Research and development on energy- and resource-saving technologies for future commercial vehicles

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Abstract. Urban and interurban road freight transport is one of the fastest growing modes of transportation. Today 20 percent of all transport-related CO2 emissions in Germany are caused by commercial vehicles. Due to this situation new innovation technologies for future vehicles are needed, especially to improve energy efficiency and to minimize emissions in a cost-effective way.
Amongst others, powertrain electrification and reduction of the driving resistance, e.g. by means of lightweight technologies, are specific possibilities to achieve these goals, which have to be holistically matched to the particular transport task.

In the context of this paper a systematic approach for analysis and validation of novel technologies is presented regarding light commercial vehicles within urban traffic applications.
Based on Modelica / Dymola libraries new powertrain technologies were analyzed with respect to the individual transport solution and the customer's boundaries conditions. These results are considered in the design and dimensioning of commercial vehicles.
In the holistic approach to the transport task, this considers the advantages and disadvantages of the different technologies and is evaluated by a total cost of ownership (TCO) and well-to-wheel analysis of two vehicle concepts. The result is a coordinated systematic design of the car structure and the powertrain, than can also partially prototypically implemented and validated.

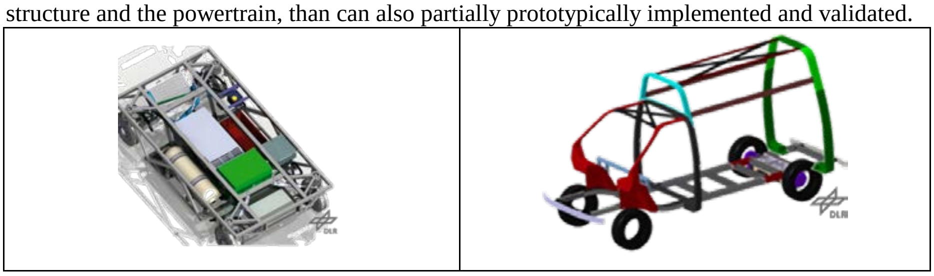


Fig. 1: The design of a drive concept (left) and a structural analysis (right).

1 Motivation, trends and drivers for future commercial vehicles

From 1960 to 2011, freight transport services in Germany have more than tripled, with the greatest rates of growth seen in road traffic [8]. This trend has remained unbroken, which leads to the logical assumption that the road freight transport volume in the EU will grow by more than 30% over the next 20 years [3].
At the same time, we must take into account global developments and trends such as the necessity for resource conservation ("peak oil"), protection of the environment through emission reduction (greenhouse gases, legislation) and the demographic shift in individual countries as well as continuing urbanisation [1, 4, 6].
In addition to these global developments, specific local challenges represent a particular challenge, especially in urban areas. Local emissions (CO_2, NO_x, and particulate matter), time- and area-related access restrictions, guaranteeing traffic safety and the development of cities regarding land and infrastructure consumption must be taken into account when implementing or retracting logistics concepts involving trucks. The objective here is to control development in such a way that an essentially CO_2- and particulate matter free city logistics plan has been implemented in larger urban centres by 2030. This plan must minimise the respective negative effects of commerce traffic for the cities' populations, yet still be affordable [4, 5, 7].

Attainment of this goal requires innovative solutions and holistic views of vehicle concepts which are co-ordinated with specific transport tasks. Innovative solutions regarding increasing loading space, low-emission power train technologies, traffic management and driver assistance systems, reduction in driving resistance through aerodynamic optimisation and lightweight construction strategies represent possible starting points for this [1, 2, 3, 4, 7].

