

WHAT TECHNOLOGIES FOR TOMORROW'S LONG-HAUL TRUCKS?

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SUMMARY

EXECUTIVE

In France and Europe, **the goal is clear: to achieve carbon neutrality by 2050**. For the transport sector, whose emissions are currently divided between the travel of people (60%) and the transport of goods (40%), this translates on a national scale into **a phase-out of diesel and a complete decarbonization of the sector in the space of 25 years, with a radical 30% drop in emissions over the next 5 years**. Freight transport is dominated by road, which accounts for 90% of flows and more than 10% of national GHG emissions.

For small- and regional-scale road haulage, the way is clear towards electrification, whether through regulations (ban on sales of combustion-powered LCVs from 2035) or technology (electric trucks have a range of 300-400 km, which is sufficient). **For long-haul road haulage**, on the other hand, where the constraints of range and recharging are greater, **the way out of diesel is less clear to industry players**. This publication provides a detailed analysis of the different decarbonizing alternatives (electric, biofuels, biogas, hydrogen and e-fuels) from an operational, energy, economic, climate and resource point of view, in order to determine tomorrow's landscape.

This shows that the solutions that are closest to diesel in terms of use are also the most limited in terms of resources and costs. On the one hand, sustainable **liquid and gaseous biofuel** resources **will eventually cover less than 10% of the transport sector's needs**, with priority given to very long-distance use, i.e. air and sea transport. As such, **they are more of a transitional solution** to start decarbonizing **than a future solution** in which to invest for the long term. On the other hand, **hydrogen and e-fuels have a degraded energy efficiency**, requiring 3 to 4 times more electricity for their production than for direct use, **which makes them more expensive, and puts a strain on decarbonized electricity resources**.

On the other hand, battery-powered electric vehicles have fewer structural constraints, notably in terms of resources, **and current obstacles are gradually being overcome**: new 2025 models with 600km range, development of a network of very high-power recharging stations, lower TCO surcharges as production becomes more widespread. Considering the evolution of infrastructures and costs, **electric motorization will gradually take the lion's share, including on long-distance routes, and could eventually represent around 90% of the vehicle fleet by 2050**.

This massive transition implies major changes and **needs to be anticipated by the entire value chain**, both in terms of fleet renewal strategy and in supporting the use of electric trucks, **to take advantage of the energy transition in freight transport rather than undergo it**.



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1.

Which alternative engines to choose for decarbonized heavy transport

1.1. Possible alternatives considered today

Six energy sources are commonly cited as interesting alternatives to diesel for decarbonizing the transport sector:

- **Liquid biofuels:** marketed in the form of B100, HVO100, or blended with diesel (B7, B30, etc.), these are fuels obtained from biomass (raw material of plant, animal or waste origin¹). Biofuels are said to be 1st generation when they compete with the food chain. 2nd-generation biofuels are produced mainly from food waste. Combustion emissions are not counted, as the carbon emitted has been captured by the biomass during its growth and follows a short cycle. Nevertheless, there are major carbon-related issues concerning land-use changes² for 1st generation agrofuels.
- **Electricity:** an energy carrier produced from fossil fuels (coal, gas, nuclear) or renewable sources (hydro, wind & solar). There are no emissions during vehicle use, but upstream emissions during electricity production must be taken into account. These emissions are highly dependent on the method of electricity production.

¹ Read more in our [publication](#) on advanced fuels.

² Read more in our [publication](#) on land use change for French rapeseed.

- **Hydrogen:** an energy carrier produced from electricity or fossil fuels. As with electricity, the vehicle does not emit when driving, but hydrogen production is energy-intensive and can be highly emissive when produced from fossil fuels.
- **Natural gas:** a gaseous mixture of hydrocarbons naturally present in certain porous rocks. It is a fossil fuel with high combustion emissions.
- **Biogas:** renewable gas produced from food industry waste. Combustion emissions are not counted, as the carbon emitted has been captured by the biomass during its growth and follows a short cycle.
- **Synthetic fuels:** commonly referred to as "e-fuels", these fuels produced from electricity or fossil fuels are a new alternative to diesel. Carbon emissions linked to combustion are not accounted for, as the carbon emitted is derived from carbon captured upstream.

1.2. The relevance of different alternatives

The choices to be made today among these alternatives, for both freight carriers and public players, must consider different parameters. Tomorrow's heavy-duty transport must not only be sufficiently carbon-free, but also meet the technical (autonomy, recharging, infrastructure, resources) and economic (investment & operating costs) constraints borne by freight carriers. We therefore propose a multi-criteria analysis of the relevance of each of the alternatives, taking into account:

- 1) **The decarbonizing potential of the alternative**
- 2) Operational constraints linked to range and recharging time
- 3) Truck investment and operating costs
- 4) Developing the necessary infrastructure
- 5) **Availability of energy resources**

However, it is important not to put these 5 criteria on the same level:

- Criteria 1) and 5) **are physical, invariant criteria**. They are shown in **orange** on the figure and are critical in the event of a poor score.
- The other criteria are cyclical and subject to significant change. A poor rating on one of these criteria today is not prohibitive, as it may change over time.

Figure 1 provides a multi-criteria analysis of all alternative fuels. It is based on the analysis grid presented in Figure 2.

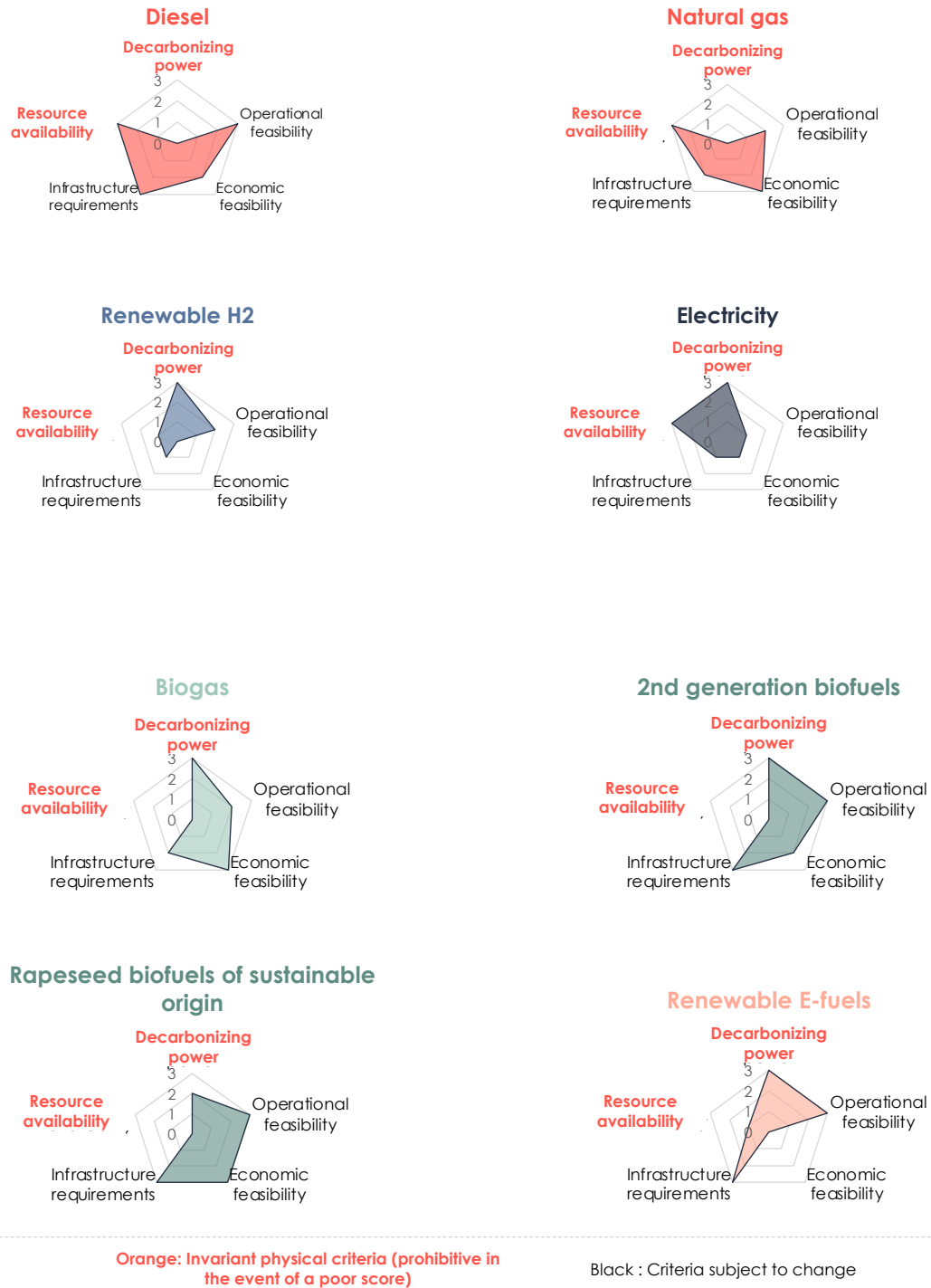


Figure 1: Multi-criteria analysis of the suitability of various alternative fuels for long-distance heavy haulage

