SMART ELEKTRO MOBILITY FOR CITY BUSES – A ZF SYSTEM APPROACH

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ABSTRACT

Global megatrends have a great impact on future's powertrain concepts. Main drivers are the emission protection legislation, sustainability and, from a customer's view, competitive pressure, represented by the total cost of ownership.

The conventional powertrain with the internal combustion engine will successively leave its dominant position. Electro mobility for city buses demands for hybrid systems, and, finally for electric busses. ZF was among the first to offer electric drivetrains for city busses in the late 90's.

The commercial breakthrough of electric drivetrains depends on legislation/subsidies and commercial advantage derived from the total cost of ownership. ZF has shown a variety of systems, beginning with electric axles, best suitable for all type of electric mobility, parallel hybrid transmissions and full electric drivetrain solutions. Full electric drives are a major future technology for commercial vehicles as they may significantly contribute to achieving future CO2 reduction targets as well as ambitious fuel consumption improvements. Hybrid solutions have also their markets, but not in city bus applications, Main market will be in intercity, coach and long haul truck applications. ZF will take an active part in the definition of future electric powertrains – mainly for city busses, but also intercity and potentially long distance traffic - and safeguard a fruitful cooperation with OEs and operators as well.

Keywords: E-Mobility, Sustainability, Innovation, System Approach, Hybrid, E-Driveline

INTRODUCTION

The todays world of public transportation is highly influenced by global megatrends leading to the powertrain concept of the future. These future concept have to deal with different challenges and conflics of aims. On the one hand, a growth of population effects and impacts also a growth of economies and drives the social concept into the direction of urbanization. All three factors will also lead to an increase of the transport volume for both passengers and goods. On the other hand, the limited resources are characterised by the resource scarcity, an increasing demand for energy, a rising need for raw materials and also a mandatorily stronger consideration of environmental aspects.

Regarding the above mentioned future's powertrain concepts, most important aspects are the emission protection legislation and sustainability and – from a customer's view – a competitive pressure, represented by the total cost of ownership. The conventional powertrain with the internal combustion engine will successively leave its dominant position. Electro mobility for city buses demands for hybrid

systems, and, finally for electric buses. The commercial breakthrough depends on two major issues:

1. Legislation and subsidies
2. Commercial advantages derived from the total cost of ownership

The first one is very volatile and differs worldwide, depending on the markets and the legislative directions accordingly. The second has been developed consequently by the bus industrie and theri suppliers and partners. The diagramm below demonstrates the general conditions regarding E-Mobility referring to the two major issues described above:

On the way forward to the powertrain of the future, the first step will be with battery driven vehicles, followed by a technolog such as fuel cell as energy source.

This paper and the presentation will describe the composition of the powertrain, its different transmissions and the parts of electric systems from a supplier's point of view.

The Powertrain Of The Future – Incentives From A Legal, Economic And Market Point Of View

As described in the introduction, there are different drivers for the powertrain of the future. One is the legal incentives in different markets and regions worldwide. In the following overview, which does not claim to be complete, some of the most important market areas are put on spot regarding the legal incentives:

- Europe:

UK: "Green bus fund 2013"

Germany / Baden-Württemberg: subsidies for hybrid- / electro buses, subvention half of the additional

costs for such a bus (max. 150,000 € per bus)

Miscellaneous: LEZ in many European countries

Hamburg: Until 2020 only emission-free buses

Paris: Reduce emissions with fuel cell and pure electric buses until 2025

- North America:

California (Truck + Bus): 2012 / 13 promotional programs for hybrid + electric buses: 8,000 $ -

65,000 $ for "qualified vehicles".

- South America:

Brasilia: In São Paulo city, there is a law demanding all the buses to run without fossil fuels by 2020.

(Law 530 / 2008)

- Colombia: there is a federal rule called "Green solutions", (477 / 13) which involves use of hybrid,

pure electric and gas bus, with no specific target.

