ESG Economist

No easy road to decarbonizing road mobility

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- **The aim of the EU to be net zero by 2050 is an enormous challenge**
- **The mobility sector is responsible for 20% of total greenhouse gas emissions, with road mobility being the biggest emitter. Therefore the EU has set ambitious targets for road mobility to reduce emissions.**
- **Where GHG emissions across the European economy declined by 32% between 1990 and 2019, GHG emissions from road mobility increased by 7%. So road mobility needs to step up efforts to reduce emissions substantially.**
- **There are several technologies and solutions that are crucial to reduce these emissions. Battery electric vehicles use lithium-ion batteries and permanent magnets. Fuel cell electric vehicles use fuel cells mainly fuelled by hydrogen. Vehicles with internal combustion engines could be fuelled by synthetic fuels.**
- **The choice of technology or technologies for each subsector in road mobility depends on availability of a technology, the efficiency, the cost and infrastructure.**
- **There are numerous challenges to the technologies/solutions to reduce emissions. For battery electric vehicles these are affordability (cars), infrastructure and range. For fuel cell battery electric vehicles these are efficiency, infrastructure and price to produce low-emission hydrogen and for synthetic fuels efficiency, affordability and limited supply.**
- **Therefore reaching the ambitious European and Dutch targets may prove to be difficult.**
- **Without the infrastructure (battery electric and fuel cell electric vehicles) and/or substantial production (synthetic fuels) vehicles will not be able to reduce the needed emissions.**

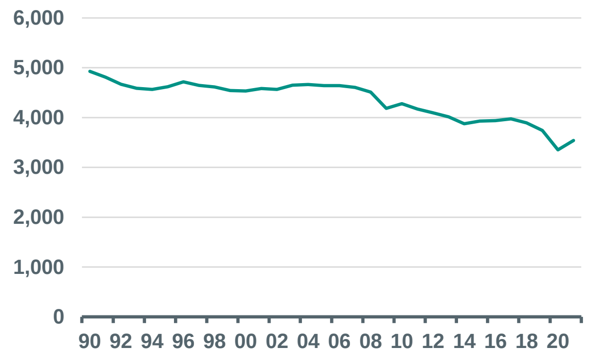
In this ESG economist we start with an overview of greenhouse gas emissions of the mobility sector and the recent state of play in terms of the vehicle fleet followed by setting out the policy measures taken by the EU and the Netherlands to reduce emissions. Then we highlight the technologies used in road mobility that help to reduce emissions. However, each technology has its challenges and we give a detailed overview of the obstacles on the path to net zero. We wrap up with our judgements on what would at this point in time be the most viable technology for the various road mobility sectors.

Emissions of road mobility EU 27 and the Netherlands

According to Eurostat, the EU emitted 3,541 Megaton of greenhouse gas emissions in 2021 and the mobility sector accounted for 22% of those emissions or 782 Megaton. EU 27 GHG emissions are down 28% at the end of 2021 compared to 1990. However this doesn't apply to emissions from road mobility which are 16% higher compared to 1990. Emissions from the different sub-categories of road mobility show increases between 12% (emissions by cars) and 64% (emissions by light duty vehicles) compared to 1990. In 2021 the Netherlands emitted 175 Megaton and the mobility sector accounted for 15% of those emissions or 25.5 Megaton. According to CBS, the mobility sector in the Netherlands emitted 29.6 Megaton in 2022, meaning that there is a moderately downward trend excluding the impact of the pandemic compared to 1990 when the mobility sector emitted 32.2 Megaton. So if we take this all together the mobility sector clearly lags behind in terms of reducing greenhouse gas emissions compared to the EU as a whole and the Netherlands. For the EU the trajectory for emissions in road mobility needs to change completely.

GHG emissions EU 27

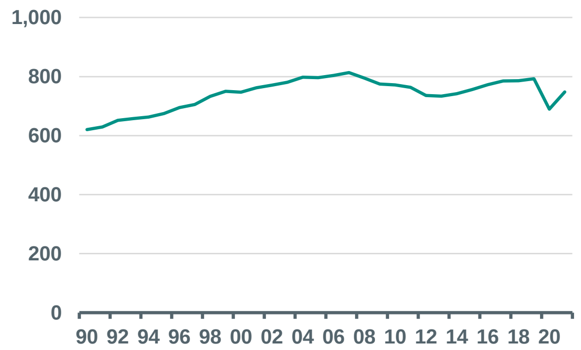
In Mt



Source: Eurostat, ABN AMRO Group Economics

GHG emissions road transport

In Mt



Source: Eurostat, ABN AMRO Group Economics

Road transport is the biggest emitter in the mobility sector. It is responsible for around 95% of the total emissions of the mobility sector. Passenger cars account for around 50% of emissions of the mobility sector. The table on the left shows the greenhouse gas emissions of EU 27 in 2021 of the mobility sector in Megaton and as percentage of the total of mobility. The table on the right show the situation for the Netherlands. So cars emit a higher percentage of the total for EU 27 than for the Netherlands namely 56% versus 52%. Commercial vehicles account for around 40% of the GHG emissions (38% for EU 27, 43% for NL). This is the sum of emissions and percentages of heavy duty, light duty vehicles, buses and construction traffic (the last two are not in details mentions in the Eurostat data). The percentage of emissions from commercial vehicles is higher for the Netherlands compared to EU 27; 43% versus 38%.