	Description	Parameter values
Decarbonizing power	Percentage decarbonation of the solution compared to diesel in life cycle vision (which integrates vehicle manufacturing, fuel production, fuel combustion and vehicle end-of-life)	0 : <25% 1 : 25% - 50% 2 : 50% - 80% 3 : >80%
Operational feasibility	Evaluates operational constraints to date (2024) in terms of range and recharge time	0: Range < 300km <u>and</u> slow recharge 1: 300km < Autonomy < 600km <u>and</u> slow recharge 2: Range > 600km <u>or</u> rapid recharge 3: No constraints
Economic feasibility	TCO (Total cost of Ownership) compared to diesel at date (2024), in % surplus to diesel.	0 : At least 20% > diesel 1 : 10% to 20% > diesel 2: 0% to 10% > diesel 3 : < diesel
Infrastructure requirements	Need to invest in new infrastructure for recharging and for the smooth operation of the technology (electric highway, etc.)	0 : Substantial investment 1: Major investment 2: Limited investment 3: existing infrastructure
Resource availability	Potential availability of energy resources (bioenergy, electricity, renewable electricity, etc.) to cover the needs of heavy transport , taking into account conflicts of use.	0: - 20% of requirements covered 1: 20 to 50% of requirements covered 2: 50% to 80% of requirements covered 3: All needs can be covered

Figure 2 : Multicriteria analysis of alternative fuels (Figure 1)

1.3. What engines for tomorrow's heavy transport?

1.3.1. Some fuels, such as natural gas, are not and will not be decarbonizing enough.

While **the decarbonization objectives for heavy-duty transport are total decarbonization within 26 years for France, and almost complete decarbonization at European level, several alternative engines do not meet this objective** and therefore cannot be considered as part of a decarbonized fleet. Figure 3 provides a detailed analysis of the decarbonizing potential of the various alternatives from a life-cycle perspective:

- The manufacture of the vehicle and its components (battery, H₂ tank, etc.);
- Exhaust emissions, i.e. emissions linked to the combustion of fossil fuels. They are classified in the "Use" category of the figure;
- Emissions linked to the production (refining, manufacturing processes, etc.) and distribution of the energies used. They are classified in the "Use" category of the figure;
- Emissions linked to the end-of-life of the vehicle and its components.

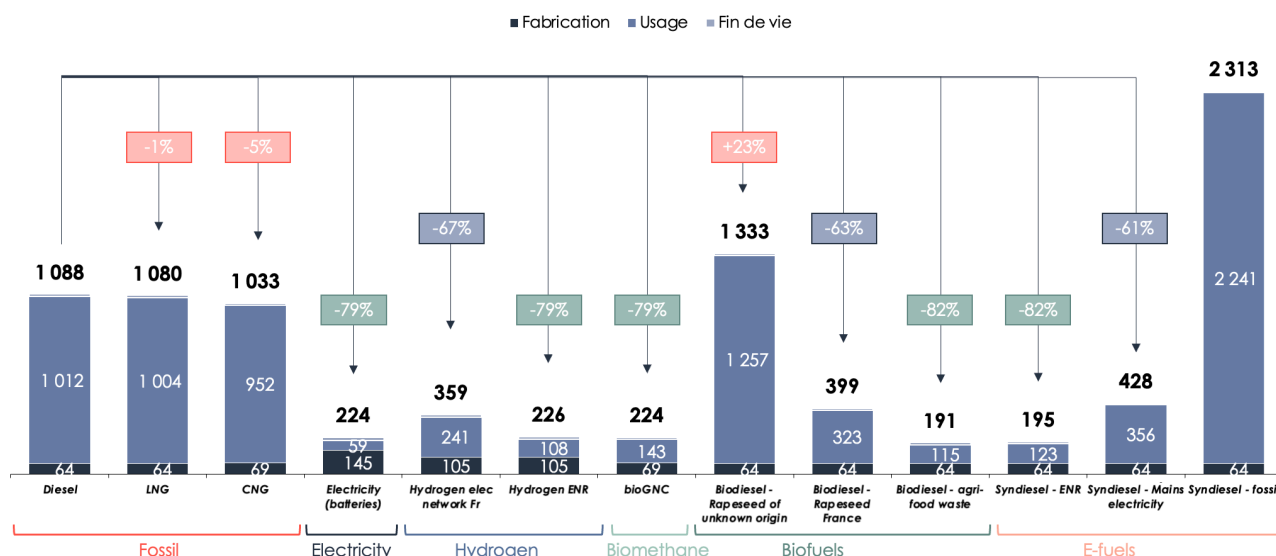


Figure 3 : Average carbon footprint over the lifetime of a new 44t articulated unit in France (gCO₂e/km)³

Tomorrow's heavy-duty transport will therefore not be able to rely on diesel, natural gas, uncontrolled biodiesel or e-fuels derived from fossil fuels⁴.

1.3.2. Other fuels, such as hydrogen and e-fuels, are not very energy-efficient and will be limited by the availability of low-carbon electricity.

Hydrogen and e-fuels both have clear operational advantages:

- They enable rapid recharging of vehicle energy
- E-fuels can be used by thermal vehicles with a similar range

However, **hydrogen**, which seemed to hold great promise for heavy-duty transport, **is now disappointing in terms of sales** (around 100 sales in Europe per year, compared with 2,500 for battery-powered trucks by 2023⁵), and e-fuels are being put forward as a solution for very long-distance transport by air or sea⁶. **This is due to their high energy intensity**: the production of low-carbon H₂ and e-fuels requires a significant amount of low-carbon electricity. Indeed, **the overall energy efficiency of hydrogen and e-fuel vehicles is low** due to fuel manufacturing processes and vehicle performance, as shown in Figure 4.

³ Carbone 4 analyses based on data from ADEME, manufacturers, IPCC, JEC & the Globiom report

⁴ Read more about the carbon footprint of different alternative powertrains in our dedicated [publication](#)

⁵ [JCCT - European heavy-duty vehicle market development](#)

⁶ Connaissance des énergies, September 2023, [Les "e-fuels" : quel rôle dans la transition énergétique ?](#)