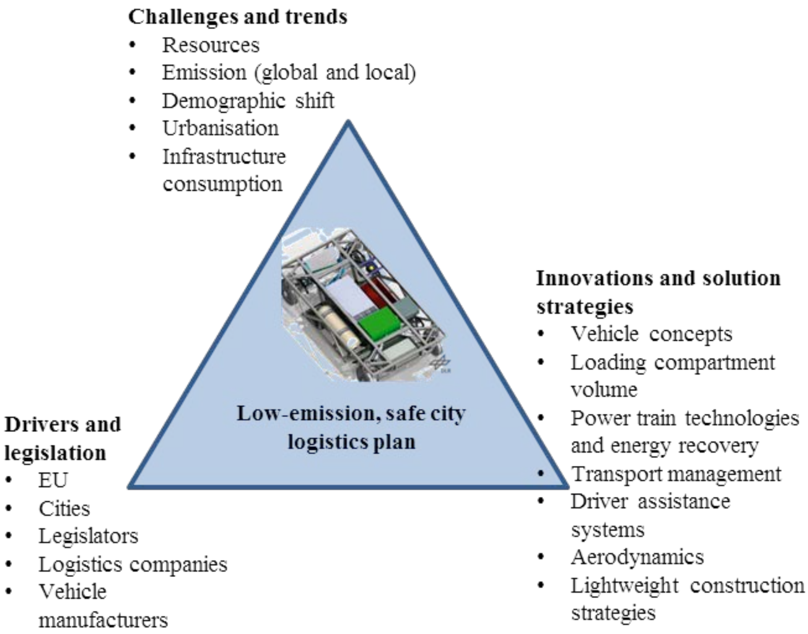


Fig. 2: Challenges and solution approaches to future city logistics planning and the required road freight vehicles

The holistic approach to developing new vehicle concepts mentioned above is being pursued at the Institute of Vehicle Concepts. As part of this paper, the process will be presented for future inner-city commercial traffic using a vehicle concept design ("Citylog EMV[1], Electric Multifunction Vehicle") as an example. The focus here is on deriving possible vehicle concepts and power train technologies in accordance with binding transport-specific requirements. Finally, the necessary considerations regarding costs (total cost of ownership) and well-to-wheel analysis are presented so that the potential of this systematic procedure and concept development can be evaluated.

2 "Citylog EMV" – Inner-city commercial traffic

In the future, delivery vehicles which will be able to supply freight locally, emission free, within cities will become increasingly necessary for inner-city commercial traffic. This chapter covers the topology of the area of implementation (Stuttgart in this example) and the derivation of an idealised driving cycle for the Citylog EMV. The performance and energy demand, together with the requirements of the transport task, are determined as input variables for the definition of the vehicle concept using this driving cycle as a basis.

[1] The Citylog EMV was a joint research project from DLR and the company HET Verkehrstechnik (Austria)

2.1 Framework conditions in the Stuttgart emission zone

Not only because of the immediate proximity, it is Stuttgart's first place standing in the 2012 Germany-wide fine-dust ranking [13] (a position not new to the city) which highlights the need for action with regard to low-emission distribution vehicles. Fig. 3 shows the current progression of the Stuttgart emission zone (area within blue border) and the route selection (red and green routes) for the Citylog EMV.

A delivery at the edge of the emission zone was chosen to serve as an example here. The starting point was somewhat inside the emission zone, since access occurred over a national motorway and this position is suitable as a possible transfer and loading point for the Citylog EMV. The EMV thus gains access via the inner-city streets marked in red in Fig. 3.

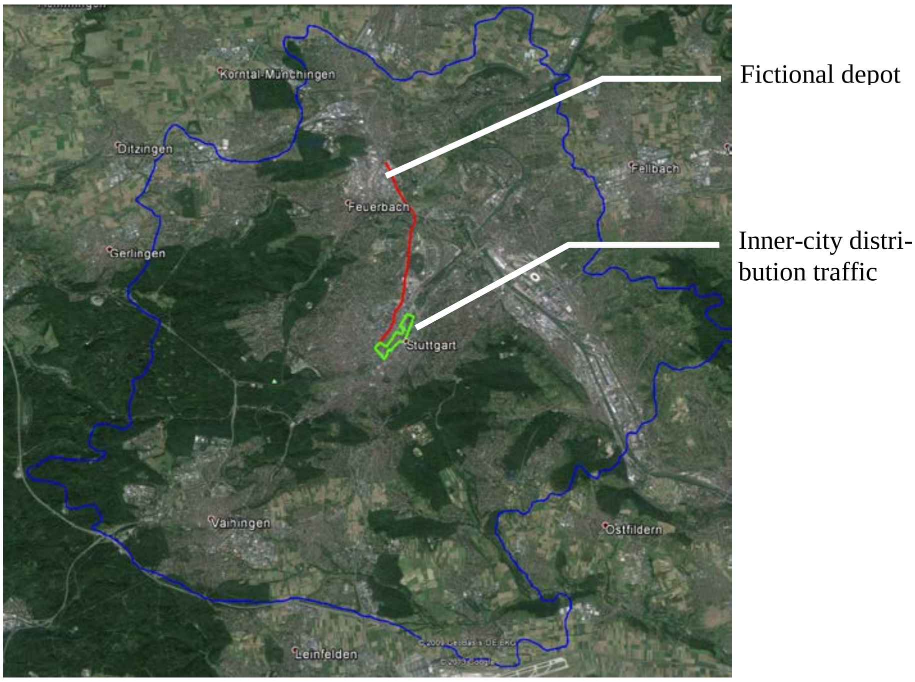


Fig. 3: Stuttgart emission zone (blue) with commute to depot (red) and delivery cycle (green)