- Asia:

China: Subsidies for mega-cities, key regions. Only for electric, plug-in and fuel cell vehicles.

Plug-in hybrid and electric buses listed in catalogue can get full exemption of vehicle and vessel tax,

hybrid buses listed in catalogue can get half exemption.

The described laws and regulations are continuously extended and new countries, regions or cities are joining. Beside of this, an analysis regarding the main market trends shows that electric powertrains in buses will increase and compete with Diesel buses; on the long run they will dominate, if they will be superior in terms of Total Cost of Ownership (TCO). Therefore, the commercial aspect of shifting into direction of E-Mobility needs to be considered.

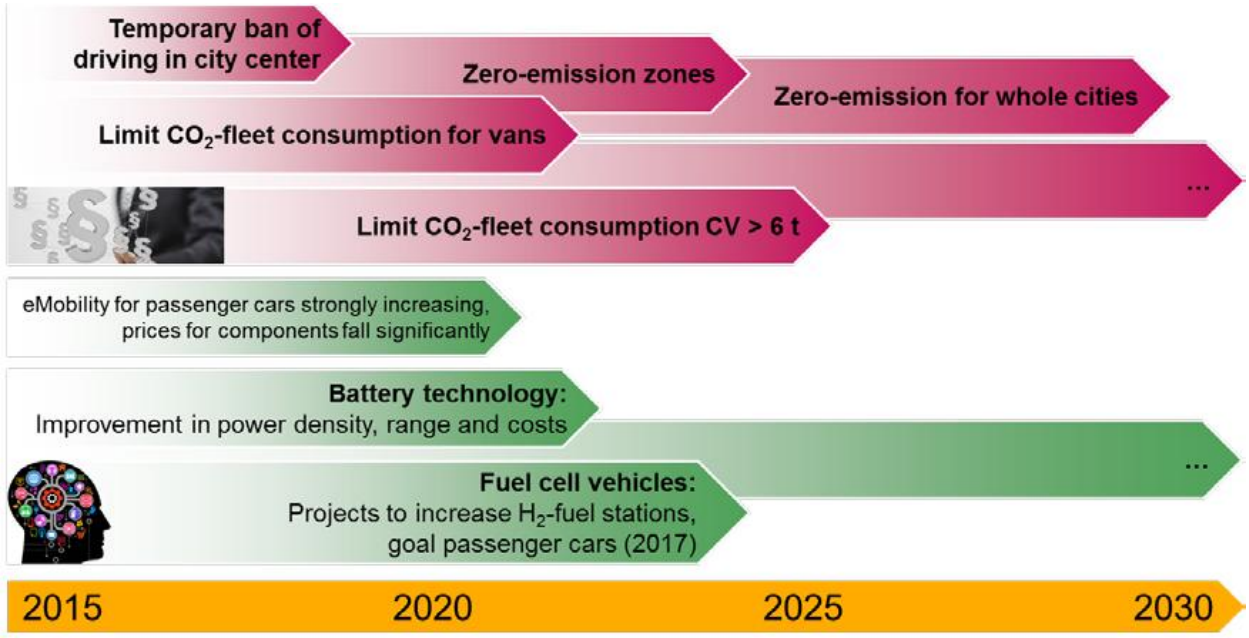

Figure 1: General Conditions Regarding E-Mobility

In several cities/megacities electric / hybrid buses are requested, as partly shown above. For the time being subsidies are very important for the success (Zero emission in inner city districts). An important aspect to be considered is that in China, the actual subsidy policy only concentrates on electric buses; former programs with hybrid buses are finished.

Considering the above, ZF sees the future trend towards electric buses (partly also plug-in hybrid solutions) in cities / megacities, mainly driven by a green image. In this context, not only the fuel efficiency of conventional powertrains needs to be taken into account, but also the emissions and its negative impact both health and environmental wise, but also political wise, which the latest discussions from passenger car technology demonstrates.

