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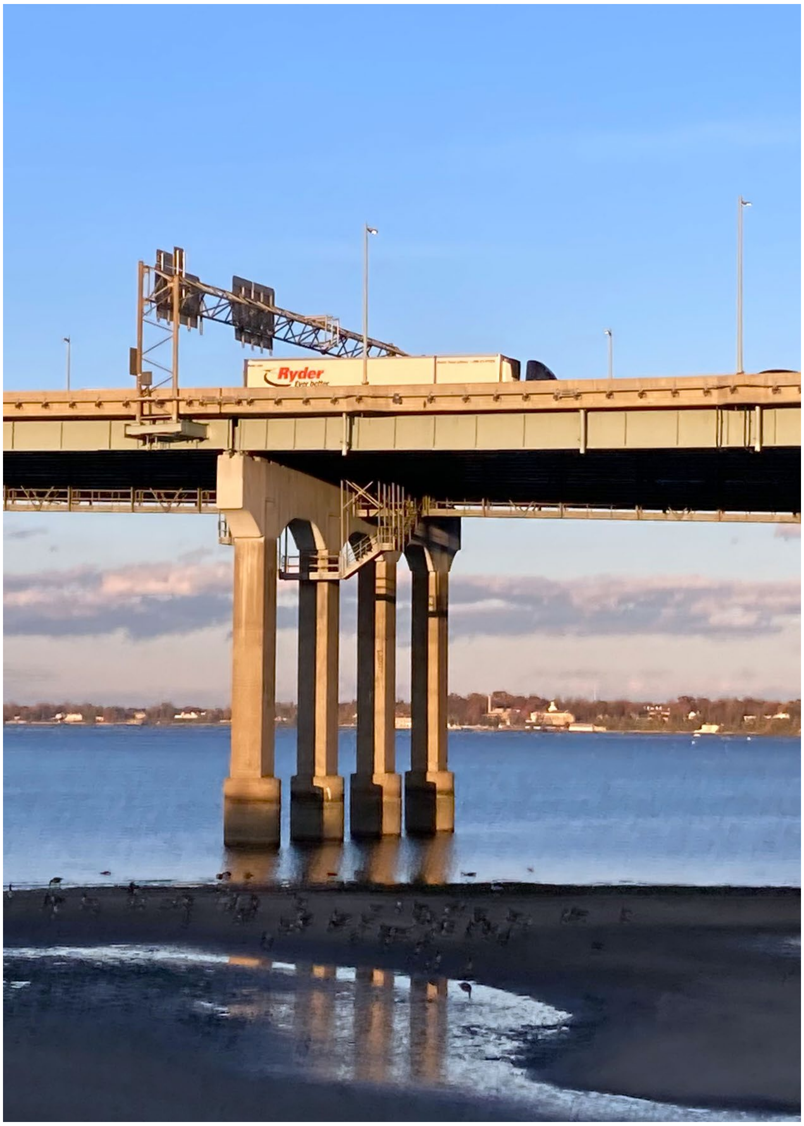


Decarbonizing heavy-duty road transport in Europe

ZenVn Research | KEARNEY

Acronyms

BET: battery electric truck

BEV: battery electric vehicle

FCET: fuel-cell electric truck

FCEV: fuel-cell electric vehicle

GHG: greenhouse gas emissions

GWP: global warming potential (The GWP is a measure of how much energy the emissions of one ton of a gas will absorb over a given period of time, relative to the emissions of one ton of carbon dioxide (CO_2). It allows for comparisons of the global warming impacts of different gases; the larger the GWP, the more that a given gas warms the Earth compared with CO_2 over that time period [US Environmental Protection Agency]).

HDV: heavy duty vehicle (freight vehicles of more than 3.5 tons for trucks or passenger transport vehicles of more than 8 seats for buses and coaches)

HPC: high-power charging (charging power greater than 50 kW)

HRS: hydrogen refueling station

LEV: low-emissions vehicle (LEVs are trucks with a technically permissible maximum laden mass of more than 16t, with CO_2 emissions of less than half of the average CO_2 emissions of all vehicles in its group registered in the 2019 reporting period.)

SMR: steam methane reforming (the most common chemical process to produce hydrogen)

TTW: tank-to-wheel (This type of analysis only focuses on the part of the energy chain going from the tank/battery to the wheels of the vehicle.)

WTT: well-to-tank (This type of analysis only focuses on the part of the energy chain going from the production to the tank/battery of the vehicle.)

WTW: well-to-wheel (This type of analysis considers the entire energy chain to power a vehicle, from the production of the fuel to the energy delivered at the wheels.)

ZET: zero-emissions truck (lorries with no tailpipe CO_2 emissions)

ZEV: zero-emissions vehicle (vehicles with no tailpipe CO_2 emissions)

Amid ambitious net-zero goals and growing demand for road transport, there is no doubt it is time to embrace greener options for heavy-duty vehicles. But one question remains: which technology holds the most promise?

The path to decarbonize heavy road transport can follow multiple technology routes, with BET and FCET solutions being the more promising ones. Batteries have long been ignored as a viable solution for heavy-duty mobility, but now, technology innovation is changing the game.

Comparing BET and FCET performance requires taking a look at three dimensions: operational performance, greenhouse gas (GHG) emissions, and financial performance: there is no clear winner across all dimensions. While FCETs have a longer potential range (1,200 km), better payload performance (about 1.5t), and shorter recharging time (about 15 minutes), BETs are more energy efficient roundtrip (70 to 75 percent well to wheel), have a better GHG footprint (for comparable electricity sources), and have lower initial and maintenance costs.

The impact of switching part of the truck fleet to hydrogen or batteries is still unclear. Several questions need to be considered to better understand the implications of switching to a new technology and to know if the switch will be beneficial. From an energy system perspective, assuming the full switch of short-, medium-, and long-haul, FCETs would require about three times more green electricity than BETs (about 25 percent versus about 9 percent of total green power in the EU, respectively), with a larger required investment on infrastructure.

Beyond the performance of technologies, the selection of BETs or FCETs options must also consider their deep implications on energy networks. Similarly, other strategic constraints such as those imposed by the supply chains of raw material and technologies or energy security priorities must also be considered in the decision-making process.