2.2 Transport task

The Citylog EMV must fundamentally fulfil a variety of transport requirements. For this conceptual design following requirements are important:

- Cross-loading of the drivable delivery unit to a common truck cargo area.
- Loading of the delivery unit with up to three Europool pallets (as per EN 13698).
- Zero-emission and silent running for urban areas.
- Solution with a simple chassis frame.

An important criterion for deciding on the size is the vehicle's use as an intermodal system in conjunction with larger trucks for longer transport routes. The dimensions of a drivable delivery unit are limited to 2,400 mm in length and to 1,200 mm in width (without conversion).

Another important criterion is to designing the maximum payload. This was set at 2.25 tonnes, making a total permissible weight of 3 tonnes. It follows that three Europool pallets with 12 x 0.75 L glass bottles, including beverages and crates, and 40 crates/pallets, for example, can be transported.

The delivery route selected for the example is located in the Stuttgart city centre, with its shopping centres and retailers (see Figure 2, green marking). Local zero emissions and silent running is also important. This is especially necessary in sensitive inner-city areas, e.g. in pedestrian areas with old buildings and pedestrian traffic. A number of different technical propulsion concepts are available for implementing a zero-emission vehicle. Of these, concepts with a fuel cell system and purely battery-powered power train concepts can be examined and evaluated for the Citylog EMV. Additionally, the vehicle should be able to transport people, e.g. in national parks and amusement parks. This opens up an additional area of use which can be realised by modifying the design.

The simple chassis frame design is to be implemented without suspension, which results in a reliable maximum velocity of 40 km/h.

2.3 Definition of a driving cycle for the transport task

A driving cycle which is as close to realistic as possible for the purpose is necessary for designing the power train systems and working facilities of vehicles. To generate this driving cycle, actual recorded trips of different vehicles and purposes are analysed. The analysis of the driving cycles begins with a static frequency distribution of the velocities and elevations experienced. In another step, the time-based progressions of individual load cases are considered. Acceleration processes, i.e. how frequently and strongly the vehicle is accelerated, provide relevant information. The number of stop-and-go phases can be derived from this. Finally, the base, average and peak loads are evaluated. The peak load can arise as a result of driving up rises in elevation, as in the case of the Stuttgart emission zone, or as a result of heavy acceleration processes. The difference between an empty trip and a trip with a maximum load can be illustrated with the base and average loads. A statistical relevance analysis, under consideration of the load component weighting and the areas prepared in advance yield the specific reference cycle.

The specific reference cycle is the basis for a true-to-reality consumption simulation. Vehicle simulation models are created with the Modelica/Dymola simulation environment and the AlternativeVehicles Modelica library developed at the Institute of Vehicle Concepts, which is specially designed to determine the energy and performance requirements of alternative power train technologies. The simulation results describe the energy consumption of the vehicle in a realistic usage scenario. Operating strategies can be further adapted and configured individually.

Fig. 4 shows the idealised driving cycle for the Citylog EMV. It is comprised of three sub-areas: arrival, the distribution trip and the return trip. The arrival and return trip from the fictional depot to the junction in inner-city distribution traffic take place on public roads (see red progression in Fig. 3 and Fig. 4). A maximum velocity of 40 km/h is reached here, whereby the average velocity was 30 km/h over a driving time of about 12 minutes each.
Three velocities appropriate for driving in low-traffic areas and pedestrian areas are assumed for inner-city distribution traffic (4 km/h, 7 km/h and 12 km/h) (see green progression in Fig. 3 and Fig. 4). Six stations were stopped at for loading and unloading in 37 minutes. The average velocity was 6.3 km/h. Together with the assumed loading and unloading times of a total of 10 minutes, the vehicle is under way for a total of 71 minutes and covers 15 kilometres for a delivery trip from the fictional depot to the inner city and back to the depot again. Assuming an 8-hour work day, this delivery trip can be repeated six times, leaving 54 minutes available for loading and unloading at the fictional depot.

