

## **Zero-emission commercial vehicles – A closer look on economic and ecological aspects**

Michael Faltenbacher<sup>1</sup>, Alex Auf der Maur<sup>2</sup>, Stefan Eckert<sup>1</sup>, Sven Altenburg<sup>2</sup>

<sup>1</sup>*thinkstep AG, Hauptst. 111-113, Leinfelden-Echterdingen, Germany, michael.faltenbacher@thinkstep.com*

<sup>2</sup>*Prognos AG, Goethestr. 85, 10623 Berlin, Germany*

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### **Summary**

Political efforts to decarbonize the vehicle fleet so far focus on cars, busses and delivery trucks. However, there is a considerable number of commercial vehicles like construction machines, agricultural vehicles and various special-purpose vehicles, that contribute significantly to GHG emissions as they are nearly 100% diesel-powered. In this study, the regulatory framework and the economic as well as the ecological relevance of the different commercial vehicle segments are assessed. For five selected commercial vehicles, the total cost of ownership and the life-cycle impact of zero-emission drivetrains are analysed in comparison to conventional diesel engines.

*Keywords: LCA (Life Cycle Assessment), LCC (Life Cycle Cost), ZEV (zero-emission vehicle), BEV (battery electric vehicle), fuel cell vehicle*

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### **1 Study background**

In December 2015, 195 countries have signed the Paris Agreement aiming to limit global warming to less than 2 °C. To do so, the global emissions of greenhouse gases (GHG) must be cut substantially in the next three decades. While other sectors (e.g. industry or heating) have successfully lowered their GHG emissions, the transport sector hasn't been able to contribute accordingly: in Germany (like in most other countries), the GHG emissions of the transport sector in 2015 were just on the same level as they were in 1990. Therefore, ambitious steps have to be taken to decarbonize the transport sector [4].

However, GHGs are not the only relevant air emissions from transport. On a local level, also nitrogen oxides (NO<sub>x</sub>) and particulate matter (PM) have to be considered, both of which are especially relevant for diesel vehicles. Especially in Baden-Württemberg, numerous cities established a Low Emission Zone ("Umweltzone"), and only vehicles with a green emission sticker (EURO 5 or EURO V, respectively) are allowed to enter this area. Furthermore, the exhaust fumes from diesel engines are of special interest in closed working environments, as there are stringent occupational health limits for NO<sub>x</sub> and PM for workplaces like tunnels, mines, warehouses or construction sites.

Taking a closer look at the transport sector, 95% of its air pollutants are emitted by road vehicles [4]. Of these, about one third originates from commercial vehicles [3]. While trucks are clearly the most numerous and therefore most important segment, commercial vehicles cover a wide variety of vehicle concepts and utilizations. Corresponding to the necessary decarbonization of the transport sector and the reduction of local

air pollutants, zero-emission alternatives to diesel engines need have to be considered for all commercial vehicle segments.

On behalf of e-mobil BW, Prognos and thinkstep conduct a study to describe the potential of zero-emission drivetrains for the whole range of commercial vehicles. With a focus on Baden-Württemberg, at first a quantitative and structural inventory of the commercial vehicle stock is established, and their general suitability for zero-emission drivetrains is discussed. Furthermore, the economic and ecological relevance of the commercial vehicle segments for Baden-Württemberg is pointed out. We also look at the current and expected regulatory framework affecting the choice of drivetrains of commercial vehicles. In a further step, we conduct an in-depth analysis of the use of battery-electric or fuel-cell drivetrains compared to conventional diesel engines in five selected commercial vehicle segments. The analysis comprises two parts, both taking into account the entire life cycle of the vehicles: With a total cost of ownership (TCO) analysis, we evaluate the economic aspects, while energy and raw material consumption as well as related emissions are examined by means of life cycle assessment (LCA). The findings are merged into conclusions and recommendations on how the diffusion of zero-emission commercial vehicles can be supported by legislative and economic provisions.

As the final report is projected to be published in autumn 2017, the project is not finished in all aspects yet. Therefore, this paper describes some exemplary and preliminary results.

## 2 Preliminary results

### 2.1 Commercial vehicle stock: how many of what kind?

Apart from trucks, there is a vast variety of commercial vehicles that can be structured by technical attributes and type of utilization. Applying these criteria, also the truck segment can be split into smaller and more homogeneous sub-segments, following German motor vehicle registration legislation. In order to get highly representative vehicle groups, we decided to differentiate the following segments:

