

STUDY

Requested by the TRAN Committee



Alternative fuel infrastructures for heavy-duty vehicles

Study



Policy Department for Structural and Cohesion Policies
Directorate-General for Internal Policies
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RESEARCH FOR TRAN COMMITTEE

Alternative fuel infrastructures for heavy-duty vehicles

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Abstract

This study presents the opportunities and challenges for the use and deployment of alternative fuels infrastructure in the EU for heavy-duty vehicles, in particular trucks. The current state of play and future needs are presented in the context of the ambitions of the Green Deal, the proposal for an Alternative Fuels Infrastructure Regulation published mid-July 2021 and the upcoming review of the TEN-T Regulation.

This document was requested by the European Parliament's Committee on Transport and Tourism.

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LIST OF ABBREVIATIONS

AC	Alternating current
ACEA	European Automobile Manufacturers' Association
AFI	Alternative fuels infrastructure
AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
BET	Battery electric truck
CAPEX	Capital Expenditures
CEF	Connecting Europe Facility
CNG	Compressed natural gas
CCS	Combined Charging System
DAC	Direct air capture
DC	Direct current
DME	Dimethylether
EAFO	European Alternative Fuel Observatory
EC	European Commission
EEA	European Economic Area
EP	European Parliament
ETS	Emission Trading System
EU	European Union
ERS	Electric Road System
EV	Electric vehicle
FAME	Fatty Methyl Ester

FCEV	Fuel cell electric vehicle
FCET	Fuel cell electric truck
FQD	Fuel Quality Directive
GHG	Greenhouse gas
GVW	Gross vehicle weight
HVO	Hydrotreated Vegetable Oil
HDV	Heavy-duty vehicle
HRS	Hydrogen refuelling station
ICCT	International Council on Clean Transportation
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
ISO	International Organization for Standardization
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MCS	Megawatt Charging System
NGO	Non-governmental organisation
NUTS	Nomenclature of territorial units for statistics
OEM	Original equipment manufacturer
OPEX	operational expenditure
PCI	Projects of Common Interest
PEMFC	Proton-exchange membrane fuel cell
PHET	Plug-in hybrid electric truck

RED	Renewable Energy Directive
RFF	Recovery and Resilience Facility
RRP	national recovery and resilience plans
SOFC	Solid oxide fuel cell
UCO	used cooking oil
SME	small and medium-sized enterprises
TCO	Total cost of ownership or total cost of operation
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European Transport Network
tkm	Tonne-kilometres
TRAN	(European Parliament's Committee on) Transport and Tourism
TTW	Tank-to-wheel
vkm	Vehicle-kilometres
WLPGA	World Liquid Petroleum Gas Association
WTW	Well-to-wheel

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EXECUTIVE SUMMARY

KEY FINDINGS

- Given the Green Deal decarbonisation targets, there is a need to decarbonise truck transport, but at present there is only minimal publicly accessible refuelling and recharging infrastructure for battery electric trucks (BETs) and hydrogen-fuelled trucks.
- The proposal for an Alternative Fuels Infrastructure Regulation (AFIR) aims to ensure a **minimum level of infrastructure** and includes binding **distance-based targets** for the realisation of recharging and hydrogen refuelling points for trucks.
- Estimated future infrastructure requirements point to a need for overnight depot charging points as the main recharging concept for BETs. To a lesser extent, public overnight chargers and ultra-fast opportunity charging are required. For medium- and long-haul transport, however, **publicly accessible fast-charging and lower power overnight charging infrastructure is essential**.
- Given the high power demand of truck charging at depots and roadside public charging stations, **the power grid and its capacity need to be suitably** extended and adjusted to become future-proof.
- A strategic roll-out plan published together with the proposed Regulation contains a strategy and clearly defined actions to reduce barriers. For example, by means of funding mechanisms, standardisation and development of a data governance framework.

Vehicle technologies and their need for infrastructure

About 19% of transport green house gas (GHG) emissions are caused by heavy-duty vehicles (HDV's) in road transport (EEA, 2020)¹. Given the Green Deal objective of reducing transport GHG emissions by 90% in 2050, more effective action is required to decarbonise this vehicle segment. To reach the goals, zero emission technologies such as battery electric and hydrogen fuelled trucks will play an important role. All Original Equipment Manufacturers (OEMs) have battery electric trucks (BETs) ready to enter the market, while fuel cell electric trucks (FCETs) are likely to become commercially available after 2025. Electric Road System (ERS) trucks are not commercially available yet, but are piloted in Germany and Sweden. These zero-emission powertrains offer major reduction potential, however, without sufficient and appropriate recharging and refuelling infrastructure they will fail to deliver. At the moment there is still little infrastructure installed for these new technologies, and a scale up is needed. Charging systems up to 350 kW are already available for battery electric trucks (BETs), while Megawatt Charging Systems (MCS) are in development. Compressed hydrogen refuelling stations are available in an early phase of commercialisation but limited in terms of daily capacities, while liquid hydrogen fuel stations are not yet available. Electric road systems (ERS) as a charging concept for BETs are only in the pilot phase.

¹ See EEA, 2020, table and dashboard of Figure 3

Minimum infrastructure

As an important next step, the objective of the [proposal for an Alternative Fuels Infrastructure Regulation \(AFIR proposal\)](#) is to ensure 'minimum infrastructure to support the required uptake of alternative fuel vehicles across all transport modes and in all Member States to meet the EU's climate objectives'. This AFIR proposal is accompanied by [a strategic roll-out plan](#) to overcome major barriers. Both documents are part of the 'Fit for 55' legislative package aimed at aligning EU policies with the Green Deal objectives.

Distance-based targets

For trucks, the **AFIR proposal contains distance-based targets for both recharging points and refuelling stations for BETs and FCETs along the Trans-European Transport Network (TEN-T) corridors**. Fleet-based targets and population density are less suitable indicators to base the location of truck recharging and refuelling infrastructure on, as these indicators have no direct correlation with the need for public charging infrastructure due to the long distances and transboundary nature of international goods transport. The **TEN-T network is a relevant choice as a starting point for the roll-out of infrastructure** as the network has a relatively high traffic intensity of long distance trucks that particularly will need public recharging and refuelling infrastructure when electrified or fuelled with hydrogen.

Location of recharging and refuelling infrastructure

In terms of geographical location of recharging and refuelling infrastructure, the Commission has opted for infrastructure along the TEN-T core and comprehensive networks, at urban nodes and with due attention to safe and secure parking areas and fast-charging provisions. For hydrogen, freight terminals are to play a key role as well. **The AFIR proposal seems to cover the most relevant types of recharging and refuelling locations**. The proposed Regulation states, however, that authorities will need to support private parties in deploying such infrastructure at private locations as well. This is crucial, because overnight charging and destination charging at specific (private) locations are expected to be the most important means of recharging and infrastructure realisation will be challenging for private actors.

Technological choices

Regarding the technological requirements in the AFIR proposal, the choice for at least 700 bar hydrogen refuelling points seems to be justified, since both heavy duty vehicles and light duty vehicles can make use of these refuelling points. Although liquid hydrogen can be a game changer in the coming years, the introduction of **binding targets for liquid hydrogen might be too early given the early phase of development of liquid hydrogen technology**. Indicative targets might be an alternative.

For battery electric trucks, the minimum power output levels of 350 kW are a good start for trucks with a high number of stops and longer legal breaks but might not be sufficient in case of breaks close to the legal minimum. **Higher minimum levels of power output (>500 kW) might be considered in the AFIR. The sector itself is also working on higher power output levels such as 1 MW and above.**

The Commission has decided to extend the 2020 targets for LNG until 2025, but no further policy incentives will be provided. LNG and other fossil fuels need to be replaced by biofuels or low carbon synthetic fuels. Given the technological developments, these choices seem to be justified.

The level of ambition of the AFIR proposal given future needs

Based on the length of the TEN-T network and the number of urban nodes and safe and secure parking areas, we have estimated that the targets for 2030 in the [AFIR proposal](#) correspond to a total of 17,314 charging points and 728 hydrogen refuelling stations (HRS). The four studies examined for the analysis on the future needs of charging infrastructure expect the need for 11,000-85,000 public charging points by 2030, with two studies (ACEA and T&E) expecting a considerably higher number of charging points needed than the minimum estimated based on the AFIR proposal. The AFIR proposal, however, sets targets for a minimum of infrastructure to allow BETs and FCETs to circulate through the EU and allows the market to further develop the required infrastructure based on demand. To allow circulation through the EU, however, the estimated minimum number of charging points at overnight parking areas seems low (a factor 10 lower) as compared to the expected required charging points. **A higher minimum requirement of charging stations for each safe and secure (overnight) parking area dedicated to heavy-duty vehicles might be considered.**

Other preconditions

Lack of investment security as well as a lack of a stable long-term policy framework and of a targeted, uniform approach are hampering the accelerated roll-out and increasing realisation times of infrastructure. The AFIR proposal therefore places a strong emphasis on technological standardisation to reach harmonisation. Several provisions lay down requirements for user-friendliness (of payment options, for example), information provision at recharging and refuelling points and data governance (with respect to e.g. reservation systems). In the strategic roll-out plan these issues are addressed as well, together with the power output implications, funding mechanisms and stakeholder cooperation.

Other Policy recommendations

Furthermore, policy makers can contribute to the development of infrastructure for trucks by removing barriers in the following ways:

- There is only limited time for testing and revision of national policies and revision of the AFIR before 2030. One option would be to speed up the development of national policy frameworks;
- Provide sufficient support to local authorities (financially, but also in terms of knowledge and organisationally), since much of the progress will depend on procurement procedures;
- In terms of grid capacities, Member States should ensure that sufficient grid capacity is available for deployment of fast charging stations, as fast charging is important to reduce both recharging times and other operational barriers. Grid developments should be taken into account in the Trans-European Networks for Energy (TEN-E) Regulation revision and are also partly addressed in the AFIR;
- Grid impacts of 'Fit for 55' policy proposals should be further investigated, including cost projections for grid adjustment (in addition to those for recharging and refuelling points) and the impact of additional renewable energy.

INTRODUCTION

1.1. Background to the study

This report contains the results of a study on alternative fuel infrastructures for heavy-duty vehicles.

About 19% of transport green house gas (GHG) emissions are caused by heavy-duty vehicles (HDVs) in road transport ([EEA, 2020](#))². Given the Green Deal objective of reducing transport GHG emissions by 90% in 2050 and the European Union's new target of reducing GHG emissions by 55% by 2030, major action is required across all sectors of the European economy. It also means that the majority of energy and climate legislation will have to be amended.

While alternative fuels and zero-emission powertrains offer major reduction potential, without sufficient and appropriate recharging and refuelling infrastructure they will fail to deliver. From 2014 the Alternative Fuels Infrastructure Directive (AFID) has focused mainly on creating fuelling infrastructure for passenger cars and, when for trucks, geared mainly to LNG for trucks rather than zero-emission technologies.

The 'Fit for 55' legislative package, aimed at aligning EU policies with the Green Deal objectives, contains [a proposal for an Alternative Fuels Infrastructure Regulation \(AFIR proposal\)](#) accompanied by [a strategic roll-out plan](#) to overcome major barriers. A legislative proposal for revising the TEN-T Regulation is also planned for the third quarter of 2021. In parallel with the proposals of the Commission, the preliminary results of this study have been published in an [overview briefing in July 2021](#). Like the briefing, this report aims to inform the Members of the Transport and Tourism Committee of the European Parliament on the current status of the topic. The scope of this study focuses on heavy-duty vehicles (HDV), in particular trucks³, and includes a wide range of alternative fuels as part of the policy debate.

1.2. Approach and methodology

This study has been based on desk study, case study analysis and a range of stakeholder interviews.

Desk study: evidence has been collected by carrying out a thorough literature review, covering academic papers, research reports, position papers and policy documents. For the overview of current alternative fuel infrastructure, statistical sources have been used complemented by other quantitative estimates.

Case study analysis: additional data collection has been carried out to provide insight in the deployment of alternative fuel infrastructure in other parts of the world.

Stakeholder interviews: Ten targeted interviews with experts and stakeholders have been conducted in order to complement and verify the results found by the desk study. The interviews especially complement the desk research and have been used to verify conclusions. The interviews have indeed resulted in confirmation of the conclusions. Given the role of the interviews, it has been decided to only refer to the type of stakeholders that have been interviewed, both in Annex 0 as well as in the main text. Reference to the interviews are made by referring to "Stakeholder interviews" in combination with the stakeholder group, e.g. OEMS, Logistics, Infrastructure, Research, Policy, as defined in Annex A. When reference is made to all stakeholders, no group is mentioned.

² See [EEA, 2020](#), table and dashboard of Figure 3

³ The N2 and N3 categories of heavy-duty vehicles are considered.

Compared to the [overview briefing](#), this full-length study provides a more in-depth analysis, an update of the policy context based on the 'Fit for 55' package and outcomes of stakeholder interviews and case study analysis.

1.3. Overview of the study

This study starts in Chapter 2 with a description of the current policy context. Chapter 3 provides an overview of the technologies currently available to power HDVs, trucks in particular, and current infrastructure for refuelling and recharging these vehicles. Chapter 4 describes the barriers and enablers associated with the roll-out of truck refuelling and recharging infrastructure and describes how the [proposed Alternative Fuels Infrastructure Regulation](#) and [the Commission's strategic roll-out plan](#) aim to overcome these barriers. Chapter 5 then describes future needs for alternative fuels infrastructure, given the various policy objectives and projected vehicle fleet developments, and discusses the main factors and uncertainties involved. The chapter also provides a comparison between the level of ambition of the AFIR proposal and the infrastructure needs identified by different stakeholders. The study ends in Chapter 6 with conclusions and a set of policy recommendations.

2. POLICY CONTEXT

KEY FINDINGS

- The **EU Green Deal, Climate Target Plan and European Climate Law** will together form the main drivers of truck decarbonisation and thus determine the demand for alternative fuels and alternative powertrains with their associated infrastructure.
- The 'Fit for 55' package published mid-July 2021 contains a series of revisions aligning various policies with the higher ambition level, including a proposal for an **Alternative Fuels Infrastructure Regulation (AFIR)** together with a **strategic roll-out plan** and a proposal for a revision of the **Renewable Energy Directive (RED)**. When the revisions of the **TEN-T and TEN-E Regulations** and **CO₂ standards for trucks** are finalised, the policy framework will be realigned.
- To date, policy initiatives on refuelling and recharging infrastructure for road vehicles have focused mainly on **passenger cars and vans**, with limited attention to **trucks**.
- At the **national level**, several Member States have recently developed **hydrogen strategies**, including use of this fuel by trucks, while electric trucks are only recently being included in **national charging infrastructure strategies**.
- Analysis of the policy strategies in three non-EU countries shows **similar trends and that growth in alternative-fuelled vehicles and related infrastructure occurs mainly when strong government support** is in place.

2.1. EU strategies

There are several EU-wide strategies of relevance for alternative fuels infrastructure for HDV. We discuss the following in turn: we will start with the Green Deal, together with the 2030 Climate Target Plan and the European Climate Law. Secondly, the Sustainable and Smart Mobility Strategy is discussed, followed by the Recharge and Refuel project and finally, the Hydrogen strategy.

The [EU Green Deal](#), launched in December 2019, has set the target of reducing transport-related emissions by 90% in 2050. As part of the Green Deal, the [2030 Climate Target Plan](#) has raised the greenhouse gas emission reduction target for 2030 to at least a 55% reduction compared with 1990 levels. On 28 June 2021 the European Council adopted the new [European Climate Law](#), making the Green Deal ambition legally binding ([European Council, 2021b](#)). The European Commission has been preparing detailed legislative proposals on how this more ambitious reduction target should be achieved. Mid-July 2021 a number of these proposals for revision have been published under the 'Fit for 55' package. The package aims to accelerate decarbonisation of the fuel mix and vehicle fleet renewal, with several transport-related Directives and Regulations being revised.

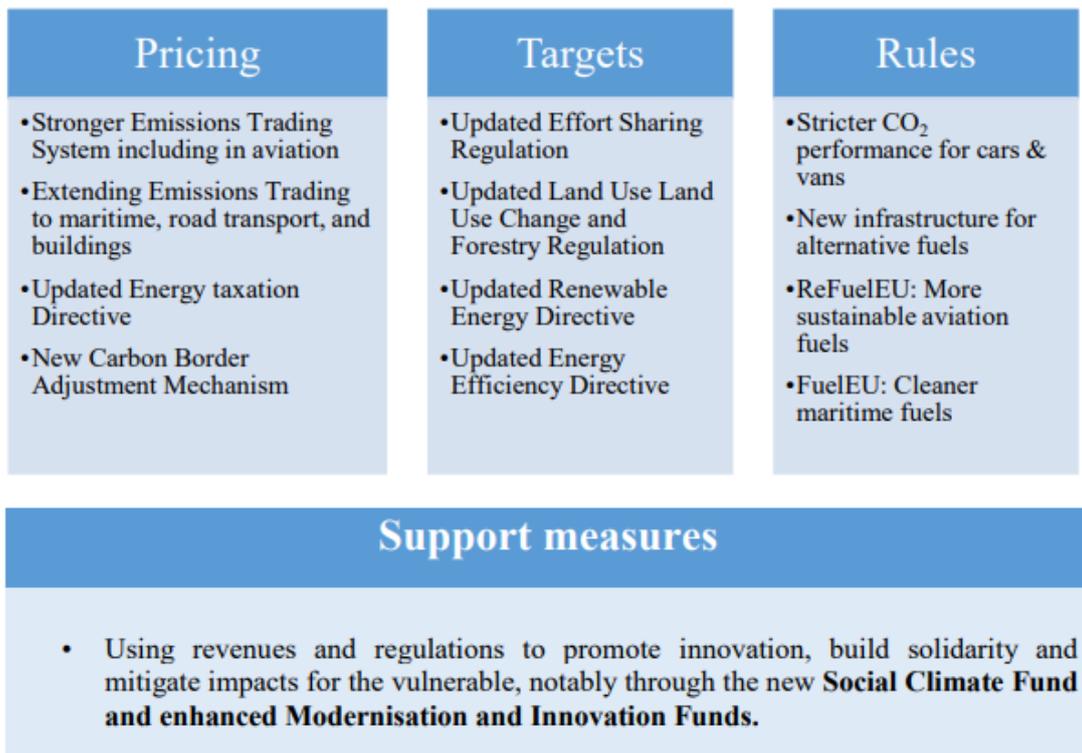
Modal shift from road freight to inland waterway and rail as well as road pricing are also mentioned in the Green Deal. These will provide opportunities for multimodal refuelling and recharging options but could also result in competition between infrastructure investments. Road pricing could be designed with lower tariffs applying to trucks running on low- or zero-carbon fuels (see section 2.2.4 on a [new Emissions Trading Scheme](#) (ETS) for buildings and road transport). In parallel, the Commission is to support deployment of public recharging and refuelling stations where persistent gaps exist, notably for long-distance travel, which will be beneficial for trucks.

The [EU Hydrogen strategy](#) was launched in July 2020 and identified mobility as one of the two lead markets for green hydrogen (the other being industrial applications). By first building local hydrogen networks where hydrogen is consumed near production sites, the second step would require transport of hydrogen over longer distances. This process requires a revision of the [Trans-European Networks for Energy \(TEN-E\)](#) (see section 2.2). This should go hand-in-hand with the roll-out of refuelling stations, linked to the review of the AFID and a revision of the TEN-T Regulation. The strategy counts on the CO₂ emission standards regulation being an important driver for creating a market for hydrogen solutions ([EC, 2020a](#)).

Recharge and Refuel is one of seven flagship projects under the [NextGenerationEU Recovery and Resilience Facility](#) for the [2021 annual sustainable growth strategy](#). The concrete aim is to build, by 2025, half the 1,000 hydrogen stations and one million out of three million public recharging points needed in 2030. With a total of 672.5 billion euros allocated, the Recovery and Resilience Facility is the key instrument to help the EU emerge stronger and more resilient from the current crisis caused by the global pandemic.

The [Sustainable and Smart Mobility Strategy](#) (December 2020) states that “greening mobility must be the new licence for the transport sector to grow”. This implies that an efficient and interconnected multimodal transport system should be enhanced by, among other things, ‘abundant recharging and refuelling infrastructure for zero-emission vehicles and supply of renewable and low-carbon fuels’. The communication also stressed that compared to the previous decade, additional investments of 130 billion euros per year will be needed for 2021-2030 (vehicles, vessels, aircraft, infrastructure). For the ‘green and digital transformation investment gap’ for infrastructure, an additional 100 billion euros per year would be needed. Completing the TEN-T core network is an important step of the Strategy and requires 300 billion euros over the next ten years ([EC, 2020d](#)).

On July 14th 2021 the Commission published the communication ‘[Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality](#)’ accompanying the package of proposals to align EU legislation with the EU Green Deal. According to the Commission it is the most comprehensive set of proposals ever presented on climate and energy. Great emphasis is placed on reaching the targets in a fair, cost-efficient and competitive manner, which should engender a socially fair transition, tackling inequality and energy poverty through climate action. The package is strongly based on the polluter pays principle by putting a price on carbon in more sectors than at present, creating fairer competition with fossil fuels. Overall, the ‘Fit for 55’ package consists of a set of interconnected proposals, including eight proposals for revision of existing legislation and five new initiatives. The proposal covers a wide range of policy areas and economic sectors from climate, energy and fuels and transport to buildings, land use and forestry. The impact assessments behind the proposals have concluded that carbon pricing alone is not enough to secure the envisaged target, while too tight regulatory policies would result in high economic burdens. A policy mix with a judicious balance between pricing, targets, standards and support measures has therefore been adopted.

Figure 1: The Fit for 55 Package: At a glance

Source: [European Commission, 2021](#)

2.2. Relevant Directives and Regulations

The overarching strategies and communications often refer to changes to specific Directives and Regulations. This section describes the most relevant of these.

2.2.1. Infrastructure-related Directives and Regulations

From a Directive to a Regulation

The [Alternative Fuels Infrastructure Directive \(AFID\)](#) is the main policy instrument for advancing an EU-wide strategy to implement alternative fuels infrastructure. The existing AFID came into force in November 2014. The AFID is a common framework of measures for deploying alternative fuels infrastructure with a view to minimising the dependence on oil and mitigating the environmental impact of transport. It sets minimum requirements for establishing alternative fuels infrastructure, including recharging stations for electric vehicles and refuelling points for liquefied natural gas (LNG), compressed natural gas (CNG) and hydrogen to be implemented by means of Member States' non-binding national policy frameworks. The AFID has also guided standardisation of charging points and contains provisions regarding user information, which are also relevant for biofuels. It is important to note that the AFID is aimed at public infrastructure, while private charging points are also an important issue, particularly for HDVs.

As part of the 'Fit for 55' package a proposal for an [Alternative Fuels Infrastructure Directive \(AFIR proposal\)](#) has been published by the Commission. The shift from a Directive to a Regulation implies that Member States have less flexibility in their national implementation, but ensures '*a rapid and coherent development towards a dense widely spread network of fully interoperable recharging infrastructure in all Member States*'. This is especially relevant since the first proposed targets would have

to be reached by 2025 already. A full review of the Regulation is foreseen for 2026, owing to the early stage of the development of certain fuels.

The next paragraphs provide an overview of the targets as proposed in the [AFIR proposal](#). Chapter 5 provides a detailed comparison of the level of ambition of those targets compared to estimates on future required infrastructure from other studies. With respect to the level of ambition, it should be noted that the proposed Regulation aims to ensure (only) the minimum infrastructure to support the required uptake of alternative fuel vehicles across all transport modes and in all Member States.⁴ Besides this, the proposed Regulation should ensure the infrastructure’s full interoperability, full user information and adequate payment options. When discussing the level of ambition, this aim for a minimum level of infrastructure should be taken into account.

Recharging points for BETs

While national fleet-based targets have been proposed for EVs, distance-based targets are required in the AFIR proposal to ensure sufficient infrastructure for BETs. The AFIR proposal acknowledges the different needs for recharging heavy-duty vehicles. In order to ensure sufficient coverage of publicly accessible infrastructure for BETs, the AFIR proposal adopts a combined approach of distance-based targets along the TEN-T network, targets for overnight recharging infrastructure and targets for urban nodes.

Table 1 provides the targets as formulated in the proposal. Table 12 presents our estimates in absolute numbers based on the AFIR proposal requirements and combined with e.g. the length of the TEN-T corridor. Sufficient power output should be provided to permit vehicle recharging within the driver’s legal break time. For the long-haul sector, overnight recharging should also be possible along the main transport network. Fast-recharging infrastructure at urban nodes should facilitate destination charging for long-haul trucks as well as delivery trucks. Privately owned recharging infrastructure that is accessible to the public should also be counted as publicly accessible infrastructure according to the AFIR proposal.

Table 1: Targets for publicly accessible electric recharging infrastructure dedicated to heavy-duty vehicles as laid down in Article 4 of the AFIR proposal

	2025	2030	2035
TEN-T core network	At least one recharging pool with a power output of 1,400 kW every 60 km At least one recharging station with an individual power output of at least 350 kW	At least one recharging pool with a power output of 3,500 kW every 60 km At least two recharging stations with an individual power output of at least 350 kW	
TEN-T comprehensive network		At least one recharging pool with a power output of 1,400 kW	At least one recharging pool with a power output of 1,400 kW

⁴ See article 4-1, article 6-1 in [AFIR proposal](#)

	2025	2030	2035
		power output every 100 km. At least one recharging station with an individual power output of at least 350 kW.	output of 3,500 kW every 100 km. At least two recharging stations with an individual power output of at least 350 kW.
Safe and secure parking areas		At least one recharging station every safe and secure parking space (at least 100 kW)	
Urban nodes	Publicly accessible recharging points dedicated to heavy-duty vehicles providing an aggregated power output of at least 600 kW provided by recharging stations with an individual power output of at least 150 kW	Publicly accessible recharging points dedicated to heavy-duty vehicles providing an aggregated power output of at least 1200 kW provided by recharging stations with an individual power output of at least 150 kW	

Source: [AFIR Proposal](#)

Table 2: Estimated minimum number of charging points in 2030 required by AFIR proposal

	Estimated minimum number of charging points in 2030 required by AFIR proposal
Core network	11,990
Comprehensive network (non-core)	3,901
Safe and secure parking areas	719
Urban nodes	704
Total	17,314

Source: aggregated output of Table 12

No targets are defined for overnight charging at non-publicly accessible private locations (private depots and logistic centres), but public authorities should support private actors in realising this infrastructure as well. In addition to the targets, the proposal also defines requirements for recharging infrastructure in Article 5 regarding price information, payment systems, automatic authentication, etc. These requirements should ensure full accessibility and operability for all stakeholders.

Hydrogen refuelling points

For hydrogen the proposed Regulation refers to a statement in the Commission’s communication ‘[A hydrogen strategy for a climate-neutral Europe](#)’, which mentions that the heavy-duty segment was identified as the most likely segment for the early mass deployment of hydrogen vehicles. Recital (28) of the proposed Regulation therefore states that hydrogen refuelling infrastructure should in first instance focus on the heavy-duty segment, while at the same time allowing light-duty vehicles to make use of the same refuelling points. The total number of HRS comes down to a minimum of 728 stations (see Chapter 5 for more information).

For interoperability reasons refuelling points should deliver at least gaseous hydrogen at 700 bar. Because new emerging technologies such as liquid hydrogen are promising solutions for the future, a minimum number of refuelling points should also supply liquid hydrogen by 2030.

Table 3: Targets for publicly available hydrogen refuelling infrastructure for road vehicles as laid down in Article 6 of the AFIR proposal

	2030
TEN-T core network	Hydrogen refuelling stations with a minimum capacity of 2 t/day and equipped with at least a 700-bar dispenser, deployed every 150 km at most
TEN-T comprehensive network	Liquid hydrogen every 450 km at most
Urban nodes	At least one publicly accessible hydrogen refuelling station deployed at each urban node; locations within the urban node to be determined

Source: [AFIR proposal](#). The refuelling points at urban nodes should preferably be realised at multimodal freight centres, which are not only an important destination for trucks, but can also serve other transport modes such as rail and inland shipping.

Similar operational requirements as for electric charging stations, such as payment options, have been determined for hydrogen refuelling stations in Article 7.

Cross-border sections

For both electric charging points and hydrogen refuelling points, neighbouring Member States shall ensure that the maximum distances are not exceeded near the borders of Member States.

Electric road systems (ERS)

The proposed Regulation does not include specific targets for Electric Road Systems (ERS), because the technology is not yet sufficiently mature to be considered. These are therefore only briefly referenced, mentioning that emerging technologies like ERS need to be borne in mind when it comes to data provision and technical specifications.

Gaseous fossil fuels

The Commission envisions a continued role for gaseous fossil fuels in maritime shipping, but no longer in inland shipping and road transport. Consequently, the AFIR proposal sees only a limited role for such fuels in road transport. They should only be used with increased blending with renewable fuels like biomethane, advanced biofuels or other renewable and low-carbon gaseous fuels (and should preferably be superseded by them). In the case of LNG, this implies a greater use of bio-LNG or e-gas. In terms of infrastructure, TEN-T should remain the basis for both LNG and bio-LNG. Further efforts

in the coming years by Member States are recommended only for closing any remaining gaps. The earlier objective of the AFID (refuelling stations every 400 km along the TEN-T core network) should now be reached by 2025, with the target then being dropped. Vehicles using non-renewable gaseous fuels like Liquefied petroleum gas (LPG) and CNG need to be gradually replaced by zero-emission powertrains.

Renewable low-carbon and biofuels

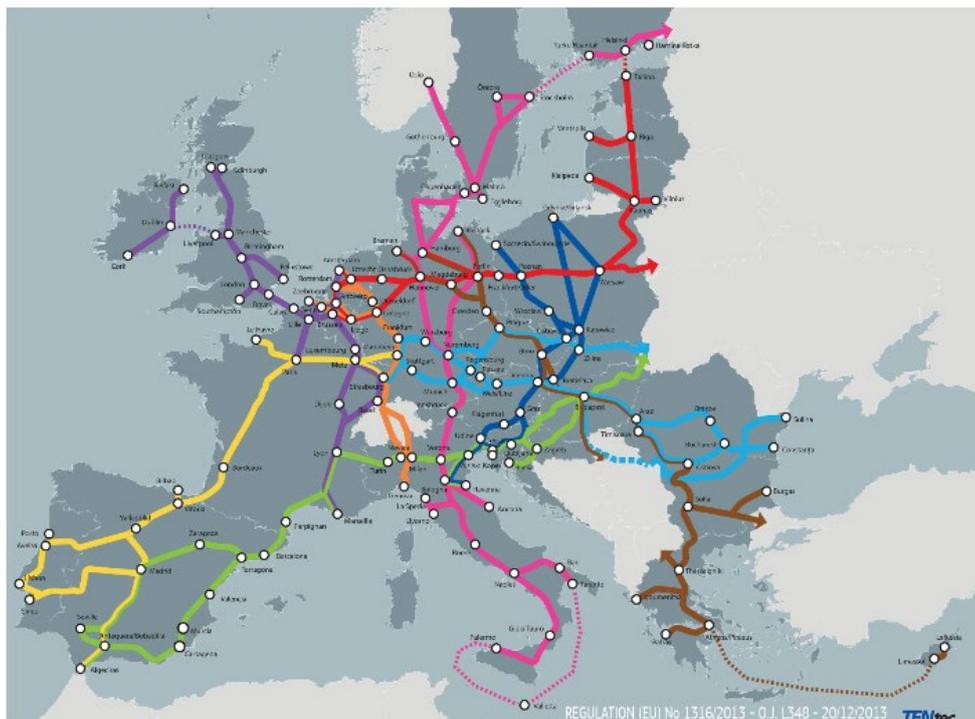
These remarks on gaseous fossil fuels hold for liquid fuels, too: they should only be used if they lead to decarbonisation, through increased blending with renewable fuels like bio-methane, advanced biofuels or renewable and low-carbon synthetic gaseous and liquid fuels (and preferably replacement by them). The Commission confirms that such fuels may be used with minor adaptations and can be distributed, stored and used with the existing or similar infrastructure. No specific targets have been defined.