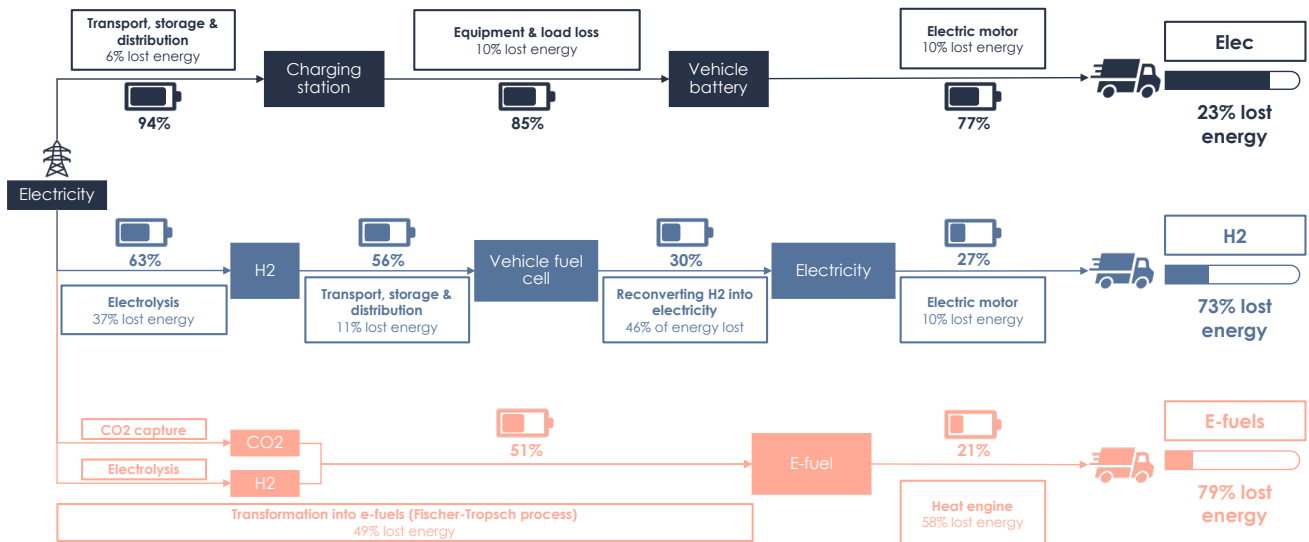


Figure 4 : The overall energy efficiency of vehicles running on e-fuels, hydrogen and electricity⁷

Hydrogen and e-fuel vehicles consume three to four times more electricity than battery-powered electric vehicles, due to the high energy losses associated with upstream processing and fuel use by the vehicle. This high energy consumption intrinsically implies a dual challenge in terms of fuel prices and the availability of low-carbon electricity resources.

- On the economic front, since it requires a great deal of energy to produce, **hydrogen is and will remain more expensive than using electricity as a direct source**. What's more, hydrogen-powered trucks call on new and less mature technologies (H₂ cylinder, fuel cell, electric motor), which entail a higher vehicle purchase cost than a battery-powered truck, let alone a diesel truck. For example, for a road tractor, the purchase price is around €420,000 excluding subsidies, compared with around €320,000 for an electric tractor with 350km range, and €115,000 for a diesel tractor⁸. Overall, trucks running on H₂ and e-fuels have the highest TCO under current economic conditions, as shown in Figure 5.
- What's more, **the resource of low-carbon electricity is not unlimited, and is already being fought over by the various economic activities** in transition. It is important to note that industry (oil refining, methanol and ammonia production) consumes 100 Mt of hydrogen per year worldwide, 98% of which is still produced by fossil fuels and must be decarbonized, without even considering additional uses for transport⁹. What's more, decarbonized electricity is also the key to decarbonizing many sectors (heat production, buildings, industry, transport, etc.), which also have high energy demands.

⁷ Based on Transport & Environment data, May 2020, [Comment décarboner le fret français d'ici 2050 ??](#)

⁸ Carbone 4 analysis based on carrier returns, cross-referenced with the ICCT publication in 2023: [A total cost of ownership comparison of truck decarbonization pathways in Europe](#), and the [VerdirMaFlotte](#) tool.

⁹ Carbone 4, October 2022, [Low-carbon hydrogen: what are the relevant medium-term uses in a decarbonized world?](#)

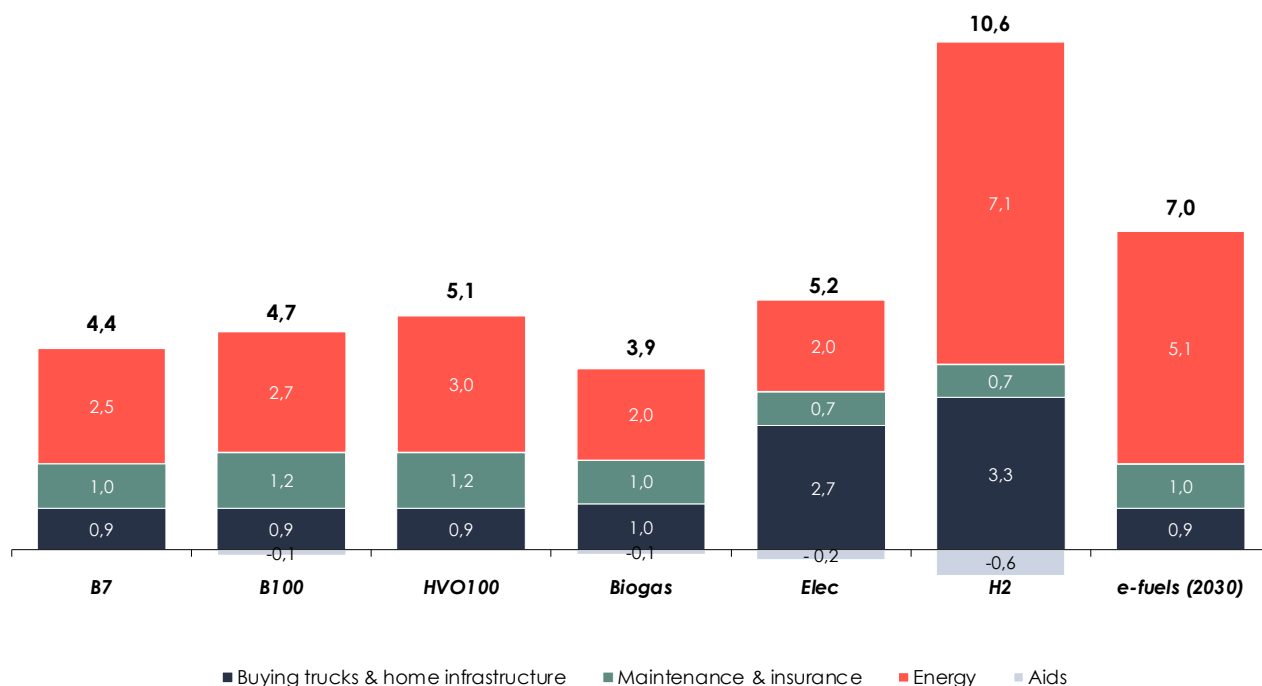


Figure 5 : Comparison of the TCO (cents/tkm) of different engines for a 44t tractor unit¹⁰

This dual physical and economic constraint, which cannot be overcome since it stems from energy yields that cannot be improved, means that **hydrogen and e-fuels energy vectors will naturally be oriented towards uses where the need for strong autonomy and recharging, with no viable alternative, justifies the degradation of economic performance and the preemption of resources. This is the case**, for example, for air and sea transport, but **for heavy-duty road transport, it will be confined to a few niche uses**, as we shall see later in this publication.

1.3.3. Although interesting, bioenergy from sustainable sources will cover less than 10% of the energy needs in 2050.

Energy produced from biomass (liquid or gaseous) offers several operational advantages (autonomy like diesel and rapid recharging time) and economic benefits (see Figure 5). However, it cannot be the only solution for heavy-duty transport, as **biomass is limited and highly prized by all sectors** (building, industry, agriculture, carbon sinks, etc.). The General Secretariat for Ecological Planning has proposed a systemic analysis of the use of available biomass energy by 2050¹¹. A comparison between available energy and the energy required for certain modes of transport (see Figure 6) shows **that bioenergy will eventually be able to cover no more than 10% of the energy needs of the transport sector**. In addition, **air and sea transport**, which have fewer

¹⁰ Carbone 4 analysis based on field data. Assumptions made for a 40-44t road tractor driving 94,000 km per year. Biogas is particularly inexpensive thanks to subsidies, but its price is likely to rise according to IEA projections (see Figure 8). The price of electricity is estimated on the basis of 80% home charging and 20% public charging stations.

¹¹ France Nation Verte, July 2024, [Bouclage biomasse : enjeux et orientations](#).

alternatives for decarbonizing their activities, **could be given priority**, as for e-fuels (current French e-fuels production projects are almost entirely dedicated to air and sea transport).

