THE PATHWAYS COALITION

Fossil-free alternatives for heavy-duty transports in Germany

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Executive summary

Commercial transport is expanding rapidly around the globe as a result of rise in trade and diversification of value chains. Flexible and dependable commercial transports play an important role in the economic system and a central role for CO_2 emissions. Using road transport for freight, in particular trucks, is the most appropriate and effective solution for short and direct routes and thus also widely used. The solution will remain the dominant mode of cargo transportation for several years to come. Although trucks only stand for around 5 percent of vehicle stocks globally, they represent 20 percent of road transport fuels and a third of global diesel demand. In Germany, heavy commercial vehicles are accountable for approximately 24 percent – or 40 million tonnes CO_2e – of annual transport emissions.

To reach the targets outlined by the Paris Agreement a drastic reduction in GHG emissions from transport is essential. This in turn requires knowledge on the different alternatives available today, in the local markets as well as on a global level, to identify pathways towards fossil free heavy-duty transports.

This report attempts to describe the current and near future situation of efficiency measures and low-carbon transport alternatives available within the German road transport system. This is the second status report exploring decarbonization alternatives, supporting the overall objective of The Pathways Coalition. The Pathways Coalition is formed by E.ON, H&M Group, Scania and Siemens to accelerate decarbonization of heavy transports. The four companies that have formed The Pathways Coalition represent different parts of the value chain; infrastructure, energy solutions and supply, vehicle manufacturing as well as retail with the transport buyer perspective. The overall objective is to reach zero emissions in line with the Paris agreement by accelerating the pace of change.

The report shows that reducing future and current dependence on fossil fuels is possible, however the speed of change requires an agile fuel-strategy that can tackle the risks and opportunities arising. The long-term overarching climate targets are clear, and stricter requirements regarding several sustainability parameters affecting the transport sector are in the pipeline. However, the path to reach these targets is not clearly set which further adds to the need for engagement and action from all stakeholders of the commercial transport value chain.

Presently, for long-haul road trucks, renewable alternatives are limited and the infrastructure for several alternatives is in its cradle. However, the technologies are developing fast and with falling costs and continued investments, new fuel technologies will be viable in the near future. Also, successfully implemented efficiency measures can reduce both cost and emissions already today, increasing competitiveness and knowledge for the future.

Regarding short-haul and distribution, options are more versatile and the infrastructure more mature since it, to a large extent, can build on the existing service infrastructure for passenger cars. For these transports a collaborative approach becomes even more important, to utilize vehicles at hand in a cost- and resource-efficient way.

A procuring company shows leadership when choosing a different course from long used "paths" by taking initiative and responsibility to be a part of the necessary development, where environmental impact from transportation has the same level of importance as cost, safety and reliability.

KEY TAKEAWAYS FOR PROCURING COMPANIES INCLUDE:

1. A shifting landscape requires increased knowledge on available alternatives
The transport sector is developing rapidly. Keeping updated on current status as well as what lies in the pipeline is key to generate opportunities for action and make well-informed decisions.

2. Create a fuel-strategy: don't put all eggs in one basket
With the uncertain developments of the economic and political landscape of emerging technologies and infrastructure progress, the key is to; find your business strategy for renewable fuels, establish a baseline and utilize multiple fuels/solutions to minimize your risk and create further opportunities for infrastructure.

3. Put demands on your suppliers – use your influence
Make use of all indirect possibilities to steer other transport actors towards sustainable solutions. Be clear about the fossil free direction you as a procuring company want to take; push your providers and influence the political developments to reach the CO_2 reduction targets.

4. Cooperate with other actors in the value-chain – speed up the transition
Cooperation will increase sustainability and drive more efficient use. Horizontal collaborations and coordinated transports will enable more resource efficient utilization of the transportation system – and remember that emission reductions can be highly cost-effective!

Content

1 Introduction

In the spring of 2018, Scania, H&M, Siemens Sverige and E.ON Sverige formed a coalition with the joint vision to achieve fossil-free commercial transport by 2050 at the latest, in accordance with the Paris Agreement. The Pathways Coalition pushes for an accelerated decarbonization of commercial road transport, based on conclusions from *The Pathways Study*[1] - an analysis of different pathways to a fossil-free commercial transport sector by 2050.

As a first step towards building knowledge on these pathways, The Pathways Coalition made an overview of the status of fossil free alternatives in the Swedish market. The findings are presented in the report *Fossil free alternatives for commercial road transportation in Sweden*. Next, focus has been set on the possibilities for decarbonization in the German commercial transport market.

This report attempts to describe the current and near future situation of efficiency measures and low-carbon transport alternatives available within the German road transport system. The content is a compilation of previous reports and analyses on the topic, complemented with interviews with representatives from business associations and agencies as well as experts within transport efficiency and alternative fuels or drivetrains. Possible efficiency measures are described in more general terms, as they can be applicable on a transport system regardless of the availability of alternative fuels and drivetrains. These are described from a German perspective, in terms of fuel and infrastructure availability, vehicle supply, pricing compared to fossil alternatives, important regulatory frameworks affecting development as well as additional societal and environmental values.

The alternatives for decarbonizing commercial transportation covered in this report are;

- **Efficiency measures**
- **Electrification (electric drivetrain solutions)**
  - Plug-in Electric Vehicles
  - Electric Road Systems
  - Fuel Cell Electric Vehicles
- **Alternative fuels for internal combustion engines**
  - Biofuels (biomethane, biodiesel)
  - Synthetic fuels /E-fuels (Power-to-liquid)

The study may be subject to limitations, especially regarding the full price picture and near-term development of service infrastructure for different alternatives. Fuel prices and additional vehicle costs vary over time and between different suppliers, and these parameters are typically also negotiable from case to case. Infrastructure development involves numerous actors, of which some may have been overlooked by this study.

1.1 BACKGROUND: NATIONAL COMMERCIAL TRANSPORT OUTLOOK

Flexible and dependable commercial transport play an important role for competitiveness and economic growth in Germany's export-driven economy. Given its logistics advantages, trucking is the dominating mode of transport for domestic and international trade, moving 73 percent of freight volumes[2]. Nonetheless, road transport is also coupled with high GHG emissions, and increasing traffic volumes pose a challenge to necessary fulfillment of set climate targets.

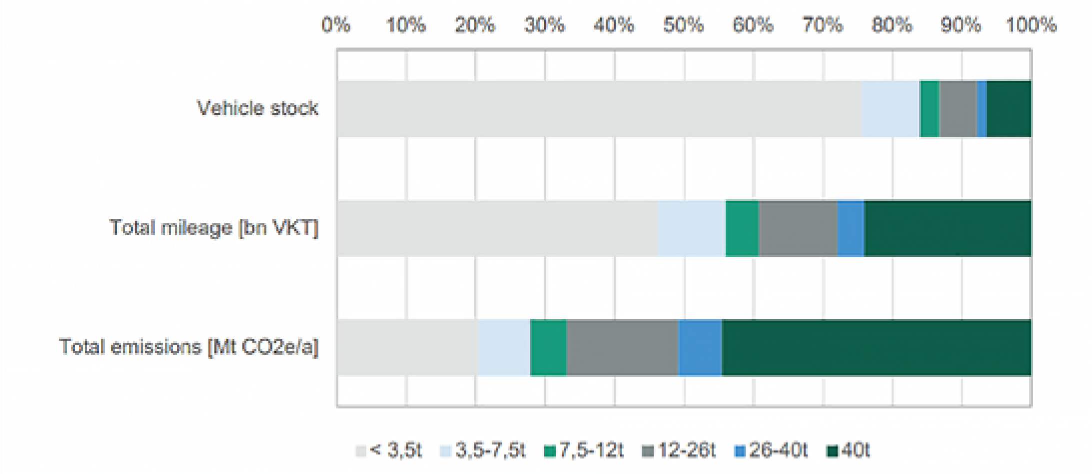
1 Scania, 2018. "The Pathways Study: Achieving fossil-free commercial transport by 2050". https://www.thepathwayscoalition.com/resources/the-pathways-study-achieving-fossil-free-commercial-transport-by-2050/

2 Clean Energy Wire, Road freight emissions in Germany, published Aug 2018. https://www.cleanenergywire.org/factsheets/road-freight-emissions-germany

Reaching the targets outlined by the Paris Agreement requires a drastic reduction in GHG emissions from transport already today, but in recent years growth in mileage has resulted in an opposite trend, with a net increase of emissions. In Germany, heavy commercial vehicles are accountable for approximately 24 percent – or 40 million tonnes COe – of annual transport emissions. Figure 1 shows the relation between vehicle stock, mileage and coupled emissions for different weight categories of trucks. The absolute majority of the current domestic truck fleet operates on conventional diesel engines, which is a challenging baseline, but also offers opportunities for measures resulting in substantial emission reductions.[3]

To achieve this, all stakeholders in the road freight transport value chain need to contribute and collaborate to push for a diversity of sustainable transport concepts.

FIGURE 1 | *Vehicle stock, total mileage and associated CO_2 emissions for commercial vehicles in Germany (2016), differentiated by gross vehicle weight. Source: Öko-Institut, 2018. "Alternative drivetrains and fuels in road freight transport – recommendations for action in Germany".*



1.2 TRANSPORT STAKEHOLDER VALUE CHAIN

To understand the value chain and the stakeholders involved is key for commercial transport actors making procurement requirements. The freight transportation supply chain is undergoing major developments, roles are changing, competitive vehicle manufacturers are emerging, new technologies are transforming the market and there are more opportunities in collaborations between actors. When so much is changing so quickly, it is important to understand the different stakeholders involved in the development.

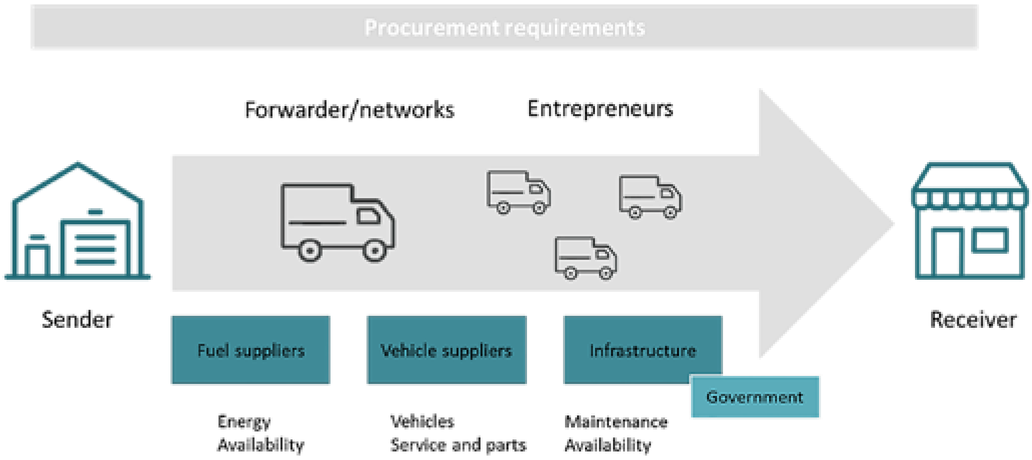
In a nutshell, the freight transport value chain is illustrated in Figure 2 on the next page. Depending on freight terms the transport buyer is the sender or receiver (or both) of transported goods. The actual freight is carried out by one or several vehicles.

For a transport buyer the contractual part could be either a forwarder or a freestanding entrepreneur. The forwarders are often large international networks who offer national and international freights and associated services such as route planning, customs issues, warehousing and other logistic services. The forwarders do not own all the vehicles that operate under their brand. Instead their fleets are made up of a combination of fully owned vehicles and subcontractors.
The entrepreneurs are mostly freestanding smaller local or regional businesses, with a much more straightforward transport focused offer.

3 Öko-Institut, 2018. "Alternative drive trains and fuels in road freight transport – recommendations for action in Germanylimate friendly road freight transport". https://www.oeko.de/fileadmin/oekodoc/Climate-friendly-road-freight-transport.pdf

All transport companies need vehicles, energy and an efficient infrastructure. Infrastructure is a key prerequisite for new technologies while almost forgotten for regular transport needs. Here the government plays a key role for road safety and investments for new construction, restoration and modernization of infrastructure.

FIGURE 2 *The value chain of freight transportation. Actors, stakeholders and the main tasks.*



1.3 REGULATORY ENVIRONMENT

In 2016, the Federal Cabinet adopted a *Climate Action Plan 2050*[4], demonstrating the German government commitment to tackle climate change and implement the Paris Agreement. The main objective is achieving greenhouse gas neutrality by 2050. Also, renewables are to make up a minimum of 80 percent of the country's gross power consumption by the middle of the century.

Targets that impact the development of vehicles:

- 55 % emissions reduction by 2030 compared to 1990
- 41 % emissions reduction in the transport sector by 2030 compared to 1990
- 70 % emissions reduction by 2040 compared to 1990
- Greenhouse gas emissions – neutral by 2050.

The action plan also set reduction targets for each economic sector to be achieved by 2030, including the transport sector. The target is 40 to 42 percent emission reduction (95 to 98 million tonnes CO_2e) compared to 1990 (163 million tonnes CO_2e). As of 2018 the status for that target was 0.6 percent reduction (162 million tonnes CO_2e).[5]

In September 2019, the German government agreed on supporting a new package of climate policies, needed to reach the 2030 reduction target. A cornerstone of the package is a national emissions trading system (ETS), covering fuel providers within the transport sector. The ETS will be launched in 2021, with an initial fixed price of EUR 10 per tonne CO_2, which will increase to EUR 35 per tonne CO_2 by 2025 and a free-market exchange will open afterward. For the transport sector, measures encouraging electromobility and better use of national railways are part of the package. Policies or measures, with relevance to the transport sector[6]:

4 BMU, Climate plan 2050. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutzplan_2050_en_bf.pdf
5 BMU, National Climate Policy. https://www.bmu.de/en/topics/climate-energy/climate/national-climate-policy/ and https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets
6 https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080

- Promotion of public and private charging stations by mandatory requirements for all German petrol stations to offer charging possibilities as well as simplification of the legal provisions regarding installation of charging infrastructure. Landlords will also be required to tolerate the installation of charging infrastructure.
- Up until 2030, the German government and the railway company Deutsche Bahn are to invest 86 billion euros in modernization, expansion and electrification of the rail network. This will allow more goods to be transported by rail.
- Vehicle tax for passenger cars will gradually move towards a CO_2 emissions based tax, starting with vehicles registered for the first time as of January 1st 2021.
- By the end of 2019 the German government will finalize a Hydrogen Strategy. Hydrogen is viewed as pivotal to the efforts to make the German economy more climate-friendly.
- Approximately one billion euros in financing earmarked for development of domestic battery cell production. The overall concept "Forschungsfabrik Batterie" (Research Factory for Batteries) supports capacity and technology development all the way along the battery cell value chain.

Renewable energy sources, including wind and solar, will be expanded in an effort to increase their share to 65 percent of total German energy supply by 2020.On a European level the European Commission has proposed a legislative emission standard for commercial vehicles. The standard would apply to new trucks, with the following target levels[7]:

- In 2025, 15% lower CO2 emissions than 2019
- In 2030, at least 30% lower CO2 emissions than 2019.

Initially the targets would only affect heavy trucks, but by 2022 the proposal is to include all other commercial vehicles. The 2025 target should be mandatory while the 2030 target is aspirational and will be reviewed in 2022. Included in the proposal is also a technology-neutral mechanism to incentivize uptake of zero- and low-emission vehicles.

As a measure to mitigate local air pollution from traffic, low emission zones have been introduced in many German cities. The emission zones regulate which Euro class vehicles are allowed within the zones through a system of stickers displayed on the vehicle's windscreen. Euro 4 diesel vehicles or newer are allowed in all zones.[8] From June 2018, the German government also introduced a support program for investments in low-emission commercial vehicles, funding up to 40 percent of the additional investment cost of a gas truck or electric truck compared to a diesel equivalent[9].

1.4 TOTAL COST OF OWNERSHIP

The term Total Cost of Ownership (TCO) is used in the report to mirror the total operating cost including all cost items for running a transport. To calculate total operating cost for a transport company, items such as salaries, insurance, head office administration, depreciation, interest rates, tax, maintenance, repairs, fuel and additives are included. The share of each cost item varies with the kind of vehicle, type of transport work and market. In general, the cost associated with the choice of technology and fuel will influence 35-50% of the total cost. Salaries, administration and insurance are cost items that would not be influenced by the choice of technology.

7 European Commission, 2018. "Reducing CO2 emissions from heavy-duty vehicles". https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

8 BMU, Low emission zone / emissions-control sticker. https://www.bmu.de/en/topics/air-mobility-noise/air-pollution-control/low-emission-zone-emissions-control-windscreen-sticker/

9 BMU, Neues Förderprogramm für mehr Energieeffizienz und CO2-Einsparung im Straßengüterverkehr. https://www.bag.bund.de/SharedDocs/Kurzmeldungen/DE/2018/foerderprogramm_%20mehr_%20energieeffizienz.html

When a transport company establishes the price for a specific transport work, several aspects are taken into consideration. Aside from the TCO, the transporter will evaluate the associated risk. For instance, if a customer requires transports with lower CO_2 emissions using a technology that requires a different kind of vehicle and at the same time maintains very short contract periods, this implies a higher risk for the transport company. If the long-term legislation and taxation principles are unclear, the risks associated with new technologies are higher. The residual value of a vehicle that is adapted to certain renewable fuels may be uncertain if the long-term cost of the fuel is not predictable or if the market demand in the future cannot be taken for granted. Most transporters add a premium to cover for:

- Higher TCO (if this is the case)
- Increased risk (if this is assessed to be the case)

2 Efficiency measures

The diverse nature of the road freight sector means that there is not a single industry-wide decarbonization solution and thus a range of solutions need to be considered to significantly reduce emissions from freight. In addition to adopting alternative fuel and powertrain solutions there are several efficiency measures related to logistics systems, vehicle operation and non-powertrain improvements available to push the shift to fossil free commercial transport. These efficiency measures have potential to cut GHG emissions from commercial transports by more than 20%[10] and are also often linked to cost-savings.

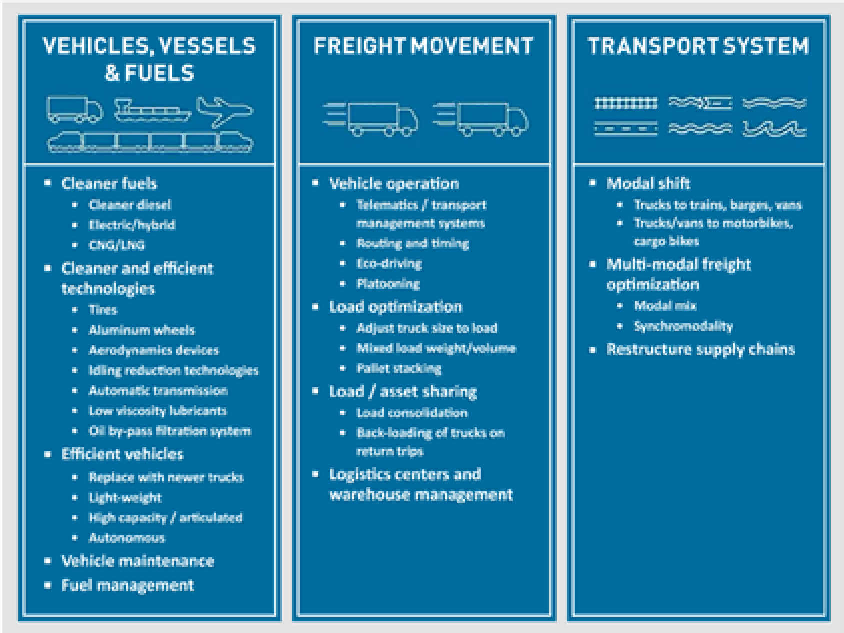
A general strategy aiming for a more sustainable transport sector, is the Avoid-Shift-Improve strategy, which promotes efficiency measures in all its forms:

- Avoid focuses on demand reduction,
- Shift involves moving to more carbon efficient modes such as from private vehicles to transit and from trucks to rail or waterways,
- Improve is about increasing the carbon efficiency of existing modes – such as increasing fuel efficiency and switching to clean technologies like gas or electric.