Because the strategic roll-out plan accompanying the proposal is concerned mainly with actions to overcome barriers, more information on this issue is provided in Chapter 0 of this report.

Trans-European Networks

The [Trans-European Transport Network \(TEN-T\) Regulation](#) aims to develop a Europe-wide transport network by closing gaps, removing barriers and applying innovative technologies. There is a core network of ten corridors which is to be completed by 2030. The [Commission](#) plans to put forward the revised TEN-T regulation in November 2021, to coincide with the revised Directive on Intelligent Transport Systems.

Figure 2: TEN-T core network corridors



Source: [\(EC, 2021b\)](#)

The [Trans-European Networks for Energy \(TEN-E\) Regulation](#) aims to link the energy infrastructures of EU nations, with nine priority corridors for gas, oil and electricity and three priority thematic areas: smart-grid deployment, electricity highways and a cross-border carbon dioxide network. In December 2020, the Commission came forward with [a proposal](#) to revise the EU rules on the TEN-E Regulation to make the TEN-E fit to support the achievement of climate neutrality in 2050. The revised TEN-E framework is thus to include hydrogen infrastructure, power-to-gas and smart grids to support electric charging and hydrogen refuelling infrastructures and integration of offshore wind ([EC, 2020b](#)). On the other hand, [natural gas \(methane\)](#) infrastructure projects would no longer be eligible as projects of common interest (PCIs) and can therefore no longer make use of funding under the Connecting Europe Facility (CEF).

2.2.2. Vehicle-related Directives and Regulations

Vehicle emission standards are one of the key drivers of alternative fuel uptake in the EU. Stricter standards also make zero-emission vehicles more attractive for manufacturers. Emission standards for heavy-duty vehicles (HDV) are in force for emissions of both GHG ([Regulation 2019/1242](#)) and air pollutants ([Regulation 595/2009](#)).

[Regulation 2019/1242](#) was the first EU-wide CO₂ regulation for HDV, setting a 15% CO₂ emission reduction requirement for new HDVs for 2025-2029 and 30% reduction for the year 2030 and beyond. These reduction requirements (and potential higher ambition after revision) will be a key driver for the uptake of zero-emission trucks as OEMs will introduce ZE trucks to meet the -30% target. The reduction target applies to manufacturers and is based on reference emissions reported in the period of 1 July 2019 to 30 June 2020. It concerns the regulation of simulated emissions rather than real world emissions. The Regulation also contains an incentive mechanism for zero- and low-emission vehicles by means of a system of credits for manufacturers. In 2025 it is to be replaced by a benchmark system. The 2030 benchmark level will be set during the 2022 review, which also includes an assessment of the CO₂ standards. During that review hydrogen will also be included and there may also be an introduction of an assessment of lifecycle CO₂ emissions and CO₂ credits for manufacturers ([EC, 2019a](#)).

[Regulation 595/2009](#) established the Euro VI (air pollutant) emissions standards for HDV. As part of the Green Deal, the Commission has proposed [an initiative for Euro 7 standards](#)⁵, planned for adoption at the end of 2021. The Euro standards also apply to Internal Combustion Engine vehicles (ICEVs) fuelled with alternative fuels.

The Green Deal also suggested that a change to the [Eurovignette Directive](#) might be an option for maintaining its original high level of ambition. Eurovignette is a road toll system for trucks with a gross vehicle weight of 12 tonnes or more that has higher tariffs for lower Euro emission classes, but the system has played a limited and inconsistent role, depending on Member States.

2.2.3. Fuel-related Directives

The [Renewable Energy Directive II \(RED II\)](#) was adopted in 2018 and is the successor of the RED. The RED II sets EU targets for the consumption of renewable energy sources in 2030 based on the overall EU objective (of 32% renewable energy in final energy consumption) and outlines requirements for national contributions to these targets. For transport, the RED II obliges fuel suppliers to ensure that the share of renewable energy in the final energy consumption of the transport sector is at least 14% by 2030, with a sub-target of 3.5% for advanced biofuels. This minimum of 14% can in part be

⁵ The Euro standards cover the exhaust emissions of all petrol and diesel cars, vans, trucks and buses. Euro 7 is planned to be announced in 2021 and come into force by 2025. It will probably be the last emission standard implemented before the phase-out of Internal Combustion Engine Vehicles.

administratively achieved, using so-called multiplication factors. Biofuels, bioliquids and biomass fuels can only count towards the targets if certain sustainability criteria are met. The Commission is still currently working on the calculation methodologies for renewable electricity and renewable fuels of non-biological origin, such as (renewable) hydrogen; these will be adopted through delegated acts.

While the RED II sets a target for the minimum share of renewable energy in transport, the [Fuel Quality Directive \(FQD\)](#) has a reduction target for the average GHG intensity of fuels. Use of renewable energy in transport thus contributes to both the FQD target and the RED II target. No decision has yet been made on extending the FQD target towards 2030. Besides the reduction target, the FQD also lays down fuel specifications determining how much biofuel can be blended with regular road transport fuels. Biofuel blends not meeting the fuel specifications for regular road transport fuels, such as the so-called 'high blends', must be marketed as a different product. Fuel specifications (and consequently vehicle compatibility) are issues both for part of the FQD and the user information provisions of the AFID and the [AFIR proposal](#).

Because of the higher ambition of the Green Deal, the RED II is already being revised even before many Member States have transposed the 2018 Directive into national legislation. The 'Fit for 55' package therefore contains the proposal for the revised directive, also referred to as the [Renewable Energy Directive III](#).

In order to achieve the 2030 target, the proposal suggests increasing the overall binding target from the current 32% to a new level of 40% of renewables in the EU energy mix. This will be complemented by indicative voluntary national contributions, showing what each Member State should contribute to secure the collective target. The Directive aims for large-scale renewables-based electrification. In transport and industry, with market segments that are harder to electrify such as shipping and aviation, renewable fuels like clean hydrogen should also play a major role. The transport target, aiming for a certain share of renewables in final consumption, will be replaced by a GHG intensity target: the GHG intensity of fuels (in gCO₂/MJ) is to be reduced by at least 13% by 2030 compared to the baseline. In this way the aforementioned target of the Fuel Quality Directive (FQD) will be included in the RED and no longer be part of the FQD.

Besides a subtarget of 2.2% by 2030 for the share of advanced biofuels and biogas ([based on feedstocks from Part A of Annex IX](#)) the proposal for RED III also introduces a subtarget for the share of Renewable Fuels of Non-Biological Origin (RFNBOs) of 2.6% by 2030. Renewable hydrogen also falls within this category and this subtarget implies a stronger push for hydrogen. Member States should also enable economic operators to receive credits for renewable electricity supplied to electric vehicles. Until now this has been arranged mainly for liquid and gaseous fuels only.

The RED II also contained various multiplication factors that meant some of the targets were met in purely administrative fashion. By abolishing these multiplication factors, the proposal for revision makes the targets more ambitious.

2.2.4. Other Directives and Regulations

In addition to the infrastructure- and energy-related Directives, other legislative developments will impact decarbonisation of road transport and will affect infrastructure development as well.

As part of the EU's 'Fit for 55' package of climate and energy laws, the European Commission has adopted a proposal amending the [Emissions Trading Scheme](#) (ETS) in relation to buildings and road transport ([EC, 2021](#)). This scheme should be a separate, independent system adjacent to the current EU-ETS (which covers energy and heat generation, energy-intensive industry and commercial aviation). The proposed ETS will cover, besides the current ETS sectors, the built environment and road transport as new sectors as well. From 2026 onwards, participants in the scheme (fuel suppliers or tax warehouse

keepers) will need allowances for emitting CO₂. If they have too few allowances, they must either implement CO₂ reduction measures or buy allowances on the market (from other participants or at an auction). This trading component ensures that emission reductions are achieved at the lowest cost, while the cap ensures that the CO₂ reduction target is achieved.

The allowances for the new emissions trading will be auctioned, as no free allocation is provided. The auction revenues will be used by Member States to contribute to decarbonisation of the built environment or road transport sector (25% of the auction revenues need to be allocated to the Social Climate Fund, to address the financial impacts of the scheme on vulnerable households). In this respect the new ETS for buildings and road transport can directly contribute to meeting the objective of the AFIR. More indirectly, the new ETS may complement the AFIR by stimulating the uptake of zero-emission vehicles, which in turn may improve the business case of alternative refuelling and recharging infrastructure. Together, road transport ETS and CO₂ based tolls could result in a double taxation of CO₂ for trucks. Currently, it is not clear whether this should be handled and how this should be handled.

Besides these plans for a broader EU ETS, several other Directives are also relevant, such as the [Energy Performance of Buildings Directive](#) (EPBD), of which the revision will be presented in Q4 2021.

2.3. National strategies of EU Member States

National strategies may also be relevant for assessing the state-of-play across the EU. To identify issues requiring harmonisation and interoperability at the European level, we identified the main differences in national policies aimed at alternative fuels infrastructure.

2.3.1. AFID implementation and national policy frameworks proposed by the AFIR

In March 2021 the Commission published [a report on implementation of the AFID in Member States](#). Based on national implementation reports, the document showed the importance of the AFID for the roll-out of alternative fuels infrastructure. In certain Member States successful roll-out was hampered to varying degrees by a range of issues, including lack of national coordination and low initial investments. In 2020 most countries had not met the required targets, although there were large differences between Member States ([EC, 2021a](#); [IEA, 2021](#)).

In relation to HDV, Member States' strategies regarding alternative fuels infrastructure differ in their level of ambition and policy focus. By and large, it is western European Member States that have begun developing specific strategies for hydrogen or electric HDV (such as Netherlands, Portugal, Germany, France, Spain, Italy).

National policy frameworks

The evaluation of Member States' implementation looked at the different national policy frameworks. The new proposed Regulation also includes requirements with respect to the development of national policy frameworks. According to Article 13 Member States need to submit to the Commission a draft national policy framework by 1 January 2024. No later than six months after submission, the Commission shall assess the draft national policy frameworks and may issue recommendations. By 1 January 2025, each Member State should deliver its final national policy framework. With this approach the Commission is aiming for concise planning to deploy infrastructure and to meet the targets with an iterative process between Member States and the Commission.

In line with Article 15, the Commission shall assess the national policy framework notified by Member States by 1 January 2026 and will submit to the European Parliament and to the Council a report on the assessment of those national policy frameworks and their coherence at Union level.

Progress reports

According to Article 14 a standalone progress report by each Member State needs to be submitted to the Commission for the first time by 1 January 2027 and every two years thereafter. The report should cover the implementation of the national policy frameworks.

The Commission will assess the progress reports submitted by Member States and will provide recommendations. Based on those recommendations Member States need to issue an update of their progress report within six months after having received the recommendations.

Based on the national policy frameworks and national progress reports, the Commission will regularly publish and update information on the national targets and objectives, regarding for example the number of publicly accessible recharging points and stations and the number of publicly accessible hydrogen refuelling points.

Other reporting obligations

In advance of the national policy frameworks and progress reports, Article 16 requires Member States to report to the Commission the total aggregated recharging power output, the number of publicly accessible recharging points and the number of registered battery electric and plug-in hybrid vehicles deployed on their territory on 31 December of the previous year. The first reporting moment will be by 28 February of the year following the entry into force of the AFIR and every year thereafter by the same date.

Article 14 also requires a periodical assessment of how deployment and operation of recharging points could enable electric vehicles to further contribute to the flexibility of the energy system. The regulatory authority of a Member State needs to submit this periodical assessment by 30 June 2024 at the latest and periodically every three years thereafter. Within the same timeline the regulatory authorities should also deliver an assessment on the potential of bidirectional charging based on the input from transmission system operators and distribution system operators.

2.3.2. Hydrogen strategies

Several Member States (Netherlands, Portugal, Germany, France, Spain, Italy) have announced a hydrogen strategy, all containing specific targets for (mainly heavy-duty) transport, including hydrogen refuelling stations (HRS). Germany aims to have 400 HRS by 2025 and 1,000 by 2030, France 100 by 2023 and 400-1,000 by 2028, Spain 100-150 in 2030 and the Netherlands 50 by 2025, while Italy plans to have 2% of their roughly 1 million trucks⁶ fuel cell electric trucks (FCET) by 2030 ([Lambert & Schulte, 2021](#); [FuelCellsWorks, 2020a](#)). Enabling cross-border EU transport is also part of the strategies. In 2021 several Eastern European Member States also announced hydrogen strategies or road maps involving transport ([Euractiv, 2021b](#)).

2.3.3. Strategies related to battery-electric trucks (BET) and Electric Road Systems (ERS)

In contrast to electric buses, it is only recently that battery-electric trucks (BETs) have gained momentum as a serious option. National strategies for electric trucks are hence only at an early stage of development, as yet not comparable to hydrogen strategies, or lacking entirely. The total number of new BETs registered in Europe was no more than 360 in 2019 and 450 in 2020 ([IEA, 2021](#)).

The Netherlands has a 'National Charging Agenda' in which implementation of urban zero-emission zones is identified as the main factor driving demand for truck charging points. The Agenda also

⁶ For number of trucks in Italy, see Section 3.1.

emphasises the importance of connecting urban centres with logistical and distribution hubs in terms of charging locations. Additional research is considered necessary, though ([RVO, 2020](#)).

The German government has developed '[An Overall Approach to Climate-Friendly Commercial Vehicles](#)' to reach zero-emissions road logistics by means of alternative powertrains. The objective of the 2030 Climate Action Programme aims for vehicles powered by electricity or electricity-based fuels to account for around one third of the mileage in heavy road haulage by 2030. It can be achieved by a technology mix of options. To this end, the Federal Ministry of Transport and Digital Infrastructure will guarantee 'the necessary planning and investment certainty through an integral package of measures'. In terms of infrastructure, the Federal Government will manage the deployment of refuelling and charging infrastructure geared to the vehicle ramp-up, including the creation of necessary conditions for a market penetration of the right vehicles. Advancing charging infrastructure is a key measure of the federal government, with fast charging receiving two-thirds of the total budget for charging infrastructure (300 million euros) ([German Government, 2019](#)). The [German Ministry](#) has now defined the first three innovation clusters. More information on these pilots can be found in Chapter 3.

[Sweden](#) is a frontrunner in ERS, with four different test sites for ERS on public roads. Building a 25-30 km pilot ERS is the next step of the [Swedish ERS roadmap](#) and should be finalised by 2025. Pilot projects in Sweden are primarily funded by the Swedish Transport Administration in order to contribute to Swedish climate objectives. The [government](#) is also working on rules on the construction, operation and maintenance of (state) electric roads in relation to the existing Roads Act and the Electricity Act.

2.3.4. Low- and zero-emission zones

Increasingly, low- and zero-emission zones and other access restrictions are being introduced in urban areas in certain EU countries, with access of the worst polluting categories of vehicles restricted permanently or in certain periods. These zones can be instrumental in shifting city logistics to zero-emission. Most such zones are in Italy, Germany, Belgium and the Netherlands, but urban access restrictions have also been introduced in Poland, Spain and France ([Urban access regulations, 2021](#)).

2.4. Policies and strategies of third countries

2.4.1. China

General

China has a [national goal](#) of net-zero carbon emissions by 2060. Regarding zero-emission technologies, China is leading in battery-electric trucks, but is also putting efforts into developing hydrogen infrastructure (for trucks as well as for other road vehicles). The relatively higher pace of infrastructure development compared to the EU seems to be the result of top-down policy support and reduction of air pollution as a short-term goal. China is allocating substantial national budgets to the realisation of infrastructure and development of vehicle technology. A major increase in BETs is expected, in particular for [urban delivery](#). As follow-up to the introduction of strict emission limits for new road vehicles between 2016 and 2018, the [Clean Air Law now has](#) stronger measures. Together, the emission limits and Clean Air Law are expected to result in a fairer playing field in terms of cost, in favour of electric vehicles.

LNG

China has seen a rise in the use of natural-gas trucks, driven by favourable prices and government policies, motivated by both air-quality and energy-security considerations. In 2016 there were 7,950 refuelling stations supplying natural gas. However, the majority of natural gas vehicles are light-duty vehicles. Natural-gas trucks are common in inland provinces where gas is produced domestically (OECD, 2017). In 2017, 96,000 LNG trucks were produced by OEMs, representing nearly 10% of the Chinese truck sector. LNG trucks can receive up to around 1,300 euros (10,000 Renminbi) government support, with additional funding of around 2,600 euros (20,000 Renminbi) for purchasing LNG trucks from local authorities.

Hydrogen

China has high ambitions for hydrogen in transport and its 13th five-year plan (2016-2020) included the target of a large-scale deployment of hydrogen refuelling stations (HRSs) in China. China already accounts for 94% of currently operational fuel-cell buses worldwide and 99% of fuel-cell trucks (IEA, 2021), but its future strategy seems to focus mainly on passenger transport. For 2025 the target is 300 HRSs with 50,000 fuel-cell electric vehicles (FCEVs) in service, 80% of which are passenger cars. In 2030 there should be over 1,000 HRSs and over a million FCEVs. Local and regional authorities may also have their own HRS targets (Verheul, 2019).

Hydrogen trucks attracted greater interest in 2020, backed by domestic manufacturers and government support (Asia Times, 2021). The [Development Plan for the New Energy Automobile Industry \(2021-2035\)](#) (RMI, 2021) focuses strongly on the [development of hydrogen fuel cells, hydrogen storage and hydrogen transportation](#) (Clean Technica, 2020), especially for trucks and buses, with [refuelling infrastructure at 350 bar](#). [Financial awards](#) are granted to city clusters achieving certain standards. As a result of all this governmental support, 35 hydrogen-related projects ranging from fuel cells to refuelling stations with a value of 110bn yuan (\$17bn) have been signed in the first [five months of 2021, while about 24 provinces and cities](#) have plans to develop hydrogen. Taken together, all the support should result in [1,000 hydrogen refuelling stations](#) by 2025 and up to 1 million fuel-cell vehicles by 2035.

Battery-electric

Currently, China has the world's largest electric vehicle market, comprising around half the world's EVs and over [90% of electric buses and trucks](#). Despite commercial trucks being major contributors to air-pollutant and climate emissions, however, developments with respect to electrification of commercial trucks are far less advanced compared to EVs. In China, [battery swapping](#) in heavy-duty trucks competes with hydrogen fuel-cell vehicles.

2.4.2. Norway

Among European Economic Area (EEA) countries, Norway has the majority of newly registered cars now electric, while the government has set the objective of 50% of all newly registered trucks being zero-emission in 2030. In addition, goods distribution in the biggest urban centres must be virtually zero-emission by 2030. By the end of 2019, 1 hydrogen truck and 21 electric trucks were registered in Norway, with at least 70 more hydrogen trucks and 75 electric trucks on order (Scania, 2020).

Norway sees hydrogen for heavy-duty vehicles as a potentially good interim solution, but it expects battery-electric trucks to increasingly catch up with the benefits of hydrogen as more and more high-speed charging points become available along major corridors (Norwegian Government, 2020). Access to charging infrastructure is identified as one of the main bottlenecks for a successful transition to battery-electric trucks, including depot-charging and fast-charging facilities on main roads

([Hovi, Pinchasik, Figenbaum, & Thorne, 2020](#)). Norway has put forward as a key condition that development of alternative fuels infrastructure be market-driven, with government funding available for the initial stage only ([Norwegian Government, 2020](#)). For EVs the Norwegian government has already proven that [this approach](#) stimulates private investments, once government support for EVs and infrastructure have resulted in a higher uptake of EVs and thus more demand for infrastructure has been created. Bio- and e-fuels are not deemed suitable for large-scale application for trucks (being aimed at other transport modes).

Norway has several direct and indirect policies to stimulate uptake of zero-emission transport, including tax benefits and reduced tariffs for infrastructure. Local authorities can decide whether to exempt electric vehicles from road tolls or parking fees. A national rule stipulates that zero-emission vehicles pay no more than half of toll station and ferry tariffs.

In 2021, the Norwegian government has also decided on measures aimed at private (dedicated) alternative fuels infrastructure. The [EFTA Surveillance Authority](#) has decided that those funding measures are allowed as state aid under the EEA agreement.

2.4.3. United States

Natural gas infrastructure has been promoted since 2015 by the [Fixing America's Surface Transportation Act](#), which requires the United States Department of Transportation to set aspirational targets for the deployment of alternative fuels infrastructure along key corridors. Existing taxation disadvantages for alternative fuels were also addressed ([OECD, 2017](#)).

In 2019 the US Senate passed the America's Transportation Infrastructure Act, earmarking \$1 billion to support the development of fuelling infrastructure for electric, natural gas and hydrogen-powered vehicles ([FuelCellsWorks, 2019](#)).

In the [2020 Hydrogen Program Plan](#), long-haul HDV is mentioned as an important growth market for hydrogen ([US DOE, 2020](#)); as of 2021, [there are 45 hydrogen refuelling stations in the US \(not specified per vehicle type, but only in California\)](#).

The North American Council for Freight Efficiency has identified charging infrastructure as one of the main sources of concern for adoption of electric fleets. The Council believes that, for trucks, the principal charging infrastructure should be private, at depot or 'return-to-base' ([NACFE, 2019](#)).

In 2021 the Biden Administration announced an action plan to advance electric vehicle charging infrastructure and to realise a national network of [500,000 charging stations](#). Charging for freight infrastructure is an integral part of the plan. The plan has been developed in conjunction with the '[alternative fuel corridor program](#)' for electric, hydrogen, propane and natural gas. This programme aims to create a network for alternative fuel infrastructure built around interstate corridors ([The White House, 2021](#)).

The federal structure of the U.S. means that different states have different policies, with California the most ambitious state. California has adopted the 'Advanced Clean Truck' regulation, initiating phased introduction of zero-emission trucks (no tailpipe emissions). The regulation puts a zero emission vehicle sale requirement on manufacturers. By 2035, zero-emission truck/chassis sales would need to be between 40 and 75%, depending on type and class. The rule also contains a one-time reporting obligation for large entities and fleets in order to identify challenges and design strategies for the future ([California Air Resources Board, 2020](#)).

2.5. Conclusions

Overall, policy initiatives in the EU have so far been limited to ambitions in strategies, with no strict, binding targets. Compared to gaseous fuels like LNG, hydrogen refuelling infrastructure and recharging infrastructure for BETs have received only limited attention. It is only recently that the need for specific policy measures for zero-emission HDVs has been acknowledged in national strategies. Several Member States have developed broader hydrogen strategies or have been focussing on BETs and their (static) charging infrastructure strategies, or both static (parked) and dynamic (while driving). Both Sweden and Germany have several Electric Road System (ERS) pilots as result of policy actions aimed at developing this technology. The analysis of the policy strategies in three non-EU countries shows similar trends and that growth in alternative-fuelled vehicles and related infrastructure occurs mainly when strong government support is in place.

Minimum infrastructure versus full roll-out

The [AFIR proposal](#) marks a major change, both in terms of level of ambitions and with respect to its binding targets and scope. While Chapter 5 provides a more detailed assessment of the level of ambition, it is important to note that the Commission aims to ensure minimum infrastructure to support the required uptake of alternative fuel vehicles across all transport modes and in all Member States, but does not aim to realize the full network. As seen with other clean technologies, government support (subsidies or targets) should help to overcome the main barriers hindering the widespread roll-out of such technologies. Above the minimum and with probably an improved business case as result of the higher uptake of alternative fuel vehicles, private investments should further complement the network. Norway has followed the same approach with government funding only at the initial stage of infrastructure realization.

Monitoring and reporting

Close monitoring should help to determine whether additional policy incentives are needed, especially given the tight time schedule to meet the climate objectives, or whether authorities can leave further roll-out to the market.

The Commission has laid down an iterative monitoring and reporting process with obligations for both the Commission itself, Member States and regulatory authorities. It can be queried to what extent this timing will permit timely adjustment with respect to the 2030 targets, especially given the fact that roll-out will probably not follow a linear trend.

Distance as indicator

The AFIR proposal contains distance-based targets rather than a target based on national fleets or population density in a certain area. While fleet-based targets and population density might work for setting the charging requirements of electric passenger cars, those indicators are less suitable to apply to trucks, because of the long distances and transboundary nature of international goods transport. Other indicators, like traffic intensity on specific roads, might be relevant but are still not linked to trip patterns and technical characteristics, such as average range and battery capacity. In addition, in case there is high demand for refuelling and recharging on these busy roads, market actors are likely to start with the roll-out of infrastructure on those roads, even without government support. Other proposals that are part of the 'Fit for 55' package intend to improve the level playing field for alternative fuels relative to fossil fuels and are likely to increase demand for both the alternative fuels and the vehicles concerned. The final policy framework will be determined by the interinstitutional negotiations on further amendments to and the final adoption of the 'Fit for 55' proposals and revision of other relevant Directives and Regulations.

The next chapter presents the wide range of technological options for refuelling and recharging infrastructure that can be targeted by policy instruments in the short term.

3. EXISTING TECHNOLOGIES TO POWER HDV

KEY FINDINGS

- Although recharge and refuel technologies for alternatively fuelled HDVs exist, **further technological development** and **an increase in production capacity** are required to enable the possibility of a large-scale application of alternatively fuelled powertrains and further cost reduction.
- From an environmental perspective, **BETs and FCET** will deliver the greatest GHG emission reduction when powered **with renewably sourced hydrogen or electricity**. **Low-carbon fuels** can also contribute significantly, while better performing fossil fuels contribute less on a well-to-wheel (WTW) basis.
- Besides environmental reasons, the policy focus on BET and FCET is also justified, as most OEMs have recently started to produce BETs in series, and have announced the series production of FCETs in about 5 years. The BETs and later on the FCETs are in need of new recharging and refuelling infrastructure.
- Refuelling and recharging infrastructure needs differentiation on **short-, medium- and long-haul transport**, in particular for battery electric trucks (BET). On short-haul distribution trips, BETs will rely mainly on charging infrastructure **at the depot**, whereas on long-haul trips, **public charging** stations will be essential.
- **Pilots and first-mover initiatives** on BETs and fuel-cell electric trucks (FCET) and electric road systems (ERS) are taking place mainly in **Western European countries**.
- **Drop-in fuels** (liquid biofuels, gaseous biofuels and e-fuels) can be used in existing vehicles and infrastructure. The limited potential and large-scale availability of E-fuels, however, clearly limits their contribution to the 2030 CO₂ reduction targets.

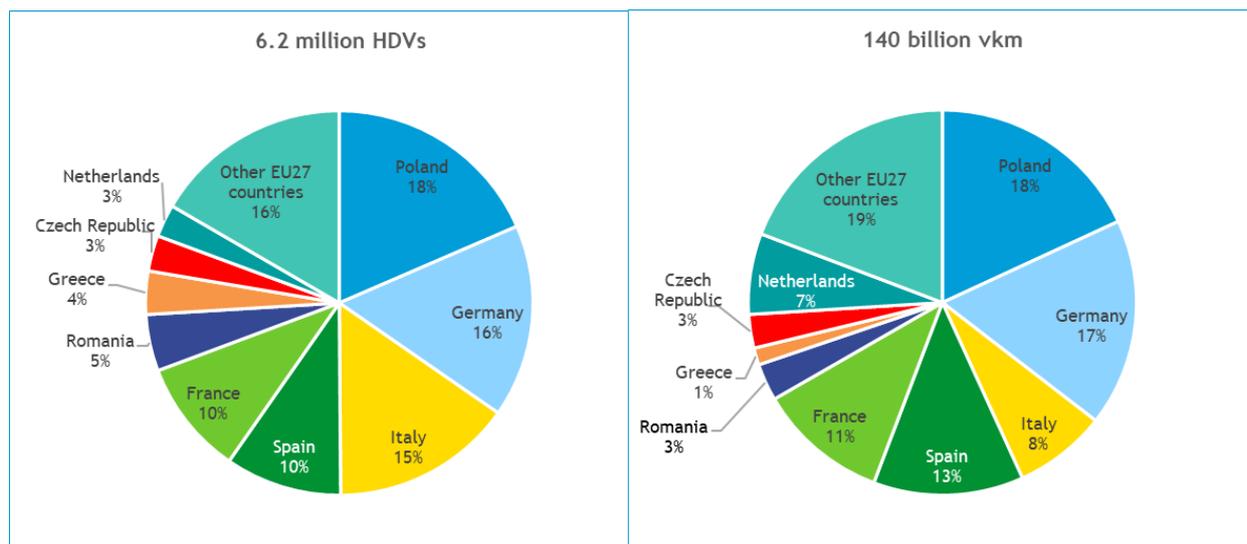
The ambition of the EU Green Deal is bound to affect fuel mix and vehicle fleet composition. In the long term, the aim is essentially zero-emission mobility, implying the need for a major shift from internal combustion engines (ICE) to alternative power trains. How fast and to what extent policy objectives can be met in time depends partly on the current status and availability of recharging and refuelling concepts. In this chapter we present an overview of these concepts, starting in Section 3.1, with a description of the current truck fleet and average truck performance. Section 3.2 describes the environmental performance of alternative fuels compared with fossil fuels, indicating the potential role of each in transport decarbonisation. Then follow reviews of the technologies to power electrical HDVs by means of charging technologies (Section 3.3) and electric road systems (Section 3.4). For refuelling concepts we present the options for hydrogen (Section 3.5), gaseous fuels (Section 3.6), liquid biofuels (Section 3.7) and e-fuels (Section 3.8). This chapter concludes with the main conclusions in Section 0.

3.1. Current truck fleet, segmentation and performance

3.1.1. Current truck fleet and performance

The EU27 HDV fleet currently comprises [6.2 million trucks](#) of different types (categories N2 and N3) that in 2019 drove 140 billion vehicle-kilometres (vkm). Figure 3 shows the relative shares of registered trucks per country. As can be seen, Poland and a handful of large West-European countries operate the bulk of trucks in the EU, while the fleets of Spain and the Netherlands, in particular, have a larger share in vehicle-kilometres compared with their comparative fleet size, indicating a relatively high share of their trucks in long-distance transport.