Shares of GHG emissions mobility EU 27

In % and Mton

EU 27	Emissions GHG in %	GHG end 2021 in Mton
Cars	56%	440.5
Heavy duty	27%	209.4
Light duty	11%	88.1
Motorcycles	1%	9.8
Other road transporation	0%	0.1
Railways	0%	3.8
Domestic navigation	2%	16.0
Domestic aviation	1%	9.8
Other transporation	1%	4.7
Mobility total	**100%**	**782.1**

Source: Eurostat, ABN AMRO Group Economics

Shares of GHG emissions mobility Netherlands

In Mton

NL	Emissions GHG in %	GHG end 2021 in Mton
Cars	52%	13.4
Heavy duty	28%	7.0
Light duty	15%	3.7
Motorcycles	1%	0.4
Other road transporation	0%	0.0
Railways	0%	0.1
Domestic navigation	3%	0.8
Domestic aviation	0%	0.0
Other transporation	0%	0.1
Mobility total	**100%**	**25.5**

Source: Eurostat, ABN AMRO Group Economics

Total fleet

At the end of 2019, the global fleet of cars stood at 1.083 billion, while the fleet of commercial vehicles stood at 406 million (source **www.wardsauto.com**). These commercial vehicles mainly have internal combustion engines that use fossil fuels.

In 2021 nearly 287 million cars were on the road in total in the EU. 29.5 million vans (up to 3.5 tonnes) were in circulation throughout the European Union and 6.4 million medium and heavy commercial vehicles and 714,000 busses. Heavy duty vehicles are responsible for 27% of the CO2 emissions from road transport in the EU, but they are only 2% of the vehicles. In the Netherlands 8.8 million passenger cars, 158,000 trucks, 1.06 million vans and 9,316 busses were on the road in 2021. In 2021 79.1 million motor vehicles were produced around the world (source **ACEA**)

Battery electric vehicles sales versus fleet

Sales

Worldwide more than 10 million EVs were sold in 2022. Of that total, 70% were full battery EVs, with the rest being plug-in hybrids (IEA). For the EU 12.1% of the new cars sold in 2022 were battery electric. For the Netherlands this share was 24%.

Fleet

The share of battery-electric cars in the fleet in the European Union was only 0.8% (in 2021) and the fleet of battery electric cars in the Netherlands stood at 328,295 passenger cars and 596 fuel cell electric cars at the end of December 2022 (**RVO**). At the end of 2021 the total stock of electric trucks stood at 66,000, representing of just 0.1% of the fleet. According to the IEA, the fleet of electric buses was 670,000 at the end of 2021 or 4% of the global bus fleet. For the Netherlands in 2022 0.2% of the fleet of trucks are electric vehicles, 1.2% of the vans are electric vehicles and 17% of the busses are. So there is room to grow.

Policies to reduce emissions in road transport

Reduction targets

The EU and the Netherlands have set the goal to reduce emissions of greenhouse gasses (GHG) by at least 55% and make the EU climate neutral by 2050. The policy in the Netherlands is aimed at a reduction of 60% by 2030 and to be net zero in 2050. To reduce GHG emissions by the mobility sector the EU and the Netherlands have set ambitious targets for this sector.

Policy to reduce emissions from mobility

In this section we discuss the emission targets and policy announced by the Dutch government and the European Commission (EC) to reduce emissions for the mobility sector. We start with the Netherlands followed by that of the EC.

<u>The Netherlands</u>

The government target for the mobility sector is to reduce greenhouse gas emissions to 21 Megaton in 2030, this means a reduction of 8.6 Megaton compared to 2022 (for the Netherlands we also have the full year 2022 from CBS). Every sub-category needs to contribute its share. As there are no sub-sector target we assume that the reductions are all the same in percentage terms. We have taken the percentages of emissions of each subsector on the table on the left on page 2. This table shows that cars account for 51% of the emissions and commercial vehicles for 44% of the emissions. The reduction target is 8.6 Megaton by 2030 so cars need to emit 4.4 Megaton (52% x 8.6 Megaton) less by 2030 and commercial vehicles 3.8 Megaton less (43% x 8.6 Megaton).

