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Roadmap for an overhead catenary system for trucks: SWOT analysis

Strategic analysis of the overhead catenary system for trucks and competing
operating concepts in heavy road freight transport

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1 Summary

The aim of the “Roadmap for an overhead catenary system for trucks” project is to investigate systemically the logistical, economic and operational challenges associated with the introduction of trucks powered by an overhead catenary system. The project will examine suitable application scenarios, potential development pathways, and the parameters required for the system.

In this analysis, the framework of heavy road freight transport is investigated with regard to some of the key issues surrounding the introduction of alternative drive systems (Chapter 3). In this context, analysis was conducted into the strengths, weaknesses, opportunities and threats (SWOT analysis) of diesel trucks and three alternative truck drive technologies which are capable of making a significant contribution to the achievement of greenhouse gas reduction targets, and which have reached a certain level of technical maturity (Chapter 4). The results of the SWOT analysis were evaluated in relation to the criteria of economy, environment, operator’s viewpoint, and organisation.

The first issue to note in relation to **economy and innovation** is that all of the drive options discussed here (including diesel drive) can generally be “decarbonised”, as all of the required energy source material can in principle be produced from renewable electricity¹. Any differences between the drive options are in relation to the expected costs, the primary energy requirements, and the essential infrastructure. The differences in the total cost will be dominated by the energy costs in the long term. In the short term, however, they are dominated by the introduction of new vehicle technology (before economies of scale take full effect), the development of the infrastructure (provided that it is not yet at capacity), and the cost of adjusting operational procedures and the acceptance of technological and operational risks by the operators.

The current climate protection policy in the transport sector follows the paradigm of technology neutrality to a large extent. This generally always benefits those technologies with low investment costs and few other obstacles during the introductory phase, regardless of their energy efficiency, their long-term strategic implications (keyword: energy security), their long-term costs, and their long-term CO₂ reduction potential. More precisely, the effect of technology neutrality is that the market makes incremental improvements in the efficiency of conventional drive systems and does not allow the alternative drive systems to overcome the initial obstacles.

In particular, it is expected that a market ramp-up of the technology required for the overhead catenary system for trucks cannot be achieved under these constraints due to the relatively high initial investment cost and organisational obstacles. One key task in the “Roadmap for an overhead catenary system for trucks” project is therefore to determine which technology-specific state funding measures are required to realise the long-term

¹ Due to the limited potential of biofuels, it is assumed that they will not be available for the decarbonisation of road transport in the long term.

potential of the overhead catenary system technology in relation to climate protection, energy efficiency and cost-effective freight transport.

In terms of **environment, energy and resources**, primary energy efficiency has been identified as a key distinguishing criterion of the drive systems. In this regard, the overhead catenary system for trucks is clearly superior due its high level of system efficiency. As battery or fuel cell hybridisation facilitates operation without pollutant emissions, even when disconnected from the overhead line, the overhead catenary system for trucks also contributes to the reduction of air quality problems in urban areas, which are likely to be extremely harmful in the medium term. As the project continues, the question arises as to how the introduction of the overhead catenary system for trucks could benefit from current and planned air pollution control measures. It would also be useful to investigate potential synergies with the infrastructure used for trolleybuses.

The market for freight forwarding services is highly fragmented. In order to ensure the requisite planning capability and to manage the investment risk, potential **operators** of overhead catenary systems for trucks must be of a certain size and already have longer-term contractual relationships for certain routes.¹ The frequency with which individual vehicles travel on certain routes also depends to a large extent on the structure of the logistics networks. As the project continues, it would therefore be worthwhile to investigate these structures in greater detail, in addition to the planned use of a transport model and telematics data.

In terms of **organisation and acceptance**, scientific and actor-related obstacles to the further development of the overhead catenary truck system were identified. Detailed basic data on vehicle operations and logistics processes is required in order to maximise the development pathway for an overhead line infrastructure. This data is currently only available for subsections of the market. It may therefore prove useful to draw up case studies for the use of an overhead catenary system for trucks on the basis of individual data records (e.g. for a larger freight forwarder or factory transport) and to review these in terms of their generalisability. Limited application scenarios which at least approximate commercial operation are also an essential condition for the introduction of the system after the pilot phase.

A synergetic combination of an overhead catenary system for trucks and rail freight transport could enfold commercial application scenarios, especially with regard to the introductory phase of the overhead catenary system. For example, it may be worthwhile checking whether there are heavily frequented pre-carriage and on-carriage routes in combined transport which could be served by overhead catenary systems, and whether there are longer routes on which a relocation of larger transport volumes to the railways does not appear to be a realistic option in the long term.

¹ Another conceivable option may be to lease the vehicles initially.

2 Background and objective

In the past there has been a steady increase in road freight transport services. Current predictions indicate that this growth is likely to continue in the future. Simply improving the efficiency of diesel drive systems will not be sufficient to comply with climate protection targets agreed by the international community. While alternatives to the internal combustion engine are already in use in passenger cars and light commercial vehicles, alternative energy sources and drive systems must also be introduced in heavy commercial vehicles used on long-haul routes.

The overhead catenary truck system represents another opportunity to make progress with the decarbonisation of the transport sector. The overhead catenary system for trucks is powered by an electric drive system in which the traction current is drawn from a network of bipolar overhead lines. This system has significant potential to reduce greenhouse gas (GHG) emissions for truck transportation and to improve the energy efficiency of heavy trucks (per transported tonne). It can also circumvent the technical limitations of electric mobility, including those associated with the battery storage system (energy density, charging power, weight). The introduction of an overhead catenary system for trucks implies huge logistical, economic and operational challenges. The project “Roadmap for an overhead catenary system for trucks” investigates these challenges from a systemic point of view. The key questions in relation to the implementation and dissemination of the overhead catenary system for trucks are addressed in three structured work packages (APs):

- Commercially beneficial application scenarios for the overhead catenary system for trucks (AP1)
- Potential introductory pathways in the development phase until 2050 (AP2)
- Business models for the market ramp-up (AP3)

The SWOT analysis – in other words, the investigation of the strengths, weaknesses, opportunities and risks associated with different truck operating concepts – constitutes part of the first work package and helps to define the strategic framework for the overhead catenary system for trucks. To begin with, the specific environment of heavy road freight transport is investigated (Chapter 3). This environment comprises commercial and logistical, actor-specific, vehicle-related, infrastructural and political constraints. Taking this as a basis, the overhead catenary system for trucks is then compared with other alternative truck operating concepts (Chapter 4). Firstly, the system’s strengths and weaknesses are investigated, along with the market-related opportunities and risks. While the diesel truck is used as a reference due to its high market share, the consideration of LNG and H₂ trucks as an alternative to the overhead catenary system is based on their technical maturity and commercialisation potential. For successful decarbonisation of trucks, it must be assumed in all three cases that the energy source material (electricity, LNG, H₂) was produced from renewable electricity.

Finally, key points about the respective operating concepts are derived from the studies in relation to the following strategic dimensions:

- Economy and innovation
- Environment, energy and resources
- Operator's viewpoint
- Organisation

For the further investigation of the overhead catenary system for trucks, the strategic dimensions included in the SWOT analysis provide initial indications of potential drivers and obstacles in the system along with criteria for potential application scenarios, thus providing important reference points for the ongoing potential analysis.

3 Environment analysis of heavy road freight transport

Freight transport is an integral component of a highly complex network of diverse logistics services in our national economy, which is structured according to division of labour and has a high level of international interdependence. Freight transport procedures are shaped to a large extent by the following aspects:

- The integration of planning, coordination and implementation of logistics processes (transport, storage and transshipment), in which road freight transport plays a central role
- The shippers' requirements regarding reliability, planning capability, responsiveness and cost of their transport operations
- The stakeholders involved (in particular shippers, freight forwarders and carriers)
- The means of transport used
- The infrastructural framework
- The political framework (national and EU)
- International competition in long-haul transport.

The following questions are posed as a means of identifying the key issues associated with the environment of heavy road freight transport in order to give a sufficiently clear outline of the parameters of established and alternative truck operating concepts. The specific details of the individual drive systems are then evaluated in Chapter 4.

3.1 Which key players are involved in the transport industry?

Although the division of labour within the logistics sector is becoming increasingly blurred, we can distinguish between three different groups of actors in freight transport:

- **Shippers** are responsible for the production of goods and the commissioning of transportation
- **Freight forwarders** are transport market agents which organise transportation or assume responsibility for commercial freight shipments by carriers
- **Carriers** perform transportation, i.e. they are commercial companies which specialise in freight transport

Shippers can influence the means of transport as they select the carrier. Though in addition to commercial reasons, other corporate, industry-related and organisational factors play a crucial role. These include supplier structures and established customer

relationships with freight forwarders and carriers. These well-established relationships can also influence how shippers deal with new technologies in transport, particularly alternative drive systems. However, as international competitive pressure is increasing the relevance of the make-or-buy decision along the entire value chain, individual shippers are increasingly outsourcing unprofitable processes – such as the organisation of transport services – so they are then grouped together efficiently. This means that there is greater focus on the producers' core competencies.

Moreover, the areas of competency within the logistics industry frequently shift in practice. As a result, individual actors have to assume the tasks of other actors, which can make it more difficult to allocate the decision for selecting a means of transport. Furthermore, an increasingly complex network featuring countless subcontractors fosters a lack of transparency and leads to diffusion in the decision-making process in relation to transport.