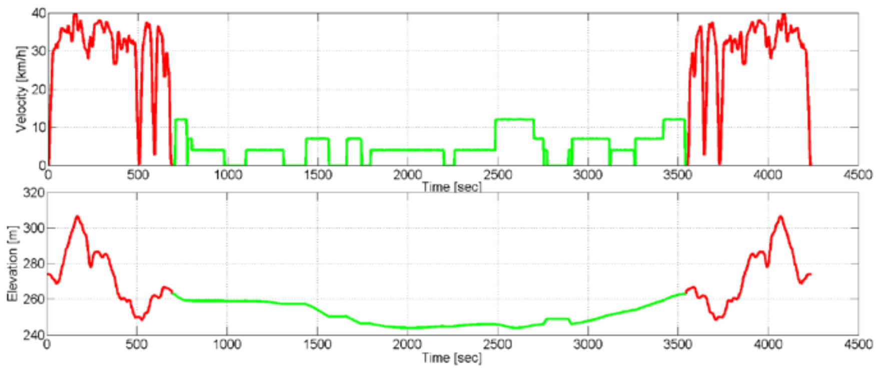


Fig. 4: Stuttgart velocity and elevation profile for the EMV

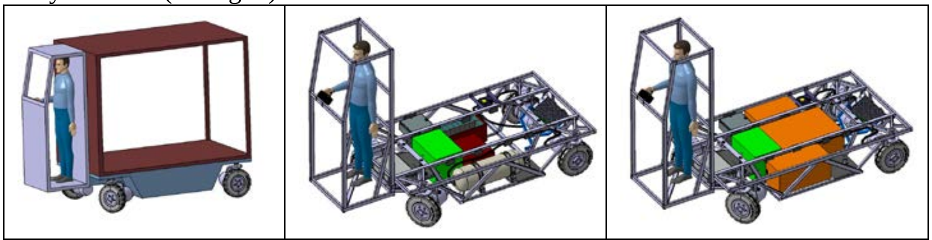
2.4 The Citylog EMV design

The basis for determining the energy requirement and performance demand of the Citylog EMV is the idealised driving cycle. The following vehicle parameters are used for the energy and power calculation:

- gross vehicle weight 3 t
- drag coefficient 0,8
- drag area 3,78 m^2
- Rolling resistance 0,02

The result is an energy consumption value of 2.7 kWh for the lap of one driving cycle, with a brief maximum required propulsion power of 26 kW.

Based on the framework conditions and requirements (see chapter 2.2), two different vehicle concepts and package arrangements were derived. A hybrid-concept version (combination battery and fuel cell system) and a purely battery-driven version are analysed here. (cf. Fig. 5)



Packaging space	Fuel cell hybrid-concept	Battery-powered concept

Fig. 5: Design space analysis and vehicle architecture

As noted in the previous section (2.3), a work shift of 8 hours is assumed. The vehicle should drive without being supplied with any additional external energy for this amount of time. This results in the following design parameters for the two versions being considered:

Table 1: Power, energy, weight and package size for both vehicle concepts

	Power / Energy	Weight	Package
Rated asynchronous machine power	**20 kW**	**28 kg**	**301 L**
Battery-powered version:			
Lithium-iron phosphate battery system	**21 kWh**	**210 kg**	**161 L**
Fuel cell hybrid concept:			
PEM[2] Fuel cell system power	**6 kW**	**18 kg**	**40 L**
Hydrogen tank (40 l):	**36 kWh**	**22 kg**	**59 L**
	(1.08 kg H_2)		
Battery capacity (lithium-iron phosphate):	**6 kWh**	**60 kg**	**46 L**

The power train system is comprised of the converter, the power train motors and the system components of the energy supply. The system components of the fuel cell hybrid version are a battery, fuel cell and hydrogen tank.

[2] Polymer electrolyte membrane

3 Overall assessment of the Citylog EMV

To get an overall assessment of the two different propulsion concepts and to demonstrate real value to the customer, systematic analyses based on the transport task presented is necessary.

3.1 Total cost of ownership consideration

The economic assessment of a commercial vehicle concept based on the respective area of use, much more so than technical feasibility, is decisive for customer acceptance. The total cost of ownership (TCO) method developed within the framework of the acquisition strategy is a suitable tool for this purpose. A life cycle-oriented assessment which considers both the manufacturing costs and the costs of operative use is paramount here. **Fig.** 6 illustrates the composition of the life-cycle costs and shows scope of the total cost of ownership (TCO) within this overall picture.