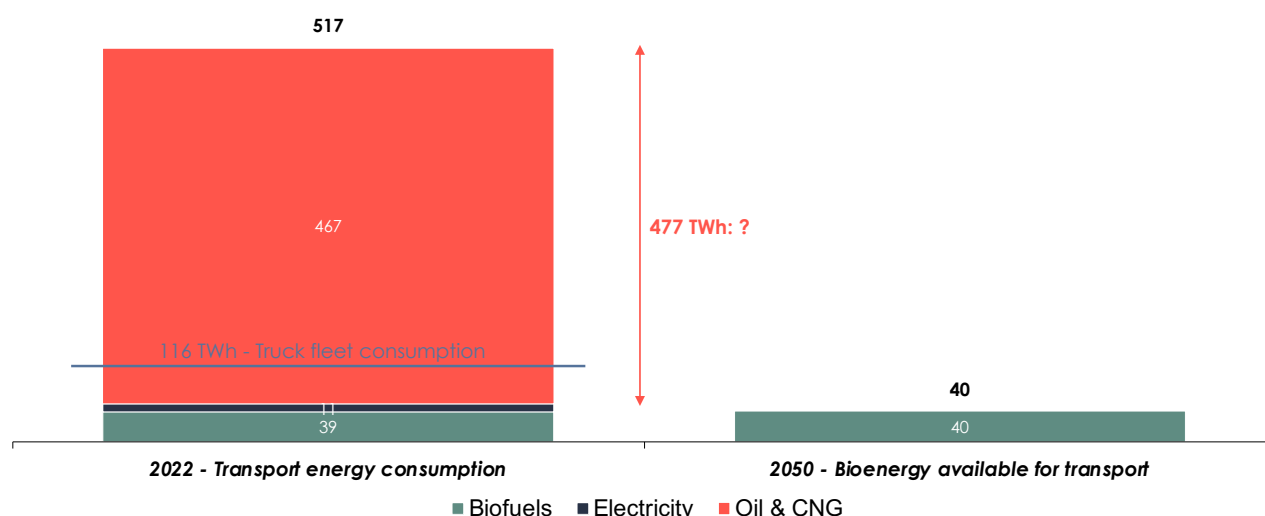


Figure 6 : Comparison between available biomass and energy consumed by the main transport activities using bioenergy to 2050 (TWh)¹²

This strong constraint on the resource also presents the risk of drifts if demand significantly exceeds supply, with the possibility of resorting to carbon-based resources to make up for the shortfall, such as diesel or biofuels from uncontrolled sources whose impact may be greater than that of diesel, or fossil natural gas instead of biogas. As a result, a carrier who buys thermal trucks today with the ambition of running on bioenergy to decarbonize his activities runs the risk of running on carbon-based fuels again in a few years' time, once resource constraints are felt and suppliers no longer have a sufficient supply of low-carbon biofuels. Moreover, **the future of gas engines for vehicles is uncertain because gas trucks**, for which no distinction can be made between CNG & bioNGV, **do not contribute to the decarbonization targets for new trucks set out in European regulations** (-45% emissions by 2030 & -90% by 2040), so it's not certain that manufacturers will invest in this engine¹³.

¹² Carbone 4 analysis. The energy consumed by transport in 2022 is based on the report [chiffres clés des transports](#), MTE, 2024 edition. Biomass energy available for transport is based on the report [Bouclage biomasse : enjeux et orientations](#), MTE, July 2024.

¹³ Institut mobilités en transition, January 2023, [What will be the role of bio-CNG/LNG in road transport by 2030 in France?](#)

1.3.4. Despite current constraints, electric power is an attractive future solution for heavy-duty transport.

Electric vehicles are both sufficiently low-carbon (see Figure 3) and **energy-efficient** (see Figure 4). There remains, however, a greater impact on demand for metals and critical materials, such as copper, lithium, etc. However, apart from the fact that any road tractor construction requires a significant amount of metal, moderating the size of batteries could help limit this impact (without annihilating it). What's more, the truck's TCO is attractive despite the vehicle's higher purchase cost, thanks to lower energy costs when recharging at home (see Figure 5), and lower maintenance costs.

This solution would be ideal without the operational constraints associated with limited autonomy, long recharging times and the need to develop substantial infrastructures, to a greater extent than for gas and hydrogen motorization. However, **unlike the energy resource limit, these two parameters are not fixed and can evolve**. Even if investment costs are high, the development of public charging infrastructures for trucks is currently being rolled out¹⁴, and the installation of private charging stations for businesses is encouraged by public subsidies¹⁵. At the same time, the range of HGVs is increasing rapidly as manufacturers roll out new models (currently around 400km¹⁶, it could exceed 500km by 2025¹⁷) and is already enabling trucks to make regular regional rounds. Finally, several interesting projects to overcome range constraints, such as electric highways or truck-mounted battery-changing systems, are beginning to take shape (see section 2.3).

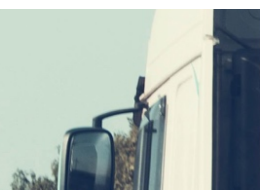
Faced with natural gas that is not sufficiently decarbonized, e-fuels and hydrogen that consume too much energy, and the limited resources of liquid and gaseous biofuels, electric vehicles appear to be the solution with the fewest inflexible physical constraints, although there are still constraints linked to range and the availability of recharging infrastructures, which are nevertheless diminishing (see next section). It could be complemented by hydrogen, biomethane or liquid biofuels/e-fuels, bearing in mind that resources will necessarily limit the size of the latter in tomorrow's fleet, and concentrate them for long-distance use.

¹⁴ Transport Info, May 2024, [Bornes de recharge privées : Les solutions pour recharger son camion électrique](#).

¹⁵ Advenir program. [Point de recharge à destination de flottes de poids lourds](#).

¹⁶ Transport info, June 2023, [Spécial camion électrique : tous les modèles 2023 et calendrier des sorties](#).

¹⁷ Transport & Environment, December 2022, [Camions électriques : pourquoi et comment accélérer leur déploiement](#).





2.

Tomorrow's heavy haulage

As we saw earlier, **decarbonized heavy-duty transport will have to rely on alternatives other than bioenergies**, which are simpler to implement but will only be able to cover part of the fleet's energy needs. Electric trucks offer a less resource-intensive option. Nevertheless, **the significant development of long-haul electric tractor units will require several changes to overcome operational barriers** such as high purchase costs, lack of range, charging times and the lack of public charging stations for trucks. Although these barriers can be overcome, the momentum is still in its infancy, notably due to a lack of a clear vision of the alternatives to be prioritized, and less substantial subsidies than for electric cars.

The European VECTO regulation is already setting a strong direction by requiring a high level decarbonization of heavy-duty vehicle exhaust emissions (-43% CO₂ by 2030 compared with 2025, -64% by 2035, -90% by 2040). **Compliance with these criteria will require strong development of "0-emission" trucks (H₂ and electric)**, which will gradually become the norm. ICCT's analysis shows that 78% of "0-emission" trucks will be needed by 2040 to meet the emission ceilings¹⁸. And, as detailed below, this is in line with expected industrial and economic developments.

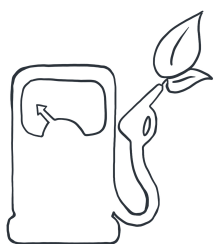
¹⁸ ICCT, May 2023, [An analysis on the revision of Europe's heavy-duty CO₂ standards](#).

2.1. Road infrastructure must evolve to better accommodate the new alternatives to diesel.

Diesel is the main energy carrier for road transport, and today's network is densely networked with service stations where trucks can fill up. This contributes to the current operational ease of running on this fuel. To ensure the development of other alternatives, the development of new infrastructures is crucial.

2.1.1. The infrastructure needed to liquid and gaseous alternatives

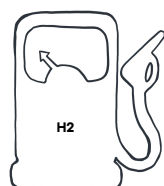
Alternative energies will each require different infrastructures.



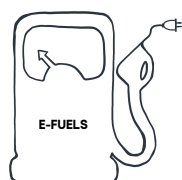
Pure **biofuels** are currently only used by captive truck fleets, although distribution at the pump has recently begun¹⁹. Transporters are therefore in direct contact with suppliers and refuel on site. Even if biodiesel sold at public stations were to develop, **it could be based on existing diesel infrastructures without requiring major investment**.



A limited number of **biogas** stations in France (**around 200**) can be identified on the [Gaz-mobilité](#) interactive map. The “Association des agriculteurs méthaneurs” de France (AAMF) has set a target of 500 bioGNV stations by 2025²⁰, but **national development ambitions remain unclear**.



