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Corrected version (Table on page 293)

287 Report by Wolf-Peter Schill, Julius Jöhrens, Dominik Räder, Hendrik Beeh, Josef Klingl, and Markus Werner

The future is battery electric: Climate change mitigation in road freight transport

- Road freight transport was responsible for around six percent of total German greenhouse gas emissions in 2022
- Market developments, costs, and efficiency advantages favor battery-electric trucks with stationary charging
- Government should continue to support expansion of charging infrastructure with fast charging options

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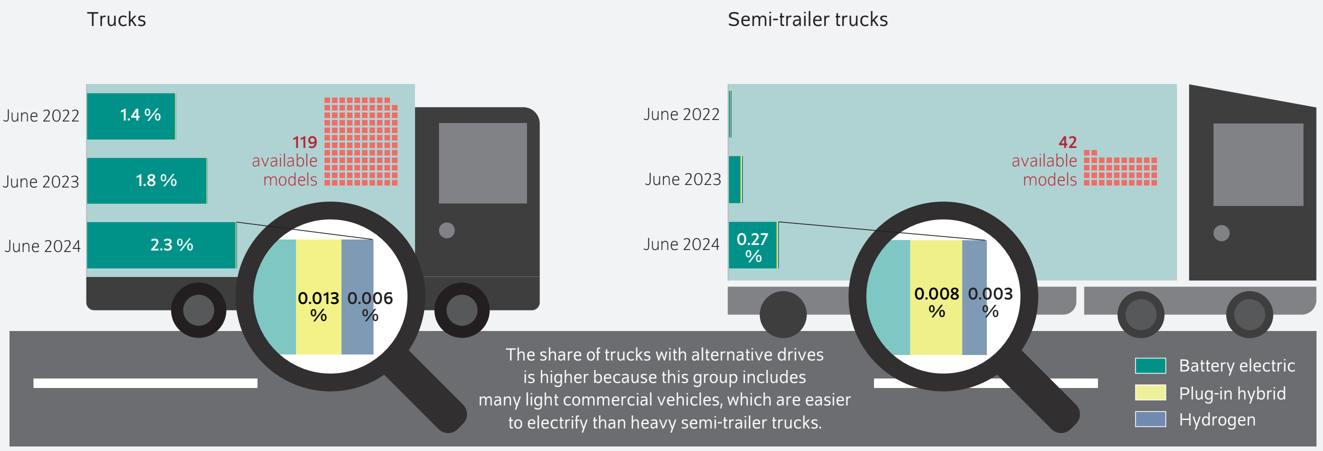
AT A GLANCE

The future is battery electric: Climate change mitigation in road freight transport

By Wolf-Peter Schill, Julius Jöhrens, Dominik Räder, Hendrik Beeh, Josef Klingl, and Markus Werner

- Heavy-duty road freight transport was responsible for around six percent of total German greenhouse gas emissions in 2022
- Battery-electric truck fleet is growing from a low level, while hydrogen trucks are stagnating
- Number of available models has increased; major manufacturers are mainly selling battery-electric drives
- Market developments, costs, and efficiency advantages clearly favor battery-electric trucks with stationary charging
- Government should continue to support the expansion of the charging infrastructure with fast charging options for trucks

Market development favors battery-electric drives in road freight transport



Sources: Data from the Federal Motor Transport Authority, aggregated and visualized in the Open Energy Tracker; ifeu's truck database.

FROM THE AUTHORS

"The market development as well as energy efficiency and cost advantages clearly favor battery-electric drives in road freight transport. Policymakers should set a clear focus on this technology and specifically eliminate bottlenecks in the expansion of the charging infrastructure to create investment security for manufacturers and logistics firms."
— Wolf-Peter Schill —

The future is battery-electric: Climate change mitigation in road freight transport

By Wolf-Peter Schill, Julius Jöhrens, Dominik Räder, Hendrik Beeh, Josef Klingl, and Markus Werner

ABSTRACT

Road freight transport must switch to alternative drive technologies, such as battery-electric or hydrogen vehicles, to mitigate its impact on the climate. Preliminary results from an ongoing research project show that the fleet of battery-electric trucks as well as the number of models on offer have recently grown significantly, albeit from a very low level. This is not the case for hydrogen trucks. Considerable amounts of investment from the private sector are flowing into the charging infrastructure. Compared to hydrogen trucks, battery-electric vehicles have major advantages when it comes to energy efficiency, foreseeable energy costs, and their expected and realistic contribution to climate change mitigation. Policymakers should therefore set a clear focus on ramping up battery-electric trucks while expanding the charging infrastructure, the fast charging network more vigorously in particular. To face possible challenges, especially when it comes to grid connections, battery swapping systems, or overhead line systems—which have a large technological overlap with battery-electric trucks—could be tested further. Furthermore, the energy efficiency advantages of battery-electric trucks should be considered in the greenhouse gas reduction quota system.

Germany has set a goal to become climate neutral by 2045. This requires climate change mitigation measures in all economic sectors, including road freight transport. One important strategy for this sector is switching from diesel trucks to battery-electric or hydrogen trucks.

This Weekly Report provides an overview of the current fleet and market development trends of battery-electric and hydrogen trucks as well as of the expansion of the charging and refueling infrastructure. Next, it discusses the advantages and drawbacks of alternative technologies as well as their possible contributions to climate change mitigation. The data used in this Weekly Report are drawn from preliminary results of an ongoing research project of the Institute for Energy and Environmental Research (*Institut für Energie- und Umweltforschung Heidelberg*, ifeu), TU Dresden, and DIW Berlin.[1]

Necessity of and options for climate change mitigation in road freight transport

Road freight ranges from urban distribution and delivery transport via light commercial vehicles to trans-national heavy goods transport. A variety of vehicles are used for such transport, differing in aspects such as configuration and permitted gross weight. Vehicles heavier than 3.5 tons are known as heavy-duty vehicles. The Federal Motor Transport Authority (*Kraftfahrt Bundesamt,* KBA) differentiates between straight trucks (*Lastkraftwagen*) and tractor units (*Zugmaschinen*). Especially relevant for heavy goods transport is the subgroup of semi-trailer trucks.[2] Semi-trailer trucks cover daily distances of 400 to 500 kilometers on average, much greater than other trucks (around 300 kilometers).