Policy on cars

The Dutch government's policy is that every new car sold from 2030 onwards has to be a zero-emission car. This can be battery electric car or a hydrogen fuel cell electric car. In the Netherlands, the fleet of 8.8 million passenger cars was responsible for roughly 14.8 Megaton greenhouse gas emissions in 2022. In 2030 the fleet of cars that emit greenhouse gasses is expected to be 6.3 million passenger cars (internal combustion and hybrid vehicles). This is based on the assumption that the share of battery electric vehicles in the sales will increase by 9% annually to reach 100% in 2030 and that the annual sales will roughly remain around 440,000 on average. The total greenhouse gas emissions of these 6.3 million passenger cars could be around 10.7 Megaton. So, by introducing the measure that all new passenger cars in 2030 have to be zero-emission cars, greenhouse gas emissions could drop from 14.8 megaton to 11 Megaton or a reduction of 3.8 Megaton by 2030. So based on these assumptions and our own calculation making and an approximation of emission per vehicle and fleet we expect cars to emit 3.8 Megaton less by 2030. This falls short of the 4.4 Megaton needed (mentioned above).

What if the reality differs from these assumptions for example that the adoption of battery electric cars will slow in pace. At some point in time the consumers that could afford battery electric vehicles already bought them and consumers that can't afford them decide to drive longer with their cars that emit emissions. As a result total sales will slow and the amount of battery electric vehicles in the total fleet will rise more slowly. Therefore emissions will reduce at a slower pace than the above mentioned scenario. We think that if the total fleet has 500,000 less zero-emission cars then emissions could only reduce by 3 Megaton compared the initial estimation of 3.8 Megaton. So the Dutch government may need to fine-tune the policy in the coming years to make zero emission cars more affordable via for example subsidies. Another option is that the government may opt to speed up the adoption of zero-emission vehicles by consumers if it turns out to be that there are more challenges to bring down emissions of commercial vehicles.

Policy for commercial vehicles

From 2025, all new buses used in public transportation should be zero-emission buses and they must use regional produced renewable energy. From 2030 all buses used in public transportation should be zero-emission buses. In addition, all vehicles used by the state should be zero emission as well in 2030. In 2019, the European Clean vehicles directive (CVD) was adopted and in 2021 this directive was implemented in the Netherlands as the 'Regeling bevordering schone wegvoertuigen' (Pianoo, 2021b). The regulation obliges government agencies to tender a minimum percentage of clean vehicles in

European tenders for vehicles and transport services. All modes of road transport are covered by the regulation. This regulation is forecast to reduce emissions by 0.4 Mton in 2025 (source CE Delft). Finally, there are also new developments on city logistics. In 2025, in the Netherlands, 30 to 40 municipalities have zero emissions zones for trucks and vans. The expected CO2 reduction of this measure is 1 Megaton (Klimaatnota 2022). The other possible effects of the measures taken by the government in the table above are based on data from the government and from CE Delft. So if the effects of all the measures are taken together the mobility sector could emit around 8.6 Megaton less in 2030. This is the total needed reduction for the mobility sector. So based on this the government could hit the target for mobility. The table below shows an overview of the policies announced so far and the amount of emissions they could reduce.

Climate deal 2019 and Climate nota 2022 the Netherlands

Measures and possible effect in Megaton reduction

	Targets Climate deal 2019 and Climate nota 2022	Possible effect in Mton
2025	All new buses used for public transportation are zero-emission	
	And they use regional produced renewable energy	
	Transportation of people that have a limitation to move only on zero-emission vehicles	
	City logistics: In 30 to 40 municipalities middelsized zero-emission zones for trucks and vans	-1,0
	European Clean Vehicles Directive	-0,4
2030	All new cars zero emissions	-3,8
	8 bln less work related kilometres by car	
	Zero emission transport: all public transportation buses (approximately 5,248)	-0,5
	Zero emission transport: all construction traffic (including vans), mobile tools and machinery	-0,4
	Expectation is that there are 115.000 zero emission vans	-0,4
	Expectation is that there are 5.000 zero-emission/plug-in hybride trucks	-0,2
	30% reduction in CO2 emissions from hinterland and continental transport by 2030	-1,9
	Total expected reduction in Mton by 2030 based on Climate policy	**-8,6**

Source: Climate Deal, Climate nota 2022, CE Delft, ABN AMRO Economisch Bureau

Will the target be reached?

We doubt that the target will be hit. The adoption of battery electric vehicles could slow down. Moreover the trajectory is substantially steeper compared to the historical trend. Road mobility emitted in 1990 32.3 Megaton. So between 1990 and 2022 emissions only fell by 2.6 Megaton. By 2030 the mobility sector needs to decline by 8.6 Megaton. Compared to historical standards this seems very steep and may be improbable. For personal cars affordability and charging infrastructure are the main challenges. For commercial vehicles to meet emission reduction targets there are three main challenges: the range and freight challenge, refuelling infrastructure challenge and the charging infrastructure challenge. Later in this report we focus on the challenges to reach the reduction target.