Due to their core competency as trade agents in the transport markets, freight forwarders are responsible for dispatching 80% of transport volumes in commercial road freight transport (Bühler, 2006). The freight forwarder selects the means of transport, taking into account the requirements of the shipper, potential cost advantages, and the requisite dispatch costs. However, freight forwarders often outsource transport services to various carriers as a result of the significant escalation of the price war between different carriers, primarily as a result of the further development of the European Single Market.

3.2 What are the requirements of transport services in terms of demand?

The freight requiring transportation places corresponding demands on the transport service, which the different transport systems can handle to varying degrees (Müller, 2016):

- Quantity requirements
- Price requirements
- Time/speed requirements
- Security requirements
- Distribution requirements

Thus, for example, freight with high volume and price requirements usually have a low value density. These include bulk materials, which are very sensitive to transport costs and are therefore usually transported using the means of transport associated with energy cost advantages and high mass-transport capacity – almost always rail or inland waterway.

Distribution requirements are key criteria for the introduction of alternative drive systems, since in the initial phase a limited infrastructure can restrict the feasibility of certain application profiles. For example, application profiles with a high proportion of non-motorway routes are more challenging for commercial applications for trucks powered by an overhead catenary system. In addition, security requirements may be relevant to the choice of vehicle (for example, natural gas engines are not approved for the transportation of hazardous materials due to their current lower output).

Cost considerations are not the only issue when it comes to selecting a transport mode (road, rail, water). Flexibility and fast response times are important motivating factors for users of road freight transport, while the price difference is a secondary consideration.

3.3 What are the current economic trends in the transport industry?

- **The freight structure effect**
refers to the changing nature and composition of the transported goods, whereby there is a clear structural change in terms of a decrease in the transportation of low-value bulk freight such as coal and ores, and an increase in high-quality and urgent unit load freight.
- **The freight quantity effect**
refers to the fact that freight transport services generally increase disproportionately to the gross domestic product. This is triggered by the internationalisation of production processes and a reduction in manufacturing depth at individual sites.
- **The logistics effect**
refers to the introduction of new production and logistics concepts and the associated changes in the spatial division of labour and the international interdependence of production sites. The intensification of exchange relationships resulting from the reduction in manufacturing depth favours smaller transport units and leads to a further increase in transport intensity. The trend towards smaller transport units is also enhanced by just-in-time deliveries (without a buffer warehouse).
- **The integration effect**
refers to the impact of the spatial expansion of freight transport (evidenced by the increased growth of transport services (tonne-kilometres) in relation to the transport quantity (tonnes)).
- **Harmonisation**
refers to the alignment of the framework for road freight transport between the EU member states (with the aim of creating equal competitive conditions).

These economic trends increase the urgency of transport services, increase the cost pressure, and place higher demands on the flexibility of shipments. In this regard, the growth of transport services is closely tied to economic performance, and foreign trade in particular (Clausen, Holloh, & Kadow, 2014; Kille & Schmidt, 2008). These aspects also lead to an integration of planning and management processes within the logistics concepts. Road transport can best serve these requirements at this time, which is why attempts to shift freight transport from road to rail and inland waterway in recent years have been largely unsuccessful.

3.4 What role do rail and inland waterway transport play in comparison with long-distance road freight transport?

Road freight transport has dominated the entire domestic freight transport market for many years. This can also be seen in an exclusive consideration of long-haul transport

covering distances of 150 km and above (see Figure 1), although rail transport does emerge as competitive for long-haul transport with appropriate transportation requirements (such as quantity and cost requirements).

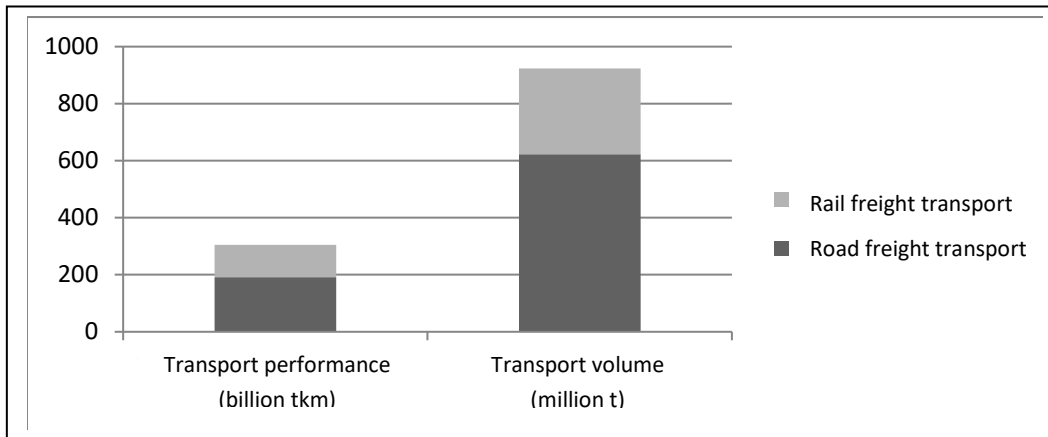


Figure 1: Transport performance and transport volume for distances of 150 km and above (BMVI, 2016)

Rail transport accounts for an 18% share of transport services for long-haul freight transport. In addition to wagonload freight, trainload freight is a particularly attractive option for the transportation of bulk freight (Kille & Schmidt, 2008). Although the investment in rail infrastructure over the last ten years has increased more quickly than the investment in roads, there has been no change in the modal split of freight transport. This is due to the economic demand for flexibility, which road freight transport can better fulfil than rail freight.

Rail freight transport in Germany is concentrated on a few routes due to the benefits of route specific directionality, related to a correspondent forerun. Important routes include the Rhine Valley and the Hamburg-Fulda-Nuremberg-Munich corridor, as well as some connecting routes to neighbouring countries. The reasons for this include the aforementioned market effects, the decline in private railway sidings and the decrease of the rail network so that it no longer provides area-wide coverage. Generally, in the past, the rail transportation of passengers rather than freight was taken into account when planning the transport network and services, and this is partly responsible for the decline in the railway's modal share of freight transport. This results in capacity bottlenecks at rail transport hubs, particularly in relation to freight transport. Noise problems are another important issue in relation to rail freight transport. Significant investment in railway freight cars would be required in order to make substantial improvements.

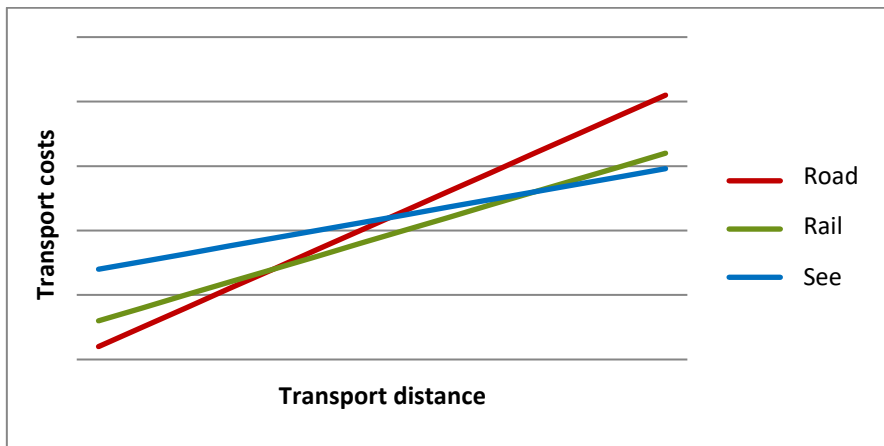


Figure 2: Comparison of road, rail and sea transport costs (Rodrigue, Comtois, & Slack, 2006)

Ultimately, inland waterways account for a stable but relatively small proportion of German freight transport services. In particular, the transport of bulk materials (gravel, coal, etc.) is economically viable by inland waterway (BMVI, 2016). Due to its specific strengths, inland waterways are in greater competition with rail than with road freight (Müller, 2016). As a result, there is relatively little interaction between inland waterway transport and road freight transport.

3.5 What are the key features of combined transport (CT)?

As a result of Germany's central location in Europe, freight transport performance is growing more quickly than the transport volume. This means lengthened transportation distances, which also provide an opportunity for combined transport, i.e. different modes of transport linked within a single transport chain. As combined transport involves shifting freight to more environmentally friendly modes of transport like rail and water, these receive public backing. Trucks that are used solely for pre- and on-carriage in CT are therefore eligible for the following legal benefits:

- Exemption from motor vehicle tax
- No driving ban on Sundays and public holidays
- 44t gross vehicle weight rating (GVWR) instead of 40t

Combined transport must comply with the following conditions in order to be eligible for these benefits:

- The distance between the shipper and the shipping terminal and between the recipient and the receiving terminal has to be as short as possible (max. 150 km as the crow flies pursuant to Council Directive 92/106/EEC)
- The majority of the route must be covered by rail or ship (min. 80%)

Combined transport is an alternative to road freight, primarily for long-haul transport. In 2014 the share of combined transport in long-distance haulage (distances over 150 km) was 14.6% (BMVI, 2016). The CT infrastructure currently has a good level of coverage, with

around 70 accessible transshipment terminals. CT terminals therefore often play a role in site selection for logistics centres because the rail connection also represents an alternative to the overstretched road network. Challenges for the combined transport in Germany are currently:

- The higher level of capital commitment costs for rail compared to road transport due to the lower response and transport speed
- The integration of all different stakeholders (e.g. shippers, recipients and rail transportation companies)
- The overloading of CT terminals at peak times
- The poor accessibility of some CT terminals by road

In regards to the introduction of alternative drive systems, the Combined Transport can provide examples of certain incentives such as the aforementioned operational benefits as well as indication of potential origin-destination relations. In this context, greater attention should be paid to the highly-frequented routes used for pre-carriage and on-carriage in CT.