10 Scania, 2018. "The Pathways Study: Achieving fossil-free commercial transport by 2050".

The figure below describes the most relevant solutions for road freight[11].

FIGURE 3 | Solutions, technologies and measures relevant for road freight. Source: Smart Freight Center.



2.1 HIGH CAPACITY TRANSPORTS

Allowing greater load and/or additional trailers (higher capacity) for long haul trucks can increase energy efficiency and thereby reduce cost and contribute to lowering CO_2 emissions.

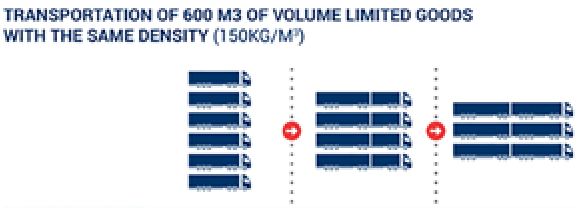
According to a recently published study[12], high-capacity vehicles can reduce carbon emissions at the individual vehicle level in the range of 15 to 40 percent related to transported volumes, depending on vehicle configuration and usage. Three high-capacity trucks could replace six regular trucks and reduce emissions by up to 27% (see graphics below). Other studies also suggest emission reductions between 10 and 35%[13].

In Germany several regions took part in a field trial to raise the efficiency in freight traffic and to examine the impacts on the environment, infrastructure and transport system. The Federal Highway Research Institute's (BASt) interim report on high capacity (long) trucks, from 2014, confirmed the positive effects from fleet fuel savings and lower CO2 emissions.[14] The study also concluded that required infrastructure maintenance costs as well as exhaust emissions were reduced.

Since the end of 2017, long trucks (18 and 25 meters long) are allowed to drive on roads designated by the Ministry of Transport in Germany – the list is constantly updated.

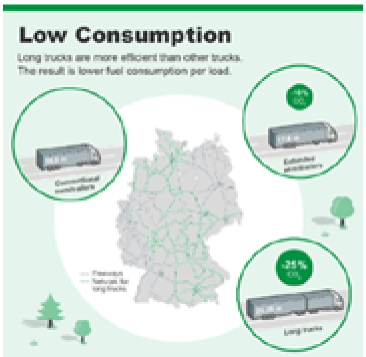
11 Smart Freight Centre, 2016. "Barriers for Carriers to adopt fuel-saving technologies and measures". https://www.smartfreightcentre.org/pdf/Barriers-for-Carriers-SFC-2016-FINAL.pdf
12 ACEA, 2019. "High Capacity Transport - Smarter policies for smart transport solutions". https://www.acea.be/uploads/publications/ACEA_Paper-High_Capacity_Transport.pdf
13 ITF, 2019, "High Capacity Transport: Towards Efficient, Safe and Sustainable Road Freight", International Transport Forum Policy Papers, No. 69, OECD Publishing, Paris.
14 VDA, The Field Trial with Long Trucks. https://www.vda.de/en/topics/environment-and-climate/long-truck/the-field-trial-with-long-trucks.html

FIGURE 4 *Potential fuel savings and emission reductions from High Capacity Transports (Source: HCT DUO2-project) and opportunities in Germany (Source: VDA).*



Vehicles (and drivers)	6	4	3
Vehicle length	16.5 m	25.25 m	32 m
Load per vehicle	100 m³	150 m³	200 m³
Fuel consumption	3.5 ml/m³km	3 ml/m³km	2.5 ml/m³km
CO2 emissions	100%	85% = -15%	73% = -27%
Road use	499 m	368 m	296 m

Source: Cider L, Larsson L, HCT DUO2-project Gothenburg-Malmö in Sweden, 2019



2.2 COORDINATED TRANSPORTS

Coordinated transports is an effective way of solving logistic issues with collaboration. The idea is to have a collective distribution center and coordinated system with a mix of actors in one region.
In Sweden, Beloved City is one example of a successful collaboration between the city council and corporates with the aim of reducing the impact of traffic in Stockholm's city center. The solution replaces a waste (recycling) truck and delivery truck with a shared smaller electric vehicle with a load carrier specially built for this transport service. One of the greatest values is the reduced use of vehicles in operation, which has a direct effect on emission reduction, noise reduction and increased traffic safety. A study from KTH Royal Institute of Technology in Stockholm shows that the project reduces emissions by 73 percent (13.4 g CO_2/kg transported goods compared to 50 g CO_2/kg)[15].

2.3 ECO-DRIVING

Driver behavior is one of the greatest factors determining fuel consumption and related carbon dioxide emissions from a heavy commercial vehicle. Education, monitoring, and feedback are ways of guiding drivers toward more fuel-efficient driver behavior[16]. For large fleets, monitoring driver behavior and climate impact can reduce emissions by 4 to 15%[17]. Eco-driving courses are also reported to decrease fuel cost by 2 to 5 percent, maintenance cost by approximately 4 percent and accident cost by 14 to 40 percent[18]. Speed reduction alone is a significant quick win for CO_2 reduction. Transport companies have reported setting speed limits of their fleet at 80 km/h to deliver fuel savings. This also reduced emissions of other pollutants, such as NO_x and particulate matter.

Keeping track of the progress, by measuring and monitoring fuel efficiency as well as giving feedback to help drivers improve, is key for a successful implementation. There are several software providers that offer systems for automatic measurements and feedback related to driving behavior.

2.4 ROUTE OPTIMIZATION

Combined measures on eco driving and route optimization have a cost-saving potential in parity with an increase in energy efficiency of 10 to 20 percent. This is a result of reduced fuel use and wear on vehicle components due to forward-thinking driving and smart planning of routes in time and stretch. Adoption at an operational level can also improve working conditions and contribute to keeping and recruiting personnel.

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15 Älskade stad, 2019. Älskade stad sparar energi enligt KTH-rapport. http://www.alskadestad.se/artikel/spara_energi_kth-rapport/

16 Liimatainen, Heikki. (2011). Utilization of Fuel Consumption Data in an Ecodriving Incentive System for Heavy-Duty Vehicle Drivers. IEEE Transactions on Intelligent Transportation Systems. 12.

17 ERTICO, 2016. "ITS4CV – ITS for Commercial Vehicles". http://erticonetwork.com/wp-content/uploads/2016/09/ITS4CV-Report-final-2016-09-09.pdf

18 Energy Saving Trust, 2005. "Ecodriving – Smart, efficient driving techniques". United Kingdom.

Successful implementation requires convincing leadership to ensure the drivers operate in accordance with guidelines. To build credibility and engagement at the operational level it is important to address the problems that drivers experience in their every-day work environment, e.g. stress to keep up with lead-times as well as delegating responsibility. Results from mapping of driving patterns and fuel use can be useful in promoting behavioral changes. Another helpful tool can be check-lists reflecting set priorities, where fuel saving might be prioritized over delivery time.

2.5 DESIGN OPTIMIZATION (OF VEHICLES)

Potential energy efficiency through design optimization of vehicles is limited, but a fuel consumption reduction of up to 5 percent can be possible[19].

2.6 MULTI-MODAL SOLUTIONS

Multi-modal solutions are – as the name suggests – a combination of different modes of transport where road transport (when possible) is shifted to rail transport or sea freight, in line with the Avoid-Shift-Improve hierarchy. This is a solution especially suitable for loads of high weight or volume[20], as both the economic gain and climate effect is served by economy of scale. Improved information sharing through digitalized platforms could facilitate multi-modal solutions through a better overview of available options within different modes of transport.

Rail freight is predestined to be a key element of a sustainable transport strategy and will relieve the pressure on the roads. However, while the shift from road to rail is key for more efficient transportation, studies show that

even with optimistic assumptions regarding rail capacities, freight transport on rail cannot fully satisfy freight needs. It is estimated that at least two thirds of freight transport will be road-based even in the future.[21]

For last mile transports in urban areas, there is already a diversity of modal solutions being tested at large scale. The relatively short distances and limited volumes of commodities per transport make cargo bikes and pedelecs (pedal electric bikes) a promising alternative, contributing to both reduced emissions and air pollution as well as less traffic congestions. In cooperation with local companies in Stuttgart, Fraunhofer IAO is testing pedal-powered vehicles concepts for urban delivery[22].

2.7 DIGITALIZATION / AI

Innovative, digitalized trucking solutions represent a piece of the puzzle for fossil-free and efficient freight transports. Already, GPS-based predictive cruise can be used to manage engine speed uphill and downhill, with a 2 percent fuel reduction potential.[23]

With greater access to data, the Internet of Things (IoT), automated driving, blockchain and Artificial Intelligence (AI) will continue to offer possibilities that will have a positive impact on transport management. Digital supply chains can offer cost reductions; enabling timely, more safe and predictable operations based on accurate information. The digital transformation will also facilitate multi-modal transport solutions.

19 Interview, Scania.

20 DBSchenker, https://www.dbschenker.com/resource/blob/488558/c71cb87de94becb963563b7ab7a7d642/tuote-esite-multimodal--fi-en--data.pdf

21 Öko-institut, 2018. "Alternative drive trains and fuels in road freight transport – recommendations for action in Germany". https://www.oeko.de/fileadmin/oekodoc/Climate-friendly-road-freight-transport.pdf

22 Fraunhofer IAO, logSPAZE. https://www.muse.iao.fraunhofer.de/de/ueber-uns/projekte/logspaze.html

23 ACT Research, Potential Aerodynamic & Powertrain Improvements Could Enhance Fuel Efficiencies by 8%. Published Dec 2016. https://content.actresearch.net/blog/potential-aerodynamic-improvements-could-improve-fuel-efficiencies-by-8

Diving into the digital transformation is a subject of its own, this study only scratches the very surface of the solutions for trucking.

One up-coming solution is autonomous (self-driving) trucks. Today vehicle manufacturers are developing both autonomous heavy-duty trucks and last-mile delivery trucks. In most cases the targeted level of automation (level 4) is enabling trucks to travel most frequent and predictable routes autonomously. Falling cost of safety technology is pushing the development and research suggests that the number of trucks with automated driving features will grow 11.5 percent a year through 2030[24]. The growth is delayed due to safety testing and regulations.

There are several examples of test pilots and R&D projects being carried out right now. Vehicle manufacturer MAN and logistics company Hamburger Hafen und Logistik AG (HHLA) will test autonomously driven trucks on a 70-kilometer-long section of the A7 German national motorway in the coming two years as part of the *Hamburg TruckPilot*[25]. Scania is also using self-driving trucks programmed to carry out specific tasks, as in the Rio Tinto operations in Australia[26]. Einride's T-pod is another example of an autonomous pilot in Sweden, a fully electric driver-less truck powered by 5G operating in DB Schenker's logistics facilities[27]. Within a decade, Daimler Trucks plans to commercialize high-automation (level 4) heavy-duty trucks that can handle self-driving in most situations. Prototypes of these trucks are being tested on public roads in Virginia[28].

AI could also be applied to traffic management and decision-making systems in order to streamline traffic management and make roads smarter, reducing accidents and increasing fuel efficiency.

24 TRUCKS, Automated Driving Tech to Grow 11.5% per Year Through 2030. Published March 2019. https://www.trucks.com/2019/03/28/automated-driving-tech-grow-through-2030/

25 MAN, Automation. https://www.truck.man.eu/de/en/Automation.html

26 Scania, Scania and Rio Tinto trialling autonomous truck in Western Australian mine. Published Dec 2018. https://www.scania.com/group/en/scania-and-rio-tinto-trialling-autonomous-truck-in-western-australian-mine/

27 internet of business, Ericsson, Einride, Telia connecting self-driving trucks with 5G. Published Nov 2018. https://internetofbusiness.com/ericsson-einride-telia-connecting-self-driving-trucks-with-5g/

28 Freight Waves, https://www.freightwaves.com/news/daimler-trucks-begins-level-4-autonomous-testing-on-public-roads

3 Electrification

The transition from combustion engines to electric-drive vehicles is widely regarded as critical for the transportation sector. Electric-drive vehicles are divided into battery electric vehicles (BEV), plug-in hybrids and hydrogen fuel cell vehicles. Together they offer the potential for a vehicle fleet to shift away from fossil fuels and bring the dramatic emission reductions that are needed to mitigate climate change and achieve long-term air quality requirements. The transition to electric drive is already underway for passenger cars, with millions of electric cars on roads around the world as of 2018. Furthermore, hundreds of thousands of electric buses have been put into local service. Progress with heavy-duty commercial freight vehicles has been more limited but is now rapidly accelerating with dozens of demonstrations and prototypes.

3.1 THE ELECTRIC GRID

Germany faces the challenge to electrify the transport sector, phase out nuclear power by 2023 and at the same time reduce the use of fossil fueled power plants. However, based on the expected introduction speed of renewable electricity and following network capacity, the introduction of electric roads and charging stations should not imply any significant challenges with regards to capacity and electricity supply.

In 2018 the average electricity emission factor for delivered electricity in Germany was 474 g CO_2/kWh, according to AIB's annual report[29]. This is high compared to the average Nordic electricity mix and above the EU average. However, the emission factor is trending downward and Germany recently announced it will close all of its coal-powered plants by 2038.[30] Additionally, it is possible to buy electricity from renewable sources in Germany by purchasing Guarantees of origin. In spite of the challenges to decarbonize the electricity network, the target is to supply at least 35 percent of gross electricity consumption with electricity from renewable sources by 2020, and at least 50 percent by 2030.[31]

3.2 PLUG-IN ELECTRIC VEHICLES

The adoption of electric vehicle technology in the transport sector is moving fast. How large the market share of fully electric trucks may be in the coming years is still uncertain. However, a review of future scenarios predicts a significant increase of electric vehicles in global truck sales – expected to reach 15 percent by 2030. Expected volumes in the European market are even higher, reaching 21 to 29 percent of total truck sales in 2030. The uptake in Europe will be driven by TCO advantages and the regulatory environment, such as emission-free zones and carbon dioxide fleet targets.

One of the key factors for electric vehicle development is the cost of batteries. This has been a major hurdle standing in the way of widespread use today. Decreasing prices will pave the way for a more rapid transition as the price drop will close the price gap of the traditional internal combustion engine (ICE) vehicles. Another important development further described in Appendix 1 is the increased range in relation to the battery weight. The relatively low maintenance and charging cost are other attractive attributes for an EV owner. Estimates predict that price parity for the majority of the electric truck segments (compared to diesel trucks) will be reached within 10 years[32]. Still, the challenge remains for the charging infrastructure, which requires a collaborative effort and effective investments.

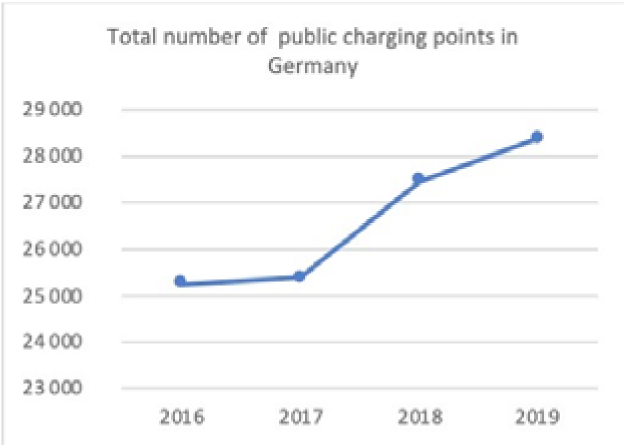
CHARGIN STATIONS - IN GENERAL AND FOR HEAVY TRUCKS

The charging infrastructure in Germany is relatively well-developed, albeit being almost entirely adapted for light vehicles such as passenger cars.

In total, there are currently 28,377 public charging points, of which 16 percent are fast charging points (> 22 kW). Per 100 kilometres of highway there is on average 35 fast charging stations, which is slightly above the EU average of 32 fast chargers per 100 km highway.[33]

29 Umwelt Bundesamt, 2019. https://www.umweltbundesamt.de/themen/co2-emissionen-pro-kilowattstunde-strom-sinken
30 Reuters, Germany to phase out coal by 2038 in move away from fossil fuels. Published Jan 2019. https://www.reuters.com/article/us-germany-energy-coal/germany-to-phase-out-coal-by-2038-in-move-away-from-fossil-fuels-idUSKCN1PK04L
31 Federal Ministry for Economic Affairs and Energy, 2018. "Sixth 'Energy Transition' Monitoring Report".
32 McKinsey, 2017. "New reality: electric trucks and their implications on energy demand". https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/
33 European Alternative Fuels Observatory, 2019, https://www.eafo.eu/countries/germany/1734/infrastructure/electricity

FIGURE 5 | *Development of number of public charging points in Germany over the last four years. Source: Data from European Alternative Fuels Observatory, 2019.*



The infrastructure for public charging for heavy trucks is poor if not non-existent. According to a recent report from the European Automobile Manufacture Association (ACEA), there are no public charging points at all in the EU, designed for long haul heavy commercial trucks.[34] ACEA claims that the EU would need 6000 DC > 500 kW public charging points along motorways by 2025/2030 to cater for long haul commercial transport. For Germany, that would correspond to approximately 600 public charging stations, as a complement to custom charging points at truck depots.

For heavy-duty transports, the transporters need to invest in proprietary charging points or rely on the truck manufacturer to facilitate charging services. An example is Telsa, that according to Reuters, is about to build on-site (non-public) charging terminals for their first US customers Anheuser-Busch, PepsiCo and United Parcel Service Inc[35]. DHL is also setting up their own charging infrastructure for their 5000 StreetScooters[36]. The charging points are installed at their logistics centres in Germany, and nine other European countries, and are developed together with Innogy. The StreetScooters charge overnight at a rate of 3.7 or 11 kW.

VEHICLE MARKET STATUS

Today there is a wide range of different types of commercial vehicles from several manufacturers, suiting different needs. There is a much wider adoption of light commercial electric vehicles compared to medium and heavy trucks. Heavy trucks driving longer routes are technically more challenging compared to smaller trucks for e.g. urban delivery.

Vehicle manufacturers announcing launches of heavy electric trucks today include, among others, Daimler/Mercedes, Einride, Volvo Group, Volkswagen, Tesla, Emoss and Scania/MAN. Several of these manufacturers just released full electric trucks or are planning to do so in the coming years.

A successful case of electric vehicles being used for distributing smaller loads, is the StreetScooter vehicle. The vehicles are used for Deutsche Post DHL Group's first and last mile services. Due to the success, they are currently producing 20,000 vehicles per year, that are also sold to external customers.

34 ACEA, 2019. "Alternatively-powered trucks, Availability of truck-specific charging and refuelling infrastructure in the EU".
35 Johnsson, M., Reuters. Exclusive: How Tesla's first truck charging stations will be built. Published Feb 2018. [
36 Randall, C, electrive.com, Innogy to provide charging to DHL StreetScooters. Published Feb 2018.

The American market research company Navigant Research predicted in 2017 that the global annual sales of electric trucks are expected to grow from about 31 000 vehicles in 2016 to 332 000 by 2026. Still, that would only constitute 5 percent of the total truck sales by 2026.[37]

A number of commercial heavy-duty zero emission electric vehicles, as of May 2019, are presented in a table in Appendix 2. As visible in the table, there are some technical challenges with fully electric vehicles; the range, the load capacity and the time it takes to charge the battery. Compared to today's combustion engines, the fully electric vehicles are also dependent on infrastructure developments.

Some vehicle manufacturers have also developed hybrid trucks, which are less sensitive to current lack of charging points. Scania, for instance, offers a hybrid truck which is charged while using the brakes and has a range of 2 km if only driving on electricity. The truck has a main diesel engine which can operate on biodiesel or renewable diesel (FAME or HVO), reducing CO_2 emissions by up to 92 percent when distributing in cities[38].

The payload allowance is another important factor for delivery trucks. In general, an electric truck with four batteries can carry about one tonne less payload compared to ICE counterparts[39]. However, the capacity varies with application areas. Trucks operating in urban conditions can be optimized to maximize the payload and minimize the battery need.