Decarbonization of heavy-duty transportation is a must to achieve EU net zero targets

Even though heavy-duty vehicles make up only 1 percent of the European Union's road mobility fleet, they are responsible for more than 26 percent of road transport emissions and about 5 percent of all emissions across Europe. The EU has put a spotlight on this issue in its long-term strategy to reach net zero, adopting CO_2 emission standards for heavy-duty vehicles and aiming to reduce the average emissions from new lorries by 15 percent in 2025 and by 30 percent in 2030. Covering around two-thirds of the total CO_2 emissions from heavy-duty vehicles, the regulation includes incentives for zero-emission vehicles (ZEV) and low-emission vehicles (LEV) along with financial penalties for non-compliance.[1]

In this environment, achieving the EU's ambitious net-zero targets will require decarbonizing a significant share of the heavy-duty fleet. Another motivating factor is that major cities across Europe have committed to banning combustion engine vehicles in key urban areas by 2035, strengthening the need for low-carbon vehicles. And demand for heavy-duty freight has recovered from its pandemic-induced slowdown. After road freight transport dropped 9.7 percent between Q2 2019 and Q2 2020, it bounced back 2.4 percent in Q3 2020 and 3.3 percent in Q4 2020 compared with same period the year before.

So, what are the potential solutions?

Heavy road transportation, together with rail, remains an essential part of international freight. Although intergovernmental cooperation will be necessary to improve Europe's efficiency and environmental performance, the decarbonization of heavy-duty road transport mostly relies on the sector improving its own performance. This paper maps out the potential ways Europe can make trucking more sustainable.

[1] LEVs are lorries with a technically permissible maximum laden mass of more than 16t, with CO_2 emissions of less than half of the average CO_2 emissions of all vehicles in its group registered in the 2019 reporting period. The level of the penalties is set to €4,250 per gCO_2/tkm in 2025 and €6,800 per gCO_2/tkm in 2030. The certification regulation currently applies to vehicle groups four (4x2 rigid), five (4x2 tractor), nine (6x2 rigid), and 10 (6x2 tractor) with a technically permissible maximum laden mass TPMLM > 16t.

The path to decarbonize road transport can follow multiple technology routes

Europe's heavy-duty transport sector has no choice but to start developing low-carbon power trains to align with the EU's net-zero vision. Accordingly, several manufacturers have introduced ZEVs. However, several options for which technology is best are still on the table, but none of them is a silver bullet since they are all facing challenges in either the technology's maturity, cost, or implementation.

The main technologies include biofuels and biogas, catenary electric vehicles, battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs) based on low-carbon hydrogen. Although sustainability constraints are limiting the potential of bio-energies, there are more pressing demands from other industrial sectors that have less mature technology alternatives but similar regulatory pressure to decarbonize, such as in aviation and shipping. As for catenary electric vehicles, creating the right infrastructure would require very high upfront investments and would only work for trucks that spend most of their time on highways.

Thus, BEV and FCEV solutions are the more promising ways to decarbonize heavy road transport. Batteries have long been ignored as a viable solution for heavy-duty mobility, but now, they are being rapidly adopted in the bus and medium-duty vehicles segments. For long-haul heavy-duty applications, technology innovation is changing the game, making batteries another feasible option as improvements in the power train design promise performance that is comparable to internal combustion engines and hydrogen.

Until 2018, more than 90 percent of the global zero-emission heavy-duty vehicles (ZE-HDVs) were buses. But this is changing: in 2020, trucks accounted for a quarter of new ZE-HDV registrations, up from 9 percent in 2018. Battery electric technology dominates the ZE-HDV market with 95 percent of new registrations; meanwhile, the penetration of fuel-cell electric technologies remains negligible. First initiatives on battery electric trucks (BETs) and fuel-cell electric trucks (FCETs) are taking place mainly in Western Europe. Most of the other alternatively fueled trucks are registered in Germany (BETs) or the Netherlands (BETs and hydrogen FCETs). In 2020, the uptake of hydrogen trucks in the EU 27 was still minimal, with only 11 trucks registered in the Netherlands for a pilot project. Meanwhile, more than 1,000 BETs were registered in Germany, the Netherlands, and a few other European countries.

FCEVs and BEVs benefit from massive governmental support in multiple areas. For example, hydrogen is at the heart of the European Green Deal and has been cascaded into national recovery plans with ambitious targets supported by significant financial incentives, such as in France, where €275 million will be given through a public tender to develop low-carbon hydrogen production.

It's time for Europe's heavy-duty transport players to make an important decision, choosing between BET or FCET technologies. Only a massive technology adoption can get the cost of heavy-duty vehicles on par with their diesel equivalents. To shed light on the best route forward, the latest BET and FCET technologies have been compared, including new truck designs, taking a close look at their technical and economic performances today and their potential for the near term. Various types of freight transport (short, medium, and long distance) have been considered, providing a high-level analysis of their large-scale deployment in the EU and identifying the practical challenges, bottlenecks, and consequences for energy systems and demand.

The performance of BET and FCET technologies are converging thanks to new truck design and technology innovations

Comparing BET and FCET performance requires taking a look at three dimensions: operational performance, greenhouse gas (GHG) emissions, and financial performance (see figure 1 on page 4). Operational performance can be further broken down into four subdimensions: autonomy range, payload, energy and fuel efficiency, and recharging time. There is no clear winner between BET and FCET across all dimensions.

Theoretically, FCETs have a longer potential range than BETs (1,200 km versus 800 km) and better payload performance (about 1.5t versus 3.8t penalty compared with a diesel truck). Let's put this into perspective: more than 80 percent of trucks travel a maximum of 750 km a day; more than half travel less than 400 km a day.[2] Also, the traveled distance needs to comply with the 2006 European directive, which says daily driving time cannot exceed nine hours and a driver must take an uninterrupted break of at least 45 minutes after driving for 4.5 hours. For weight-limited trips, BETs have a slightly lower payload than FCETs because hydrogen has higher energy density than lithium–ion batteries, both in terms of energy stored per unit weight (MJ/kg) and energy stored per unit volume (MJ/L). Two moves could potentially reduce the weight penalty. First, switching from a conventional central motor to an electric drivetrain close to the wheels can reduce the weight by more than two tons. Second, BETs payload will benefit from increasing energy density of batteries. Both FCETs and BETs benefit from European regulations that allow for a higher weight limit on zero emission trucks—two more tons than for an equivalent diesel truck.[3] In addition, the truck load bottleneck is mostly driven by volume rather than weight: truck capacity is often saturated by volume, not by weight.