Table1: Commercial vehicle segments

Name	(technical) definition	Field of application	Vehicle stock Baden-Württemberg (2016)
Light trucks	GVWR* 3.5 tons up to 7.5 tons	Regional transport, especially urban distribution	29,000
Medium trucks	GVWR 7.5 tons up to 12 tons	Regional transport	9,000
Heavy trucks	With and without trailer, GVWR 12 tons up to 40 tons	Long-distance transport, heavy goods distribution	24,000
Semi-trailers	Tractor and trailer, GVWR up to 40 tons	Long-distance transport	23,000
Busses and coaches	Transporting > 8 persons	Mostly regional / urban transport, partly long-distance transport	9,000
Construction machines and vehicles for other applications	Specialized vehicles for particular labour applications	Construction sites, mines, partly in closed rooms as well	Approx. 1,000 with road permission

Ground conveyors	Vehicles for local (horizontal) moving of goods	Industry, logistics and warehouses, often in closed rooms	Approx. 72,000
Garbage truck	Vehicles for garbage collection	Inner city or regional	2,000
Street cleaning vehicle	Vehicles for cleaning roads or sidewalks	Inner city public areas	2,000
Tractors and agricultural vehicles	Vehicles for agriculture and forestry	Fields and forests, public and non-public roads	Approx. 220,000 overall

\* GVWR: gross vehicle weight rating

Data Sources: Statistics of the German Federal Office for Motor Traffic and data of the German Mechanical Engineering Industry Association

## 2.2 Electricity and hydrogen: which alternatives are possible?

Among of the most promising alternatives to diesel are natural gas (CNG or LNG) and bio-fuels. As both fuel types do not comply with the local zero-emission requirement, they are not considered in this study. The remaining options are thus battery-electric vehicles (BEV) and fuel-cell vehicles (FCV). Because of the different utilization requirements, not both concepts are suitable for all segments for the time being. While there have already been some zero-emission prototypes in most segments, only some of them have reached marketability until now.

Table2: Examples for emission-free vehicles per segment

Name	BEV	FCV
Light trucks	Fuso eCanter Available	None
Medium trucks	Smith Newton Available	None
Heavy trucks	Mercedes-Benz Urban eTruck Prototype	Scania (Asko) Prototype
Trailer truck	Terberg YT202-EV Limited-lot production	Toyota 'Project Portal' Prototype
Busses and coaches	Sileo S12/18 Available	Van Hool A 330 hybrid FC Available
Construction machines and vehicles for other applications	Kramer KL25.5e Available	None
Ground conveyors	Still RX 60-25 Available	Still R 60-25 Fuel Cel Available in small quantities
Garbage truck	Build Your Dreams (BYD) Concept	APU von FAUN/ Heliocentris Protoype
Street cleaning vehicle	Bucher municipal, CityCat 2020ev Available	EMPA, PSI and other Prototype
Tractors and agricultural vehicles	John Deere, SESAM Prototype	New Holland, NH2 Available

## **2.3 Is there a significant share of zero-emission commercial vehicles in today's stock?**

According to data of the German Federal Office for Motor Traffic, the overall share of zero-emission commercial vehicles presently is more or less zero [6]. Not surprisingly, there is a close correlation between the number of BEV in a segment and the respective vehicle weight: The heavier the vehicles, the more marginal is the share of BEV due to current battery capacity limitations.

There are only two segments where already a considerable number of zero-emission commercial vehicles are operated. About 0.6% of the buses in Baden-Württemberg are driven by electricity or hydrogen. These buses are all used in urban transport, as the regular pattern of the service facilitate the operation of zero-emission fuels.

The other segment are ground conveyors. As they are predominantly used in closed areas like warehouses, and because of their small weight and the comparably short distances they drive, electric propulsion is standard since decades. Diesel driven ground conveyors are only used in special applications where particularly heavy goods have to be moved (e.g. in the paper industry) or where distances are unusually long (e.g. at harbours). Therefore, it is not surprising that 83% of ground conveyors are electrified already today. This extreme value is clearly not representative for the commercial vehicle sector.

It can be stated that currently diesel is the utterly predominant drivetrain in the commercial vehicle sector. Considerable shares of zero-emission vehicles are only found in singular segments, namely ground conveyors and, with increasing numbers, buses.

## **2.4 Legislation: Which regulations can give advantage to zero-emission fuels?**

There is a diverse set of instruments for authorities on various levels to give financial or regulatory advantages to zero-emission vehicles. In Germany, the following measures and regulations are relevant.

### **2.4.1 Road charging**

For trucks or articulated trucks with a GVWR over 7.5 tons, a toll has to be paid on all German motorways and main state roads, based on the distance travelled. The fare per kilometre is based on the number of axles and the truck's emission class. For a EURO VI truck, no additional air pollution component has to be paid, resulting in a fare of 8 ct per kilometre, which is 2 ct cheaper than EURO V and only half of all other emission classes. As of 2018, the truck toll scheme will be extended to all federal roads.

Currently, there are no exceptions for zero-emission trucks as for these the same fee is applicable as for EURO VI trucks. However, the European Commission is working on a set of legislative initiatives within the "Europe on the Move" framework. One of these initiatives will likely be a proposal to link road toll fees closer to vehicle emissions, which may result in a significant discount for zero-emission vehicles.