The list of electric trucks suggests that by 2020 there will be several different alternatives on the market. The big manufactures will continue to offer electric solutions and new entrants will challenge and compete for the growing market.

The vehicles will be viable commercial solutions for short haul transport., As the technical challenges are overcome and price parity is reached, all segments will be of high demand. The short and medium haul battery electric commercial vehicles could reach 8 to 35 percent of sales by 2030 - in US, China and Europe - depending on scenario[40].

A number of Medium/Light-trucks electric vehicles, as of May 2019, are presented in Appendix 2.

REGULATORY ENVIRONMENT

Regulations can facilitate and accelerate the shift towards electric trucks, see Appendix 3 for more information on current tax benefits and incentives for BEVs in general.

The German Electric Mobility Act (Elektromobilitätsgesetz, EmoG), which entered into force in 2015 does not yet include commercial trucks heavier than 3.5 tonnes (Vehicle categories, N2 and N3). However, the last progress report recommended that the act should include these vehicle categories in the scope to increase the electrification of urban logistics in local communities. The purpose of the law is to grant special privileges to electric-powered vehicles on the roads, such as allocating them special parking spaces near charging stations in public areas, lowering or eliminating parking fees, and exempting electric vehicles from certain access restrictions.

37 Navigant Research, 2017. "Global Annual Sales of Electric Trucks are Expected to Reach 332,000 by 2026".
38 Scania, https://www.scania.com/se/sv/home/products-and-services/trucks/our-range/scania-hybrid.html
39 Volvo, https://www.volvotrucks.com/en-en/news/volvo-trucks-magazine/2018/jun/quick-facts-electric-trucks.html
40 McKinsey, 2017. "New reality: electric trucks and their implications on energy demand".

COMPARATIVE PRICING

Purchase price
Currently there is a higher price on heavy electric vehicles compared to corresponding conventional diesel vehicles. For example, the Tesla Semi costs 180 000 USD[41] compared to new diesel trucks starting at 80 000

USD. However, for a custom featured diesel truck the price can reach 200 000 USD. The electric trucks are often designed to fit a specific customer need and the price will therefore vary depending on model.

Moreover, the purchase price of the vehicle does not account for the total cost of ownership. This is also comprised of daily driving distance, electricity consumption, fuel price, salary cost for drivers etc. By 2025 the cost parity with diesel trucks is likely to be reached[42]. This point is not a fixed date and is highly dependent on the specific ranges and routes driven by the trucks. The clearest economic rationale seems to be for light duty trucks – with an operational distance of 100 to 200 km/day.

The Federal Ministry of Transport and Digital Infrastructure has launched a program to promote energy-efficient and/or low CO2 heavy commercial vehicles[43], which subsidises investments in Electric trucks as well as CNG and LNG trucks. The investment subsidy per vehicle is EUR 12,000 for trucks up to 12 tonnes and EUR 40,000 for trucks from 12 tonnes. The annual maximum subsidy per company amounts to EUR 500,000.

Secondary market
The residual value of electric trucks is uncertain as the market is still in its infancy. When it comes to the secondary market of the components of the vehicle, such as batteries and engine, the electric vehicle has an advantage compared to ICE. The components can be reused for other purposes, in completely different products – for example storing solar energy.

Cost of maintenance
The technical lifespan of electric trucks is expected to be longer than for ICE trucks (with a lifespan of around 8 years). This is due to fewer service-needing components resulting in a lower cost of maintenance. In general, the engine contains less than ten components compared to more than a hundred in an ICE. The durability of batteries depends on different charging aspects, such as charging speed, but lifetime warranties of battery systems are typically set to match the lifetime of the vehicle. However, current vehicles are still in their infancy and may suffer from teething problems.

Fuel cost
The fuel cost for electric vehicles is directly dependent on the price of electricity. The electricity cost is uncertain as it varies with the seasons and the specific time of day as well as the electricity contract. In Germany, the cost per kWh varies between 0 and 60 ct[44] (the average household electricity price was around 29 ct/kWh 2018). Each operator has its own tariff system. Innogy, the largest charging station operator, charges a flat rate of € 7.95 per charge for combined AC / DC charging stations and 39 ct/kWh for pure AC charging stations.[45]

Another important aspect is the cost of a charging station. The construction cost varies depending on different factors: type of charger, location, proximity to electricity supply and the grid's capacity at the location. To invest

41 Trans.info, Record orders for Tesla truck. Is Semi really profitable?. Published Dec 2017. https://trans.info/en/record-orders-tesla-truck-semi-really-profitable-76528
42 McKinsey, 2017. "New reality: electric trucks and their implications on energy demand".
43 Bundesamt Für Güterverkehr, 2018, Neues Förderprogramm für mehr Energieeffizienz und CO2-Einsparung im Straßengüterverkehr
44 LichtBlick, Ladesäulen-Check 2018: Teure Tarife und regionale Monopole bestimmen den Markt. Published July 2018. https://www.lichtblick.de/presse/news/2018/07/13/ladesaeulen-check-2018-teure-tarife-und-regionale-monopole-bestimmen-den-markt/
45 Ibid.

in a fast charging (DC) station the cost is approximately € 47,000 – of which 50 percent of the cost derives from connecting the station to the electricity grid. A station for night-time charging costs approximately € 1,400, including installation.

The fuel cost is also indirectly dependent on the time spent charging, as this can be a productivity loss for the driver.

Other TCO factors

Insurance and personnel cost are other factors that need to be accounted for in the operational cost of a vehicle. The regulatory environment is also highly significant for the total cost, for example road charges, tolls and fuel taxes. Increased fuel taxes could be used to fund the transition towards electrification.

CLIMATE PERFORMANCE AND ADDITIONAL EFFECTS

Reduced harmful exhaust emissions from commercial vehicles leads to cleaner air resulting in less health problems. According to a study by the European Federation for Transport and Environment, there are no emissions of pollutants such as NOx, SOx and PM, from a battery electric truck powertrain perspective. The study also shows that long range battery electric trucks in the EU have 51 to 67 percent less CO2 emissions compared to equivalent fossil fuel powered trucks.[46] With the German electricity mix of comparably high CO2 emission intensity, the reduction of CO2 emissions is probably in the lower part of that range. Note that although the electricity mix in Germany is currently fossil dependent, renewable electricity is available by either charging at charging points supplied with 100 percent renewable electricity, or by buying renewable electricity based on the system for Guarantees of Origin.

There are additional values such as:

- **Reduction of noise:** potential for urban deliveries during off-peak hours reduces the burden on frequently traveled roads and allows 24/7 utilization of the vehicles. This benefit may however be downplayed by new regulations within the EU, stating that electric vehicles are not allowed to be completely silent.
- **New job creation:** electrification of transports will create job opportunities in both vehicle development and charging infrastructure construction.
- **Health benefits:** it is estimated that electric vehicles can increase health care savings due to harmful pollutant reduction. It is estimated that traffic pollution cost 60 billion euros per year in healthcare in the EU[47].
- **Environmental benefits:** lower climate impact due to a more effective drive train. In an extended timeframe, with a less CO2 intensive electricity mix, there is a good potential for even better climate performance.
- **Energy security:** enabling trucks to run on domestically produced electricity is a great boost to energy security, as fossil fuels used in transport are predominantly imported, often from politically unstable or unreliable regions.

46Earl, m.fl., 2018. "Analysis of long haul battery electric trucks in EU". https://www.transportenvironment.org/sites/te/files/publications/20180725_T%26E_Battery_Electric_Trucks_EU_FINAL.pdf

47 European data journalism Network, 2019 https://www.europeandatajournalism.eu/eng/News/Data-news/Traffic-pollution-costs-60-billion-per-year-in-healthcare

SWOT

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Reduced GHG emissions • Zero local air pollution • Increased energy efficiency • Low maintenance costs • Low noise volum	• Not yet widely available for high loads of cargo • Charging time • No adapted charging infrastructure • Complex charging (different standardizations for charging) • Infrastructure cost • Short/limited range • Higher vehicle cost • Not fully technically developed • Lifetime of batteries	• Fast technical development (batteries) towards increased range and lower cost • The grid will evolve (charging) • Political support (road taxesm special lanes, subsidies) • Higher accessability that fossil fuelled trucks due to potential introduction of environmental zones • Synergies with renewable electricity development • Lower operational costs (fuel/energy)	• Uncertain supply of raw material and components for batteries • Other technologies for electrification • Electricity (and power) supply • Rising electricity prices • Price uncertainty on secondary market

KEY TAKEAWAYS

Barriers to widespread viability:

- **Limited range.** Today's batteries have twice the range (370 km, 2019) compared to ten years ago (190 km, 2009), but it is not yet enough for long-haul logistics.
- **Battery cost.** The manufacturing cost of an EV battery pack has fallen significantly over the past eight years, due to more cost-effective production methods. Compared to 2018, prices have come down by around a factor of four. Still, estimates predict that the price parity of electric trucks compared to diesel trucks is to be reached by 2025 at the earliest.
- **Charging issues.** Most commercial heavy-duty truck models need 6-8 hours of charging, which can imply a significant productivity loss. However, fast charging requires more expensive high-power charging stations and may lead to reduced battery lifetimes.

Promising commercial segments:

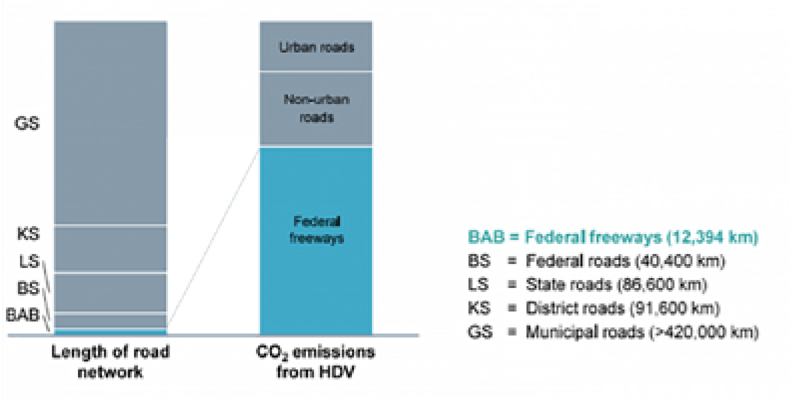
- **Light-duty urban delivery vans.** The clearest economic rationale seems to be for light duty trucks with an operational distance of 100 to 200 km per day.
- **Medium-duty regional delivery trucks.**
- **Refuse trucks.**

Photo: Scania

3.3 ELECTRIC ROAD SYSTEMS (ERS)

According to the German Federal Ministry of Transport (BMVI), long haul transport is highly concentrated to the highway network. 60 percent of emissions from heavy commercial vehicles derive from only 2 percent of the road system, corresponding to the Autobahn (BAB).[48] Coupled with the fact that 89 percent of German truck trips - after leaving the highway - are 50 km or less[49], this makes Electric Road Systems (ERS) an interesting option for a sustainable German transport system. Where long-distance heavy traffic is concerned, studies suggest there is no cheaper alternative which is equally energy-efficient, has such low carbon dioxide emissions and for which the energy supply is assured in Europe.[50]

FIGURE 6 *Infrastructure on heavily use roads and related heavy-duty vehicle emissions Source: Siemens, 2018.*



48 BMVI website. https://www.bmvi.de/DE/Home/home.html

49 BMVI website (SIEMENS presentation, 2018 "eHighway, electrified heavy duty road transport")

50 Trafikverket, RISE, 2017. "Förstudie av affärsekosystem för elvägar". https://www.viktoria.se/sites/default/files/pub/viktoria.se/upload/publications/rapport_affaersekosystem_elvaegar_20170926.pdf

The development of ERS in Germany has come further than anywhere else in the world, with several field tests on public motorways currently underway, using trucks from an OEM (Scania). Furthermore, the establishment of a domestic ERS-network is being openly discussed and promoted by both academia and industry. Siemens has piloted small-scale electric road systems in Sweden since 2016 and a recent study of these tests, by the Swedish research institute RISE, concluded three general characteristics for electric roads to offer a viable option in the transition to a sustainable heavy freight system:[51]

- An electrified road distance of at least twenty kilometers,
- Annual average daily traffic (AADT) of electric trucks on electrified roads should (in both directions) be at least twice the number of electrified kilometers in one direction, and
- The electrified stretch should comprise 60 percent or more of the trucks' overall distance driven each year.

These characteristics are based on Swedish case studies but are applicable to Germany as well, especially since German highways are approximately ten times more trafficked than Swedish highways.[52] For further information on the various technologies for ERS, please see Appendix 4.

INFRASTRUCTURE AVAILABILITY – DEVELOPMENT OF ELECTRIC ROADS

There are currently no long-distance electric road systems in Germany, but several overhead (OH) catenary field tests are underway, in a collaboration between the German government and different tech providers. Siemens inaugurated a five-kilometre catenary system on a public road outside Frankfurt in May 2019 (project ELISA). Another two pilots will be initiated in 2019, outside Lübeck (Project FESH, Siemens) and Baden-Württemberg (eWayBW, yet to be awarded).[53] The most suitable routes for roll-out of electric highways have been identified, and it is likely that this development will move forward during the first half of the 2020s. For more information on the development of electric roads in Germany, please see Appendix 4.

VEHICLE MARKET STATUS

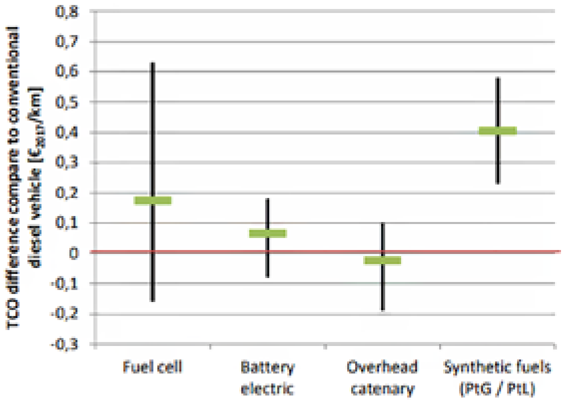
The current status of catenary trucks among the major truck manufacturers in Europe is compiled in a table found in Appendix 4. As visible in the table, Scania is pushing the development of catenary trucks quite on their own, which is confirmed by Stefan Ziegert, Product manager for sustainable transport solutions at Scania in Germany.[54]

COMPARATIVE COST / TCO

Several independent German institutes (Oeko Institute, Fraunhofer ISI and IFEU) concluded in April 2019 that OH catenary would be the most cost effective way to reach the climate goals for heavy trucks, see total cost of ownership (TCO) comparison in Figure 7 below. Overhead catenary is the only alternative that has a lower mean TCO per kilometre than diesel. Apart from the fact that electric drives have low operating costs for trucks, catenary systems have advantages in energy economy, as the electricity requirement is comparatively low and is distributed more evenly over the route network and over time. Additionally, it is flexible to provide energy to both fully electric vehicles and hybrid trucks. The TCO comparison below have large variations regarding assumptions about future fuel costs and framework conditions, which leads to an uncertainty of the actual differences between the different alternatives.[55]

51 Trafikverket, RISE, 2017. "Förstudie av affärsekosystem för elvägar".
52 Interview with Håkan Sundelin, RISE Viktoria, 2019-10-24.
53 Siemens Mobility Gmbh, 2019.
54 Interview with Stefan Ziegert, Product manager for sustainable transport solutions, Germany and Austria within Scania. 2019-05-15
55 Öko-Insititut, 2019. "Alternative drive trains and fuels in road freight transport – recommendations for action in Germany".

FIGURE 7 | *Variation in TCO of different alternative drivetrains / Fuel options relative to fossil diesel in the period 2020-2030. Source: Öko-Institut, 2018.*

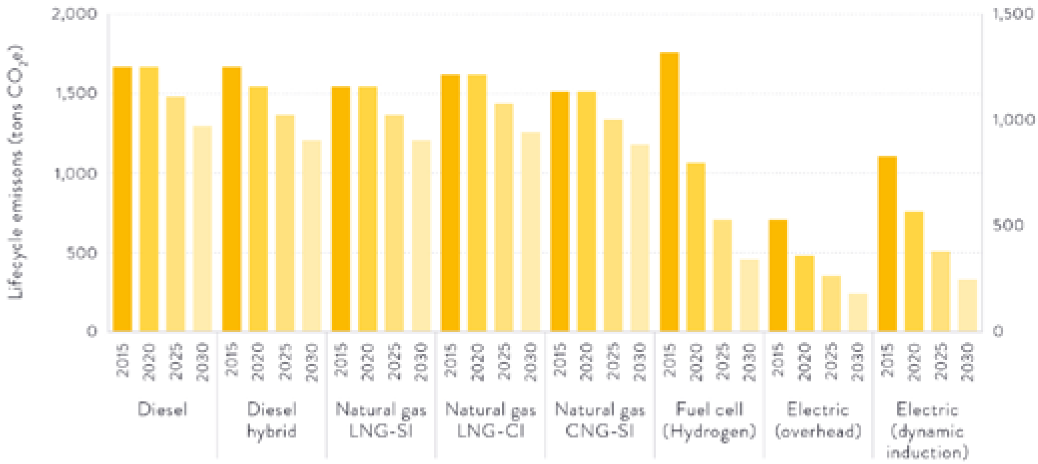


When comparing the cost parity of ERS to other alternatives, it is necessary to include factors such as cost of refuelling, in addition to vehicle purchase costs. Such a system cost assessment was made by ICCT and concludes that efficiency of energy supply plays a far greater role than vehicle and infrastructure costs, whereby ERS shows significantly lower total costs than other alternatives.[56] This is an important insight since major truck manufacturers avoid developing ERS-models due to the initially large infrastructure costs (see Vehicle market status above). It also underlines the importance of a transparent development plan for the infrastructure; otherwise the risks for trucking companies are too big, as pointed out by IFEU.[57]

CLIMATE PERFORMANCE AND ADDITIONAL EFFECTS

To a large extent, additional effects of ERS are similar to effects described in the chapter Plug-in electric vehicles above. There is an apparent environmental benefit of ERS (see Figure 8) as less batteries are needed. Furthermore, ERS constitutes a more stable load for the grids.

FIGURE 8 | *Well-to-wheel lifecycle analysis of CO_2e emissions for long-haul heavy-duty freight truck in Europe purchased in 2015 through 2030. Source: ICCT, 2017.*



56 ICCT, 2017. "Transitioning to zero-emission heavy-duty freight vehicles". https://www.theicct.org/publications/transitioning-zero-emission-heavy-duty-freight-vehicles
57 IFEU, PTV. Roadmap OH-Lkw Potentialanalyse 2020-2030, p. 22

In contrast to BEV's however, necessary infrastructure will be installed in a public domain. Even though there is a strong public discussion regarding climate change and a generally positive view on electrification, the local understanding and acceptance for overhead lines is low[58]. Simultaneously, large OEMs, like Scania and Volvo have expressed their readiness to develop and industrialize such vehicles, as soon as governments commit to an infrastructure deployment plan[59]. Herein lies a challenge for policy makers.

SWOT

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Ready for implementation in the short term • Reduced GHG emissions • Reduced local air pollution • Increased energy efficiency • Low maintenance costs • Very cost-efficient solution in relation to CO2 reduction • Combination of ERS and other drive trains possible, e.g. with BEV with small(er) batteries	• Initial infrastructure investment • Time consuming implementation • Complex integration with electric grid • Limited range where the ERS-vehicles can utilize ERS-technology • Higher vehicle cost compared to conventional trucks • Not fully technically developed • Attractiveness requires widespread roll-out.	• Synergies with renewable electricity development, other alternative fuels and transportation trends (e.g. level 4 automated trucking on highways, high capacity transport) • The grid will evolve (charging) • Low-cost batteries • Political support (road pricing, special lanes, subsidies) • Lower cost of use and service • Domestic rail companies have experience in OH catenary technology	• Limited charging infrastructure • Price uncertainty in secondary market • Rising electric prices • Competition of funding with other public investment • Political hesitation to invest in large-scale novel solutions, partly due to low public acceptance.