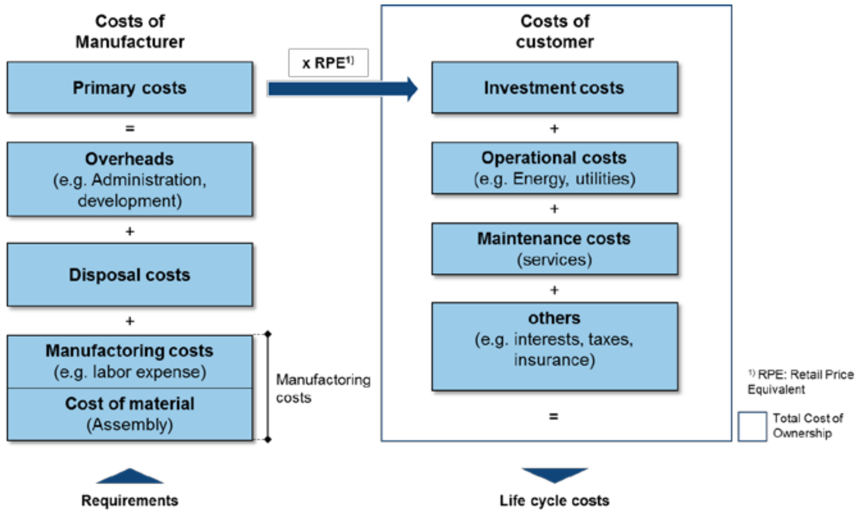


Fig. 6: Composition of the life-cycle costs [8, 9]

The assessment model used is oriented toward the system represented in Fig. 6 and determines the total cost of ownership based on the previously defined vehicle configurations, the usage and driving profile-characteristic data. The specific total costs of ownership are based on an annual value (€/a), the number of kilometres (€/km) or the transport capacity (€/tkm).

In the following, the vehicle concepts considered in the chapters above are assessed using the TCO method demonstrated. The calculations are based on 20,000 km per year of driving and a service of 10 years. The prices of the key components are taken from Boer et al. [10]. Accordingly, the basis used for the battery system was €$_{2010}$450/kWh; for the fuel cell system, it was €$_{2010}$975/kW [10]. These values apply for currently limited quantities. In addition, a low-price scenario (dark bar) and high-price scenario (light bar) were presented by analogy with Boer et al. [10]. The prices of the battery and fuel cell system were varied by +/– 25% here. The corresponding prices of the energy sources were also taken from Boer et al. [10]. Table 2 shows the underlying assumptions.

Table 2: Scenario assumptions as per Boer et al. [10]

		Low-price scenario	High-price scenario
Battery system	€$_{2010}$/kWh	338	563
Fuel cell system	€$_{2010}$/kW	731	1,219
Electricity price	€$_{2010}$/kWh	0.105	0.135
Hydrogen price	€$_{2010}$/kg H_2	3.29	7.41

Considering the configurations shown in Section (2), the vehicle investment costs result as shown in Table 3..

Table 3: Investment costs of the vehicles (separate calculation)

Investment costs		Low-price scenario	High-price scenario
EBV	€$_{2010}$	18,432	25,722
FCHEV	€$_{2010}$	18,526	25,067

To overcome the currently insufficient cycle stability of batteries[3] and fuel cell systems[4], a spare battery or fuel cell system, depending on the vehicle, was taken into consideration during the utilisation phase.

Similar to the outline data described and the vehicle configurations derived from them, this yields the total cost of ownership shown in Fig. 7 specified in €$_{2010}$/km.

[3] Approx. 1,500 cycles or 6 years [10]; Required: 10 years
[4] Approx. 10,000 actual operating hours [10]; Required: 15,400 operating hours