### **2.4.2 Vehicle tax**

New BEV and FCV get a tax exemption for 10 years. After this period, they are only taxed with 50% of the normal tax, so zero-emission vehicles profit from a considerable tax reduction.

However, not all commercial vehicles are obliged to pay the vehicle tax. Buses in line operation, communal road construction and road cleaning vehicles, emergency vehicles, certain agricultural and forestry vehicles as well as some other special vehicle categories are legally exempted from the vehicle tax. Thus, there is no tax bonus for BEV and FCV in these sectors.

### **2.4.3 Energy tax**

The energy tax also influences the economic framework of the different energy carriers used in road transport. By charging every unit of fuel with an energy tax, national authorities have a great impact on price levels. Today, the price of one litre of Diesel includes 47 ct of energy tax. On the other hand, electricity is taxed with 2 ct/kWh, but further mandatory components like net fees and the renewable energy surcharge have to be considered, too.

#### 2.4.4 Low emission zones

In 2016, over 50 low emission zones were established in German municipalities, nearly half of them located in Baden-Württemberg. Municipalities are eligible to define low emission zones based on high local concentrations of air pollutants, mostly PM. Only vehicles that meet a specific emission level may then enter these confined areas (mostly inner-urban zones). Most low emission zones already require a green badge (meaning EURO V or better) to pull in. Furthermore, there are political efforts to introduce a blue badge that would correspond to EURO VI, therefore banning even EURO V vehicles from the inner-city area.

#### 2.4.5 Emission standards

On EU level, the provision of mandatory emission standards is one of the strongest instruments. Since 2014, EURO VI is mandatory for new road vehicles. In the future, a further differentiation between low emission (EURO VI) and zero-emission standard may be made by creating a new emission class (e.g., EURO VII).

For non-road vehicles such as construction machines, EU 2016/1628 defines emission limits for all categories of non-road engines. Manufacturers must meet the defined emission standards for vehicle type approval and market placement. The standards have been tightened in 2017, and further reductions of the allowed emission levels are conceivable as the European Commission is obliged to assess the further pollutant emission reduction potential for non-road engines by the end of 2020. The latest standards require a highly efficient particle control technology. However, they are effective only from 2019 or 2020, depending on the engine power.

#### 2.4.6 Operational health and safety standards

For vehicles and machines operated in closed rooms, operational health and safety standards have to be considered. There are several obligations to minimize emissions by e.g. diesel particulate filters or waste gas exhaust. For diesel vehicles and machines in mines, a minimum of 4 m<sup>3</sup>/min of fresh air supply is required for every kW of rated engine power. Consequently, the more diesel engines are used, the more expensive the ventilation.

The limitations for NO<sub>x</sub> have been lowered significantly in 2016 and will be mandatory for indoor construction sites and mines as of October 2017 or October 2021, respectively. It is questionable whether the new limits can be met by exhaust gas treatment of the machinery and ventilation measures [8]. Thus, besides ultra-low emission engines, the use of battery electric drivetrains is tested [7].

### 2.5 When will zero-emission commercial vehicles will be competitive?

After describing today's situation regarding vehicle stock and regulative framework, it is important to deeper examine the economic parameters that influence which drivetrains are used. As zero-emission technologies are still in a phase of steady development in most commercial vehicle segments, our calculations are done for a 2030 horizon to show if and when their competitiveness will be reached in comparison to Diesel.

Therefore, we take a comprehensive look on the total costs of ownership (TCO), including assumptions for the future development of the relevant cost categories. TCO calculations are done for five exemplary zero-emission commercial vehicles in their specific use context, each compared to its conventional diesel counterpart.

Table3: Example segments for TCO and LCA analysis

Segment	Fuel Today	Alternative Fuel
Light trucks	Diesel	BEV
Heavy trucks	Diesel	FCV
Urban busses	Diesel	FC-REX <sup>1</sup>
Construction machines (wheeled loader)	Diesel	BEV
Garbage truck	Diesel	FC-REX

<sup>1</sup> BEV with a Fuel Cell-Range EXtender

By the time of writing this paper, the analysis has been performed for the urban busses segment, of which the preliminary results are presented. The calculations are based on the following vehicle data for a diesel and a FC-REX bus. Consumption data is projected for the year 2030 and considers the expected efficiency improvements.