Figure 3: Overview of EU truck fleet (2019) and vehicle-kilometres (2019) by country



Source: registered vehicles per country: (ACEA, 2021b) vehicle kilometres in 2019: (Eurostat, 2020)

Given the differences in ranges of the different alternative fuel technologies, trip distance is an important criterion for assessing infrastructure needs. Truck trips can be divided into three rough categories: short-haul (intra-region; approx. 0-50 km), medium-haul (inter-regional; approx. 50-400 km) and long-haul (international, 400+ km) (T&E, 2020a; T&E, 2020b). Trucks involved in short-haul transport – typically city-logistics and port-to-warehouse trips – will return to base one or more times a day. Trucks in the medium-haul segment represent one-day round trips or one-way trips to destination. Trucks in the long-haul segment make multi-day trips, with overnight stops at trucking resting locations.

3.1.2. Segmentation and distribution of truck freight transport

As trucks fulfil multiple roles in the transport of goods (main-, intermediate- or last-mile transport), truck activity (measured in tonne-kilometres) is fragmented across a wide range of trip distance classes and the intensity by which they use the TEN-T network. Truck size and truck type are further parameters that can be used to categorise or characterize freight transport segments.⁷

Figure 4 shows the distribution of trips, vehicle-kilometres (vkm) and tonne-kilometres (tkm)⁸ over six distance classes for the EU27. As can be seen, approximately 90% of truck trips are in the short- and medium-haul segment⁹, corresponding to approximately 50% of both vkm and tkm. The long-haul segment represents only about 10% of trips, covering about 50% of tkm as well (Eurostat, 2020). According to T&E, about 1.3 million (20%) of the trucks are active in long-haul transport (T&E, 2021)¹⁰, typically tractor-trailers having a gross vehicle weight above 26 tonnes.

Given the permitted daily driving period of 9-10 hours under **Regulation (EC) No 561/2006**, most long-haul trips in the 400-1,000 km range can be covered in one day. Trips around and over 1,000 km take several days, or are performed with two drivers, thus extending daily driving time. Alternatively

⁷ E.g. trucks size in terms of gross vehicle weight (tonnes) of engine power and truck types such as rigid or tractor-trailers, and conditioned or not. See also the segmentation applies in the CO₂ regulation for trucks (<https://eur-lex.europa.eu/eli/reg/2019/1242/oj>).

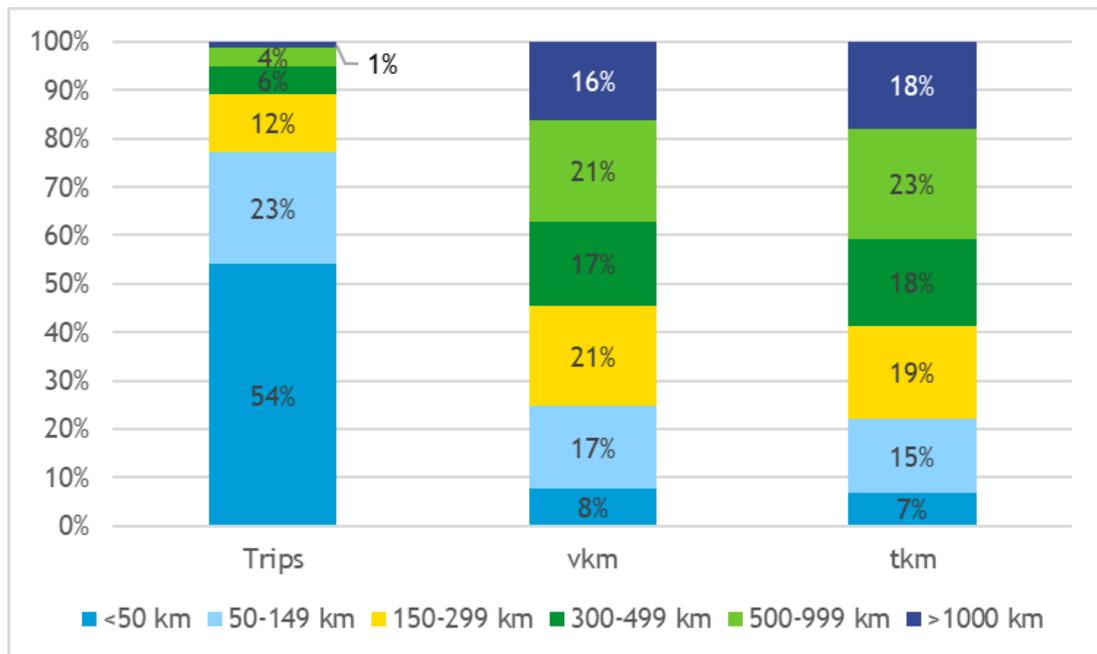
⁸ Vehicle-kilometres express the distance travelled by vehicles, while tonne-kilometres express the transport work they provide, each tonne of freight moved over one kilometre contributing 1 tonne-kilometre.

⁹ Assuming short- and medium- haul trips are up to 400 km, and long-haul trips are 400+ kilometres.

¹⁰ Figure 13 and text below in T&E, 2021: 580,00 long-haul vehicles correspond to 45% of the long-haul fleet in 2035 (total long haul fleet therefore 1.3 million).

fuelled trucks operating on distances over 400 km, and especially over 1,000 km, will need to be refuelled en route, especially alternative trucks with a limited range.

Figure 4: Distribution of EU27 truck trips, vkm and tkm over distance classes (based on year 2019)



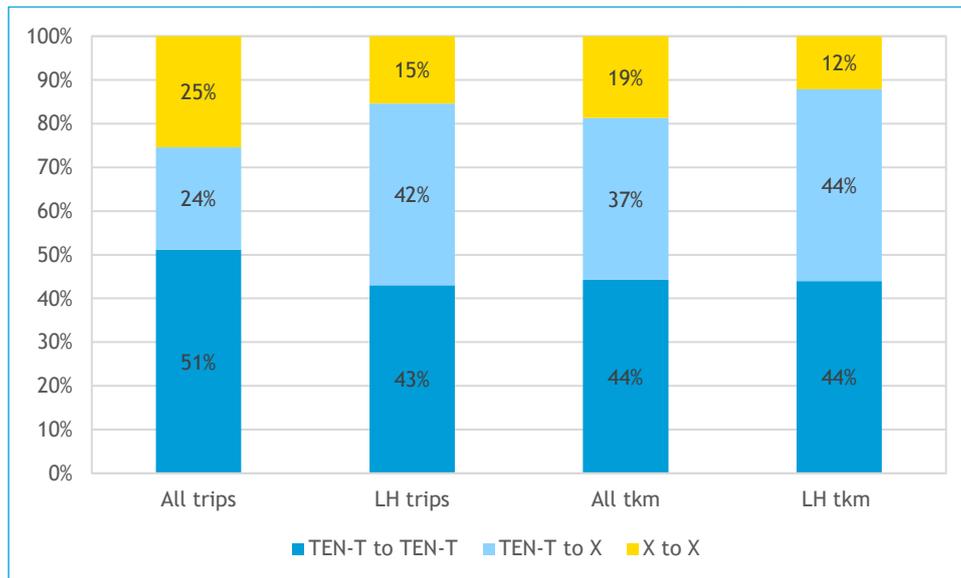
Compiled by authors, based on Eurostat data ([Eurostat, 2020](#))

A large proportion of the road-freight transported across Europe is by way of the TEN-T routes. According to [T&E, 2021](#), almost 75% of all freight trips by truck are made either on or at least partly on the TEN-T network, as indicated in Figure 5, showing the share of trips and transport activity¹¹ per TEN-T category: *TEN-T to TEN-T* trips have their origin and destination in a NUTS 3 region connected to the network¹², *TEN-T to X* (same as *X to TEN-T*) trips have their origin in a NUTS 3 region connected to the network and destination in a region not connected to the network, or vice-versa. *X to X* trips are trips between regions not connected to the network, as described in [T&E, 2021](#). For the long-haul (400 km and up) trips, almost 85% of the trips are related to the TEN-T corridor. When the amount of truck transport is captured in tonne-kilometres, the figures are fairly similar: over 80% of all tonne-kilometres use the TEN-T, at least in part, with an even higher figure (88%) for the long-haul segment.

¹¹ Trucks flows between regions in the EU27 and UK.

¹² The NUTS classification is set up by [Eurostat](#) to have as a single, coherent system for dividing up the EU's territory to produce regional statistics for the Community. The NUTS 3 regions are areas with a population between 150,000 and 800,000 inhabitants. NUTS 3 areas are much smaller in densely populated areas such as Germany than in areas with a low population density, such as in Scandinavia.

Figure 5: Shares of trips covered by the TEN-T routes (total and long-haul)



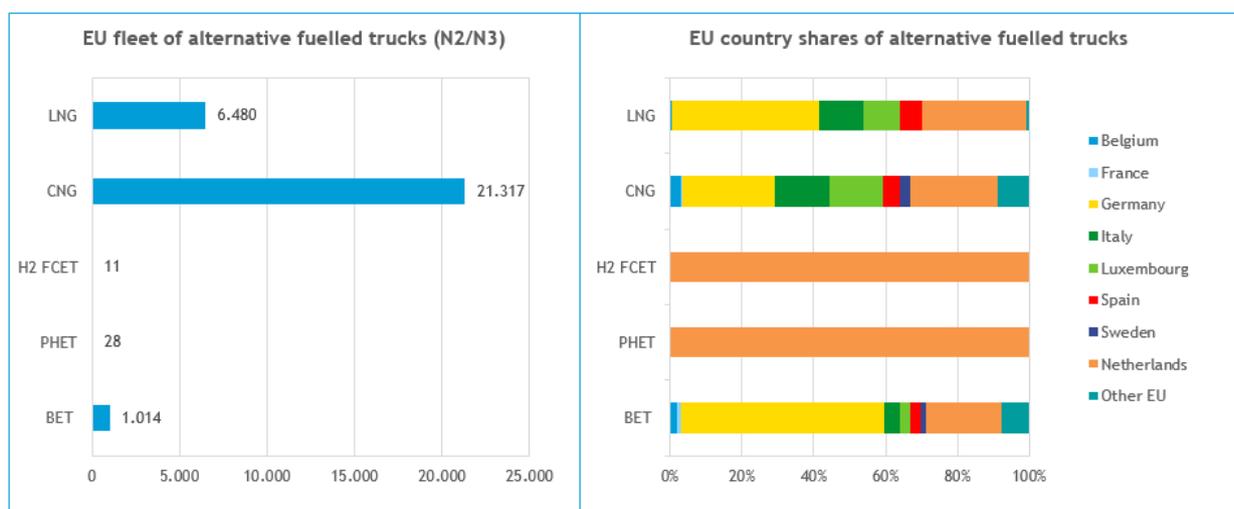
Source: Reproduced from [T&E, 2021](#). T&E used 2018 truck flow data from the [Eurostat database](#). LH stands for: long haul transport.

The above figures confirm the key role that TEN-T corridors play in providing connections between destinations for freight transport. This observation also shows the importance of the TEN-T corridor in the roll-out of alternative charging infrastructure.

3.1.3. Alternatively fuelled truck fleet

The vast majority of trucks in the EU27 – about 98% – still runs on diesel ([ACEA, 2021b](#)). However, the number of alternatively fuelled trucks is increasing. Figure 6 shows the number of such vehicles by type of powertrain and country ([EAFO, 2021a](#)).

Figure 6: EU alternatively fuelled truck fleet: totals and shares per country in 2020



Source: Compiled by authors based on data for 2021 from [European Alternative Fuels Observatory \(EAFO, 2021a\)](#) (extracted on 15 June 2021)

There are vastly more gas-fuelled trucks than BETs, plug-in hybrid electric trucks (PHETs) and hydrogen-fuelled FCETs. This can be attributed to the gas fuelled powertrains being longer on the market already. Most of the other alternatively fuelled trucks are registered in Germany (BET) or the Netherlands

(BET, PHETs and H₂-FCET). Uptake of hydrogen trucks in the EU27 is still minimal, with only eleven trucks registered in the Netherlands ([EAFO, 2021a](#)).

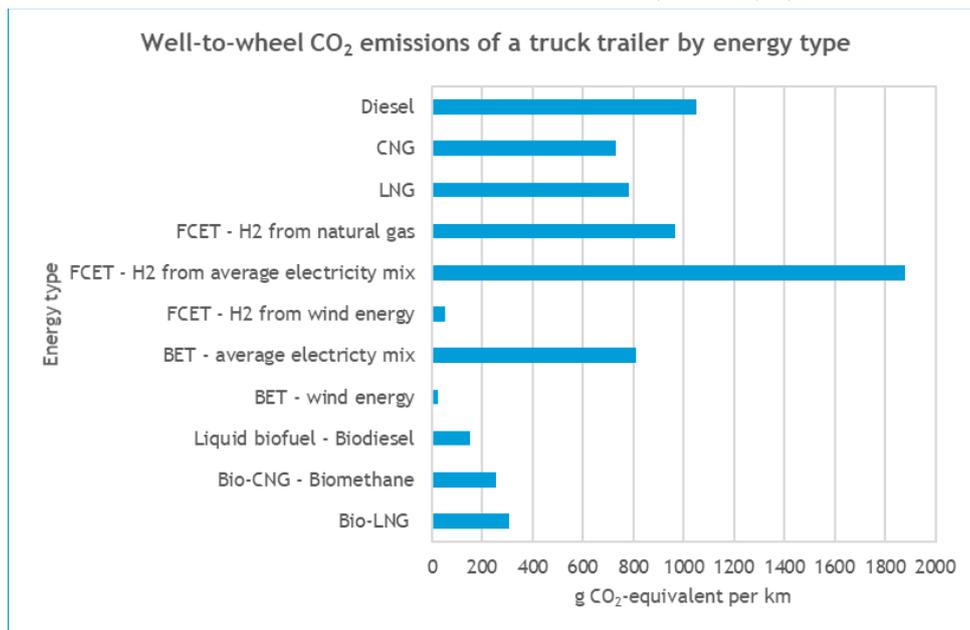
3.2. Environmental performance

Improving the environmental performance of truck transport is the main factor driving deployment of alternatively fuelled trucks. This section focuses on the GHG emission performance of the various truck technologies. It should be noted, though, that moving from fossil to alternative fuels also generally reduces air-pollutant emissions, depending on the fuel/energy type, but this lies out of the scope of this study.

Figure 7 presents the well-to-wheel (WTW) CO₂-equivalent emissions per kilometre of a reference truck-trailer of 40 tonnes gross vehicle weight (GVW) with different fuels and powertrains as reported in the 2020 'Outlook Hinterland and continental freight' ([CE Delft & TNO, 2020](#)) for the year 2018. WTW emissions are based on the Dutch energy mix and average feedstocks used in the year 2018.

A truck trailer running on gaseous fuel has 25-30% lower CO₂-emissions per km compared with one burning conventional diesel fuel, mainly because of the fuel's lower carbon content. FCETs and BETs also are more energy-efficient than trucks with internal combustion engines, owing to their electric powertrains. FCETs and BETs also have zero Tank-to-Wheel (TTW) emissions. As can be concluded from Figure 7, WTW emissions strongly depend on the primary energy sources used for electricity and hydrogen production ([Steenberghen & López, 2008](#)); ([ICCT, 2017](#))

Figure 7: Well-to-wheel emissions of 40t GVW truck-trailer by energy type



Source: ([CE Delft & TNO, 2020](#))

As shown in Figure 7, a BET powered by renewable sourced electricity has 98% lower emissions than the diesel reference, whereas a BET charged with the average (Dutch) grid mix in 2018, only has 23% lower WTW emissions than the diesel reference. A similar pattern is seen with FCETs using hydrogen produced from either renewable (wind) energy (-95% WTW), natural gas (-5% WTW), or electricity from the grid (+78% WTW). It should be noted that the WTW carbon intensity of the average Dutch electricity mix in the figure amounts to 480 gram CO₂/kWh. The carbon intensity of the average EU27 electricity

mix in 2018 was approximately [33%](#) lower, and would result in 33% lower WTW figures for the corresponding BET and FCET in the EU27. The figures based on the average electricity mix will further decrease towards the future, both in the Netherlands and in the EU27, with further increase of renewable energy in the electricity mix. Interviewees see renewable hydrogen as the right pathway for the long term, but acknowledge that it will take time before this becomes economically viable. It will take several years to plan and construct large scale electrolyzers. While fossil-based hydrogen is competitive, it is not environmentally beneficial. Until renewable hydrogen is available on a large scale, blends of hydrogen produced from different sources are expected to be used.

While the GHG emissions occurring during production of the vehicles and (recharging/refuelling) infrastructure should in principle also be considered, in practice they have a negligible impact on the comparison between the various options ([Ricardo Energy & Environment, 2020](#); [CE Delft, 2021](#)).

The (gaseous) fuels of biological origin have the potential to reduce emissions by 70-85%. These cuts depend very much on the feedstock used for biofuel production, though. At the EU level, the Renewable Energy Directive II aims to phase out biofuels made from food and feed crops because of the negative impact of the indirect emissions associated with land use change, while aiming for growth of so-called advanced biofuels from waste and residues.

The Renewable Energy Directive has restricted the use of food and feed crops to a maximum of 7% of final energy consumption in the road and rail transport sector in any Member State (EC, 2018). The 'Fit for 55' package proposal ([EC, 2021g](#)) puts additional constraints on the use of forest wood, to preserve biodiversity and soil quality. Secondly, there is a limit to the availability of sustainable biomass feedstocks, and thus to the potential role of biofuels, too. For example, the future supply potential of used cooking oil (UCO) in the EU has been estimated to be roughly 50% higher than the current UCO supply ([CE Delft, 2020](#)). If priority is given to using biomass where it has the highest economic and environmental added value, utilisation in the chemical industry and in aviation may be preferred. Finally, it is argued by NGOs that large-scale use of biofuels in the short term creates a risk of delaying the transition to zero-emission trucks. This concern is also recognised by ([SEI, 2019](#)), that states too much focus on fuel switching from fossil to biofuels could strengthen lock-in into the general infrastructure associated with the internal combustion engine and possibly delay the eventual system change to clean electrification. However, the aforementioned restrictions proposed on biofuel use, should make such a lock-in less likely.

For all energy sources, the availability of renewable sources, such as renewable hydrogen or feedstocks for advanced biofuels, might form a barrier ([Trencher & Edianto, 2021](#)). However, having a strong and stable demand from the transport sector will also boost investments in production capacity.

With respect to LNG, fugitive emissions of methane along the LNG supply chain need to be addressed, as they have a much higher global warming potential than CO₂. Gas leakage from LNG tanks during venting need to be effectively recovered through boil-off recovery systems in order to prevent additional emissions ([Serra, et al., 2019](#)).

Finally, more aerodynamic truck designs and leveraging complementary technologies, like (Cooperative) Intelligent Transport Systems ((C)-ITS) and automation might play a complementary role in achieving GHG reduction targets in transport ([Serra, et al., 2019](#)).

3.3. Technologies to power HDVs running on electricity: charging technologies

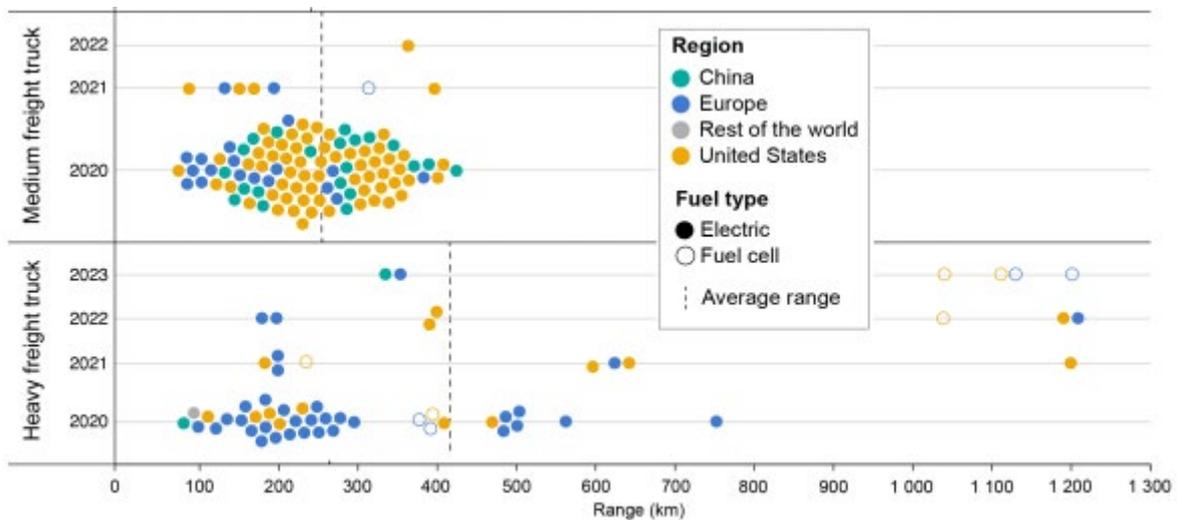
3.3.1. Vehicle developments

Battery-electric trucks (BETs) with ranges up to 400 km are already being commercially produced (e.g. Volvo, DAF, Mercedes, Renault, VW (MAN, Scania)), while R&D to increase ranges continues.

Figure 8 from the [IEA, 2021](#) shows the number of HDV models announced per continent, with the expected release year on the y-axis and the distance range (with a full battery/tank) in kilometres on the x-axis. Many medium-freight truck models (< 12 tonne) are being produced or have been announced in the US. In the heavy-freight truck market the number of models produced and announced in Europe is relatively high compared with other parts of the world. Currently, BETs are used mainly for city logistics by frontrunners and to gain experience. Besides Germany, a relatively high number of current BETs are operating in the Netherlands, where zero-emission zones for freight transport are set to be introduced by 2025 in 30-40 cities ([Dutch Government, 2019](#)).

For trucks on the road for less than 12 hours per 24 hours and driving less than 750 km – which account for the bulk of logistical activity in Europe ([T&E, 2020a](#)) – BETs may soon become a cost-effective zero-emission solution, before other zero-emission options ([Clean Energy Wire, 2020](#)).

Figure 8: Current and announced zero-emission HDV models by segment, release year and powertrain in major markets, 2020-2023



Source: Global EV Outlook 2021 ([IEA, 2021](#)); IEA, All rights reserved. As modified by authors.

3.3.2. Infrastructure developments

The infrastructure requirements of BETs depend on the recharging method employed. There are several options for charging: plug-in cable charging, charging via a pantograph, inductive charging (wireless) and battery swapping. Plug-in charging, charging via a pantograph and inductive charging take place at charging stations/points and takes time (during which the vehicle remains idle). Battery swapping means batteries can be charged before swapping, saving time and limiting idle time substantially. As yet, however, batteries are still in the development phase, there is no universal system and battery swapping stations come at high cost, because of the high number of extra batteries needed ([McKinsey, 2020](#)). Except for few passenger cars in China from manufacturers NIO and BAIC ([Danilovic & Liu, 2021](#); [Bloomberg, 2021](#)), battery swapping is currently scarcely applied.

With pantograph charging vehicles are charged either by lowering a pantograph on the collectors positioned on the roof of the vehicle or by raising a pantograph on top of the vehicle to an overhead wire. Pantograph systems are momentarily applied for electric buses, and are especially suited for short charging sessions during stops (Siemens, 2021). Inductive (wireless) charging is another alternative to plug-in cable charging that is more user-friendly and durable and of higher aesthetic quality. It is currently used for buses in cities like London, Madrid and Turin (IPI Technology, 2021). Both pantograph charging and inductive charging can be applied during driving as well, as electric road systems (ERS). ERS is separately discussed in Section 3.4.

At the moment, though, it is only plug-in cable chargers that are commonly used for BETs. An important consideration is that these systems have a higher energy efficiency and lower costs than the other options (Brenna, Foadelli, Leone, & Longo, 2020). Plug-in cable chargers for BETs are similar to those for passenger cars (Combined Charging System, type 2), as standardised by the AFID for public charging points. In principle, charging points for HDV do not differ from those for light-duty vehicles (LDVs). Since HDVs are several times larger than LDVs, however, not all recharging points will be accessible for them. Because of the larger battery packs, moreover, in practice only fast-charging is an option for charging HDVs within a reasonable time. Current fast-chargers are in the power range of 50 kW-350 kW. Even higher-power chargers (up to 1 MW) are foreseen for the largest trucks (Buck Consultants; CE Delft; et al., 2019; T&E, 2020a), which would allow them to charge for an extra 100-150 km in ten minutes. This implies several megawatts of power being needed to supply a motorway charging station during peak hours.

Several studies have shown that trucks involved in short- and medium-haul transport will charge mainly at depots and distribution centres overnight (McKinsey, 2020; Buck Consultants; CE Delft; et al., 2019; Rodríguez, Hildermeier, & Jahn, 2020). A larger battery to complete the trip without needing to recharge during the day at a third-party location is often favoured in terms of costs as charging at depot during idle times in the night has the lowest costs and outweighs the higher battery investment costs. In addition, trucking companies in city logistics prefer to rely on their own charging station at depot in terms of technique and availability (McKinsey, 2020; Buck Consultants; CE Delft; et al., 2019). For long-haul trips, besides chargers at depots, charging stations at overnight and resting places along the road (TEN-T corridors) are needed (ACEA, 2019; T&E, 2020a). BET recharging infrastructure is dependent on the physical presence and capacity of the local energy grid. Considerable grid investments and realization time can be needed at depots with many overnight locations for trucks and fast charging stations that require high power connections to the grid (Buck Consultants; CE Delft; et al., 2019).

3.3.3. Existing infrastructure

The number of public electric recharging points in the EU is growing rapidly (from 120,000 in 2018 to around 225,000 in 2020), with around 10% fast-charging points (22 kW+) (EFAO 2021). However, existing public recharging infrastructure is dedicated to serving passenger vehicles and light commercial vehicles, given the physical space and power level available. According to the ACEA, as of May 2021 there were fewer than ten publicly accessible charging points for electric trucks available and operational in the EU (ACEA, 2021a). In all likelihood the 1,042 (hybrid) battery-electric trucks currently operational will have their private (depot) charging infrastructure in place for charging these short- and medium-haul vehicles.

Charging stations are offered by several suppliers, including OEMs. DAF provides charging solutions for commercial vehicles, with (mobile) chargers up to 50 kW for overnight (depot) charging, and ultra-fast chargers with a capacity up to 350 kW recharging an average truck battery in approximately two hours (DAF, 2021). Volvo Group, Daimler Truck, and the Traton Group have teamed up to invest

in a high-power public charging network for heavy duty trucks, with the intention to realize 1,700 charging points within 5 years from 2022 ([INSIDEEVs, 2021](#)) ([Reuters, 2021](#)).

3.3.4. Recharging times

The various different recharging and refuelling methods each have their own specific technical characteristics, translating to varying times for fully recharging batteries or refilling fuel tanks. As it is generally known, recharging electric vehicles at a charge point may take longer than refuelling with fossil fuel. For recharging it has been assumed that the battery is recharged from 0% to 100%, unless stated otherwise, although public fast charging would usually only be 10 – 80% charging.

T&E's report ([T&E, 2020](#)), comparing hydrogen and battery electric trucks, has extensively explored the parameters and expected specifications for BETs and FCETs at the current state of play and expected in the year 2030. They draw a distinction between BETs aimed for regional-haul and long-haul operation. Assumptions on mileage, range and battery size are determining factors for the duration of BET recharging. Energy consumption at the wheels is a key factor determining required energy storage and consequent vehicle range. By the year 2030, energy efficiency improvements are expected, resulting in a smaller truck battery pack. Current BET and anticipated recharging times in 2030 are presented in Table 4 (Next to the T&E figures, figures from [Connekt, 2021](#), and [Giuliano, et al., 2020](#)) are presented).

Table 4: Overview of BET recharging times

Factors	Regional-haul 2020	Regional-haul 2030	Long-haul 2030
T&E, 2020^a			
Range on full battery (km)	400	400	800
Battery size (kWh)*	720	575	1,150
Overnight depot charging capacity (kW)	75	75	150
Duration of overnight recharge	8 hours	8 hours	8 hours
Fast-charging capacity (kW)	150	600	1,200
Duration of recharge (0-100%)	4 hours	60 minutes	60 minutes
Connekt, 2021^b			
Battery size (kWh)	200	200	-
Overnight depot charging capacity (kW)	22	50	-

Factors	Regional-haul 2020	Regional-haul 2030	Long-haul 2030
Duration of overnight recharge (0%-80%)	9 hours	4 hours	
(Ultra-) Fast-charging capacity (kW)	150	1,000	
Duration of recharge (0%-80%)	80 minutes	12 minutes	
(Giuliano, et al., 2020)^c			
Battery size (kWh)	240	-	650
Duration recharge (0%-80%)	3 hours	-	3 hours
Duration recharge (80%-100%)	2 hours	-	2 hours

Sources: ^a (T&E, 2020), data summarised from tables on p. 3, 8 and 9. ^b Taken from [Connekt, 2021](#), Figure 2.4, p. 14. ^c Taken from [Giuliano, et al., 2020](#), Table 1, p. 11

* Usable capacity capped at 80%.

Charging time depends on the location, trucks battery capacity and power capacity of the recharging infrastructure. According to the sources in Table 4, BETs are expected to require five to nine hours overnight charging at (relatively) low-power depot chargers. At high-power fast chargers up to 80 minutes is expected for full recharging, depending on the power capacity of the charger and the battery capacity of the truck. For technical reasons, recharging the final 20% (from 80 to 100%) requires a disproportionately long time compared with the first 80% ([Giuliano, et al., 2020](#)). Batteries should therefore be dimensioned with a higher capacity than the range needed.

Megawatt public truck chargers are assumed for 2030 to allow long haul trucks to fully charge within an hour. The rationale for the introduction of megawatt chargers can also be found in the EU regulations on driving times. This regulation requires obligatory stops for the driver every 4.5 hours (ca. 400 km on the highway) of at least 45 minutes ([Regulation 516/2006](#)). Megawatt chargers (e.g. 1 MW) would allow trucks with an energy consumption of 1.4 kWh/km¹³ to charge for 400 km in about 35 minutes.¹⁴ These high-power fast chargers are not yet available, as the technique is still under development ([Charin, 2021](#)). If sufficient high-power chargers are deployed along high-volume freight corridors, BETs can recharge during these obligatory stops. It can consequently be argued that batteries do not need to be fully charged at the journey's start¹⁵ and/or that smaller battery packs, allowing a range of 400 km, will also be sufficient for long distance trucks.

In Germany, several partners under the flag of the VDA (Verband der Automobilindustrie) have started an initiative to install megawatt charging facilities at four locations along the A2 from Berlin to Ruhr area by 2023 ([VDA, 2021](#)). Spain's energy company Iberdrola plans to develop in the coming 5 years charging facilities for 100% electric transport in the Region of Murcia and the Valencian Community.