3.6 What vehicle types are currently used for which application profiles?

According to the Federal Motor Transport Authority (KBA), the vast majority of trucks (over 90%) have a standard assembly. This includes platforms, insulation structure, open boxes and other closed boxes. Trucks with closed boxes are the largest single item, accounting for approximately 43% of all assemblies. However, these statistics include all weight classes, and some of the special assemblies used in the construction industry are not used for heavy trucks. Additionally, car transporters are not usually classified in the heaviest weight class. The allocation of the different types of assembly makes it possible to draw some conclusions about usage. One conclusion is that tractor units are used primarily to transport conventional break bulk freight or container freight. A detailed overview of the various assemblies in the different size classes is shown in Figure 3.

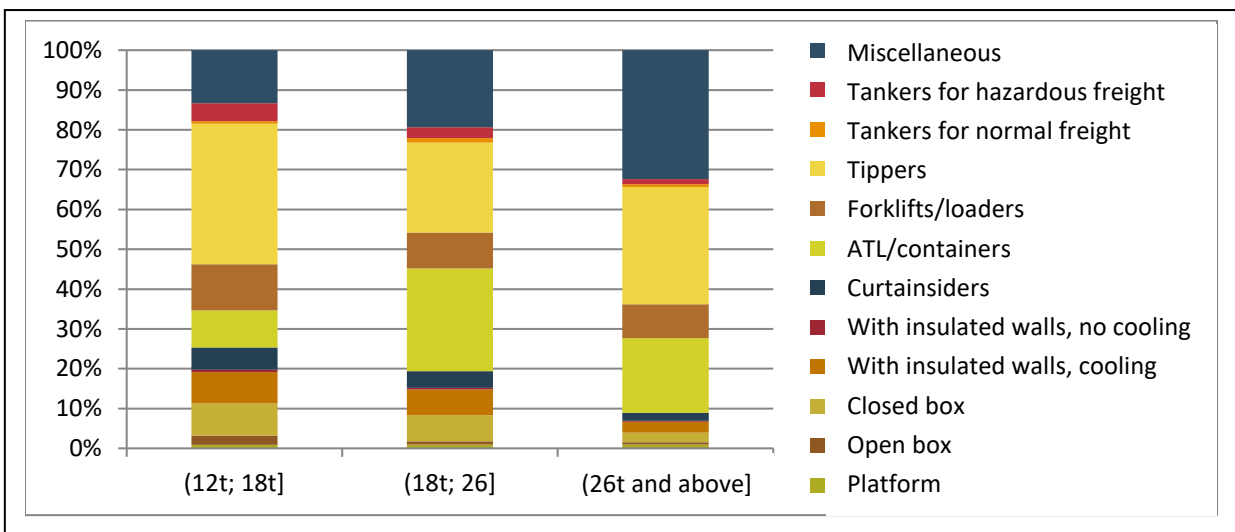


Figure 3: Overview of the vehicle assemblies for the size classes from 12t GVWR and above (KBA, 2016)

The issue of the vehicle types used is closely linked with the choice of transport routes and distribution systems and therefore also with the industry which has ordered the transportation. The following factors have a major impact:

- The question of **flexibility** on the forwarders side in relation to scheduling and transport quantity
- The nature of the **procurement strategy** (single, dual, multiple or global sourcing). Small numbers of fixed suppliers with a greater planning capability for production or sales volumes require less “mixed transport”, i.e. consolidated shipments from multiple producers
- The choice of **logistics sites** (also depends on the sector). This makes it possible to differentiate between industrial logistics sites, central logistics sites, and logistics sites in metropolitan areas. The type of logistics site affects the preferential types of truck used, but there are also other factors influencing the vehicle choice. In food retailing for example, subsidiaries are not only supplied by local transport vehicles but also by articulated trucks, which means an exception to a type of distribution, which normally relies on medium weight vehicles.

3.7 What role do non-resident vehicles and cabotage play in German long-distance freight transport?

The mileage covered by non-resident trucks has risen steadily in recent years. They accounted for around 40% of the entire truck mileage on German motorways and toll roads in 2015 (BAG, 2016). Polish, Dutch and Czech vehicles have the largest share. If this trend continues, it is predicted that, by 2040, the majority of the mileage covered on toll routes will be attributable to non-resident trucks (Fahren et al., 2016). The term “cabotage” means that non-resident carriers provide transport services within a country following cross-border carriage. Cabotage accounts for around 5% of the above-mentioned 40% of German road freight transport provided by foreign vehicles.

For a long time, foreign transport services were largely prohibited in order to protect the domestic transport industry. However, this led to increased empty runs and associated economic and ecological disadvantages. For this reason, cabotage services within the Internal European market were generally approved (see the EU’s cabotage regulation 1072/2009/EC or the German Ordinance on International Road Haulage and Cabotage [GüKGrKabotageV]). Regulated is amongst others the number of follow-up runs of an incoming foreign truck, before it has to leave the country again. According to these regulations, trucks may make three follow-up contracts, before they have to return to the country in which the transport company’s registered office is located.

The easing of cabotage restrictions promotes a further increase in the proportion of non-resident trucks covering domestic mileage. This has several direct implications for the logistics sector:

- Intensification of competition in road freight transport
- Increasing heterogeneity of stakeholder interests
- Increasing complexity of transport chains (including connecting journeys)

The described trend towards non-resident vehicles also has an impact on the market opportunities for an alternative energy supply infrastructure: If this infrastructure achieves

relevant coverage only in Germany, the transition to this system will present significantly greater obstacles for non-resident vehicles. In the case of the overhead catenary system for trucks with diesel hybridisation, the vehicles would be able to use their combustion engines abroad, but the high procurement costs would only be viable for very high mileages on electrified routes in Germany.

3.8 What would the introduction of CO₂ limits mean for trucks?

While mandatory fleet targets for CO₂ emissions for passenger cars have been in place for some years, for trucks so far only the pollutant emissions (including CO and NO_x) have been regulated on the engine test bench¹. The EU is currently looking into options for introducing CO₂ limits also for trucks.

The current plan is to introduce CO₂ monitoring for heavy commercial vehicles on the basis of corresponding simulation software (VECTO)². The monitoring process, which is expected to start in 2018 and last for two years, could form the basis of a future limit or target value legislation. Monitoring is also designed to promote the standardised recording of energy consumption and CO₂ emissions from heavy commercial vehicles on the market. At the same time, it provides the basis for certification of the consumption and CO₂ emissions from heavy commercial vehicles, and for the development of new measuring procedures to test components which affect consumption.

The introduction of CO₂ limits could lead to a breakthrough for a range of efficiency technologies in the truck sector whose amortisation period currently exceeds the operators' planning horizon. Depending on how ambitious the limit values are, they may also favour the introduction of alternative drive systems. The extent to which the various drive options would benefit from this depends largely on their design. The crucial issue here is: Which vehicle segments will be addressed? For example, battery electric drives are more likely to be used in smaller delivery trucks.

The efforts being taken by several countries and the claims from various companies in the private sector to implement a legislation for CO₂ limit values for heavy commercial vehicles, show an awareness of the urgency of CO₂ reductions in road freight transport.

"We therefore call on you to propose post-2020 standards that reduce CO₂ emissions and fuel consumption of new trucks and trailers" (IKEA, Nestlé, DB Schenker, PHILIPS, & other companies and NGOs, 2016)

However, the CO₂ limit legislation remains largely dependent on the efforts of the European Commission (to whom the letter quoted above is addressed) and its monopoly of initiative in relation to European legislation. Nevertheless, the urgency of increasing the efficiency and reducing emissions from drive systems in heavy trucks is reinforced to a large extent by the climate protection targets agreed by the international community. The development of the commercial vehicle industry and the parameters for vehicle fleet operators will in future be more closely flanked and determined by political measures such as the CO₂ limit legislation.

¹ EU Directive 91/542/EEC and EU Directive 595/2009

² <http://www.acea.be/publications/article/infographic-vecto>; Last accessed on 21 April 2017.

3.9 What role does the electrification of long-haul freight transport currently play at EU level?

The current White Paper on Transport (2011)¹ elevates climate protection in transport to a primary objective and calls for a 60% reduction of greenhouse gas emissions in the transport sector by 2050 compared to 1990. It also advocates shifting long-haul freight transport from road to rail and includes key EU directives for the development of trans-European transport networks (TEN-T) (TEN-T 1315/2013², CEF 1316/2013³). As the overhead catenary system for trucks is likely to address similar transport markets as the railway due to its alignment with traffic routes and its high demand for grouped transport, it must be assumed that there might be a contradiction to the EU's transport policy.