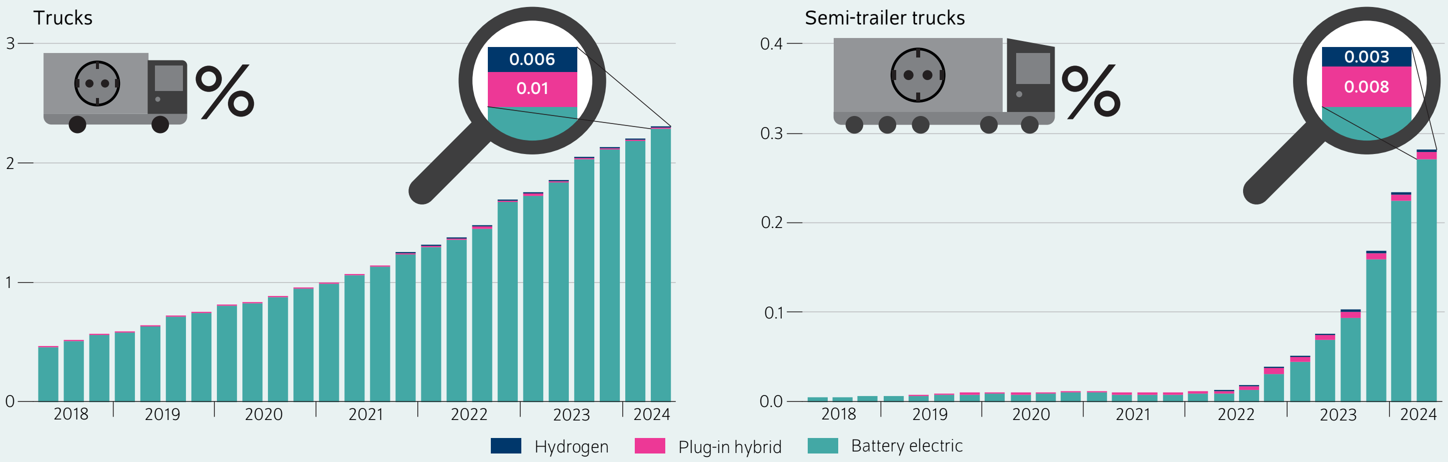
1 This Weekly Report is based on two recently published project reports: Julia Pelzeter et al., *Bewertung von Technologiekonfigurationen für den Straßengüterverkehr* (ifeu, TU Dresden, DIW Berlin: 20224) (in German; available online. Accessed on October 28, 2024. This applies to all other online sources in this report unless stated otherwise) as well as Julius Jöhrens et al., *Komplementärtechnologien zu BEV-Lkw – ein techno-ökonomischer Vergleich* (ifeu, TU Dresden, DIW Berlin: 2024) (in German; available online).

2 Colloquially and also in this report, the term "truck" is used in such a way that it includes both trucks and tractor units as defined by official statistics.

DOI: https://doi.org/10.18723/diw_dwr:2024-47-1

Figure 1

Road freight vehicle fleet in Germany
Share of alternative drives in percent



Note: Hydrogen includes fuel cells and hydrogen combustion engines.

Sources: Data from the Federal Motor Transport Authority, aggregated and visualized in the Open Energy Tracker (in German; available online).

The battery-electric vehicle fleet is growing from a low level, while the hydrogen fleet is barely growing.

Road freight causes significant greenhouse gas emissions in Germany, and the emissions keep rising. Commercial vehicles weighing over 3.5 tons were responsible for 28 percent of emissions from the transport sector and for around six percent of total German greenhouse gas emissions in 2022.[3] Around two thirds of these commercial vehicles weighed over 26 tons; they are mainly used for long-distance routes.

Various alternative drive options

Possible strategies for climate change mitigation in road freight are avoiding transport, switching to rail freight, and using alternative drives. There appears to be limited potential for avoiding transport and switching to rail freight.[4] Thus, the focus is on switching from diesel trucks to battery-electric vehicles, which requires an expansion of the fast-charging infrastructure. There are also two hydrogen-based options: Vehicles with hydrogen combustion engines and vehicles with fuel cells and an electric motor. Both types require hydrogen refueling stations.

There has also been some discussion of retaining diesel engines while using biofuels or synthetic fuels based on green hydrogen (e-fuels). However, we do not investigate these options further in this Weekly Report as they do not appear to be affordably scalable.[5]

No technology-specific goals to date

The German Federal Government's Climate Action Programme 2030 stipulates that around one third of heavy road freight transport mileage must be electric or powered by electric fuels by 2030.[6] Using alternative drives for road freight thus poses an especially large opportunity for decarbonization.[7] However, there are no concrete targets for newly registered trucks or the fleet of electric trucks, unlike for electric passenger vehicles.

In 2024, stricter fleet targets for carbon emissions of newly registered heavy commercial vehicles were set at the European level.[8] By 2030, newly registered trucks over 7.5 tons must have 45 percent lower CO_2 emissions compared to 2019. By 2035 and 2040, they must have 65 and 90 percent lower emissions, respectively, than in 2019.[9] These targets

3 Authors' calculations based on the Transport Emission Model (TREMOD), version 6.61 as well as data from the Federal Environment Agency (*Umweltbundesamt*, UBA) (in German; available online).

4 Cf. The second section of the Spring Report 2024: Sachverständigenrat für Wirtschaftsfragen, *Güterverkehr zwischen Infrastrukturanforderungen und Dekarbonisierung* (2024) (in German; available online).

5 Wolf-Peter Schill, "E-Fuels: Ja, aber nicht für Pkw," commentary in DIW Wochenbericht no. 17 (2021): 304 (in German; available online); as well as Falko Ueckerdt and Adrian Odenweller, E-Fuels – Aktueller Stand und Projektionen (2023) (in German; available online).