To make on aspect from above more clear, the following diagram shows the current life cycle costs for different technologies and powertrain concepts splitted into energy cost, service and maintenance, capital employment and cost infrastructure. Additionally, the cost trend for the next decades is shown.

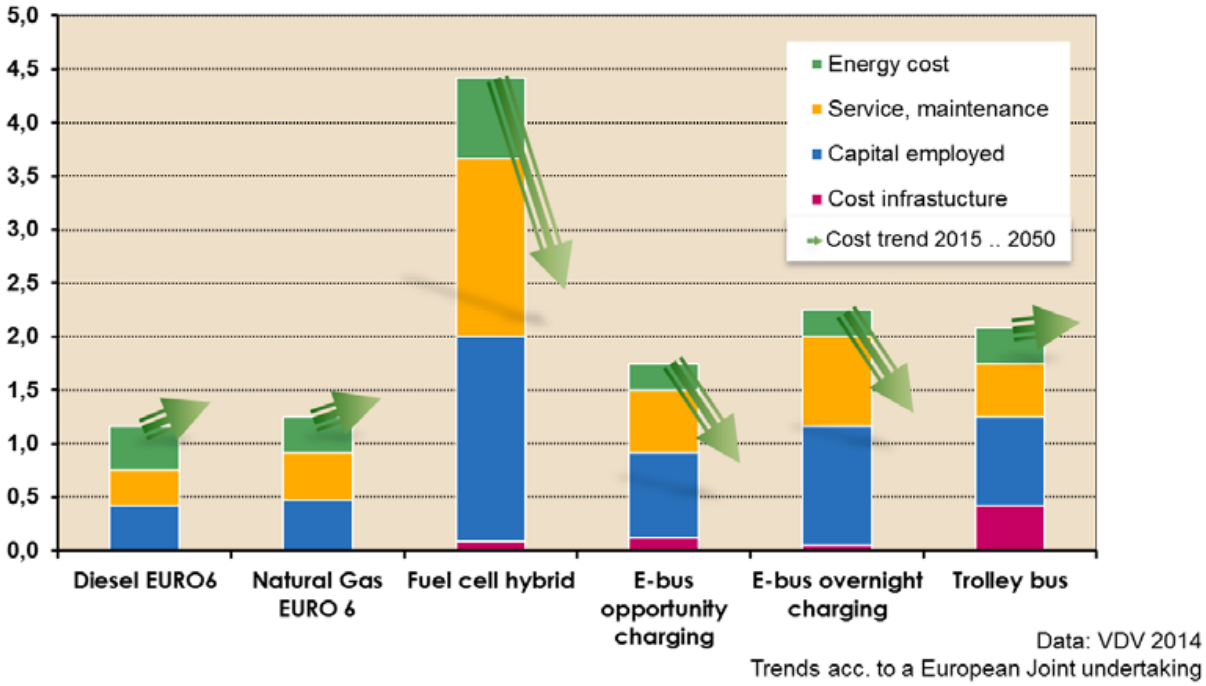

Figure 2: Life Cycle Costs For Different Technologies And Powertrain Concepts

The main statement of the above figure is that currently, the life cycle costs for fossil energy sources are lower compared the hybrid or E-drives, however, the cost trend in the next 35 years indicate a turnover in this scenario. In order to consider this trend already at an early stage, ZF was among the first to offer electric drivetrains for city busses in the late 90's. The powertrain was based on wheel hub electric engines, fed by all types of electricity (Batteries, serial hybrid with Diesel engine, fuel cell and overhead lines.

The Powertrain Of The Future – Intermediate Step: ZF Hybrid Approach Hytronic

During a certain period of time, ZF followed the trend of hybrid technology due to several reasons. Firstly, the hybrid solution seems to have the advantage of combining well known technologies regarding combustion engines with the advantage of not needing long time available electric energy storage. This concepts lead to a positive total cost of ownership for these systems, which is nowadays pushed to the back by subsidies. Secondly, the availability of accordant hybrid modules and solutions pushed the trend further. Accordingly, ZF has shown a variety of systems, beginning with electric axles, best suitable for all type of electric mobility, and two types of parallel hybrid transmissions (powershift and automated manual transmissions). In the figure below, the ZF HyTronic lite and its intercity bus components are shown.