Table4: Vehicle data (consumption data for 2030)

	Diesel Bus	FC-Rex Bus
Engine power diesel (kW)	220	
Engine power electro (kW)		160
Capacity battery (kWh)		240
Fuel cell power (kW)		30
H <sub>2</sub> storage (kg)		15
Spec. energy consumption (l Diesel/100km)	35.4	
Spec. energy consumption (kWh/100km)		86.3
Spec. energy consumption (kg H <sub>2</sub> /100km)		1.88
Annual mileage (km/a)	60,000	60,000
Expected useful life (a)	12	12
Overall mileage (km)	720,000	720,000

For buses, the following cost components are considered: investment, costs for the energy carrier and repair and maintenance costs. Taxes and other charges were not taken into account. The main cost driver of FC buses is the investment for the specific powertrain components (battery and fuel cell) [1]. Purchase prices of FC-REX busses are expected to decrease to EUR 335,000 in 2030 (-49% compared to 2015) as shown in Figure1. Taking into account the interest rate of 5%, capital costs can be calculated (cf. Figure2). Despite the significant reduction in capital costs, additional yearly capital costs of 45% compared to diesel buses will remain in 2030.

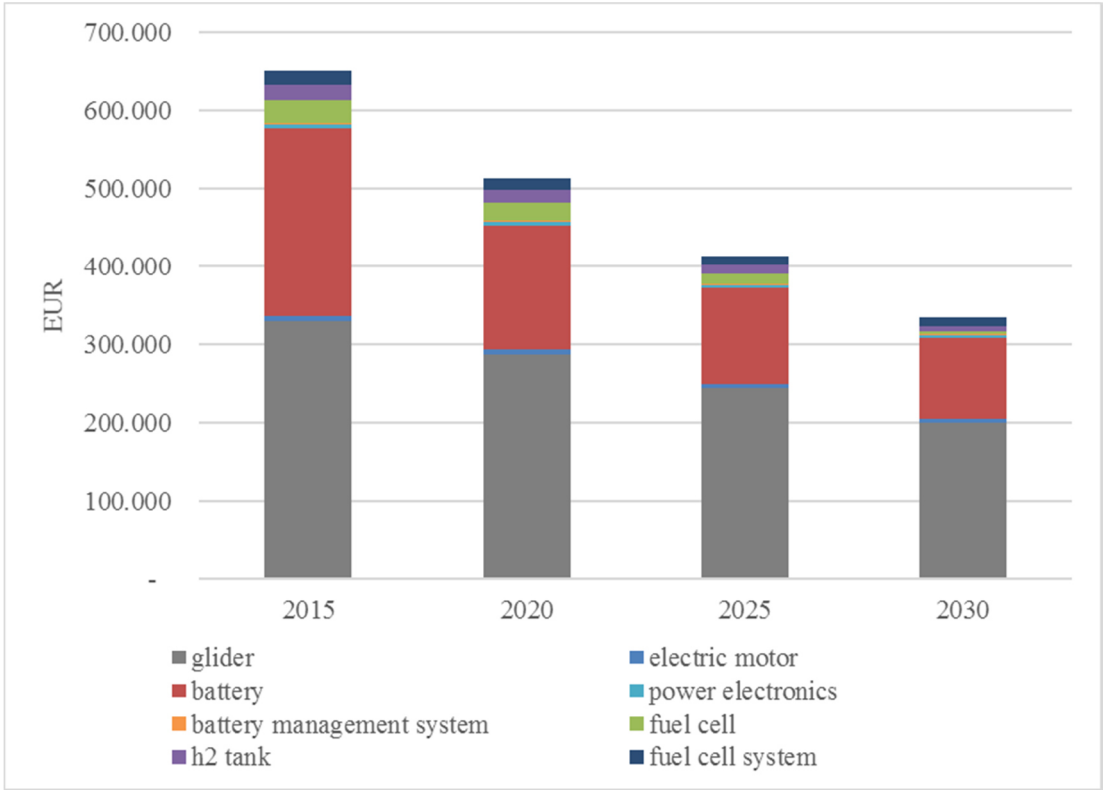


Figure1: Production costs for fuel cell bus according to components for 2015 to 2030