6 Bundesregierung, *Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050* (2019) (in German; available online).

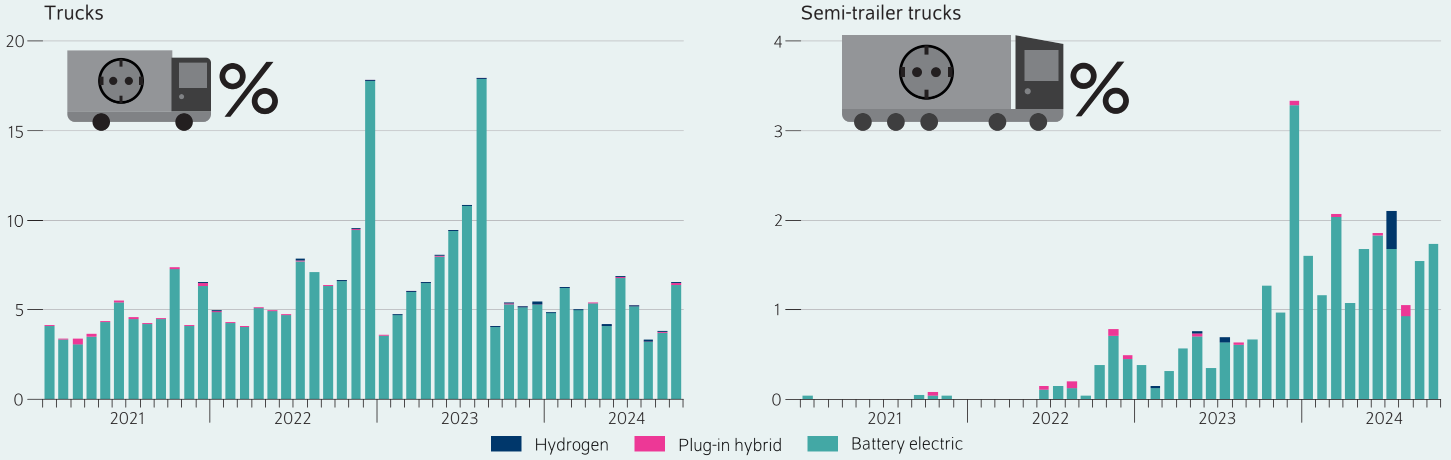
7 Sachverständigenrat für Wirtschaftsfragen, *Güterverkehr zwischen Infrastrukturanforderungen und Dekarbonisierung.*

8 Regulation (EU) 2024/1610 of the European Parliament and of the Council of 14 May 2024 (available online).

9 There are exceptions for small-volume manufacturers, mining, agriculture, and forestry, as well as for vehicles for military, civil defense, public safety, and medical care purposes.

Figure 2

Monthly new road freight vehicle registrations
Share of alternative drives in percent



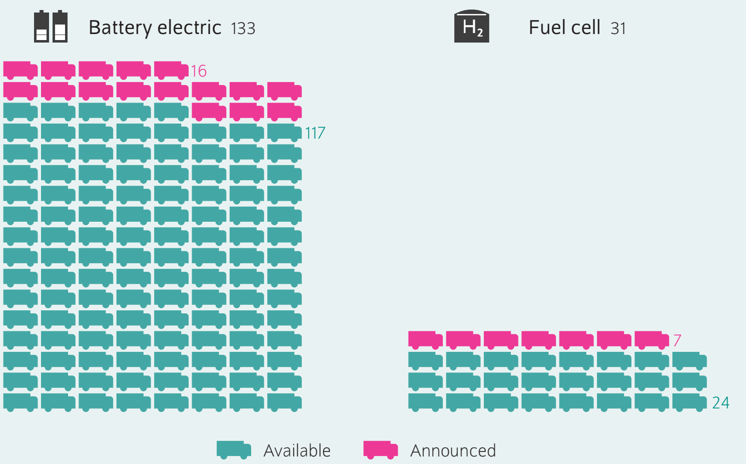
Note: Hydrogen includes fuel cells and hydrogen combustion engines.

Sources: Data from the Federal Motor Transport Authority, aggregated and visualized in the Open Energy Tracker (in German; available online).

Registrations of heavy battery-electric semi-trailer trucks increased considerably recently.

Figure 3

Announced and available vehicle models in Germany
Number as of October 2024



Note: Because there are different configurations per model, only the highest battery capacity and the smallest number of axels are evaluated as separate models. Hydrogen combustion engines are not included in these figures.

Source: The ifeu's truck database.

Most vehicle models are battery electric.

can probably only be achieved with a rapid increase in newly registered trucks with electric drives.[10]

Current market development favors battery-electric vehicles

Currently, there are around 3.8 million trucks in Germany, 530,000 of which weigh more than 3.5 tons. In addition, there are 236,000 semi-trailer trucks (Figure 1).[11] Diesel engines dominate overwhelmingly in both sectors: 92 percent of trucks and 97 percent of semi-trailer trucks have diesel engines. Only around 2.3 percent of trucks are pure battery-electric trucks; most are light commercial vehicles weighing less than 3.5 tons. Only 0.3 percent of semi-trailer trucks are battery electric.

However, the shares of new registrations of battery-electric vehicles are markedly higher (Figure 2). This has resulted in a considerable recent increase in the fleet of battery-electric vehicles, albeit from a low level. On average over the last

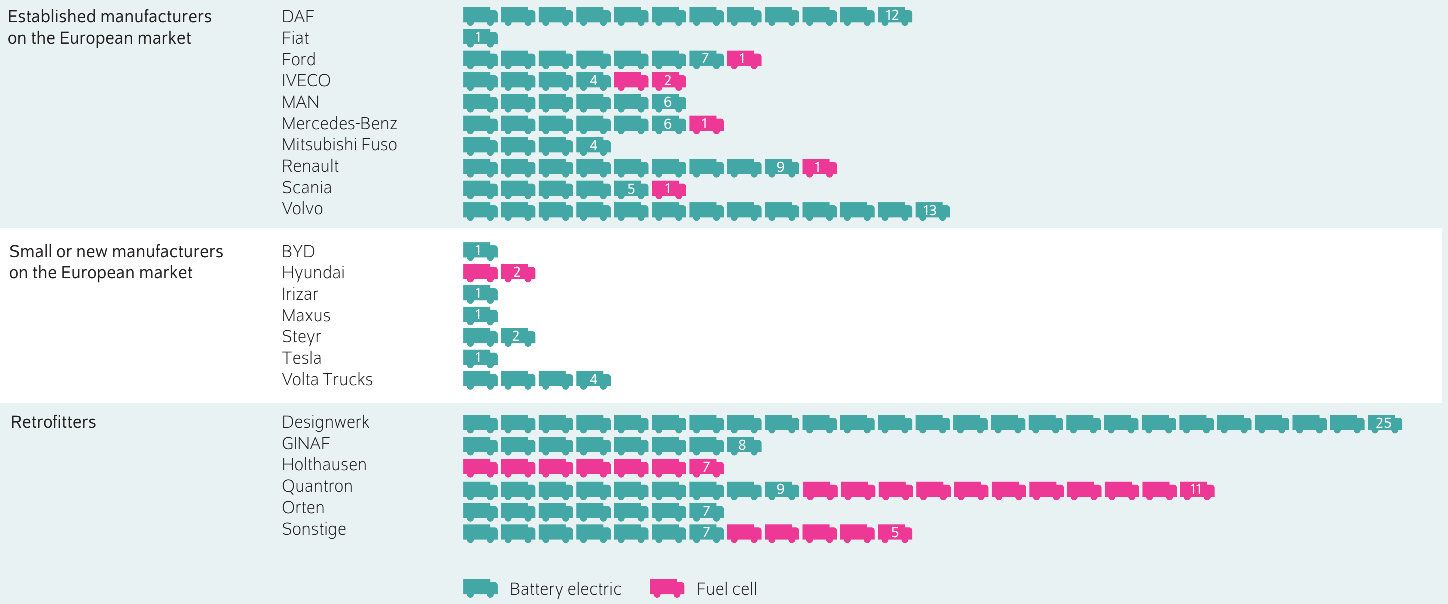
10 For more on the decarbonization of road freight and the possible roles different technologies can play, cf. Alexander Roth and Wolf-Peter Schill, hosts, "Elektro-Lkw, Teil 1: Batterien oder Wasserstoff," fossilfrei (podcast) episode 18, June 14, 2024 (in German; available online); and Alexander Roth and Wolf-Peter Schill, hosts, "Elektro-Lkw: Technologieoffenheit als Kampfbegriff?" fossilfrei (podast) episode 19, June 28, 2024 (in German; available online).