KEY TAKEAWAYS

Barriers to widespread viability:

- Achieving critical mass of ERS-networks. ERS requires large infrastructure investments and is very suitable for high volume applications. Initially these systems will inevitably be under-utilized.
- Standardization across regions. It is crucial to synchronize German e-road technology with the roll-out in other countries, such as France and Italy.
- Visual impact. Introducing new infrastructure on the motorway needs to be carefully communicated, to address concerns and explain the benefits, such as improving the air quality for residents next to busy highways.

Promising commercial segments:

- Heavy-duty trucks and tractor-trailers on medium distance routes with high transport density
- Closed cargo systems, e.g. ports.

58 Interview with Hendrik Paul, E.ON Energy Networks, Essen, Germany. 2019-05-09

59 https://www.linkedin.com/pulse/more-hesitation-take-decisions-build-electric-roads-now-henriksson/?trackingId=9GHCDmslXziDdSetD7Odsg%3D%3D

3.4 FUEL CELL ELECTRIC VEHICLES (FCEV:S)

There is a growing consensus internationally that hydrogen will have an important role in the world's transition to a sustainable energy future. Hydrogen is versatile and can be used in a range of ways across the energy sector. However, when and how the hydrogen market may develop is still highly uncertain.

Fuel cell electric vehicles (FCEV) use an electric powertrain, but instead of an electric battery FCEVs carry fuels cells which are fueled with hydrogen gas. The fuel cells then generate electricity by using oxygen from the air and the compressed hydrogen gas – emitting only water and heat.

Hydrogen gas is mainly produced from natural gas through gas reformation or from water through electrolysis (currently only 0,1% of global production[60]) – two quite energy-intensive processes. Theoretically hydrogen gas can be produced from biogas as well, but as biogas is already a viable biofuel this is not common practice.

Currently the primary applications for hydrogen gas are on-site use in chemical industries and oil refineries, while the use as vehicle fuel is limited to 0.01 million tonnes (out of the 69 million tonnes annual production) due to significant economic disadvantages compared to conventional powertrains and battery electric vehicles.

While the bottleneck of commercially available heavy commercial vehicles is expected to diminish in the long term, with global manufacturers entering the market, the refueling infrastructure as well as relatively high costs related to hydrogen gas production and fuel cell production remain as barriers for rapid expansion. The fuel cell trucks are not forecasted to be a competitive alternative in a at least within the next couple of years[61]. However, with the significant benefits that the technology can offer the environment and with manufacturers developing prototypes, the hopes are high for long-range heavy-duty transports, expected to be commercially available in Germany by 2030[62]. The German government has announced that they will release a hydrogen strategy before the end of 2019.

VEHICLE MARKET STATUS

Globally, fuel cell vehicle deployment has been concentrated to the US market, especially California, followed by Japan and Europe. The race to be in the forefront in fossil fuel free transports is on and there is a strong interest in the trucking industry, with pilot projects and collaborations recently announced. Several manufactu-rers invest heavily in R&D and have plans for vehicle deployment. However, the vehicle supply in the German market is still in its infancy.

In Europe, Switzerland stands out. Hyundai Motor in cooperation with H2 Energy, announced the delivery of 1,600 heavy fuel cell electric trucks between 2019 and 2025. The joint venture focuses on the Swiss market, with the intention to expand to other European countries as quickly as possible.

The retailer COOP has already developed a tailored fuel cell truck for its own regional distribution together with OEM Esoro. The Coop truck is refueled at the company's own filling station in Hunzenschwil, in the Swiss Canton of Aargau.

Nikola Motors Company, a fuel cell truck manufacturer, has announced several developments during the past year. In 2018 a major deal with the American beverage company Anheuser-Busch was announced, with an order of 800 fuel cell trucks to be delivered in the beginning of the 2020's[63]. The model Nikola Tre is adapted for the European market and Bring has already ordered a truck to be part of the testing that will take place in Norway,

60 IEA, The Future of Hydrogen Report Seizing today's opportunities, June 2019

61 Larsson, M. 2015, The role of methane and hydrogen in a fossil-free transport sector. Doktorsavhandling, KTH, Skolan för kemiveten-skap.

62 Based on Germans national strategic framework for hydrogen infrastructure.

63 Nikola Motors https://nikolamotor.com/press_releases/anheuser-busch-continues-leadership-in-clean-energy-places-order-for-800-hydrogen-electric-powered-semi-trucks-with-nikola-motor-company-23

beginning in 2020[64]. Serial production is set to begin 2022/2023. The company also states that they will provide hydrogen for the truck owners, planning to roll out a fueling station network by 2028.

Scania is developing a fuel cell refuse truck together with the waste handling company Renova in Sweden, expected to be delivered by the end of 2019/ beginning of 2020[65]. Scania has also announced a cooperation with the Norwegian food wholesaler Asko including delivery of four 26-tonne fuel cell distribution trucks with a range of 500 km. Asko has established its own production facility for sustainable hydrogen gas.[66]

FIGURE 9 *One of Scania's fuel cell distribution trucks, delivered to the Norwegian food wholesaler Asko.*

Please see Appendix 2 for a table of manufacturers and models.

There are also medium-duty trucks entering the market. In Germany, DHL subsidiary StreetScooter recently announced the development of "H2 Panel Van", a 4.25-ton electric van powered by hydrogen fuel cells, with a range of 500 kilometres. The delivery of 100 vehicles is said to start in 2020. DHL is the exclusive user of the van, with no current plan of making the van commercially available[67].

INFRASTRUCTURE AVAILABILITY

The development of hydrogen infrastructure networks is concentrated to areas where vehicle manufacturers, hydrogen suppliers and governments share an interest and are ready to pave the way for FCEV deployment, and so far there has been a focus on infrastructure adapted for light-duty vehicles.

There are currently around 70 publicly accessible hydrogen filling stations in total in Germany. In 2018, 17 domestic filling stations were put into operation[68]. The nation has the second largest hydrogen refueling

64 VIA tt, 2018. https://via.tt.se/pressmeddelande/bring-har-bestallt-vatgasdriven-lastbil?publisherId=110414&releaseId=3244636
65 Scania https://www.scania.com/group/en/scania-delivers-fuel-cell-refuse-truck/
66 Volkswagen https://www.volkswagenag.com/presence/investorrelation/publications/annual-reports/2019/scania/Scania_Annual_Report_2018.pdf
67 Forbes, Hauling With Hydrogen: DHL Adding Fuel-Cell Vans To Its Delivery Fleet. Published May 29, 2019 https://www.forbes.com/sites/alanohnsman/2019/05/29/hauling-with-hydrogen-dhl-adding-fuel-cell-vans-to-its-delivery-fleet/
68 netinform, 2018. https://www.netinform.net/h2/aktuelles_detail.aspx?ID=3573

infrastructure worldwide, only surpassed by Japan. The German industry initiative H2 MOBILITY[69] has already started planning for another 30 to be built in 2019, with the target of reaching 400 by 2023[70]. The website H2stations.org provides interactive maps of all globally listed hydrogen refueling stations (planned, in operation and already closed). These fueling stations are said to be compatible with light commercial trucks. Heavy commercial trucks require different design to handle larger amounts of fuel and pressure storage.

For heavy trucks, the refueling infrastructure in Europe is currently in its infancy, being non-existing or in the initial developing stages. The European Automobile Manufacturers' Association estimates that around 1,000 fueling stations suitable for H2 heavy trucks are needed by 2025/2030 in Europe[71]. Vehicle manufacturers are planning to fill the gap, but there is an uphill challenge to tackle the chicken-egg dilemma of building hydrogen stations alongside truck deployments and truck demand.

The complex nature of developing a wide hydrogen infrastructure in the German market requires collaboration, joint vision and political commitment for planning the rollout. The Federal Ministry of Transport and Digital Infrastructure in Germany states that *"Currently, the biggest challenge in the expansion of hydrogen refueling stations is no longer the system technology nor the construction, but rather the approvals process".*[72]

HYDROGEN PRODUCTION

Hydrogen can be produced from different energy sources and with diverse processes. One process used is from natural gas or methane via steam reforming. Another alternative is through electrolysis (breaking the bond of hydrogen and oxygen) using electricity. All processes need energy to pump, store, compress and deliver the hydrogen at different stages. Even though the FCEVs are zero emitting in the operational phase, well-to-wheel emissions are currently only 30 percent lower than from ICE vehicles due to the energy intensity of the production process.[73] For further information on the regulatory environment for hydrogen in Germany, please see Appendix 3.

COMPARATIVE COST / TCO

The key components of a FCEV powertrain are the hydrogen tank, fuel cell stack, electric machine and lithium-ion battery. A study by ICCT estimated that the component costs for the vehicle was around 342 000 US in 2015. In 2020 the cost is estimated to 281 000 USD in the European market[74]. In the Pathways Report, the total acquisition cost (including fuel cell stack components, compressed gaseous H2 tank, battery cost, vehicle, transmission + driveline, electric motors, Aux FCEV system components) is estimated at 427 000 EUR (2017), projected to decrease to 265 000 EUR by 2030 (5 percent cost reduction per year). The most expensive drivetrain components for FCEVs are the fuel cell and the compressed gaseous hydrogen tank[75].

The figure below illustrates the differences of several technologies and the associated total cost of ownership. For fuel cell technology, there are two different scenarios for the TCO depending on if the hydrogen is produced from natural gas of from a renewable source. The fuel cell technology shows the largest reduction in cost over time (2015-2030) compared to other technologies, due to the expected drops in the cost of fuel cells and hydrogen.[76] Currently there is still a significantly higher cost associated with the use of fuel cell trucks[77].

69 Air Liquide, Daimler, Linde, OMV, Shell and TOTAL.

70 https://www.gasworld.com/h2-mobility-plans-for-400-german-hydrogen-stations/2009381.article

71 ACEA, 2019. "Alternatively-powered trucks Availability of truck-specific charging and refuelling infrastructure in the EU". https://www.acea.be/uploads/press_releases_files/Infrastructure_alternatively-powered_trucks_January_2019.pdf#page=5

72 NOW, 2017. https://www.now-gmbh.de/content/service/3-publikationen/1-nip-wasserstoff-und-brennstoffzellentechnologie/electric-mobility-with-hydrogen-2017_en_310817.pdf

73 The Linde Group, 2019. H2 Production. https://www.the-linde-group.com/en/clean_technology/clean_technology_portfolio/hydrogen_energy_h2/h2_one_stop_shop/h2_production/index.html

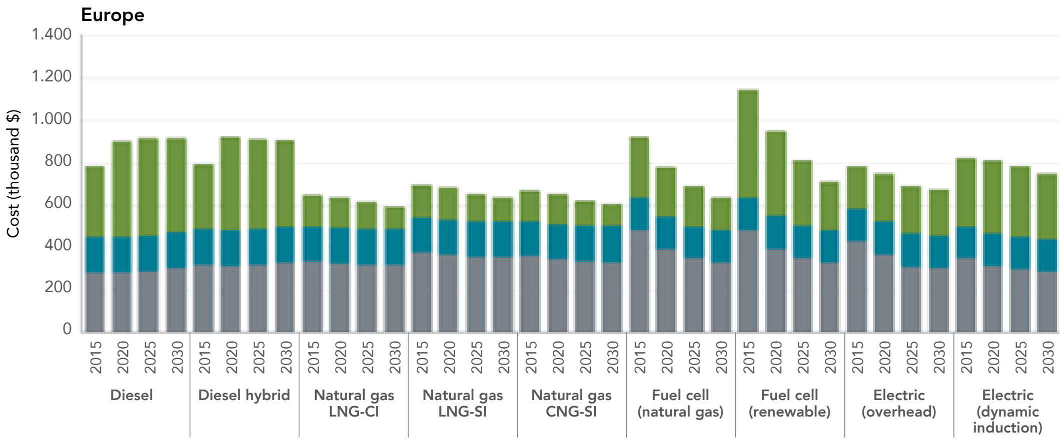
74 ICCT, 2017. "Transitioning to zero-emission heavy-duty freight vehicles".

75 Scania, 2018. "Pathways to sustainable transport, Meeting the Paris Climate Agreement targets for greenhouse gas emissions".

76 ICCT, 2017. "Transitioning to zero-emission heavy-duty freight vehicles".

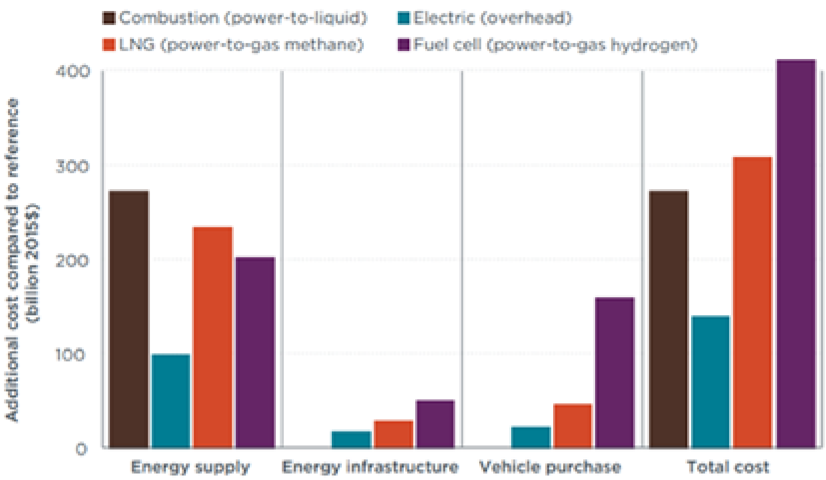
77 Öko-Insititut, 2018. "Alternative drive trains and fuels in road freight transport – recommendations for action in Germany".

FIGURE 10 *Cost distribution and forecasted development for different fuels and drivetrain technologies. Source: ICCT, 2017.*



Comparing the additional cost for heavy duty long-haul vehicles powered by fuel cells with fossil fueled vehicles, such as the cost of energy supply infrastructure and vehicle purchase cost, the fuel cell technology has the highest TCO[78] (see Figure 11 below). The technology also has higher total cost of ownership compared to hybrid or battery electric vehicles.

FIGURE 11 *Additional costs for four different GHG reduction scenarios compared to the reference case (100% fossil fuel use) for the long-haul heavy commercial transport sector in Germany. Source: ICCT, 2017 (based on Kasten et al., 2016).*



There is still potential for fuel cell technology for heavy duty trucks. The use of hydrogen as fuel has the advantage of longer ranges with shorter refueling times, compared to battery electric vehicles. The fuel cell stacks also offer 50 percent efficiency compared to the diesel engines with efficiencies of 37-39 percent[79].

78 Key assumptions: Length of electric network 4000 km; Infrastructure costs 2,2 million EUR; Maintenance 2,5% of investment per year, Additional vehicle costs: per today 50.000 EUR/truck; per 2050 19.000 EUR/truck, share of electric traction 60% in 2050.
79 ICCT, 2017. "Transitioning to zero-emission heavy-duty freight vehicles". http://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

Studies have identified FCEV as solutions to suburban deliveries such as drayage trucks due to the flexibility and longer ranges.[80]

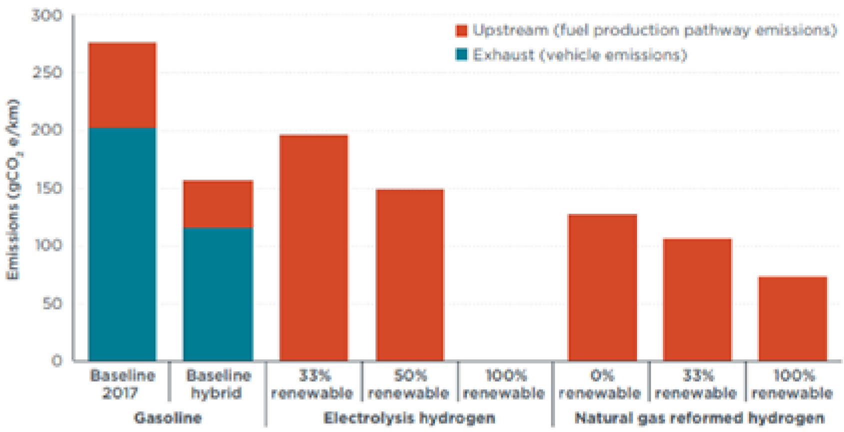
In the long run, an analysis made by the International Energy Agency shows that the cost of producing hydrogen from renewable energy is likely to fall 30 percent by 2030, due to declining cost of renewables and scaling up of hydrogen production.[81]

CLIMATE PERFORMANCE AND ADDITIONAL EFFECTS

In Germany 2018, a majority of domestic electricity was generated from non-renewable sources: the burning of Lignite and hard coal (22.5 percent and 12.9 percent respectively), nuclear power plants (11.8 percent) and natural gas (12.9 percent). Only 34.9 percent of German power comes from renewable energy sources (wind, biomass, solar or hydropower) which means that production of hydrogen is not zero-emitting[82]. The production cost of hydrogen from a renewable hydroelectric power plant is also significantly higher than from hydrogen produced from fossil fuels, which implies that climate friendly hydrogen production is not yet cost effective[83].

According to a study by ICCT[84], FCEV have the potential to reduce CO2 emissions by 62-67 percent compared to high-efficiency diesel. However, there are significant differences in environmental impact between electrolysis and natural gas reformed hydrogen.

FIGURE 12 *CO_2e of hydrogen fuel cell vehicle compared to hybrid and gasoline vehicle. Source: ICCT, 2017.*



The Mission Innovation initative recognizes the great potential for hydrogen in energy transition in the society at large. Hydrogen can be produced and stored at times of low demand and utilized when needed, which enhances the energy productivity of renewable sources. In the transport sector the technology would serve as a good complement to battery electric veichles – acheiving high GHG abatement and improving air quality.

80 ”Development of Business Cases for Fuel Cells and Hydrogen Applications for European Regions and Cities” https://www.fch.europa.eu/sites/default/files/FCH%20Docs/171121_FCH2JU_Application-Package_WG2_Delivery%20vans%20%28ID%202910565%29%20%28ID%202911651%29.pdf and ICCT, 2017. “Transitioning to zero-emission heavy-duty freight vehicles”.

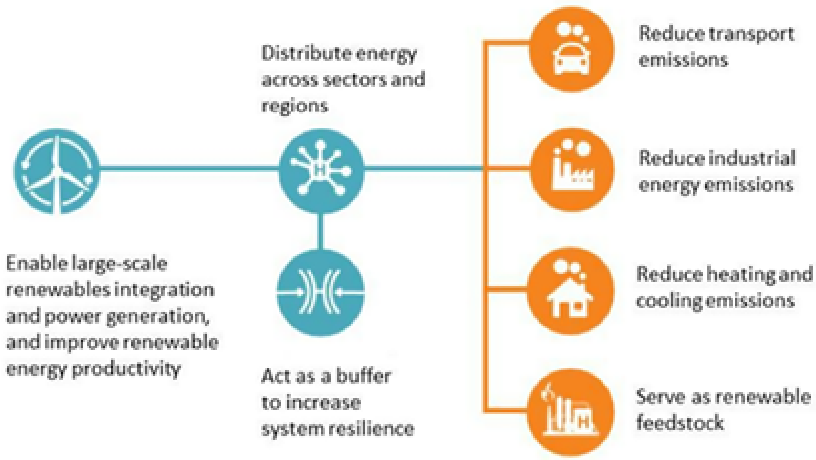
81 International Energy Agency, 2019. “The Future of Hydrogen”. https://www.iea.org/publications/reports/thefutureofhydrogen/

82 Clean Energy Wire. Published June 2019. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts

83 GasTerra. Published March 2019. https://www.gasterra.nl/en/news/green-hydrogen-is-far-too-expensive-for-the-moment

84 ICCT, 2017. “Developing hydrogen fueling infrastructure for fuel cell vehicles: A status update”. https://www.theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf

FIGURE 13 *The multiple roles of hydrogen. Source: Mission Innovation IC8: RENEWABLE AND CLEAN HYDROGEN, 2019.*



SWOT

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Reduced GHG emissions/zero tank-to wheel emission • Reduced local air pollution • Low noise volume • Longer range than BEVs • High payload compared to BEV trucks • Enables smart nighttime deliveries in cities • Enables storage of energy	• Not commercially available • Availability of refueling infrastructure • Infrastructure cost • Potential for CO_2 reductions is highly dependent on type of hydrogen production • Storage and distribution of fuel • Higher TCO • Low energy efficiency • Insufficient power from fuel cells	• Potential for long-haul trucks • Hydrogen is an attractive option for several major truck manufacturers when developing zero emission strategies, due to zero tailpipe emissions • Increased energy security through domestic fuel production • FC trucks could benefit from development of hydrogen production in other sectors	• Fuel (hydrogen) price uncertainties • Uncertain regulatory environment • High production cost; breakeven dependent on fuel prices • Lagging behind other technologies • Lack of renewable energy could be a showstopper

KEY TAKEAWAYS

Clean option with renewable hydrogen for long haul trucks
The technology offers GHG reductions, no air polluting emissions and less noise pollution. However, GHG reductions depend on the hydrogen production being green and the market penetration depends on the cost of renewable hydrogen. In the long run, the IEA analysis shows that the cost of producing hydrogen from renewable energy is likely to fall with 30 percent by 2030.