The European Commission

The EU has set the goal to reduce emissions of greenhouse gasses (GHG) by at least 55% and make the EU climate neutral by 2050. As indicated in the previous paragraph the emissions of road transport are in an upward trajectory compared to 1990. So there not only needs to be a change in direction but also a substantial reduction in emissions. To reduce GHG emissions by the mobility sector the EU has set ambitious targets for this sector.

Ban on new sales of cars and vans with internal combustion engines by 2035

A key policy is the ban on sales of new cars and vans with internal combustion engines by 2035. In June 2022, the European Parliament backed the European Commission’s proposal. Intermediate emissions reduction targets for 2030 would be set at 55% for cars and 50% for vans compared to 2021. Members of the European Parliament voted to ban the sale of new combustions engine cars by 2035. The Environment Ministers at the European Council agreed to this ban from 2035. However, the European Council left the door open to CO2 neutral fuels as decarbonization alternatives to electrification. The ban was approved by Parliament in February 2023 by a tight margin. But it had to be formally endorsed by the Council on 7 March. This vote was postponed but in the end approved. EU ministers signed off on 28 March on the ban of sale of combustion engines from 2035. But there will be extra technical legislation setting out a workaround for e-fuels. This still needs to be approved by EU institutions.

ETS

On 22 December 2022, the European Council and Parliament agreed to create a new, separate emissions trading system for the buildings and road transport sector and fuels for additional sectors, in order to ensure cost-efficient emissions reductions in these sectors that have been difficult to decarbonise so far. The new system will apply to distributors that supply fuels to buildings, road transport and certain other sectors. The co-legislators agreed that the system will start in 2027. The linear reduction factor is 5.43% from 2028. So from 2028 the number of allowances will decrease by 5.43%. On top of that they will auction upfront in 2027 30% of the total volume of the number of allowances to secure a smooth transition path. In the case that energy prices were to be exceptionally high, the start of the new ETS would be delayed until 2028. Once the system has started if the price of allowances exceed EUR 45 over a certain period of time, additional allowances will be released increasing the supply on the market. In the table below an overview of the targets and policy in place of the EC to reduce emissions from road mobility.

Other measures

On 14 February 2023, the European Commission proposed ambitious new CO2 emissions targets for new heavy-duty vehicles (HDV). The proposed targets for new HDV are as follow: 45% emission reductions by 2030 compared to 1990 levels, 65% emission reductions by 2035 and 90% emission reductions by 2040. So HDV should from 2030 on emit 45% less CO2 emissions compared to 2019 levels. Emissions in the HDV sector have been increasing year-on-year since 2014 (except 2020). Especially in the freight sector emissions are increasing rapidly. These vehicles run for 99% on internal combustion engines largely fuelled by diesel. City busses will have to be zero emissions by 2030 according to the plans.

Climate policy EU on road mobility

In red the proposed ambitions on 14 Feb 2023

	EU Climate policy mobility
2025	By end 2025 recharging stations every 60 km on main roads for cars/trucks < 3,5 tonnes
2027	ETS for buildings and road transport sector will start
2030	55% CO2 emission reduction taget for new cars compared to 2021 levels
	50% for new vans by 2030 compared to 2021 levels
	16 countries (incl the Netherlands) have target of 30% zero-emission truck and bus sales
	By end 2030 recharging stations every 60 km on main roads for trucks above 3,5 tonnes
	By end 2030 hydrogen refuelling stations at least every 200km on main roads
	Proposed 14 Feb 2023: 45% emissions reductions new HDV
	Proposed 14 Feb 2023: City buses zero emissions
2035	100% CO2 emission reduction target for both new cars and vans by 2035
	Proposed 14 Feb 2023: 65% emissions reductions new HDV
2040	16 countries (incl the Netherlands) have target of 100% zero-emission truck and bus sales
	Proposed 14 Feb 2023: 90% emissions reductions new HDV

Source: EC, ABN AMRO Economisch Bureau

The Netherlands has done better in terms of emission reductions compared to 1990 than the EU. But both the EU and the Netherlands are lagging behind. Any way we look at it the targets are very ambitious and the annual pace of emission reduction is high compared to historical standards. So task to bring down emissions for road transport is enormous.

Technologies for road mobility

Introduction

The aim of the EU to be net zero by 2050 is an enormous challenge. There are several technologies and solutions that are crucial in the transition. Lithium-ion batteries, fuel cells that use hydrogen, permanent magnets and zero-carbon synthetic fuels are technologies for the mobility sector to reduce greenhouse gases. The choice of technology or technologies for each subsector in mobility depends on technical readiness of a technology, the efficiency, the cost and infrastructure. We first explain the four different technologies for road transport and in the next sections what the challenges are and what technology is the most viable for each subsector.