11 The data in this section is drawn from the KBA's statistics on commercial vehicles (FZ 25, available online), the quarterly vehicle fleet (FZ 27, available online), and monthly new registrations (FZ 28, available online) (all in German). This data is regularly evaluated and visualized in the Open Energy Tracker (available online).

Figure 4

Vehicle models listed by manufacturer

Number as of October 2024



Notes: Retrofitters are specialist firms that usually have a low number of vehicles they produce, as they mainly focus on retrofitting vehicles of other manufacturers.

Source: The ifeu's truck database.

The major manufacturers mainly offer battery-electric trucks. Most fuel cell trucks are offered by retrofitters.

12 months, five percent of all new trucks as well as 1.6 percent of all new semi-trailer trucks were pure battery electric.[12]

Despite being a frequent topic of policy discussion, hydrogen has not yet played any meaningful role in road freight. Currently, there are around 400 pure battery-electric trucks for every hydrogen truck in the fleet, while there are more than one hundred times as many battery-electric semi-trailer trucks as hydrogen semi-trailer trucks. Further, there is no positive trend in new registrations of hydrogen vehicles.

Considerable increase in number of electric vehicle models

A wide variety of available models is important for the market potential of electric trucks due to factors such as route profiles, differing requirements in the logistics sector depending on the type of good being transported, and the often strong brand loyalty of truck operators.

In total, 164 different models in the sector of heavy trucks and semi-trailer trucks weighing over 3.5 tons could be identified on the German market in October 2024 (Figure 3).[13] One hundred and forty-one of these models (86 percent) are already available and 23 have been announced (14 percent). Thus, compared to an earlier evaluation in October 2022 when 65 models were available, the number of models on offer has more than doubled.

Around 80 percent of these models are battery electric, while the remaining 20 percent have a fuel cell drive. Hydrogen vehicles are rather well represented in the model range compared to their current niche role in existing and new vehicle registrations.[14] However, a small number of specialist companies produce a large share of hydrogen trucks, and most of them concentrate on converting vehicles from other manufacturers. Of the major manufacturers in Europe, in contrast, only six offer or have announced fuel cell vehicles (Figure 4).

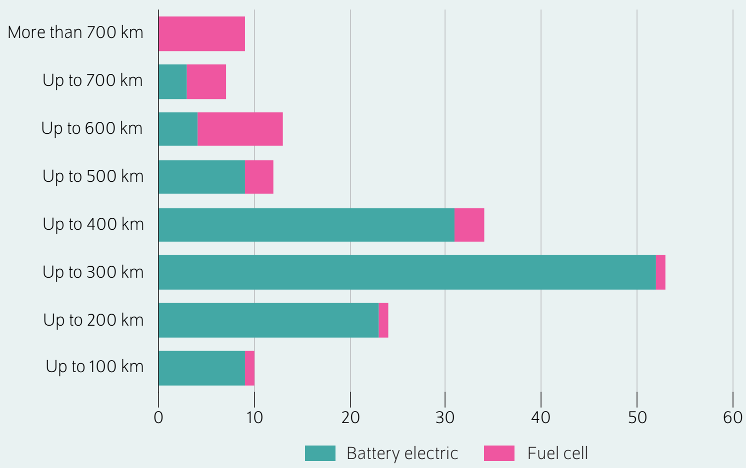
12 Among other things, changes to the fleet targets for newly registered trucks as well as to subsidy programs account for outliers in individual months. At the federal level, for example, there was a subsidy financed by the Climate and Transformation Fund (*Klima- und Transformationsfonds, KTF*) for the purchase of battery-electric or hydrogen commercial vehicles until 2023. This subsidy was ended without a replacement following the ruling of the Federal Constitutional Court on November 15, 2023, and the subsequent budget consolidation. However, there are still individual subsidy programs at the state level, cf. ifeu overview (in German; available online).

13 A vehicle model is determined by eight parameters: manufacturer, drive system, drive power, battery capacity, hydrogen tank capacity, fuel cell capacity, and number of axels. As there can be many different configurations per model (for example, battery capacity or number of axels), only the greatest battery capacity and the smallest number of axels are evaluated as separate models.

14 This also applies when compared to the significantly larger passenger vehicle market, in which only two fuel cell models are currently available in Germany.

Figure 5

Range of available and announced vehicle models
Number of models as of 2024



Note: The figure shows the total number of available and announced models.

Source: The ifeu's truck database.

The range of most vehicles on offer can cover distances required for regional transport.

A good 80 percent of the models, almost exclusively battery-electric trucks, have a range of less than 500 kilometers. The focus is on ranges of 200 to 300 kilometers, which can cover regional transport (Figure 5).[15] There are a few battery-electric models with a range of over 500 kilometers, but most of these are equipped with a fuel cell drive. Range is an important aspect in ongoing discussions about potential benefits of fuel cell vehicles, which is clearly reflected in the available models.

The available models cover all size classes of commercial vehicles.[16] More than half of the models have a gross vehicle weight of over 12 tons. While the larger vehicles tend to have a somewhat greater range, the range profile is similar for all vehicle sizes. This also applies to the semi-trailer trucks that are common in long-distance transport, as these can currently usually only be ordered with the same battery sizes as trucks over 12 tons.