The network of charging facilities for hydrogen-powered vehicles is still in its infancy with **42 stations** currently open on the interactive [H₂ mobile](#) map. The network is struggling to develop, and the initial targets of 100 stations by 2023 and 400 to 1000 stations by 2028²¹ have been revised downwards²².



Finally, **e-fuels** are not currently available for road transport and probably won't be in **the near future** since all e-fuel production projects to date are almost entirely focused on air and sea transport²³.

¹⁹ Europe 1, October 2024, Carburant : trois questions sur le XTL, ce nouveau biocarburant disponible à la pompe.

²⁰ GRDF, September 2022, [Monter sa station BioGNV](#).

²¹ MTE, [Plan de déploiement de l'hydrogène pour la transition énergétique](#).

²² France Hydrogène, December 2022, [Trajectoire pour une grande ambition hydrogène à 2030](#)

²³ French e-fuels office, French e-fuels observatory, September 2024. [Available here](#)

While gaseous fuels have the advantage of providing long autonomy for HGVs and therefore require a much smaller network of recharging stations than for electric vehicles, biogas and hydrogen require new infrastructures, which superimposes investment costs. However, there is **no guarantee that local authorities will be able to invest in three alternative infrastructures at once**, and it is possible that the network will be disparate, particularly for hydrogen and biogas if the electric vehicle takes the lead. Liquid alternative fuels will not suffer from this problem, as they can benefit from existing diesel infrastructures.

2.1.2. The rapid development of recharging infrastructures for electric vehicles will make it possible to cover long distances.

First of all, it's important to emphasize that **carriers will be able to cover a good part of their routes by recharging only with a home terminal**. Slow recharging is to be preferred, as it is **less expensive** (fast recharging should cost around 2 to 4 times more to recoup the connection and terminal costs), generates fewer power calls and therefore **less local stress on the electrical grid**, and induces **less battery ageing**.

The network of ultra-fast charging stations for heavy-duty vehicles is beginning to expand, with the first charging stations on the Paris-Lyon route recently opening²⁴. **There are strong ambitions for the development of charging stations for heavy-duty vehicles on a European scale**, with the ambition of installing **charging stations every 60km along major freeways and every 100km on secondary freeways by 2030**²⁵. A [roadmap](#) has been proposed by a consensus of companies (electricity producers, motorway concessionaires, car manufacturers, etc.) to intelligently network the country with more than 10,000 HGV charging points, particularly at service and rest areas on high-traffic routes²⁶. Despite **relatively high investment costs**, estimated at 60 million euros, **the development of these terminals presents no technical difficulties, and should be planned on a national scale as of now** to ensure the proper electrification of long-haul tractor units.

In parallel with the development of infrastructures, the range of trucks' offer is evolving very rapidly, so much so that **manufacturers are projecting that by 2030, almost half of the truck's sale will be "0-emission"**²⁷. This rapid take-up in the development of "0-emission" trucks, particularly electric ones, will lead to rapid progress in technology, which is already promising, and to an **improvement in truck range, which will exceed 500 kms in the near future**²⁸. Some manufacturers are even announcing trucks with a 600km range this year²⁹.

²⁴ October 2024, APRR, [Inauguration d'un réseau de bornes de recharge pour poids lourds électriques entre Paris et Lyon](#).

²⁵ T&E, April 2023, [Il n'y aura pas assez de bornes de recharge en France d'ici 2030 pour permettre une électrification rapide des camions](#).

²⁶ Consensus d'entreprises (Enedis, Vinci Autoroutes, TE, IVECO, MAN, Mercedes, Renault trucks, Scania, Volvo), March 2024, Electrification de la mobilité lourde longue distance - Besoins et enjeux de la recharge en itinérance. [Available here](#)

²⁷ Transport & Environment, December 2022, [Camions électriques : pourquoi et comment accélérer leur déploiement](#).

²⁸ *Ibid.*

²⁹ Actu transport logistique, December 2024, [Le Renault T E-TEch électrique 2025 atteindra 600 km d'autonomie](#).

97% of tractor-trailers travel less than 800km per day

Truck tractors travel an average of 530km per day

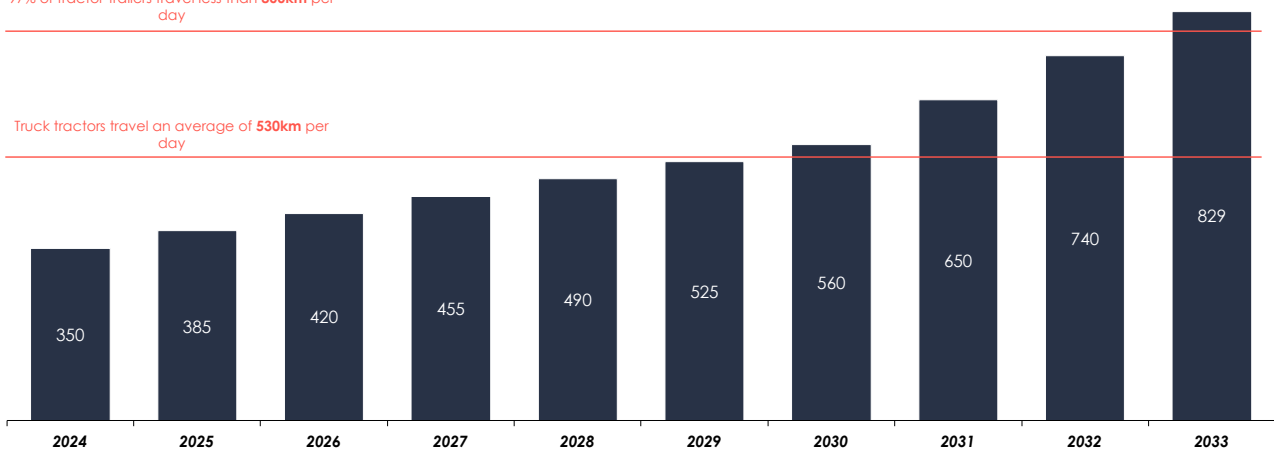


Figure 7: A possible scenario for the evolution of the average range of no-load electric trucks (km)³⁰

Given that **European tractor-trailers cover an average of 530km a day, most of them are already able to carry out their rounds without any operational constraints** in terms of the legal framework and mandatory breaks (see Figure 8), **provided they have access to a fast-charging station**. Figure 8 shows that **the development of infrastructure combined with progress in supply** means that **long-haul trucks can cover their daily distance without constraint**, since almost all of them cover a distance of less than 800km per day³¹.

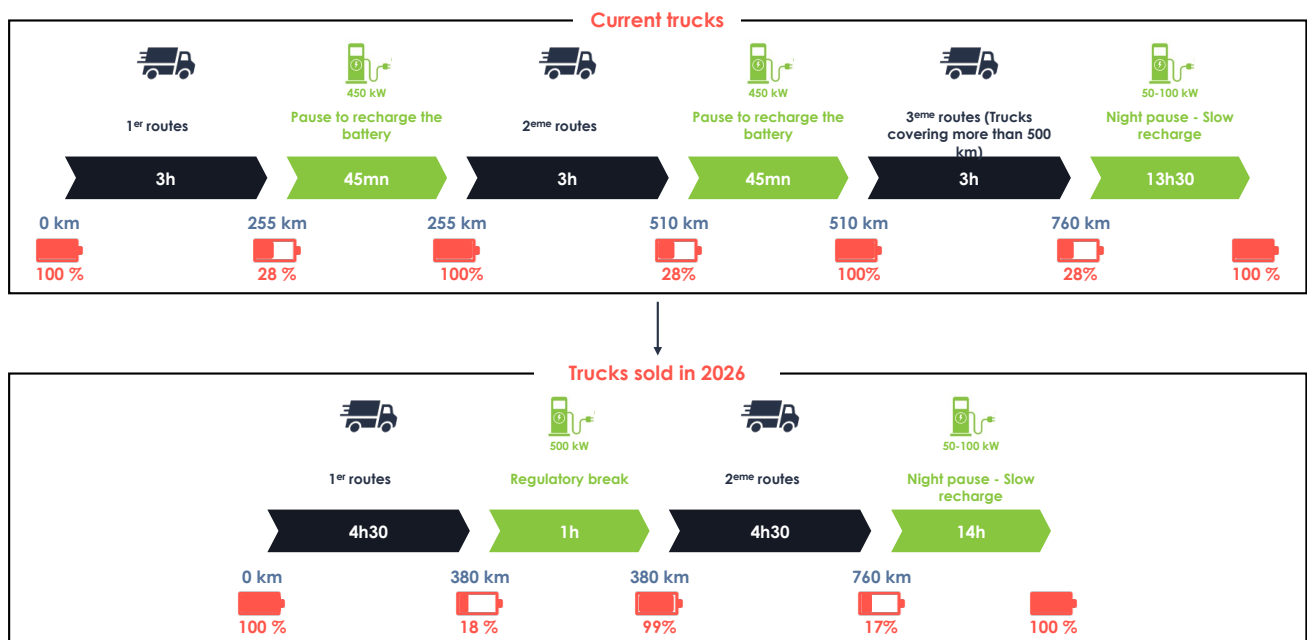


Figure 8 : Daily activity of an electric road tractor driving 760km on major roads³²

