in order to become greener and smarter.[84] However, there is a large number

[73] Economic Commission For Europe 2012
[74] United Nations 2011
[75] International Electrotechnical Commission 2011
[76] United Nations 2009
[77] Federal Ministry of Transport and Digital Infrastructure
[78] European Parliament et al. 2007
[79] European Parliament et al. 2009
[80] European Commission 2014
[81] European Commission 2002
[82] European Commission 2011
[83] ZeEUS
[84] Horizon 2020

of other European and nationwide projects concerning alternative propulsion systems in public transport.

4.3.2 Policies and regulatory framework in India

Indian regulations regarding automotive industries are issued by the Ministry of Road Transport & Highways and legitimized by the Motor Vehicles Act and Central Motor Vehicles Rules.[85] Within this framework the Automotive Industry Standards Committee (AISC) is the major institution responsible for designing regulations concerning the technical standards of vehicles.[86] The regulations AIS-38 until 41, 49 and 102 address electric and hybrid vehicles. Furthermore, the AIS-52, 63 and 68 provide standards for buses in general.[87] Besides that, the Ministry of Urban development regulates the appearance as well as the technical standards of city-buses within its Urban Bus Specifications - II. However, the specifications provided do not differentiate between the requirements for different propulsion systems.[88]

Additionally, Indian policy makers are concerned with increasing emission levels. Based on the policy recommendations of the Auto Fuel Policy Committee in 2003, India introduced the Bharat Stage Emission Standards (BSES). They are based on the European emission norms and have been gradually been extended since 2003. It is expected that until the end of 2015 the 50 largest cities in India will have adapted the BSES-4, which is equivalent to the Euro-4 norm. Currently, most of India complies with the BSES-3. Furthermore, BSES-5 is going to be rolled out in 2020.[89]

Even though there is no current funding program for alternative propulsion systems in place, the Indian government drew up The National Electric Mobility Mission 2020. It provides a road map for future policies and subsidies regarding the development of electric mobility in India based on the propositions of all key stakeholders from the public and private sector. Concerning public transport, it proposes an incremental incentive scheme tiered by the type of propulsion system. In this proposal serial hybrid buses should receive a subsidy from $8,077-32,309, parallel hybrid buses $29,078-54,926 and PEBs $32,309-59,773. Additionally, the road map proposes to initiate pilot projects and fleets in order to test the economic viability and the public approval of alternative propulsion systems in public transport.[90] Former projects include the JNNURM program, which invested in the modernization of the urban centers of India from 2005 to 2014.

Furthermore, India has liberalized foreign direct investment significantly since the 1990s. Post-liberalization, the automatic procedure allows European bus OEMs and suppliers to establish a subsidiary neither without a local partner nor with the approval of the Indian government or the Reserve Bank of India.[91] However, the comparably restrictive tariff and non-tariff barriers are still a problem for European companies to set a foot in India. Just recently India has announced a rise in the basic customs duty for commercial vehicles from 10 to 40% and in the effective customs duty from 10 to 20%. However, there is a reduced duty for completely knocked down (CKD) kits of 10% in place.[92]

[85] Parliament of India 1988; 1989
[86] Automotive Research Association of India
[87] AISC
[88] Ministry of Urban Development India 2013
[89] Bansal et al. 2013
[90] Ministry of Heavy Industries & Public Enterprises India 2012
[91] Frank et al. 2014
[92] Business Standard 2015; Reuters 2015

4.4 SWOT-analysis from an EU perspective

Strengths

- European OEMs and suppliers have strong superiority in the technology as well production of HEBs as well as PEBs
- European brands tend to be perceived as producer of high-quality vehicles, which might ease the market entry

Weaknesses

- Products are comparably more expensive than those of Indian OEMs
- European OEMs have to adapt their products to the Indian market in terms of quality and price
- Due to the long isolation of the Indian economy, non-Indian companies have difficulties of establishing an extensive service- and sales network comparably to those of Indian OEMs