Technologies

Lithium-ion batteries for battery electric vehicles

A lithium-ion battery is a family of rechargeable battery types. The battery has a cathode, anode, electrolyte and a separator. During a discharge cycle, lithium atoms in the anode are ionized and separated from their electrons. The lithium ions move from the anode and pass through the electrolyte until they reach the cathode, where they recombine with their electrons and electrically neutralise (source **Clean Energy Institute**). The electrolyte doesn't let the electrons pass. Electrons move through the wire. During a charging cycle the opposite occurs. The cathode is responsible for the capacity and the power. Most cathodes contain nickel, lithium, cobalt and manganese but in different quantities. Some batteries contain aluminium. Nickel has high capacity, manganese and cobalt have high safety and aluminium increases the power of the battery (source Samsung). The anode is responsible for the lifespan. The anode is mostly made of natural or synthetic graphite. The electrolyte and separator determine the safety of a battery. The main focus is how to improve the range and to increase the energy density. Energy density is the measure of how much energy a battery contains in proportion to its weight. It is typically presented in Watt-hours per kilogram. A higher energy density means that vehicles can travel further without the need to recharge and/or it can be loaded with lighter weight and smaller size battery onto the EV. Safety and durability are also important to take into account. Each battery chemistry has a specific energy density, stability& safety and durability and one chemistry could be better suited for electric vehicles while others for storage.

Permanent magnets for battery electric vehicles

Permanent magnets are magnets that can maintain their magnetism for a long time. Permanent means that the magnet is rotating even with no electrical current applied, magnetic flux will still be present. Magnets have a high efficiency. Neodymium is the primary Rare Earth Element present in these magnets in an alloy of Neodymium-Iron-Born (NdFeB). The alloy is then doped with other rare earth elements such as Praseodymium and Dysprosium to improve the operating characteristics of the magnet like to increase the operating temperature of the magnet without becoming demagnetised. The majority of battery electric vehicles have these permanent magnets in their motors. The performance of electrified vehicles relies on generating a magnetic field with a sufficiently strong repulsive effect as a result of these permanent magnets. A electric vehicle contains 2 to 4 kg of permanent magnets.

Fuel cells for vehicles

A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. If hydrogen is the fuel, the only products are electricity, water, and heat. Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst (such as platinum) at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat. (source **energy.gov**).

There are different forms of fuel cells but not every form is suitable to be placed in a vehicle. The fuel cell that is mostly used is the Polymer Electrolyte Membrane (PEM) fuel cell also called a proton exchange membrane fuel cell. They use solid polymer as an electrolyte and porous carbon electrodes containing platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air and water to operate. They are typically fuelled with pure hydrogen supplied at storage tanks or reformers. PEMs operate at relatively low temperatures, 80 degrees Celsius. Low-temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components. Another fuel cell that is used in vehicles is the solid oxide fuel cell. Solid oxide fuel cells (SOFC) have also been used in vehicles for example in the e-biofuel cell. They use a hard non-porous ceramic compound as electrolyte. It has ethanol or ethanol blended water as fuel source. This fuel cell vehicle can use the existing infrastructure of biofuel. A reformer produces hydrogen from bioethanol and a SOFC stack generates electricity from a reaction between the hydrogen and oxygen (air) in the stack. Power is generated from the movement of oxygen ions in an electrolyte solution. The generated electricity is stored in the on-board battery. The heat that is generated during the power generation is reused in the generation of hydrogen. It has a higher efficiency than PEMs and the electrolyte will not leak (but can crack). But SOFCs operate at very high temperatures – as high as 1,000 degrees Celsius. So, it requires significant thermal shielding but there is no need for a catalyst. High temperatures have large wear on the system components. The SOFC has an efficiency of around 65% (source **energy.gov**)

Production of synthetic fuels for vehicles with internal combustion engines

What are synthetic fuels? Synthetic fuels are liquid fuels that have the same properties as fossil fuels but are produced artificially. Synthetic fuels can be blended with fossil fuels or replace the fossil fuel in internal combustion engines. There are three types of synthetic fuels and the way they are produced makes the difference (source **Synhelion**).

- Biomass-to-liquid produces biofuels (any fuel that is derived from biomass) such as renewable diesel/hydrotreated vegetable oil (HVO)
- Power-to-liquid produces e-fuels such as e-methane, e-kerosine and e-methanol
- Sun-to-liquid produces solar fuels such as hydrogen, ammonia (source **energy.gov**)

For mobility if synthetic fuels are mentioned they often refer to is e-fuels or electrofuels. These fuels are produced via the power-to-liquid method. First, renewable electricity is generated, which then drives an electrolyser that splits water into hydrogen and oxygen. Next, the hydrogen is mixed with carbon dioxide and turned into syngas via the reverse water gas shift (RWGS) reaction – a process that is conducted at high temperatures and driven by electricity.