Various manufacturer strategies

Individual manufacturers differ greatly in their view on the strategic importance of hydrogen drives. While the TRATON Group (MAN / Scania), for example, has strongly emphasized the economic advantages of battery-electric vehicles in recent years and views them as the clear focus of its corporate strategy,[17] Daimler is pursuing a dual strategy with battery-electric drives and fuel cells to power heavy long-haul transport.[18] Other manufacturers use a "three-pillar model" including renewable fuels (Volvo)[19] or a "technology-neutral multi-drive approach" (Iveco).[20] Only Renault Trucks will explicitly exclude fossil combustion engines from 2040 onward.[21] Volvo, MAN, DAF, and Iveco also include the hydrogen combustion engine as an option to varying degrees.

Information provided by manufacturers at "cleanroom discussions",[22] which have been initiated by the Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr, BMDV) to better assess the future roll-out of low-carbon trucks, shows that the market share of pure battery-electric drives in heavy commercial vehicles is expected to increase significantly in the coming years. By 2030, they will make up around half of all sales in the over 12 tons weight class. Various other technologies will play more of a supplementary role.

Ramp-up of charging and refueling infrastructure

Battery-electric and hydrogen drives face different challenges when it comes to their public energy supply infrastructure. In many cases, battery-electric trucks can recharge the majority of their battery at a depot, provided that the grid connections and vehicle profiles allow it. However, a certain amount of fast charging is required, especially in long-distance transport.[23] Hydrogen trucks, on the other hand, cannot be refueled in depots, but are generally dependent on public hydrogen refueling stations, as the construction and operation of refueling stations is expensive compared to electric depot charging stations.

Expansion of the fast-charging infrastructure

The established Combined Charging System (CCS) standard is available for charging infrastructure up to a capacity of 400 kilowatts. Currently, 31,000 CCS charging stations are publicly available in Germany.[24] In general, they are designed for passenger cars, but some can also serve trucks.

15 The range is calculated per vehicle model using the net battery capacity as well as typical energy consumption (battery capacity/energy consumption = range).

16 Here we consider the size classes N2 (< 12 tons) and N3 (> 12 tons). Light commercial vehicles (N1) are not included.

17 MAN, *Strategie – MAN auf einen Blick* (2024) (in German; available online); Scania, *Das Bekenntnis von Scania zu batteriebetriebenen Elektrofahrzeugen* (2021) (in German; available online).

18 Daimler Truck, *Diskussion Batterie vs. Wasserstoff: Daimler Truck setzt mit beiden Technologien konsequent auf Doppelstrategie* (2022) (in German; available online).

19 Volvo Trucks, Gemeinsam in Richtung null Emissionen: Unser Weg zur Dekarbonisierung des Transports (2024) (in German; available online).

20 IVECO Group, *Iveco Group präsentiert Multi-Antriebs-Strategie und stellt innovative Lösungen auf der IAA TRANSPORTATION 2024 vor* (2024) (in German; available online).

21 Renault Trucks, *Renault Trucks bietet ab 2023 eine elektrische Baureihe für jedes Marktsegment an* (2021) (in German; available online); cf. Renault Trucks, *Towards low-carbon transport* (2024) (available online).

22 NOW, *Marktentwicklung klimafreundlicher Technologien im schweren Strassengüterverkehr. Nationale Organisation Wasserstoff und Brennstoffzellentechnologie* (2024) (in German; available online).

23 Daniel Speth and Patrick Plötz, "Depot slow charging is sufficient for most electric trucks in Germany," *Transportation Research Part D: Transport and Environment*, vol. 128 (2024).

24 Bundesnetzagentur, *Ladeinfrastruktur in Zahlen* (2024) (in German; available online). Information on the charging infrastructure is regularly prepared in the Open Energy Tracker (in German; available online).

Corrected version (Table)

Table

Truck charging infrastructure activities
As of October 2024

	State	Private sector				
	Initial charging network (BMDV, BMWK)	e.On, MAN	Milence	Aral Pulse	TST+EWR (PVSM Energy)	CityWatt
Planned locations	350	125 (DE), 170 (EU + UK)	25 (DE), 70 (EU)	30	41	N. a.
Planned charging points	4,200	400	570 by 2025, 1,700 by 2027 (EU)	N. a.	N. a.	N. a.
Existing locations	0	1 (DE)	0 (DE) / 4 (EU)	25 (DE) / 26 (EU)	1	50
Type of location	Rest areas	Near highways (first location)	Near highways, truck stops, city center	Aral truck stops	Near highways	City centers/industrial areas, near highways, federal highways
Planned finish date	Until 2030	TBD	2025	2024	2025	2024
Charging capacity	1,800 x MCS, 2,400 x CCS	Initially 400 kW CCS, MCS to be added later	CCS+MCS (at five existing locations first)	CCS 300 kW	CCS 400 kW	CCS 300 kW

Source: Authors' research.

However, much higher charging capacities may be necessary to recharge the batteries of heavy long-distance transport trucks quickly enough during the drivers' breaks. To solve this issue, a new fast charging standard is being developed and is nearly ready to be introduced, the Megawatt Charging System (MCS). The MCS should make charging capacities of up to 3.75 megawatts (3,750 kilowatts) possible.[25]

Recently, various private sector actors have announced plans to build specific truck charging stations in over 200 locations, and construction has already begun on some of them (Table). On the government side, the BMDV and the Federal Ministry for Digital and Transport (*Bundesministerium für Digitales und Verkehr*, BMDV) have launched an initiative for a fast-charging network for trucks[26] that includes around 350 locations on federal highways. An initial tender for truck charging stations at around 130 unmanaged rest areas has already been launched,[27] with another to follow. For all planned station locations, the electrical connection capacities required and corresponding grid connections have already been planned and applied for.

The public fast charging infrastructure is primarily needed to make it possible for battery-electric trucks to cover the typical long-distance transport profiles. This infrastructure will likely be of great importance for compliance with the stricter European fleet CO_2 targets from 2030 onward. Until public truck charging infrastructure is widely available, many battery-electric trucks can rely on depot charging, especially trucks used for regional transport, which can in turn promote the market ramp-up of electric trucks.[28]

Challenges for hydrogen refueling stations

To date, hydrogen refueling stations have mainly been planned for passenger cars at a pressure level of 700 bar. However, trucks require a lower pressure of 350 bar, which only around half of the existing refueling stations can currently provide. As of September 2024, there are 42 refueling stations with a pressure level of 350 bar.[29] Some manufacturers are also considering using liquid hydrogen in future vehicle models, which entails uncertainty regarding the construction of new refueling stations.[30] The previous funding for hydrogen refueling stations from the Climate and Transformation Fund (*Klima- und Transformationfonds*, KTF) was discontinued due to funding problems.