¹³ Based on T%E figures in Table 3: 575 kWh/ 400 km = 1.4 kWh/km

¹⁴ 1.4 kWh/ km*400 km/1,000 kwh/h*60 minutes/hour = 35 minutes.

¹⁵ If the truck has just one driver.

This will include, “extremely” fast charging infrastructure delivering up to one megawatt for trucks ([Electrived.com, 2021](#)).

As a conclusion, recharging and refuelling times for BETs will be significantly longer than for reference diesel trucks, with the same holding for hydrogen-powered FCETs. Recharging times will be longest for long-haul trucks and low-power (depot/overnight) chargers. With megawatt chargers becoming available in a few years, however, charging times are expected to fall drastically, removing barriers for transport operators.

3.3.5. Developments in third countries

United States

In 2019, four charging stations were launched in California by Penske Truck Leasing, designed and deployed specifically for HDVs. A total of fourteen fast chargers of 50-150 kW direct current (DC) capacity are installed, making these the first charging points in the USA for battery-electric HDVs ([Electrek, 2019](#)). Since April 2021, a charging station with several 150-200 kW public chargers dedicated to HDVs has been operational in Portland, Oregon, by Daimler in cooperation with the local grid manager PGE. This public station is serving as a pilot for Daimler Trucks for further deployment of HDV charging infrastructure ([OPB, 2020](#); [Electrek, 2021](#)). Daimler’s main strategy in the EU and North-America is development of HDV charging infrastructure at truck customers’ depots, providing mainly overnight charging solutions for BETs ([Daimler Truck AG, 2021a](#)). In order to make charging infrastructure compatible for HDV, the charging industry is working to standardise high-power charging for commercial vehicles, with power levels of over 1 MW becoming available in the future ([RMI, 2020](#)).

Norway

In Norway, there were 34 BETs on the road as of early 2021 ([EAFO, 2021a](#)). They are used for city distribution by retailers and supermarkets and have depot overnight charging infrastructure with a maximum charging power of 150 kW ([Scania, 2020](#); [InsideEVs, 2020](#)).

China

Globally, China has the highest number of electric trucks on the roads, with the country accounting for around 90% of new electric trucks registrations worldwide in 2019 and 2020 ([IEA, 2021](#)). Refuse collection trucks, in particular, are being electrified ([World Economic Forum, 2020b](#)).

According to the World Economic Forum, China has a fleet of over 60,000 electric trucks and vans ([World Economic Forum, 2020a](#)), most of them active in city logistics and municipal services. The number of electric charging points geared to and suitable for BETs is unknown.

3.4. Technologies to power HDVs running on electricity: electric road systems

3.4.1. Vehicle developments

Electric road systems (ERS) are systems that provide energy to trucks while driving, providing a zero-emission solution for motorway freight transport, and potentially highly efficient traffic flows, as they also create opportunities for autonomous vehicles. There are three main concepts: overhead conductive lines, conductive rails in a road surface and wireless, inductive charging solutions. All concepts have been or are being tested in demonstration projects in Sweden on stretches of about 1- 2 kilometre ([Colliers, 2019](#)); ([Colliers, 2020](#)). In Germany there are several projects with overhead lines

on stretches up to 5 kilometre length. Compared to the other concepts, overhead lines have the benefit that no changes to the road pavement are needed ([CollIERS, 2020](#)).

In the demonstration project vehicles have been adjusted to be able to collect the energy from the energy supply system, and to convert it into either propulsion of the vehicle or to charge the battery with. For the overhead lines, Siemens has developed a prototype pantograph to draw electricity from a catenary system. The system has been applied at several test locations with hybrid Scania trucks ([Siemens, 2021](#)). The overhead lines provide electricity to BETs or hybrid trucks, with either a battery or a combustion engine to cover the distances between the ERS sections of the route. According to Siemens, 89% of non-motorway truck movements are less than 50 km and if long stretches of motorway are electrified as ERS, battery capacity of BETs as well as charging infrastructure requirements can be kept significantly lower. The vehicles using electric rail, connect through a pantograph under the vehicle ([ABB, 2021](#)). For inductive charging the trucks are equipped with a receiver coil ([Smartroadgotland, 2021](#)).

3.4.2. Existing infrastructure

Electric road systems are not yet available for commercial use, only as demonstration or pilot projects. Sweden has a 1.6 km stretch of road with coils for wireless power transfer on the island of Gotland ([Smartroadgotland, 2021](#)). A one-kilometer section of such a wireless electric road will also be realised on the A35 in [Italy](#). In Sweden also a conductive rail systems has been deployed on a 2 km stretch in the area of Stockholm ([CollIERS, 2020](#)). The most widely applied system is the overhead conductive line. In Sweden, it is applied on a 2 km stretch of catenary infrastructure on the E16 highway north of Stockholm for testing two diesel-hybrid trucks ([Siemens, 2021](#)). In Germany a 5 km stretch at the A5 motorway has been fitted with overhead lines in both directions for diesel-hybrid trucks. A 10 km section of the A1 in Schleswig-Holstein and 4 km of the B462 in Baden-Württemberg are scheduled for testing in 2021. Very recently the German government has announced an extension of the A5 catenary road system and a catenary road system in Bavaria ([BMVI, 2021](#)). The Swedish transport administration has announced a permanent ERS (system still to be decided) on the E20 Hallsberg–Örebro of about 20 km by 2025 ([Trafikverket, 2021](#)).

3.4.3. Developments in third countries

United States

ERS infrastructure in the US presently comprises a two-mile-long overhead catenary system for hybrid electric trucks installed between the ports of Los Angeles and Long Beach. It is only accessible for dedicated trucks participating in the pilot project.

Norway

We are not aware of any initiatives in Norway on overhead catenary systems or other ERS.

China

According to [Danilovic et al., \(2019\)](#) China is not working on the development of ERS.

3.4.4. Infrastructure developments

Catenary infrastructure requires precise coordination of routes and comprehensive investments and installation measures before the benefits can be reaped. Considering these restraints, it is highly unlikely that catenary systems will be applied on all freight transport routes. The first iterations of ERS will probably cover fixed shuttle services and motorway stretches with the highest intensities of truck traffic.

Germany and Sweden have several pilot projects testing operation of overhead catenaries under everyday road conditions ([Siemens, 2021](#)). In Germany some of these are cooperative projects involving local government and commercial parties ([Electric Roads, 2021](#)). In Sweden there is also a new pilot project underway with a wireless (induction-based) ERS.

3.5. Technologies to power HDVs running on hydrogen

3.5.1. Vehicle developments

Fuel cell electric trucks (FCETs) are currently being piloted. According to OEMS series production of FCETs is expected to take 5-10 years ([Daimler AG, 2021c](#)) ([DAF, 2021](#)). The current generation of fuel cell electric trucks (FCET) is powered mainly by proton-exchange membrane fuel cells (PEM) using hydrogen as a fuel. In the longer term, solid oxide fuel cell (SOFC) technology that can convert other, denser fuels (like methanol), may also be an option; this is currently being researched. Different modes of on-board storage of hydrogen are feasible (liquid at minus 253 °C, compressed at 350 or 700 bar), with different implications for refuelling architecture ([CNHi, 2020](#)). As passenger cars have little room for on-board tanks, the hydrogen is usually compressed to 700 bar. For buses with roof space available, 350 bar is often applied ([FCEB, 2021](#)). The first FCETs on the road are equipped with 350 bar hydrogen storage tanks ([Berger, 2020](#)) ([Hyundai MC, 2020](#)). For long-haul transport, trucks with 700 bar hydrogen storage tanks are announced (Berger, 2020) ([Air Liquide, 2020](#)). Daimler Trucks aims at using liquid hydrogen for its trucks ([Daimler AG, 2021c](#)).

Because of hydrogen's high mass energy density, FCETs are considered promising for long-haul transport ([CE Delft & TNO, 2020](#)). Its relatively low volume energy density, however, requires a greater internal tank volume (approx. 7 times for H₂ at 700 bar) to reach the same range as a diesel truck ([CNHi, 2020](#); [JEC, 2020a](#)). Although still in the pilot stage, FCETs that have been developed often have ranges over 400 km, which is more than current BETs ([CE Delft & TNO, 2020](#)). In April 2021 Daimler and Volvo announced the creation of a fuel-cell joint venture aiming to start series production of fuel cell systems in 2025 ([Daimler Truck AG, 2021b](#)) and having series-produced FCET on the market from 2027 on ([Daimler AG, 2021c](#)). According to the two companies, hydrogen-fuelled FCETs will be the preferred option for heavier loads and longer distances. Other OEMS, such as Renault ([Renault group, 2021](#)), Toyota and DAF ([DAF, 2021](#)) are also investing in hydrogen technology. The STRATON group (Scania, MAN, Volkswagen), however, sees more future for BETS than for FCETs, because of the high costs for H₂ fuelling, and the need for green H₂ in other industries (STRATON, 2021) ([Scania, 2021](#)).

Hydrogen can also be used to fuel ICEs, which requires minor adaptation of the ignition and ventilation system to cope with the high flammability of hydrogen. This is currently being researched ([FEV, 2021](#); [Volkswagen, 2020](#)).

3.5.2. Infrastructure developments

The infrastructure for FCETs requires additional safety measures compared with conventional refuelling infrastructure, but refuelling time is equally short (under eleven minutes). Refuelling stations can be supplied by trucks, pipelines (possibly retrofitted gas pipelines) or by on-site hydrogen production. As yet, however, there is no standardisation of pressure level or storage technology. Mobile refuelling stations have also been developed, introducing a high degree of location flexibility ([FuelCellsWorks, 2020b](#)). The volume energy density of hydrogen is low compared with diesel. Supplying hydrogen to a refuelling station by truck therefore requires far more truck movements compared with supplying the same diesel energy content ([TNO, 2019](#)), according to the figures provided in ([CNHi, 2020](#); [JEC, 2020a](#)) at least seven times more.

3.5.3. Existing infrastructure

As of 2021, there are 144 hydrogen refuelling stations (HRS) in operation in the EU, the majority in Germany, France, Denmark, the Netherlands and Belgium. They offer hydrogen compressed to either 700 or 350 bar; as yet there are no liquid refuelling stations in the EU. The bulk of these 145 HRS service passenger cars, with only sixteen delivering 350 bar H₂ to HDVs, mainly city buses ([HRS map EU, 2021](#)). Depending on compressor type and on-board storage pressure, these HRSs might be suitable for refuelling hydrogen trucks, but this is not made clear in the literature or in the information provided by HRS operators. The European Commission has prescribed a least 700 bar in the proposed AFIR Regulation. The amount of H₂ stored at the HRS is crucial for such application, because of the greater fuel demand for long-haul transport compared with city buses and passenger cars.

3.5.4. Refuelling times

The various different recharging and refuelling methods each have their own specific technical characteristics, translating to varying times for fully recharging batteries or refilling fuel tanks. Similar to electric charging, longer refuelling times also hold for hydrogen and other energy carriers. For refuelling it has been assumed that the fuel tank is refilled from 0 to 100%, unless stated otherwise.

T&E's report comparing hydrogen and battery electric trucks has extensively explored the parameters and expected specifications for BETs and FCETs at the current state of play and in the year 2030. The outcomes for FCETs are presented in Table 5.

Table 5: Hydrogen truck refilling times from various sources

Source and factors	Regional-haul 2020	Regional-haul 2030	Long-haul 2030
(T&E, 2020) ^a			
Maximum range without refuelling	400	400	1,200
Energy consumption at wheels (kWh/km)	2.53	1.95	1.95
H ₂ tank size (kg H ₂) – 700 bar	30	23	70
Dispenser flow rate (kg H ₂ /min)	3.6-7.2		
Duration of refuelling time (full H ₂ tank - minutes)	4.2-8.3	3.2-6.4	9.7-19.4

^a Data summarised from tables on p. 3 and 8, duration is calculated from dispenser flow rate and H₂-tank size.

3.5.5. Developments in third countries

United states

According to the US Alternative Fuels Data Center (AFDC) there are 48 hydrogen refuelling stations (status 11 October 2021) in the US ([US DOE, 2021](#)). Most of these stations are stated to be for local users of hydrogen-fuelled electric vehicles, as the number of hydrogen trucks in the US is negligible.

China

FCEVs in China are almost exclusively buses and trucks, unlike most other countries where cars predominate. China accounts for 94% of global fuel-cell buses and 99% of fuel-cell trucks. In absolute

numbers these are approximately 5,500 buses and 3,500 trucks¹⁶, while the country has 16% (around 90) of the world's hydrogen refuelling stations ([IEA, 2021](#)), but another source already mentions 101 operational HRS ([Yicaiglobal, 2021](#)). Most HRS are 350 bar installations used mainly for refuelling buses and commercial vehicles, a large proportion of which are deployed as pilot vehicles ([Verheul, Netherlands Innovation Network China, 2019](#)).

3.6. Technologies to power HDVs running on gaseous fuels (LNG, CNG, LPG)

3.6.1. Vehicle developments

Trucks running on gaseous fuels have already been on the market for some time. CNG and LNG are both derived from natural gas, with the natural gas being compressed at high pressure in CNG and liquified at very low temperatures in LNG. CNG has a lower energy density and is therefore not optimal for long-haul heavy transport, whereas LNG trucks have ranges over 1,000 km and are suitable for such transport. LNG trucks have an around 30% higher purchasing price than diesel trucks, but this can be recuperated because of the lower fuel costs ([CE Delft & TNO, 2020](#)). An LNG truck takes around seven minutes to refuel. Some OEMs, including Volvo, are investing in LNG technology as one option to reduce the climate impact of truck transport, while for others, like Mercedes, LNG trucks are not part of their decarbonisation strategy ([Schuckert, 2020](#)).

LPG is a mix of propane and butane and has a relatively low energy density. It is used mainly in passenger cars, buses and forklift trucks and is not in widespread use for (road transport) trucks (approx. 9,000 trucks in the EU27, of which 8,000 in Poland ([Eurostat, 2021](#))). According to the World Liquid Petroleum Gas Association (WLPGA) in 2017, there has been little development of new LPG engines for HDVs in recent years ([WLPGA, 2017](#)). LPG will consequently not be discussed in detail in this report.

3.6.2. Infrastructure developments

Refuelling stations will generally be supplied by truck or pipeline. There may be on-site liquefaction at refuelling stations in the case of LNG, and on-site compression with CNG. LNG/CNG refuelling stations require dedicated storage and fuelling infrastructure. When gaseous biofuels are used, biogas is usually upgraded to biomethane and processed to meet CNG or LNG quality standards, enabling replacement of fossil LNG and CNG by bioLNG and bioCNG. In the future, renewable fuels of non- biological origin (gaseous e-fuels) could be used as well.

3.6.3. Existing infrastructure

There are currently over 400 LNG filling stations in the EU, mainly in Spain, Italy, France, Germany, the Netherlands and Sweden. They are rare in Eastern EU Member States. There are around 4,000 CNG filling stations in the EU, dispersed over more countries and mainly used by passenger cars ([NGVA Europe, 2021b](#)). Italy accounts for over a third of them, reflecting its disproportionate share (55%) of registered CNG passenger cars in the EU ([NGVA Europe, 2020](#)).

The number of LNG refuelling stations in the EU grew by 60% in 2020, mirroring the trend in new LNG vehicle registrations. In that year the number of CNG stations in the EU was 8% higher than in 2019, indicating that this technology is also maturing ([NGVA Europe, 2021a](#)).

¹⁶ Estimated from graph presented in source (Figure page 36).

3.6.4. Refuelling times

Gaseous fuels have similar refuelling times to diesel, or may be slightly longer owing to safety procedures associated with truck coupling and decoupling of refuelling provisions.

3.7. Technologies to power HDVs running on liquid biofuels

3.7.1. Vehicle developments

Some internal combustion engines can be directly fuelled with bio-alternatives for diesel. Biodiesel can be blended with regular diesel, or either used as neat (100%) fuel in engines suitable (in many cases adapted) to run on neat biodiesel. For biodiesel the two most familiar and widely applied options are: Fatty Methyl Ester (FAME) and Hydrotreated Vegetable Oil (HVO)¹⁷. According to the current fuel specifications, regular diesel may contain up to 7% (volume %) of FAME (B7). Most conventional diesel engines can run on blends up to 10 or 20%. Not all vehicle manufacturers provide warranty if blends higher than 7% are used, because FAME can potentially cause fuel quality and microbial growth issues. On the contrary, HVO is a drop-in fuel: a fuel without the need for any significant modification in engines and infrastructures. Many truck manufacturers have their Euro VI engines cleared to run on 100% HVO, important for maintaining engine warranties. The advantage of drop-in fuels is that they can be applied in the current fleet, providing a rapid decarbonisation option in the short term.

Biofuels are considered an important option to decarbonise during the transition towards BETs and/or FCETs; for the existing fleet, especially, it is seen as intermediate fuel ([CE Delft & TNO, 2020](#); Stakeholder interviews: OEMs, Shippers, infrastructure, research). In the short run, it is anticipated that a higher demand for biofuels from the logistics sector can be delivered sustainably and fairly. In the long run, the share of biofuels will diminish and biofuels should be prioritised in other modes like aviation and maritime shipping, where zero-emission options are harder and more expensive to realise (Stakeholder interviews: logistics). Future utilisation of biofuels will also depend to a major extent on whether OEMs continue to build internal combustion engines (ICE). Current expectations are that for HDV the ICE will still exist in 2040 and beyond, most probably for very heavy vehicles used in rural areas (Stakeholders interviews: OEMs).

3.7.2. Infrastructure developments

To an extent, the midstream and downstream infrastructure for biofuels can use existing infrastructure for conventional, fossil fuels, since storage and refuelling conditions are similar. From an infrastructural angle, liquid biofuels are consequently the best positioned of all alternative fuels, especially the drop-in biofuels.

3.7.3. Existing infrastructure

Liquid biofuels can be applied as a drop-in for conventional mineral oils or in low blends in regular diesel and petrol (adhering to the fuel specifications laid down in the Fuel Quality Directive (FQD)). Most diesel already contains a small amount of biodiesel, thanks to the Renewable Energy Directive and the GHG intensity target of the FQD. Since fossil fuels make up the vast bulk of transport fuels, the required infrastructure is widely available throughout the EU in the form of conventional filling stations ([EAFO, 2021b](#)), where specific medium and high blends can be added to the range of products on offer.

¹⁷ FAME stands for 'fatty acid methyl esters', a biofuel with similar physical properties to conventional diesel fuel. HVO stands for 'hydrotreated vegetable oil' and is produced by the hydroprocessing of (waste) oils and fats ([ETIP, 2021](#)).

3.7.4. Refuelling times

According to [Giuliano et al., \(2020\)](#), the average refuelling time for diesel trucks is fifteen minutes. We assume similar refuelling times for biofuels, because of similarity in substance and existing refuelling infrastructure is suitable for supplying these fuels in the future if necessary.

3.8. Technologies to power HDVs running on e-fuels

3.8.1. Vehicle developments

E-fuels are synthetic fuels made from hydrogen synthesised using renewably powered electrolysis and carbon dioxide (CO₂) captured from a concentrated source (industrial flue gases) or the air (direct air capture) ([Concawe, 2020](#)). E-hydrogen is an E-fuel itself, but in this section we particularly refer to e-fuels such as e-diesel, e-methane, e-methanol, and e-ammonia. E-fuels can be used with relatively minor adaptations in internal combustion engines, still in use in over 98% of EU27 trucks. E-fuels are still only in the pilot phase, and are not expected to play a significant role on the short term (2030). The big drawback for E-fuels is the low energy efficiency well-to-wheel due to the conversion steps from electricity via hydrogen to E-fuel. Therefore also fuel costs are high as compared to electricity and hydrogen ([CE Delft & TNO, 2020](#)). Concawe expects E-fuels also to be more expensive than fossil fuels up to 2050. The application of E-fuels is expected to focus on aviation, maritime and the long-haul road transport segment ([Concawe, 2020](#)).

3.8.2. Infrastructure developments

The diversity of e-fuels means a range of different storage and distribution conditions and systems. E-methane is compatible with existing powertrains and can use existing infrastructure for gaseous fuels like CNG and LNG. E-hydrogen requires the same (new) infrastructure as other types of hydrogen. E-ammonia is readily stored in liquid form, but distribution infrastructure is still lacking ([Concawe, 2020](#)). It is currently more mentioned as a decarbonisation option for maritime shipping. In contrast to gaseous e-fuels, most liquid e-fuels are relatively easy to store and transport and can be used in existing ICE vehicle fleets.

3.8.3. Existing infrastructure

Existing transportation infrastructure and storage facilities as well as filling stations can be used for e-fuel supply and distribution. Depending on the type and form of the e-fuel, the dedicated infrastructure for oil-like fuels and gaseous fuels can be used.

From a technological perspective a wide range of options exist to facilitate the recharging and refuelling of trucks, but it can be questioned how fast these infrastructures can be realised. In the next chapter, the main barriers are discussed which hinder a fast roll-out and which could be (partly) reduced by policy intervention.

3.8.4. Recharging and refuelling times

According to [Giuliano et al., \(2020\)](#), the average refuelling time for diesel trucks is fifteen minutes. We assume similar refuelling times for e-fuels, because of similarity in substance and existing refuelling infrastructure is suitable for supplying these fuels in the future if necessary.

3.9. Conclusions

From an environmental perspective, zero-emission technologies like BET and FCET have the greatest reduction potential when powered using renewable energy sources. It is therefore justified that

European policies focus mainly on these powertrains. While these technologies are sufficiently mature, they are still at an early stage of commercialisation. BETs are just starting to be produced in series, whereas series production of FCETs is expected to still need 5 years. Current uptake of BETs and FCETs is still minimal, although particularly the share of BETs in vehicle sales is rising, as more and more OEMs bring models onto the market and developments in battery capacity enable longer distances.

Electric road systems, e-fuels and liquid hydrogen are seen more as options for the medium to long term, as they are still at a very early phase of development. The main challenges facing refuelling and recharging concepts for gaseous hydrogen and renewable electricity relate to size and scale compared with refuelling and recharging of LDVs. This is mainly the result of the higher energy demand of trucks. Linked to this challenge is the need to significantly reduce refuelling and recharging times. Yet 300- 350 kW fast-charging points are already available at charging stations for LDVs.

Besides refuelling and recharging times, trip distance is an important criterion determining infrastructure needs. Approximately 90% of truck trips are in the short- and medium-haul segment¹⁸, corresponding to approximately 50% of both vkm and tkm. The long-haul segment represents only about 10% of trips, covering about 50% of tkm as well. With respect to location of infrastructure, the focus on the TEN-T network is justified, because almost 75% of all freight trips by truck have their origin and destination in a NUTS region 3 (see footnote 12) connected to the TEN-T network. For long-haul trips (> 400 km), this share amounts almost 85%. Depot charging will be the main form of BET recharging infrastructure in the future, but publicly accessible fast-charging stations along the TEN-T network are in any case essential for long-haul as well as medium-haul transport.

¹⁸ Assuming short- and medium-haul trips are up to 400 km, and long-haul trips are > 400 km.

4. BARRIERS AND ENABLERS

KEY FINDINGS

- Although action is required in the short term, the **lack of investment security, of a stable long-term policy framework and of a targeted, uniform approach** is hampering a rapid roll-out and increasing realisation times (both implementation of policies as well as development of technology on the ground). The strategic roll-out plan published by the European Commission together with the proposal contains a strategy and clearly defined actions to reduce these barriers.
- A range of future and ongoing **standardisation initiatives** would result in greater harmonisation and less uncertainty with respect to the operational performance of infrastructure. New standardisation initiatives will be especially beneficial for hydrogen infrastructure, as certain key choices are still to be made.
- **Grid-related barriers**, although addressed in the strategic roll-out plan, will probably remain a concern, in terms of both technical aspects and lead times.
- **Funding mechanisms** with large budgets allocated to infrastructure deployment would significantly reduce economic barriers, though market actors would need to find their way through the wide range of financing options with care being taken that procedures do not constitute an additional barrier.
- **Procurement and permit procedures** need to be improved and simplified, to significantly reduce roll-out times and make concessions more transparent and competitive.
- Stakeholder and knowledge platforms like the **Sustainable Transport Forum** and the **European Alternative Fuels Observatory** will play an important role in stakeholder cooperation and data governance, which will remain complex owing to the numerous stakeholders and emerging technologies involved.

As we saw in the previous chapter, alternative fuels infrastructure for trucks is still very limited, especially for zero-emission technologies, where it is still mostly in the pilot phase. The feasibility of the various refuelling and recharging concepts over the coming decade will be determined by the extent to which deployment is hampered or accelerated by barriers and enablers. Where possible, an example is provided for each one of the alternative fuels. On 14 July 2021 the European Commission published the communication [‘A strategic rollout plan to outline a set of supplementary actions to support the rapid deployment of alternative fuels infrastructure’](#) describing how barriers should be overcome at the EU level. These scheduled EU actions have therefore been added to our initial analysis of barriers and enablers.

4.1. Technical barriers and enablers

Standardisation

The development of technical standards for alternatively fuelled trucks and refuelling/recharging systems, will contribute to a swifter and smoother uptake of these technologies. For BETs, the power sockets on the trucks and plugs of the charging points should be standardised across the EU, so trucks can recharge anywhere. Also, if the same power capacity levels are used at charging stations throughout Europe, road hauliers will have greater certainty about probable charging times. The same

holds for the available hydrogen pressure levels at Hydrogen Refuelling Stations (HRSs). Furthermore, European standards can prevent the use of converters that could affect power quality and thus truck batteries. When it comes to development of recharging stations and hydrogen refuelling stations, a European standard on design of such stations could help ensure they are safe, secure and are able to provide high-quality services. Design requirements could also help recharging station developers determine the optimal proportion of charging points and parking spaces for BETs depending on installed power capacity. On the other hand, a mandatory set of design requirements could also work restrictive and deter investments or delay realisation of such stations.

In its [communication on the strategic roll-out plan](#), the European Commission points out that, despite the progress achieved, there are still many outstanding needs regarding standardisation as a result of new technological developments and higher digital and communication requirements. The strategic roll-out plan defines electric recharging and hydrogen refuelling points for HDV as priority for standardisation. The Commission will be working together with the European standardisation organisations and bodies towards adoption of new standards. Article 19 of the [AFIR proposal](#) requires that for interoperability reasons, all recharging and refuelling concepts need to comply with technical specifications as laid down in Annex II of the [proposal](#). The technical specifications cover vehicle connector type, fuel labelling, etc. and refer to the different European and ISO standards.

Hydrogen refuelling points

With a view to creating a coherent network of hydrogen refuelling infrastructure, there is an urgent need to finalise the technological approach to be adopted. The current lack of standardisation of on-board H₂ storage systems for trucks affects the entire value chain, including refuelling equipment. The various options (350, 500 and 700 bar, liquid, cryo-compressed) all have their pros and cons. A coordinated approach is lacking, however, with individual OEMs focussing on different types of solutions. Once the market has greater certainty as to which on-board storage technologies are to be used, deployment of hydrogen refuelling stations (HRS) can be accelerated. Article 6 of the proposed Regulation requires publicly accessible hydrogen refuelling stations to be deployed with at least a 700-bar dispenser (and a minimum capacity of 2 tonnes/day every 150 km) and also requires liquid hydrogen to become available every 450 km along the TEN-T core and comprehensive network. Operators of publicly accessible refuelling stations in freight terminals should supply liquid hydrogen as well. As a result of these specific technical requirements, the proposed Regulation is contributing to the standardisation of hydrogen refuelling points.

A further barrier is the lack of a good communications interface between trucks and hydrogen refuelling stations or in other words: how the truck and hydrogen refuelling station exchange information ([Ruf, Baum, Zorn, Menzel, & Rehberger, 2020](#)).

Electric recharging

For charging electric vehicles, the charging protocol of a Combined Charging System (CCS)¹⁹ is available and seen as European and North American standard, while a [Megawatt Charging System](#) (MCS) is in development and will probably be ready in a few years. Standardisation for electric road transport (both passenger and freight transport) has until now been focused on electro-technical issues (plugs, outlets and electrical safety specifications), but what is now required is standardisation of communication interfaces, development of new data models to integrate vehicles into the grid

¹⁹ The Combined Charging System (CCS) is one of the charging plug standards for charging electric vehicles (DC fast charging).

and development of EU-wide e-roaming networks. With e-roaming a driver can recharge everywhere at stations of any (electro) mobility service provider²⁰ without any issues.

Adequate power levels

Adequate power levels are another barrier related to the technical aspects of electric truck charging. In the first place, the power levels of today's charging stations are too low for adequate BET charging during stops (driver resting times). [Regulation 516/2006](#) requires breaks of at least 45 minutes to be taken after 4 ½ hours at most. Current fast-chargers are in the power range of 50 to 350 kW, with 1 MW charging points still under development. As shown in Section 3.3.4 (Table 4), 600 kW-1.2 MW chargers will enable complete recharging within 60 minutes for ranges of 400 and 800 km. The first megawatt chargers are expected to become available in the coming 5 years. There is still some uncertainty about to what extent it will be allowed during resting times to drive the truck from a parking lot to a charger or vice versa.

The proposed Regulation requires an adequate number of publicly accessible fast recharging points dedicated to heavy-duty vehicles to be deployed along the TEN-T network with sufficient power output to allow recharging during the driver's legal break time:

- All recharging pools to be realised along the TEN-T core network should be equipped with at least an individual power output of at least 350 kW by the end of 2025 and at least two by the end of 2030;
- For the recharging pools along the TEN-T comprehensive network these requirements should be met by the end of 2030 and the end of 2035, respectively.

Based on the analysis of refuelling times, it can be queried to what extent the requirement of at least 350 kW will result in sufficient power levels to allow recharging within driver resting times.

Grid capacities

Another technical aspect relates to the impact of alternative fuel infrastructure development on the energy grid. This concerns first and foremost the recharging infrastructure for BETs. Considering that fast chargers with a capacity in the order of 1 MW are preferred by the logistics sector and that a charging station will contain multiple charging points, a high-capacity connection to the (medium or high-voltage) power grid is necessary. The power grid at truck charging locations will often need strengthening to deliver the required power capacity ([Hendriksen, Sloots, & Jong, 2021](#)). For grid connections to private charging points at depots and distribution centres, too, the power distribution grid may need to be strengthened. Here, much time and money could be saved by adopting an integrated grid reinforcement strategy factoring in the projected growth in private (and public) recharging capacity in the power distribution grid as a whole.

Grid balancing

A second power grid impact concerns the balancing of electricity supply and demand. The mass introduction of wind and solar power in the power system complicates electricity system balancing, increasing the need for end-user flexibility. BETs using recharging stations *en route* cannot provide such flexibility, as they must recharge right away. While BETs charging at night may be able to provide flexibility by shifting the charging pattern somewhat towards the night, the potential for this depends on the power capacity of charging points and the minimum required energy level of the truck battery.

²⁰ According to the strategic roll out plan: 'a commercial actor who provides services to an end user, including the sale of a recharging service'.

Logistics companies might be incentivised in this direction through dynamic electricity pricing and fitting power chargers with an automatic control system.