Low carbon fuels

Are synthetic fuels low carbon, carbon-neutral or zero-carbon fuels? Low carbon fuels emit less carbon than fossil fuels. Renewable diesel, biodiesel, hydrogen/methanol/ammonia when produced using fossil fuels with carbon capture and storage are examples of low carbon fuels. Renewable diesel's CO2 emissions are highly dependent on the feedstock used. Often, this results in life-cycle emissions above zero. Shell and Volvo indicate that the use of hydro-treated vegetable oil could enable a reduction of fossil CO2 emissions by up to 90%. The higher the blend-in percentage, the higher the CO2 reduction.

Carbon neutral fuels

Carbon neutral fuels are fuels that do not increase or decrease the amount of carbon in the atmosphere through their life-cycle. Power-to-liquid fuels e-methanol and e-kerosine are carbon neutral fuels. They are considered carbon neutral if renewable resources are used in the production process and the carbon captured from the atmosphere is later released back into the air.

Zero-carbon fuels

Zero-carbon fuels are fuels that do not release carbon at the time of usage. For example hydrogen when produced by electrolysis and renewable electricity and ammonia when produced by renewable electricity and green hydrogen as the source are zero-carbon fuels (source **Cummins**).

Challenges for battery electric vehicles

Battery electric vehicles

There are several ways to reduce emissions from vehicles. First, a larger share of the vehicle fleet being made up of zero-emission vehicles (battery electric of fuel cell electric vehicles). Second, using fossil free biofuel and renewables instead of fossil fuels in internal combustion engines. Third, a combination of both. In this section we focus on battery electric vehicles. Battery electric vehicles generally use two main technologies, namely lithium-ion battery and permanent magnets. A battery electric vehicle car has a battery pack and an electric traction motor (instead of internal combustion engine). A battery can be packed in various ways: cylindrical, prismatic or pouch. But this technology/solution also has major challenges which we will focus on below.

Total cost of ownership battery electric cars versus internal combustion cars

Currently battery electric cars are more expense to buy even considering government subsidies. The average purchase price of an electric vehicle in the US was USD 66,000 in June 2022 compared to the broader car market of USD 48,043 (source: **Kelley Blue Book estimates**). However, according to a recent study from **LeasePlan** electric vehicles in nearly every segment and in nearly every European country are now at the same price or cheaper than petrol or diesel cars when all costs are included. The analysis is based on the total costs of owning and operating a car (TCO) including energy/fuel, depreciation, tax, interest, insurance and maintenance. The study notes that "fuel costs remain significantly lower for electric cars than petrol and diesel cars: fuel costs represent 15% of the total cost of ownership of an EV, while this is 23% and 28% for petrol and diesel drivers. So battery electric vehicles have a higher initial investment but lower running costs. Government incentive programs cover some of this higher initial investment. For example for the Netherlands the subsidy for buying a new electric car is EUR 2,950 and for a used electric car EUR 2,000 (the amounts for 2023). To achieve the goal of getting more zero-emission passenger cars on the road, purchase costs will have to fall (or subsidies will need to rise) so that electric driving becomes accessible to a large number of people.

Range and freight challenge

For shorter ranges, battery-electric vehicles are a good solution. However for longer ranges and/or transporting heavy cargo, battery electric vehicles may not be up to the challenge. This is because the longer the range, the larger and the heavier the battery would need to be, given the current state of technology. This will increase the load for the commercial vehicle. Currently battery electric trucks on the market have a range up to 300 km with an average weight of 30 tonnes. According to Eurostat statistics, around 45% of all goods transported by road in Europe travel less than 300 km. 33% of trucks cover daily distances of 500 km or less. In Europe, drivers are legally required to stop for a break after a maximum of four and a half hours, and in reality, will typically have a break after 3-4 hours. Since the distance covered in this time will be less than 300 km, there is the possibility to charge the truck during the driver's break. So for almost half of the freight in the EU, the current battery electric trucks on the market are up to the challenge. It is expected that the range of the electric trucks available will increase to 500 km in the coming years. The key factor for an electric truck is being able to have charging opportunities readily available in its schedule. A strategically placed charger – ideally at a location and time when the vehicle must stop anyway – would have a significant impact on a truck's range. However grid congestion might be a limitation for such infrastructure at scale in a short time scale (more on this below).

Charging infrastructure challenge

Ways of charging

For battery electric vehicles there are four ways of charging: wired stationary charging infrastructure (home/depot, destination or public), battery swapping, overhead catenary charging and wireless in-road charging. Stationary charging involves charging a vehicle at home, at the office or at the depot. This can be overnight or a moment that the vehicles is not used. The charging infrastructure for battery electric trucks differs from the charging infrastructure (with sufficient grid capacity) of electric cars. Trucks need fast and ultrafast charging infrastructure. These options range from slow alternating current (AC) charging with power below (kW) to fast 150-350 (kilowatt DC) and ultra-fast direct current fast charging with power up to multiple MW (750kW-3 MW DC) (source **the ICCT**). The estimated charging time of fast and ultrafast is around 30 minutes. Trucks need to have larger parking spaces.