While there are concrete private sector activities and government tenders being undertaken for the battery-electric truck charging infrastructure, there is much more planning uncertainty when it comes to the construction of hydrogen refueling stations. On the government side, the main issue is how to ensure compliance with the European minimum infrastructure requirements[31] and whether the targets need to be adapted to the new market reality.[32]

25 The charging infrastructure capacity for passenger vehicles is considerably lower in contrast. Currently, direct current fast charging stations can achieve a maximum of 0.4 megawatts. Typical alternating current charging stations only achieve 0.022 megawatts.

26 BMWK and BMDV, "Startschuss für das Lkw-Schnellladenetz," press release from July 3, 2024 (in German; available online).

27 BMDV, "Ausschreibung für Lkw-Schnellladeinfrastruktur gestartet," press release from September 16, 2024 (2024) (in German; available online); Nationale Leitstelle Ladeinfrastruktur, *Standorte für das LKW-Schnellladenetz an Rastanlagen mit benötigten Netzanschlussleistungen* (in German; available online); Nationale Leitstelle Ladeinfrastruktur, *Standorte für das LKW-Schnellladenetz an Rastanlagen mit benötigten Netzanschlussleistungen* (in German; available online).

28 Pelzeter et al., *Bewertung von Technologiekonfigurationen für den Straßengüterverkehr.*

29 BMDV, *Informationsveranstaltung zum nationalen Strategierahmen gemäß EU-Verordnung über den Aufbau der Infrastruktur für alternative Kraftstoffe (AFIR)* (2024) (in German; available online).

30 Cf. Sachverständigenrat für Wirtschaftsfragen, *Güterverkehr zwischen Infrastrukturanforderungen und Dekarbonisierung.*

31 These involve, among other things, location density and the quantities dispensed, cf. BMDV, *Informationsveranstaltung zum nationalen Strategierahmen*

32 Cf. Sachverständigenrat für Wirtschaftsfragen, *Güterverkehr zwischen Infrastrukturanforderungen und Dekarbonisierung.*

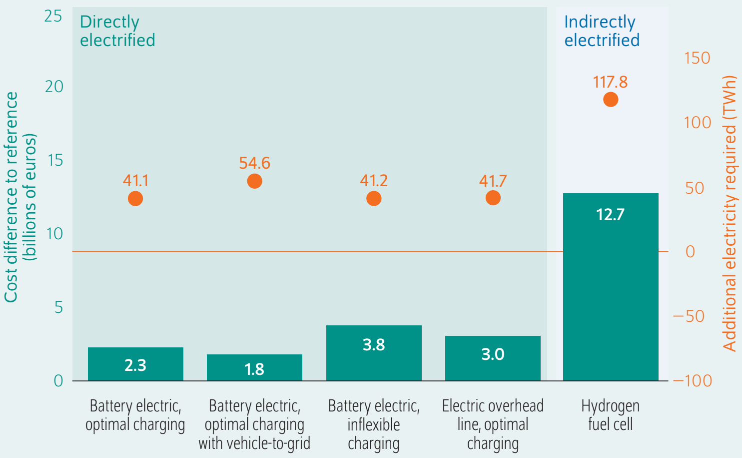
Box

Electricity sector analysis: Advantages of hydrogen storage do not outweigh energy-efficiency drawbacks

Figure

Change in electricity sector costs compared to the reference (diesel trucks) as well as the electricity consumed by vehicles

Billions of euros (left axis), terawatt hours (right axis)



Notes: Calculations for 2030 under the assumption that heavy road transport has been completely electrified with the technology in question. Green hydrogen is assumed to be produced in Germany.

Source: Carlos Gaete-Morales et al., "Power sector effects of alternative options for de-fossilzing heavy-duty vehicles—Go electric, and charge smartly," *Cell Reports Sustainability* 1, no. 6 (2024): 100123 (available online).

The electricity sector costs of battery-electric trucks are lower than for hydrogen fuel cell trucks, even when the batteries are inflexibly charged.

An analysis using DIW Berlin's open-source electricity sector model DIETER shows that battery-electric vehicles with fast charging capabilities result in the lowest electricity sector costs of all options under observation. Even if the battery-electric vehicles are not optimally charged, they still have clear advantages compared to hydrogen fuel cell vehicles or synthetic hydrogen-based e-fuels. The advantages are even greater if the batteries are flexibly charged based on the electricity market price in combination with vehicle-to-grid charging, where electricity is fed back to the grid at times.

Battery-electric vehicles have such an advantage due to the poor energy efficiency of hydrogen and e-fuels, which are assumed to be domestically produced in the model. Domestic production results in considerable costs for the renewable energy used. However, it is often argued that this drawback could be offset by the advantageous storage capacity of hydrogen and e-fuels, which will become more important in a future energy system with a high share of variable wind and solar energy. However, the model analyses show that the energy efficiency drawbacks of hydrogen and e-fuels clearly outweigh their storage advantages (Figure).[1]

1 Carlos Gaete-Morales et al., "Power sector effects of alternative options for de-fossilizing heavy-duty vehicles—Go electric, and charge smartly," *Cell Reports Sustainability* 1, no. 6 (2024): 100123 (available online). A condensed version in German is available in DIW Aktuell: Wolf-Peter Schill et al., "Klimaschutz im Güterverkehr: Batterieelektrische Antriebe können günstiger mit erneuerbarem Strom versorgt werden als Wasserstoff-Lkw," *DIW Aktuell* no. 94 (2024) (in German; available online).

Challenges facing battery-electric trucks and possible contributions of other technologies

The developments on the vehicle market and in the charging infrastructure as well as energy efficiency and energy system analyses suggest that battery-electric vehicles in combination with stationary charging will become a key building block of climate-friendly heavy road freight transport. However, a systematic comparison of different criteria shows that this technology is also facing various challenges,[33] including integration into the power grid and the effects on the stability of the energy system, the space required for the charging infrastructure, the raw materials required for batteries, the operational changes required for logistics firms, and the cost of vehicles.