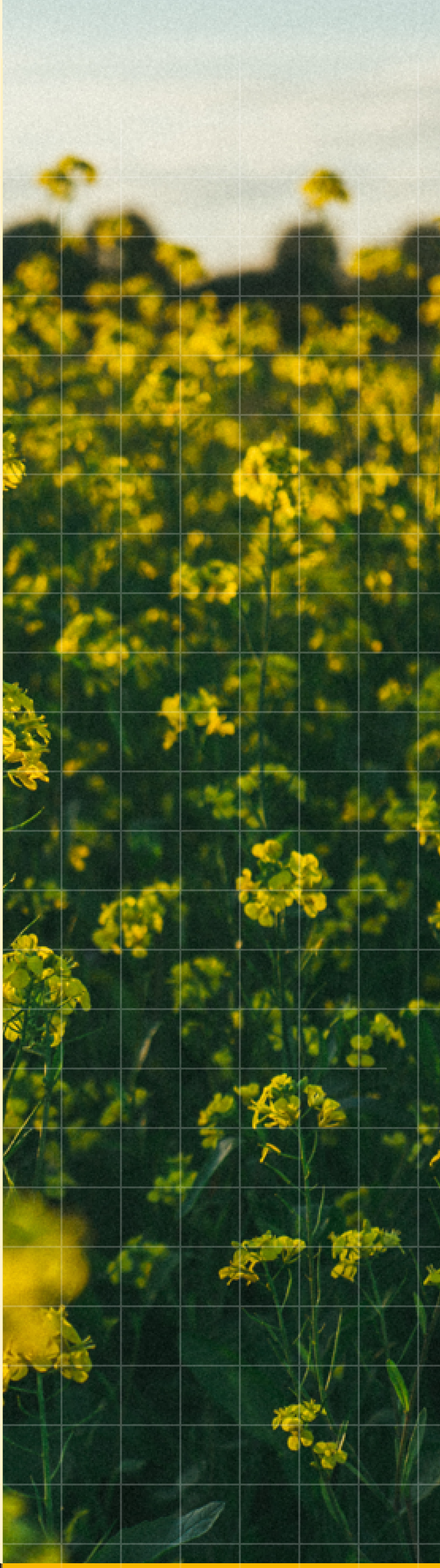
Vehicle manufacturers are stepping up the pace to become FCEV-frontrunner
Manufacturers – such as Scania, Nikola Motors and Toyota/Kenworth – are in varying phases of development, planning vehicle deployment, vehicle prototypes or delivering vehicles designed to serve specific costumers. The technology is a promising alternative for a decarbonized transport sector, especially for longer-distance duty transportations, competing with the battery electric vehicles in range, charging time and payload.

Critical issues of hydrogen refuelling stations
The availability of refuelling infrastructure is more or less non-existent for commercial heavy trucks in Germany today. When available, the hydrogen fuel cell technology would offer much faster refuelling times compared with electric charging, therefore an attractive alternative for freight transports with tight schedules. Coordination of infrastructure across the markets for passenger vehicles, freight, and fuel cell buses can be an opportunity for urban deliveries.

Implementation challenges
Parallel development of infrastructure, green hydrogen gas production and demand is needed for fuel cell hydrogen trucks to become fully commercially available. Challenges such as difficulty in securing renewable energy, storing and transporting hydrogen as well as the low lifecycle energy efficiency compared to direct use of electricity (BEVs) remain an Achilles heel. Also, the approval process for establishing new fuelling stations present a challenge.

Innovative, new technology creates opportunities for market leadership
There is a general lack of up-to-date knowledge on the development status among transport actors. However, the technology also creates a market opportunity. Early efforts can create business opportunities and technological lead on a global market. As with other novel technologies, such as ERS and BEVs, there are opportunities for companies that procure transports to cooperate throughout the value chain (hauliers, vehicle suppliers, public actors, fuel suppliers) to help create the platform for the expansion of hydrogen fuel cell vehicles.

4 Alternative fuels for internal combustion engines (ICE:s)



There is a wide range of alternative fuels compatible with conventional or adapted internal combustion engines available today, which present both short- and long-term solutions for a decarbonized commercial transport sector. These include biofuels and different kinds of synthetically produced fuels (e-fuels) with characteristics similar or identical with those of fossil alternatives. The technological and commercial maturity of different solutions vary, but for several options there is a possibility to make use of existing service infrastructure and vehicle fleets, which make them viable options here and now.

The Pathways Study concludes that a development scenario with high deployment of biofuels could offer the greatest cumulative GHG emissions abatement, approaching year 2050, relative to the other pathways outlined in the study. On a global scale, this scenario assumes a widespread adoption and use of biofuel-based ICE:s with a maximized utilization of potential biofuel supply. The high abatement potential springs from the possibility to substitute fossil fuels with biofuels in existing or slightly modified vehicles, making biofuels a good short-term option. The Pathways Study however suggests that this scenario comes at a higher price than full electrification, despite the possibility to make use of current fueling infrastructure and vehicles. This is due to the high energy intensity and cost related to production of many biofuels relative to renewable electricity production.[85]

85 Scania, 2018. "The Pathways Study: Achieving fossil-free commercial transport by 2050".

4.1 BIOFUELS – BIODIESEL AND BIOMETHANE

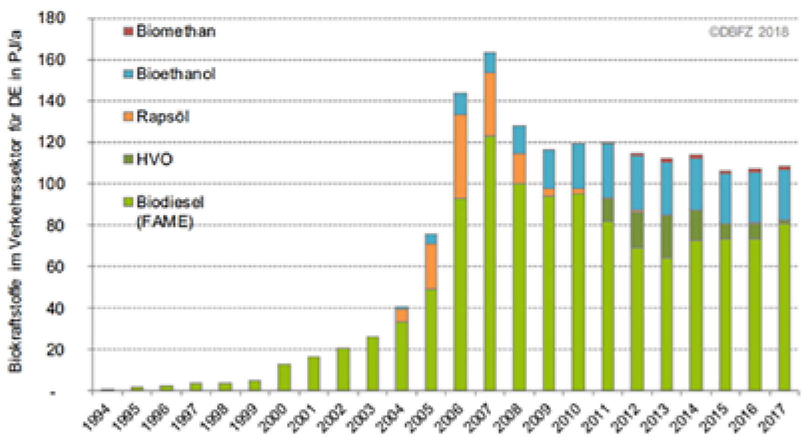
Biofuels are a diverse group of fuels that can be produced from a variety of sources with the final product showing different properties with regards to GHG abatement, energy content, quality and compatibility with conventional ICE powertrains. The general scepticism towards crop-based biofuels – linked to discussions on monocultures and food versus fuel production – in many cases overshadows the benefits of second-generation biofuels produced from waste/residues regarding both resource efficiency, waste handling and emissions reduction potential. Also, the public awareness of these benefits is low, contributing to a decrease in demand for pure biofuels.

Based on availability and use on the German commercial transport market during recent years, the two most relevant biofuels for heavy transports are biodiesel and biogas (biomethane) – although the use and service infrastructure availability of both in pure form are limited[86]. Biodiesel can be produced from different vegetable oils and is often referred to as FAME (Fatty Acid Methyl Esters). When produced solely from rapeseed oil, the biodiesel product is called RME (Rapeseed Methyl Ester). Germany is a net-exporter of biodiesel (FAME) but most of the domestic consumption goes to low blend use in fossil diesel. Renewable diesel (HVO) only plays a marginal role, with less than one percent of the market in 2017, and this volume is imported.[87]

Biogas upgraded for vehicle fuel use is mainly comprised of methane and is commonly referred to as biomethane (CBM) or bio-CNG. The chemical composition of upgraded biogas is virtually the same as for natural gas, allowing mixing or substitution of natural gas with biogas in different areas of application, in gaseous and liquid form respectively. Liquefied biomethane (LBM) can be produced through an additional purification and cooling step in the biomethane production, making it less voluminous and therefore more efficient to store and distribute than compressed biomethane. Accordingly, the higher energy density allows an extended reach for vehicles on LBM in comparison with CBM, given the same size of onboard fuel storage. However, there is currently no production of domestic LBM, and development within this segment is uncertain.

Although the biogas production in Germany is substantial, only a small fraction (4.3 percent or 0.4 TWh) is used as vehicle fuel, while the majority (85 percent) is used to produce electricity and heat. However, from the producers' perspective there is a growing interest in biomethane upgrading technology and offset within the transport market.[88] On a small scale, some bus companies are testing buses running on biomethane[89].

FIGURE 14 *Development of biofuels use in the German transport sector, based on energy content. Source: DBFZ, 2019.*



86 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage". https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_11_4.pdf

87 Ibid.

88 Biosurf, 2017. "Biomethane roadmap in Germany". http://www.biosurf.eu/wordpress/wp-content/uploads/2015/06/Trebon-VPB-PS_2017_14_FVB_Hofmann.pdf

89 Interview with Frank Scholwin, Professor and biofuels expert, Rostock University. May 2019.

As can be seen in Figure 14, bioethanol is the second most common biofuel on the German market, but this bioethanol is primarily used as drop-in fuel in gasoline and exclusively used for light vehicles/passenger cars. For long, bioethanol has not been an option for heavy transport due to low energy density and lack of compatibility with diesel engines. In recent years Scania has developed a diesel engine for high blend ethanol (ED95) which opens up for the use of bioethanol in the commercial transport market. However, Scania is currently the only supplier of such trucks, and filling stations for ED95 in Germany are non-existent, hence this alternative has not been explored further within the German context.

PRODUCTION AND AVAILABILITY

Biodiesel (FAME)

Germany is the largest producer of biodiesel (FAME) in Europe, with an annual production volume of approximately 3,500 million litres during recent years[90]. In 2017 there were around 30 out of more than 50 domestic biodiesel production plants in operation.[91] This development is closely linked to government policy, which shows a lack of incentives for investments in increased domestic production. The tendency is rather towards increased import.

By 2017, the primary feedstock for biodiesel production was rapeseed oil (56 percent) followed by an increasing share of used cooking oils (25 percent)[92]. From a lifecycle perspective, biodiesel produced from waste streams - such as used cooking oils - generally has higher emission abatement than crop-based biodiesel.

Germany is the second largest consumer of biodiesel in Europe (approx. 2,500 million litres in 2016), primarily due to the large use of biodiesel as drop-in fuel in fossil diesel to reach the GHG reduction quota. As previously mentioned, the market for high blend biofuels is very limited with only a handful of operating public filling stations throughout Germany offering 100 percent biodiesel or renewable diesel (HVO). The low demand for high blend biofuels is largely explained by a combination of reduced tax exemptions, increased prices of vegetable oils and a decline of crude oil prices[93]. See Figure 17, for the development of service infrastructure for pure biodiesel (B100).

Biomethane (biogas)

Germany has been a frontrunner for development of biogas production in Europe and has by far the largest number of operational biogas plants, spread across the country (reported numbers differ, but somewhere between 9,500[94] and 11,000[95] plants). Additionally, there are around 200 biogas upgrading plants, upgrading crude biogas to vehicle fuel quality (biomethane or bio-CNG)[96].

The main feedstock for the German biogas production is energy crops (primarily maize) and agricultural residues, but biogas upgraded for vehicle fuel use is exclusively produced from municipal and industrial biowaste[97]. Future potential for increased production and upgrading is dependent on agricultural land available, regulations regarding different feedstocks, availability and price of biogas upgrading technology as well as political support. There is a growing interest in biogas upgrading technology from both small-scale producers and politicians who see the public welfare benefits connected to biogas, but a more widespread implementation requires increased access to affordable technology for upgrading.

90 GAIN, 2017. EU-28 Biofuels annual. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_6-19-2017.pdf
91 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage".
92 Ibid.
93 Ibid.
94 Fachverband Biogas, 2018. https://www.biogas.org/edcom/webfvb.nsf/id/EN-German-biogas-market-data/$file/18-07-05_Biogasindustryfigures-2017-2018_english.pdf
95 EBA Statistical Report 2018: European Overview Chapter.
96 Ibid.
97 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage".

The short-term outlook for LBM availability is poor, given the current situation with no domestic liquefication facilities. The small share of liquefied natural gas (LNG) sold on the German market today is imported via Rotterdam.

FIGURE 15 *Feedstocks for biomethane production (biogas upgrading) in Germany (DE) and other European countries. Source: EBA Statistical Report 2018.*

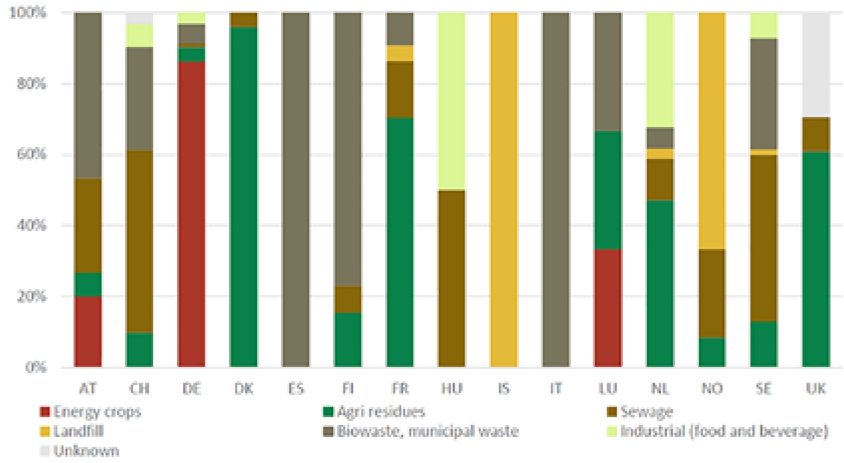
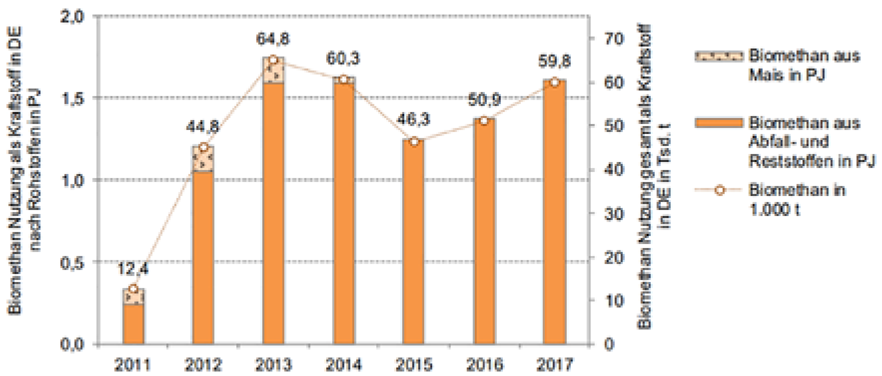


FIGURE 16 *Changes in feedstock for biomethane used as vehicle fuel within the German transport sector, 2011-2017. Source: DBFZ, 2019.*



There could be an untapped potential in increasing production from manure, as only one third of this feedstock is currently utilized. Increased acreage devoted to energy crops for biogas production could potentially increase current crop-based production by approx. 30 percent, but this is not an expected progress. A development towards doubled overall production is theoretically feasible but lacks political support. A more likely development is a maintained production level with an increased share of biowaste and manure.[98]

A somewhat grey area in the feedstock spectra is sewage sludge from wastewater treatment plants, which contributes marginally to the current feedstock. Only 13 percent of German wastewater treatment plants currently produce biogas, and the biogas yield is mostly used for internal electricity and heat production. The untapped potential from sewage sludge is uncertain, but a comparison with Sweden – where wastewater

98 Interview with Frank Scholwin, Professor and biofuels expert, Rostock University. May 2019.

treatment plants produce around 0.7 TWh biogas per annum – suggests that it could be substantial. Incentives for more efficient production are low due to high electricity production costs and low revenue from excess electricity sold to the grid. The use of sewage sludge for biogas production is further complicated by the Biomass Ordinance, which determines what feedstocks and products that classify as biomass. The ordinance limits the share of sewage sludge in the biogas production to ten percent by mass, for the biogas product to be classified as a biofuel.

FILLING STATION INFRASTRUCTURE

For compressed gas, the filling station infrastructure for passenger cars and light commercial vehicles is quite well developed, with approximately 850 stations distributed in a nation-wide network. A little over a hundred of these offer 100 percent biomethane and an additional 100 to 170 offer a biomethane blend, ranging from 10 to 90 percent.[99,100] The remaining majority of filling stations are currently supplied with compressed natural gas (CNG).

The last years have shown a slight decrease in number of CNG filling stations, as domestic fuel suppliers generally do not see gas as an attractive alternative. On an international arena the gas market is viewed in more positive terms, and international actors show interest in establishing gas filling stations in Germany.

The availability of pure biomethane or biomethane blend in public filling stations is dependent on the policies of the local or regional suppliers. For instance, the communal energy utility in Munich has decided that all their gas filling stations should offer 100 percent biomethane[101]. For a carrier or a large transport buyer, there are also opportunities to establish customized solutions even in regions where public filling stations may not offer bio-CNG.

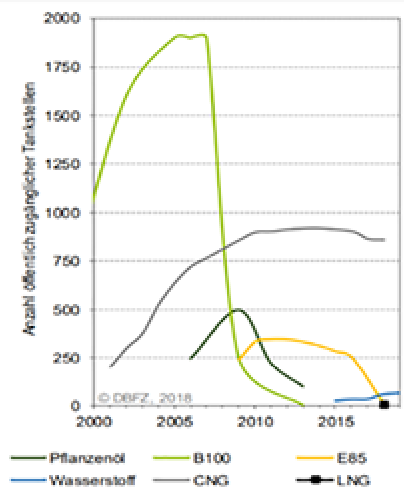


FIGURE 17 *Development of filling station infrastructure for alternative fuels. Filling stations for natural gas (CNG and LNG) are relevant for distribution of both compressed and liquefied biomethane, as the same infrastructure can be utilized. Source: DBFZ, 2019.*

Regarding liquefied gas there are currently only seven filling stations in operation, but the interest in liquefied natural gas (LNG) and biomethane (LBM) as an alternative to diesel for heavy transport is traceable up to the EU level, e.g. in form of the *LNG Blue Corridors project*[102] supported by the European Commission. On a national level, LNG and LBM is a topic of discussion, with several actors pushing for faster roll-out of service infrastructure. The political awareness does not entirely match this commercial interest and current filling stations

99 EBA Statistical Report 2018: European Overview Chapter.

100 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage".

101 Interview with Frank Scholwin, Professor and biofuels expert, Rostock University. May 2019.

102 LNG Blue Corridors, 2018. http://lngbc.eu/

were established with financial support from the Netherlands through Brussels. Development of these stations has been carried out in close collaboration with transporters and two out of the four first stations are located directly in logistics centers.