The truck load bottleneck is mostly driven by volume rather than weight.

BETs are more energy efficient roundtrip than FCETs (70 to 75 percent well to wheel versus 25 to 35 percent). Because of this efficiency gap between the two technologies' value chains, two to three times as much electricity is needed to power a fuel cell truck than a battery truck (275 to 375kWh/100km versus 100 to 130kWh/100km).

[2] Daniel Speth and Simon Funke, 2021, scope: Germany
[3] Directive (EU) 2015/719 of the European Parliament and of the Council of 29 April 2015 amending Council Directive 96/53/EC laying down for certain road vehicles circulating within the community the maximum authorized dimensions in national and international traffic and the maximum authorized weights in international traffic

Figure 1

There is no clear winner between BET and FCET in terms of operational performance, carbon footprint, and cost

Comparison of key performance indicators

		Hydrogen fuel cell trucks (FCET)	Battery electric trucks (BET)
Operational performance	Maximum forecasted autonomy range	Up to **1,200 km** Examples: Hyzon (600), MAN (800), and Mercedes GenH2 (1,000)	Up to **800 km** Examples: Renault ZE (300), Mercedes eActros (200, long-haul 500 (2024), Nikola Tre (480), Tesla Semi (800), and Scania (240)
	Payload	**Payload penalty: 1–1.5t** Hypotheses: 150 kWh battery about 0.82 t; 35–70kg H2; 175–490kg of tank	**Payload penalty: 3.3–3.8t** Hypothesis: 700kWh battery
	Energy and fuel efficiency	**Well-to-wheel energy efficiency: 25–35%**	**Well-to-wheel energy efficiency: 70–75%**
		Fuel consumption: 275–375kWh/100km (6.5–7.8kg H2/100km)	**Fuel consumption: 100–130kWh/100km**
	Charging and refueling time	**5–15 minutes**	**8 hours (overnight)** **1.5 hours (destination)** **45 minutes (HPC)** (Note 1)
GHG emission	GHG emissions (gCO_2/km) Diesel: 1,051gCO_2e/km	**37–45** (onshore wind 2022) **805–971** (EU 27 average electricity mix 2022) **520–936** (H2 from SMR)	**13–16** (onshore wind 2022) **283–340** (EU 27 average electricity mix 2022) **867–1041** (Poland electricity mix 2022)
Financial performance	Fuel price per km	**€0.39–€0.55/km** €6–7/kgH2 (2020)	**€0.16–€0.23/km** €16–€18cts/kWh (renewables, 2020)
	Investment costs	€160–€345k (Nikola One and TE)	**€165–€215k** (Tesla Semi and TE)

Notes: 1. Swappable batteries / engines are also a potential alternative; 2. Average mix from UPDATE: T&E's analysis of electric car life-cycle CO_2 emissions (2022), H2 SMR emissions from RMI Hydrogen's Decarbonization Impact for Industry

Sources: Transport Environment, Zemo; Zenon and Kearney analysis

However, FCETs can be refueled in less than 15 minutes—about the same amount of time as diesel trucks, while BETs need to be charged for eight hours with the current charging technology at 50kW and a 400kWh battery. (Manufacturers already offer trucks with up to 560kWh.) However, with power outputs of 1 MW, the recharging time could theoretically be reduced to one hour so trucks could recharge faster and expand their daily range. In addition, technologies such as battery swap trucks and catenary systems could shorten the refueling time. Defining the most suitable technology will depend on the charging or refueling opportunities and the infrastructure.

The GHG footprint is better for BETs than for FCETs for comparable electricity sources. FCETs also have a higher initial cost, higher maintenance costs (leak and corrosion checks), and less already-available recharging infrastructure because BETs benefit from the spill-over effects of the electric passenger car industry in terms of charging infrastructure and a lower battery price. Also, the global warming potential of hydrogen was recently raised to 33 over a 20-year period, with an uncertainty range of 20 to 44, which might impact the attractiveness for hydrogen solutions implying potential leaks across the value chain.

The impact of switching part of the truck fleet to hydrogen or batteries is still unclear.

Going the distance: considering short, medium, and long haul in the EU

Despite what is known about Europe's road freight sector, the impact of switching part of the truck fleet to hydrogen or batteries is still unclear. What would the electricity demand be to power these vehicles? How does that compare with the size of Europe's electricity system? What infrastructure would be required to operate those trucks? What investments would be needed to make that infrastructure a reality? What would the contribution be to the CO_2 reduction targets? All these questions will need to be considered to better understand the implications of switching to a new technology and to know if the switch will be beneficial.

To quantify the impact of a massive deployment of hydrogen fuel cell trucks or BETs in Europe, the truck activity in 2025, 2030, and 2035 has been modeled with three levels of technology penetration: 10, 50, and 100 percent. Considering the range of existing and announced BETs, the truck activity has been split in three categories, short haul (less than 150km), medium haul (150 to 400km) and long haul (more than 400km).

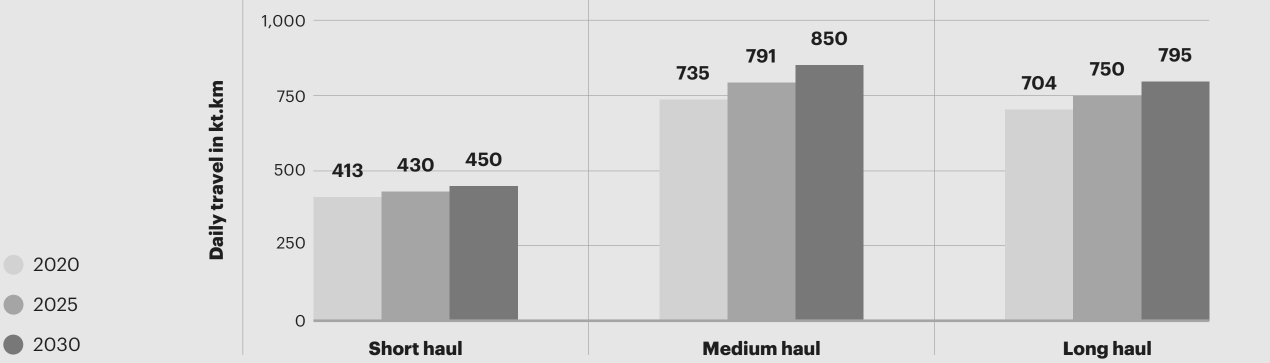
In 2018, about 62 percent of Europe's heavy-duty truck activity in ton-kilometers (t.km) was carried out by vehicles traveling less than 400 km per trip, and 78 percent was for daily distances of less than 800 km (see figures 2 and 3 on page 6). Thus, it's possible to use electric vehicles for most of Europe's road freight with models that are already on the market.