³⁰ Carbone 4 analysis based on the evolution of battery performance and capacity, as well as the penetration (from 2030) of technologies currently under development. In addition, the model takes into account changes in tractor performance and a slight increase in battery weight between now and 2030 (IEA, ICCT, T&E, Enedis and manufacturer projections).

³¹ Transport & Environment, December 2022, [Camions électriques : pourquoi et comment accélérer leur déploiement](#).

³² Carbone 4 analysis based on field feedback, Transport & environnement & report "Electrification de la mobilité lourde longue distance" (source n°14).

In the final analysis, the main challenge in electrifying a tractor truck will not be to ensure sufficient range for almost all road tractor applications. Rather, it will be a question of targeting the right battery capacity to ensure sufficient autonomy for your needs, while limiting purchase costs and manufacturing impact.

In addition to the development of electric recharging infrastructures, other infrastructures are planned to improve the penetration of electric power in long-distance road transport.

2.1.3. Other innovative infrastructures will accelerate the penetration of electric vehicles in the long-distance market

The impact of vehicle manufacturing increases with the size of the on-board battery, especially due to the high carbon content of the critical metals used to manufacture it, prompting us to **imagine solutions other than battery capacity to improve the range of road tractors**. Several innovations in the exploratory phase, such as electrified highways or swapping systems, which are explained below, can improve range without affecting battery size.

Electrified freeways are currently being studied by some companies in several countries, including France, where a portion will be tested from 2025³³. These freeways are equipped with electricity distribution systems (catenaries, ground rails or induction). The main advantage of these solutions is, of course, that they can be recharged while driving, which de facto reduces the size of batteries, the carbon footprint of vehicle manufacture and material requirements. In particular, this solution would enable **the electrification of long-distance HGVs while maintaining a reasonable battery size**. What's more, its implementation would require only a slight operational adaptation on the part of transport operators. Nevertheless, ambitious deployment of these technologies would require **substantial investment, and would entail a significant carbon cost**. As a result, **these infrastructures need to be used by a large number of vehicles, a priori including light vehicles**, which would only be possible in the case of electrified freeways by rail or induction, as catenary systems can only be used by large vehicles. And **strong political will will be essential to guarantee strong adoption of this practice**, which is essential to amortize the carbon costs of deployment.

Another system that saves recharging time and reduces the size of electric truck batteries is the **"swapping" of either tractors** (the trailer is swapped onto another tractor, which is charged and the first is recharged at a station), or **batteries directly** (the entire battery pack is exchanged for another already charged at a "swapping station"). **The latter system is now widespread in China**³⁴. These two schemes, which are modern versions of the post office relay system, ensure that the goods being transported are not immobilized while they are being recharged. What's more, while tractor swapping leads to a larger tractor fleet, it also **has a social advantage, as truck drivers can work on regional routes and avoid the need for overnight stays**. For these technologies to be widely adopted, there needs to be standardization, which requires the involvement of manufacturers, as well as the development of swapping infrastructures.

³³ Le Monde, September 2024, [France is set to test freeway that charges electric vehicles in 2025](#)

³⁴ ICCT, August 2023, [China is propelling its electric truck market by embracing battery swapping](#).

2.2. The purchase and operating costs of the various alternatives will evolve

While alternatives to diesel tend to be more expensive today (see Figure 5), **their cost will decrease with the development of vehicle production methods** and, in some cases, changes in the price of different energies. A distinction is made between the purchase cost, which corresponds to the price of a new vehicle, and the operating cost, which corresponds to the expenditure on vehicle maintenance and the energy used to run it.

On one hand, **the cost of purchasing new alternative vehicles such as electric and hydrogen is expected to fall, thanks to the scale effect on production**. In fact, manufacturers are forecasting strong growth in supply, with almost one in two trucks sold in 2030 being "0-emission". In contrast, trucks running on biofuels, biogas or e-fuels are based on more mature technologies (diesel and gas trucks), for which the price will not drop as much.

On the other hand, the price on the road will depend on changes in the price of the various energy carriers. **The future cost of the various energies depends on numerous parameters whose evolution is difficult to anticipate:**

- Market trends. Gas and diesel prices, and in turn electricity prices, are more unstable due to their dependence on international market prices, which depend on various geopolitical contingencies (oil shocks, war in Ukraine, etc.). **This favors battery-powered electric motors**, which have much lower operating costs and are therefore less sensitive to price variations;
- The increasing internalization of the carbon price (tax, emissions quota, etc.), which **economically favors low-carbon energy sources**. For example, the entry of road transport into the European carbon market in 2027 will give an economic advantage to low-carbon alternatives;
- The **scarcity of resources can also have an effect by unbalancing the supply/demand equilibrium**. This is the case, for example, with sustainable biofuels, whose resources are limited, and for which conflicts of use could eventually lead to higher prices, or with raw materials for batteries such as lithium, nickel or cobalt;
- There is still uncertainty about the sustainability of biomethane subsidies, which could push up the price.

Overall, the TCO (Total Cost of Ownership) of tractor-trailers will tend to move in favor of the new alternative engines, as shown in the following figure, the figures for which are taken from a Europe-wide ICCT study.

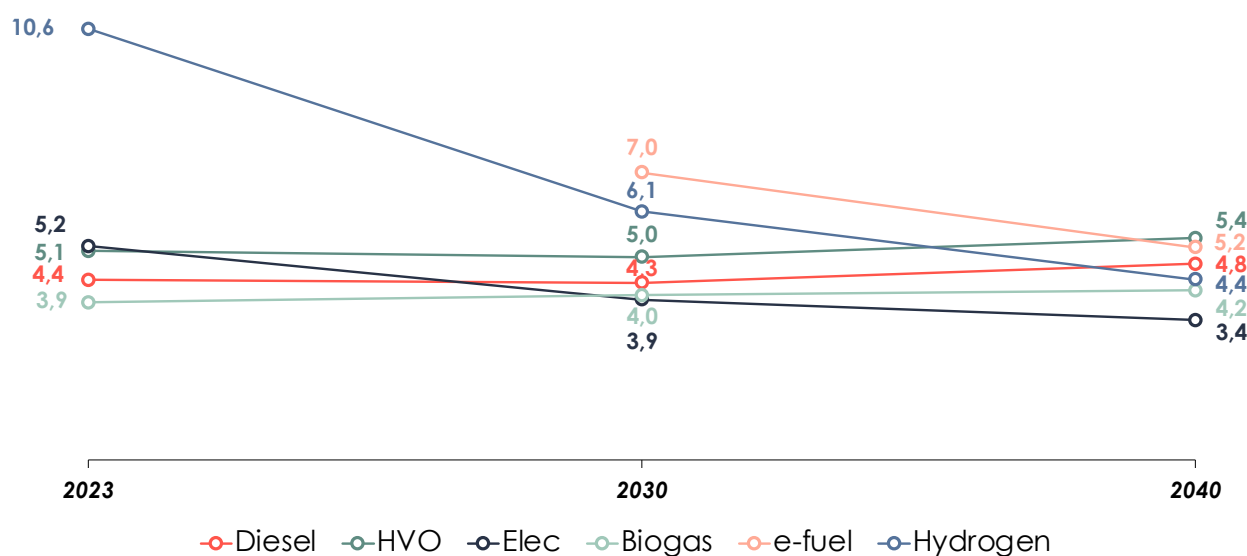


Figure 9 : Projected evolution of TCO (cts/tkm) of different engines for a road tractor³⁵

Electricity, followed by hydrogen in the longer term, will thus become the most cost-effective alternatives. **Electricity becomes the most relevant alternative based on the multi-criteria analysis in Part 1**, as shown in the figure below.