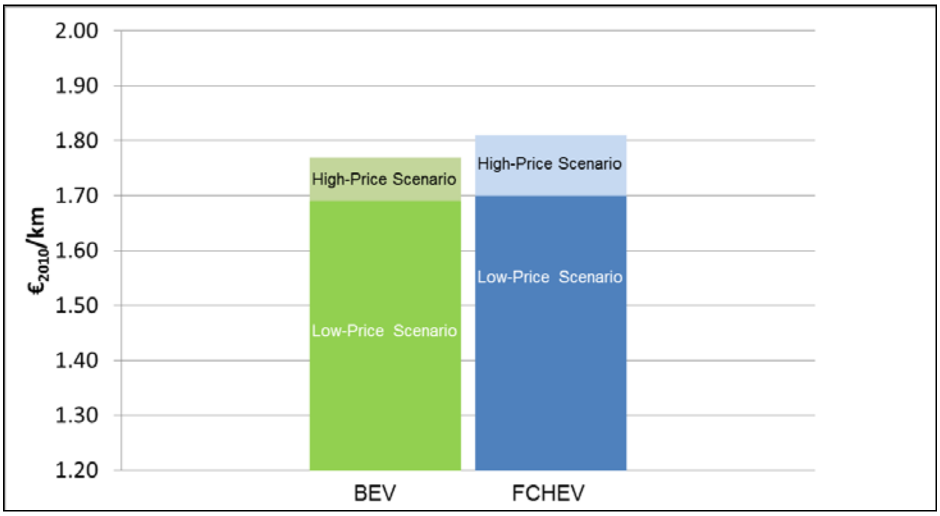


Fig. 7: Total cost of ownership of the vehicle architectures considered

According to Fig. 7 the battery-powered vehicle is cheaper with regard to the total cost of ownership (€1.69–1.77$_{2010}$/km). The total cost of ownership of the fuel cell/electric hybrid vehicle is €1.70$_{2010}$/km to €1.81$_{2010}$/km. Considering the maximum transported payload of 2.25 tonnes (corresponds to 100% utilisation), this results in the corresponding total cost of ownership with regard to transport capacity of: BEV (€$_{2010}$0.75–0.79/tkm) and FCHEV (€$_{2010}$0.76–0.80/tkm).

In the low-price scenario, the battery-powered electric vehicle profits from low investment costs[5] and low operating costs due to the lower energy demand[6] and the lower price of the energy source. In the high-price scenario, the investment costs of the fuel cell hybrid vehicle are lower, but the high costs of the energy source and the generally higher energy consumption[7] in comparison lead to higher costs during the utilisation phase, which outweighs the advantage in acquisition.

Finally, it should be noted that additional consideration of the costs arising due to missing availability, e.g. caused by loading times of different duration, can change the ranking in the total cost of ownership consideration.

3.2 Well-to-wheel analysis

Over the past few years, a large number of technological innovations have been developed to reduce the environmental burden of the transport sector. In the case of light commercial vehicles, ecological advantages can be achieved, by the use of alternative fuels and power train technologies, for instance. The emission of greenhouse gases, in particular, plays a decisive role as an indicator for ecological assessment of vehicles and as motivation for technological developments.

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[5] The costs of construction are not taken into account in the investment cost.

[6] Conservative assumption: The EBV tank-to-wheel (TTW) efficiency is 73%.

[7] Conservative assumption: The FCHEV TTW efficiency is 45%.

In general, the ecological assessment of vehicles can be made using the methodology of life cycle assessment (ISO 14040 and ISO 14044). In "cradle to grave" analyses, the entire life path is taken into account, i.e. vehicle and fuel provision, use and the end of the vehicle's life, including all upstream chains. If only the fuel chain, i.e. production and use in the vehicle, is examined, this is considered to be a well-to-wheel (WTW) analysis. Potential environmental burdens are derived from the modelled material and energy flows of a product system using various impact chains. These environmental influences encompass various different aspects such as climate change, acidification, toxicity potential and others. In this presentation, four impact categories are selected as an example: greenhouse gas emissions as an indicator of effects on the climate (CO_2eq), the consumption of fossil raw materials (oil-eq), the acidification potential (SO_2-eq) and the depletion of metals (Fe-eq).

Alternative propulsion concepts such as fuel cells and battery-electric power trains are generally accompanied by a reduction in local emissions from vehicle operation. However, the advantages can be partly or fully offset by environmental burdens resulting from energy and fuel production. In this article, the above-named impact categories of the Citylog EMV power train alternatives presented in Chapter 2 are analysed from a well-to-wheel perspective.

The product system considered includes the production of lithium-ion batteries and a PEM fuel cell as components of the power train and the production of the hydrogen for the fuel cell hybrid vehicle (FCHEV) and the electricity for operating the battery-operated vehicle (BEV), including the required distribution infrastructure. The functional unit is the operation of the Citylog EMV over a period of 10 years with a driving distance of 20,000 km per year. The specifications of the batteries and the consumption of hydrogen or electricity correspond to the specifications in Chapter 2. The batteries of both vehicles being assessed and the fuel cell are replaced once during this period. The data for manufacturing components and fuels is taken from the ecoinvent v3 LCA database [11]. The specifications are based on current production conditions. The data for fuel cell and battery production do not correspond to the exact specification of the Citylog EMV, so the calculations presented here represent an initial approximation. The calculation of impact categories is carried out using characterisation factors of the ReCiPe impact assessment method [12].