Figure 2

Most of Europe's heavy-duty truck activity is from vehicles that travel less than 400 km per trip

Characteristics of transport in Europe (2020–2030)

	Short haul	Medium haul	Long haul
Truck segment	Retail and regional logistics	Wholesale	International and National logistics
Journey distance	**Less than 150 km**	**More than 150 to 400 km**	**More than 400 km**
Gross vehicle weight	3.5–12 t	12–26 t	26–40 t



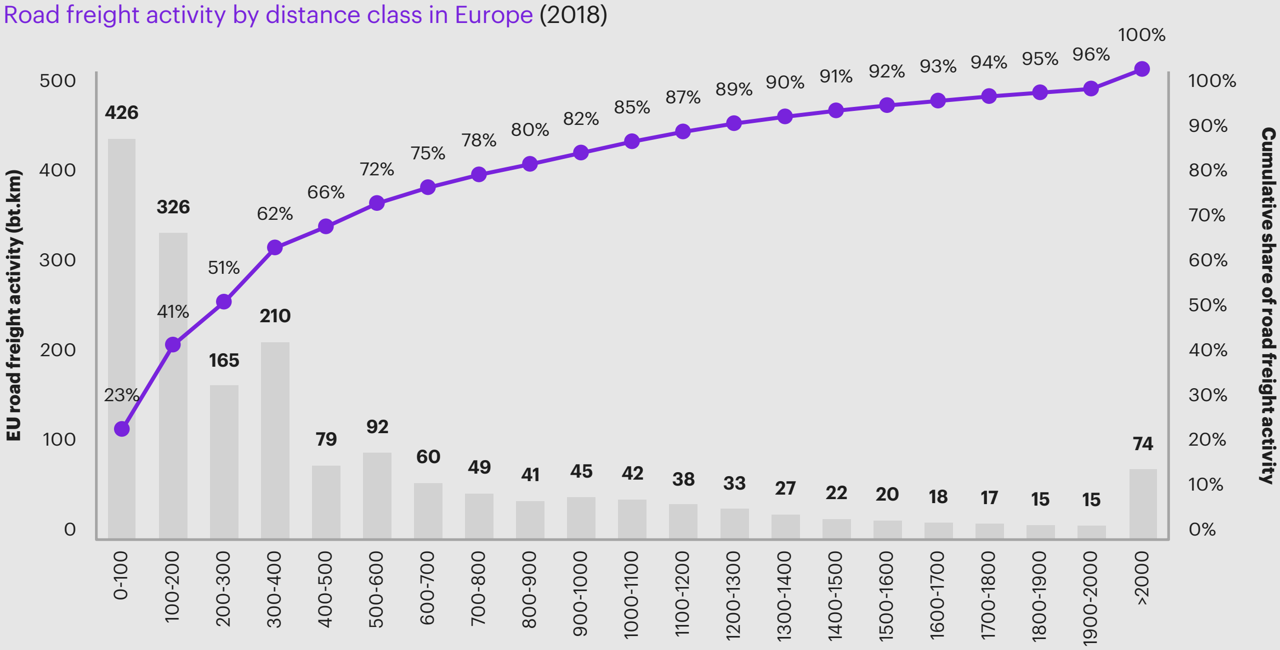
Note: The total truck activity for each distance segment was assumed to follow the same growth as it did over the past five years, which is in line with expert-based scenarios. t.km is ton-kilometers.

Sources: ILB Logistics, Zenon, Kearney Energy Transition Institute

Figure 3

Most of Europe's heavy-duty truck activity is from vehicles that travel less than 400 km per trip

Road freight activity by distance class in Europe (2018)



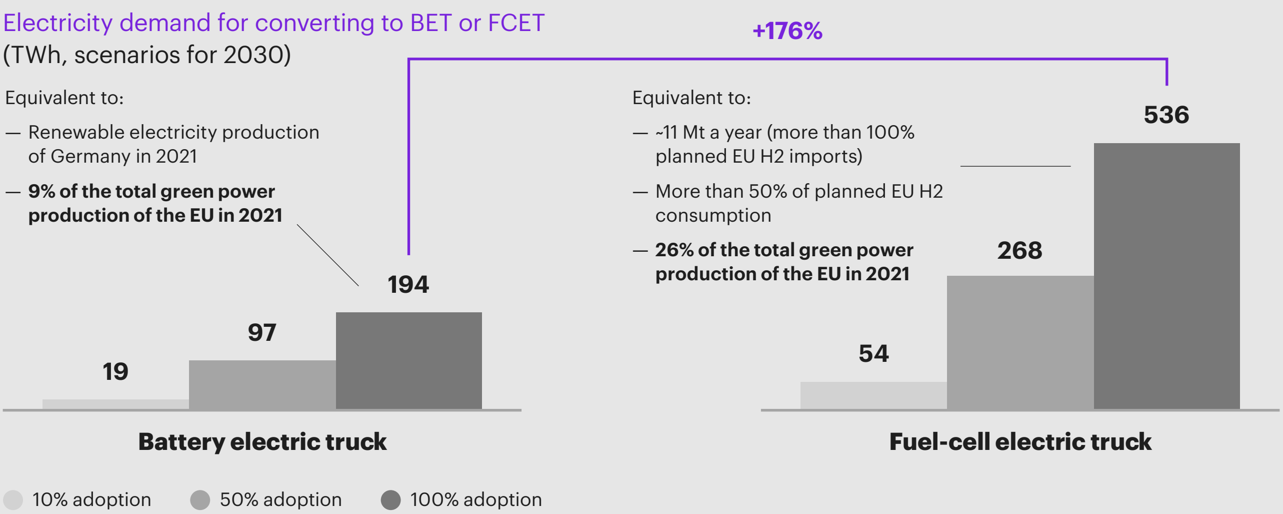
Sources: Transport & Environment's Unlocking electric trucking in the EU; Zenon and Kearney analysis