Opportunities

- Increasing urbanization has created pressure on city development
- Indian municipalities and the government strive to decrease GHG and noise emissions in cities
- BRTS have already been considered a mean to ease congestion, pollution as well as commuting time in major Indian cities
- India offers a large pool of qualified-engineers, which allows European OEMs to reengineer their products for the Indian market
- Volvo has already established a paradigm shift in the Indian bus market, which made Indian bus providers and their customers more quality-conscious in terms of lifecycle costs and comfort
- A large number of old buses will be upgraded over the middle- and long-term

Threats

- India's inefficient bureaucracy and restrictive trade policy creates a lot of red tape for European companies considering for instance applying for permissions to produce on an industrial scale
- Import duties range on average from 25.85 to 28.85%, which makes the import of key components like the EES and the powertrain expensive.
- The recent rise in customer duties for commercial vehicles
- The possibility of intellectual property theft
- Ashok Leyland and Tata are rapidly closing the technology- and quality-gap to foreign OEMs
- Cities tend to favor metro as the central mean for public transport since it is independent from traffic and despite having higher capital expenditure

4.5 Strategic recommendation for validation and commercialization of technology in India

There are mainly two core issues that European OEMs have to consider if they want to enter the Indian bus market. First, how does the company want to commit to the Indian market considering legal structure and capital expenditure? Second, which product strategy is suitable for a long term success in India (See fig. 9)?

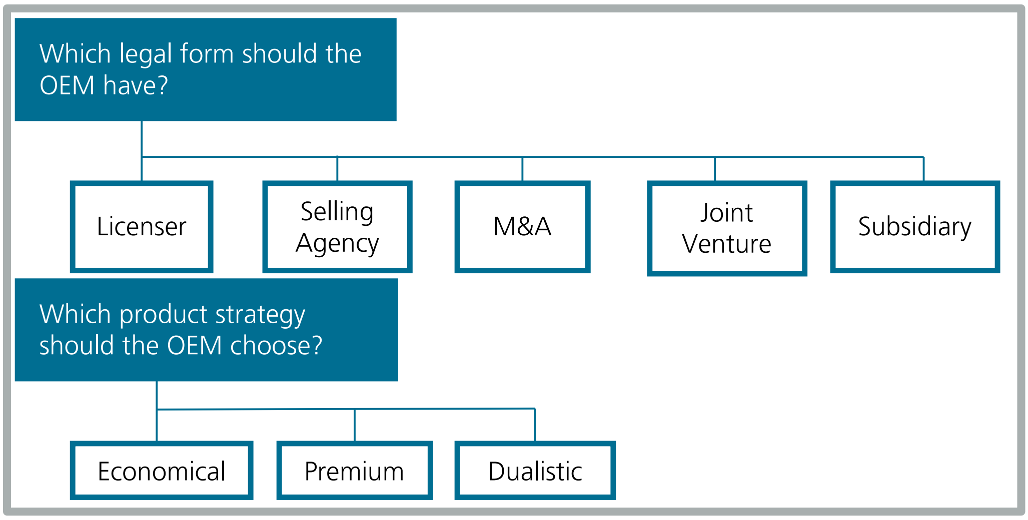


Fig. 6: Central legal and strategic questions

Source: Fraunhofer MOEZ, Meckl (2014)

4.5.1 How does the company want to commit to the Indian market?

This report recommends European OEMs to choose long term solutions like M&A or the establishment of a subsidiary to enter the Indian market since it offers them the most benefit from its tremendous growth potential. Furthermore, they would be able to use India as a production and distribution hub for the upcoming markets in Africa, Southeast and South Asia in the future. These are the reasons that make a market entry via licensing unappealing. In this case European OEMs would have to share their technological competencies with their Indian licensees.

However, a full commitment via M&A or subsidiary allows European OEMs to adapt their market entry to local requirements and to bypass high import duties. Thus, a market entry via selling agents is misguided, if one takes the comparably higher prices of European HEB or PEB into consideration. The most recent example is Daimler, which has entered the Indian market by founding a fully-owned subsidiary for their bus production under the Mercedes-Benz brand.[93]

Nevertheless, entering the Indian market on a full scale means high monetary risks by setting up production facilities in order to scale up the production, finding suitable human resources, establishing a functioning value chain as well as setting-up a distribution and after-services network. Other obstacles are the organizational barriers of the Indian bureaucracy.