For hybrid system a general approach was utilized to take responsibility for the complete system and its components (electric motor, transmission, power converter, hybrid control unit, operative and strategic functions). The energy storage and system integration was governed by the OEs.

The responsibility for electric systems will be shared by the OE and system suppliers. ZF will take an active part in the definition of future electric powertrains and safeguard a fruitful cooperation with OEs and operators, as well. This statement is valid for both hybrid solutions – in dependence of truck solutions for long haul operation conditions – and for full electric powertrain solutions for city buses. Especially the full electric solutions for city buses is in the focus of ZF development and research driven by fuel consumption as well as emission regulations for urban areas now and in the future.

The development of hybrid modules for ZF transmissions was the right decision at the right time. For intercity buses, coaches and trucks, there is certainly a market for this type of technology, and the further developments regarding battery technology will enable the combination of combustion engine with a sufficient possibility of storage of electric energy. ZF has with the newly developed automated manual transmission Traxon and its hybrid module the right technology in place to support these kind of applications. However, the fast development of key components of full electric powertrains such as inverters of different types of electric motors (ASM and rPSM motors) coming along with the fast development of battery technology also driven by other industrial branches (photovoltaic systems etc.) as well as the continuously stricter legal regulations regarding emissions in urban areas lead to the direction of full electric solutions – and here especially for city buses. In order to be ready for these actual and future challenges, ZF is focusing especially for city bus applications on full electrical powertrain solutions such as AVE 130 electrical axle and central motor solutions.

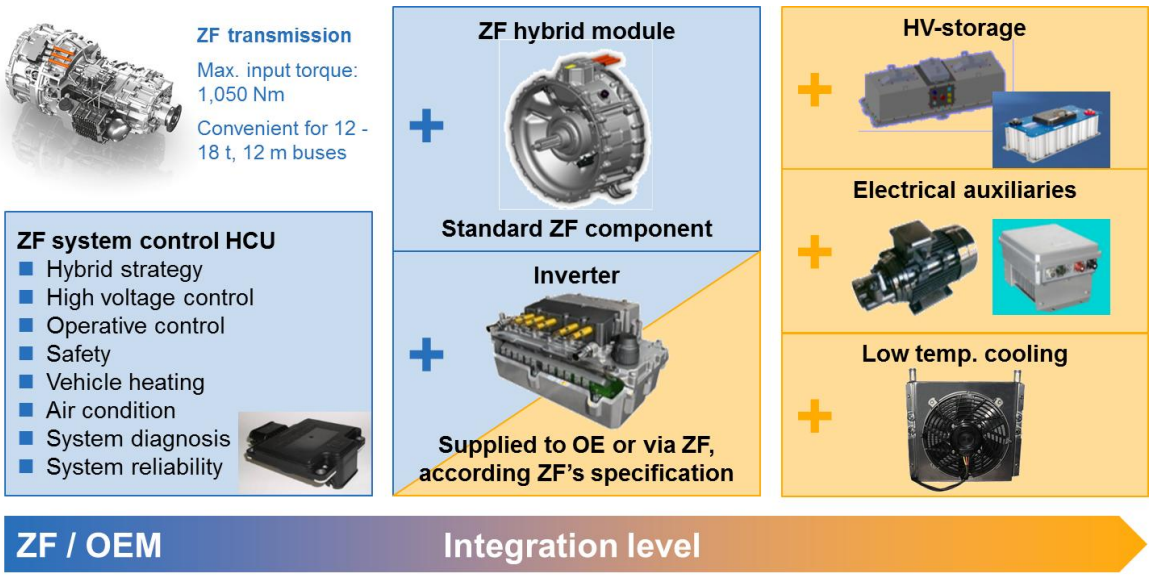

Figure 3: Hytronic Lite – Intercity Bus Components And Its Integration Level

The Powertrain Of The Future – ZF Electrically Driven Portal Axle AVE 130

ZF has furthermore set up a possibility for city buses to drive completely electrically – the electrically driven portal axle AVE 130. The reasons for an electrically driven axle can be summarized as follow:

• Purely electrically driven
• Optimum emission reduction (greenhouse gases, noise)
• Suitable for all different electrical energy sources
• Considerable fuel savings by recuperation of brake energy and in case of hybrid application by
engine downsizing
• Electric start-up possible when departing from the bus stop in case of hybrid application

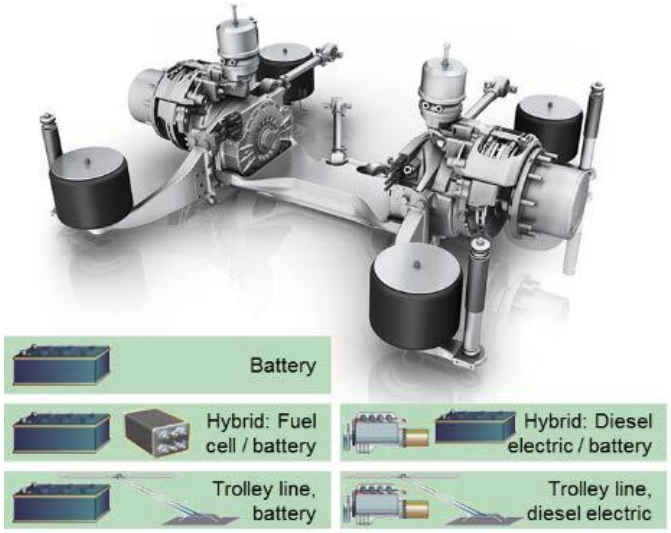

Figure 4: Electrical Portal Axle AVE 130

Currently, more than 200 axles are delivered to different OEMs in Germany (EvoBus), China (Foton, Ankai), Bozankaya (Turkey), Trolza (Russia) and others. Beside of the application in city buses, also special vehicles such as applications on airports (prototype catering vehicles) or garbage collecting vehicles (project discussion).

The advantages of AVE 130 can summarized as follow:
- Saving of at least 200 kg of weight compared to current available central motor solutions
•Integration of electric motors within the axle
•No separate motor and motor mount
•No prop shaft
- More space and clearance
•By integrating the electric motors into the wheel heads
- Enables
•Optimized design of interior room
•More powerful battery and/or more load capacity

•Better weight distribution

Beside of the electrically driven portal axle AVE130, ZF offers also axles for hybrid and central motor

architectures with portal axles. In Figure 5, an overview of the different systems is shown:

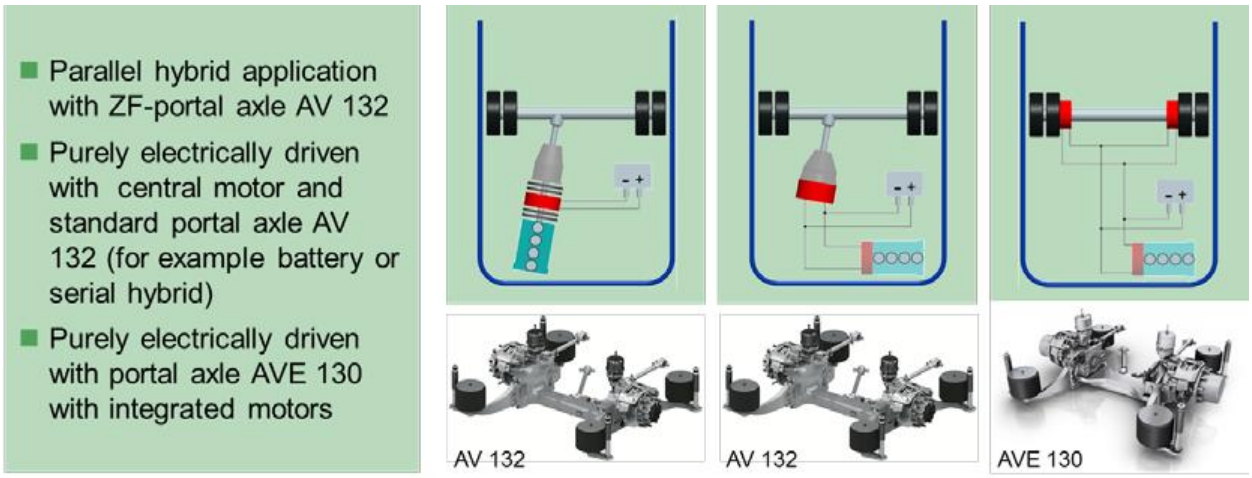

Figure 5: ZF Portal Axles For Electrically Driven Systems

In order to extend the benefit of the electrically drive portal axle AVE 130 for the customer, ZF will extend the scope of supply by adding the drive control unit considering both hardware and software to it. Furthermore, ZF will provide a list of inverters which will harmonize with the drive control unit and the axle AVE130 itself. The vehicle control unit (HCU) including vehicle operation strategy, battery management and control of auxiliaries will remain completely in the OEM responsibility. Figure 6 shows the AVE 130 System scope of supply:

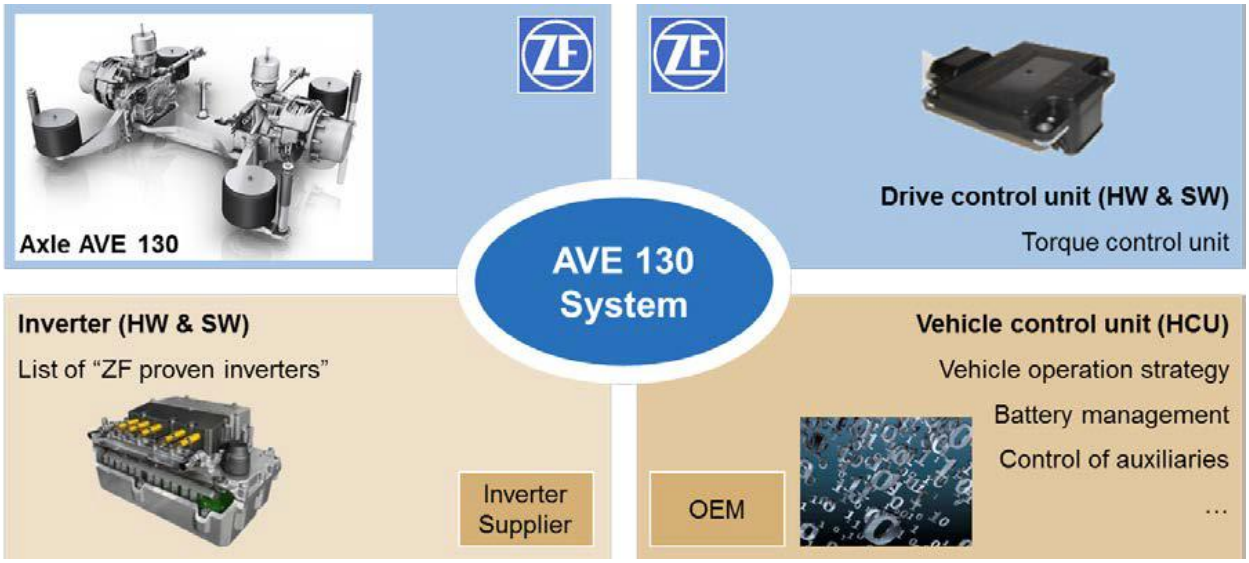

Figure 6: AVE 130 System – Scope of Supply

The Powertrain Of The Future – Market Demands For Central Electric Motors

Beside of the shown electrically drives, ZF sees also a market demand for a central electric motor. Additionally to wheel hub motors, this alternative is needed, mainly driven by cost issues. From ZF perspective, central electric motors will be used mainl in solo buses < 12 m and in midi buses. Predominantly price sensitive buses and markets are in focus – especially outside of Europe. On the other hand, there is a growing demand for low entry buses.