On the other hand, the TEN-T directives are also accelerating the electrification of road transport, such as the AFI Directive⁴. The directives do not contain any specific reference to the use of overhead catenary systems to power road transport because the technology had not yet been discussed at international level when the directives took effect. As overhead catenary systems can contribute to the specified decarbonisation targets, they might be expected to qualify for TEN-T funding from the CEF Innovations scheme. However, the first three calls for funding have almost exhausted the resources of the CEF, which have so far been directed mainly into the development of LNG and H₂ infrastructure and vehicles in a few member states.

Although the overhead catenary system for trucks is consistent with the EU's climate protection targets and the efforts to electrify road transport as the most important alternative energy source, it does not (yet) fit with the EU's transport policy, as it is not aligned with the shift to rail.

3.10 What plans are in place for the development of transport routes?

At national level, the Federal Transport Infrastructure Plan (FTIP) is the key planning instrument for obtaining, developing and building new transport routes across all modes of transport. One of the primary issues of the current FTIP published in 2016 is a focus on maintenance rather than new construction, highlighting the importance of preserving the substance of transport routes. The FTIP is drawn up by the Federal Ministry of Transport and Digital Infrastructure (BMVI) and approved by the cabinet. In 2015, investment in the federal highways network⁵ totalled approximately €5.13 billion (BMVI, 2016). The

¹ EC (2011): White Paper on Transport. Roadmap to a single European transport area – towards a competitive and resource-efficient transport system. COM (2011) 144, Luxembourg.

² Regulation (EU) No 1315/2013/EU of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU.

³ Regulation (EU) No 1316/2013 of the European Parliament and of the Council of 11 December 2013 establishing the Connecting Europe Facility, amending Regulation (EU) No 913/2010 and repealing Regulations (EC) No 680/2007 and (EC) No 67/2010 (OJ L 348 dated 20/12/2013).

⁴ BMVI (2016): National Strategic Framework for expanding the infrastructure for alternative fuels, part of the implementation of Directive 2014/94/EU.

⁵ This refers to the gross capital investment which includes both capital-widening and rationalisation investments, as well as replacement and maintenance investments.

transport infrastructure available for road freight transport in Germany includes about 13,000 km of federal motorway and a regional road network of approximately 231,000 km (BMVI, 2016).

However, key impulses for infrastructure development are increasingly being initiated at European level. The core network (to be implemented by 2030) and a comprehensive network (to be implemented by 2050) have been defined. As an implementation tool, nine Core Network Corridors have been specified. Along these corridors the gaps and bottlenecks in the transport networks between the member states will be eliminated in order to achieve progress with the integration of the European Single Market. Six of these nine corridors have a direct impact on Germany.

Although these corridors include all modes of transport, the focus is on the integration of the rail network. This is because different technical standards and organisational regulations have become established in individual European countries, which means complication to international rail freight within the European Union. For example in the USA, more than 40 % of freight transport is related to rail freight, as the majority of long-haul transport there is by rail (e.g. from the west coast to east coast). Similar long-haul transport in Europe always crosses national borders. Therefore the European Commission is aiming for the elimination of obstacles to cross-border rail transport. The plan is therefore to expand and upgrade the network infrastructure in the nine corridors, and also to harmonise and standardise the control systems and significantly increase the number and capacity of multimodal transshipment terminals.

The infrastructural obstacles to the wider prevalence of rail freight transport (or combined transport) include:

- Lack of overtaking tracks for 740-metre trains
- The necessity of renewing the existing rolling stock (primarily for reasons of noise protection)
- Transport services for the complex coordination processes involved in multimodal transport are still insufficient.

3.11 What are the plans in relation to the expansion of the infrastructure for alternative drive systems?

The Renewable Energy Directive¹ requires renewable energy to account for a 10% share of the transport sector in 2020. This target and the greenhouse gas reduction targets at European level² create the framework for the EU directive on the development of an infrastructure for alternative fuels³. This directive contains details of the specific measures for developing an infrastructure for alternative drive solutions. The roads in the TEN-T core network are of particular importance here. In particular, the aim is to achieve harmonisation of the development of the infrastructure network for electricity, natural gas and hydrogen.

¹ Renewable Energy Directive 2009/28/EC – (RED)

² 406/2009/EC

³ Alternative Fuels Infrastructure Directive 2014/94/EU – (AFID)

The recommended average distance between compressed natural gas (CNG) filling stations is 150 km. The European Commission views LNG as a cost-effective fuel for heavy commercial vehicles, and the guideline here is an average distance of 400 km between filling stations. The final deadline for compliance with the requirements of the appropriate number of LNG and CNG filling stations is the end of 2025. These requirements must be implemented via a national strategy framework. The standardisation of fuel tank technology for the alternative drives systems is another important point.

The national strategy framework plan for the development of the infrastructure for alternative fuels envisages the development of LNG filling stations for heavy commercial vehicles along the European transport corridors. However, with only 6 to 10 filling stations, this is an extremely cautious approach. The development of the hydrogen supply, which is currently still in test mode, will be expedited, as is the development of the charging infrastructure for electric vehicles. By contrast, the overhead catenary system technology for road vehicles has not yet played a role in the directive.

4 SWOT analysis of competing truck operating concepts

The alternatives to diesel drive in heavy commercial vehicles differ considerably in terms of their technical maturity, beneficial application areas, and levels of commercialisation. The following SWOT analysis is designed to classify the overhead catenary system for trucks in comparison with other technologies, and to identify research priorities for the remainder of the project. The SWOT analysis investigates the diesel truck as a reference value, the operational concepts of LNG (gas) trucks, H₂ (hydrogen) trucks, and hybrid trucks powered by an overhead catenary system. Profiles of the different operating concepts will be created to illustrate the key features and facilitate a comparison. Thus the system-related strengths and weaknesses of the drive systems will be addressed and their market opportunities and risks will be considered. The comparison of the examined strengths, weaknesses, opportunities and threats will be used to derive strategic areas for action relating to the different truck operating concepts on the basis of the following dimensions:

- Economy and innovation
- Environment, energy and resources
- Operator's viewpoint
- Organisation

The aim of the comparison is to evaluate the environment of the overhead catenary system for trucks in relation to competing drive systems and to decide on this basis which drive systems need to be taken in to consideration for particular application scenarios as the project progresses.

4.1 Diesel trucks

The diesel engine is by far the most common drive system used in heavy commercial vehicles today and it therefore provides a reference for the evaluation of alternative drive concepts. The major strength of the diesel drive system is the high energy storage density of diesel, which means that the weight of the diesel fuel in the vehicles only marginally reduces the attainable payload. Despite the moderate efficiency of the diesel drive system, trucks can cover large ranges of several hundreds of kilometres. There is also an established, comprehensive refuelling infrastructure, which means that refuelling imposes hardly any restrictions on logistical freedom. In addition, the diesel drive system also benefits from favourable fiscal conditions. In contrast the weaknesses of the diesel system are found primarily in relation to its environmental characteristics (greenhouse gas, pollutant and noise emissions) and its limited potential for further development.

Table 1: Strengths and weaknesses of diesel trucks

Strengths	Weaknesses
<ul style="list-style-type: none"> ● Comprehensive experience with the technology → reliability ● High energy density of the fuel [→ small, lightweight tank → high range] Example: 400 l diesel → > 1,000 km range ● In a heterogeneous market, the high range enables cost-optimized refuelling (e.g. refuelling diesel in countries with a low rate of diesel duty) ● Renewable drop-in substitutes for diesel (biodiesel, Power to Liquid diesel) are technically available. Some have been available on the market for a long time and have the potential to further reduce greenhouse gas emissions. ● Wide variety of different vehicle types and configurations available (optimum adaptation of the vehicles to specific application profiles) ● Relatively low procurement costs of vehicles due to production of large quantities ● Comprehensive refuelling infrastructure worldwide ● Comprehensive service network ● Costs for stakeholders are easily calculable by standardised procedures for dealing with cost risks ● Global market for diesel trucks (new trucks and secondary market) 	<ul style="list-style-type: none"> ● Further engine-related optimisation is limited or likely to be very cost-intensive ● Complex exhaust gas treatment is required in order to comply with current emission limits; some older vehicles in the fleet have high pollutant emissions. ● Diesel substitutes from renewable energy (biodiesel, Power to Liquid diesel) which can reduce greenhouse gas emissions in a well-to-wheel analysis <ul style="list-style-type: none"> – are considerably more expensive than fossil diesel – are generally in conflict with other ecologically and socially protected goods (land use, biodiversity, etc.) ● Fuel price depends on international crude oil price ● Relatively low efficiency: peak values of up to 45%, but on average lower [around 40%] ● Diesel engine is relatively high-maintenance; service life of the engine is significantly less than that of the rest of the vehicle ● Complex gearbox required → extra weight

If the strengths and weaknesses of diesel trucks shown in Table 1 are considered in relation to the framework of road freight transport, the key opportunities and risks of the diesel system are revealed (see Table 2).