The second way of charging is battery swapping. Battery swapping technology is a system where the drained battery is taken out of the vehicle and is replaced with a fully charged battery from the battery swapping station. This minimizes the charging time and the costs of the electric vehicle could be lower (battery is a large component of the costs of a vehicle) as the battery could be part of a service agreement. So the fleet owner would only pay for the vehicle body without the battery. Battery swapping could be offered under a battery-as-a-service (BaaS) business model. There are challenges to battery swapping. First, batteries for electric vehicles are currently not standardized. They vary in shape and size and packed in the truck in different ways. Second, there needs to be a large battery inventory, a backup for each vehicle. Third, the costs to set up a battery swapping station are high. One advantage is that the battery can be charged off-peak

The third way of charging is overhead catenary charging. Overhead catenary charging allows trucks to charge while driving with electricity flowing through a pantograph connected to an overhead contact line. This technology is complementary to wired stationary charging technology, as the goal is not to electrify the entire road network. As of 2022, this technology is still at an early stage; however, several pilot projects have already been conducted, mostly in Europe and North America (source **the ICCT**).

A fourth way of charging is wireless in-road charging. This works by transferring electricity from magnetic coils embedded in the road to receiving coils fitted to electric vehicles. Michigan is expected to operate the first electrified roadway in 2023. The roadway's coil segments transmit power to an EV undercarriage-mounted receiver via magnetic resonance induction as the EV moves or is parked directly above the coils. A power-management unit located either underground or above-ground near the roadside will transfer the energy from the electric grid to the roadway's copper-coil infrastructure. Both the battery size and the number of receivers connected to an EV influence the charging time. Larger vehicles can support multiple receivers. But there are some challenges such as high costs to set it up, the need of technical standardization and unification of operational standards of vehicles and the impacts of radiation from high-energy wireless charging on humans and animals is currently unclear (Liu et al., 2021). As these major challenges are to date unaddressed, wireless in-road charging is still at a very early demonstration stage and is not in commercial use.

A more general consideration is that a battery electric vehicle needs to be able to charge when it is connected to a charging source. For example, a vehicle could fail to connect to a charger. So chargers, batteries and electric vehicles need to communicate. Interoperability regarding chargers and software means the ability to operate any software and any charging and energy hardware with each other because they are standard conforming; that is, they are compliant to publicly available technical standards published by standardization organizations.

Amount of charging points

According to the IEA at the end of 2021 there were 1.8 million charging points worldwide. There are 422,000 AC chargers and 57,000 DC charging points in the EU 27 based on the Alternative Fuels Infrastructure Regulation (=AFIR) classification in 2022 (source **EC**). Most of the charging points are in the Netherlands, Germany and France. Together, these countries make up just 23% of the EU's total surface area. The total number of charging points (including private) in the Netherlands increased substantially, to 119,197 in December 2022. This is an increase of 44% compared to 2021. In the Netherlands, there are 69,804 regular public charging points that are 24/7 publicly accessible, 49,393 semi- regular semi-public charging points and 4,164 fast charging points. Regular charging points (public and semi-public) have smaller or equal than 22kW capacity while fast charging points have larger than 22 kW (**RVO**). There are also an estimated 345,000 private charging points. The RVO published a survey on charging in the Netherlands (National Laadonderzoek). According to this survey, 68% of electric car users have solar panels and 95% of this group would like to use solar power for charging or are already doing so. Currently there are 4.1 cars (BEV, PHEV) per public and semi-public charging points. If we also consider the private charging points then there are 1.1 cars per charging point. In China this is 5 cars per charging point and in Germany 12 cars per charging point. So looking at other countries the number of charging points should currently be enough. However, in densely populated areas where there is also limited possibility for private charging points it is likely that the number of cars (BEV, PHEV) per charging point is much higher and that there are not sufficient charging points. In addition, as EV sales are expected to grow rapidly, the number of charging points would need to keep up.

The Dutch government aims to have 1.8 million public, semi-public and private charging station in 2030. However, according to the European Automotive Manufacturers' Association (ACEA) up to 6.8 million public charging points are required by 2030 in order to reach the proposed 55% CO2 reduction target for passenger cars. Trucks will require up to 279,000 charging points 2030 of which 84% will be in fleet hubs, the remaining predominantly fast public chargers along highways. And for buses 56,000 charging points will be needed by 2030 (source **ACEA**).

Energy implications

The energy implications from e-mobility are substantial. According to **European EV Charging Infrastructure Masterplan** electricity demand created by EV charging (public and non-public) is likely to increase from 9 TWh in 2021 to 165 TWh in 2030. This 165 TWh represents 6% of the expected EU-27 electricity consumption in 2030. The total of 165 TWh can be split into 113 TWh for cars, 23 TWh for light commercial vehicles, 26 TWh for trucks and 3 TWh for busses.