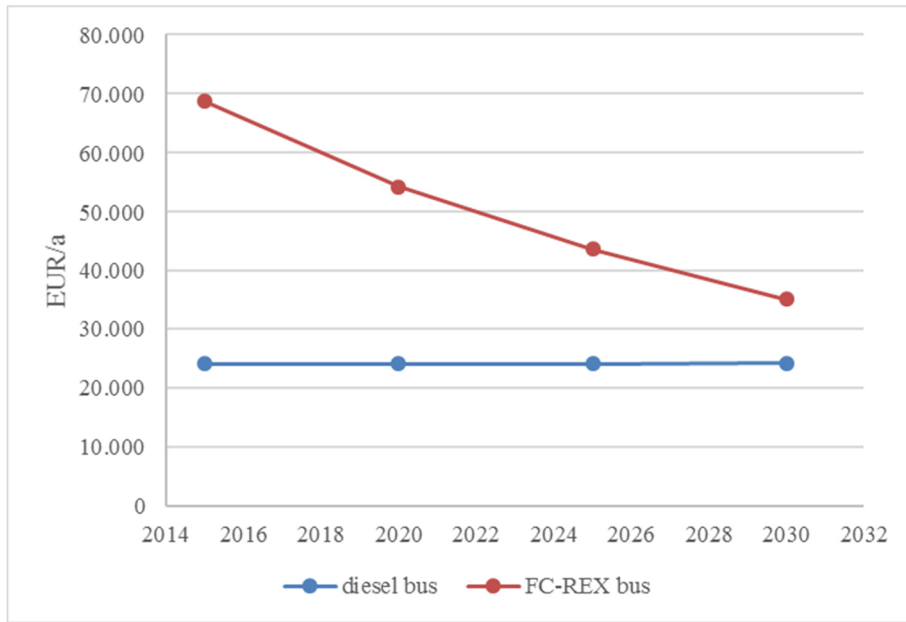


Figure2: Capital costs per year compared diesel und FC-REX bus, for 2015 to 2030

Significant cost reductions are also expected for energy costs (-28% 2030 compared to 2015) and repair and maintenance (-32%; 2030 compared to 2015). Energy costs for FC-Busses are expected to be lower than for diesel busses in 2030, while costs for maintenance reach about the same level as for diesel busses after 2020 [1].

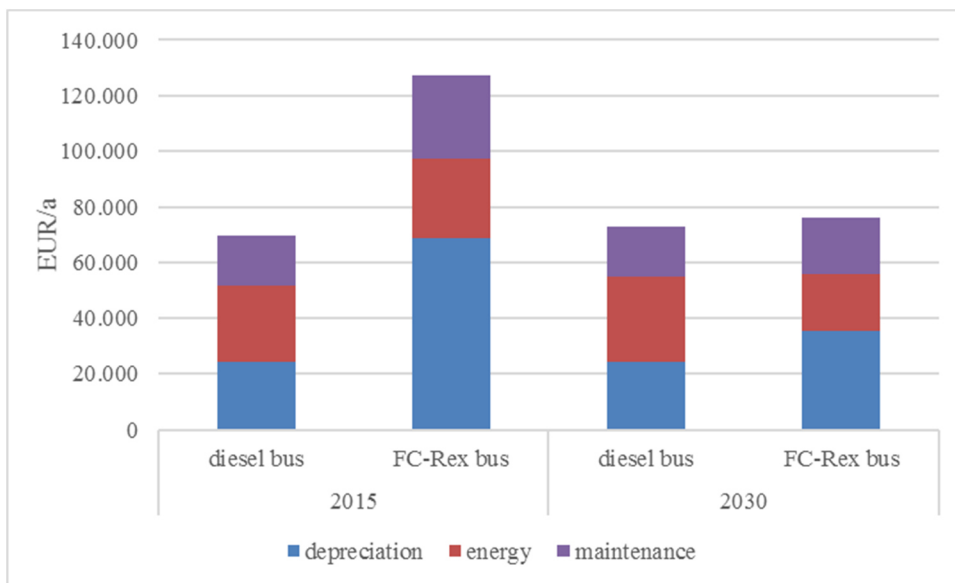


Figure3: Annual costs for the diesel and FC-REX bus, 2015 and 2030

Annual vehicle costs are expected to decrease below 80,000 EUR/a in 2030 for the FC-REX bus. In 2015 annual costs of FC-Rex busses are 83% higher compared to diesel busses. Although the costs of FC-Rex busses decrease dramatically, a cost premium of 5% remain in 2030.

### 2.6 What is the overall ecological footprint of zero-emission vehicles?

BEV and (hydrogen-oxygen) FCV are zero-emission technologies only on a Tank-to-Wheel (TtW) scale, i.e. when regarding driving emissions. To assess their ecological impact over the entire life cycle, the vehicle production and especially the generation of the used energy carriers have to be taken into account. Thus, a comparative LCA is conducted, including energy and material consumption as well as emissions generated along the whole production chain in a Well-to-Wheel (WtW) approach.

As for the TCO, we present preliminary results for urban bus segment. Figure4 depicts the material input used in the LCA model for the FC-REX urban bus, Figure5 for the conventional diesel driven bus.