FCETs require about three times more green electricity than BETs

We calculated the annual electricity consumption of each technology for three scenarios corresponding to different market shares (see figure 4). In the most ambitious scenario, where BETs replace the entire European truck fleet by 2030, the amount of electricity needed from the grid each year would be about 200 TWh, equivalent to all of Germany's renewable electricity production in 2021— or about **9 percent of the EU's low-carbon power production**. In comparison, the annual electricity consumption for a 100 percent green FCETs fleet would be about 538 TWh considering a 73 percent efficiency for hydrogen production in 2030, which is similar to Germany's annual electricity consumption or **about 26 percent of the EU's total low-carbon power production in 2021**. Overall energy efficiency of the technological solution should be carefully considered as renewable power sources will be scarce compared to demand for multiple decarbonization applications.

The hydrogen demand in 2030 if all truck activity was powered by hydrogen would be around 11 Mt per year, which represents more than half of the hydrogen volume targeted in the REPowerEU plan. (Twenty million tons of hydrogen will be used in the EU, half of which will be imported from other countries.) Hence, powering a fully FCET fleet would need more than the total expected hydrogen imports in 2030.

Figure 4
FCETs would require about three times more green electricity than BETs for a full switch of the heavy-duty vehicle fleet



Note: Assuming EU Green Power production in 2025 of 2,060 TWh (International Energy Agency Stated Policies Scenario); The energy consumption values in kWh/km for each segment for 2025, 2030, and 2035 were obtained by extrapolation using the estimated data from Fuel Cells and Hydrogen report for 2023, 2027, and 2030. Because our technology penetration scenarios are based on truck activity, the value of the average payload moved by each truck segment was needed to be able to use the energy consumption values. Eurostat data and T&E activity categorization have been used to compute the average payload for each distance segment. For the FCET energy consumption, the well-to-tank efficiencies in 2025, 2030, and 2035 were interpolated from T&E data for 2050.

Source: Zenon and Kearney analysis

The need for infrastructure varies per technology and distance traveled and is constrained by the charging time

The best announced BETs can barely exceed 800 km on one charge. For urban and regional haulage trucks traveling less than 400 km per journey, charging along the way won't be necessary since their range will be enough to cover their daily deliveries. But for long-haul trucks, fast-charging infrastructure will be required. Taking this into account, three types of charging stations with different charging power can be defined since the trucks will not have the same time available to charge their batteries at each station (see figure 5).

Trucks can be recharged at the depot **overnight** (eight hours) using relatively low power stations or can be recharged at their **destination** using relatively higher power station, as unloading generally takes about 2.5 hours. In addition, **high-power charging** stations will be needed to charge long-haul BETs along the way. Considering the mandatory break for drivers of 45 minutes for every 4.5 hours of driving (equivalent to more than 400 km for long-haul trucks), it is safe to assume that trucks will be able to fully charge during these breaks.

Quantifying the number of charging stations requires knowing the share of energy delivered for each type of station and for each truck segment. The following formula was used for calculating the average power of each charger, assuming battery charge reaches 100 percent at each stop:

$$P = \frac{d * SoC * E}{t}$$

With:

— P the average power of the charger in kW

— d the average distance travelled by trucks daily for each segment in km

— SoC the state of charge of the battery

— E the energy consumption of the truck in kWh/km (takes into account the green hydrogen production efficiency in the case of FCETs)

— t the charging time available at each type of charging station in h

Figure 5
Three types of BET charging stations and FCET refueling stations can be used to serve the heavy-duty truck market

Summary of the assumptions regarding charging and refueling stations

			Urban–regional		Regional–national		Long haul		
BET	Type of charging		Overnight	Destination	Overnight	Destination	Overnight	Destination	Public HPC
	DC charging power required (kW)		**25**	**150**	**75**	**350**	**150**	**750**	**1500**
	Share of energy delivered by recharging mode	2025	85%	15%	85%	15%	65%	15%	20%
		2030	75%	25%	75%	25%			
		2035							
FCET	HRS daily capacity (kg/day)		**6,000**		**1,000**		**400**		

Notes: Based on T&E "Unlocking electric trucking in the EU" series assumptions.
Source: Zenon and Kearney analysis

SoC assumption is conservative because BETs won't always be able to charge completely, especially at the destination and at public fast charging stations. Moreover, with time, the maximum capacity of the battery will also decrease, and hence reduce the maximum SoC.

The following charging factors have been considered in the model:

— Charging time: eight hours for the depot, 1.5 hours for the destination, and 45 minutes for the HPC

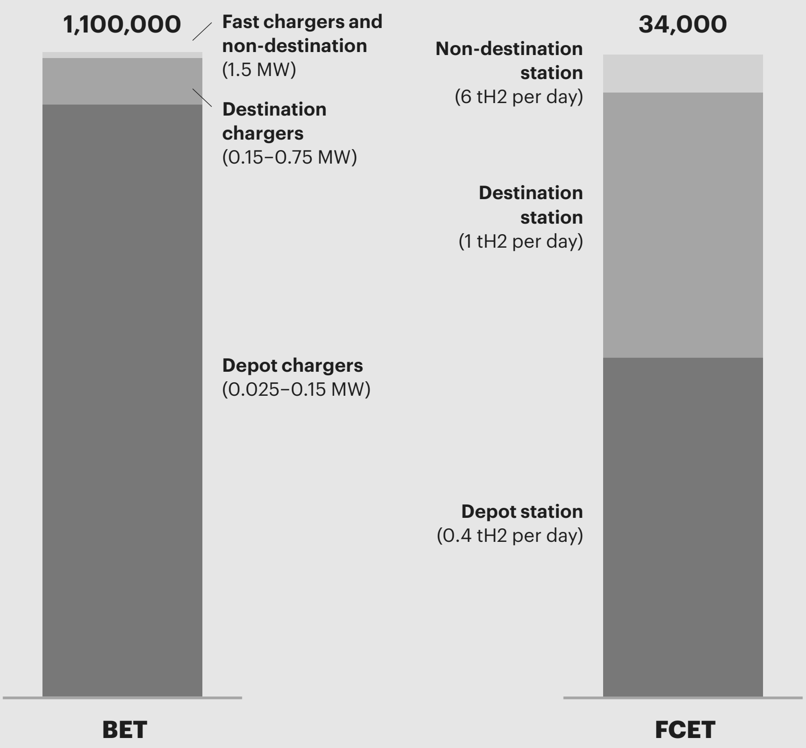
— Number of trucks recharged per day: one truck for depot chargers, three trucks for destination chargers, and six trucks for HPC