The proposed AFIR Regulation stresses the need for smart recharging and smart metering systems to ensure grid stability and the recharging of electric vehicles in a way that “does not cause congestion and takes full advantage of the availability of renewable electricity and low electricity prices in the system”.

The [proposal](#) also acknowledges the relevance of bidirectional (vehicle-to-grid) recharging points for the power grid. Article 14 requires the regulatory authority of each Member State to assess by 30 June 2024 at the latest (and every three years thereafter) the potential contribution of bidirectional charging to the penetration of renewable electricity into the electricity system. Such potential contribution should be based on the input from transmission system operators and distribution system operators. Member States should take appropriate measures if deemed necessary. This could include adjustments to the availability and geographical distribution of bidirectional recharging points. In this way, BETs could also act as an enabler for penetration of renewable electricity.

4.2. Operational barriers and enablers

The main operational barrier for BETs and FCETs is the lack of a connected national and international network of refuelling stations, and for ERS trucks a completed Electric Road System (ERS) network. Other operational barriers relate to shared use of charging stations and the simultaneous recharging needs of companies with similar trip characteristics. The availability of charging points at certain times of day is crucial for companies’ operational planning, and sharing public (or private) infrastructure might lead to unacceptable uncertainties. To avoid excessive time losses, sufficient (fast-)charging points and a well-functioning reservation system will need to be developed, as will an overall information system on public and private charging points (in terms of characteristics and accessibility), which is currently still lacking.

The accessibility of public, unattended areas (without staff) where charging infrastructure is available is often high, whereas attended areas (with staff) are often less accessible. One disadvantage of public, unattended charging points is that charging sometimes requires drivers to leave their vehicles unattended, which might violate insurance conditions ([Hendriksen, Sloots, & Jong, 2021](#); [Ruf, Baum, Zorn, Menzel & Rehberger, 2020](#)).

Existing infrastructure can provide opportunities to make them fit for truck refuelling. For example, existing hydrogen refuelling stations for cars and buses could be upgraded. After upgrading, capacity utilisation could rise close to 100%, reducing operational expenditure (OPEX) by up to 25% ([Ruf, Baum, Zorn, Menzel & Rehberger, 2020](#)).

The proposed AFIR Regulation also lays down requirements linked to the operational aspects of infrastructure, like payment methods and rules for automatic authentication. With respect to prices, these should be ‘reasonable, easily and clearly comparable, transparent and non-discriminatory’. At the least, the price per session, price per minute and price per unit of energy should be displayed. Member States should ensure appropriate signposting within parking and rest areas on the TEN-T network. In addition, Article 17 of the AFIR proposal on User information describes several additional requirements relating to information on vehicle compatibility and labelling provisions.

Data provision/information provision

A standard information system informing truck drivers about European station locations, the number of dispensers/chargers, currently available power capacities/pressure levels and estimated charging time would be very valuable for road hauliers. It would create transparency and interoperability.

Developing such a system will be challenging, as OEMs, station operators and third market parties are likely to have or develop different information systems. However, all parties would benefit from the sharing of information, in order to make the switch to alternatively fuelled trucks as attractive as possible for road hauliers. OEMs are already moving in this direction by sharing [information on truck stop location data](#) and the Dutch government has also been working on [an interactive map](#). A study of Fraunhofer ISI on behalf of the European Automobile Manufacturers' Association (ACEA) indicates key locations for future deployment of infrastructure, including at long-haul and regional stop locations in the European Union, the UK and other countries in the EU.

The same can be said about the development of a single payment system for BETs. Furthermore, it would be helpful for road hauliers if a standard protocol was developed for determining the energy level to which the truck batteries are recharged when there is a (digital or physical) waiting line at a recharging station.

Article 18 of the AFIR proposal requires Member States to appoint an Identification Registration Organisation (IDRO) to govern the availability of static and dynamic data and accessibility of this data by means of identification codes. Article 18 also states that 'operators of publicly accessible recharging and refuelling points (...) shall ensure the availability of static and dynamic data concerning alternative fuels infrastructure operated by them and allow accessibility of that data through the National Access Points at no cost'. Static data includes data on geographic location of the infrastructure, number and type of connectors, type of current (AC/DC) and power output (kW). Dynamic data includes operational status (whether infrastructure is operational or off-line), whether it is currently available or in use, and ad hoc price. In the future the Commission may introduce additional categories of data that must be communicated.

In the strategic roll-out, the Commission elaborates in greater depth the need for a data and governance framework, especially for the electro-mobility ecosystem, but for other fuel types, too. The Programme Support Action on 'Data collection related to recharging/refuelling points for alternative fuels and the unique identification codes related to e-mobility actors (PSA IDACS)' should improve data collection and the development of new digital services. Those services will improve quality and user-friendliness of the alternative fuels infrastructure, but will strongly depend on the openness of the data to the user and the level of connectivity with other data. Until now, the European Alternative Fuel Observatory (EFAO) has provided online data on alternative fuel infrastructure, including an interactive map and with the focus on policy monitoring. A new Knowledge Platform for public authorities will be added, together with a consumer information section. According to [the strategic roll-out plan](#), EFAO has the potential to become the common European data access point. Discussions will be held in the Sustainable Transport Forum on the specifications required for development of an open data ecosystem and as input for a possible delegated act planned for 2022.

4.3. Economic barriers and enablers

Level playing field

The main economic barrier for alternative fuels and the related infrastructure is the competition with a well-established transport system that has been operated and optimised for over a century. The infrastructure for alternative fuels is still to be built, at both higher cost and higher risk, creating less predictable business cases for investors ([IEA Bioenergy, 2020](#)). The price per kWh needs to go down at public charging stations as well, because the difference between public and private charging is too large and will form a barrier for commercial users (stakeholder interviews: research). For hydrogen refuelling stations, the lack of targeted funding and incentive schemes has been identified as the main economic barrier ([Ruf, Baum, Zorn, Menzel, & Rehberger, 2020](#)).

For BETs, a lack of funding and incentive schemes is probably not a main economic barrier, especially because BETs are expected to reach cost parity with diesel-powered trucks by 2025 and even have a more cost-effective total cost of ownership (TCO)²¹ in the case of a lower-range BET, compared with diesel trucks. However, infrastructure and more systematic costs are often not included in TCO calculations. Annex A of this report provides more insight in cost projections and Total Cost of Ownership and highlights some specific cost aspects, such as the operational cost.

Barriers for SMEs

Larger companies are better placed than small and medium-sized enterprises (SME) when it comes to investing in charging infrastructure for BETs. Large companies can benefit from economies of scale and take greater risks, reducing the need to insure against loss of turnover. They can also benefit from lower tax tariffs. For example, in the Netherlands energy taxes per kWh are lower for heavier grid connections. Moreover there might also be fiscal policies that impair SMEs compared to larger companies ([Hendriksen, Sloots, & Jong, 2021](#)).

Fiscal incentives and barriers.

In terms of fiscal incentives, [Hendriksen, Sloots and Jong \(2021\)](#) also mention barriers related to differences in energy taxation between large companies and SMEs. In some Member States, like the Netherlands, energy taxes decrease per unit of energy in case of larger use, which is a disadvantage for SMEs. There are also examples of energy taxes being paid twice in the context of storage and certain forms of smart charging (vehicle-to-grid), both valid for SMEs as well as larger companies. For example, subsidy schemes sometimes favour grid feed-in of electricity generated on-site rather than direct consumption for charging the haulier's own fleet. Schemes and conditions differ per Member State.

LDV versus HDV

In terms of investment security, the market for shared truck charging infrastructure is not yet sufficiently mature and therefore less attractive for investors compared with investment in similar infrastructure for passenger vehicles. Investors would also like to have some certainty on the number of users, which again favours larger-scale user groups and therefore larger companies ([Hendriksen, Sloots, & Jong, 2021](#)).

Policy support to overcome barriers

Two key financial barriers – developing a positive business case and the high alternative fuel prices and electricity prices compared to diesel – can be addressed by a variety of policy measures. Developers of alternative fuel infrastructure could be supported through investment funds, such as the Recovery and Resilience Facility (RRF), providing them with investment capital on favourable terms. This would be especially helpful for SMEs wanting to invest in refuelling/recharging infrastructure, but with limited access to capital. For logistics companies investing in a private charging point, obtaining permission to sell electricity to other parties using the point will make the business case more attractive. For road hauliers, the financial appeal of purchasing and using alternatively fuelled trucks could be positively influenced by a range of policy instruments:

- closing the Total Cost of Ownership (TCO) gap between diesel versus alternative fuel trucks;
- 'green tax tariffs' for alternatively fuelled trucks;
- lower tax rates for alternative fuels/electricity;

²¹ A calculation method that determines overall cost of a vehicle or service throughout its life cycle, including direct and indirect costs.

- road toll discounts, zero-emission zones;
- a tax on truck CO₂ emissions.

The European Commission has confirmed that public support for installing recharging and refuelling points will often remain necessary. The European Green Deal projects that a more than fourfold increase in electric recharging infrastructure will be needed by 2025 to cater for the projected increase in the electric vehicle fleet (all types of vehicles). [The strategic roll-out plan](#) states that for road transport alone, the total investment costs between 2021 and 2030 under the Commission's proposal amount to approximately € 1.5 billion annually.

Funding mechanisms

Various funding mechanisms have been identified to overcome the economic and financial barriers in the coming years.

First of all, the [Annual Growth Strategy 2021 \(AGS 2021\)](#) identifies investment in sustainable transport as a key priority for the **national recovery and resilience plans (RRPs)** to be prepared by Member States in the context of the [Recovery and Resilience Facility \(RRF\)](#). In tandem with the growing demand for ZE vehicles, RRP should boost roll-out of recharging and refuelling infrastructure. The flagship area [Recharge and Refuel](#) under the RRF also promotes charging and refuelling stations, while the [Power-up](#) flagship area focuses on hydrogen lead markets and related infrastructure. Member States are encouraged to make full use of these funding opportunities and work together to maximise the benefit of RRF-supported investments. The Commission's Technical Support Instrument (TSI), with a budget of € 864 million for 2021-2027, can provide Member States with technical support. For the 2022 cycle, Member States can make use of this funding as part of a technical support project under the Recharge and Refuel flagship aimed at measures on alternative fuels infrastructure.

During the 2014-2020 financing period the [Connecting Europe Facility \(CEF\)](#) supported the roll-out of a large number of electric vehicle (EV) recharging points, hydrogen refuelling points, LNG/CNG refuelling points and Onshore Power Supply (OPS). For the upcoming financing period 2021-2027 (CEF II), a substantial increase in support for roll-out of alternative fuels infrastructure can be expected by means of complementary funds and financial instruments. Of the overall budget, 60% will be used to co-finance initiatives that support climate objectives and aim to accelerate the transition to zero-emission mobility. To this end, CEF II will create a dedicated **Alternative Fuels Facility (AFF)**, funding alternative fuels infrastructure for renewable and low-carbon fuels by combining CEF grants with financing from finance institutions in order to increase the impact. The Commission, for example, intends to define 'an appropriate fixed co-funding rate for electricity and hydrogen alternative fuels infrastructure projects for all modes of transport', both under the CEF as well as under the Cohesion envelope.

Attract private investments

The roll-out strategy mentions many more partnerships and funds, furthermore, such as the Horizon Europe partnerships, as options for attracting private investment in the deployment of refuelling and recharging infrastructure.

Taxonomy Regulation

Finally, the European Commission also adopted the [Taxonomy Regulation](#) in 2020, including a classification system for green economic activities. This system will help scale-up of green financial

products (green bonds and green securitisation), which are also suitable for promoting investment in alternative fuel infrastructure deployment, including infrastructure for heavy-duty vehicles.

State Aid

State Aid rules apply when the market, left to its own devices, does not achieve the required investments and public support is needed. The Commission has provided specific [guidance](#) on how to deal with State Aid rules for recharging and refuelling infrastructure for road vehicles, specifically for electricity and hydrogen (or other gases as a transitional solution).

4.4. Institutional and regulatory barriers and enablers

Institutional and regulatory barriers for BETs

There are several institutional and regulatory barriers for BETs. First, logistical parties aiming to share infrastructure are failing to come to appropriate agreements because it is unclear how liability and damage will need to be handled from a legal perspective. Secondly, to optimise the use of charging infrastructure, subsidy schemes could be designed to include requirements for sharing this infrastructure, although for some stakeholders these requirements might act as a barrier for shifting to EV. For example, companies could be classified as energy supplier when they share private infrastructure with accompanying requirements (stakeholder interviews: research). Thirdly, companies often experience problems with investment security in the absence of stable support mechanisms over the longer term ([Hendriksen, Sloots, & Jong, 2021](#)). A more technical institutional barrier concerns the difference in permissible weight between ICE trucks and BETs, but if the EU takes steps to allow extra battery weight in BETs this will no longer be an issue (stakeholder interviews: research, NGO, logistics). In relation to grid adjustments, in the Netherlands it is national energy legislation that determines when new infrastructure is deployed. Infrastructure will only be developed where there is guaranteed demand, which can be seen as counterproductive for the development of HDV charging infrastructure.

Institutional and regulatory barriers for HRSs

For hydrogen refuelling stations (HRSs), the [HyLaw project](#) has described multiple legal and administrative barriers (Hydrogen Europe, 2019). The permit process for HRSs is currently long and costly, while the outcome is uncertain. The stakeholders involved have insufficient knowledge to streamline efforts and guarantee a smooth process, resulting in cost increases and delays. Current permit requirements for HRSs are based mainly on EU-level obligations, including:

- risk assessment ([Seveso Directive](#))²²;
- health and safety requirements together with conformity assessment procedures ([ATEX Directive](#))²³;
- integrated environmental obligations (Industrial Emissions Directive);
- environmental Impact Assessment procedures ([SEA](#) and [EIA](#) Directives).

These directives are designed mainly for regulating large-scale, heavily polluting industrial processes, but they also apply to small-scale, non-emitting hydrogen initiatives. While HRSs with on-site electrolysis cannot be classified as such, the same requirements apply, which severely inhibit

²² Directive on the control of major-accident hazards involving dangerous substances, named after the town Seveso, where catastrophic accident took place.

²³ European Directive 2014/34/EC relating to equipment and protective systems intended for use in potentially explosive atmospheres.

deployment of such HRSs, and push up the overall costs and time required for development ([Hydrogen Europe, 2019](#)). Moreover, transposition of these EU directives into national law has resulted in differences in procedures between Member States.

Although multifuel stations offering hydrogen have already been realised, safety distances and other rules limit the options for co-locating hydrogen in existing refuelling stations. Currently, on-site production of hydrogen requires HRSs siting in industrial zones, as hydrogen production is deemed an industrial activity. The rules on storing low to medium quantities of hydrogen also create barriers for siting in areas where HRSs would be close to consumers. For the use of hydrogen in vehicles, regulatory and administrative barriers are limited ([Hydrogen Europe, 2019](#)).

Institutional and regulatory barriers for ERS infrastructure

The decision-making process for ERS infrastructure deployment is more complex than for recharging/refuelling infrastructure, as ERS infrastructure is stretched out and needs to cover complete corridors to be functional. This also takes longer implementation time. Moreover investment costs are high, and during implementation traffic may need to be re-routed. For cost-efficient decision-making, the costs and benefits of multiple infrastructure routes also need to be analysed. Furthermore, there is little experience with development of ERS infrastructure and limited to a few Member States (Germany and Sweden are working on pilots).

Common aspects

There are two general barriers to a rapid realisation of alternative fuels infrastructure for trucks. First, finding locations for public recharging stations near the TEN-T corridor may be difficult. When charging points are installed at existing refuelling stations, the lack of space for the charging points themselves as well as for truck parking may require a redesign of the station. When a new recharging station is planned, finding a plot of land may prove difficult owing to competition for land purchase and use and possible resistance from citizens.

Secondly, a major threat for the successful deployment of recharging points (both public and private) is the possible need for power grid reinforcement. Public station developers might be able to reduce roll-out time by locating new stations near power grid sections that have greater residual transport capacity or are easier to reinforce. For private charging points on hauliers' own sites, the time to obtain a permit may vary among countries, regions and municipalities. If the company wishes to make its private charging point available to others, moreover, permit procedures may mean additional time losses, as the company then becomes an energy supplier.

If these two barriers are addressed through harmonisation and simplification, deployment times will be speeded up. Lengthy power grid reinforcement processes could be avoided by a fundamental regulatory change with respect to investment in grid expansion. Today, investments are often reactive, with grid operators only allowed to invest when the need for grid expansion is proven in terms of actual congestion problems. Investments relating to recharging infrastructure should become more proactive, allowing grid operators to anticipate the future development of recharging stations at certain locations. These locations could be determined by national governments early on in the TEN-T framework, which would limit the risk of stranded assets.

Better planning, permitting and procurement

Many institutional and regulatory barriers can be reduced by improving the overall framework for planning, permitting and procurement of infrastructure. Long concession procedures can be a major constraint on efficient realisation and public authorities can take steps to reduce them and improve transparency and competition.

The Sustainable Transport Forum²⁴ has already formulated a set of Recommendations to support public authorities in procuring and awarding concessions, licences and other types of support for electric recharging infrastructure for passenger cars and vans. A 'sub-group on best practices of public authorities to support the deployment of recharging infrastructure' established early 2021 is to update these Recommendations. They will also compile a summary Handbook and will aim for harmonisation and simplification of permitting and grid connection procedures. Deliverables of the sub-group will be shared on the new dedicated Knowledge Platform for public authorities of the European Alternative Fuels Observatory (EAFO).

Enablers from an institutional and regulatory perspective

There are also policy instruments geared to increasing demand for alternatively fuelled trucks by means of obligations: renewable energy obligations for trucks, [zero-emission zones and ICE bans](#), for example, compelling logistics companies to move away from diesel trucks. In addition, existing CO₂ standards induce truck OEMs to switch to the production of alternatively fuelled trucks.

4.5. Social attitudes, user acceptance

For biofuels as well as for other sustainable fuels, user acceptance has been identified as a barrier. Negative public perception and fundamental scepticism will need to be overcome to achieve user acceptance. With biofuels, users may be concerned about sustainability risks and engine compatibility. If there is uncertainty about operational performance, companies may be hesitant about switching to BET, FCET or low-carbon drop-in fuels, an hesitation which has been confirmed by the interviews. Low user acceptance also often relates to a lack of financial incentives to attract potential user groups ([IEA Bioenergy, 2020](#)). Specifically for hydrogen mobility limited experience as well as safety concerns constrain user acceptance. This holds for both industry and the public ([Ruf, Baum, Zorn, Menzel, & Rehberger, 2020](#)).

4.6. Organisational barriers and enablers

Stakeholder cooperation

A well-functioning and well-used alternative fuels infrastructure for trucks in Europe requires cooperation among numerous stakeholders: governments, truck OEMs, fuel technology providers, fuel suppliers, grid operators, refuelling/recharging system operators and road hauliers.

- Governments should create a favourable investment climate for refuelling/recharging station developers and close the TCO gap for road hauliers to use alternative fuels. They should realise standardisation and interoperability of alternative fuel technologies and remove regulatory barriers to power grid reinforcement. Truck OEMs in Europe should develop an alternative fuel strategy, expand the production volumes of alternatively fuelled trucks and cooperate with station developers to ensure technical compatibility of trucks and refuelling/recharging systems.
- As with most types of alternative fuels, station developers should build new refuelling/recharging points to match the rising alternative fuel demand from trucks and integrate these into existing stations.

²⁴ The Sustainable Transport Forum is the Commission's main expert group working on the subject of alternative fuels infrastructure. The forum brings together representatives from all Member States and from key interest organisations and industry players.

- Grid operators should reinforce the power grid in anticipation of recharging station construction.
- Road hauliers should make a commitment to shift to an alternative fuel.

If the various stakeholders coordinate their plans and efforts, this will reduce market uncertainties, improve the speed of implementation and reduce switching costs.

Cooperation among EU Member State governments is needed in order to harmonise the support schemes, and level taxes and fuel prices for the truck sector.

Collective decision-making by national governments (or EU decision-making) on specific, critical barriers is needed. An important barrier is limited access to refuelling/recharging stations. Tesla's recharging stations are only accessible for Tesla vehicles, for example. Universal access to refuelling/recharging stations maximises accessibility, making alternative fuel technologies more attractive to road hauliers. It also means more efficient use of stations and of public capital to build them. Another barrier related to accessibility that should be tackled by collective decision-making is coordinated planning of future station siting, along all TEN-T corridors. Finding means to support European countries with lower funding capacity in building alternative fuel infrastructure would make an important contribution to such full network coverage.

Stakeholder cooperation

Effective deployment of BET charging infrastructure is currently being hampered by the involvement of numerous stakeholders in the supply chain, by a dearth of initiators and by a lack of clarity on business models and division of labour. Mutual cooperation agreements between end users and owners are needed to remove charging-related uncertainties, but at present stakeholders are not readily finding one another. Public authorities can help accelerate this process ([Hendriksen, Sloots, & Jong, 2021](#)).

The Commission has acknowledged these barriers and stresses the need for effective and efficient cross-border and cross-sector cooperation among all public and private-sector stakeholders. To this end the Commission has involved the [Sustainable Transport Forum](#) in the development of the strategic roll-out plan. In the coming years the Commission will continue this broad stakeholder cooperation and has set up various new expert sub-groups under the auspices of this forum in order to support the activities of fact-finding and decision-taking in key areas such as data governance, communication protocols and interfaces, planning, permitting and concession practice.

Another important forum is [the European Alternative Fuel Observatory \(EAFO\)](#). This initiative makes key data on alternative fuels infrastructure available online. The functionality of this policy monitoring tool will be improved in the coming years by including a new Knowledge Platform for public authorities and a consortium information section. Overall, EAFO has the potential to become the common European access point for real-time data on alternative fuels infrastructure.

In addition to the Sustainable Transport Forum and the European Alternative Fuel Observatory, the Commission mentions in [the strategic roll-out plan](#) it will closely follow developments in other relevant fora. Member States are also encouraged to involve stakeholders at all levels of governance in national policy discussions.

Space requirements

Alternative fuels infrastructure for trucks will generally require additional space alongside existing fuel infrastructure. This is especially true for recharging infrastructure, since BET recharging takes much longer than truck refuelling with a renewable fuel, creating a need for numerous charging points and truck parking spaces. Many of today's refuelling station will have insufficient space for this, so new land

will need to be acquired. In some cases, redesign of the refuelling station may suffice, but both routes involve organisational challenges. There may be insufficient unused adjacent land and there may also be a need for local motorway adaptation, for example.

Redesigning a refuelling station, in tandem with organising and installing a high-capacity power grid connection, may take a long time and hamper ongoing daily refuelling activities. The station operator needs to plan and manage the changes carefully. Investors in recharging stations at new locations face similar organisational challenges, although they do not need to deal with impacts on current refuelling activities.

Hydrogen refuelling stations may not require a lot of additional space, as FCETs can be refuelled just as quickly as conventional diesel trucks. Extra space will be needed for a compressor unit, to bring the hydrogen to the required pressure level (at least 300 bar) as well as for cooling units, hydrogen dispensers and certain safety features ([Rose & Neumann, 2020](#)). If the hydrogen is supplied by road, a hydrogen storage facility will need to be added. The station operator will then also need to acquire a hydrogen storage permit, obliging him to adhere to relevant safety regulations, which may differ from country to country. Pipeline hydrogen supply comes with fewer organisational barriers for the station operator, but is predicated on prior existence of a hydrogen grid connecting the station with one or more hydrogen production or import locations.

The roll-out strategy states that public authorities must consider how to allocate this scarce space among competing demands within overall plans for sustainable urban mobility.

Realisation of multimodal hubs

Besides barriers, there are also opportunities for increased HRS utilisation. Establishing a network of multi-purpose HRSs for different transport modes will lead to improved asset utilisation and consequently lower costs for stakeholders. Synergies can also be achieved by aligning TEN-T and TEN-E corridors, thus linking HRS with energy infrastructure ([Ruf, Baum, Zorn, Menzel, & Rehberger, 2020](#)). The proposed Regulation specifically mentions multimodal transport in relation to hydrogen refuelling stations. It suggests that authorities consider siting refuelling stations along urban nodes at multimodal freight centres, since these are typical destinations for heavy-duty vehicles and could at the same time supply hydrogen to rail and inland shipping. Examples of multimodal hubs include ports.

4.7. Conclusions

Many of the barriers identified in the earlier briefing, such as long lead times and the strong need for data governance, are addressed in the Commission's strategic roll-out plan. The Commission also acknowledges that addressing these barriers will be an ongoing process, due in part to the fact that emerging technologies will be constantly creating new challenges. With respect to the long list of funding opportunities, it can be queried to what extent stakeholders will find their way to the various budgets allocated to infrastructure deployment. Among the numerous barriers, adequate power output and grid reinforcement remain a particular challenge. Space requirements may also often be a major constraint.

Together, these barriers may stand in the way of achieving an optimal level of infrastructure by 2030, i.e. with sufficient recharging and refuelling infrastructure to effectively meet and spur demand. In the next chapter, we present an initial estimate of infrastructure requirements based on vehicle projections.

5. FUTURE INFRASTRUCTURE REQUIREMENTS

KEY FINDINGS

- **Fleet projections** point to trucks employing a **wider variety of powertrains in 2030**, with the main focus on the increase of **battery electric trucks**, followed by **hydrogen-powered fuel-cell trucks**. In the meantime, **biofuels** and at a later stage maybe **e-fuels** can contribute to low-carbon transport replacing liquid and gaseous fossil fuels.
- Consulted sources expect that European climate ambitions should result in a number of **270,000-520,000** BETs and **60,000-75,000** FCETs in 2030. The AFIR proposal is based on a lower number of BETs (110,000) and a similar number of FCETs (60,000) in 2030.
- A tremendous increase in investment and subsequent **large-scale roll-out** of recharging and refuelling infrastructure is needed. The majority of electric recharging points is expected **at (semi-)private depots and distribution hubs, providing overnight charging** at 50 to 100 kW. More or less for each BET a charging point is needed.
- **Publicly accesible charging on major freight corridors (TEN-T)** is needed for BETs, particularly in long haul transport. Both **fast chargers (> 500 kW)** for recharging during the day and **overnight chargers (about 100 kW)** at publicly accessible resting places along the TEN-T corridor are needed. In addition, fast chargers are needed at **urban nodes**, to allow reaching for short and medium distance transport as well. The AFIR proposal provides minimum targets for these locations.
- The minimum number of publicly accessible chargers estimated from the 2030 targets in the AFIR proposal is about **17,000**, and should allow for the market to further develop the infrastructure based on demand. The total number of required charging points estimated by the studies examined in the context of this analysis goes up to **85,000** in 2030.
- **The minimum number of publicly accessible overnight chargers** required by the AFIR proposal (one per safe and secure parking area) seems low compared to the required number of overnight chargers and **might be reconsidered** as these charging points are especially of importance to allow long-distance transport to circulate throughout the Union.
- While the AFIR proposal demands a minimum number of charging stations with a power output of at least 150 kW at urban nodes and 350 kW along the TEN-T corridors, the sources studied recommend to guarantee **chargers with a minimum power output of 350 kW at urban nodes** and over **500 kW along the TEN-T corridors**.
- **Hydrogen refuelling stations** need to be located strategically along major freight routes (TEN-T corridor), while technological standardisation for trucks and refuelling infrastructure is necessary for international coverage. The AFIR proposal sets targets for both liquid hydrogen and 700 bar fuel stations by 2030. Voluntary instead of binding targets for liquid hydrogen might be considered as the technology is still at an early development stage.
- To service hydrogen trucks it is expected that some 345-1,000 HRSs will be needed in 2030 along the **TEN-T corridor and in urban nodes**. The AFIR proposal is in line with these numbers, setting a target of about 700 HRSs in 2030. However, the minimum capacity set by the AFIR proposal (2t H₂/day) is lower than proposed by consulted sources (6-25 t/day).
- Kilometre projections of overhead catenary infrastructure in the EU depend very much on the extent to which ERS is to become the major technology.

The previous chapter set out the main factors hampering or enabling the deployment of alternative fuels infrastructure. These factors form an important consideration in formulating policy recommendations on the actions to be taken in the coming years. Another relevant consideration is the amount of infrastructure required to meet policy objectives. This chapter therefore discusses scenario projections of the need for dedicated alternative refuelling and recharging infrastructure for HDVs.

To understand the data on future infrastructure requirements, in Section 5.1 we first present projections of HDV fleet composition in 2030. Next, in Section 5.2. we review the projections of dedicated HDV refuelling and recharging infrastructure requirements in 2030 found in impact assessments and other literature. The HDV fleet and infrastructure projections are based on a number of institutions' predictions for the future technologies used in the HDV segment. In most instances we present the baseline figures – indicating the state of play under current and intended policies, and a regulatory path – providing estimates under an ambitious policy scenario, in which the more ambitious overall EU goal of 55% GHG emission reduction in 2030 is secured. In Section 5.3 we look at specific infrastructure needs related to different trucks segments (distance classes) and locations (e.g. highway, urban).

In each section we make a comparison with the AFIR proposal (EC, 2021e) from the 'Fit for 55' package. We discuss whether the proposed targets of the new [AFIR](#) can provide sufficient recharging and refuelling capacity to support the transition of freight transport to alternatively fuelled trucks according to the studied sources.

5.1. Vehicle fleet projections

The vehicle fleet projection figures cited in different sources ([the impact assessment of the European Climate Target plan](#), [IEA](#) and [ACEA](#)) are listed in table 6. As can be seen, these projections include different electrification options. In mild hybrid trucks, an electric motor assists the internal combustion engine and generally allows recovery of braking energy, feeding it into (small) batteries. A mild hybrid's motor cannot power the vehicle on its own and mainly reduces combustion engine efficiency losses. Plug-in trucks and traditional hybrids, on the other hand, do have an electric motor that can power the vehicle on its own. While conventional hybrids are charged during driving, plug-in hybrid electric trucks (PHET) can also be charged by connecting the battery to the grid. Battery-electric trucks have no combustion engine, only a battery and an electric motor.

[The impact assessment of the European Climate Target plan](#) (2020c), presents shares of the heavy-duty vehicle stock²⁵ in 2030 by type of powertrain (no absolute figures are given). The shares are given for several scenarios. Here we consider the baseline scenario (covering current and planned pre-2030 policies to achieve the energy and climate 2030 targets) and the regulatory scenario (REG), in which a higher ambition is assumed, aiming for 55% reduction of EU GHG emissions in 2030 ([EC, 2020c](#)). For these two scenarios, the shares of HDVs by type of powertrain are presented in Table 6. In the baseline scenario for 2030, the vast majority of vehicles is still diesel-powered, with 77.5% conventional diesel and 16% mild hybrid diesel trucks. Only 0.5% of the fleet is expected to consist of BETs. In the baseline, the share of hydrogen-powered trucks is negligible. In the 'high ambition scenario' the share of hydrogen fuel cell trucks in 2030 rises to 0.5%, while the share of BETs is still only 0.5%. The share of diesel trucks has decreased to 74%, mainly in favour of more gas-powered HDVs (9% compared to

²⁵ No definition of 'heavy-duty vehicles' is given, so we assume these EU Climate Target figures include buses, trucks and trailers, among other types of heavy commercial vehicles.