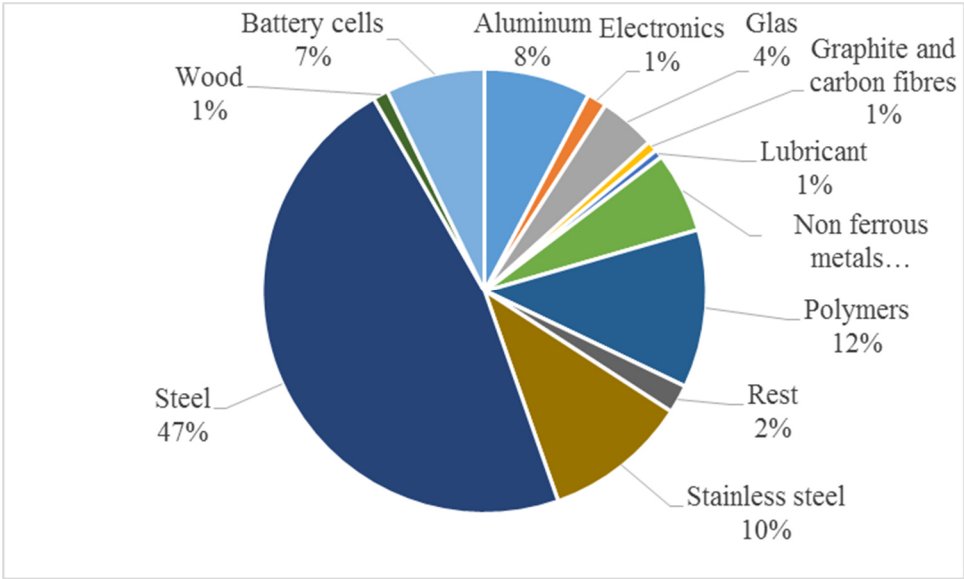


Figure4: Material composition for a 12-meter urban FC-REX bus

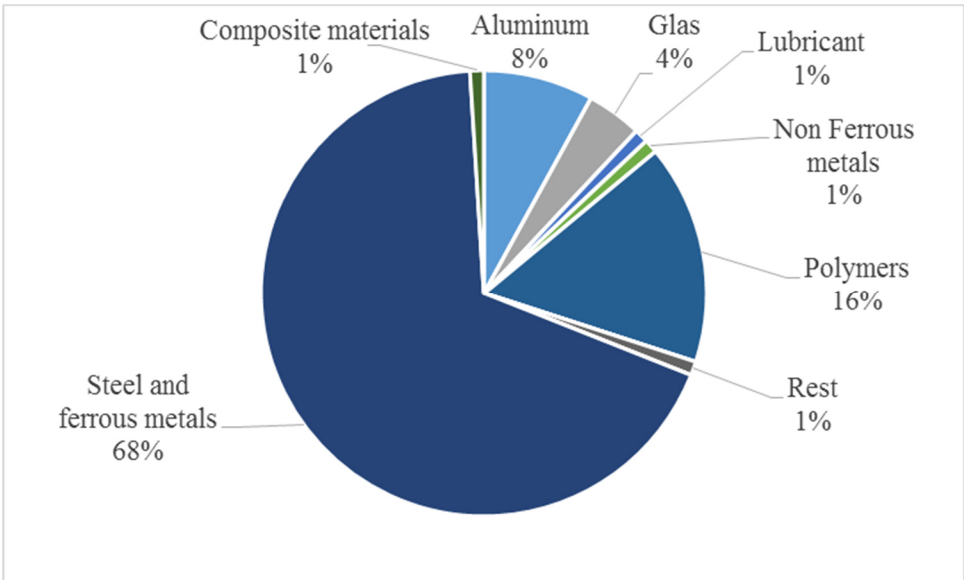


Figure5: Material composition for a 12-meter urban diesel bus

For the bus's use phase, diesel B11 is assumed as fuel, i.e. conventional diesel with a share of 10.8% biodiesel. For biodiesel production own assessments and [5] were considered. We suppose that hydrogen is generated by electrolysis in a power-to-gas process. Consequently, the ecological impact of the energy consumption of the FC-REX bus primarily depends on the energy sources from which electricity is produced. To demonstrate the full potential of GHG reduction by zero-emission vehicles, we anticipate a 100% renewable power mix as depicted in Figure6. This results in a GHG emission factor for diesel B11 of 2.818 kg CO<sub>2</sub>e/l, for electricity of 0.048 kg CO<sub>2</sub>e/kWh, and for hydrogen of 2.976 kg CO<sub>2</sub>e/kg H<sub>2</sub>.