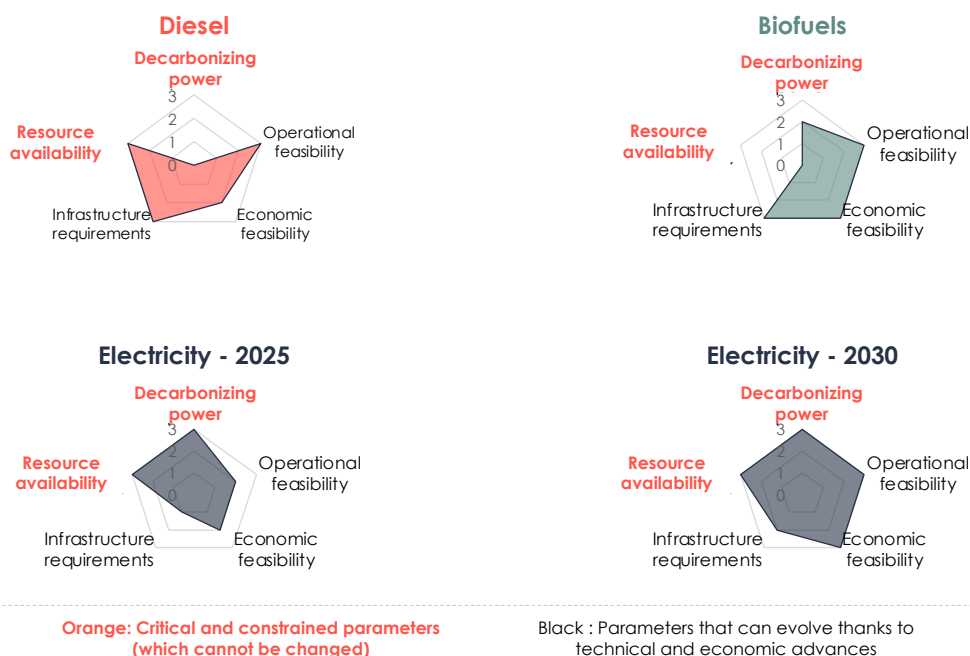


Figure 10: Multi-criteria analysis of the relevance of electric power in the short and medium term

³⁵ Based on changes in purchase costs (ICCT), changes in truck fuel efficiency (ICCT) and changes in energy costs (Analyses Carbone 4). Subsidies are not taken into account, and maintenance costs are assumed to remain constant. ICCT, November 2023, [A total cost of ownership comparison of truck decarbonization pathways in Europe](#). Does not take into account carbon price internalization.

2.3. What kind of carbon-neutral landscape for long-distance road haulage?

While the path towards electrification is taking shape for suburban and regional transport, the direction to take for long-distance road haulage is still the subject of debate. Based on the analysis of technical and economic developments in this publication, **Carbone 4 proposes a possible scenario for the evolution** of the road tractor fleet, with a view to achieving carbon neutrality by 2050:

- **Bioenergy is seen as a relevant transition fuel for very long-distance transport in the short term.** As bioenergy available for the transport sector by 2050 is very scarce (see Figure 6), the residual will be used primarily for maritime and air transport, where electrification is physically impossible on a large scale given current and future battery technologies. **They will thus represent 2% of the mix in 2050, for specific very long-distance uses.**
- **Electricity is the alternative that will gradually take over the truck fleet.** Already relevant for most of the daily distances covered by tractor-trailers, the development of the technology and the charging network will gradually make it possible to cover all distances.
- **Hydrogen and e-fuels**, which will remain more expensive than electric (see Figure 4), **are chosen for niche markets**, where the advantages of autonomy and fast recharging times justify the extra operating costs.
- **Fossil fuels (diesel and gas) will disappear completely from the mix**, as this is a necessary condition for achieving the SNBC objective of carbon neutrality in the transport sector.

Figure 9 proposes a scenario for achieving neutrality that follows these trends. It represents the motorization mix of the rolling stock (not the new fleet) of long-haulage tractor units. The failure of electric vehicles to gain a firmer foothold is mainly due to the inertia of truck ownership: trucks purchased today will still be in the fleet in 2030.

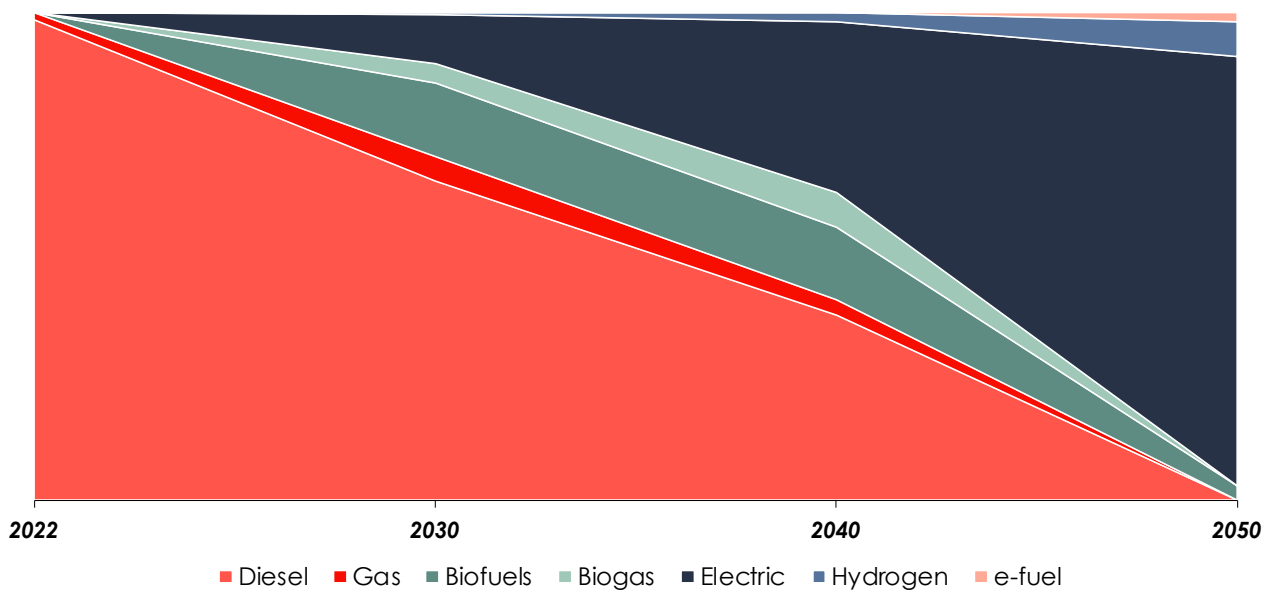


Figure 11: Possible scenario for the evolution of the long-haul truck fleet to achieve carbon neutrality by 2050

As the fleet is the result of trucks sold over the last 10 years, the mix of new vehicles must evolve all the more rapidly, as shown in Figure 12. VECTO regulations are pushing in this direction, and manufacturers are already producing electric tractors, with plans for half of all trucks sold in 2030 to be "zero-emission". "0-emission" trucks.