LNG is commonly promoted as an environmentally friendly alternative to conventional diesel, with a GHG reduction potential of up to 20 percent due to higher carbon to hydrogen ratio. These figures, however, refer to tailpipe (tank-to-wheel) emissions. When accounting for emissions from the entire fuel lifecycle, the potential climate benefits are more uncertain, hinging on several factors regarding upstream emissions (production and distribution) and methane slip from incomplete combustion. The GHG reduction potential is also affected by the type of engine and its efficiency. So called High Pressure Direct Injection (HDPI) engines have an efficiency comparable with a diesel-powered engine. With the higher carbon to hydrogen ratio of natural gas, this would imply lower tailpipe emissions, but real-world tests show variances in tailpipe emissions of +/- 10 percent relative to diesel. For a medium upstream emissions scenario, lifecycle emissions for an LNG truck vary between -7 to +5 percent and a CNG truck between -1 to -6 percent, compared to a diesel baseline[103]. Given these uncertainties and the relatively marginal reduction potential, CNG and LNG should only be viewed as a stepping-stone for CBM and LBM in terms of service infrastructure development and vehicle supply.

An interactive map of all CNG and LNG stations in Germany (and Europe) can be found on NGVA's website. An important supplier of biomethane is the Dutch company OrangeGas, running a gas stations network in the Northwest and central Germany. Their stations can be found here.

VEHICLES MARKET STATUS

Scania, Iveco and Volvo provide gas trucks for long haul transport in the German market. Light commercial vehicles for distribution purposes are offered by Scania/MAN, Iveco, Volvo and Mercedes-Benz. These are primarily adapted for CBM/CNG, but one of the models from Iveco is a hybrid equipped with both a CBM/CNG and gasoline tank. Please see Appendix 2 for a table of gas vehicle models available in the German market.

Biodiesel (FAME/RME) is compatible with conventional diesel engine technology but has a corrosive effect which requires some adaption of plastic components and filters. Since Q2 2019 Scania offers several truck models approved for RME use.

COMPARATIVE PRICING / TCO

Biodiesel

Since biodiesel can be used more or less directly as a substitute for fossil diesel, the most substantial difference in TCO compared to a vehicle on fossil diesel is the fuel cost and increased need for maintenance. The potential additional cost with regards to purchase price for a biodiesel approved or prepped vehicle is marginal.

Maintenance cost differs between various RME vehicle models but generally RME-vehicles require more frequent maintenance than conventional diesel vehicles, due to different fuel characteristics. In general terms the maintenance cost is about 2 to 2.5 times as high as for an equivalent diesel vehicle. In relation to TCO this is a minor increment. To some extent the maintenance cost also depends on the quality of the fuel: High quality RME has a higher energy content and wears the vehicle less, which reduces the need for maintenance.

Biomethane

The Federal Ministry of Transport and Digital Infrastructure has launched a program to promote energy-efficient and/or low CO2 heavy commercial vehicles[104], which subsidises investments in both CNG and LNG trucks,

103 Transport & Environment, 2018. "CNG and LNG for vehicles and ships - the facts". https://www.transportenvironment.org/sites/te/files/publications/2018_10_TE_CNG_and_LNG_for_vehicles_and_ships_the_facts_EN.pdf

104 Bundesamt Für Güterverkehr, 2018, Neues Förderprogramm für mehr Energieeffizienz und CO2-Einsparung im Straßengüterverkehr

as well as Electric trucks. The investment subsidy per vehicle is EUR 8,000 and EUR 12,000 for CNG and LNG trucks respectively. The annual maximum subsidy per company amounts to EUR 500,000.

The purchase price of a gas truck varies with model, size and customized solutions, but roughly estimated a heavy truck for LBG/LNG could cost an additional EUR 30,000 to 50,000 compared to a diesel equivalent. For CBG/CNG-trucks the difference is less, approximately EUR 20,000. This means the investment subsidy would cover 24 to 40 percent of the investment increment.

Since Q1 2019, gas vehicles have been exempted of the kilometre-based road tolls[105]. With the current toll of 15.6 EURcents/km and an annual driving range of 100,000 taxable kilometres, this reduces operational costs for a gas truck with EUR 15,600 per year in comparison with a diesel truck. Gas vehicles, on the other hand, require more frequent maintenance than diesel vehicles which in relative terms imply an additional cost of maintenance of approx. 50 percent. However, in a TCO context this is a relatively small extra cost. The technical lifetime of a gas vehicle is correspondent with a diesel vehicle.

Due to continued reduced tax on gas fuel until 2024, the fuel cost for CNG/CBM is favorable in comparison with average diesel prices. According to Erdgas, the average diesel price in 2018 was 1.28 EUR/liter while the average CNG/CBM price equaled 1.10 EUR/kg. From an energy perspective, one kilogram of CNG/CBM corresponds to approximately 1.1 liters of diesel which further increases the price gap.[106]

CLIMATE PERFORMANCE AND ADDITIONAL EFFECTS

Biodiesel

The GHG reduction potential of biodiesel depends on the feedstock and energy used in the production process. According to DBFZ, the average lifecycle emissions from crop-based biodiesel are 50.1 g CO_2eq/MJ and from biodiesel produced from used cooking oils 14.9 g CO_2eq/MJ. This corresponds to a reduction of approximately 40 to 80 percent compared to fossil diesel.

In addition to climate benefits, an important advantage with RME is its completely non-toxic nature. This reduces both environmental and health related risks when handling the fuel and in case of unintended spillage. Used as an interannual crop, rapeseed also improves future harvests by fixating nutrients and contributes to preserving open landscapes and biodiversity among pollinators.

Biomethane

There are several environmental and social values of biogas that go beyond the direct use as fuel. Biogas production is a natural part of a circular economy, where resources and materials are used and reused for further areas of applications. The added values arise in different stages of the lifecycle; in the production process where waste is utilized and nutrients can be recovered, as well as in the use phase where biomethane can replace fossil fuels, resulting in reduced emissions of GHG and other air pollutants. When making use of local waste products and recirculating the residues from local agriculture as feedstock as well as using the biofertilizer that comes out from the production process, biogas production is particularly in line (or loop) with the intentions of circular economy.

The total environmental benefits of biogas depend on several factors, e.g. from which substrate the biogas is produced, production method and area of application. Management and use of the digestion residues is also important. The differences in lifecycle emissions between best and worst practices regarding cultivation and harvest of maize used as feedstock for biogas amounts to 20 g CO_2e/MJ biomethane, which corresponds to

105 Transportnet, Scanias största beställning av gasbilar någonsin. Published April 2019. https://www.transportnet.se/article/view/656101/scanias_storsta_bestallning_av_gasbilar_nagonsin?ref=newsletter&utm_medium=email&utm_source=newsletter&utm_campaign=daily
106 Erdgas https://www.erdgas.info/erdgas-mobil/erdgas-fahren-rechnet-sich/

80 percent of the average lifecycle emissions[107]. In a best-case scenario, greenhouse gas reduction (compared to fossil diesel) is more than 100 percent. This applies when biogas is produced from manure and the methane emissions from manure management is reduced. Significant reductions also occur when the digestion residue is used as (organic) fertilizer and emissions from mineral fertilizers can be avoided. Moreover, using waste products from the agricultural sector, such as manure, can contribute to reducing leakage of nutrients to waterways and thereby decrease the harmful effects of eutrophication of ecosystems in rivers, lakes and seas.

According to a report by DBFZ, the GHG emissions reduction potential from German biomethane as vehicle fuel is a little over 90 percent (based on energy content), compared to the fossil diesel baseline as stated in the RED (83.8 g CO_2e/MJ diesel).[108] In absolute numbers, reported lifecycle emissions range between 7.77[109] and approximately 12[110] g CO2e/MJ for biomethane used as vehicle fuel.

Indirect benefits coupled with biogas production are creation of local job opportunities and added economic value, as well as increased export opportunities, through production growth. Furthermore, biogas contributes to increased food security, for example by increasing Germany's self-sufficiency of nutrients.

REGULATORY ENVIRONMENT

The German market prices for biofuels are largely dependent on the GHG reduction potential, where producers can charge a higher price for high reduction alternatives.

National policies tend to favour electrification, and incentives for increased domestic production of biodiesel and bioethanol are lacking. For biomethane, changes in energy taxation will likely increase the profitability of upgrading biogas for vehicle fuel use as opposed to using it for electricity and heat production.

For a list of national and EU level regulations relevant for biofuels can be found in Appendix 3.

SWOT

Biodiesel

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Completely non-toxic fuel (RME) • Flexible, can be used in existing diesel vehicles • Existing fuel distribution infrastructure can be used	• Low energy yield for rapeseed • Relatively low GHG abatement • The bad reputation of low-quality FAME damages the perception of high-quality FAME	• Rapeseed is an important in-between crop for soil fertility resulting in higher yields of the main crop • Blooming crops contribute to biodiversity • Increased share of waste feedstock (UCO)	• Sceptic public opinion of biofuels produced from energy crops • Lack of policy support • Stagnant domestic production levels • Low availability of filling infrastructure for high blend biodiesel • Competition with other transport segments over biodiesel as an energy resource

107 Biosurf, 2015. "D4.2 | Report on current and future sustainable biomass supply for biomethane production". http://www.biosurf.eu/wordpress/wp-content/uploads/2015/07/BIOSURF-D4.2.pdf
108 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage".
109 BLE, 2018. "Evaluations- und Erfahrungsbericht für das Jahr 2017". https://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2017.pdf?__blob=publicationFile&v=3
110 DBFZ, 2019. "Monitoring Biokraftstoffsektor - 4. Auflage".

Biomethane

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Low emissions of air pollutants • High GHG abatement • Resource efficient handling of municipal biowaste • Local energy security • Organic fertilizer • Possible night-time distribution in cities due to low noise pollution from gas trucks	• Requires specialized vehicles • Costly fuel distribution and filling infrastructure • Limited reach	• Broad feedstock spectrum • Potential production increase from manure • Regulative changes increasing economic feasibility of biomethane upgrading to fuel use • Promotion of second-generation biofuels	• Limited supply of different vehicle models • Low public awareness of societal benefits • Uncertain secondary value of vehicles • Competition with other sectors and segments over biogas as an energy resource

KEY TAKEAWAYS

High blend biodiesel currently a limited alternative
Today, the market for and access to high blend biodiesel is very limited and there are little to no incentives for investment in increased domestic production. However, biodiesel is an important contribution to decarbonizing the commercial transport sector, given the compatibility with existing drivetrains and service infrastructure.

Biomethane a realistic option for distribution but currently a limited option for long haul transport
An extensive filling station network for compressed gas is already in place, but infrastructure for liquified gas is still in its infancy (currently only 4 stations), which limits transports using biomethane to the shorter range of CNG/CBM vehicles.

Natural gas only a stepping-stone for biomethane deployment
Due to its fossil origin and uncertain climate benefits, natural gas is not a long-term solution. However, development of service infrastructure and vehicles for LNG and CNG could open up market opportunities for biomethane.

High GHG reduction potential creates opportunities for advanced biofuels within the transport sector
The regulatory environment for biofuels in general focuses on promoting high GHG reduction alternatives, which lends support to biomethane and biodiesel produced from biowaste. This boosts competitiveness in comparison to fossil fuels and could contribute to increased economic clearance for investments in biomethane upgrading technologies.

4.2 SYNTHETIC FUELS / E-FUELS

Synthetic fuels or electricity-based fuels (e-fuels) are produced through chemical process conversions with the purpose to be used in conventional combustion engines. This could enable resource efficient use of existing vehicle fleets and distribution infrastructure, allowing GHG reduction from long haul road transports where electric drivetrains are currently a no-go due to limitations in range and underdeveloped charging infrastructure.

CURRENT PRODUCTION STATUS

The production of e-fuels – by power-to-gas (PtG) or power-to-liquid (PtL) technologies – is energy intensive and quite inefficient, requiring a large input of electricity. The feedstock is hydrogen gas, produced from electrolysis of water, and carbon dioxide, originating from fossil substrates (such as coal or natural gas) or biomass. These two components are then combined to different hydrocarbons through a synthesis process. However, for synthetic fuels to be a sustainable option the feedstock and electricity used in production need to be renewably sourced.

E-fuel production technologies are is still in early stages of demonstration. Pilot projects have been carried out, but economic feasibility of large-scale production has so far been lacking, due to high production costs related to electricity demand. An increasing urge for rapid reduction of GHG emissions from commercial transport could push for an improved business case[111], but considering the low energy efficiency compared to direct electricity, fully electric alternatives will challenge the competitiveness.

For more information on production status and feedstock potential, please see Appendix 5.

COMMERCIAL AVAILABILITY

E-fuels are not yet a commercially available alternative in Germany. However, if development moves towards economic competitiveness for large-scale production, e-fuels could quickly reach a high degree of market penetration due to compatibility with existing vehicles and infrastructure.

SWOT

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
• Flexible and adaptable • Compatible with existing vehicles and service infrastructure • Potentially high GHG abatement	• High production cost • Low energy efficiency • Need a CO_2 source	• Concentrated CO_2 from biogas production • R&D funding • Interest from many different actors	• Increasing electricity prices • Market competition with other sectors • Insufficient growth of renewable electricity

KEY TAKEAWAYS

Flexible solution with market potential.
E-fuels are compatible with conventional ICE drivetrains and filling station infrastructure which offers flexibility and adapted solutions for different transport needs.

111 Auto Tech Review, E-Fuels As A Disruptor For The Transportation Sector. Published Feb 2018. https://autotechreview.com/opinion/guest-commentary/e-fuels-as-a-disruptor-for-the-transportation-sector

Production technology still at a demonstration stage.
Large-scale production currently not economically feasible due to low efficiency and high electricity demand in production. This could change with technological development, regulatory incentives and increased prices of fossil alternatives.

Requires substantial growth in the renewable electricity sector.
The energy-intensive production creates increased demand for renewable electricity, which is a necessity for sustainable e-fuels.

5 Recommendations

This report aims to increase knowledge about fossil free alternatives for commercial transport in Germany and constitutes a support for procuring companies in moving towards decarbonization of transports. Given the complexity of the transport sector in terms of variety of regional preconditions, type of transport, timeframe and range of possible solutions, conclusions regarding a single most suitable option would be ill-advised to draw. Instead, the complexity advocates a mix of solutions, to better cope with future uncertainties and specific needs.

The recommendations below are based on the analysis of the German market, as well as an analysis of samples of transport work within H&M Germany's distribution network. Decarbonizing transports in Germany today is a challenge that requires a combination of efficiency measures and utilization of alternative fuels, drivetrains and/or modes of transport.

In the long term, the German transport sector at large is moving towards electrification, enhancing the possibility for reducing emissions from heavy-duty transports. The climate benefits of this development are however closely linked to the roll-out of renewable electricity supply. To secure a fossil free electrification of transports even in the short term, transport buyers can finance expansion of wind or solar power, sufficient to cover the increased energy demand.

Regarding the uncertain or low climate benefits of natural gas, a change to gas should include requirements of a transition to a gradually increasing share of biomethane. Where availability allows, transport buyers in cooperation with fuel suppliers and carriers could install customized biomethane solutions. This secures natural gas independency and contributes to development of the service infrastructure.

To assess the cost for decreasing emissions from transport, one has to take into consideration the potential increase in TCO for the transport operators, as well as the fact that the process to get there will require extra work and higher levels of competence within the organization. To purchase traditional transports is by far simpler and less time consuming. In the long run, purchasing transports with low emissions will not necessarily be more complicated, but during a transition period there will be a need of increased level of dialogue and cooperation, not only with transport operators, but also with fuel suppliers and other transport purchasing companies. However, the earlier procuring companies take on this challenge, the bigger the opportunity to influence the market in a desired direction.

5.1 OUR STRONG RECOMMENDATIONS FOR PROCURING COMPANIES

Cooperate across the transport value chain. Horizontal collaborations and coordinated transports will enable more resource efficient utilization of the transportation system; a single company can't solve this puzzle on their own. An example could be to investigate the potential for cooperation with other large transport buyers in the vicinity of operations, to establish new filling infrastructure that could enable usage of alternative fuels, such as CBM/LBM and biodiesel.

Commit to contribute to the Paris agreement and set science-based climate targets. The science is clear, we need to keep global warming to a maximum of 1.5C above the pre-industrial level. This requires all companies to set targets based on science and set a transportation and logistics strategy consistent with the long-term target.

Again, **use your influence**. Be clear on the fossil free direction you as a procuring company want to take, based on reduced GHG-emissions; push your providers and influence the political developments to reach the CO2 reduction targets.

Initiate dialogue with the carriers

- Base your supply chain management on dialogue and cooperation with your carriers. Understanding and discussing processes and possibilities is a vital key for continuous improvements.
- Invite several possible carriers before new procurements to explain, discuss and get a better understanding of targets, what they aim to achieve, current barriers and future potentials.
- Different requirements should be made for different kinds of transport work since the prerequisites differ. In some cases, renewable alternatives are easier to implement for distribution transports than for long-haul transports.
- To compensate for possibly uncertain residual values of vehicles, include an option of prolonged contract periods with service providers. This creates more space for action and security for long-term investments.
- Distribution transports may lack in efficiency due to route and time constraints set by the purchasing company. It is important to evaluate the climate effects of these policies. Therefore, it is recommended to initiate a dialogue with the service provider regarding obstacles for increased transport efficiency and possible ways to plan routes, adjust time constraints and co-load with other goods to make best use of available transport capacity.

Lack of knowledge is a barrier for change. We recommend that large procuring companies offer and set up a platform for competency-enhancing programs together with the vehicle suppliers, experts in the transportation industry and the providers of different fuel alternatives. These programs could be offered to increase the apparent lack of knowledge amongst many carriers in the market, as well as tackling myths regarding renewable alternatives.

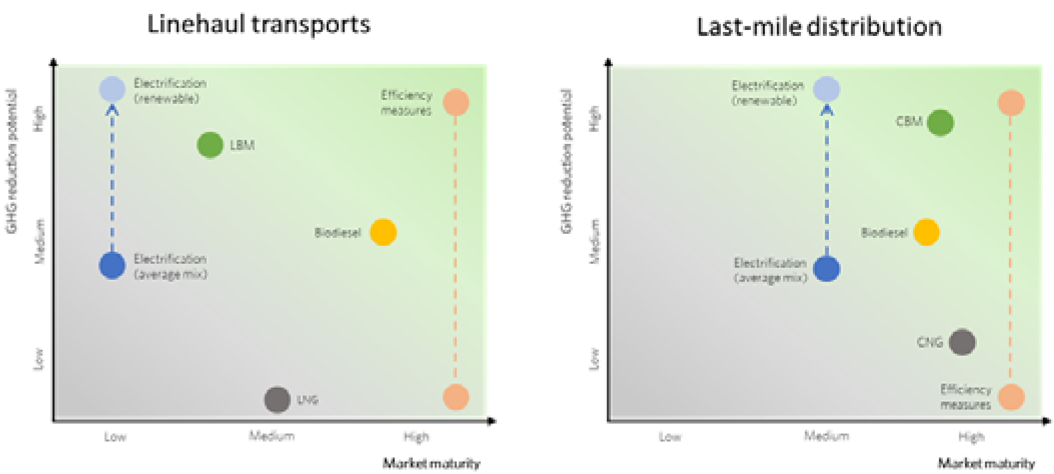
Move transports from road to rail. Longer linehaul transports may be feasible to move from road to rail. Such a modal shift contributes to significant GHG emission reductions even with the current electricity mix in Germany. Extended time limits for deliveries could be required for modal shifts, e.g. to railway.

Establish a plan for how to substitute fossil fuels in road transports. For long-haul, biodiesel/renewable diesel could be a viable option and in the longer term, liquid biomethane (LBM) and electrified transports (ERS or BEV) could be possible as well. Reward fuel suppliers offering biodiesel with a large share of waste feedstock e.g. used cooking oils. Solutions with HVO or FAME/RME currently require customized fuel supply setups due to lack of public service infrastructure. Depending on the transport pattern, this may be feasible at a reasonable cost. A shift to LNG is only advisable in combination with an active plan to move towards liquid biomethane (LBM), that offers a GHG emissions reduction of 81% compared to fossil diesel. However, there is currently no domestic production or import of LBM and availability in the near future will most likely be limited unless there is a clear demand from transport companies and transport buyers.