6% in the baseline). The 'high ambition scenario' envisions larger shifts to BET and hydrogen trucks after 2030 (not shown in Table 6).

The [International Energy Agency](#) (IEA) assumes a 2030 European fleet of approx. 7.5 million trucks. The IEA baseline²⁶ projects a 1.7% share of electric trucks in 2030, comprising PHETs (0.8%), BETs (0.9%) and hydrogen-powered FCETs (0.02%). In the IEA's 'sustainable development' scenario, the share of electric trucks is 10%, comprising PHETs (4.1%), BETs (4.9%) and hydrogen-powered FCETs (1.0%).

In its position paper on recharging and refuelling infrastructure requirements, ACEA presents its expectations on the alternatively fuelled HDV fleet in 2025 and 2030. ACEA distinguishes no scenarios. Its predictions are based on current and intended climate commitments and the strategies and efforts of governments and the truck manufacturing industry regarding carbon-neutral powered vehicles, especially in relation to the CO₂ standards for trucks laid down in 2019/1242 ([ACEA, 2021a](#)). ACEA projects 270,000 BETs and 60,000 hydrogen FCETs by 2030 and considers these numbers minimum estimates, as the technology strategies of the various manufacturers differ and the impact of further changes to the regulatory framework (e.g. the European Green Deal) was not considered.

Table 6: EU fleet projections by powertrain type, 2030

Source	Diesel (ICE) trucks	Diesel mild-hybrid trucks	ICE gas trucks (LNG/CNG)	PHET	BET	Hydrogen (FCET)	Total
Impact assessment EU Climate Target plan part 2 (2020)^a							
Baseline scenario	5,813,000 (77.5%)	1,200,000 (16%)	450,000 (6.0%)	-	37,000 (0.5%)	1,000 (0.01%)	7,500,000 (100%)
High ambition scenario (-55%)	5,550,000 (74%)	1,200,000 (16%)	675,000 (9%)	-	38,000 (0.5%)	38,000 (0.5%)	7,500,000 (100%)
IEA EV database (2021)^b							
Baseline scenario	7,371,000 (98.3%)			61,000 (0.8%)	66,000 (0.9%)	1,600 (0.02%)	7,500,000 (100%)
Sustainable development scenario (-55%)	6,752,000 (90%)			309,000 (4.1%)	364,000 (4.9%)	75,000 (1.0%)	7,500,000 (100%)
ACEA position paper on HDV charging infrastructure (2021)^c							
ACEA scenario	NS	NS	NS	NS	270,000	60,000	NS
T&E: Unlocking electric trucking in the EU: recharging along highways (2021)^d							
Baseline scenario	NS	NS	NS	NS	236,000	NS	NS
Road 2 Zero scenario	NS	NS	NS	NS	617,000	NS	NS
T&E: recommendation	MS	NS	NS	NS	520,000	NS	NS

Note: numbers are rounded to 1,000; the sum of the figures per category may not add up to the total because of rounding; NS: not specified in the source; - : no trucks of this type in scenario:

²⁶ Similar assumptions on the effect of existing and planned policies apply to the IEA baseline as for the baseline in the impact assessment of the European Climate Target.

- a The absolute figures are approximated, using the fleet stock data (1,500,00 vehicles) projected by the IEA (see below under b), as absolute numbers are not given in the Climate Target plan impact assessment. The relative figures are estimated from Figure 61 part 2.
- b IEA figures for Europe include the EU27, Norway, Iceland, Switzerland and the United Kingdom. The total number of 1,500,000 trucks was calculated by dividing the number of EVs by the share of EVs in the total.
- c ACEA figures for Europe include EU27 and the UK. Excluding UK: 230,000 (ACEA & T&E, 2021).
- d T&E figures are for the EU27. The baseline and "Road 2 Zero" figures include non-regulated trucks (approx. 15%). The recommendation excludes non-regulated trucks and corresponds to 85% of the 'Road 2 Zero' scenario without the 15% non-regulated trucks.

T&E uses three different scenarios for the number of BETs. The figures of their baseline (low) and 'Road 2 Zero' scenario (high) are also presented in Table 6. The Baseline scenario is based on average sale shares of battery-electric trucks of 2.8% in 2025 and 20% in 2030, based on announcements by OEMs (taking 0% for OEMs with no announcements). The 'Road 2 Zero' scenario is based on T&E's 2050 transport decarbonisation strategy (T&E, 2021). The number of trucks used for the T&E recommendation is based on the 'Road 2 Zero' scenario, excluding 15% non-regulated trucks above 16 tonnes, for which charging requirements are deemed uncertain.

We can conclude that the predictions for the alternatively powered HDV fleet composition in 2030 do not lean towards one specific technology, and that the shares of these alternatively powered trucks span a vast range. This is in line with the current degree of uncertainty on (the speed of) developments in HDV powertrain technology. It can be concluded, nonetheless, that by 2030 most sources expect higher number of BETs than FCETs, which given the start of series production of BETs (Chapter 3) and the later stage of development of FCETs makes sense.

Considering the different scenarios, we conclude that diesel ICE trucks will still constitute the overwhelming majority of vehicles in 2030, comprising approx. 7 million of the estimated fleet of 7.5 million trucks. To achieve lower emissions, the EU Climate Target plan impact assessment assumes a significant share of liquid and gaseous biofuels to power transport²⁷ (EC, 2020c). Estimates of the number of alternatively fuelled trucks vary among the sources, owing to uncertainties about development of the supporting infrastructure, vehicle and operational cost structure and the vehicle range of these types of trucks. The Climate Target impact assessment is on the low end, with 37,000 BETs in the baseline, while the IEA predicts about 360,000 BETs in the 'high ambition scenario' in 2030 and T&E even 617,000 BETs in the 'Road 2 Zero' scenario. In all the projections there are fewer hydrogen-powered trucks than BETs. Estimates of hydrogen-powered FCETs range from a couple of thousand to 75,000 in the IEA's 'high ambition scenario'. There are no specific estimates of the number of catenary-powered trucks, nor for other alternative fuels.

Comparison with AFIR proposal

In the baseline of the AFIR impact [assessment](#)²⁸, in 2030 there are 50,000 BETs estimated in the EU, and an uptake of 110,000 BETs in the policy options. Fuel-cell trucks are projected to play a more limited role by 2030 in the baseline (3,000 FCET) and 60,000 FCETs are assumed for 2030 in the policy options. The EU fleet of LNG-powered trucks is projected to reach approximately 510,000 vehicles in 2030 and 1.1 million in 2040 in all 3 policy options of the impact assessment. After 2040, these types of trucks are expected to be gradually replaced by zero-emission technologies.

The estimate for BETs in the baseline of the AFIR impact [assessment](#) (50,000) is comparable to the IEA baseline estimate of 66,000 BETs in 2030. However, the figure for the higher ambition scenarios of the

²⁷ This figure includes aviation and maritime transport, however.

²⁸ Impact assessment, Table 4 page 50.

AFIR impact [assessment](#) (110,000) is much lower (2.5-5 times) than the projections in the sources consulted, ranging from 236,000 (T&E baseline) to 520,000 (recommended by T&E, see Table 6). For LNG trucks, the impact assessment of the EU Climate target plan estimates 675,000 LNG trucks in the high ambition scenario. The impact assessment of the [AFIR proposal](#) estimates a similar amount of 510,000 LNG trucks.

These large differences may be due partly to different calculation methods and expectations regarding the adoption rates of alternatively fuelled powertrains in the truck fleet. If these higher estimates become reality in the coming years, however, the proposed targets may be insufficient to provide the necessary infrastructure to support the fleet of alternatively powered trucks. The more ambitious scenarios are more likely with the increased CO₂ mitigation ambition of the EU under the Fit for 55 package.

5.2. Demand for infrastructure based on vehicle trends

As the fleet projections include alternatively powered trucks as part of the operational fleet in 2030 and beyond, the question remains how these trucks are to be recharged and refuelled. For a number of energy carriers, alternative infrastructure will be needed to supply trucks with the required power.

In the following sections we present projections of refuelling and recharging infrastructure requirements, broken down by type of energy carrier, in the same sequence as in Chapter 3. [The impact assessment of the European Climate Target plan, \(2020C\)](#) and the [IEA, \(2021\)](#) give no precise estimates of demand for dedicated recharging and refuelling infrastructure for trucks. We therefore gathered data from a variety of institutional sources. A compilation of the findings can be found in the following sections and in Table 7.

Table 7: Estimated current and future needs (2025 and 2030) for alternative fuel recharging and refuelling infrastructure in the EU

Type of refuelling and recharging infrastructure for trucks	Number of refuelling and recharging points		
	Current	2025	2030
Overnight depot charging points	n.a.	40,000 to 127,000	270,000 to 470,000
Public overnight chargers	< 10	2,000 to 14,000	11,000 to 40,000
(Ultra-)fast 'opportunity charging'	n.a.	900 to 6,000	7,000 to 45,000
Electric road systems (ERS)	< 10 km	500 km	1,700 km
Hydrogen refuelling stations (350 bar)	< 16	0 to 300	345 to 1,000
LNG refuelling stations	400	750	1,500
CNG refuelling stations	4,000 (but mainly for passenger cars)	400	500

Source: Compiled by authors from sources in the following Sections 5.2.1-5.2.4. Current numbers are taken from Chapter 3

5.2.1. Battery recharging infrastructure

Although exact numbers are debatable, BETs are expected to have a substantial share in the future fleet and will need recharging infrastructure to match. Given the different cost structure of BET operation, different charging strategies could arise in different trucking segments ([McKinsey, 2020](#)). Depending

on the daily energy use and distance covered by a truck, fleet owners may opt for overnight-charging only, or a combination of overnight, mid-route and destination charging. Needs for charging infrastructure therefore depend very much on trip profile and available options and choices with regard to the truck range.

Allego, a European supplier of battery-charging infrastructure, also divides the trucking market into distance segments, leading to a diversified recharging infrastructure landscape. For long-haul transport, Allego proposes opportunity charging²⁹ stations every 75-100 km, each station having at least twenty chargers (with 450 kW DC power outlets) along the main logistics corridors (i.e. TEN-T). Furthermore, port sites should also be equipped with charging infrastructure for use during freight transshipment. For the majority of last-mile transport, overnight depot and destination charging would suffice (50-150 kW) ([Allego, 2020](#)). Absolute numbers for the EU are not given.

E-Laad, a Dutch knowledge and innovation centre in charging infrastructure, has also made a projection of charging infrastructure needs. Once again, the location of charging stations and consequent share of daily energy demand per location is a function of average daily trip length. As 80% of European truck trips are under 150 km, the vast majority of the BET fleet can operate using overnight depot charging only ([E-Laad, 2020](#)). The estimated number of charging points per 1,000 operational BETs is shown in Table 8. Additionally, we have made a rough estimate of the required number of recharging points in the EU, both private (depot) and public, based on the IEA fleet projections in the scenario of 55% emission reduction (Sustainable Development Scenario), considering this scenario as an average of the presented fleet scenarios that are targeting the 55% emission reduction.

Table 8: Energy demand per location and number of charging points per BET in 2030

Charging type	Share of daily energy demand	Required charging points per 1,000 BET ^a	Required EU charging points ^b
Overnight depot (50 kW)	80%	800	288,000
Shared charging hubs (50 kW)	10%	150	54,000
Public overnight (70-100 kW)	3%	30	10,800
Motorway service area (500 kW+)	7%	20	7,200

Source: [E-Laad, Outlook E-trucks internationale logistiek](#) (2020):

- a) These numbers should be seen as minimum numbers of charging points deployed. The sum total of these figures gives the total number of public and privately deployed recharging points required per 1,000 BET in 2030.
- b) Own calculations based on IEA fleet projections for BETs in the 55% emission reduction scenario. These figures are totals for the EU27, Norway, Iceland, Switzerland and the United Kingdom.

The [ACEA \(2021b\) bases its estimate](#) of charging infrastructure needs for battery-electric HDVs on its estimated HDV fleet segmentation, as described in Section 5.1. The ACEA numbers include infrastructure requirements in the EU27 and the UK and are presented in Table 9. To recharge the projected (hybrid) electric truck fleet, a tremendous growth of public and private charging points is needed throughout the EU. The ACEA distinguishes between public chargers and destination chargers. Most of the charging in this segment is expected to be from overnight charging and charging while loading and unloading at logistics hubs. The destination chargers should be located at logistics

²⁹ Opportunity charging is charging during the time trucks are idle during loading/unloading or during obligatory driver resting times.

hubs or at private transport companies where trucks are loaded and unloaded. For long-distance transport, the ACEA advises that the revised AFID should require at least one high-power charging station (500 kW+) with at least four charging points on the TEN-T network every 100 km in 2025 and every 50 km in 2030. Also, at least one charging point per station should be accessible for coaches ([ACEA, 2021a](#)).

Table 9: ACEA estimate of number of HDV charging points by location and power type (EU27+ UK) (trucks and buses)

Charging type	No. of charging points in 2025	No. of charging points in 2030
Overnight depot chargers (50-100 kW)	40,000	270,000
Public and destination chargers (< 350 kW) ^a	1,000 (4,000 ^b)	5,000 (40,000 ^b)
Public and destination fast chargers (350 kW) ^c	12,000	15,000
Public ultra-fast chargers (500 kW+)	2,000	30,000

Source: ([ACEA, 2021a](#)):

- These charging points should be located at public stops and logistics hubs/distribution centres of private companies where trucks load and unload.
- Required number of public overnight chargers if fast and ultra-fast charging points are not equipped to deliver lower-power night charging.
- These fast chargers should allow upgrades to ultra-fast charging (also called megawatt charging system (MCS, 500 kW+)) when technology is available.

According to the ACEA, for the powering of long-haul BETs approximately 40,000 100 kW public overnight chargers will need to be deployed at truck parking areas along motorways in 2025. The ACEA also estimates that every BET will need a depot charging point, implying some 270,000 depot charging points in 2030 across the EU27 and the UK.

In the Cambridge Econometrics report '[Trucking into a greener future](#)' (2018), it is assumed that 65% of the trips by EU trucks are under 600 km³⁰. Assuming a 700 kWh battery, the daily distance can be covered without en-route charging for this truck segment. This means public chargers will only need to be installed for a third of the BETs, assuming that sufficient depot and destination chargers are deployed for the aforementioned short- and medium-haul trucks. Cambridge Econometrics estimates that sixteen trucks can use a single charger per day, for a period of 45 minutes (during obligatory rest times). An estimated 11,000 fast-charging points (700 kW DC output) will be needed to support the EU BET fleet in 2030, and a total of 320,000 depot chargers of which 95,000 with low and 225,000 with high power ([Cambridge Econometrics, 2018](#)). This is shown in Table 10.

³⁰ This differs from the Eurostat data in Figure 4, with 77% of the trips below 150 km.

Table 10: Projected number of chargers by type in the EU27 + UK

Charging type	No. of charging points in 2025	No. of charging points in 2030
Overnight depot (low: 22 kW)	70,000	95,000
Overnight depot (high: 90 kW)	57,000	225,000
Public fast (700 kW)	4,000	11,000

Source: ([Cambridge Econometrics, 2018](#)); The figures are estimated by adding up the annual figures as read from Figure 4.4 and 4.5 of the reference.

In its policy recommendations ([T&E, 2021](#)), T&E anticipates a need for 3,000 public charging points in 2025 (2,100 of 150 kW and 900 of 620-850 kW) and 15,000 in 2030 (11,000 of 150 kW and 4,000 of 620-850 kW). They project a need for 5,000 destination charge points (350 kW) in 2025 and 27,000 in 2030, furthermore, and for 109,000 depot chargers in 2025 and 470,000 in 2030, 0.9 for every truck.³¹ These projections are summarised in Table 11.

Table 11: T&E estimate of number of HDV charging points by location and power type (EU27)

Charging type	No. of charging points in 2025	No. of charging points in 2030
Public overnight charge points (150 kW) ^a	2,100	11,000
Public fast (high-power) chargers (620-850 kW)	900	4,000
Destination charge points (350 kW)	5,000	27,000
Private chargers (150 kW) ^b	109,000	470,000

Source: ([T&E, 2021](#)), Table 8: a) derived by subtracting high-power chargers from the total public charging points reported in the source; b) equal to number of trucks according to ([T&E, 2020b](#)).

We observe that the requirements, conditions and assumptions vary across the various sources consulted. Most sources have a wide geographical coverage of Europe, including countries adjacent to EU Member States. The sources reporting HDV charging infrastructure needs are considering trucks/trailers only, except the ACEA, which also includes buses. However, it is still acceptable to compare the figures from the different sources, including the ACEA, as buses are expected to rely solely on overnight (depot) charging and destination charging. Public charging is thus geared to the commercial freight transport sector.

There is a limited spread in the estimates. The breakdown of truck trip length is the main factor determining the need for charging infrastructure and its local development and distribution. The overall expectation is that overnight charging infrastructure will be supplying the lion's share of truck battery energy. According to the sources discussed above, approx. 40,000 to 127,000³² overnight charging points at depot, 2,000 to 14,000 public overnight charging points and 900 to 6,000 public and

³¹ (T&E, 2021) states 1.1. battery electric truck per depot charger, page 44.

³² 70,000 low and 57,000 high power depot chargers according to Cambridge Econometrics, Table 10).

destination fast-chargers are already needed by 2025. Overnight charging points are needed both at depots and at public trucking stops for long-haul transport. The total number of depot charging points is close to the total number of BETs. According to ACEA, IEA and T&E figures, by 2030 the number of charging points required across the EU and in the UK will have risen to between 270,000 and 470,000.³³ Estimates of the number of public overnight charging stations in 2030 (approx. 100 kW charging) have a wide range: from 10,800 to as many as 40,000. The projections expect and require the development of ultra-high power (500 kW+) charging technology, moreover. The projected number of (ultra-)fast high-power charging points (350 kW+) required in 2030 is between 7,000 and as many as 45,000 in the most optimistic scenario of fast technology adoption and fleet composition. This technology is still in the development phase, however.

Given the current number of public charging points for trucks (less than 10 in the EU27 according to ACEA [\(ACEA, 2021a\)](#), the figures presented indicate a need for tremendous investments, growth and efforts for the roll-out and installation of appropriate charging infrastructure for trucks. As overnight charging is expected to play a significant role in the BET energy supply, there will need to be active involvement and cooperation from and with the private transport companies where overnight charging takes place in order to obtain adequate deployment and international coherence in the required infrastructure.

Comparison with AFIR proposal

The EC proposes for the [AFIR](#) the following targets for charging infrastructure (see also Table 1):

- Member States shall ensure that along the TEN-T **core network**, publicly accessible recharging pools³⁴ dedicated to heavy-duty vehicles are deployed in each direction of travel with a maximum distance of 60 km in-between them:
 - by 31 December 2025, each recharging pool shall offer a power output of at least 1400 kW and include at least one recharging station³⁵ with an individual power output of at least 350 kW;
 - by 31 December 2030, each recharging pool shall offer a power output of at least 3500 kW and include at least two recharging stations with an individual power output of at least 350 kW.
- Member States shall ensure that along the TEN-T **comprehensive network**, publicly accessible recharging pools³⁶ dedicated to heavy-duty vehicles are deployed in each direction of travel with a maximum distance of 100 km in-between them.
 - by 31 December 2030, each recharging pool shall offer a power output of at least 1400 kW and include at least one recharging station³⁷ with an individual power output of at least 350 kW;
 - by 1 December 2035, each recharging pool shall offer a power output of at least 3500 kW and include at least two recharging stations with an individual power output of at least 350 kW.
- By 31 December 2030, in each safe and secure (overnight) parking area at least one recharging station dedicated to heavy duty vehicles with a power of at least 100 kW is installed.

³³ According to the impact assessment of the EU Climate Target plan, the projected number of BETs in 2030 is only 37,000, which is very low as compared to the other sources.

³⁴ 'Recharging pool' means one or more recharging stations at a specific location.

³⁵ 'Recharging station' means a single physical installation at a specific location, consisting of one or more recharging points, A charging recharging point is able to recharge only one electric vehicle at a time.

³⁶ 'Recharging pool' means one or more recharging stations at a specific location.

³⁷ 'Recharging station' means a single physical installation at a specific location, consisting of one or more recharging points, A charging recharging point is able to recharge only one electric vehicle at a time.

- By 31 December 2025, in each urban node publicly accessible recharging points dedicated to heavy duty vehicles are deployed, providing an aggregated power output of at least 600 kW, provided by recharging station with an individual power output of at least 150 kW. In 2030 the total power output should be 1,200 kW.

To be able to compare the [AFIR proposal](#) with the number of charging points proposed by the studied sources, Table 12 has estimated the number of charging points based on the requirements proposed. To do so, it has been assumed that the minimum required power outputs mentioned for at least one or two stations is the minimum power per charging point for all charging points at the pool.³⁸ The total number of charging points is at 17,314 minimally.³⁹

Table 12: Estimated minimum number of charging points in 2030 required by AFIR proposal

	Network length (km)	Number of pools ^a	Minimum power output per pool ^a in 2030 (kW) (AFIR proposal)	Estimated chargers per pool ^{a,b}	Estimated minimum number of charging points ^a required by AFIR proposal	Comment
Core network	35,969 ^c	1,199 ^d (every 60 km)	3,500	10	11,990	based on 350 kW charging points ^a
Comprehensive network (non-core)	48,763 ^c	975 ^d (every 100 km)	1,400	4	3,901	based on 350 kW charging points ^a
Safe and secure parking areas		719 ^e	100	1	719	based on 100 kW charging points ^a
Urban nodes		88 ^f	1,200	8	704	based on 150 kW charging points ^a
Total					17,314	

^a for pool and points see footnotes on previous page; b calculated by minimum power output divided by assumed power per charging point (last column) ^c Figures from : [TEN-T 2017 performance report](#) (CEDR, 2018); ^d Calculated from Network length*2/60 or Network length*2/100 ^e Based on a safe an [secure parking area every 100 km](#) in both directions along the TEN- T core network (35,969 *2/100); ^f 88 urban nodes according to [vital nodes project](#).

³⁸ In principle a charging station can have more than one charging point. The power per charging point, however will then be lower when used simultaneously.

³⁹ The Impact assessment of the [AFIR proposal](#) reports only 6,500 charging points in 2030 for policy option 2 (preferred policy option). However, the AFIR proposal proposes a higher power output per station along the TEN-T corridor than policy option 2.

According to the sources cited in the preceding sections, the required numbers of publicly accessible charging points in 2030 are as follows (see Table 8):

- 18,000 charging points based on E-laad, of which 7,200 ultra-fast (500 kW+);
- 50,000-85,000 charging points⁴⁰ according to ACEA, of which 30,000 ultra-fast (500 kW+);
- 11,000 fast (700 kW) according to the Cambridge Econometrics study; and
- 42,000 charging points according to T&E, of which 4,000 ultra-fast (620-850 kW).

The number of charging points that we estimated based on the targets of the [AFIR proposal](#) (17,314, see Table 12) are in line with estimates based on the E-Laad study and higher than the figures by Cambridge Econometrics. It should be noted that Cambridge Econometrics does not include numbers for public overnight chargers.

The numbers of ACEA and T&E are considerably higher than the estimates based on the AFIR proposal. The target for deployment of overnight public charging points by the AFIR proposal seems especially low as compared to these sources. The projected requirement for this type of charging point in 2030 is between 11,000 and 40,000 according to T&E and ACEA, instead of 719 based on the AFIR proposal (see Table 8). In the AFIR proposal minimum target are set and countries can of course exceed the minimum.

5.2.2. Infrastructure for overhead catenary

The impact assessment of the European Climate Target plan does not make any assumptions on the deployment of a European network of overhead catenary infrastructure on motorways. Individual member states or local governments may initiate this type of infrastructure for specific operations (e.g., between ports and haulage and storage locations with a high intensity of road freight transport).

A report by the ICCT ([Moultak, Lutsey, & Hall, 2017](#)) states that the total cost of ownership (TCO) of overhead catenary HDVs (including charges for the ERS infrastructure) would be approximately 25-30% lower than that of diesel vehicles. The TCO is lower than for other technologies, irrespective of the technology chosen to complement the catenary systems (viz. overhead catenary in combination with either diesel, battery-electric or fuel-cell electric trucks equipped with pantographs). However, realisation of overhead catenary infrastructure requires a major (coordinated) effort on infrastructural investment and development from Member States ([Moultak, Lutsey, & Hall, 2017](#)).

Cambridge Econometrics presents estimated cost figures for infrastructure development. The figures for estimated infrastructure requirements are presented in Table 13. The scenario in which electric road systems (ERS), i.e. overhead catenary lines, constitute the key technology for long-distance HDVs is its 'ERS scenario' and can be seen as maximum ERS deployment along the main transport routes, with the assumption that it will be deployed across the core TEN-T network. In two other scenarios where battery-electric and fuel-cell HDVs are the key technology (the BET scenario and FCET scenario, respectively), ERS is still deployed across the main TEN-T routes as a supplementary technology, although on a smaller scale than in the ERS scenario.

⁴⁰ 50,000 (5,000+15,000+30,000) if fast and ultra-fast charging points are equipped to deliver lower-power night charging, 85,000 (40,000_15,000_30,000) if they are not.

Table 13: Projected kilometres of overhead catenary infrastructure in the EU+UK

Deployment (km) of ERS by scenario	2020	2025	2030	2040	2050
ERS scenario	50	600	1,700	9,000	15,500
BET and FCET scenarios	0	250	500	900	1,600

Source: [Cambridge Econometrics, 2018](#), figures are estimated using [Figure 4.2 in reference](#)

Even though member OEMs of the ACEA are currently performing pilots with overhead catenary trucks, the ACEA position paper on the infrastructure for alternatively fuelled HDVs includes no scenarios or assumptions for overhead catenary-powered trucks as part of the solution for a zero- and low-carbon future. The same holds for the other institutional sources, which make no allowance for large-scale roll-out of overhead catenary infrastructure.

Comparison with AFIR proposal

Interviews and literature indicate at the moment, apart from a few players, there is little support and/or belief from the car manufacturing industry and transport operators that ERS will be used on a major scale. Also according to the [AFIR proposal](#), the technology is not yet sufficiently mature and uptake of vehicles uncertain. However, a definition has been introduced in the proposed AFIR to recognise ERS as an alternative fuels infrastructure.

5.2.3. Fuelling infrastructure for hydrogen

The future need for hydrogen refuelling stations (HRSs) for HDVs is mentioned in several scenario reports. The Fraunhofer Institute for Systems and Innovation Research ISI has [calculated](#) that a national network of 140 HRSs in Germany is sufficient to meet the hydrogen demand of fuel cell electric trucks (FCETs) in 2050. This figure will be 70 in 2030, supplying around 50,000 trucks ([Fraunhofer ISI, 2020](#)). This comes down to the deployment of approximately one HRS per 700 hydrogen fuel cell trucks.

According to the ACEA, in 2025 300 and in 2030 a 1000 HRSs are needed, suitable for trucks to refuel. Compressed hydrogen at 350 bar and 700 bar and liquefied hydrogen refuelling technology should be considered. Because there is as yet no standardised refuelling concept, nor market-proven, truck-suitable HRSs, there needs to be a coordinated effort on infrastructure development. Table 14 reports the ACEA's estimates for the number of HRSs required in the EU27 and the UK, based on the number of hydrogen-fuelled trucks in operation in 2025 and 2030.

Cambridge Econometrics has projected the required number of HRSs in their FCET scenario, which can be seen as a 'high' scenario for hydrogen-powered trucks (Table 15). It distinguishes HRSs with daily dispensing capacities of 10,000 and 25,000 kg hydrogen, with 17 and 42 dispensers, respectively. A dispenser for hydrogen refuelling will be comparable to a dispenser for conventional fuels at today's filling stations.

Table 14: Required number of hydrogen refuelling stations (EU27 + UK) - ACEA

HRS	2025	2030
Truck-suitable HRS (700 bar)	300	1,000

Source: ([ACEA, 2021a](#)). A minimum daily fuelling capacity of 6,000 kg H₂ is necessary according to the source.

Table 15: Projected number of hydrogen refuelling stations (EU27 + UK) - Cambridge Econometrics

HRS type (capacity)	2025	2030
10,000 kg/day	0	250
25,000 kg/day	0	95

Source: ([Cambridge Econometrics, 2018](#)); The figures are estimated by summing the annual numbers as read from Figure 4.6 of the reference.

Comparison with AFIR proposal

The distance-based targets for hydrogen refuelling infrastructure in the AFIR proposal are as follows (see also Table 3):

- By 31 December 2030, Member States shall ensure that publicly accessible hydrogen refuelling stations with a minimum capacity of 2 t/day and equipped with at least a 700 bars dispenser are deployed with a maximum distance of 150 km in-between them along the TEN-T core and the TEN-T comprehensive network in both directions or serving both directions⁴¹. The station is designed to serve light-duty and heavy-duty vehicles;
- By 31 December 2030, member states shall ensure that at least one publicly accessible hydrogen refuelling station is deployed in each urban node;
- In addition, Member State have to ensure that every 450 km on the TEN-T network a hydrogen refuelling station serves liquid hydrogen to trucks.

The targets translate⁴² into the following infrastructure deployment figures by 2030:

- 480 HRSs with at least a 700 bar dispensers and 160 HRSs serving liquid hydrogen along the TEN-T corridor;
- 88 HRSs at urban nodes (one for every node);
- the total number of HRS then comes down to a minimum of 728.

These number of stations resulting from the AFIR proposal requirements are in between the number of HRS stations projected by the industry and the institutional sources we consulted (345-1000). However, the daily capacity per refuelling station mentioned by the sources is much higher. The ACEA estimates a need for 1,000 HRSs with a daily supply capacity of 6 ton hydrogen and Cambridge Econometrics estimates around 250 stations with a daily supply capacity of 10 ton hydrogen in combination with 95 stations with a daily supply capacity of 25 ton hydrogen. Whereas the consulted sources do not mention figures for the number of HRSs serving liquid hydrogen, the proposal for the AFIR does, taking into account the development of liquid hydrogen fuelled trucks, as announced at least by [Daimler](#). It might, however, be a bit early to already decide on the number of HRSs serving liquid hydrogen and hydrogen at 700 bar, as it is not yet clear how the role of liquid hydrogen and hydrogen at 700 bar will develop ([Berger 2020](#)). Several sources believe that FCETs will not be the principal alternative truck type adopted in the future, but only in niche market segments. Given the

⁴¹ The regulation proposal is not explicitly mentioning both directions but the accompanying information in Annex 7 of the commission staff working document does give this interpretation.

⁴² Calculation based on the length of the TEN-T network.

uncertainty in the development of FCETs on the market, for the time being, then, the targets might be sufficient to support the future fleet of FCETs. However, higher minimum capacities per station might be considered in the AFIR. Also, binding targets for liquid hydrogen stations might be a bit premature, considering that the fuel tanks are still in development ([Hydrogen Central](#)) and liquid hydrogen fuelled trucks are not on the road yet ([Air Liquide 2021](#)).