The results of the calculations are presented in **Fig.** 8, where the values of the BEV version are shown in relation to the FCHEV. The components of the FCHEV include the fuel cell and lithium-ion battery; in the case of the BEV, it is a correspondingly larger lithium-ion battery. Accordingly, fuel means hydrogen provision in the case of the FCHEV and electricity provision in the case of the BEV. With regard to greenhouse gas emissions, the FCHEV exhibits clear advantages due to the high electricity consumption and the associated emissions of the BEV. The consumption of fossil resources is highly correlated with the emission of greenhouse gases, as in the scenarios presented both the production of hydrogen and electricity in Germany at present are predominantly based on fossil energy sources. In the categories of acidification and, particularly, metal consumption, the production of power train components results in considerably greater emissions overall. It can be seen in both catego-

ries that the FCHEV has an advantage based on the calculated hydrogen consumption and the smaller required battery size.
Overall, it is apparent that in the case of the presented requirements and specifications of the Citylog EMV, the FCHEV has an ecological advantage. Both in the production of hydrogen and electricity, the environmental burdens for future vehicles can be reduced considerably if the fuels are obtained from renewable energies to a greater degree.

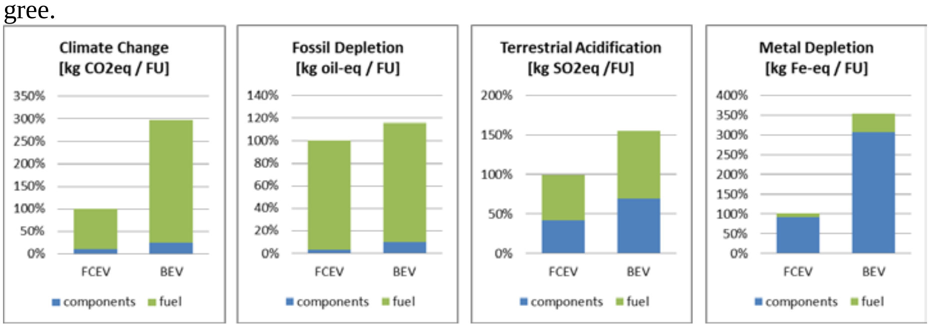

Fig. 8: The results of the four example impact assessment categories for the Citylog EMV with a fuel cell propulsion system (FCHEV) in comparison to a battery power train (BEV)

4 Prototypical implementation and validation

To validate the virtually developed concept, the equipment and resources available at DLR were used to build prototypes of the subsystems and validate the benchmark data on test benches. In this way, the fuel cell system was measured (for performance and consumption) as a hybrid system on a test bench and the operating parameters were specified based on the data obtained.
The following test benches were used for systematic analysis of the power train system:

- Battery test rig
- Fuel cell laboratory with explosion-protected equipment
- Electric motor test bench

An adjustable unit with a maximum output/input voltage of 600 V and a total output of 150 kW served as a source/sink for the test benches. This enabled test operation of the individual sub-components of the power train for commissioning or further development. After commissioning of the individual systems, it is possible to connect the individual sub-components to one another in succession, thus enabling examination of their behaviour in the system network.
Finally, the entire vehicle can be built at the Institute's own workshop and tested under realistic conditions (temperature, humidity etc.) on the climate chassis dynamometer test bench. This enables results which can be referenced to be generated, including for the EMV.

Fig. 9: Example development of a prototype construction

An important point regarding this procedure is the possibility of being able to carry this out not only on the power train side, but also on the structural design side. The fact that the payload can be increased through systematic lightweight construction without compromising the required safety plays a special role here. A special challenge is posed by ensuring passive safety here, as the alternative power train components must be protected in case of an accident. This is done using a rigid frame structure and by placing critical components in protected areas. Further considerations are also planned for the future.

5 Summary and Outlook

In this article, a systematic approach for developing vehicle concepts designed for specific transport tasks could be demonstrated using an inner-city distribution vehicle as an example. The presented approach enables various different vehicle concepts to be assessed using TCO and WTW analyses based on the transport task and the driving cycles used as a basis. Realistic comparative values can be derived using this assessment so that the optimum vehicle concepts and power train architectures can be selected for the transport task. In this approach the fuel cell hybrid-concept requires 10% lesser design space and 52% lesser weight than the battery-powered concept. The vehicle has a lesser curb weight and can carry more loads. The vehicle has a lesser curb weight and can carry more loads. Furthermore the total cost of ownership different is marginal compared to the BEV. These analyses must then be validated by implementing prototypes.