Table 2: Opportunities and risks of diesel trucks

Opportunities	Risks
<ul style="list-style-type: none"> ● Increased efficiency due to hybridisation ● Further improvement of exhaust gas treatment ● Tried and tested technology (trusted by fleet operators) ● Adding synthetic diesel from renewable electricity can reduce the well-to-wheel greenhouse gas emissions without requiring any conversion on the demand side. ● Automotive manufacturers are very interested in the future role of the diesel drive system due to their extensive expertise and the high added value of engine production. 	<ul style="list-style-type: none"> ● Finite nature of fossil fuels and restriction of their availability for economic or political reasons ● Volatile oil price ● Economic use of renewable energy through alternative drive concepts ● Bans on diesel vehicles as part of air pollution control measures ● Rise in cost of CO₂ emissions due to regulations ● Introduction of CO₂ emission limits for commercial vehicles ● Increase of limit values for pollutant emissions ● Tightened environmental requirements for transport services (“green logistics”) ● Deterioration of the CO₂ balance sheet (well-to-wheel) by increasing the share of unconventional oil resources in the total funding volume

The following conclusions can be drawn for diesel trucks in relation to the key strategic assessment criteria:

- **Economy and innovation:** In terms of economic efficiency, diesel trucks are currently the benchmark and have had a significant influence on the development of the logistics industry and its cost structures. Global sales market ensures high quantities. Nevertheless, the market is exposed to uncertainty as a result of volatile oil prices and future emissions legislation. In order to counter this uncertainty, the scope for further vehicle-side innovations is limited.
- **Environment, energy and resources:** The pollutant emissions from diesel engines can be reduced to an ecologically harmless level with a certain degree of technical effort. However, the energy efficiency of modern diesel engines is approaching its physical limits. Significant CO₂ reductions can be achieved only through decarbonisation of the upstream fuel supply chain, which in turn leads to resource problems.
- **Operator’s viewpoint:** Diesel drive systems have the lowest risk of any drive system. The service network is good, drivers are familiar with the technology, and the risk of fuel costs is passed on to the carrier in many instances. An indirect risk might arise from access restrictions for diesel vehicles, e.g. in city centres.

- **Organisation:** The entire structure of road freight transport is currently weighted towards the diesel drive system and its characteristics (in particular its flexibility and widespread availability).

4.2 LNG trucks

In recent years, gas drive systems have become increasingly important as an alternative to diesel technology worldwide. These are essentially petrol engines with modified fuel supply and storage, engine management system and exhaust gas treatment. Biogas can also be used instead of fossil natural gas. In contrast to biodiesel, any degrees of admixture can be used (up to 100%) without requiring any modification of the vehicle. Whereas compressed natural gas (CNG) is often used in passenger cars and light commercial vehicles, liquefied natural gas (LNG) is suitable for use in heavy commercial vehicles due to its greater density. Stoichiometric petrol engines ($\lambda=1$) are common. LNG engines are a viable second technology, following on from the self-ignition of the diesel engine (high-pressure direct injection – HPDI). These have an energy efficiency that is similar to diesel engines and require similar exhaust gas treatment technology, but generate approximately 20% less local GHG emissions than diesel engines.

The suitability of gas drive systems for heavy trucks is currently being tested as part of the “Blue Corridors”¹ field trial (funded by the EU). This project also represents a step towards pan-European harmonisation of technical standards and the identification of associated limitations. Gas producers such as Linde and filling station operators including Eni are involved in the field trial alongside manufacturers such as Volvo, Renault and IVECO. In addition to some technical obstacles to the development of a standardised infrastructure which still have to be addressed, there are also some regulatory hurdles in relation to the technology, for instance LNG vehicles cannot be accepted for transport by Eurotunnel.

The potential of natural gas drive systems for heavy commercial vehicles is examined as an alternative to conventional diesel drive on the basis of the Strengths and weaknesses of LNG trucks shown in Table 3.

Table 3: Strengths and weaknesses of LNG trucks

Strengths	Weaknesses
<ul style="list-style-type: none"> ● Natural gas drive systems have already achieved technological market maturity and are offered for various applications (e.g. LNG tractor units, including those available from IVECO, Mercedes Benz and Volvo) ● High range (600 to 1,400 km/tank filling; latter applies to dual LNG tanks) ● Can be operated with up to 100% 	<ul style="list-style-type: none"> ● To date only a few manufacturers and relatively expensive vehicles on the market ● Comprehensive refuelling infrastructure not yet in place ● Efficiency of the petrol engine is approx. 10% less than comparable diesel vehicles (Fahren et al., 2016), HPDI has similar energy efficiency

¹ <http://ec.europa.eu/transport/sites/transport/files/themes/urban/studies/doc/2016-01-alternative-fuels-implementation-good-practices-appendix-d.pdf>

<p>renewable methane, without requiring any modification of the vehicle</p> <ul style="list-style-type: none"> • Compared to diesel, gas burns with lower air pollutant emissions, which therefore means lower costs for exhaust gas treatment in petrol engines • An addition of biogas improves the CO₂ balance (well-to-wheel) 	<ul style="list-style-type: none"> • Reduction of the permissible payload due to heavy LNG tanks • Refuelling requires special driver training and the use of safety equipment (due to the low temperature of the LNG) • Higher maintenance costs than diesel trucks due to more complex technology and in particular higher combustion temperatures • Significant energy losses within the energy supply chain (especially liquefaction) • Gas-powered engines still have lower power output → restriction of areas of application (e.g. they cannot be used to transport hazardous materials) • High pressure and low temperature → complex storage of LNG and risk of “boil-off” due to heating, e.g. during long stationary periods • Residual values of the first generations LNG trucks ought to be close to zero
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The Strengths and weaknesses of LNG trucks reveal the different opportunities and risks in the context of the specific parameters of heavy road freight transport (see Table 4):

Table 4: Opportunities and risks of LNG trucks

Opportunities	Risks
<ul style="list-style-type: none"> • Previously untapped efficiency potential for gas engines can be developed quickly → GHG emissions then well-to-wheel approx. 5-20% less than diesel (both clean fossil fuels) • Synthetically produced gas from renewable energy sources (RES) may also be liquefied and added to LNG • Separation of the gas price from the crude oil price likely, to the benefit of the gas price • High range means long distances between filling stations (up to 250 km) for an initial expansion scenario • Lower fuel costs compared to diesel → 	<ul style="list-style-type: none"> • Further development is required in order to improve the efficiency of mono-fuel engines or to achieve emission standard Euro VI for bi-fuel vehicles • High procurement and maintenance costs • Lack of transparency in the vehicle manufacturers' market structure • Political uncertainty regarding the availability of existing natural gas reserves • In terms of climate protection, introducing this technology is only worthwhile if accompanied by significant decarbonisation of the upstream chain,

operating cost benefits	i.e. long-term production of synthetic gas from renewable electricity (PtG). However, this in turn has a significant impact on energy costs
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Considering the framework of heavy road freight transport, the following conclusions can be drawn from examination of the strengths and weaknesses:

- **Economy and innovation:** Gas drive systems are a viable alternative to diesel drive systems for heavy commercial vehicles as the technology can be adapted easily from the internal combustion engine. However, the application scenarios are restricted by the high procurement costs in comparison with diesel drive systems, lower engine efficiency, and the reduced range of the gas engine. The primary challenges associated with gas drive systems are the increasing transport distances and the international networking of freight transport. Above all, the lack of planning security due to unclear manufacturer, operator and political strategies is currently a significant investment risk, enhanced by the long-term uncertainty related to natural gas reserves and its substitutes, which must be subjected to critical evaluation.
- **Environment, energy and resources:** While gas drive systems can help to reduce local emissions, their current environmental footprint, taking into account the energy supply chain, is not significantly better than that of the diesel drive system. This can be blamed on high energy losses involved in the liquefaction of natural gas, the complex storage of LNG, and the lower energy efficiency of today’s gas engines. In the long term, it does not appear that gas drive systems will make a sufficient contribution towards to decarbonisation of road freight transport under the current conditions. At best, the admixture of biogas and/or gas from renewable sources could make a substantial contribution to decarbonisation. The finite nature of fossil natural gas reserves and the energy-intensive production of synthetic methane must also be taken into account.
- **Operator’s viewpoint:** The high acquisition and maintenance costs of vehicles, the lack of experience regarding residual values and a missing infrastructure of LNG filling stations are the main obstacles to the use of natural gas drive systems for long-haul road freight transport. In addition, the lack of transparency in the vehicle manufacturers’ supply structure compounds the issue of selecting a suitable vehicle.
- **Organisation:** Where freight transport remains regionally restricted (for instance, delivery traffic) and is not reliant on a national refuelling infrastructure, there are already beneficial use cases for gas drive systems. Whether LNG drive systems can also be used on a larger scale in the medium term for national and international long-haul transport depends on a range of issues, including whether the European AFI Directive facilitates construction of a comprehensive LNG refuelling infrastructure – the member states can interpret the directive in a variety of ways.

4.3 H₂ trucks

Fuel cell drive systems consist of an electric motor which is supplied with power from a fuel cell. A backup battery is generally required in order to reduce the effect of power surges. The generation of electricity from hydrogen and oxygen in the fuel cell causes no CO₂ or pollutant emissions, but the production and liquefaction of hydrogen is an energy-intensive process. The way in which hydrogen is produced as an energy source is crucial for the climate assessment of this drive system. CO₂ neutrality is only assured if the hydrogen is produced by electrolysis using renewable electricity. Initial field trials with fuel cell vehicles are being conducted using light commercial vehicles and city buses. The suitability of fuel cell technology for use in heavy commercial vehicles depends to a large extent on the specific strengths and weaknesses of the operating concept, shown in Table 5.