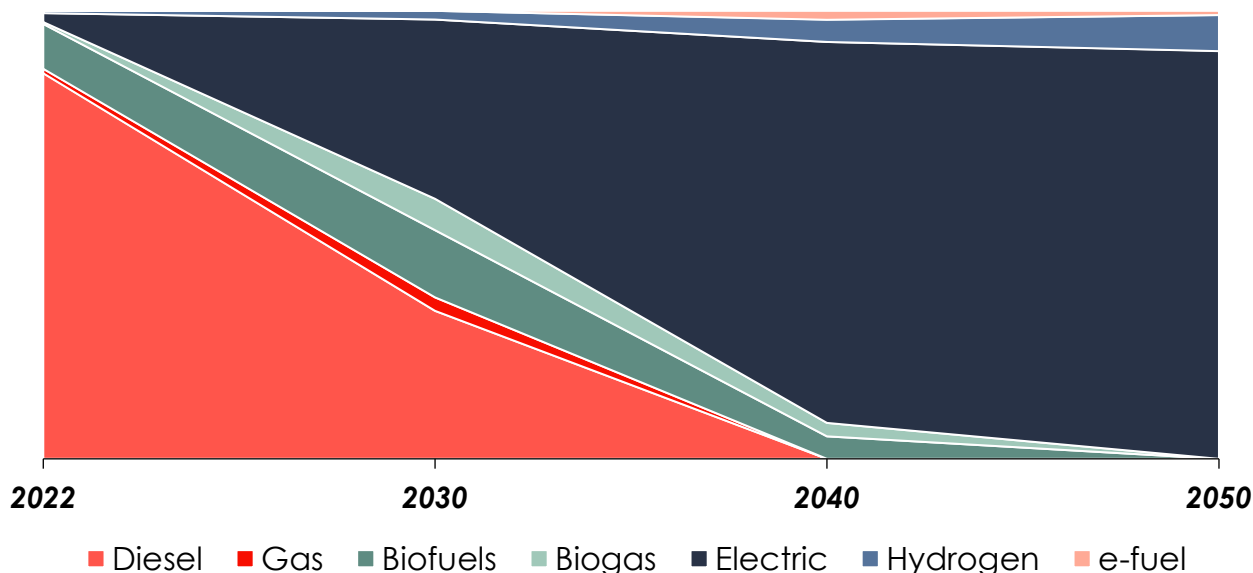


Figure 12 : Possible scenario for sales of tractor-trailers to achieve carbon neutrality by 2050

Tomorrow's freight transport landscape will of course undergo other changes that are not developed in this publication. Modal shift to river and rail transport will be necessary, distances covered by goods will evolve, routes will be optimized to improve load factor, trucks will be better adapted to needs, etc. These other levers for decarbonizing freight transport are detailed in our [FAQ on freight transport](#).

2.4. It's in the best interests of industry professionals to start their transition to electric vehicles, starting today

It's in the industry's interest to be ahead of the curve and begin the transition today:

- **The regulatory trend is against fossil fuels.** Entry of road haulage into the European carbon market from 2027³⁶, reform of the Eurovignette directive, Low Emission Zones, the end of the diesel excise tax rebate currently under discussion, and so on. Carriers who anticipate by purchasing low-carbon road tractors now **can avoid the risk of seeing the cost of transporting their goods rise as a result of an excessively high-emission fleet.**
- **A carrier who buys only thermal trucks with the ambition of running on bioenergy to decarbonize his activities runs the risk of running on carbon-based fuels again in a few years' time**, once the resource constraint is felt and suppliers no longer have a sufficient supply of low-carbon biogas and biofuels (See 1.3.3). **There's a real danger in betting too much on this limited resource**, with the risk of losing markets in the future, for not being able to put truly decarbonized energy in the tank. Electricity must therefore be one of the solutions considered today.
- Shippers and end customers are increasingly concerned about reducing their carbon footprint, which means cutting transport emissions. **Investing in alternative engines is therefore essential if we are to retain markets with ambitious shippers.** There's no shortage of examples of shippers with plans to move away from diesel: Ikea, Unilever, Nestlé, Michelin, Decathlon, Carrefour, ADEO, etc.
- Several interesting subsidies make it possible to acquire and use road tractors with alternative engines at attractive prices.

However, **carriers will not be able to bear the cost of the energy transition alone**, especially as alternative engines are still more expensive than diesel today. It is therefore **essential to work in partnership with shippers to identify together the flows to be decarbonized, share the additional costs and review together the organization of goods transport** (lead times, logistics, etc.) to encourage the integration of decarbonized modes. This could, for example, take the form of **multi-year contracts** to amortize the acquisition cost of alternative tractors, with **the price of electricity indexed to the current price of diesel**, or **the installation of charging stations on the shipper's site** for partial recharging during delivery.

Carbone 4's transport division has developed its sector expertise by working with various carriers and shippers and has noted the growing interest and willingness of players in the sector to embark on a decarbonization strategy to reduce their impact and anticipate the risks of transition.

³⁶ Ministère territoire écologie logement, October 2024, [Marchés du carbone - SEQE-UE 2](#).

Carbone 4 has, for example, worked with a federation of carriers over a long period, and the results are positive and concrete:

- The subject was of great interest to the various members of the consortium, who remarkably gained in climate expertise;
- **Each carrier now has its own tool for calculating its complete carbon footprint** (including emissions from logistics sites);
- **The group has set itself an ambitious target of reducing** its carbon footprint by 2030;
- The combination of the group's transport expertise and Carbone 4's climate expertise **has enabled us to devise practical, affordable and accessible operational solutions** to help transport companies reduce their impact and better anticipate the risks of transition;
- **Many carriers have begun their transition** by incorporating an increasing share of bioenergy in the diesel & gas trucks they use, but some carriers have also installed terminals and bought their first electric road tractors, and it's been a success;
- In addition to the motorization changes discussed at the heart of this publication, **the work identified other operational levers** relating to route optimization, improved load factor, modal shift and fleet energy efficiency.

CONCLUSION

While decarbonizing engines can meet a variety of needs, it **would be illusory to try and remain technologically neutral**. Severe constraints on biomass resources severely limit the role of bioenergies, just as the degraded energy efficiency of hydrogen and e-fuels increases their cost. For both resource and economic reasons, **battery-powered electric motorization will take the lion's share, including on long-distance routes**, and VECTO regulations strongly support this choice. **Being aware of this means anticipating this major transition for road transport**. Starting to operate trucks today in areas of current relevance, such as peri-urban and regional routes (< 350km)³⁷, allows us to get used to these operating modes and to make the transition gradually. It also allows **for innovative contracts between carriers, freight forwarders and shippers**, as electric vehicles require greater investment than diesel, with conversely lower operating costs. The transition to electric motorization (as well as biogas or hydrogen to a certain extent) with its more limited range is also an opportunity **to review opportunities on other decarbonization levers**:

- Are there any possibilities for combined rail or river transport which would make it possible to use trucks upstream/downstream over short distances?
- Is it possible to further optimize routes, by working jointly on specifications between shippers and carriers, so that they can be carried out with more constrained trucks?
- Should we review our eco-driving techniques to maximize our truck's limited autonomy?
- Isn't the switch to electric trucks an opportunity for new markets favoring short circuits?

The road transport industry is often forced to evolve, so **rather than undergoing this transition, taking hold of it can enable you to evolve your business model and stay anchored in the market**.

³⁷ Carbone 4, September 2022, [Camion électrique : il est temps d'embrayer sur la logistique urbaine](#).

Glossary

CAS: Land use change

ENR: Renewable electricity (hydro, wind, solar)

CNG: Natural gas for vehicles

HVO: Hydro Vegetated Oil. Biofuel obtained by hydrotreating vegetable oils, with the same characteristics as diesel.

SNBC: Stratégie Nationale Bas Carbone. French national roadmap for the transition to a low-carbon economy and society.

e-fuel: Synthetic fuel that can replace diesel. It is produced from renewable (ENR, biomass) or non-renewable (gas, coal) sources.

MTE: Ministry of Ecological Transition and Territorial Cohesion

T.km: tonne-kilometer. Unit of measurement for the transport of goods, designating the transport of 1 ton of goods over 1 kilometer.

Carrier: Individual or legal entity responsible for transporting goods to a given location.

Shipper: entrusts goods to the carrier for delivery to a specific destination.

OEM: Original Equipment Manufacturer

TCO: Total cost of ownership, which corresponds to the life-cycle cost of a product. For a truck, for example, this includes purchase costs and operating costs (energy, maintenance, insurance, etc.).



Carbone 4 is the leading independent consultancy specializing in low-carbon strategy, adaptation to climate change and biodiversity preservation.

Constantly alert to weak signals, we deploy a systemic vision of the energy-climate-biodiversity constraint, and put all our rigor and creativity into transforming our customers into leaders in the climate challenge.

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