This procedure was used in the first step for the distribution vehicle and must be detailed further. For example, system optimisation using simulations and optimisation of the operating strategy must still take place. More precise analysis of the concepts and structural design is also necessary.

In addition, the ecological potential of the alternative power train types presented here must be verified via greater depth in database detail. The greenhouse gas emissions of the battery-powered concept are three times higher as the emissions of the fuel cell hybrid-concept. The degree to which the use of renewable energies can be implemented for both propulsion concepts in the future and what effects this has on the ecological balance is another issue to be addressed. Future policy guidelines, as well as further development of the necessary technologies, will also play a role here.

6 Sources

[1] N.N.: Evolutionäre vs. Revolutionäre Trends in der Nutzfahrzeugindustrie – Führt die Co2-Diskussion zum Strukturwandel?, Consulting4Drive & fka; October 2011, http://www.fka.de/consulting/studien/2011-10/c4d_fka_nfz_technologietrends_111017_final.pdf; Internet survey on 27/10/11

[2] Ehniß, R.: Innovationen im Nutzfahrzeug – Visionen, Chancen und Herausforderungen, "Technologieführer der Automobilindustrie stellen sich vor" on 14/01/13 in Stuttgart

[3] Hagemann, S.: Transporteffizienzerhöhung im Rahmen zukünftiger Gesetzgebungen, 2. Zukunftskongress des Fachmagazins lastauto omnibus, Ludwigsburg, September, 24 & 25, 2013

[4] Clausen, U.; Schaumann, H.: Entwicklung eines Konzepts zur innenstadtbelieferung mittels Elektromobilität, in: Proff, H. (ed.); Schönharting, J. (ed.); Schramm, D. (ed.); Ziegler, J. (ed.): Zukünftige Entwicklungen in der Mobilität – Betriebswirtschaftliche und technische Aspekte, Wiesbaden, Springer Gabler Verlag, 2012

[5] Menge, J.: Lkw in Städten – Aktuelle und zukünftige Herausforderungen aus städtischer Perspektive; Tagung: Trends in der Nutzfahrzeugindustrie; 8. Euroforum Jahrestagung; Munich, 05–06/03/13

[6] N.N.: Die demografische Lage der Nation – Was freiwilliges Engagement für die Regionen leistet, Berlin-Institut für Bevölkerung und Entwicklung, Erste Auflage, March 2011, http://www.berlin-institut.org/fileadmin/user_upload/Die_demografische_Lage_2011/D-Engagement_online.pdf, Internet survey on 19/11/13

[7] von Lojewski, H.: "Elektromobilität bewegt die deutschen Städte", Elektromobilität bewegt weltweit – Internationale Konferenz der Bundesregierung, 27–28/05/13 – Berlin Congress Center, http://www.konferenz-elektromobilitaet.de/programm/vortraege/Lojewski.pdf, Internet survey on 27/06/13

[8] Knörr, W. and M.: Update to "Daten- und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2030" (TREMOD) für die Emissionsberichterstattung 2013 (Berichtsperiode 1990-2011), IFEU Heidelberg, September 2013, http://www.ifeu.de/verkehrundumwelt/pdf/IFEU(2012)_Bericht%20TREMOD%20FKZ%20360%2016%20037_121113.pdf, Internet survey on 19/11/13

[8] VEREIN DEUTSCHER INGENIEURE (VDI): Wirtschaftliche Entscheidungen beim Konstruieren. VDI-Richtlinie 2235, Beuth-Verlag, Berlin, 1987

[9] EHRLENSPIEL, K.; KIEWERT, A.; LINDEMANN, U.: Kostengünstig Entwickeln und Konstruieren – Kostenmanagement in der integrierten Produktentwicklung. 6. Auflage, Springer Verlag, Heidelberg, 2007

[10] DEN BOER, E.; AARNIK, S.; KLEINER, F.; PAGENKOPF, J.: Zero emissions trucks – an overview of state-of-the-art technologies and their potential, Delft, CE Delft, DLR, 2013

[11] ecoinvent Centre (2013). ecoinvent Version 3. ST. Gallen, Switzerland.

[12] Goedkoop, M. J., R. Heijungs, et al. (200). ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition Report I: Characterisation. http://www.lcia-recipe.net

[13] SWR, Feinstaub, Stuttgart – dreckig, dreckiger, am dreckigsten, http://www.swr.de/odysso/-/id=1046894/nid=1046894/did=10981614/qr3wr2/index.html, Internet survey on 03/12/13