— Utilization rate: six days a week for all chargers, to take into account the chargers maintenance and non-working days of truck drivers

Knowing the average power of each type of charger, the share of energy delivered in each charging case, and the total energy needed to power the truck fleet for one year, it is possible to estimate the number of charge points. Following this model, the number of charge points to supply the 100 percent BETs scenario would amount to about 1.1 million across Europe, with 1 million depot chargers of 25 kW to 150 kW (see figure 6).

Figure 6
Fully decarbonizing Europe's heavy-duty vehicle fleet would require a hefty investment in infrastructure

Estimated number of BET charging points and FCET refueling stations
(100% scenario adoption in 2030)



Notes: BET is battery electric trucks; FCET is fuel-cell electric trucks.
Source: Zenon and Kearney analysis

Concerning FCET infrastructure, the refueling time has been assumed to range between five and 15 minutes. Estimating the number of refueling stations needed requires determining the daily hydrogen delivery capacity and the average distance between two refueling stations:

Long haul. In 2021, ACEA concluded that long-haul FCETs in the EU would require H2 stations every 200 km with a capacity of six tons a day to enable Trans-European Transport Network (TEN-T). Similarly, the European proposal for regulating the deployment of alternative fuels infrastructure 2021/0223 (COD) suggested a minimum of one H2 refueling station every 150 km along the TEN-T in 2030 with a daily capacity of more than two tons. The following analysis consider hydrogen refueling stations with a capacity of six tons a day (every 200 km).

Medium haul. Several hydrogen stations have already been announced for regional and national truck haulage, and some are already in service in EU and the United Kingdom for buses and medium-duty trucks. The daily capacity of these stations is between 1.0 and 1.2 tons a day. The following analysis consider hydrogen refueling stations with a capacity of 1 ton a day.

Short haul. Urban–regional FCETs were considered to refill at 400 kg/day stations, considering that the biggest H2 refueling stations for fuel-cell cars announced or in activity in the UK are either 270 kg or 400 kg a day stations.

We then considered that these stations were working 95 percent of the time to take into account maintenance.

By contrast, the number of refueling stations needed to address the 100 percent FCET scenario by 2030 is much lower: 2,000 stations delivering six tons a day; 14,000 delivering one ton a day; and 18,000 delivering 400 kg a day—equivalent to the number of active petrol stations in Germany and Italy combined (35,259 stations).

These numbers are intentionally high compared to other studies due to the assumptions taken for the calculation of the energy demand and for the characteristics of the charging/refueling infrastructure. For example, the Mission Possible Partnership estimated that for 6 million to 9 million ZETs on the roads in 2030, about 1.4 million to 1.8 million overnight depot chargers will be needed for BETs, and 1,000 to 19,000 hydrogen refueling stations across key markets will be needed for FCETs. By comparison, our model considered around 800,000 BETs or FCETs on the roads in Europe in 2030 (100 percent technology penetration) needing nearly 1 million overnight chargers or 34,000 refueling stations.

Long-haul fuel-cell electric trucks in the EU would require H2 refueling stations every 200 km.

The investment required to build the infrastructure and deploy the technologies can be a big drag.

A larger investment would be needed for a full switch to FCETs than for BETs

For BETs and FCETs, the investment required to build the infrastructure and deploy the technologies on an international scale can be a big drag (see figure 7). Hence, it is interesting to estimate how much it would cost to build the infrastructure that will allow 10, 50, and 100 percent of the truck activity to become electric or hydrogen powered. For BETs, capex per type of charger given by the European Commission's EV infrastructure masterplan was used. For FCETs, the capex costs in €/(kg/day) were obtained from the Hydrogen Mobility Europe document for 2020 and 2030. The values were estimated by using a linear regression for 2025 and an extrapolation for 2035 by taking the same rate of improvement of the cost in €/(kg/day) as the period 2020–2030. Infrastructure costs of different scenarios are illustrated in figure 8 on page 12.

The upfront investment for the infrastructure for short, medium, and long-haul segments are roughly 30 percent higher for FCETs than for BETs segments, regardless of the adoption ratios.

Figure 7

The infrastructure capex will be mainly driven by the charging power for BETs and the delivery rate for FCETs

Capex assumptions for chargers and hydrogen refueling stations

Cost per kW of installing chargers

Technology	Description	Capex (k€)	Cost per kW (€)
AC 4-22kW	Separate wall box wired to home's electricity supply or public station wired to lamp post for curb side overnight charging	1	125
DC 25 kW DC 150 kW DC 350 kW	Standalone fast charging stations: these can range from 25 kW to 350 kW and charge for a range of 100 to 200 km in 10 to 20 minutes depending on the charger and the vehicle.	14 60 86	558 400 247
DC 500 kW	Standalone fast-charging stations currently ~500 kW are ready for commercial use (trucks).	104	208
DC ~1MW	In the next two to three years, about 1MW will become commercially available.	260	260