Hydrogen has some advantages, but many drawbacks

Hydrogen drives have advantages when it comes to some of the observed criteria. For example, they do not require fast charging infrastructure to be connected to the power grid, and thus neither any reinforcement measures in the higher voltage network. The space requirement and the need for operational adjustments at logistics firms are also rated as slightly more favorable than for battery-electric trucks.[34] However, hydrogen trucks have some of their own challenges when it comes to infrastructure expansion and energy costs, which ultimately comes down to their poor energy efficiency (Box). In addition, uncertainty around future energy cost appears to be significantly higher for hydrogen trucks than for battery-electric trucks. This is due to the fact that the hydrogen market hardly exists to date, but it has a large number of potential future consumers.

In light of the foreseeable high hydrogen demand from other sectors, especially industry, it seems questionable whether significant quantities of green hydrogen can be made available for road freight in the medium term. Barely any projects have been realized so far, both in domestic production as well as planned hydrogen imports.[35]

33 This section is based on an analysis by Jöhrens et al., *Komplementärtechnologien zu BEV-Lkw.*

34 Pelzeter et al., *Bewertung von Technologiekonfigurationen für den Straßengüterverkehr.*

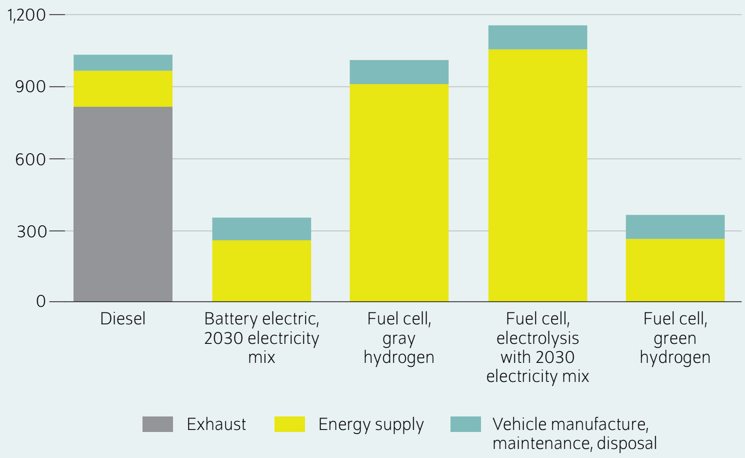
35 Cf. the Ampel-Monitor Energiewende for the state of elctrolysis and its targets as well as Martin Kittel et al., "National Hydrogen Strategy: Clear focus and consistent implementation necessary," *DIW Weekly Report* no. 40+41+42 (2023) (available online).

This also raises the question if hydrogen trucks can even contribute to quickly reducing greenhouse gas emissions in Germany. Their emissions balance over the life cycle, when including vehicle production, seems to offer little advantage in the medium term (Figure 6),[36] especially if gray hydrogen (hydrogen produced from natural gas) is used. It seems plausible that gray hydrogen will be used because the production costs of green hydrogen are likely to remain higher than the costs of gray hydrogen for some time. The emissions balance is even worse if hydrogen is produced via electrolysis powered by average grid electricity. Even if electrolysis were powered entirely by renewable electricity (green hydrogen), there would not be any emissions advantage over grid-powered battery-electric trucks, as the share of renewable energy in the power grid is set to rise to at least 80 percent by 2030. When considering life cycles, battery-electric trucks thus have considerable emissions advantages compared to hydrogen trucks, at least until 2030. Furthermore, the analysis shows that the production of vehicles (including batteries) only makes up a small share of the climate impact compared to power supply during the use phase.

Figure 6

Climate impact of semi-trailer trucks in long-haul transport in 2030

Grams of CO_2 equivalent per kilometer



Note: Considering the entire life cycle.

Source: Julius Jöhrens et al., "Perspektivische Kosten und Klimabilanz von Lkw mit alternativen Antrieben 2030," *enERSyn Schwerpunktpapier*, no. 2 (forthcoming, 2024).

Compared to battery-electric vehicles, fuel cell vehicles do not cause fewer emissions over the life cycle even when using green hydrogen.

Other electric technologies advantageous in subsectors

Other electric technologies that are not currently widely available on the market but have been tested could partially compensate for some weak spots of battery-electric trucks. Such technologies include electric road systems such as overhead line systems or third-rail systems, which dynamically power electric trucks as they drive, making it possible to reduce the size of vehicle batteries. Overhead line systems for trucks have already been comprehensively tested in Germany.[37] In addition, battery swapping systems for trucks are under discussion. While such systems are already widespread in China, they have not yet been tested much in Germany. Semi-trailers with electric axels and their own battery (e-trailer), which could initially be used in combination with diesel tractors, are another possibility.

Some of these technologies have been evaluated as advantageous with respect to a few challenging aspects for the market ramp-up of battery-electric trucks with fast charging (Figure 7).[38] Such challenges include network integration, the contribution to the stability of the energy system, and the space requirement. However, there is still no single technology that equally addresses all of the drawbacks of battery-electric trucks. In addition, each type of technology has its own challenges: An overhead line system, for example, requires high initial investment costs for the core network, and battery swapping systems must be standardized.

Greenhouse gas reduction quota could create strong incentives for hydrogen use

The greenhouse gas reduction quota (GHG quota) is a market-based climate change mitigation instrument that aims to reduce the use of fossil fuels in the transport sector. Companies that create fossil fuel emissions in transport are required to reduce their emissions (including fuel production), with the reduction quota increasing each year. Currently, the quota is 9.35 percent compared to the fossil fuel reference value; in 2030, it will rise to 25.1 percent.[39] There are various options for reducing emissions, such as using electric drives or using more electric fuels such as hydrogen. Companies do not have to meet the quotas themselves, but can rather trade emissions via certificates.

However, the GHG quota does not adequately account for the better energy efficiency of battery-electric trucks compared to hydrogen trucks. As a result, higher certificate revenues can be achieved by using hydrogen compared to a correspondingly lower amount of electricity that can cover the same mileage with a battery-electric truck. If this revenue is used to subsidize the sale of green hydrogen at refueling stations, the price of hydrogen would decline by around two euros pro kilogram at the current GHG quota price of around 70 euros per ton of CO_2. If the certificate prices once again rise to the 2022 level of around 400 euros per ton due to rising reduction quotas, green hydrogen could be subsidized to be sold

36 Julius Jöhrens et al., "Perspektivische Kosten und Klimabilanz von Lkw mit alternativen Antrieben 2030," *enERSyn Schwerpunktpapier* no. 2 (forthcoming).