Table 5: Strengths and weaknesses of fuel cell trucks

Strengths	Weaknesses
<ul style="list-style-type: none"> ● Slightly higher Tank to Wheel (TTW) efficiency (fuel cells and electric motor) than for a diesel engine ● No pollutant emissions during operation ● Short refuelling time ● High range (several hundred kilometres) ● Low-noise drive system ● No idle-running consumption ● Modular assembly ● Low maintenance costs ● Liquefaction of hydrogen can further increase energy density ● Hydrogen production can be used as a flexible consumer in the electricity system, which can help to reduce electricity prices 	<ul style="list-style-type: none"> ● TTW efficiency significantly worse than for battery or direct electric drive; approximately 30% energy loss from H₂ production by electrolysis → relatively high energy consumption per km, high energy costs ● High cost of fuel cells → depending on the catalytic converter used (platinum as a cost driver) ● On the whole, still a long way from being viable for cost-effective use in road freight transport ● Inadequate range of vehicles supplied by commercial vehicle manufacturers ● High investment costs for electrolysis plants for hydrogen production and distribution infrastructure ● In some cases, approx. 30% energy loss from hydrogen liquefaction ● Barely any public refuelling infrastructure ● High power-to-weight ratio and high installation space requirements ● Long-term behaviour of fuel cells not yet tested sufficiently, especially when used in motor vehicles (vibrations) ● High cost of H₂ pressure tanks

The Opportunities and risks of fuel cell trucks shown in Table 6 are derived from the specific strengths and weaknesses (see Table 5) of the operating concept regarding market related framework of heavy road freight transport:

Table 6: Opportunities and risks of fuel cell trucks

Opportunities	Risks
<ul style="list-style-type: none"> ● Still substantial scope for technological improvement. The technology could be competitive in the medium to long term and represent a viable alternative, particularly for regional commercial transport. ● Electric drive systems with a continuous power supply from the outside (see Overhead catenary system for trucks) can be logically supplemented by fuel cell technology, leading to increased range. ● Although the development of renewable energies facilitates climate-neutral hydrogen production, this energy source is initially required for shipping and air transport in order to achieve the decarbonisation targets in the transport sector (Pfennig, Gerhardt, Pape, & Böttger, 2017). 	<ul style="list-style-type: none"> ● Availability and cost of precious metals (as a catalytic converter) on the global market. ● Development of the hydrogen infrastructure could fall victim to the chicken-and-egg problem. There are no mandatory specifications for the development of hydrogen refuelling stations, particularly in the European AFI Directive. However, Germany has committed to the development of this infrastructure. ● Incentives for the logistics industry to invest in environmental technologies are still limited. ● Cost development for pressure gas tanks depends on: Volumetric capacity, new materials for the tank, and the development of hydrogen supply pipelines.

The following conclusions can be drawn concerning the key evaluation criteria on the basis of the aforementioned strengths, weaknesses, opportunities and risks associated with fuel cell technology:

- **Economy and innovation:** Fuel cell technology fulfils the essential criteria of a drive system resulting from the logistical requirements of transport services, such as range, efficiency and flexibility. The high energy density of hydrogen, which is stored under high pressure (700 bar), gives suitable ranges, while the modular assembly of the drive system allows an adaptation to different applications. The prevalence of hydrogen filling stations and the cost development of fuel cells and hydrogen tanks as the main cost drivers will ultimately decide whether the fuel cell system can be competitive and prevail over the other drive systems (UBA, 2016).
- **Environment, energy and resources:** The contribution of the fuel cell drive system to the decarbonisation of the transport sector stands and falls by the use of electricity generated from renewable energy sources for hydrogen production, and thus depends largely on the energy transition. Furthermore, the implementation of fuel cell drive systems is determined by the availability of the precious metals such as platinum required for catalysis. Above all, the geopolitical situation represents a significant risk in terms of the economic availability of precious metals.

- **Operator's viewpoint:** The lack of a refuelling infrastructure, inadequate range of vehicles, high costs, as well as the high power-to-weight-ratio and space requirements of the drive system have so far prevented the fuel cell from being used in heavy road freight transport. However, if the obstacles can be overcome, hydrogen-powered trucks offer several advantages such as low maintenance costs and relatively high ranges.
- **Organisation:** Barely any mandatory specifications and conflicting signals from industry, in relation to the national and international development of an H₂ infrastructure.

4.4 Overhead catenary system for trucks

By comparison with other operating concepts, powering trucks with an overhead line is an alternative that has only been discussed in the last few years. The technology of the overhead catenary system for trucks is based on the electrification of long-haul routes to supply trucks with power directly from a bipolar overhead contact line. The truck must also be hybridised with a second energy source so that it can continue to drive when disconnected from the overhead line. In previous research projects, either diesel engines or batteries were used for hybridisation, although fuel cells or gas engines could also be used in principle. The power supply to the overhead catenary trucks is based on the tried and tested technologies used in trolley buses and railway lines, which have been adapted for use in heavy trucks. The basic technical feasibility of the system has already been proven on trial routes in Germany, Sweden and USA. However, the question arises for which application the conversion of conventional vehicle models is sufficient to achieve the full benefit of the overhead catenary system for trucks.

In principle, there is also the possibility of a mobile power feed via a conductor rail recessed in the road, or by inductive energy transmission. However, the incurred costs would be likely to be significantly higher by comparison with the overhead catenary line technology. In addition, the technical maturity of the alternatives is currently lower, and operational challenges are likely (Fraunhofer ISI, Fraunhofer IML, PTV Transport Consulting GmbH, TU Hamburg-Harburg - IUE, & M-Five, 2017). The challenges associated with overhead lines also apply to the other electric road systems, which is why the following section does not consider them separately.

While overhead catenary technology brings a major reduction in greenhouse gases with simultaneous high energy efficiency if renewable electricity is used, it also requires fundamental changes to the vehicle and usage concept as well as the construction of a complex electrification infrastructure. The following specific strengths and weaknesses have been identified:

Table 7: Strengths and weaknesses of the overhead catenary system for trucks

Strengths	Weaknesses
<ul style="list-style-type: none"> ● Electric drive means high efficiency, brake energy recuperation and low maintenance ● Zero emissions when travelling under an overhead catenary line; zero-emission hybridisation options are also possible (battery, fuel cell) ● Potential for efficient use of electricity from renewable energy sources ● Low operating costs due to high drive efficiency (when sufficient distance covered by electric drive) ● Low noise and vibration in electric mode → driver comfort ● Electric drive system has high torque and good driving dynamics ● Comprehensive experience with overhead line technology in the railway sector ● Economic superiority over other alternative drive systems in an established state ● Depending on the hybridisation, trucks can also continue driving when disconnected from the overhead line; full expansion of the infrastructure is not mandatory. 	<ul style="list-style-type: none"> ● Very little previous experience using this technology in road transport ● Overhead line infrastructure not yet in place ● (Preliminary) financing of the catenary infrastructure in the construction phase remains unclear ● The catenary infrastructure requires disruption of roads → complex legal and safety issues, visual impact on all road users ● Major interaction between the required catenary infrastructure and the vehicle design, in particular the hybrid concept ● To date, overhead catenary trucks built only as prototypes (no series production; confusion about technology costs) ● The share of electric driving on routes equipped with an overhead contact line depends to a large extent on the application profile of the vehicle → reduced flexibility and cost risk for operators

According to the special characteristics of the overhead catenary system for trucks, the application context of heavy road freight transport provides both opportunities and risks for the commercial market introduction and the expansion of the system (see Table 8).

Table 8: Opportunities and risks of the overhead catenary system for trucks

Opportunities	Risks
<ul style="list-style-type: none"> • High potential for GHG savings as a result of electric driving powered by overhead catenary lines • Development of electricity generation from renewable energy sources used for the overhead catenary system can help to decarbonise road freight transport on a substantial level • Low volatility of the electricity price → cost security • The expected energy cost benefits could refinance the required infrastructure investments in whole or in part, if the capacity is utilised appropriately. • Vehicles may be able to enter any future emission-restricted areas (e.g. inner cities) with appropriate hybridisation. • Hybridisation using high-performance batteries can reduce the necessary coverage of the overhead catenary network. • New logistics concepts, such as the provision of shuttles on highly-frequented routes, could also create favourable conditions for this new technology at an early market stage. • Acceptance on the part of drivers due to lower noise level and less vibration when driving under overhead catenary lines. • New sales area for the electricity supply industry, which could contribute to the requisite investments. 	<ul style="list-style-type: none"> • Custom-fit required between the expansion of the infrastructure and vehicle use profiles for profitability of the overhead catenary system for trucks. • Dynamic market environment in the logistics sector makes it difficult for potential users to undertake long-term vehicle planning. • Disagreement among stakeholders over the allocation of financial risks associated with the introduction of the system • Legal clarification of potential allocation of infrastructure costs to users still required • Highly fragmented logistics market with international network → barriers to investment requiring a specific environment • Incentives for the logistics industry to invest in environmental technologies are still limited • Acceptance of the overhead catenary system technology from the vehicle manufacturers' viewpoint is uncertain, as it has a major influence on the value chain • National and international standardisation required in order to facilitate interoperability

The central evaluation criteria for the SWOT analysis provide the following picture of overhead catenary system technology in its various forms:

- **Economy and innovation:** The expected long-term rise in crude oil prices and the volatility of the electricity price compared to the diesel price create a relatively secure long-term planning horizon for the overhead catenary system for trucks. In the longer term, operating cost benefits could be used to support financing the overhead line infrastructure. There are risks, primarily with regard to financing the market introduction phase and the integration of a system that has not yet been rolled out into

the logistics processes. Innovative logistical business models are required in order to increase the capacity of the overhead line infrastructure in the initial phase and thus to reduce the expected upfront expenditure on infrastructure.