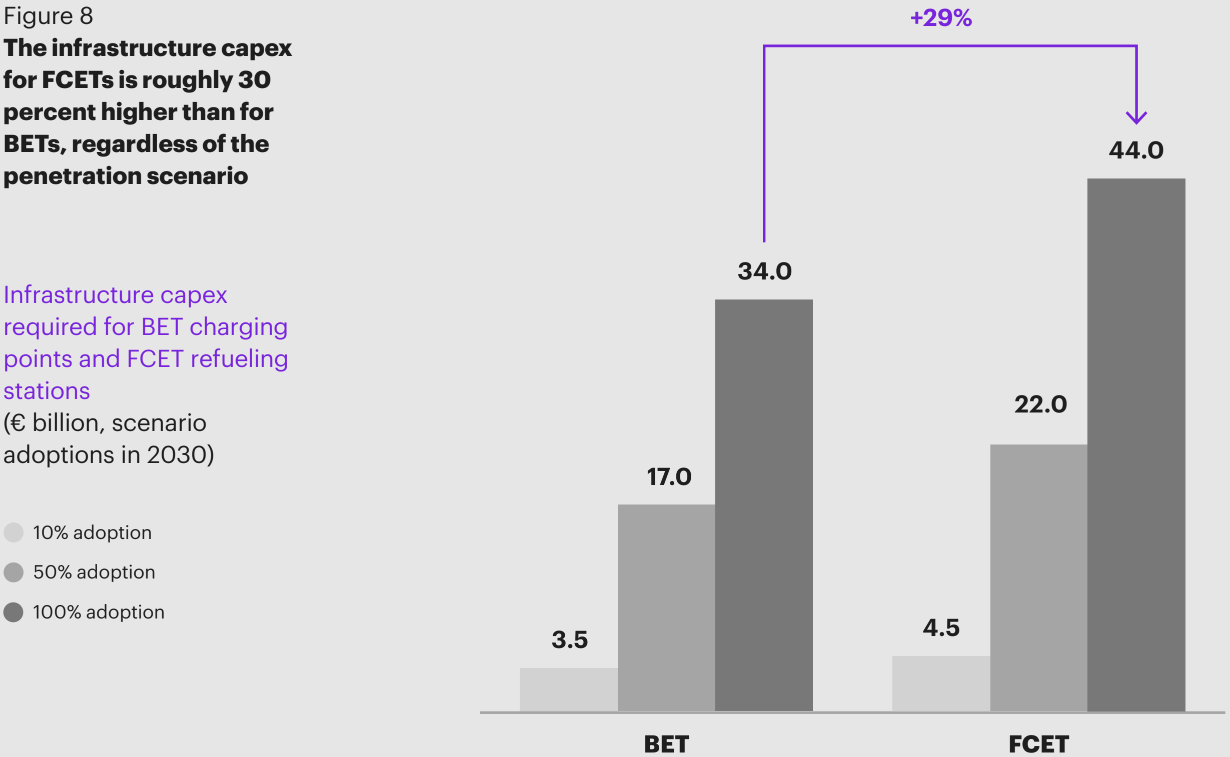
Capex of hydrogen refueling station from HME

	2025	2030	2035
HRS capex (€/kg/d)	1700	1300	805

Source: Zenon and Kearney analysis

Figure 8
The infrastructure capex for FCETs is roughly 30 percent higher than for BETs, regardless of the penetration scenario

Infrastructure capex required for BET charging points and FCET refueling stations
(€ billion, scenario adoptions in 2030)



Source: Zenon and Kearney analysis

Assuming the same power source, BETs have a better carbon footprint than FCETs

Unlike diesel trucks, BETs and FCETs do not directly emit CO_2 when they operate; their emissions are essentially concentrated at the electricity generation to recharge for BETs or hydrogen production for FCETs and at the production and end-of-life (recycling) of the vehicles. Hence, comparing the technologies in terms of GHG emissions requires considering the full life cycle of the trucks.

According to T&E, direct tailpipe emissions in 2019 were around 59 gCO_2/t.km for long-haul diesel trucks and 152 gCO_2/t.km for medium- and short-haul trucks. It also considered a reduction in emissions per t.km of 7.5 percent in 2025, 12.5 percent in 2030, and 15.2 percent in 2035 compared with 2020. To get the full WTW emissions linked to the fuel usage, we also need to know how much GHG are emitted during the production and the distribution of the diesel fuel. T&E estimates that the WTT emissions of a diesel truck increase the TTW emissions by 28 percent on average.

Contrary to diesel trucks, calculating the GHG emissions linked to the fuel usage for BETs and FCETs only implies to knowing the carbon intensity of the production and distribution. For BETs, the life-cycle carbon intensity of the European electricity grid for 2025, 2030, and 2035 has been estimated by T&E for its analysis on electric car life-cycle emissions.

The carbon intensity of green hydrogen (electrolysis of water using renewable power) typically ranges from 1 to 3kg CO_2 per kg hydrogen. But if produced from a carbon-intensive power mix (450gCO_2/kWh), the carbon intensity of the hydrogen produced can go above 25kg CO_2 per kg hydrogen. The renewable power used in the models described below has a carbon intensity of 37 gCO_2/kWh.

Since the chassis of internal combustion engine heavy-duty trucks, FCETs, and BETs are very similar, with the only real difference being the type of powertrain, it has been assumed that the gap of emissions during manufacturing to be marginal compared with the other emissions posts. The production of a diesel truck emits about 8 kg CO_2 equivalent per kg of empty truck weight. The curb weight of the categories of trucks as well as their life span were estimated by ADEME. The average curb weight of long-haul trucks is 15 tons, 10.21 tons for regional trucks, and 6.53 tons for urban trucks.