A suitable solution for these problems would be to set up a joint venture with a domestic partner, which assists in entering the Indian market in return for access to

[93] Daimler 2014

technological capabilities. One successful example is the joint venture between Volvo and Eichinger. There are a number of suitable partners in the light and heavy commercial vehicle sector like Hindi Motor, AMW, Force Motors, Mahindra, Asia Motor or Corona Bus. Despite that, one should consider that European OEMs would be reluctant to share their key technological capabilities in the HEB and PEB sector. One suitable model in that sense is one, where a domestic company is receiving access to "outdated" technology from European OEMs like efficient diesel motors in return for market access.

Another option could be to form a joint venture or syndicate with another European OEM or supplier in order to share the initial costs of entering the Indian market. This approach is naturally linked to the practical problem of competitors working together. Alternatively, a joint venture of an OEM and its key supplier or an OEM from the truck segment could be chosen. Even though this is an appealing solution, one should consider the costs and risks of finding a suitable joint venture partner. Same goes for acquiring a domestic company without even considering the public perception as well as the total costs.

However, despite the obstacles and risks this report recommends European OEMs to set up a fully owned subsidiary, since the Indian bus market and the whole Asian region offers huge growth potential, which offsets the initial costs in the long term.

4.5.2 Which product strategy should the OEM choose?

Assuming that the OEM chose its suitable legal and strategic form of organization, it is crucial to find a promising product strategy. There are mainly three approaches on how European OEMs are able to offer their products on the Indian market - economical, premium or a dualistic path.

This report favors the second option over the short and middle term and the dualistic path over the long term. First of all, "premium" with regards to the Indian market means the transfer of European product and production standards as well as service. However, this can maximally be linked to a price premium of 10 to 20%. Thus, European OEMs have to develop a local sourcing and production strategy as well as adapt their products to the local technical standards.[94] Nevertheless, it offsets them from most of the costs of reengineering their products to decrease their market price. Furthermore, they are able to transfer approved production and developing methods from their home markets to India. On the downside it increases the initial production costs due to the cost of building up production facilities and a suitable workforce, which are able to maintain a certain product quality. When considering the paradigm shift that Volvo started, the initial costs of a market entry as well as the brand awareness of European brands in India, it would not make sense to rely on an economical product strategy. Additionally, domestic OEMs are far more experienced in producing affordable products.

However, this report advises against the introduction of PEBs on an industrial scale at this early stage of development. This is related to the fact that even the European market is still at an early adaption stage in this sector, mostly in pilot projects. Additionally, the high prices of European PEBs, the disadvantageous position of European OEMs and suppliers in the EES-sector, the insufficient energy supply as well as the lack of charging infrastructure make a production of PEBs in India highly unattractive at this moment. It offers more advantages to European OEMs to wait for Ashok Leyland and Tata to lay the ground work in terms of public acceptance and lobbying for public infrastructure investment.

[94] Averbeck 2015

This approach is linked to a sustainable commitment to the Indian market in the HEB sector in order to be on-site when the Indian electric bus market is taking off. Additionally, they will be able to increase brand awareness as well as incorporating future subsidies for alternative propulsion systems. Due to the concerns with public electricity infrastructure this report recommends to introduce a serial hybrid bus that combines independence from external current supply as well as the advantages of electrified movement. Additionally, European OEMs are able to make use of their experience in efficient combustion engines and recuperation mechanisms to reduce the fuel consumption steadily. This lays the groundwork for future endeavors in the PEB sector and eases the market entry of European OEMs to the Indian market. Based on this approach, European OEMs could make use of India as a distribution hub for Asia and Africa over the long term. This will become necessary since a "solely-Indian" strategy is not profitable over the long term, since margins are very small. Additionally, European OEMs should consider that a locally driven strategy is still necessary in order to tackle emerging economies like India. This means for instance to cope with challenges in the field of compliance in these countries.[95]

[95] Averbeck 2015

5 Case study: Solaris Bus & Coach S.A.

Solaris Bus & Coach S.A. is a Polish OEM of buses and trams. The founder and former CEO of Solaris, Krzysztof Olszewski, was plant manager of Neoplan in Berlin. 1994 he moved to Poland as the general importer for Neoplan and then later 1996, as the production in Poland started, he was licensee of Neoplan in Poland. 2001 the company was renamed as Solaris Bus & Coach S.A.