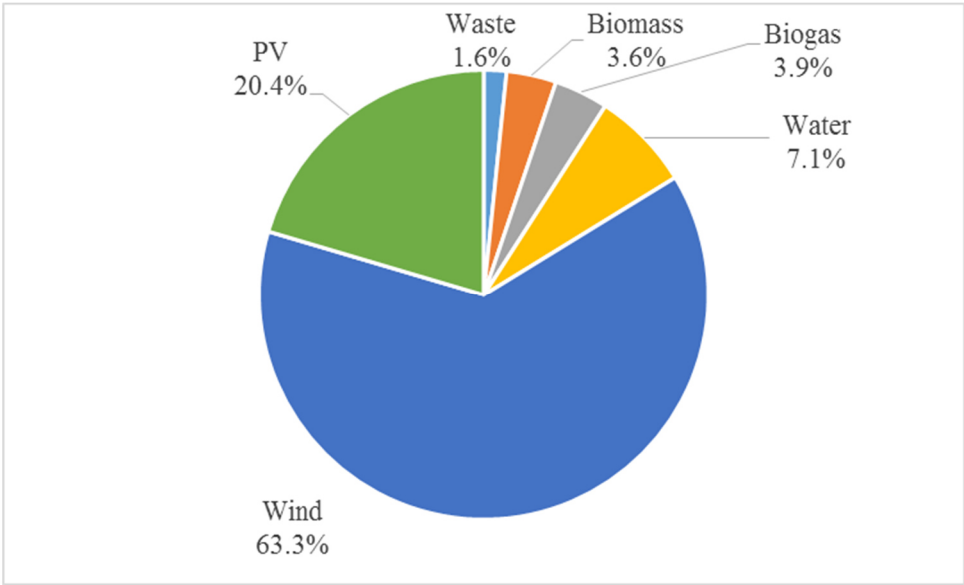


Figure6: Shares of energy carriers on electricity production

In analogy to section 2.5, the environmental performance is projected for the year 2030, comprising the whole lifetime of the vehicles based on the respective material composition and the vehicle data presented in Table4. On this basis, the lifetime GHG emissions by the different life cycle phases for a 12-meter urban bus are shown in Figure7. It can be seen that for diesel busses the highest share in GHG emissions stems from driving. Further adding the GHG emissions related to the provisioning of the diesel, the emissions associated with diesel consumption account for over 90% of the lifetime GHG emissions of the diesel bus. The GHG emissions related to the production of the FC-REX bus are about 40% higher compared to the diesel bus, mostly due to the fuel cell and the battery. While the FC-REX bus is emission-free during driving, hydrogen generation has roughly 60% of the GHG impact of diesel generation. Over the entire lifetime, GHG emissions of the FC-REX bus are about 80% lower than GHG emissions of the diesel bus.

Thus, while GHG emissions for the FC-REX bus are higher at its placing into operation, the diesel bus will outrun it after a certain mileage. Figure8 shows the development of the GHG emissions over the lifetime of the two bus concepts, and the point of intersection from which on the FC-REX bus has a lower GHG impact than its conventional diesel equivalent. With the given assumptions, the FC-REX bus is advantageous in terms of GHG emissions after having travelled only about 24,000 km.