For distribution transports, promote electric vehicles where distribution patterns are characterized by short routes and transports in urban areas. For longer distribution routes, compressed biogas (CBM) is a favorable option. Include requests for introduction of hybrid and/or fully electric vehicles in city distribution within the time frame of the procurement. To secure highest GHG abatement from electrification: invest in new installations for renewable electricity production.

Figure 18 shows the different technologies for linehaul and distribution, the potential for GHG reductions and how mature the technologies are from a market perspective.

FIGURE 18 | *Correlation between GHG reduction potential and market maturity of technology.*



New alternative technologies require pilot-testing. The procuring companies can be active and play an important role in influencing demonstration projects, to overcome technical challenges and gain acceptance of relevant actors – including government action. Examine projects relevant for your logistic chain, e.g. a pilot project for e-roads along your route or setting up fueling infrastructure for biomethane.

Increased filling degree of each transport. There may be substantial opportunities to reduce emissions by optimizing the degree of filling in transports. Utilizing the full transport capacity increases fuel efficiency and most likely reduces operational costs. This could require more flexible lead times and the possibility to set up short term storages in the distribution networks. For linehaul transports: identify the key parameters affecting current degree of filling and any obstacles or opportunities for increasing these. Set a target for the degree of filling and discuss with service providers which measures that are needed to reach the target.

Evaluate key aspects that can increase efficiency. Demand clear targets and defined measures from the carriers on how they will increase efficiency with initiatives such as;

- Co-distribution within larger cities.
- Redistribution on freight trains or other alternative means of transports.
- Coordination of return transports with other companies.
- Eco-driving training for drivers and implementation of feedback mechanisms.
- Fleet management training, e.g. the Smart Transport Manager Training offered by Smart Freight Cente focusing on increasing awareness and competence regarding streamlining the fleet operation.
- Using high capacity transports (giga-liners).
- Reduced average speed limits.

Focus on the lowest cost over time, even though that may require initial investments. The price tag for electric vehicles and vehicles adapted for renewable fuel alternatives is often higher than for conventional diesel trucks, but from a TCO perspective, investments in alternative vehicles can even reduce costs. A transition away from fossil diesel also reduces dependence on imported fuels from conflict areas and avoids economic risks related to volatile fossil diesel prices. Internal carbon pricing could be a tool for a truer cost comparison between different measures and business as usual.

Be transparent with policy makers on what you need to make the shift, both on a regional and national level. This is relevant both for alternative fuels and for electrification infrastructure.

Require reduced emissions in your road freight distribution to steer other transport actors towards sustainable solutions. **Demand strategies** from your suppliers on how to shift transportation towards fossil free alternatives with a clear road map and how this will reduce emissions within a specific time frame and how this is translated into GHG-emission reductions. There are preferably separate roadmaps for distribution and long-haul transports.

Knowledge is key to unlock opportunities. **Stay updated** on what lies in the pipeline to make well-informed decisions and minimize risk.

Freight is a fast shifting environment. Carriers without clear targets won't stay in business with the changing business environment, there is a strong business case to stick with the ones that want to be a part of the solutions and collaborate.

Communicate all the beneficial effects and spread lessons learned.

Appendices

APPENDIX 1 - ELECTRIFICATION

Appendix for further insights into electrification in the German market.

INCREASED DEMAND FOR ELECTRICITY

One of the most common discussions of broad market penetration for electric drivetrains is whether the power sector and grid can support the growth in electric vehicles. McKinsey Energy Insight estimates that the global electricity demand for electric trucks will be approximately 30 TWh by 2030. However, the electricity demand for electric trucks is likely to grow fast – just before 2050 it is estimated to reach more than 1,000 TWh[112]. The increased demand at new locations will put pressure on the power sector during peak periods. This will require local grid upgrades along highways and industrial sites for overnight charging.

In a German context, the upcoming increased demand for electricity will require expansion and reinforcement of the local power grid, as well as a reduction of the relatively high emission factor for domestic electricity generation. The German Energiewende has so far been increasing the share of renewable energy in the electricity network but at a cost of higher electricity prices for the German users. In 2017 Germany had the highest electricity prices (including tax and network prices) in Europe, with 300 EUR/MWh compared to the EU average with 200 EUR/MWh[113]. Now, Germany faces the challenge to electrify the transport sector, quit nuclear power by 2023 and at the same time reduce the use of fossil fueled power plants. However, based on the expected introduction speed of renewable electricity and following network capacity, the introduction of electric roads and charging stations should not imply any significant challenges[114]. Rather, the challenge is to accomplish sufficient battery charging speed for multiple heavy vehicles in each charging station.

112 McKinsey, 2017, https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/

113 Thalman, E., Wehrmann, B., 1 april 2019, What German households pay for power, https://www.cleanenergywire.org/factsheets/what-german-households-pay-power

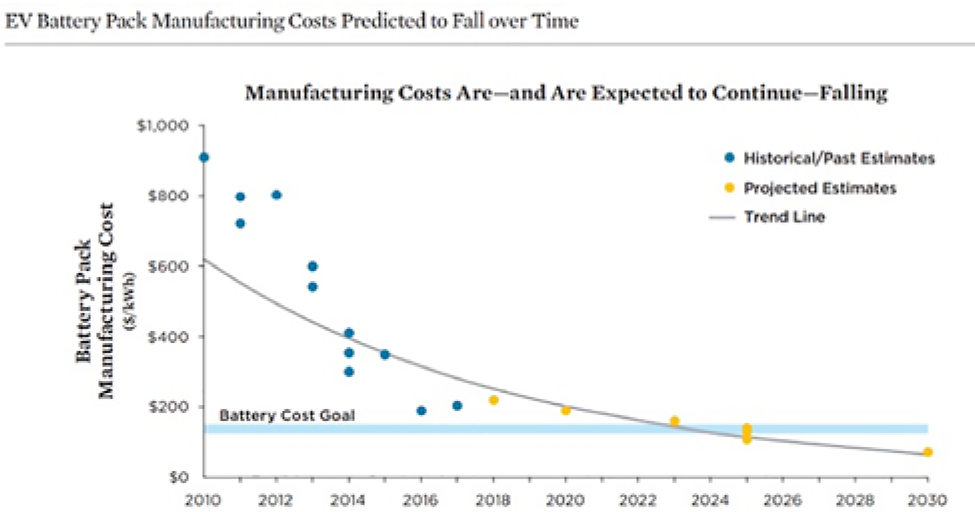
114 Interview, E.ON Energy Network, Hendrik Paul.

BATTERY COMPONENTS AND COSTS

The battery size, in terms of mass and volume, influences the payload capacity of the truck. Research has improved the capacity over the last decade. One of the first consumer fully electric vehicles (Nissan Leaf, 2009) had a battery weight of 1000 kg and a range of 190 km. Today's batteries weigh the same but have twice the range of 370 km. Nano technologies have been one reason for this development.[115]

The manufacturing cost of an EV battery pack has fallen significantly over the past eight years, due to manufacturers developing more cost-effective methods. Compared to 2018, prices have come down by around a factor of four, and densities have more than doubled[116]. The cost will continue to decline as EV production increases, with projected estimates - from automakers and academic research - reaching 125 to150 USD per kWh in the next ten years[117]. By 2030 Bloomberg New Energy Finance sees USD 70 per kWh possible, presuming a scale up to mass manufacturing[118].

FIGURE 19 *The battery cost goal of $125-$150 reached within the next ten years. Source: Multiple data points complied by Union of concerned scientist, 2017. http://www.ucsusa.org/EV-incentives 2018.*



115 Nanowerk, 2008. https://www.nanowerk.com/spotlight/spotid=5210.php

116 McKinsey, 2017. "New reality: electric trucks and their implications on energy demand", and Earl et. al, 2018. "Analysis of long haul battery electric trucks in EU".

117 Union of Concerned Scientists, 2017. https://www.ucsusa.org/sites/default/files/attach/2017/09/cv-factsheets-ev-incentives.pdf

118 Bloomberg, Electric Cars May Be Cheaper Than Gas Guzzlers in Seven Years. Published March 2018. https://www.bloomberg.com/news/articles/2018-03-22/electric-cars-may-be-cheaper-than-gas-guzzlers-in-seven-years

APPENDIX 2 – VEHICLE MARKET STATUS

PLUG-IN ELECTRIC VEHICLES: COMMERCIAL HEAVY-DUTY ELECTRIC TRUCKS

Brand	Model	Available	Range (km)	Gross vehicle weight (tonnes)	Charging time
BYD	T9	2018	270	36	100% in 84 min (fast DC) 100% in 216 min (normal AC)
BYD	T5, T7	2017	250, 200	7.3 to 11	
Charge			160	3.5 to 26	
Cummins	Aeos	2019	161	20	100% in 60 min
DAF	CF Truck	2019	100	37	100% in 90 min
Daimler	Mercedes-Benz eActros	2021	200	18 to 25	100% in 660 min
Daimler	eCascadia	2021	400	36	80% in 90 min
Daimler	eM2	2019	370	12	80% in 60 min
Daimler	Mitsubishi e-Fuso Vision One	2019	350	11	
Dennis Eagle		2017	>150	26.8	6-8 hours
E-Force		2017	300 (city) 200 (highway)	18	6 hours
Einride	T-Pod & T-Log (autonomous/remote controlled)	2019	200	16	-
Emoss	EMS 10, 12, 16, 18	2014	50-250	7 to 24	100% in 180-360 min
Ginaf	E 2114, 2115, 2116	2017	105-150	13.5	-
MAN	eTGM		130	32	
Nikola Motors	Nikola One/Two	2019/2020	800-1600	30	n/a
Scania	Hybrid, HVO and biodiesel	2019	2 km on electricity	19	n/a
Scania	Plug-in Hybrid, HVO and biodiesel	2019	10 km on electricity	27	1 hour charging = 20 km driving range
Motiv Power			80 to 130	30	8 hours
Renault	Midlum Truck		100	16	8 hours
Renault	Trucks D		120	16.3	7 hours
Tesla	Semi	2020	483-805	36	80% in 30 min
Toyota	Beta Truck	n/a	480	36	
US Hybrid	ETruck		161	36	
Volvo Trucks	FL electric	2019	300	16	100% in 60-120 min (fast DC) 100% in 600 min (normal AC)
Volvo Trucks	FE electric	2019	200	27	100% in 90 min (fast DC) 100% in 600 min (normal AC)
Volvo Trucks	Vera (autonomous)	-	-	32	-

PLUG-IN ELECTRIC VEHICLES: COMMERCIAL MEDIUM- / LIGHT-DUTY TRUCKS

Brand	Model	Available	Range (km)	Gross vehicle weight (tonnes)	Charging time
Daimler	FUSO eCanter	2018	100	3,5	
Iveco	The Daily Electric	2017	200	5	100% in 120 min
MAN	eTGE		160	0.95 to 1.7	
MAN	CitE	2018/2019	100	6	Overnight charging, but fast charge possible
Renault	Master Z.E	2019	185	1.4	-
Renault	Trucks D Z.E + Trucks D wide Z.E	2019	200-300	1.4	-
Streetscooter	Work	2019	205	2.1	
Streetscooter	Work L	2019	205	2.1	
Streetscooter	Work XL	2019	200	2.1	
Motiv Power			109-161	6	8 h (2-3 h 50%)
Volkswagen	e-Delivery	2020	200	3.5 to 13.5	100% in 280 min
US Hybrid	eCargo	2017	120	4.5	

TRUCKS FOR ELECTRIC ROAD SYSTEMS

Manufacturer	Vehicle status	Comment
MAN (Volkswagen Group) [31% of German market]	No catenary models	MAN has recently launched a large eTruck-initiative, but it is entirely focused on BEV.
Daimler & Mercedez-Benz [29% of German market]	No catenary models	Daimler has taken the position that due to the high infrastructure costs involved, the company does not see potential in overhead lines at present; also, in view of the rapid development of battery and fuel cell technology.
Scania (Volkswagen Group) [13% of German market]	3rd generation model in collabora-tion with Siemens	Claes Erixon, Executive Vice President Research and Develop-ment at Scania said: “For long-haulage transportation, Scania sees electric highways as a promising technology”.
DAF	No catenary models	Entirely focused on BEV.
Iveco	No catenary models	Entirely focused on BEV.
Renault (Volvo Group)	No catenary models	Entirely focused on BEV.
Volvo	No catenary models, testing electric rails	Volvo’s ERS solution is conductive power transfer with electric rails in the road.

FUEL CELL ELECTRIC TRUCKS

Brand	Model	Market focus	Available	Range (km)	Maximum load (tonnes)
Nikola Motors	Nikola Tre – for Europe	Europe	2022/2023	500-1200	-
Nikola Motors	Nikola One/Two	The US	2019/2020	800-1600	30
Toyota / Kenworth	Beta Truck	The US		480	36
Toyota / Kenworth	Alpha truck	The US			
Toyota / Kenworth	FCET	The US			
OEM Esoro	COOP-truck	Switzerland	2016	400	34
Scania	Asko-trucks (Renova-truck)	Norway, Sweden	2019/2020	500	26
Hyndai Motor	-	Switzerland and Europe	2019-2025	400	34

GAS TRUCKS

Brand	Model	Size	Range (km)	Load	Comment
Scania	OC13	Long haul (13-liter engine)	1000-1600 (depending on tank solution)	Up to 40 tonnes	For LNG/LMB and CNG/CBM
Scania	OC09	Light commercial vehicle (9-liter engine)	-	-	For LNG/LMB and CNG/CBM
Iveco	Stralis NP	Long haul	Up to 1600 (depending on tank solution)	-	LNG/LBM
Iveco	Eurocargo NP	Light commercial vehicle	-	-	CNG
Iveco	Daily Hi-Matic NP	Van (3-liter engine)		-	CNG/CBM
Iveco	Daily NP (hybrid)	Light commercial vehicle	440/100 km (CNG/gasoline)	3,5-7 tonnes (gross weight)	Runs on both CNG/CBM and gasoline
Volvo	FH LNG and FM LNG	Long haul	Up to 1000	-	LNG/LBM
Volvo	FE CNG	Light/medium commercial vehicle	Up to 400	-	CNG/CBM
MAN	TGM CNG	Light commercial vehicle	400-700 (depending on type of transport)	18 tonnes (gross weight)	CNG/CBM
Mercedes-Benz	Actros NGT	Light/medium commercial vehicle	Up to 650	-	CNG/CBM
Mercedes-Benz	Econic NGT	Light/medium commercial vehicle	-	-	CNG/CBM

APPENDIX 3 – REGULATORY ENVIRONMENT

Policies and regulaions affecting the market development of fossil-free alternatives.

REGULATORY ENVIRONMENT FOR PLUG-IN ELECTRIC VEHICLES

Regulations can facilitate and accelerate the shift towards electric trucks and give the underpinning that makes battery electric solutions more attractive for manufacturers and consumers.

Current tax benefits and incentives for electric vehicles in Germany:

- Privately owned vehicles: 10-year tax exemption for BEVs and FCEVs registered between 1/1/2016 and 31/12/2020.
- Company cars: Reduction of the taxable amount for BEVs (from 1% to 0.5% of the gross catalogue price per month)

Charging infrastructure

- The Federal Government is providing €300 million towards expanding the charging infrastructure. €200 million is available for fast charging infrastructure, and €100 million for normal charging.
- Public procurement: At least 20 percent of the Federation's vehicle fleet should consist of electric vehicles. If employees recharge their vehicles at their place of employment, this will no longer be deemed a taxable benefit in kind.

REGULATORY ENVIRONMENT FOR HYDROGEN IN GERMANY

Hydrogen has complex supply chains requiring governments, companies and communities to coordinate and collaborate. Regulations and permit requirements that are unclear or inconsistent across sectors need consistent standards.

The German government has supported hydrogen and fuel cell technology for ten years through the National Innovation Programme (NIP). A total of 1.4 billion euros have been invested by the government and the industry from 2007 to 2016 in hydrogen and fuel cell projects for mobile and stationary applications. The development is further supported by a hydrogen and fuel cell technology programme for the period 2016 to 2026. NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) coordinates the programme. This puts Germany in an good position to further commercialize the fuel cell technology.

On an EU level, under the Mission Innovation initiative, the launch of hydrogen and fuel cells initiative was agreed by 25 EU nations. EU energy ministers met in September 2018 to sign a hydrogen declaration, stating that green hydrogen will be a part of the EU energy future. IC8 gathered over 80 representatives from governments, industry and the research community who met in Antwerp in March 2019 for a two-day workshop on "Hydrogen Valleys".[119]

There are also several initiatives and networks in the German market pushing the political agenda:

NOW GmbH, National Organisation Hydrogen and Fuel Cell Technology, a programme management association of the federal government for sustainable mobility and energy. It is responsible for the coordination and management of the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP), the Local Electric Mobility Funding Programme (Förderprogramm Elektromobilität vor Ort) and the Recharging Infrastructure Funding Guideline (Förderrichtlinie Ladeinfrastruktur) of the Federal Ministry of Transport and Digital Infrastructure (BMVI).

119 FCH (Fuel Cell and Hydrogen), Mission Innovation 2019 https://www.fch.europa.eu/page/mission-innovation-antwerp-2019

The Clean Energy Partnership (CEP), a network across sectors in Germany working on the market establishment of mobility with hydrogen and fuel cells. Includes: Air Liquide, Audi, BMW, Daimler, GP Joule, H2 Mobility, Honda, Hyundai, Linde, OMV, Shell, Total, Toyota and the Westfalen Group.

DWV (German Hydrogen and Fuel Cell Association), an umbrella organization promoting fuel cell technology in Germany.

H2Mobility, a joint venture responsible for establishing a nationwide hydrogen infrastructure to supply cars with fuel cell initiatives in Germany. The companies behind include Air Liquide, Daimler, Linde, OMV, Shell and TOTAL.

REGULATORY ENVIRONMENT FOR BIOFUELS

Market prices for biofuels are largely dependent on the GHG reduction potential, where producers can charge a higher price for high reduction alternatives. In this context, biodiesel and biomethane produced from energy crops are less attractive, implying a continued development towards a larger share of second-generation biofuels produced from residues and/or biowaste. There is a national ordinance on further regulations for emission reduction from fuels[120], which determines that the minimum share of advanced biofuels should increase from 0.05 percent in 2020 to 0.5 percent in 2025 (based on energy content). This development is also promoted within the new Renewable Energy Directive (II) as well as the national *Integrated energy and climate programme*, which states that there should be more focus on the GHG reduction potential from biofuels usage.

With the national biomass action plan for Germany[121], the promotion of biofuels was changed from an energy quota to emission related criteria. According to the plan, the use of biofuels must contribute with a net GHG reduction of 7 percent to the reduction target for the transport sector until 2020. The plan also regulates the required GHG reduction from biofuels if they are to be subject to national subsidies. For production plants put in operation after 2017, the reduction compared to fossil fuels must be at least 60 percent.

Several national and EU-level regulations relevant for supply and demand side for biodiesel and biomethane are shortlisted below.

Supply side:

- Energy Tax Act[122]: The previously applicable tax reduction for biofuels was gradually reduced, starting 2008. The tax reduction for unmixed vegetable oils and biodiesel (FAME) amounts to 21.40 EUR for 1,000 liters from the beginning of 2013. Furthermore, the act defines biofuels which are completely exempt from the energy tax:
    - Synthetic hydrocarbons or synthetic hydrocarbon mixtures produced by thermo-chemical conver sion of biomass (Fischer-Tropsch-Diesel)
    - Alcohols obtained by biotechnological processing of cellulose
    - Energy products containing at least 70% bioethanol content (fuel blends containing a lower propor tion of bioethanol are fully taxed).
- **Gas Network Access Ordinance**[123]: Regulates the rules for accessing the public natural gas grid. Grid access for biomethane is always prioritized and gas grid operators must make all reasonable technical effort to offer grid access for requested capacity. Biomethane injecting users are exempt of the grid entry tariff corresponding to a current subsidy of 0.7 ct/kWh, which is guaranteed for 10 years, starting from the day of feed in.