Solaris is a stock listed company which is fully owned by the family Olszewski. Behind the five biggest stock-listed OEMs (Mercedes-Benz, MAN, Volvo, Scania, IVECO), Solaris belongs to a number of midsized, partly family-owned businesses in Europe. Actually around 2,400 people are employed, whereas more than 2,000 of them are employed in Poland. Headquarters, production and R&D are solely done in Poland in the area around Poznan. International branches of Solaris are responsible for sales, service and aftermarket.

Solaris actually sells its products to 26 markets in and outside Europe. In 2013, 90% of the company's revenue was generated inside Europe. The only markets outside Europe have been Israel, the United Arab Emirates and La Réunion, which exhibit a market structure similar to the European markets. With a market share of about 50% on the city bus market, Solaris is market leader on their home market in Poland since 2004. In total Solaris has a market share in Poland of about 25%.

Solaris is a family operated company and according to Stefan Baguette, the market analysis manager of Solaris, "the key to their success is pursuing a strategy with flat hierarchies which ties up no resources.[96] Additionally having a flexible organizational structure is an advantage because it allows quick responses to unexpected challenges or situations". Especially in the bus industry "developments can't be predicted easily, to a certain degree you need to trust your instincts and be flexible", he says. Due to their group structure large multinational companies like MAN or Mercedes Benz are in some circumstances not flexible enough to react to market trends, as various examples in the past have shown. However Solaris focus does not lie on a single alternative propulsion technology, they are rather trying to gain experience with different technologies in order to stay flexible.

Solaris operations on foreign markets are limited to markets with a European structure. According to Baguette "European buses are in a global comparison relatively expensive. That's the reason why there is only a very limited sales market outside of Europe". To sell products on these markets, European companies like Solaris "have to develop new, cheaper products with a lower manufacturing quality in order to compete with the competitively priced buses of domestic OEMs", he says. Based on the development-, transport- and logistics costs and the different cost structures of foreign suppliers, the economic potential of European buses with European manufacturing quality in non-European markets is small. Therefore, alongside Poland the most important sales markets for Solaris are the Czech Republic and Slovakia, followed by German-speaking countries, Scandinavia, France, Italy and Spain. According to Baguette the majority of revenue is generated by two to three major products, mainly diesel powered buses. He also predicts that they will remain the main source of revenue. Furthermore, all HEBs and PEBs "are and shall remain niche products for the foreseeable future. Especially the development of PEBs is not just a matter of economic viability, as they are not profitable in short term. Instead they have other effects, for

[96] Interview with Stephan Baguette, market analysis manager of Solaris in Berlin, February 2015.

example on quality of urban life, air purity, noise and sustainability, which may result in relieving the pressure on the health system", he says.

The Indian Market was also considered and analyzed by Solaris in the past. Baguette states that India is the second largest market after China with an enormous sales volume, but with different market requirements compared to European markets. Due to current transport problems, the development of satellite towns and a growing middle class with higher income levels, it must be assumed that there will be an increasing need for mobility in India. However, this potential for foreign OEMs is reduced by the Indian supplier landscape, as Tata Motors and Ashok Leyland already cover the Indian market. As a result Baguette notes that there are and will be limited sales opportunities like providing solely a few BRTS projects with a small number of vehicles. Therefore Solaris does not classify India as an attractive sales market but rather as an interesting manufacturing base due to the labor cost advantages. He also mentions that North- and South America are basically closed markets because of their highly established supplier structure and high market access barriers. As a result India would serve as an ideal production and distribution hub due to its geographical location. He says that "companies should use India for chassis- or CKD production, from where other markets in Africa, Asia and Australia can be served". However, "second row companies with limited resources like Solaris have to consider the necessary investments for new, market-conform products carefully", he says.

6 Summary

This report highlights the recent and future developments of cleaner public bus transport in Europe and India. Even though HEBs and PEBs are still at a nascent stage in terms of public appearance, several OEMs have found commercially applicable solutions that would benefit today's problems caused by rapid urbanization and demographic growth especially in emerging economies like India.