5.2.4. Fuelling infrastructure for gaseous fuels

In the EU Climate Target impact assessment, gaseous biomethane is estimated to comprise only about 0.2% of total transport fuel consumption in 2030 ([EC, 2020c](#)). Refuelling infrastructure for compressed biomethane is similar to that for CNG ([CNGFuels, 2021](#)). ACEA states that the infrastructure for CNG and LNG truck refuelling requires a more comprehensive network than currently exists. Natural gas refuelling infrastructure can be used for renewable gases such as biomethane as well ([Prussi, Julea, Lonza, & Thiel, 2021](#)). Considering the increase in the use of gaseous fuels in the projected scenarios, the required refuelling infrastructure estimated by ACEA seems justified. The estimated number of CNG and LNG refuelling stations required to service the growing gas-fuelled truck fleet is presented in Table 16.

Table 16: Required number of CNG and LNG refuelling stations (minimum estimates for EU27+UK)

Type of gas refilling station	2025	2030
CNG stations	400	500
LNG stations	750	1,500

Source: ([ACEA, 2021a](#))

Comparison with AFIR proposal

According to article 8 in the [AFIR proposal](#), Member States shall ensure until 1 January 2025 that an appropriate number of publicly accessible refuelling points for LNG are put in place, at least along the TEN-T core network. No specific numbers are mentioned in the AFIR proposal, but recital (29) states remaining gaps in the network, as recommended in the [AFID](#), should be filled. The current [AFID](#) targets for gaseous refuelling stations are continued according to the [AFIR](#) proposal. For LNG this means the, almost mature, network with a refuelling point every 400 km on the TEN-T core network needs to be completed. The AFIR proposal focusses on minimum target for the TEN-T corridor to allow (bio) LNG trucks to circulate through the EU. The Impact [assessment](#) of the AFIR projects the number of LNG refuelling station to go up from 242 in 2019 to 3,527 by 2030. With a minimum of LNG refuelling infrastructure established along the TEN-T corridors, the assessment states that investment security is provided to allow the market to reach the needed infrastructure stations. In the decades beyond 2040, moreover, gas trucks are expected to be phased out according to the policy scenario of the [AFIR impact assessment](#). ACEA, however, recommends targets for a more comprehensive network of LNG. Other parties ([T&E; stakeholder interviews: Logistics, Policy](#)) believe the AFIR should focus on zero-emission technologies and should not further invest in LNG.

5.2.5. Fuelling infrastructure for liquid biofuels

According to the Climate Target plan impact assessment, liquid biofuels are expected to make up 5 to 7% of the energy mix in 2030 (EC, 2020c). Concawe states that existing fuelling infrastructure can remain in use for the transportation and storage of liquid biofuels (Concawe, 2020). According to the EAFO, the refilling infrastructure for E10, which is petrol blended with 10% bioethanol, is already widely available since it is a drop-in fuel (EAFO, 2021b). No further requirements for the development of fuelling infrastructure are stated.

5.2.6. Fuelling infrastructure for e-fuels

E-fuels, made from green hydrogen produced by means of renewable electricity, include both gaseous fuels like synthetic methane and liquid fuels like synthetic diesel. We focus here on synthetic diesel. The general opinion of stakeholders (Stakeholder interviews) on the potential of e-fuels is that they are too expensive to compete with other sustainable or low-carbon fuels in the short run and that it is doubtful they will become competitive in the long run. E-fuels⁴³ are very energy-intensive to produce, and require an extra conversion step after the production from E-hydrogen with renewable electricity. The direct use of renewable electricity as a truck 'fuel', or the intermediate product E-hydrogen, is therefore cheaper. It is true that synthetic diesel is a drop-in fuel and thus requires fewer infrastructure and truck investments, but the additional energy costs (including the extra renewable electricity production capacity required) are expected to outweigh this advantage. In the short term, e-fuels have a possible role as a transition fuel. However, the production process is less well-developed than the production of biofuels (also in terms of production capacity), which may play the same role. Furthermore, the use of renewable electricity for the production of e-fuels is probably an inefficient way of utilising this electricity to reduce carbon emissions. However, synthetic diesel may be a suitable option for shifting away from fossil diesel in certain niche truck segments for which alternative trucks are not (yet) available, such as timber trucks.

As e-liquids become available on the market in the coming decades, dedicated infrastructure will be needed, depending on the type of e-fuel. For several e-fuels, their physical properties allow for use of similar refuelling infrastructure and the same storage facilities as currently in place for conventional fuels (Concawe, 2020; Searle & Christensen, 2018). The German Energy Agency, too, states that e-fuels with a high energy density can utilise the transport, storage, distribution and fuelling infrastructure already in place in Europe and internationally (Siegemund, Trommler, Kolb, & Zinnecker, 2017). For the e-fuels ammonia and dimethyl ether, there are additional infrastructural requirements for fuelling and storage, implying a possible need for investment by fuel producers and suppliers if these e-fuels are to be used by trucks.

Comparison with AFIR proposal

Very few manufacturers produce vehicles with powertrains powered only by bio- or e-fuels or have announced their intention to manufacture them in the future. In addition, the use of sustainable biofuels in the road sector will remain largely stable in the coming two decades and is expected to decline post-2040, with an envisaged shift of sustainable biofuels towards other transport sectors (maritime/aviation), indicating that there is no need for shifting towards high biofuel blends in road transport that require dedicated infrastructure.

⁴³ In this case we refer to other E-fuels than E-hydrogen.

No additional infrastructure is required, as the number of existing conventional refuelling stations (diesel and gaseous fuels) is expected to be sufficient for the coming decades. For the refuelling of bio- and e-fuels (-gases), the existing infrastructure can be used.

5.3. Deployment of infrastructure by segment and location

5.3.1. Battery recharging infrastructure

The deployment of public battery recharging infrastructure should start at corridors where many long haul trucks are driving that need to recharge during the trip. Transport activity (tonne-kilometres, tkm) is a good proxy for the truck kilometre distribution on TEN-T routes by country, making this parameter a plausible measure on which to base the deployment of charging and refuelling infrastructure⁴⁴. According to [T&E, \(2021\)](#), 81% of tkm and 88% of long haul tkm are fully or partly between NUTS 3 regions connected to the TEN-T corridors (see Figure 5). In both practical and economic terms, this high share of activity related to the TEN-T corridor motorways is a strong argument for deploying recharging and refuelling infrastructure along these routes. This will allow transport operators to build up confidence about the availability of such infrastructure and, from the perspective of both infrastructure investors and operators, provide higher utility rates in the initial phase of uptake of alternatively fuelled trucks, compared to an even distribution of infrastructure along all types of highways.

With expected ranges of 400-500 km per full recharge, BET trips over 500 km (representing about 5% of trips and 37% of kilometres; see Figure 3) are likely to need en-route recharging infrastructure at least once per trip. There will be need for both overnight and opportunity (high-voltage) charging, ultra-high-power charging would allow trucks to fully recharge during the day, enabling them to achieve 800-1,000 km per day (the distance to be covered in the 9-10 hour daily driving period permitted).

According to [T&E \(2021\)](#), [ACEA \(2021a\)](#) and interviews with transport research experts and transport operators, high-power recharging stations (> 350 kW) should be available every 50-100 km along the TEN-T core corridor, with a focus on deployment of chargers above 500 kW. In addition, lower-power charging stations (100 kW) along the highways are needed at parking areas, with at least 40,000 public chargers in 2030, according to both T&E and ACEA.

[T&E \(2021\)](#) also recommends targets for public chargers (at least 350 kW) at urban nodes: four per urban node in 2025 and at least 10 in 2030.

Finally, T&E and ACEA recommend binding targets for the number of public and destination chargers per Member State, to guarantee that infrastructure development is in line with the increase in BETs.

Comparison with AFIR proposal

The recommendation on the number of chargers along the TEN-T corridor is more or less in line with the [AFIR proposal](#) (EC, 2021e), which proposes charging pools along the TEN-T core network every 60 km and along the TEN-T comprehensive network every 100 km, with at least one or two chargers above 350 kW. T&E and ACEA, however, recommend the presence of higher power chargers (**at least 500 kW**), to allow truck to recharge for another 4.5 hours drive within about 30-60 minutes resting period. They do not specifically mention the TEN-T comprehensive network. Also for the urban nodes, the EC proposes chargers of at least 150 kW in a pool of 600 kW (2025) or 1,200 kW (2030), whereas T&E sets the **minimum at 350 kW**.

⁴⁴ The ton-kilometres are a good indicator for the kilometre intensity by truck, as the spread in the average load per truck is limited.

Finally, the EC's proposal does not set any targets per member state as proposed by T&E and ACEA to guarantee that the number of public and destination chargers increases in line with the number of electric trucks on the road.

5.3.2. Fuel infrastructure for hydrogen

In its report [ACEA \(2021a\)](#) recommends on the number of hydrogen refuelling station needed and the positioning of the HRSs along TEN-T core network. They recommend:

- a total of 300 truck-suitable hydrogen refuelling stations by 2025 and at least 1,000 in 2030;
- one hydrogen refuelling site every 200 km along the TEN-T corridor in 2030;
- a minimum capacity of 6 tonnes H₂ per day per truck refuelling station, with at least two dispensers;
- binding targets per Member State.

According to ACEA, both compressed hydrogen at 350 bar and 700 bar, as well as liquefied hydrogen refuelling technology should be considered.

Comparison with AFIR proposal

The [AFIR proposal \(2021e\)](#) sets targets only for 2030 onwards. By 31 December 2030 the proposed target is one refuelling station every 150 km along the TEN-T core and comprehensive networks, with a minimum capacity of 2 t/day and at least a 700-bar dispenser. Liquid hydrogen should be available every 450 km. By 31 December 2030 at least one publicly accessible hydrogen refuelling station is to be deployed at each urban node.

The number of refuelling stations in the AFIR proposal along the TEN-T corridor is higher than that proposed by ACEA, but the capacity per station is lower. The AFIR proposal, also mentions specifically the need of at least one HRS in each urban node. but does not propose binding targets for hydrogen refuelling stations per Member State as ACEA does.

5.3.3. Fuel infrastructure for other alternative fuels

ACEA ([ACEA, 2021a](#)) mentions that a more comprehensive network of CNG and LNG refuelling stations is needed to support long-haul and interregional transport. For other alternative fuels no specific recommendations are made by any of the aforementioned sources. As stated earlier, biofuels and e-fuels can make use of the existing infrastructure for conventional fuels.

Comparison with AFIR proposal

The target referred to in the [AFIR proposal \(2021e\)](#) is one LNG refuelling point every 400 km on the TEN-T core network, in line with [Directive 2014/94/EU](#) (see also Section 5.2.4 for interpretation of the AFIR proposal). For other biofuels and e-fuels, no targets have been set.

5.4. Conclusions

Under policies associated with the European Climate Target plan to reduce CO₂ emissions by 55% in 2030, the number of alternatively fuelled trucks is expected to grow. According to 3 of the 4 sources consulted, these climate ambitions should result in over 270,000 (270,000-520,000) BETs and 60,000- 75,000 FCETs in 2030.⁴⁵ The number of BETs according to the [impact assessment of the AFIR proposal](#) is 2.5-5 times lower (110,000), whereas the number of FCETs is in the same range (60,000).

⁴⁵ The number of the impact assessment of the EU Climate Target are much lower than the other sources (BETs and FCETs both 38,000) and are not included in the range.

The projected growth in the number of alternatively fuelled trucks means new fuelling infrastructure is also needed. According to the sources studied, it is expected that 270,000-470,000 overnight (mostly private) depot chargers will be needed for the BETs. In addition, publicly accessible overnight chargers along the TEN-T corridors and publicly accessible fast-chargers at urban nodes and along the TEN-T corridors will be needed. It is estimated that a total of 11,000-85,000 publicly accessible charging points will be required in 2030. The [AFIR proposal](#) sets minimum targets for overnight chargers and fast-chargers along the TEN-T corridors and at urban nodes. In our estimate these targets lead to a minimum of 17,314 publicly accessible charging points.

ACEA (ACEA, 2021a) and T&E (T&E, 2021), in particular, anticipate more chargers being needed, probably because of the higher number of BETs they anticipate in 2030, but also because the AFIR proposal sets minimum targets. This holds especially for the number of overnight chargers needed along the TEN-T corridor, for which the two sources project a figure over ten times higher.

Importantly, ACEA (ACEA, 2021a) and T&E (T&E, 2021), as well other stakeholder (Stakeholder interviews: research, logistics, infrastructure), stress a need for high-power chargers at urban nodes and service areas along the TEN-T corridor. While the AFIR proposal demands a minimum number of charging station with a power output at least values of 150 kW at urban nodes and 350 kW along the TEN-T corridors, the sources studied recommend 350 kW chargers at urban nodes and 500+ kW chargers along the TEN-T corridors to facilitate long-distance transport to recharge within one hour. Finally, T&E and ACEA recommend setting binding targets for the number of chargers in each Member State, to guarantee that the number of public and destination chargers rises in line with the number of electric trucks on the road. The [AFIR proposal](#) provides no such targets.

To service hydrogen trucks, it is expected that some 345-1,000 HRSs will be needed in 2030 and 0-300 in 2025. Our estimate of 728 HRSs for 2030 according to the AFIR proposal, based on the minimum target along the TEN-T corridor and the urban nodes, is in line with these numbers. However, the minimum capacity for HRS set by the AFIR proposal (2t H₂/day) is much lower than that cited in the sources studied (6-25 t/day). The AFIR proposal sets a minimum target for the number of HRSs along the TEN-T corridor (every 150 km), resulting in a bit higher density along the corridor than the figure recommended by ACEA (every 200 km). In addition, the AFIR proposal sets targets for HRSs supplying liquid hydrogen along the TEN-T core network (every 450 km) plus HRSs at every urban node. The development of FCETs and hydrogen refuelling strategies are still at an early stage. A target specifically for liquid hydrogen might be a bit early given the early stage of development of liquid hydrogen fuelled trucks for which the fuel tanks are still in development.

The future of ERS is very uncertain. Although ERS could well contribute to decarbonising truck transport, this would require coordinated roll-out. The majority of OEMs and transport operators are not focusing on ERS as a decarbonisation strategy, however. The AFIR proposal does not set any targets for ERS, but recognises ERS as part of an alternative fuels infrastructure.

The number of LNG-fuelled trucks may still increase towards 2030. The AFIR proposal focuses on completing the target already set in Directive 2014/94/EU of one refuelling point every 400 km on the TEN-T core network. This target allows LNG trucks to refuel when circulating through the EU and gives investment security for further infrastructure development where needed. Stakeholder opinions on the role of LNG trucks towards 2030 varies, given the limited potential for CO₂ reduction on the one hand and the usefulness in long-haul transport on the other. The AFIR proposal appears to provide scope for developing a (bio-)LNG truck market, without undue further stimulation of LNG at the expense of BET and FCET development.

For liquid biofuels and e-fuels no specific infrastructure development is needed, as these can make use of the existing infrastructure.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The status of alternative fuel infrastructure policy

Recent policy developments have stressed the need for a faster decarbonisation of trucks and other HDV, and consequently faster development of recharging and refuelling infrastructure. Given the **Green Deal** ambition and the efforts and realisation time needed to implement sufficient coverage of infrastructure, current developments are seriously lagging behind and a strong urgency to act today is shared by all stakeholders.

'Fit for 55': from a Directive to a Regulation

The **'Fit for 55' Package** published mid-July 2021 comprises a package of proposals to align EU legislation with the EU Green Deal. One of the proposals is **to turn the AFID into a regulation** (AFIR), with **binding targets for Member States**. The binding character of the regulation is likely to result in a more stable long-term policy framework, including greater uniformity across Member States and less uncertainty.

The AFIR proposal sets fleet-based targets for light-duty electric vehicles, while **for trucks distance-based targets along the TEN-T corridor and targets for urban nodes and parking areas are included**. Some argue that fleet-based targets, as proposed for LDVs, should be introduced for trucks as well. It can, however, be queried to what extent a fleet-based target similar as for LDVs (amount of kWh charging infrastructure to be provided per electric vehicle registered) makes sense given the wide range of trucks and operational needs in terms of charging capacity. For instance, many trucks in short-haul logistics are expected to mainly charge at private depots and not to rely so much on publicly accessible recharging infrastructure. **For medium- and long-haul transport, however, publicly accessible fast-charging and lower power overnight charging infrastructure is essential**. The TEN-T corridor is well chosen as a base for the roll-out of infrastructure, as the network has a relatively high traffic intensity of long distance trucks.

With the AFIR, the Commission redirects its focus from better-performing fossil fuels, such as LNG, to zero emission technologies such as BETs and FCETs. The AFIR proposal also stresses the need to create a shift towards renewable fuels (biofuels/e-fuels) for gas engines and ICEs.

In terms of geographical location of recharging and refuelling infrastructure, the Commission has opted for **distance-based targets along the TEN-T core and comprehensive networks, at urban nodes and with due attention to safe and secure parking areas and fast-charging provisions**. For hydrogen, freight terminals are to play a key role as well. By adopting this overall approach, the AFIR proposal seems to cover the most relevant types of recharging and refuelling locations. Although overnight charging and destination charging at specific private locations (depots and distribution centres) are expected to be the most important means of recharging, public authorities' governance mandate and main focus is limited to public recharging and refuelling facilities. The proposed Regulation states, however, that authorities will need to support private actors in deploying such infrastructure at private locations as well.

In addition, the proposed Regulation places strong emphasis on **technological standardisation**, with a view to accelerating deployment by means of **harmonisation**. Several provisions lay down requirements for **user-friendliness** (of payment options, for example), **information provision** at recharging and refuelling points and **data governance** (with respect to e.g. reservation systems). These provisions should reduce operational barriers.

'Fit for 55': other implications

Besides the proposal for an Alternative Fuels Infrastructure Regulation, the 'Fit for 55' package also contains other proposals that will contribute to transport decarbonisation. For example, the proposed revised **Renewable Energy Directive (RED)** also emphasises electrification of the energy system and a more prominent role for hydrogen (as a result of the sub-target for renewable fuels of non-biological origin (RFNBO)). The package translates the **polluter pays principle** into practice, by putting a price on carbon in additional sectors and enabling fairer competition with fossil fuels. This will certainly help to **level up the playing field for zero-emission technologies** in transport as well. A crucial question, though, is to what extent these proposals will be ultimately adopted, and whether the provisions will be weakened or strengthened in the process.

Existing technologies

From an environmental perspective, the **strong emphasis on zero-emission technologies** in the proposed AFIR is justified and will likely contribute more to the decarbonisation objectives than other options. The types of recharging and refuelling infrastructure targeted by the proposed AFIR are largely in line with the latest technological developments. The AFIR proposal sets first targets for BET charging stations in 2025 and for FCET refueling stations in 2030. This timing acknowledges that BETs have started to be produced in series and require a network of charging infrastructure sooner than FCETs, which are expected to be produced in series in about 5 years from now. However, the analysis of technological options in this study foresees a greater role (and potential) for **Megawatt Charging Systems (MSC)**. For **hydrogen** the market also expects larger capacities of 6-25 t/day compared to the 2t H₂/day of the AFIR proposal. The choice of the AFIR proposal to set **specific binding targets for stations offering liquid hydrogen on top of stations offering gaseous hydrogen at 700 bar might come a bit early**, as the development of the liquid hydrogen technology is still at an early stage. While **Electric Road Systems (ERS)** need to be factored in, these have here been identified as an emerging technology, not as a mature technology with large-scale application in the short term. The AFIR proposal also confirms that drop-in biofuels and e-fuels, should help to ensure that internal combustion engines and gas engines and the linked (liquid and gaseous) fuel pathways also contribute to the decarbonisation targets, making use of existing infrastructure.

Increased ambitions

Based on the length of the TEN-T network and the number of urban nodes and safe and secure parking areas, we have estimated that the targets for 2030 in the AFIR proposal corresponds to a total of 17,314 charging points and 728 hydrogen refuelling stations (HRS). When the BET projections used in the 'increased ambition' options of the AFIR impact assessment are compared with those cited by stakeholders, the former is found to be a factor 2.5-5 lower. A similar conclusion holds for the number of charging points anticipated: expectations among stakeholders on the required infrastructure are somewhat to considerably higher than the ambition level of the AFIR proposal. The target for overnight public charging points seems especially low. **Projections indicate a need for between 10,000 and 40,000 of these charging points, far beyond the minimum number of charging points (719)** we estimated, based on one charging point deployed at every safe and secure parking area by 2030 following to the AFIR proposal. While these major differences may stem in part from different calculation methods and assumptions, overall the targets may be insufficient to supply the future real-world BET fleet. If stakeholders' far higher projections become reality there will be a substantial risk that the attainment of the Green Deal objectives will be delayed. The AFIR proposal, however, sets targets for a minimum of infrastructure to allow BETs and FCETs to circulate through the EU and allows market actors to further develop the required infrastructure based on demand. The right amount of

infrastructure to be demanded in the AFIR depends on whether EU targets should only ensure a minimal level of infrastructure or whether the EU should guarantee full roll-out.

Barriers and enablers

Most relevant barriers have been acknowledged by the Commission in the **Strategic roll-out plan** published together with the AFIR proposal, including specific actions to be taken in the coming years. While large portions of **European funding schemes** have been reserved for alternative fuels infrastructure, there is a broad range of funding mechanisms involving numerous funding institutions. It therefore remains to be seen to what extent stakeholders will find their ways to apply to these funds. The strategy also contains many actions to be taken to improve information provision and strong data governance in order to inform stakeholders on the availability of infrastructure, as well as for policy monitoring purposes. Rapid technological developments and emerging technologies with respect to data collection and exchange will require ongoing actions. Despite all the actions formulated in the strategic roll-out plan, the two greatest factors thwarting acceleration of the deployment of charging and refuelling infrastructure remain basically unchanged: the time required to organise the market and the complex configuration of the stakeholders involved, both of which work against the need to act now. Another weak point of both the proposal and the strategic roll-out plan are the power levels envisaged. Although minimal power outputs have been defined to permit fast charging, the levels cited are fairly low compared with market actors' expectations and may hamper vehicle recharging within the actors' operational schedules (e.g. resting times, loading/unloading schedules). While the AFIR proposal demands a minimum number of charging stations with a power output of at least 150 kW at urban nodes and 350 kW along the TEN-T corridors, the ACEA and T&E **recommend to guarantee chargers with a minimum power output of 350 kW at urban nodes and over 500 kW along the TEN-T corridors.**

6.2. Policy recommendations and suggestions for further research

Based on technological developments, the recently proposed policy revisions and the analysis presented in this document, the following recommendations can be made:

- Ensure sufficient power output is deployed for fast-charging, to achieve sufficiently short recharging times and reduce operational barriers; **Higher minimum levels of power output (350 kW at urban nodes and >500 kW along TEN-T corridors) for charging infrastructure might be considered in the AFIR.**
- Indicative, rather than binding targets for liquid hydrogen might be considered **given the early phase of development of liquid hydrogen technology.**
- **A higher minimum requirement of charging stations for each safe and secure (overnight) parking area dedicated to heavy duty vehicles might be considered.**
- Further investigate the grid impacts of the additional power production implied by the 'Fit for 55' policy proposals;
- The AFIR proposal does not contain projections for the cost of grid adjustments, in addition to those for recharging and refuelling points. Insight in these costs will be helpful;
- Although the Commission has planned an extensive and iterative reporting and monitoring scheme, the development of the national policy frameworks will take place until 2025. This suggests there is only limited time for testing and revising national policies and revision of the AFIR before 2030. One option would be to speed up the development of national policy frameworks;

- New emerging technologies and their links with data governance issues and new communication technologies need to be followed closely because of the possibility of new barriers arising. This will also require flexibility on the part of policy makers to swiftly reply to these developments;
- Provide sufficient support to local authorities not only financially, but also organisationally and in terms of knowledge, since progress will depend to a major extent on procurement procedures.

REFERENCES

- ABB, 2021. *Industrial companies and startups are creating an innovative consortium to reduce carbon dioxide emissions via electric roads*. [Online]
Available at: <https://new-abb-com.translate.goog/news/sv/detail/80483/industriforetag-och-startups-skapar-innovativt-konsortium-for-att-minska-koldioxidutslapp-via-elvagar? x tr sl=auto& x tr tl=en& x tr hl=nl& x tr pto=nui>
- ACEA, 2019. *Alternatively-powered trucks: Availability of truck-specific charging and refuelling infrastructure in the EU*. [Online]
Available at: https://www.acea.be/uploads/press_releases_files/Infrastructure_alternatively-powered_trucks_January_2019.pdf
- ACEA, 2021a. *Heavy-duty vehicles: Charging and refuelling infrastructure requirements, ACEA Position Paper*. [Online]
Available at: <https://www.acea.auto/publication/position-paper-heavy-duty-vehicles-charging-and-refuelling-infrastructure-requirements/>
- ACEA, 2021b. *Vehicles in use Europe January 2021*. [Online]
Available at: <https://www.acea.auto/publication/report-vehicles-in-use-europe-january-2021/>
- ACEA & T&E, 2021. *Making AFID fit for zero-emission heavy-duty vehicles*. [Online]
Available at: https://www.transportenvironment.org/sites/te/files/publications/2021_04_letter_TE_ACEA_trucks_AFID_FINAL.pdf
- Air Liquide, 2020. *Air Liquide will build the first high-pressure hydrogen refueling station for long-haul trucks in Europe*. [Online]
Available at: <https://energies.airliquide.com/air-liquide-will-build-first-high-pressure-hydrogen-refueling-station-long-haul-trucks-europe#>
- Allego, 2020. *Getting zero-emission trucks on the road*. [Online]
Available at: <https://www.transportenvironment.org/sites/te/files/Charging%20infrastructure%20for%20e-trucks.pdf>
- Argonne National Laboratory, 2018. *International H2 infrastructure workshop*, Boston, MA, USA: Argonne National Laboratory.
- Asia Times, 2021. *Hydrogen China*. [Online]
Available at: <https://asiatimes.com/2021/03/hydrogen-fuels-a-revolution-in-chinese-trucking/>
- Berger, R., 2020. *Fuel Cells Hydrogen Trucks – Heavy-Duty’s High Performance Green Solution; Study Summary*, Brussels: FCH 2 JU.
- Bloomberg, 2021. *Hyperdrive Daily : Battery Swapping Makes A Comeback in China*. [Online]
Available at: <https://www.bloomberg.com/news/newsletters/2021-04-06/hyperdrive-daily-battery-swapping-makes-a-comeback-in-china>
- BMVI, 2021. *BMVI bringt Innovationscluster für klimafreundliche Lkw-Antriebstechnologien auf den Weg*. [Online]
Available at: <https://www.bmvi.de/SharedDocs/DE/Pressemitteilungen/2021/104-scheuer-innovationscluster-strassennutzverkehr.html>
- Brenna, M., Foadelli, F., Leone, C. & Longo, M., 2020. Electric Vehicles Charging Technology Review and Optimal Size Estimation. *Journal of Electrical Engineering & Technology*, pp. 2539-2552.