- **Environment, energy and resources:** If overhead catenary trucks are operated with renewable electricity, they allow a major reduction of GHG emissions in long-haul transport and utilise the conceivably scarce resource of “renewable electricity” very efficiently. Particularly in the case of diesel-electric overhead catenary trucks, this requires a high proportion of the mileage to be driven in electric mode. The power requirements placed on the distribution network by the overhead electric drive must be taken into account for the respective expansion pathways of the overhead catenary system. This depends essentially on the choice of hybridisation, whereas for example a system with a large traction battery may require a higher capacity from certain sections of the overhead line. On the other hand, it can reduce the required proportion of electrified sections and simultaneously facilitate zero emissions for vehicles involved in pre-carriage and on-carriage. Overall, the ongoing development of battery technology provides an opportunity to expand the potential range of application of overhead catenary trucks and to utilise the overhead line infrastructure more efficiently.
- **Operator’s viewpoint:** As overhead catenary trucks exist only in prototype form, it is not yet possible to make a reliable statement regarding potential vehicle prices in series production. However, the vehicle price will be higher than that of conventional vehicles for the foreseeable future. Key question is, whether higher vehicle costs and a generally less flexible vehicle operation (extension of the overhead catenary system) can be compensated by significantly lower operating costs. Thus fleet operators will only shift to overhead catenary trucks if heavily frequented routes are electrified sufficiently.
- **Organisation:** A number of legal questions still have to be clarified before the system can be introduced commercially. In view of the international integration of freight transport flows, it is important that crucial technical and organisational parameters (voltage level, payment terms) are standardised as early as possible. In addition, the overhead catenary system for trucks must also be integrated into the regulatory framework for alternative drive systems (e.g. the AFI Directive).

5 Conclusions

In this analysis, the environment of heavy road freight transport is investigated in respect to key issues for the introduction of alternative drive systems (Chapter 3). Thereby strengths, weaknesses, opportunities and threats (SWOT analysis) of diesel trucks and three alternative truck drive technologies which have reached a certain level of technical maturity and are capable of making a significant contribution to the achievement of greenhouse gas reduction targets were analysed (Chapter 4). The findings from the SWOT analysis were assessed regarding economy, the environment, the operator's viewpoint and organisation. To examine suitable application scenarios, potential development pathways and the parameters required for alternative drive solutions need to be specified. The basis for this includes a comparison of key characteristics of relevant drive systems (see Table 9).

Table 9: Comparison of the different truck operating concepts

	Diesel trucks	LNG trucks	H₂ trucks	Overhead catenary system for trucks
Fuel/energy source	Diesel	LNG	Hydrogen	Power + X (hybrid)
Storage	Conventional tank	LNG cryogenic tank (3-10 bar, -160°C)	H ₂ tank (700 bar)	Overhead line (depending on the system layout, supplemented by backup battery, supercapacitor, traction battery or H ₂ tank)
Fuelling/charging point	Conventional filling station	LNG filling station	H ₂ filling station	Conductive charging via contact line
Refuelling/charging time	Few minutes	Few minutes	Few minutes	Electricity: no additional charging time Diesel: few minutes
Power density	36 MJ/l	21 MJ/l	4.6 MJ/l (700 bar)	-
Usage restrictions	Political (entry restrictions etc.)	No current restrictions	Low commercialisation	Standardisation required
Achievable range	>1,000 km	>1,000 km	>800 km (today)	Infinite (depending on infrastructure development)
Area of application	Everywhere (but short-haul inefficient)	Long-haul	Medium and long-haul	Commuter and shuttle services (introductory phase) Long-haul (development phase)
Operational efficiency	Approx. 40% (TTW)	Approx. 35%	Approx. 50-60%	Approx. 80% (overhead line to wheel)
Challenges	Consumption, pollutant emissions	Consumption, pollutant emissions, infrastructure	Costs, infrastructure	Costs, infrastructure
Vehicle emissions	High	Depends on technology	No local emissions	No local emissions in electric mode

5.1 Economy and innovation

- All alternative drive systems require the development of additional infrastructure and involve higher vehicle costs (at least during the introductory phase). Both cost blocks decrease with increasing market penetration of the corresponding drive system: the vehicle costs are reduced primarily through economies of scale in production, the infrastructure costs by the increased utilisation rate.

→ In an established system, energy costs currently play a decisive role in the overall cost of truck operation – with the exception of the fuel cell drive system, which is still likely to incur significant additional vehicle costs in the distant future (UBA, 2016)

- The resulting chicken-and-egg problem between the expansion of the infrastructure and the number of users is inherent in all alternative drive systems and can only be overcome by finding application scenarios with a simultaneously high utilisation rate of vehicles and infrastructure. Commuter routes are particularly suitable for this purpose. At the same time, this requires a political environment which counteracts the investment risks for vehicle operators.

→ Both issues are core tasks of the project “Roadmap for an overhead catenary system for trucks”

- LNG is currently the only alternative solution for which a standard range of vehicles exists in the heavy truck sector. From an operator’s viewpoint, the main argument in favour of the acquisition of LNG vehicles is the operational cost savings, particularly from the tax incentives for using natural gas in the transport sector. The use of LNG vehicles is currently restricted to mainly regional delivery transport, as the infrastructure risk is manageable on this scale.
- In principle, decarbonisation (WTW) can be achieved using all of the drive technologies outlined here. With this in mind, most of the current political discourse is calling for open-minded action by the public sector, and leaves the decision for or against a technology to the market (see excursus on page 33). However, this paradigm exacerbates the previously mentioned chicken-and-egg problem as it reduces the planning certainty for market participants and increases the risk of stranded investments. If transport policy does not settle on a technological pathway, the public sector incurs high costs through the financing of R&D of multiple technologies and the market players incur costs from the necessary risk diversification due to the uncertain overall strategy of these technological pathways. This in turn decelerates the development of the infrastructure for each individual technology and thereby slows down the operators’ transition from conventional diesel drive systems to alternative technologies.

→ One crucial question in relation to the roadmap in this project therefore relates to the conditions which must be fulfilled in order to restrict the open approach to technology. It is also important to identify potential synergies between different drive systems (e.g. hybridisation of overhead catenary trucks using fuel cells).

Excursus: Opportunities and risks of an open approach to technology

Climate policy and the decarbonisation of transport are long-term tasks involving long-lasting transformations. In an early stage of such a transformation, there are usually various future technologies, which are not yet available on the market. Naturally the estimation of performance and cost of these technologies is characterized by uncertainties. In such cases, industrial players usually claim an open approach to technology from policy makers. The consequences of this open approach to technology are contradictory – a prolonged period of openness to the development of multiple technologies prevents the lock-in of a potentially inferior technology at an early stage. Above all, this reduces the risk of opting for the wrong technology. At the same time, however, it is more difficult to generate a first-mover advantage and benefit from lower costs as a result of the commitment to progressing along the learning cost curve, which primarily affects the innovating manufacturers. The most significant disadvantage of the open approach to technology is the higher cost of research and development, as state and/or private research funding has to be applied to multiple technology lines. As a result, either less funding is available for each technology, or more funding is required to promote the entire spectrum of technological approaches. From a political and industrial perspective, it is therefore important to identify the earliest point in time at which the open approach to technology should be abandoned in favour of focussing resources on the promotion of a single technology or even a small selection of promising technologies. Thereby unnecessary expenditure on inferior technologies can be avoided and more resources for successful technologies are available. The important question to ask in relation to the roadmap for an overhead catenary system for trucks is as follows: When is the appropriate time to commit to a certain technology (overhead catenary trucks, LNG trucks, H₂ trucks) to be used as an alternative to diesel drive systems?

- Overall, Germany has a well-developed transport infrastructure which is also a match for its international counterparts. However, in the past, there has often been a loss of substance (“renovation backlog”), which calls into question the capacity of the transport networks. In addition to new construction and extension work, the waiting list therefore also includes a large number of maintenance investments. New construction and expansion measures would have to be taken into account in relation to the planned construction of routes with overhead catenary lines. In this way, the implementation of the overhead catenary technology following development work would increase the capacity and, in some cases, also involve the grouping of certain sections of construction sites for road development and erection of the overhead line.
- In addition to the financing problems, difficulties have arisen in recent years in relation to the realisation of planned projects due to acceptance problems on the part of citizens who are directly affected. One common reason cited, in addition to the increasing awareness of environmental concerns, is the unequal distribution of the benefits and disadvantages of infrastructure projects. It is important to include this aspect in the discussion about the development of an alternative fuel infrastructure.