Nevertheless, OEMs and suppliers have to tackle a number of challenges. Alternative propulsion systems for buses are regarded as an economically viable alternative to diesel buses. From a technological point of view, OEMs of the first sector have to agree on a suitable solution in regards to charging infrastructure and EES. Additionally, public as well as private research endeavors in EES have to work on exhausting the potential of available li-ion technology in order to reduce the overall weight and to increase the energy density as well as their durability by using new material combinations. At the same time they have to focus on new EES-concepts, which will succeed li-ion batteries in the future.

The European market for PEBs and HEBs is still relatively small due to the saturated bus market in Europe. If European OEMs want to grow, they have to globalize their sales and production in order to be competitive with innovative and economical competitors from Asia like Tata, Ashok Leyland or BYD. India could be a key component for a OEMs long-term strategy because of two reasons:

- First, it is the second biggest bus market in the world with promising growth perspectives in the HEB- and PEB-sector.
- Second and most importantly, it combines well-educated human labor, with relatively low labor costs and a geographically excellent position in between China, South-East Asia and Africa. The latter advantage allows European OEMs to use India as a production and sales hub, which will offset potential fluctuations in demand in India or Europe and secure future growth.

However, a number of bureaucratic procedures makes the entry to India difficult and burden-some. Even though Indian governments have worked on easing the market entry for foreign companies, it is still challenging. But when considering the potential future advantages of an early market entry to India, the future benefits clearly outweigh the organizational and monetary costs. Same goes for the investment in hybrid and electric propulsion systems as well as for EES themselves. Governments, research facilities as well as companies have to allocate their resources to PEBs and HEBs in order to improve the life quality and efficiency of a rapidly modernizing and urbanizing world.

7 Literature

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8 Appendices

8.1 Overview European OEMs

Company	Country	Hybrid	Electric	Trolley	CNG
Kutsenits	AT	x	x		
Van Hool	BE	x	x	x	x
Temsa Europe	BE	x			x
VDL Bus Roselare	BE	x		x	
Carosserie Hess AG	CH	x		x	
SOR Libchavy	CZ	x	x	x	
SOR	CZ		x	x	
COBUS INDUSTRIES GmbH	DE		x		
MAN Truck & Bus AG	DE	x			x
Daimler AG	DE	x			
Göppel Bus GmbH	DE	x			
Vossloh Kiepe GmbH	DE	x		x	
Irizar S COOP	ES				
PVI	FR		x		
Heuliez Bus	FR	x			
Bredamenarinibus	IT		x		x
Solaris Bus & Coach S.A.	PL	x	x	x	

Solbus	PL				x
Aktiebolaget Volvo	SE	x	x		
Hybricon	SE	x	x		
Scania Aktioebolag	SE	x			
Bozankaya	TR		x		
Otokar Otomotiv ve Savunma Sanayi A.Ş.	TR				x
Wrights Electric	UK	x	x		
Optare	UK	x	x		
ADL	UK	x			

8.2 Overview European producers of EES-systems

Name	**Country**	**Li-ion**	**NiMH**	**NiCd**
Magna Steyr	AT	x		
Leclanché	CH	x		
Deutsche Accumotive GmbH & Co. KG	DE	x		
Hoppecke	DE	x		
Rockwood Lithium GmbH	DE	x		
Robert Bosch GmbH	DE	x		
Arts Energy	FR	x	x	x
Saft	FR	x		
Fiamm	IT		x	

8.3 Overview European producers of alternative powertrains

Name	Country	Hybrid	Electric
ZF Friedrichshafen AG	DE	x	x
Siemens AG	DE		x
Heinzmann GmbH & Co. KG	DE	x	x
Voith Turbo GmbH & Co. KG	DE	x	
Vossloh Kiepe GmbH	DE	x	x
BAE	UK	x	

8.4 Overview European producers of charging infrastructure

Name	Country	Induction	Plug-in	Overhead
ABB Ltd.	CH			x
Schunk	DE			x
Brose-SEW	DE	x		
Siemens	DE	x	x	x
Schunk	DE			x
Phoenix Contact	DE		x	
Oprid	ES			x
Ensto Finland Oy	FI		x	
MASP	GB	x		