- Brown, A., Fleming, K. & Safford, H., 2020. Prospects for a highly electric road transportation sector in the USA. *Current Sustainable/Renewable Energy Reports*, pp. 84-97.
- Buck Consultants International ; Royal HaskoningDHV, 2021. *Elektrische logistiek : Eisen voor toekomstbestendige laadinfrastructuur, Verkenning*. [Online]
Available at: https://www.topsectorlogistiek.nl/wptop/wp-content/uploads/2021/03/Eisen-voor-toekomstbestendige-laadinfrastructuur_verkenning.pdf
- Buck Consultants; CE Delft; et al., 2019. *Charging infrastructure for electric vehicles in city logistics*. [Online]
Available at: https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_4T28_Charging_infrastructure_ev_FINAL.pdf
- California Air Resources Board, 2020. *Advanced Clean Trucks*. [Online]
Available at: <https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks>
- Cambridge Econometrics, 2018. *Trucking into a greener future : the economic impact of decarbonizing goods vehicles in Europe*, Cambridge: Cambridge Econometrics.
- CE Delft & TNO, 2020. *Outlook Hinterland and Continental Freight*. [Online]
Available at: https://cedelft.eu/wp-content/uploads/sites/2/2021/03/CE_Delft_190112_Outlook-Hinterland-Continental-Freight-2020.pdf
- CE Delft, 2020. Used Cooking Oil (UCO) as biofuel feedstock in the EU. December.
- CE Delft, 2021. *STREAM freight transport 2020: Emissions of freight transport modes*. [Online]
Available at: https://cedelft.eu/wp-content/uploads/sites/2/2021/03/CE_Delft_190325_STREAM_Freight_Transport_2020_FINAL.pdf
- CEDR, 2018. *Tran-European Road Network, TENT-T (roads) 2017 Performance report*, sl: CEDR.
- Charin, 2021. *Megawatt Charging System (MCS)*. [Online]
Available at: <https://www.charin.global/technology/mcs/>
- Clean Energy Wire, 2020. *Battery-electric trucks will win race against fuel cells and e-fuels - researcher. Interview with Auke Hoekstra*. [Online]
Available at: <https://www.cleanenergywire.org/news/battery-electric-trucks-will-win-race-against-fuel-cells-and-e-fuels-researcher>
- CNGFuels, 2021. *CNG Fuels About Us*. [Online]
Available at: <https://cngfuels.com/about-us/>
- CNHi, 2020. *Truck architecture and hydrogen storage*. [Online]
Available at: https://ec.europa.eu/jrc/sites/jrcsh/files/cnh_20201028_-_truck_architecture_public.pdf
- COLLERS, 2019. *Overview of ERS concepts and complementary technologies*, sl: COLLERS.
- COLLERS, 2020. *Real-world experiences of ERS; Best practices from demonstration projects in Sweden and Germany*, sl: COLLERS.
- Concawe, 2020. *Role of e-fuels in the European transport system : Literature review*, Brussels: Concawe.
- DAF, 2021. *DAF introduces charging stations for electric vehicles*. [Online]
Available at: <https://www.daf.com/en/news-and-media/news-articles/global/2021/q2/29-04-2021-daf-introduces-charging-stations-for-electric-vehicles>

- DAF, 2021. *Hydrogen; An option in the long term for powering trucks*. [Online]
Available at: <https://www.daf.com/en/about-daf/sustainability/alternative-fuels-and-drivelines/hydrogen>
- Daimler AG, 2021c. *Fuel-cell truck Start of testing of the new GenH2 Truck prototype*. [Online]
Available at: <https://www.daimler.com/innovation/drive-systems/hydrogen/start-of-testing-genh2-truck-prototype.html>
- Daimler Truck AG, 2021a. *Comprehensive ecosystem for entry into e-mobility for truck customers*. [Online]
Available at: <https://www.daimler-truck.com/innovation-sustainability/efficient-emission-free/emobility-daimler-trucks.html>
- Daimler Truck AG, 2021b. *Daimler Truck AG and Volvo Group fully committed to hydrogen-based fuel-cells - launch of new joint venture cellcentric*. [Online]
Available at: <https://media.daimler.com/marsMediaSite/en/instance/ko/Daimler-Truck-AG-and-Volvo-Group-fully-committed-to-hydrogen-based-fuel-cells--launch-of-new-joint-venture-cellcentric.xhtml?oid=49834035>
- Danilovic, M. & Liu, L., 2021. *Exploring Battery-swapping for Electric vehicles in China 1.0*. [Online]
Available at: <https://www.hh.se/download/18.2b9e5ca178b21e43bf3d3fd/1617969815049/Sweden-China%20Bridge.%20Newsletter%202021-04-06%5B42%5D.pdf>
- Dutch Government, 2019. *Climate Agreement*. [Online]
Available at: <https://www.klimaataakkoord.nl/binaries/klimaataakkoord/documenten/publicaties/2019/06/28/klimaataakkoord/klimaataakkoord.pdf>
- EAFO, 2021a. *Alternative fuels Fleet 2020*. [Online]
Available at: <https://eafo.eu/vehicles-and-fleet/n2-n3#>
- EAFO, 2021b. *Biogasoline refilling infrastructure*. [Online]
Available at: <https://eafo.eu/alternative-fuels/biofuels-refilling-infrastructure/generic-information>
- EAFO, 2021c. *LPG refuelling stations*. [Online]
Available at: <https://www.eafo.eu/alternative-fuels/lpg/filling-stations-stats>
- EC, 2018. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).
- EC, 2019a. *Reducing CO2 emissions from heavy-duty vehicles*. [Online]
Available at: https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en
- EC, 2019b. *The European Green Deal, COM(2019) 640 final*. [Online]
Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0005.02/DOC_1&format=PDF
- EC, 2020a. *A hydrogen strategy for a climate-neutral Europe, COM(2020) 301 final*, Brussels: European Commission (EC).
- EC, 2020b. *Proposal for a Regulation of the European Parliament and of the Council on guidelines for trans-European energy infrastructure and repealing Regulation (EU) No 347/2013*. [Online]
Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:824:FIN>

- EC, 2020c. *Commission Staff working Document : Impact Assessment Accompanying the document [.....] Stepping up Europe's 2030 climate ambition*, Brussels: European Commission (EC).
- EC, 2020d. *Sustainable and smart mobility strategy, COM(2020) 789 final*, Brussels: European Commission (EC).
- EC, 2021a. *Detailed Assessment of the Member States Implementation Reports on the National Policy Frameworks for the development of the market as regards alternative fuels in the transport sector, ... SWD(2021) 49 final*, Brussels: European Commission (EC).
- EC, 2021b. *Trans-European Transport Network (TEN-T)*. [Online]
Available at: https://ec.europa.eu/transport/themes/infrastructure/ten-t_en
- EC, 2021c. *EU taxonomy for sustainable activities*. [Online]
Available at: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en
- EC, 2021d. *Report on EU-wide alternative fuels infrastructure deployment – increased level of ambition, but still no comprehensive and complete network across EU*. [Online]
Available at: https://ec.europa.eu/transport/themes/urban/news/2021-03-09-report-eu-wide-alternative-fuels-infrastructure-deployment_en
- EC, 2021e. *Proposal for a Regulation of the EP and the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the EP and of the Council. COM(2021) 559 final*, Brussels: European Commission (EC).
- EC, 2021f. *Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union*, Brussels: European Commission.
- EC, 2021g. *Proposal for a DIRECTIVE OF THE EU PARLIAMENT AND OF THE COUNCIL amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999, and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*, Brussels: European Commission.
- E-Laad, 2020. *Trucks komen op stoom*. [Online]
Available at: https://www.elaad.nl/uploads/files/20Q3_Elaad_Outlook_E-trucks_internationale_logistiek.pdf
- Electrek, 2019. *Penske debuts fast speed charging stations for commercial electric trucks*. [Online]
Available at: <https://electrek.co/2019/04/26/penske-charging-stations-trucks/>
- Electrek, 2021. *Daimler unveils new 'first of its kind' electric truck charging station*. [Online]
Available at: <https://electrek.co/2021/04/21/daimler-electric-truck-charging-station/>
- Electric Roads, 2021. *Electric Roads Research and Innovation for Electric Road Systems*. [Online]
Available at: <https://www.electricroads.org/demonstrations/>
- Electrify.com, 2021. *Iberdrola plans Mediterranean mega charger corridor*. [Online]
Available at: <https://www.electrify.com/2021/08/02/iberdrola-plans-mediterranean-corridor-to-mega-charge-electric-trucks/>
- ETIP, 2021. *European Technology and Innovation Platform : Products and end use*. [Online]
Available at: <https://www.etipbioenergy.eu/value-chains/products-end-use/products/hvo-hefa>

- EU, 2014. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance. *Official Journal of the European Union*, pp. 1-20.
- EU, 2015. *Council Directive (EU) 2015/652 of 20 April 2015 laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels.* [Online] Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32015L0652>
- EurActiv, 2021a. *EU's draft renewables law confirms 38-40% target for 2030.* [Online] Available at: <https://www.euractiv.com/section/energy/news/leak-eus-draft-renewables-law-confirms-38-40-target-for-2030/>
- Euractiv, 2021b. *Hydrogen outlook in central and eastern Europe.* [Online] Available at: <https://en.euractiv.eu/wp-content/uploads/sites/2/special-report/Hydrogen-outlook-in-Central-and-Eastern-Europe-Event-Report-2021-.pdf>
- European Council, 2021b. *Council adopts European climate law.* [Online] Available at: <https://www.consilium.europa.eu/en/press/press-releases/2021/06/28/council-adopts-european-climate-law/>
- Eurostat, 2020. *Annual road freight transport, by distance class (1 000 t, Mio Tkm, Mio Veh-km, 1 000 BTO) [ROAD_GO_TA_DC__custom_1011257].* [Online] Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=road_go_ta_dc&lang=en
- Eurostat, 2021. *Lorries, by type of motor energy.* [Online] Available at: https://ec.europa.eu/eurostat/databrowser/view/ROAD_EQS_LORMOT_custom_1032223/default/table?lang=en
- Eurovignette, 2021. *Eurovignette.* [Online] Available at: <https://www.eurovignettes.eu/portal/en/booking/booking?reset=true>
- FCEB, 2021. *COMPRESSED GASEOUS HYDROGEN ON 350 BAR.* [Online] Available at: <https://www.fuelcellbuses.eu/wiki/fuelling-hydrogen-buses-hydrogen-refueling-station/compressed-gaseous-hydrogen-350-bar>
- FEV, 2021. *FEV succesful in designing low emissions : efficient hydrogen internal combustion engine.* [Online] Available at: <https://www.fev.com/en/coming-up/press/press-releases/news-article/article/fev-successful-in-designing-low-emission-efficient-hydrogen-internal-combustion-engine.html>
- Fraunhofer ISI, 2020. *Fuel cell trucks: 140 refueling stations are enough.* [Online] Available at: <https://www.isi.fraunhofer.de/en/presse/2020/presseinfo-18-wasserstoff-tankstellen-brennstoffzellen-lkw.html>
- FuelCellsWorks, 2019. *U.S. Senate passes \$1 billion in alternative fuel infrastructure, including hydrogen, EV, and natural gas.* [Online] Available at: <https://fuelcellsworks.com/news/u-s-senate-passes-1-billion-in-alternative-fuel-infrastructure-including-hydrogen-ev-and-natural-gas/>
- FuelCellsWorks, 2020a. *Portugese government approves hydrogen strategy, EUR 7 B investments.* [Online] Available at: <https://fuelcellsworks.com/news/portuguese-government-approves-hydrogen-strategy-e7b-investments/>

- FuelCellsWorks, 2020b. *Wystrach presents the mobile hydrogen refuelling station*. [Online] Available at: <https://fuelcellsworks.com/news/wystrach-presents-the-mobile-hydrogen-refueling-station/>
- German Government, 2019. *Regulatory environment and incentives for using electric vehicles and developing a charging infrastructure*. [Online] Available at: <https://www.bmwi.de/Redaktion/EN/Artikel/Industry/regulatory-environment-and-incentives-for-using-electric-vehicles.html>
- Giuliano, G. et al., 2020. *Heavy-Duty Trucks: The Challenge of Getting to Zero*, Los Angeles, USA: Sol Price School of Public Policy.
- Hall, D. & Lutsey, N., 2019. *Estimating the infrastructure needs and costs for the launch of zero-emission trucks*. [Online] Available at: https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf
- HARC, 2021. *International hydrogen fueling stations*. [Online] Available at: <https://h2tools.org/hyarc/hydrogen-data/international-hydrogen-fueling-stations>
- Hendriksen, E., Sloots, F. & Jong, J. d., 2021. *Privaat logistiek laden bij elkaar op privaat terrein, eindrapportage*. [Online] Available at: <https://www.topsectorlogistiek.nl/2021/04/12/privaat-logistiek-laden-bij-elkaar-op-privaat-terrein/>
- Hove, A. & Sandalow, D., 2019. *Electric vehicle charging in China and the United States*. [Online] Available at: https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf
- Hovi, I., Pinchasik, D., Figenbaum, E. & Thorne, R., 2020. Experiences from battery-electric truck users in Norway. *World Electric vehicle journal*.
- HRS map EU, 2021. *European HRS availability system*. [Online] Available at: <https://h2-map.eu/>
- Hydrogen Europe, 2019. *HyLAW: Deliverable 4.2 List of legal barriers*. [Online] Available at: <https://www.hylaw.eu/sites/default/files/2019-01/D4.2-%20-%20List%20of%20legal%20barriers.pdf>
- Hyundai MC, 2020. *Hyundai XCIENT Fuel Cell Heads to Europe for Commercial Use*. [Online] Available at: <https://www.hyundai.news/eu/articles/press-releases/hyundai-xcient-fuel-cell-heads-to-europe-for-commercial-use.html>
- ICCT, 2017. *Developing hydrogen fueling infrastructure for fuel cell vehicles: A status update*. [Online] Available at: https://theicct.org/sites/default/files/publications/Hydrogen-infrastructure-status-update_ICCT-briefing_04102017_vF.pdf
- IEA Bioenergy, 2020. *The Role of Renewable Transport Fuels in Decarbonizing Road Transport*. [Online] Available at: <https://www.ieabioenergy.com/blog/publications/new-publication-the-role-of-renewable-transport-fuels-in-decarbonizing-road-transport/>
- IEA, 2021. *Global EV outlook 2021 : Trends and developments in electric vehicle markets*. [Online] Available at: <https://www.iea.org/reports/global-ev-outlook-2021>
- InsideEVs, 2020. *Scania Deploys Two Battery Electric Trucks In Norway*. [Online] Available at: <https://insideevs.com/news/399162/scania-deployed-electric-trucks-norway/>

- INSIDEEVs, 2021. *Volvo, Daimler And Traton Plan Charging Network For Trucks*. [Online]
Available at: <https://insideevs.com/news/518363/volvo-daimler-traton-charging-trucks/>
- IPI Technology, 2021. *Wireless Opportunity Charging buses in Madrid*. [Online]
Available at: <https://ipt-technology.com/case-opportunity-charging-madrid/>
- JEC, 2020a. *JEC Tank-To-Wheels report v5; Heavy duty vehicles*. [Online]
Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC117564/jec_ttw_v5_hdv_117564_final.pdf
- JEC, 2020b. *JEC Well-To-Wheels report v5 - Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*. [Online]
Available at:
https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119036/jec_wtt_v5_119036_main_final.pdf
- JRC/DG Move, 2020. *State of the art on alternative fuels transport systems in the European Union*. [Online]
Available at: <https://op.europa.eu/en/publication-detail/-/publication/fd62065c-7a0b-11ea-b75f-01aa75ed71a1>
- Lambert, M. & Schulte, S., 2021. *Contrasting European Hydrogen pathways : an analysis of differing approaches in key markets*. [Online]
Available at: <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/03/Contrasting-European-hydrogen-pathways-An-analysis-of-differing-approaches-in-key-markets-NG166.pdf>
- McKinsey, 2020. *Why most e-trucks will choose overnight charging*. [Online]
Available at: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/why-most-etrucks-will-choose-overnight-charging>
- Moultak, M., Lutsey, N. & Hall, D., 2017. *Transitioning to zero-emission heavy-duty freight vehicles*. [Online]
Available at: https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf
- NACFE, 2019. *Amping up: charging infrastructure for electric trucks*. [Online]
Available at: <https://nacfe.org/emerging-technology/electric-trucks-2/amping-up-charging-infrastructure-for-electric-trucks/#>
- National Biodiesel Board, 2021. *biodiesel buying guide*. [Online]
Available at: <https://www.biodiesel.org/using-biodiesel/buying-guide>
- Netherlands Innovation Network China, 2019. *Overview of hydrogen and fuel cell developments in China*. [Online]
Available at: <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjf6arKwMzxAhVGsaQKHQNKAA40QFnoECA0QAA&url=https%3A%2F%2Fwww.nederlandwereldwijd.nl%2Fbinaries%2Fnederlandwereldwijd%2Fdocumenten%2Fpublicaties%2F2019%2F03%2F01%2Fwaterstof-in-china%2>
- NGVA Europe, 2020. *Press Release - 2019 in numbers : gas in transport - the coice of European consumer*. [Online]
Available at: <https://www.ngva.eu/medias/2019-in-numbers-gas-in-transport-to-satisfy-european-consumers/>

- NGVA Europe, 2021a. *NGVA Europe has published 2020 gas vehicle statistics and Europe has reached a new gas refuelling infrastructure milestone*. [Online]
Available at: <https://www.ngva.eu/medias/ngva-europe-has-published-2020-gas-vehicle-statistics-and-europe-has-reached-a-new-gas-refuelling-infrastructure-milestone/>
- NGVA Europe, 2021b. *Stations map*. [Online]
Available at: <https://www.ngva.eu/stations-map/>
- Norwegian Government, 2020. *The Norwegian government's hydrogen strategy*, Oslo: Ministry of Climate and Environment.
- OECD, 2017. *The future of trucks, implications for energy and the environment*. [Online]
Available at: <https://read.oecd.org/10.1787/9789264279452-en?format=pdf>
- OPB, 2020. *PGE, Daimler team up to build charging hub for electric trucks in Portland*. [Online]
Available at: <https://www.opb.org/article/2020/12/01/portland-oregon-electric-truck-charging-stations-daimler/>
- Platform Duurzame Biobrandstoffen, 2021. *Sneak preview van de aangepaste 2030-doelen voor hernieuwbare energie in transport*. [Online]
Available at: <https://platformduurzamebiobrandstoffen.nl/sneak-preview-over-de-aangepaste-2030-doelen-voor-hernieuwbare-energie-in-transport/>
- Prussi, M., Julea, A., Lonza, L. & Thiel, C., 2021. Biomethane as alternative fuel for the EU road sector: Analysis of existing and planned infrastructure. *Energy Strategy Reviews*.
- Renault group, 2021. *On the road to carbon neutrality*. [Online]
Available at: <https://smarttransportpub.blob.core.windows.net/web/1/root/climate-report-renault-group.pdf>
- Reuters, 2020. *Hyundai delivers first fuel cell trucks to Switzerland*. [Online]
Available at: <https://www.reuters.com/article/hyundai-switzerland-hydrogen-trucks-idUSKBN26S1FM>
- Reuters, 2021. *Daimler, Volvo and Traton plan \$600 million truck-charging JV*. [Online]
Available at: <https://www.reuters.com/business/autos-transportation/daimler-volvo-traton-plan-600-million-truck-charging-jv-2021-07-05/>
- Ricardo Energy & Environment, 2020. *Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA*. [Online]
Available at: <https://op.europa.eu/nl/publication-detail/-/publication/1f494180-bc0e-11ea-811c-01aa75ed71a1>
- RMI, 2020. *The electric vehicle charging no one's talking about*. [Online]
Available at: <https://rmi.org/the-electric-vehicle-charging-no-ones-talking-about-but-should-be/>
- RMI, 2021. *How China Can Achieve Carbon-Neutral Transport by 2060*. [Online]
Available at: <https://rmi.org/how-china-can-achieve-carbon-neutral-transport-by-2060/>
- Rodríguez, F., Hildermeier, J. & Jahn, A., 2020. *Electrifying EU city logistics: An analysis of energy demand and charging cost*. [Online]
Available at: <https://theicct.org/sites/default/files/publications/EU-logistics-electrification-fv-202011.pdf>
- Rose, P. & Neumann, F., 2020. Hydrogen refueling station networks for heavy-duty vehicles in future power systems. *Transportation Research Part D: Transport and Environment*, June.

- Ruf, Y. et al., 2020. *Fuel Cells Hydrogen Trucks : Heavy Duty's High Performance Green Solution*. [Online] Available at: https://www.fch.europa.eu/sites/default/files/FCH%20Docs/201211%20FCH%20HDT%20-%20Study%20Report_final_vs.pdf
- RVO, 2020. *Nationale Agenda Laadinfrastructuur*. [Online] Available at: <https://www.agendalaadinfrastructuur.nl/default.aspx>
- SAE International, 2014. *DOE Webinar: Introduction to SAE H2 Fueling Standardization*, Warrendale, PA, USA: SAE International.
- Scania, 2020. *Scania to deliver 75 battery electric trucks to ASKO in Norway*. [Online] Available at: <https://www.scania.com/group/en/home/newsroom/press-releases/press-release-detail-page.html/3669566-scania-to-deliver-75-battery-electric-trucks-to-asko-in-norway>
- Scania, 2021. *Scania's commitment to battery electric vehicles*. [Online] Available at: <https://www.scania.com/group/en/home/newsroom/news/2021/Scantias-commitment-to-battery-electric-vehicles.html>
- Schuckert, D. M., 2020. *The Future of Zero Emission Long-Haul Trucking*. [Online] Available at: <https://www.transportenvironment.org/sites/te/files/The%20Future%20of%20Zero%20Emission%20Long-Haul%20Trucking%20Daimler.pdf>
- Searle, S. & Christensen, A., 2018. *Decarbonization potential of electrofuels in the European Union*. [Online] Available at: https://theicct.org/sites/default/files/publications/Electrofuels_Decarbonization_EU_20180920.pdf
- SEI, 2019. *Electrification and the bioeconomy: three sides to the story*, Stockholm: Stockholm Environment Institute.
- Serra, A. et al., 2019. *COLHD : Overcoming the barriers to the development of the European Alternative Fuels market*, <https://egvi.eu/wp-content/uploads/2019/05/COLHD-Report-Overcoming-barriers-to-Alternative-fuel-market-development.pdf>: sn
- Siegemund, S., Trommler, M., Kolb, O. & Zinnecker, V., 2017. *The potential of electricity-based fuels for low-emission transport in the EU : E-Fuels Study*. [Online] Available at: https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9219_E-FUELS-STUDY_The_potential_of_electricity_based_fuels_for_low_emission_transport_in_the_EU.pdf
- Siemens Energy, 2020. *Rich in sun or wind? : Here's how your country can export renewables*. [Online] Available at: <https://www.siemens-energy.com/global/en/news/magazine/2020/universal-e-fuel-hubs.html>
- Siemens, 2019. *eHighway*. [Online] Available at: <https://new.siemens.com/global/en/products/>
- Siemens, 2021. *eHighway – Solutions for electrified road freight transport*. [Online] Available at: <https://press.siemens.com/global/en/feature/ehighway-solutions-electrified-road-freight-transport>
- Siemens, 2021. *Fast Charging Systems for eBuses*. [Online] Available at: <https://new.siemens.com/my/en/markets/transportation-logistics/electromobility/ebus-charging.html>

- Smartroadgotland, 2021. *The world's first wireless electric road charging an e-bus and e-truck*. [Online]
Available at: <https://www.smartroadgotland.com/>
- Steenberghen, T. & López, E., 2008. *Overcoming barriers to the implementation of alternative fuels for road transport in Europe*. [Online]
Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0959652606004215>
- T&E, 2018. *Analysis of long haul battery electric trucks in EU - Marketplace and technology, economic, environmental, and policy perspective*, Brussels, Belgium: Transport & Environment.
- T&E, 2020a. *Recharge EU trucks : time to act. A roadmap for electric truck charging infrastructure*. [Online]
Available at:
https://www.transportenvironment.org/sites/te/files/publications/2020_02_RechargeEU_trucks_paper.pdf
- T&E, 2020b. *Unlocking electric trucking in the EU: recharging cities: Electrification of urban and regional deliveries (Vol.1)*. [Online]
Available at: <https://www.transportenvironment.org/publications/unlocking-electric-trucking-eu-recharging-cities>
- T&E, 2020. *Comparison of hydrogen and battery electric trucks*, Brussels, Belgium: Transport & Environment.
- T&E, 2021. *Battery Electric Trucks*, Brussels, Belgium: Transport & Environment.
- T&E, 2021. *Unlocking electric trucking in the EU: recharging along highways*. [Online]
Available at: <https://www.transportenvironment.org/publications/unlocking-electric-trucking-eu-recharging-along-highways>
- T&E, 2021. *Unlocking electric trucking in the EU: recharging along highways; Electrification of long-haul trucks (Vol.2)*, Brussels: Transport & Environment.
- The White House, 2021. *Fact sheet : Biden administration advances electric vehicle charging infrastructure*. [Online]
Available at: <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-biden-administration-advances-electric-vehicle-charging-infrastructure/>
- TNO, 2019. *Behoeftte aan infrastructuur voor energiedragers voor mobiliteit in Nederland*. [Online]
Available at: <http://publications.tno.nl/publication/34634981/dbdVv6/TNO-2019-R11705.pdf>
- Trafikverket, 2021. *Electric road E20, Hallsberg–Örebro*. [Online]
Available at: <https://www.trafikverket.se/en/startpage/projects/Road-construction-projects/electric-road-e20-hallsbergorebro/>
- TRATON, 2021. *Why the future of trucks is electric*. [Online]
Available at: <https://traton.com/en/newsroom/current-topics/future-transport-electric-truck.html>
- Trencher, G. & Edianto, A., 2021. *Drivers and Barriers to the Adoption of Fuel Cell Passenger Vehicles and Buses in Germany*. [Online]
Available at: <https://ideas.repec.org/a/gam/jeners/v14y2021i4p833-d493924.html>
- Urban access regulations, 2021. *Overview of urban access regulations in Europe*. [Online]
Available at: <https://urbanaccessregulations.eu/userhome/map>

- US DOE, 2020. *Hydrogen program plan 2020*. [Online]
Available at: <https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf>
- US DOE, 2021. *Alternative Fuels Data Center*. [Online]
Available at:
https://afdc.energy.gov/fuels/hydrogen_locations.html#/analyze?fuel=HY&country=US
- VDA, 2021. *www.VDA.de*. [Online]
Available at: <https://www.vda.de/de/presse/Pressemeldungen/210309-Branchen-bergreifendes-Konsortium-reicht-F-rderantrag-zum-Megawattladen-f-r-Nutzfahrzeuge-ein>
- Verheul, B., 2019. *Overview of hydrogen and fuel cell developments in China*, Shanghai: Holland Innovation Network China.
- Volkswagen, 2020. *MAN presents Zero-Emission Roadmap*. [Online]
Available at: <https://www.volkswagenag.com/en/news/2020/10/MAN-presents-Zero-Emission-Roadmap.html>
- WEH, 2021. *WEH® Fueling Nozzle TK16 H₂ High Flow - H₂ Components for Bus & Truck Dispensers*, Illertissen, Germany: WEH.
- WLPGA, 2017. *LPG for Heavy Duty Engines : Buses, Trucks, Marine and Other Applications*. [Online]
Available at: <https://www.scribd.com/document/396898467/LPG-for-Heavy-Duty-Engines-2017>
- World Economic Forum, 2020a. *Are electric trucks a highway to a low-carbon future or a dead end?*. [Online]
Available at: <https://www.weforum.org/agenda/2020/11/electric-trucks-vehicles-low-carbon-future/>
- World Economic Forum, 2020b. *Electric trucks: highway to a low-carbon future or dead end?*. [Online]
Available at: <https://www.weforum.org/agenda/2020/11/electric-trucks-vehicles-low-carbon-future/>
- Yicaiglobal, 2021. *Guangdong Leads China in Embracing Green Hydrogen With Most Refueling Stations, Report Says*. [Online]
Available at: <https://www.yicaiglobal.com/news/guangdong-leads-china-in-embracing-green-hydrogen-with-most-refueling-stations-report-says>

ANNEX A INTERVIEWEES

Table : Description of interviewed stakeholders

Stakeholder group	Stakeholder type	Geographical coverage
OEMS	Representant OEMS	EU
	OEM	Worldwide
Logistics	Carrier	EU/Germany
	Representant shippers and carriers	EU
Infrastructure	Transmission system operator	the Netherlands
	Market actor infrastructure realization	the Netherlands
Research	Consultant implementation alternative technologies	Northern Europe
	Research program focused on logistics	the Netherlands
Policy	NGO	EU/International
	Network of EU cities and regions	EU/Italy

A. ANNEX B COST DATA

Truck cost projections

The total cost of ownership (TCO), a calculation method that determines overall cost of a vehicle or service throughout its life cycle, including direct and indirect costs, is one of the principal parameters on which transport operators base their choices on the type of vehicle to be used for their operations. BETs and FCETs currently have a higher TCO than trucks powered by diesel or gaseous fuels. Table 17 presents an overview of projected truck TCO by type of powertrain.

Table 17: Total cost of ownership over five years by powertrain and year in € 2015

TCO per year	Öko-Institut, 2018 ^a		Cambridge Econometrics, 2018 ^b	
	2025	2030	2030	2050
Diesel ICE	€ 361,000	€ 349,000	€ 280,000	€ 270,000
BET (400 km range)	€ 330,000	€ 303,000	NS	NS
BET (600 km range)	NS	NS	€ 195,000	€ 180,000
BET (800 km range)	€ 367,000	€ 335,000	NS	NS
FCET	€ 523,000	€ 443,000	€ 330,000	€ 270,000
BET-ERS	€ 331,000	€ 302,000	€ 165,000	€ 155,000
LNG	€ 288,000	€ 279,000	NS	NS
PHEV-ERS	NS	NS	€ 200,000	€ 175,000

Source: [Öko-Institut, 2018](#) and [Cambridge Econometrics, 2018](#). All numbers rounded at thousands. ^a Taken from Annex 6, p. 136. Road toll excluded. ^b Taken from Figure 5.3 in Technical Report

According to both sources, BETs reach cost parity with diesel-powered trucks by 2025 and even have a more cost-effective TCO in the case of a lower-range BET, compared with diesel trucks. From 2030 onwards, BETs are expected to have a lower TCO than diesel-powered vehicles, for every indicated range. Both studies indicate a large difference in TCO between BETs (regardless of range) and FCETs. The difference in TCO is due mainly to a difference in operating costs, which according to both sources are approximately two times higher for a FCET than for a BET. For BET-ERS⁴⁶, the cost figures are similar to BETs in the sense of cost parity with diesel-powered trucks. Also, LNG-powered trucks are projected to have a significantly lower TCO from 2025 onwards.

The figures for operational cost per kilometre in 2030 reported in Table 18, according to [T&E, \(2018\)](#), confirm the lower operational costs for BETs. The per-kilometre cost is then highest for the existing fleet and lowest for BETs in the short-haul segment.

⁴⁶ BET-ERS is a truck that can use electric road system (ERS) infrastructure by overhead catenary on highways and uses its battery-powered system for last-mile transport and when no ERS is available.

Table 18: Operational cost per kilometre in 2030

Type of powertrain	2030
ICE (existing fleet 2030)	€ 1.09
ICE (theoretical best case)	€ 1.02
BET (800 km range)	€ 1.05
BET (480 km range)	€ 0.99
BET (160 km range)	€ 0.98

Source: (T&E, 2018).

Recharging and refuelling infrastructure cost projections

This subsection presents and discusses the cost of recharging and refuelling infrastructure, as found in the literature and from commercial parties, including projections for the year 2030.

There are several cost projections for truck-dedicated recharging infrastructure available in the literature. Table 19 provides a summary of average figures taken from [T&E \(2020\)](#) with a breakdown into annual operating costs and Capital Expenditures (CAPEX).

Table 19: Cost projection overview by recharging infrastructure type

Segment and type of charger		2020	2030
<i>Long-haul</i>			
Megawatt charger (1.2 MW)	CAPEX	NS	€ 364,000
	Annual operating costs	NS	€ 3,600
Overnight charger (150 kW)	CAPEX	NS	€ 193,000
	Annual operating costs	NS	€ 1,900
Total infrastructure cost per vehicle per year		NS	€ 5,700
<i>Short-haul</i>			
Fast charger (600 kW)	CAPEX	€ 223,000	€ 193,000
	Annual operating costs	€ 2,200	€ 1,900
Overnight charger (75 kW)	CAPEX	€ 42,000	€ 35,000
	Annual operating costs	€ 400	€ 400
Total infrastructure costs per vehicle per year		€ 3,700	€ 3,100

Source: [T&E, 2020](#), table on p. 8-9. An infrastructure service lifetime of fifteen years is assumed. The number of trucks supplied per night or day is 20 for the fast chargers and 0.91 per night for the overnight chargers⁴⁷. Numbers rounded to hundreds, CAPEX figures to thousands. The T&E boundary between short-haul and long-haul trucks is 400 kilometres.

For the costs of hydrogen refuelling infrastructure there are few publicly available sources. Table 20 presents the cost estimates for a hydrogen refilling station reported in T&E (2020), under the

⁴⁷ The practical meaning of 0.91 vehicles supplied per night is that vehicles may not recharge fully (up to 100% of the BET battery) using the infrastructure.

provision that the costs are still uncertain, as the technology is not yet fully scaled nor commercially available.

Table 20: Cost elements of hydrogen refuelling infrastructure

Cost elements	2020	2030
Total refuelling capacity (kg)	5,500	5,500
CAPEX (million EUR)	€ 7.0	€ 5.6
Annual operating costs	€ 69,700	€ 56,100
Total infrastructure costs per vehicle per year	€ 4,900	€ 3,900

Source: [T&E, 2020](#). The mean refilling quantity is 33 kg H₂. An infrastructure service lifetime of fifteen years is assumed. No. of trucks supplied per day is 110. Numbers rounded to hundreds, except for CAPEX

There are currently no projections of gaseous, biofuel and e-fuel refuelling infrastructure costs publicly available. As mentioned earlier, refuelling with these fuels is feasible using existing infrastructure for conventional fuels and gases. Similar (but not necessarily equal) costs can therefore be assumed for infrastructure use and deployment for gaseous, biofuel and e-fuels.

This study presents the opportunities and challenges for the use and deployment of alternative fuels infrastructure in the EU for heavy-duty vehicles, in particular trucks. The current state of play and future needs are presented in the context of the ambitions of the Green Deal, the proposal for an Alternative Fuels Infrastructure Regulation published mid-July 2021 and the upcoming review of the TEN-T Regulation.

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