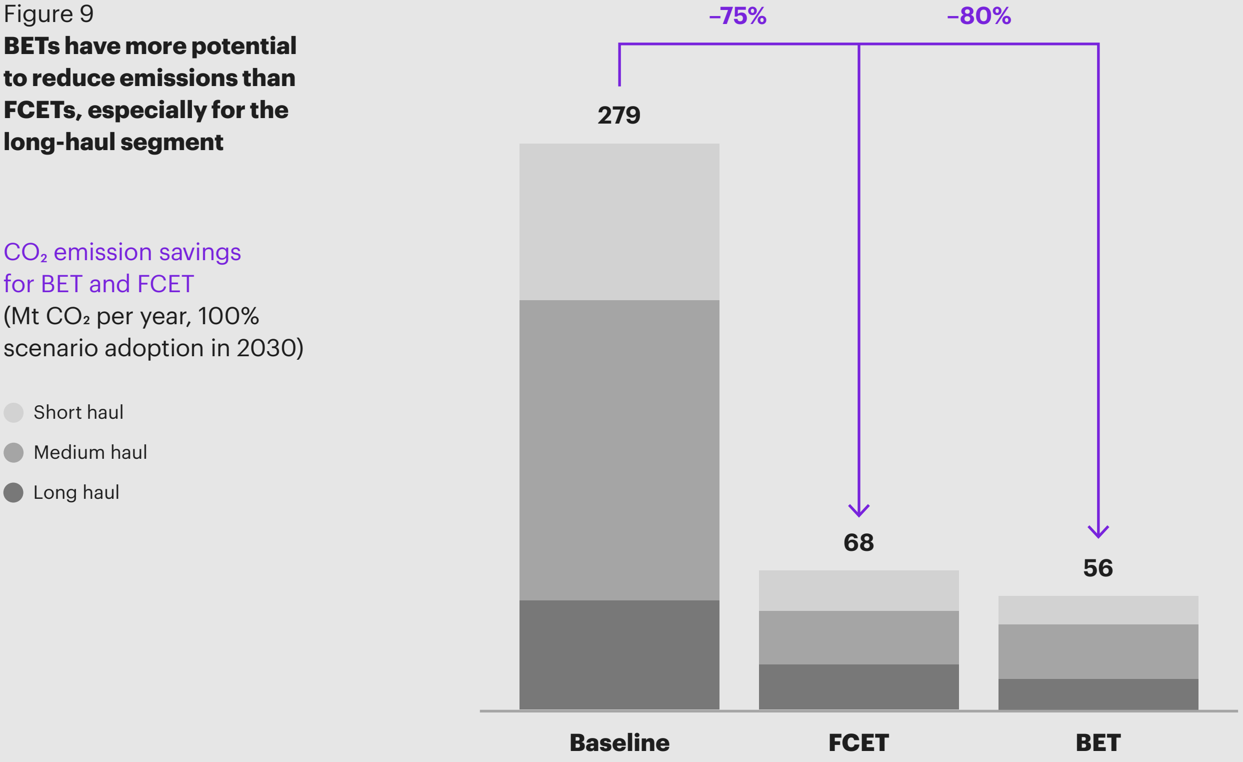
However, battery production is an energy-intensive process that emits a lot of GHG and has a significant impact on the overall carbon footprint of the BETs. Minviro's life-cycle assessment study of lithium–ion batteries gives the carbon intensity of batteries over their entire life cycle in $kgCO_2e/kWh$ in 2022 and 2030 for various countries, which were used to estimate the carbon intensity in 2025, 2030, and 2035. It has been assumed that in 2025 batteries would still be produced in China with the same carbon intensity as today. For 2030, on average, batteries would be produced partly in Europe and partly in China, which would result in a carbon intensity similar to that of European batteries in 2022. Finally, we assumed that the vast majority of batteries in 2035 would be produced in Europe.

According FCH Europa, long-haul trucks travel 140,000 km a year, regional–national trucks 90,000 km a year, and urban–regional trucks 60,000 km a year. The average payload of long-haul trucks is 14.06 tons, 11.89 t for regional–national trucks, and 11.15 t for urban–regional. Each year, truck turnover will be taken equal to 1/lifetime of a truck*volume of activity. Thus, after a period equal to the lifetime of the trucks, the whole fleet is renewed.

Based on these assumptions and insights, the emissions reduction potential of each scenario in all segments, have been estimated considering life-cycle-analyses. Figure 9 shows an example with a 100 percent technology penetration scenario in 2030. BETs have higher potential to reduce emissions than FCETs, especially for the long-haul segment. The small difference between BETs and FCETs for the urban–regional segment is the result of the relatively larger share of the battery production emissions over the life-cycle emissions for BETs, so the electricity production emissions play a smaller role. On the other hand, the emissions reduction potential of long-haul BETs is at least twice as much as for long-haul FCETs. Given the choice between a BET and a FCET in this segment, BETs should be prioritized in the current context.

Figure 9
BETs have more potential to reduce emissions than FCETs, especially for the long-haul segment

CO_2 emission savings for BET and FCET
(Mt CO_2 per year, 100% scenario adoption in 2030)



Source: Zenon and Kearney analysis

Time to make your choices

Even if BETs were not a credible and effective solution for decarbonizing the road freight sector until recently, improvements in battery density and price thanks to the growing adoption of electric vehicles in the personal car sector have allowed BETs to be technically able to cover most of the truck activity. Lithium–sulfur or metal–air battery technologies are emerging, and there are clear signs of their maturity progress and disruptive potential, which would challenge even further the competitiveness of FCET versus BET. BETs are also becoming a more financially interesting option for truck owners and are expected to come to parity with diesel within a couple years if no subsidies or carbon tax are applied.

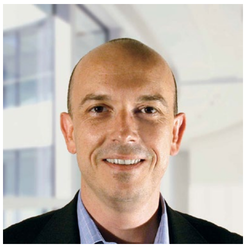
Hence, there are no real barriers to a massive deployment of BETs since they can be rolled out progressively beginning with the shorter-distance segments and then for long-haul applications with megawatts charging stations. FCETs will still be needed to decarbonize specific types of long-haul trips where BETs cannot be used, but this will require strong support from Europe to be able to create a hydrogen supply chain that can provide cheap green hydrogen at the pump. Depending on Europe's vision for the heavy-duty transport sector, FCETs could take on a larger role if the technology is rapidly scaled up and the infrastructure and supply chain are rapidly deployed since the REPowerEU plan is betting a lot on this molecule.

Beyond the performance of technologies, the selection of BETs or FCETs options must also consider their deep implications on energy networks. Similarly, other strategic constraints such as those imposed by the supply chains of raw material and technologies or energy security priorities must also be considered in the decision-making process. Beyond pure systemic considerations, the deployment of FCETs and BETs will be also triggered by the investment choices made by fleet owners that will be influenced by the Total Cost of Ownership of these competing technologies.

Considering the urgency to decarbonize heavy duty transport, the renewal of heavy-duty truck fleets should immediately switch to ZETs. With a standard fleet renewal rate of 5 percent per year, achieving 30 percent emissions abatement by 2030 implies to switch already to 100 percent ZETs, whether BETs or FCETs.

There are no real barriers to a massive deployment of battery electric trucks.

Authors



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About Zenon

Zenon Research is a non-profit think tank. Based on a rigorous scientific approach, we analyze the emerging trends in the technological innovations required to reach net-zero. We identify promising technologies and potential breakthroughs to help investors, entrepreneurs, companies, and policymakers, identify future opportunities and accelerate the transition to a low-carbon world.

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