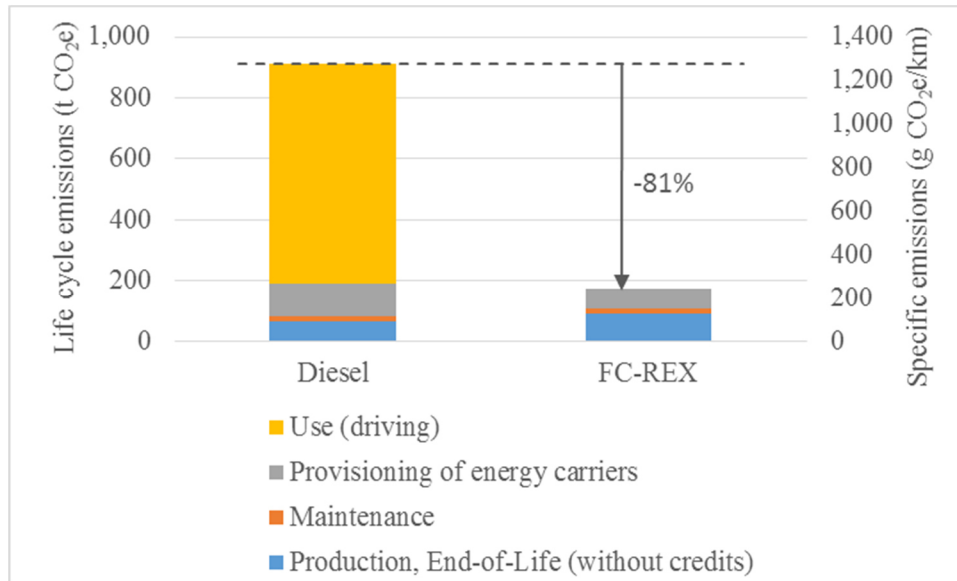


Figure7: Lifetime GHG emissions for a 12-meter urban bus, FC-REX vs. diesel

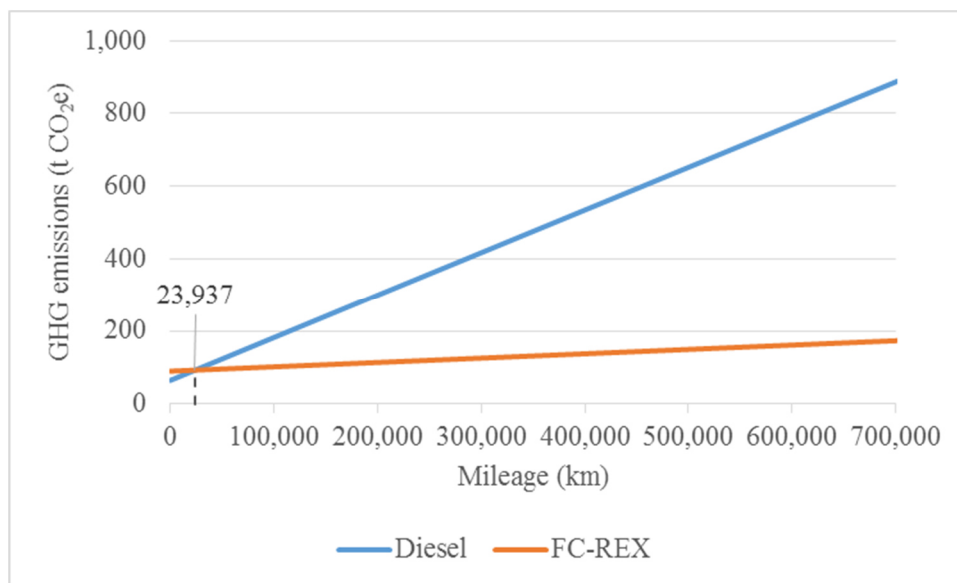


Figure8: GHG emissions by mileage for a 12-meter urban bus, FC-REX vs. diesel

### 3 Conclusion and outlook

As first out of five exemplary commercial vehicle segments, a TCO and LCA analysis have been conducted for a diesel and a zero-emission FC-REX bus. Our preliminary results demonstrate that, by applying a LCA approach, zero-emission vehicles may offer significant ecological advantages considering their lifetime GHG emissions, despite their higher production related initial impact. Additionally, as investment costs of zero-emission technologies are expected to decrease considerably over the next years, their annual costs may be even below those of diesel vehicles in 2030.

The results indicate that zero-emission drivetrains may be an appropriate measure to reduce the GHG emissions in the commercial vehicle sector. Under the assumed economic boundary conditions, zero-emission vehicles may reach TCO equality with diesel vehicles until 2030. This may raise hope that zero-emission alternatives may gain a significant share in the commercial vehicle stock, at least in some segments.

However, supporting actions may be necessary to accelerate the introduction and diffusion of zero-emission commercial vehicles. E.g., lowering the TCO of zero-emission technologies by investment grants or exemptions from taxes or road charges may be suitable instruments to accelerate their market penetration.

To get a broader picture, TCO and LCA analysis will be done for four other exemplary commercial vehicle segments as well, allowing a comprehensive view on the potential future role of zero-emission commercial vehicles. Furthermore, we will outline under which economic conditions and when zero-emission technologies become competitive in various segments. Based on the analysis, we will provide recommendations for manufacturers, end users and political authorities, on how zero-emission technologies can be supported in entering different commercial vehicle segments. To do so, the most relevant obstacles to their application will be identified. On this basis, we will outline measures for the technological, economic and legislative framework to overcome these barriers.

The release of the final report of this project is expected for autumn 2017.

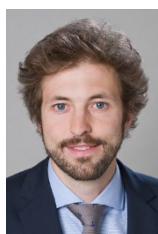
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## Authors



Dr.-Ing. Michael Faltenbacher is process engineer and did his PhD in “integrated balancing. He has been working for thinkstep since 2006. In his leading role of the mobility team, he is responsible for all national and European mandates in this field. With more than 15 years of experience, he offers sound knowledge in the transport, automotive and energy sector. The focus of his work are technological, economic and ecological assessments of transport and propulsion systems as well as the CO<sub>2</sub>-balancing of transport processes and fuels. Additionally, he is involved in LCA of transport modes and energy regimes, especially with regard to electricity and hydrogen.



Alex Auf der Maur, M.Sc. in transport economy, has been working since 2012 for Prognos (former ProgTrans respectively). He is located at the intersection between “mobility and transport” and “climate and energy policy”, where he is responsible for modelling demand, energy consumption and emissions in transport. He is specialized in the ecological and economic assessments of different propulsion systems.



Dr. Stefan Eckert has a diploma in environmental engineering and a PhD in economics. He has been working for over 20 years as consultant for industry and government authorities. He disposes of a profound expertise in the techno-economic assessment and intensively works on the use potentials and the economic effects of alternative drivetrain technologies. Furthermore, he develops CO<sub>2</sub>- and emission reduction strategies in the transport sector that he evaluates under ecological and economic criteria.



Sven Altenburg passed his diploma in social and economic geography at the university of Trier. After six years as mobility scientist at technical university of Hamburg, he joined the Prognos department «Mobility and Transport» as project coordinator in 2014. His work focusses on questions surrounding the different impacts of future technologies in the transport sector. Therefore, he is the head of the interdisciplinary Prognos-team of «Mobility 4.0», concentrating on the trends of digitalization, automation and electrification in the transport sector.