Based on these market analyses, the following e-Mobility Roadmap especially for Mega-cities / cities can be derived. Main result is that the conventional combustion engine will also have in future its market, whereas – for city buses – the hybrid solutions most likely will be an intermediate solution on the way to complete E- rive solutions (also driven by legislation):

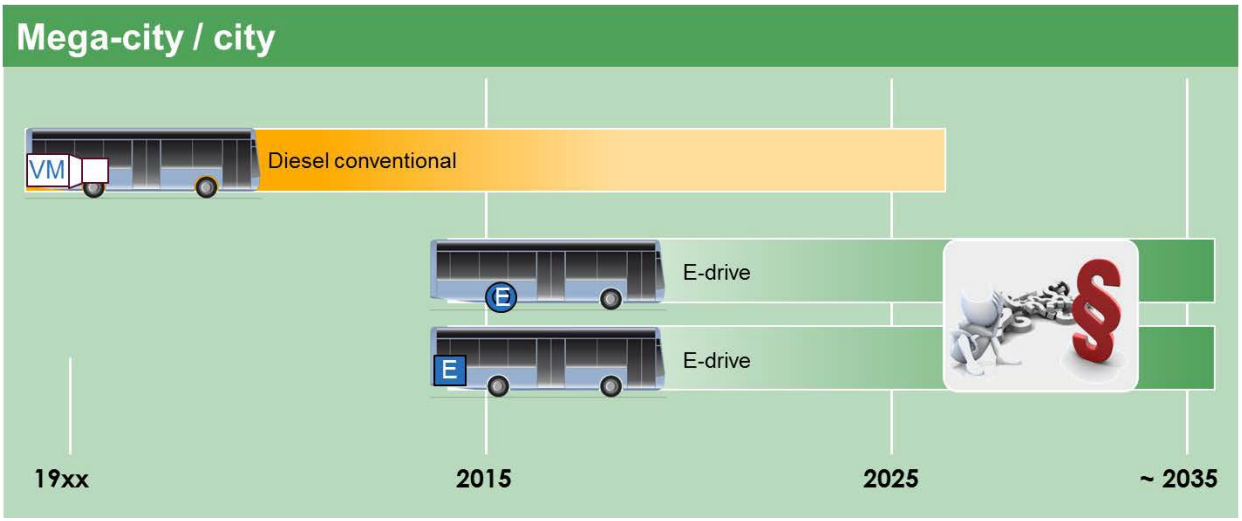

Figure 7: E-Mobility Roadmap for Mega-cities / Cities

The Powertrain Of The Future – Conclusions

Hybrid powertrain solutions have their markets especially for intercity bus, coach and truck applications. ZF has accordant technical up to date solutions with the automated manual transmission Traxon including the optional hybrid module. The hybrid technology can furthermore be taken as a bridging technology for city bus applications of the future, which will be equipped with full electric powertrain solutions. This direction is supported by both legal restrictions for emissions especially in inner city areas and mega cities as well as by the continuous ongoing development of batteries, inverters, electric motors and further components. To support and even push this trend, ZF is focusing its developments for future city bus powertrains on two main pillars: The electric portal axle AVE130 – available already today and used in different applications. Secondly, for the future, ZF is actively considering also electric central drives as part of the full electric strategy and in order to support the needs of the customer, of the people and to follow the known strategy of developing sustainable, energy efficient and environmental protecting technology for future powertrain solutions.

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