120 Verordnung zur Festlegung weiterer Bestimmungen zur Treibhausgasminderung bei Kraftstoffen, 38. BImSchV.
121 Nationaler Biomasseaktionsplan für Deutschland 2009.
122 Energiesteuergesetz 2006.
123 Gasnetzzugangsverordnung GasNZV 2010.

- **RED II:** States a cap for reporting of biofuels produced from crops. Promotes low emission alternatives and second-generation biofuels (with high GHG abatement).
- **The Greenhouse Gas Reduction Quota Act**[124]: Regulates the required GHG emission reduction from sold fuels, in comparison with fossil diesel and gasoline. The current quota is set on an emission reduction level of 4 percent. This will increase to 6 percent in 2020.
- **Different taxation on gaseous and liquid gas:** Entails limitations for conversion between gaseous and liquefied biomethane. This will hopefully change in the near future.
- **Ordinance for the crediting of upstream emissions reduction on the GHG quota**[125]: Regulatory framework for counting of upstream emissions and the corresponding certification. Up to 1.2 percent of upstream emission reduction can be accounted to the biofuel GHG reduction targets.

Demand side:

- **Exemption of road tolls** for gas vehicles and electric vehicles, effective since Q1 2019[126]. Reduces the operational cost of a gas truck in comparison with a conventional diesel (or biodiesel) truck.
- **Investment subsidies for CNG and LNG vehicles.** This compensates (to some extent) the higher purchase price of gas trucks in comparison with conventional diesel trucks.

124 38. BImschV, Verordnung zur Festlegung weiterer Bestimmungen zur Treibhausgasminderung bei Kraftstoffen.

125 Verordnung zur Anrechnung von Upstream-Emissionsminderungen auf die Treibhausgasquote, UERV.

126 Transportnet https://www.transportnet.se/article/view/656101/scanias_storsta_bestallning_av_gasbilar_nagonsin?ref=newsletter&utm_medium=email&utm_source=newsletter&utm_campaign=daily

APPENDIX 4 – ELECTRIC ROADS

TECHNOLOGIES FOR ELECTRIC ROADS

Electrified road systems (ERS) consist of electrical infrastructure along a road, which can transfer electrical energy to a vehicle while it is moving. The vehicles using such a system are equipped with a power receiving device and have a drive train that includes an electric engine, allowing for the direct use of electricity to propel the vehicle. Furthermore, all vehicles using an ERS also have an alternative source of energy, e.g. a battery, with or without a combustion engine. This is necessary since it is only meaningful to electrify the parts of the road network that have high traffic flows. In addition, sections like bridges or interceptions might not be possible to electrify. Therefore, a hybrid solution is needed for driving on the non-electrified sections.

Electric roads are of particular interest for heavy duty road transport, because it would allow long-haul trucks to enjoy the energy efficiency and operating cost benefits of direct electrification. Truck traffic is highly concentrated to the core highway network, with around 60% of fuel consumption occurring on just 2% of the road network. ERS allows trucks to go electric without the need for large on-board batteries (which come at a direct cost during the acquisition, and indirect cost via its impact on payload and range), as trucks in 90% of the cases only go 50 km or less outside of the motorway. Furthermore, ERS also alleviates the challenges of charging, as trucks spend so much of their time on the motorways and can use this to ensure that the batteries are full when leaving. These characteristics make ERS very compatible with several of the other transportation trends (e.g. highly automated highway trucking, or high capacity vehicles) that this report has highlighted, as all of those will increase the relative importance of energy efficiency and having the vehicles on the move as much as possible.

ERS technologies are often grouped into three different technical categories:

1. Conductive transmission via overhead conduit (catenary),
2. Conductive transmission via rail or conductor in the road surface, and
3. Inductive transmission via electromagnetic fields from the road body

Conductive power supply from overhead lines (1st alternative above) is the most proven technology, due to its similarities to railway and trolleybus systems. Some disadvantages are that passenger cars cannot use this ERS type, that masts and overhead lines have a visual impact, and that the overhead lines pose a risk for accidents. It is currently the dominating technology in a German context.

Transmission via road conductors (2nd alternative above) is an interesting technology with the implicit benefit that all vehicles traveling on the road can utilize the system, including private cars.[127] Conductive ground ERS technology is currently being developed by Elways, ElonRoad and a few other actors but has not yet been sufficiently tested in regard to safety and functionality, especially considering that the electric rail is located on the road surface, where it is exposed to weather and potential objects in the rail.[128]

The third alternative above is inductive transmission via electromagnetic fields, a wireless charging that transfers energy using electromagnetic induction. As it is installed in the road body, it shares some aspects with ground-based conductive (e.g. available also for cars). Where it differs is in that it leaves no conductive material exposed to vehicles on the road. This can be considered a visual benefit but given that the most likely application is on busy motorways it is not obvious that this a decisive advantage. The trade-offs with indicative solutions are the limited power rating (diminishing its value to trucks); there is some uncertainty regarding health effects of electromagnetic fields and as to whether the technology is robust enough for safe and reliable long-term operation in harsh climates, such as in northern Europe. The technology is being tested in South Korea, but in Europe it is considered to be the most expensive of the three concepts.[129]

127 Interview with Dan Zethraeus, CEO Elonroad, 2019-06-07.

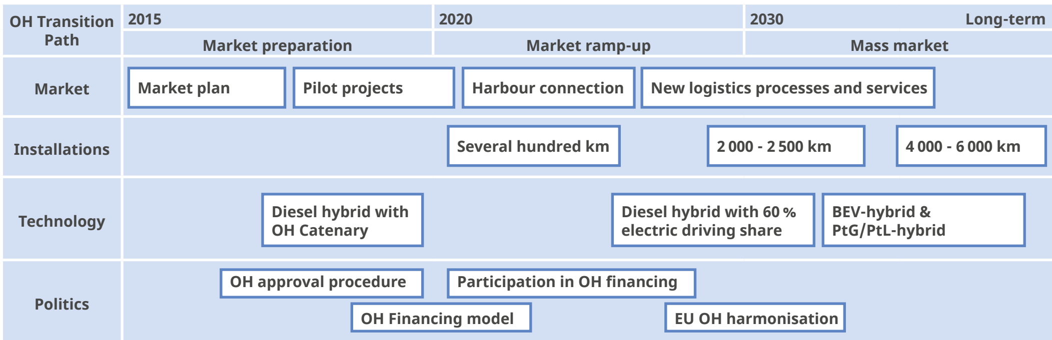
128 Electric Road Systems, J Schulte, 2018. Department of Strategic Sustainable Development, Blekinge Institute of Technology. https://www.mdpi.com/2071-1050/10/4/1148/pdf

129 Electric Road Systems, J Schulte, 2018. Department of Strategic Sustainable Development, Blekinge Institute of Technology. https://www.mdpi.com/2071-1050/10/4/1148/pdf

DEVLOPMENT OF ELECTRIC ROADS

It is too early to draw any conclusions from the German pilots[130]. Nevertheless, the necessary time needed to establish an OH catenary infrastructure should not be underestimated. Thus, there are already plans by the BMVI on how to move on, see timetable in Figure 20 (translated by author)[131].

FIGURE 20 *Time plan for roll-out of overhead catenary electric infrastructure. Source: BMVI.*



According to the timetable above, initiatives to establish the first several hundred kilometers of electric roads should be initiated by early 2020s. Based on freight flows, IFEU and PTV have identified the most suitable routes for the first 500 kilometers of a national catenary system (see the table and Fel! Hittar inte referenskälla.map below).[132]

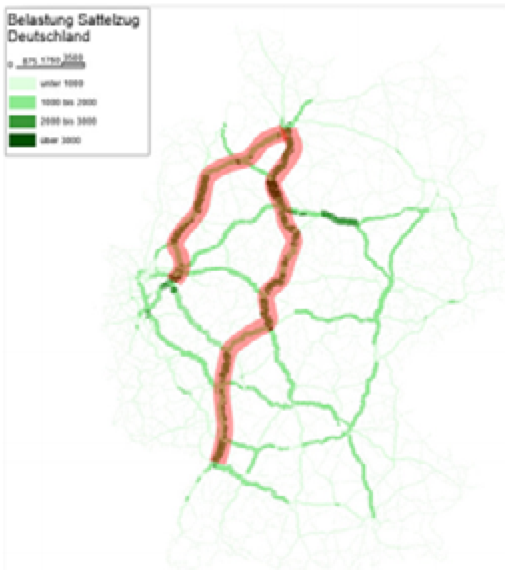
FIGURE 21 *Suitable routes for the first 500 kilometers of a national catenary system. Source: IFEU, PTV.*

Route	Federal highway	Distance
Essen/Gladbeck - Dreieck Heumar	A3/A2	85 km
Düsseldorf - Kreuz Kamen	A46/A1	81 km
Neckarsulm - Stuttgart	A81/A6	57 km
Hamburg - Lübeck	A1	49 km
Krefeld - Köln	A57	45 km
Schwerte - Lüdenscheid-Süd	A45	32 km
Essen - Dortmund	A40	26 km
Kreuz Kamen – Hamm-Uentrop	A2	23 km
Pfaffenhofen - München	A9	20 km
Bremen - Hamburg	A1/A261	81 km

130 Interview with Stefan Ziegert, Product manager for sustainable transport solutions, Scania. 2019-05-10.
131 BMVI, 2017. https://www.bmvi.de/SharedDocs/DE/Anlage/G/MKS/studie-potentiale-hybridoberleitungs-lkw.pdf?__blob=publicationFile
132 IFEU, PTV, "Roadmap OH-Lkw Potentialanalyse 2020-2030", p.30 (Siemens presentation)

Below is a map of Germany compiled by BMVI, showing the traffic intensity on the federal highways by internal German traffic of tractor units (green stretches). In a feasibility study of catenary systems from 2017, BMVI suggests the 500 kilometers of ERS above should be extended to a total of 1000 kilometers following the extension corridors (red) in the map below.[133]

FIGURE 22 *Suggested extension of OH catenary system based on traffic intensity. Source: BMVI, 2017.*



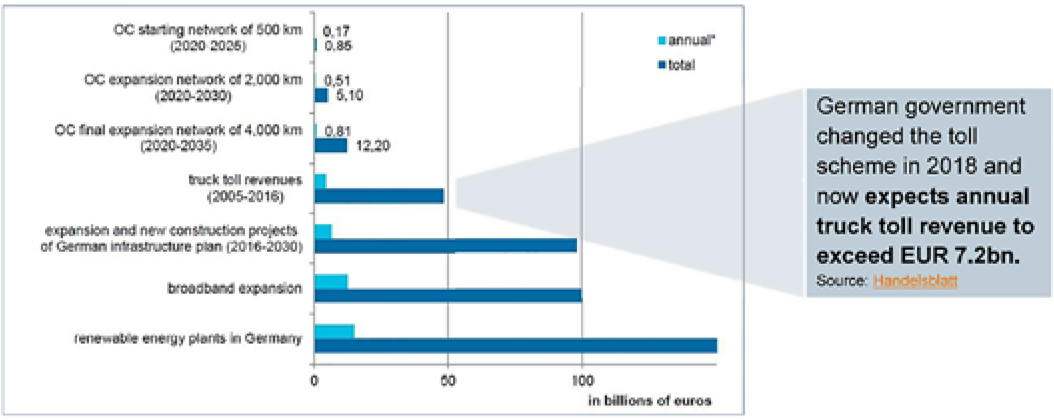
BMVI argues further that once 4.000 kilometres of highway in Germany has been electrified, 85 percent of buyers of new trucks will choose catenary hybrids over conventional diesel trucks.[134]

In 2018, BDI (the association of German industry) released their major study on how to reach Germany's climate goals in the most cost-effective way. The report sees 4,000 to 8,000 km of overhead contact lines for hybrid trucks as an important part of the solution for long haul trucks.[135] The investment for a 4,000 km catenary system corresponds to 12,200 million EUR, according to the independent Oeko Institute. This could be financed using only 11 percent of annual German road toll revenue.[136]

From a European perspective, interest in ERS is also gaining broader geographical support. The Franco-German Energy Declaration explicitly mentions a cross-border test track for an electric road.[137] Further south, in Italy, one highway operator has already announced their intention to become the first "zero impact" electric road.[138] It is crucial to synchronize these initiatives to avoid establishing different technologies that cannot be utilized by the same vehicles.

133 BMVI, 2017. https://www.bmvi.de/SharedDocs/DE/Anlage/MKS/studie-potentiale-hybridoberleitungs-lkw.pdf?__blob=publicationFile
134 BMVI, 2017. "Machbarkeitsstudie zur Ermittlung der Potentiale des Hybrid-Oberleitungs-Lkw".
135 BDI, 2018. https://bdi.eu/publikation/news/klimapfade-fuer-deutschland/ (Siemens presentation)
136 Öko-Insitut, StrattON Report (2018), p. 12 (Siemens presentation)
137 Franco-German Energy Declaration, 2018. https://www.bmwi.de/Redaktion/DE/Downloads/C-D/draft-franco-german-energy-declaration.pdf?__blob=publicationFile&v=4
138 Anders Bylund, Siemens Mobility AB. E-mail, 2018-11-18.

FIGURE 23 *Potential to finance from road toll system. Source: Öko-Institut, 2018.*



*average annual toll revenues or infrastructure investments during the indicated period

**the rising infrastructure costs per kilometre with increasing network expansion (from the start to the final expansion network) are caused by the assumed increasing performance of the infrastructure.

APPENDIX 5 – E-FUELS

SYNTHETIC FUELS / E-FUELS

The economic feasibility of large-scale production of e-fuels is so far lacking, due to high production costs related to electricity demand.

New technical breakthroughs could improve economy. The company Sunfire has developed a single-step synthetic gas production technology which reduces investment and operational costs significantly in comparison with previous two step processes[139]. The technology has been successfully tested in a pilot plant in Dresden, within the framework of the *PtX Kopernikus Project*[140] which is funded by the German Federal Ministry of Education and Research. By August 2019, plans are to deliver a plant to Karlsruhe, demonstrating self-sufficient production of e-Crude (a synthetic substitution to fossil crude oil).[141]

The PtX Kopernikus Project supports several other research, validation and implementation projects for e-fuels, undertaken by numerous actors. Another example is the collaboration between the Technische Universität Bergakademie Freiberg, Audi, VW, Shell and OMV, aiming at producing green gasoline through power-to-liquid technology. Ambitions are that the production technology will be commercially available by 2025.

FEEDSTOCK POTENTIAL OF E-FUELS

E-fuels production becomes most efficient when CO_2 from concentrated sources, such as industrial processes or biofuel production, can be used. Alternatively, CO_2 must be captured directly from the atmosphere. From an EU perspective, the potential of concentrated CO_2 from biogenic sources and industrial processes totals 164.8 million tonnes annually, according to a study by the German Energy Agency. Converted to e-fuels, this could theoretically meet 14 to 20 percent of the fuel demand in the European transport sector (including aviation). However, market competition with the energy sector – where e-fuels could offer increased stability in a system with a large share of intermittent energy sources – suggests that this is an optimistic scenario. The complexity of the interconnections between the stationary energy sector and the transport sector regarding possible power-to-X solutions is shown in Figure 25.

FIGURE 24 *Concentrated CO_2 potential and resulting PtL/PtG production potentials from biogenic and industrial sources in the EU28. Source: Dena, 2017.*

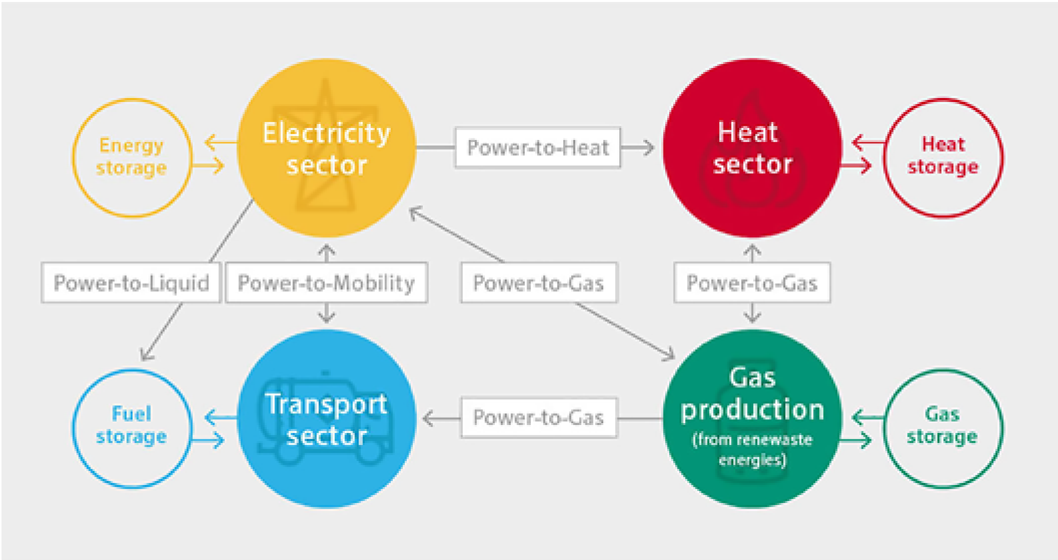
EU28		Biogenic sources	Industrial processes	TOTAL
CO_2 potential	million t/yr	85.9	78.9	**164.8**
	billion Nm^3/yr	43.7	40.2	**83.9**
PtL potential	TWh/yr	311	286	597
	PJ/yr	1,121	1,029	2,150
$PtCH_4$ potential	TWh/yr	434	399	832
	PJ/yr	1,562	1,435	2,997

139 Sunfire https://www.sunfire.de/en/company/news/detail/breakthrough-for-power-to-x-sunfire-puts-first-co-electrolysis-into-operation-and-starts-scaling
140 Federal Ministry of Education and Research, The P2X Kopernikus project. https://www.kopernikus-projekte.de/en/projects/power2x
141 Sunfire https://www.sunfire.de/en/company/news/detail/breakthrough-for-power-to-x-sunfire-puts-first-co-electrolysis-into-operation-and-starts-scaling

In a long-term perspective, the availability of concentrated CO_2 from industrial sources will likely decline as a result of more efficient processes and measures to reduce emissions. Hence, CO_2 capture from the atmosphere will be of increased importance for future production.

To meet increased electricity demand for production of synthetic fuels from available concentrated CO_2, substantial growth of installed power from wind, solar and water would be necessary. In an EU context this would imply more than doubling the current electricity production[142]. Crucial for the success of e-fuels is therefore cost-efficient expansion of renewable energy[143].

FIGURE 25 *Interacting sectors in the power-to-X system. Source: https://www.en-former.com/en/electricity-the-new-fuel/*



142 Transport & Environment, E-fuels too inefficient and expensive for cars and trucks, but may be part of aviation's climate solution – study. Published Dec 2017. https://www.transportenvironment.org/press/e-fuels-too-inefficient-and-expensive-cars-and-trucks-may-be-part-aviations-climate-solution-%E2%80%93

143 Auto Tech Review, E-Fuels As A Disruptor For The Transportation Sector. Published Feb 2018 https://autotechreview.com/opinion/guest-commentary/e-fuels-as-a-disruptor-for-the-transportation-sector

ABOUT

The Pathways Coalition

Our vision is FOSSIL-FREE COMMERCIAL HEAVY TRANSPORT by 2050, or earlier, in line with the Paris agreement, which is not only possible, but also financially sound from a societal perspective.

The Pathways Coalition was founded in 2018 to accelerate the transition to fossil free commercial transports. The stepping stone of the coalition is the study "The Pathways Study: Achieving fossil-free commercial transport by 2050". The study concludes that it is possible to achieve fossil free commercial transports within the time frame of the Paris Agreement, and that this also is socioeconomically beneficial. However, reaching the goals requires a transition of unprecedented speed and it is only when we join forces that we can achieve the speed of change required.

The member companies commit to the vision of The Pathways Coalition, to the objective to reach zero CO_2e latest by year 2050 and to contribute with real action in the partnership. We welcome all to join us in our efforts.

OUR MEMBERS

e·on ERICSSON H&M Group SCANIA SIEMENS

THE PATHWAYS COALITION