Excursus: Battery electric drive systems for heavy trucks

Due to the low energy density and the high power-to-weight ratio of battery storage, the electrification of road freight transport has previously focused on light commercial vehicles (MAM <3.5 t) and light trucks (MAM 3.5 to 7.5 t). For these vehicles, used mainly for inner-city delivery services, the benefits of electric drive, such as the high level of efficiency and brake energy recuperation, outweigh the disadvantages related to the carriage of the battery storage system. In addition, the vehicles used in regional transport cover a lot less daily mileage than those used in long-haul transport, so the limited range is actually not a restriction. By contrast, it appears that commercial use of electric drive in vehicles with a higher maximum authorised mass and higher daily mileage is possible only with continuous transmission of power from the outside (e.g. via an overhead catenary system or a conductor rail).

Aspects such as the nascent development of battery technology have an impact on the potential introduction pathways for electric road systems. This could lead to an expansion of the application areas for battery electric drive systems to include use in heavy trucks and long-haul freight transport. Although various manufacturers such as MAN, Mercedes and Terberg have produced initial prototypes and small batches of electric tractor units, their area of application remains restricted to regional transport due to the limited range. However, the American electric car manufacturer Tesla has recently announced plans to launch a tractor unit with a range of up to 800 km. However, battery storage is likely to account for significant additional weight, which will in turn increase the price. From the manufacturer's information in relation to the electric passenger cars already on the market, it can be deduced that the battery in the tractor unit is likely to weigh more than 7 tonnes and account for more than half of the total vehicle cost, taking into account the stated performance specifications. Although the electric drive train should have a longer service life than a conventional drive system, there is insufficient data about the development of the battery life cycle when used for heavy road freight transport.

The known limitations of battery technology must therefore be taken into account for heavy truck applications, at least in the medium term. In this case, fully battery electric and overhead line-powered applications for long-haul freight transport are not mutually exclusive, but ideally would complement one another. The combination of larger battery storage devices with overhead catenary systems or conductor rails can, at best, extend the range of cost-effective applications and thus accelerate the replacement of conventional drive systems.

5.2 Environment, energy and resources

- In principle, decarbonisation can be achieved with all drive systems, as all fuels can ultimately be produced from renewable electricity (electricity-based fuels). Thereby the crucial differences between these technological approaches is their efficiency (see Figure 4), the energy supply costs arising from decarbonisation, and the associated strategic supply risks (Öko-Institut, 2013). As the procedure for manufacturing and using electricity-based fuels involves high electrical energy losses during the synthesis processes, it is preferable to use direct transmission of electrical energy to the vehicle drive system.

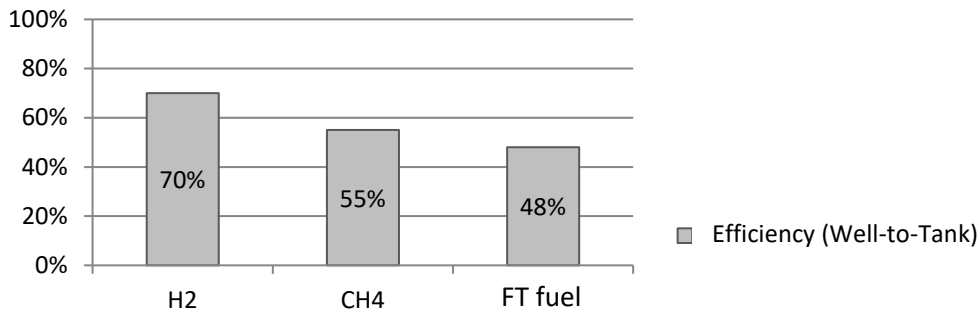


Figure 4: Efficiency (Well-To-Tank) by production of electricity-generated fuels (UBA, 2015a)

- Overhead catenary trucks have very high TTW energy efficiency. The use of an overhead catenary system for trucks is the only way in which long-haul road freight transport can make a significant contribution to the achievement of the targets for reducing total final energy consumption. The current resistance from the population to the expansion of the network and construction of wind turbines also shows that the amount of renewable electricity that can be produced in Germany in future is restricted not only by issues of cost. Energy-efficient drive systems can therefore help to limit the country's dependence on energy imports in future.
- In principle, electric drive systems are the only zero-emissions drive systems in operation. In future, unresolved air quality problems are expected to lead to stricter limit values for pollutant emissions from vehicles, which is likely to increase the cost of the exhaust gas treatment of internal combustion engines. Also entry restrictions for diesel vehicles are already under discussion in certain areas. In addition to rising fuel prices, these developments pose further risks for combustion vehicle operators.
- The energy supply infrastructure itself affects the overhead catenary system for trucks in terms of conservation issues which must be taken into account at an early stage of planning.

5.3 Operator's viewpoint

- New technologies must not only be able to compete with established technologies in business terms, but must also be user-friendly and reliable so they can be adapted by potential operators. → Favourable economic application profiles that are to be determined on the basis of the TCO approach as part of the project, must always be checked for acceptance and risks on the part of the operator.
- As a result of stronger economic fluctuation¹ and stiff price competition in the logistics sector, vehicle operators generally expect a quick return on their investment (about 2-3 years). A number of efficiency technologies that are

¹ As a rule, the quantity of transport services required fluctuates proportionally more than the economic performance.

currently available for heavy commercial vehicles do not yet comply with this requirement and so far have not achieved significant market penetration (UBA, 2015b). This effect is intensified regarding alternative drive systems, as the investment costs and risks are considerably higher during the initial phase, and the operating cost benefits can only compensate higher investment cost over a longer holding period.

- The market for freight forwarding services is highly fragmented, and a large number of services are performed by small freight forwarders with only a few vehicles. For these companies, the acquisition of vehicles with alternative drive systems is an enormous risk, especially if these vehicles require adjustments to be made to logistics processes. It is therefore likely that larger freight forwarders and fleet operators will be ready to integrate alternative drive systems into their fleet at an earlier stage → they should therefore be prioritised in the context of this project.
- With regard to the implementation of new truck operating concepts, a distinction must be made between intra-European cross-border traffic according to the supplier structure. In the case of volume production and single sourcing, changing to another system after crossing a border can certainly be worthwhile if it achieves significant cost savings. For other supply structures, the required scheduling of the transports becomes more difficult if a changeover is required. This could result in similar effects as those found in cross-border rail transport, where different technical requirements impede the interoperability to the extent that it causes significant competitive disadvantages.
- Stable relations between shippers and carriers (or freight forwarders) provide information about potential application profiles with high levels of geographical relations, frequency, and transport volume, thus providing favourable introductory pathways for new truck operating concepts.
- Whether freight forwarders will find suitable application profiles for alternative drive systems and, in particular, overhead catenary systems for trucks, depends to a large extent on the logistics structure of the respective freight forwarding company (e.g. hub-and-spoke systems, intercontinental traffic, etc.). In such cases, alternative truck operating concepts and their infrastructure must be compatible.
- Because increasing efficiency is a guiding principle of the logistics industry, the introduction of new technologies should keep additional organisational effort involved in the transformation to a minimum. → Lessons can be learned from CT, which in many cases is perceived as too inflexible.
- In Germany, the mileage covered by non-resident vehicles (and in particular the proportion of cabotage operations) has increased significantly over the past few years. This has a negative impact on the options for using an alternative energy supply infrastructure, if this can only be developed significantly in Germany during the initial phase. It is therefore necessary to consider and plan this kind of cross-border infrastructure at an early stage. There is already an EU directive for the development of passenger car charging stations and CNG, LNG, and H₂ filling stations. In future, the energy supply could also be integrated via overhead line.

5.4 Organisation and social acceptance

- Of all alternative drive systems, the overhead catenary system for trucks requires the most far-reaching interventions in terms of infrastructure. It is therefore particularly dependent on social and political backing. The prevailing paradigm of an open approach to technology entails the greatest risk by comparison with other alternative drive systems.
- Alternative drive systems and, in particular, the overhead catenary system for trucks, are dependent on an apposite infrastructure for early applications. Determining the infrastructure requires extensive data about usage profiles, which is not available in sufficient quantities.
 - Potential analyses of an alternative energy infrastructure, as carried out here, must currently be conducted using a very heterogeneous data basis. Particular attention should therefore be paid to ensuring the plausibility of the data basis. In addition, the input data may limit the type of statements that can be obtained from the evaluation of the data. For example, if the truck operation data from a single freight forwarder is available, the potential for electrification of this forwarding agent can be studied in relation to certain parameters, for instance as a case study, and generalisability has to be investigated separately.
- The complex stakeholder structure makes the formation of strategic alliances and interdisciplinary cooperation with a shared vision imperative in order to establish new technologies and operating concepts. At the same time, it is important to involve the various interest groups in the dialogue at an early stage in order to facilitate cooperation and collaboration.
 - Direct dialogue with key players is therefore an integral part of the project.
- There are many possible technical configurations for overhead catenary trucks, each with different infrastructure requirements. This complicates the discussion with politicians and the public about this new technology (people always think that **all** German motorways would have to be fitted with a catenary system).
 - If successful application scenarios with limited infrastructural effort can be demonstrated, this can also contribute to a more differentiated public discussion.
- The rail freight companies have a great deal of experience, both in the use of overhead line technology and with the challenges of intermodal transshipment. At the same time, they have a more reserved attitude towards overhead catenary systems for trucks for competition reasons.
 - In this case it is necessary to establish a common understanding of the strengths and weaknesses of the modes of transport, and to determine how to establish a political framework in which the overhead catenary system for trucks and rail transport are not pitted against each other as alternative options.

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