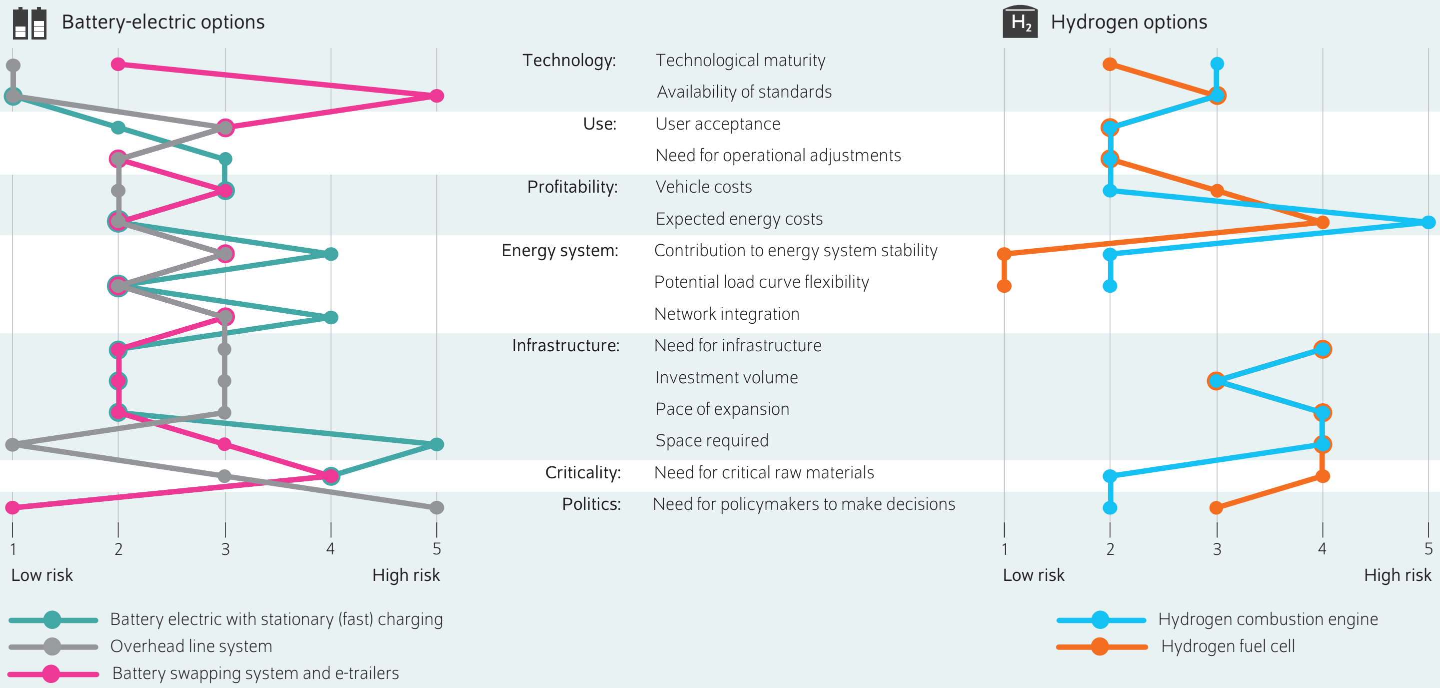
37 Julius Jöhrens et al., "Current technical findings on the eHighway system from field tests and accompanying research in Germany," Working paper compiled by the German cross-project Working Group on eHighway Technology (AG Technikbewertung) (2022) (available online).

38 Jöhrens et al., *Komplementärtechnologien zu BEV-Lkw*.

39 More information is available on the German customs website (in German; available online).

Figure 7

Evaluation of the risks for the market ramp-up of different technologies considering 15 criteria



Notes: Here it is assumed that hydrogen does not have to be produced domestically and can instead, for example, be imported from abroad. The network integration criterion only refers to the power grid and does not apply to hydrogen drives.

Source: Julia Pelzeter at al., *Bewertung von Technologiekonfigurationen für den Straßengüterverkehr* (ifeu, TU Dresden, DIW Berlin: 2024) (in German; available online).

Battery-electric vehicles have higher market ramp-up risks than other options when it comes to four criteria.

for around 12 euros per kilogram. This is in the range of current refueling station prices for hydrogen and would drastically decrease the energy costs of fuel cell trucks, which are presently high. In this way, the greenhouse gas emissions rate in its current form could create stronger incentives for the use of hydrogen drives than for battery-electric drives.

Conclusion: Focus should be on battery-electric drives and fast charging

In the debate on the use of alternative drives in heavy road freight transport, actors from vehicle manufacturing, logistics, and the hydrogen business often argue that a broad technology portfolio is required to quickly and effectively reduce greenhouse gas emissions. Some also argue that a portfolio with as many different types of technologies as possible makes sense from an industry policy perspective to provide market opportunities for domestic manufacturers.[40]

However, current market developments, systematic energy efficiency considerations, the energy system effects, and the medium-term expected contributions to emissions reduction suggest that a clear political focus on battery-electric trucks with stationary battery charging is more advantageous. On the one hand, this focus corresponds with the reality of the market and thus supports current private sector activities. On the other hand, these technologies correspond with what is currently the most plausible path for medium and long-term effective climate change mitigation in heavy road freight transport. Federal policy should clearly communicate battery-electric trucks as a key technology to give truck manufacturers and operators security in upcoming investments. Government funding of too many alternative technology options could, in contrast, lead to planning uncertainty for vehicle manufacturers, infrastructure providers, and logistics specialists and thus ultimately delay the transition of truck drives.

The current activities in the private sector for ramping up the charging infrastructure for battery-electric trucks should continue to be supported by the government; the corresponding tenders are a first positive step in this direction. Activities to provide the space needed as well as the required network connections also seem sensible. Furthermore, the regulations for the GHG quota should be adjusted to adequately account for the energy efficiency advantages of battery-electric trucks.

40 Cf. Sachverständigenrat für Wirtschaftsfragen, *Güterverkehr zwischen Infrastrukturanforderungen und Dekarbonisierung.*

As for keeping opportunities open for other technologies, focus should be on alternatives that are closely related to battery-electric trucks technologically and can possibly be combined modularly with fast charging concepts. Here, battery swapping systems as well as e-trailers could develop into complementary technologies. The technologically closely related option of overhead line trucks could also be kept open with a larger demo project.

Hydrogen trucks, in contrast, would require completely different vehicle and infrastructure technology as well as corresponding pathway decisions from truck operators. In light of the diverse challenges and so as to not further delay the drive transition, the continued support of hydrogen-powered heavy road freight transport appears unwise.

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