There have also been studies for the Netherlands. Netbeheer has done a study on the electricity needs for e-mobility under four different scenarios. In these different scenarios the electricity needed for e-mobility ranged from 27.5 TWh to 33.2 TWh. In 2021 this was 1.7-8 Petajoule which is between 0.5-2.2 TWh (source: **energieinnederland**). These numbers include all forms of mobility. E-mobility is most likely concentrated in road transport. This report was published in April 2021 so they don't include the Fit-55 targets (source **Het energiesysteem van de toekomst**). According to a study of Elaadnl (2022) the Netherlands needs an additional 16.7 TWh of electricity to accommodate the electric van and truck fleets by 2050 (15% of the current national consumption). This is based on a charging strategy of mostly through overnight depot charging (85% of the fleet demand) but also including public charging (15% of the fleet demand). To meet this considerably higher energy demand there needs to be large investments into the charging infrastructure to build extra capacity. The Dutch government has set aside 22bn euro for infrastructure (hydrogen, heating, charging infrastructure) in the Coalition Agreement for the coming 10 years. A research paper and a report from Netbeheer show that the investment needs are substantially more.

Investments needed to support for e-mobility

According to **European EV Charging Infrastructure Masterplan** for EU27 approximately 280 bn euro needs to be invested by 2030 in installing charging points (hardware and labor), upgrading the power grid and building the capacity for renewable energy production for EV charging. Meanwhile, a total investment of approximately 1,000 bn euro by 2050 in infrastructure is needed. This includes public and non-public charging points. To support the development of e-mobility and the rollout of electric vehicle charging infrastructure (EVCI), grid reinforcements will be necessary before connecting the chargers to the electricity networks.

The whole electricity network consists of transmission and distribution. The first is carrying high voltage electricity from power plant to a sub-station. The latter is carrying medium- and low-voltage electricity from substations to end consumers. Only the distribution systems are likely to be upgraded due to e-mobility. The most common upgrades will be transformer upgrades, modifications and network extensions at low-voltage grid, which is where the slow chargers will be connected. This is where peak power issues will be most critical and the largest congestion is expected. The expected cumulative investment into grid upgrades for EV between 2021 and 2030 have been calculated as 41 bn euro, 11% of the total annual investments of 363 bn euro in distribution system operator. The total of 363 bn euro includes investments into generic updates, electrification of buildings and houses, renewable energy generation systems and electrification of mobility. 75% of the investments (around 30 bn) are related to the upgrades of lines and transformers. The remaining 25% of investments are related to public fast chargers connected to the medium-voltage grid.

The lead time and costs for cables and substations depend on the type of cable and the type of station. The lead time could be 1 to 7 seven years according to Netbeheer Nederland (source **Basisdocument over energie infrastructuur oktober 2019**). For example the low voltage cable has a lead time of 6 months to 1 year and medium to low voltage station also has the same lead time. According to Netbeheer 12,000-15,000 stations need to be expanded, 8,000-12,000 stations need to be added and 61,000-83,000 km of cables need to be added. This depends on the different scenarios. Most of that expansion and additions in stations are medium to low voltage stations. Roughly half of these are low voltage cables and half medium voltage cables (source **Het energiesysteem van de toekomst**). This report is from April 2021 so the numbers have not been updated yet considering the Fit-55 targets. Nationale Agenda Laadinfrastructuur (NAL) has indicated that the logistics sector in the Netherlands needs to consider 625 mln euro of investments by 2030 to have the charging infrastructure on own premises. These are the capital expenditures. The operational costs for the charging infrastructure amount to 1.1 bn euro until 2030. A look ahead to 2050 shows that in that case an investment of 5.2 bn euro will be required for the charging infrastructure, with associated operational costs of an estimated 7.8 bn euro. (source **NAL**).

Challenges for fuel cell battery electric vehicles

Fuel Cell battery electric vehicle

There are several ways to reduce emissions from vehicles. In the previous section we focussed on battery electric vehicles and their challenges. In this section we focus on fuel cell electric vehicles (FCEV). Fuel cell electric vehicles use a fuel cell instead of a battery. There are advantages to fuel cell battery electric vehicles compared to their battery-electric counterparts. These vehicle has proton-exchange membrane fuel cell that uses compressed hydrogen as a fuel and converts it into electricity. Hydrogen pressured at 350 bar (H35) bar is for heavy-duty vehicles and at 700 bar (H70) for light duty vehicles. The refuelling time and energy density of hydrogen is close to that of diesel that is currently used. A fuel-cell heavy truck would weigh more than a diesel one, but a battery-electric one would weigh much more than either of those. The volume of the hydrogen tanks is significant, but you don't have your diesel tanks and the large engine is replaced by a fuel cell. But this technology/solution also has major challenges which we will focus on below.

Refuelling infrastructure challenge

A fuel cell battery electric vehicle is refuelled at a hydrogen refuelling station or HRS. Light-duty fuel-cell vehicles have a 5-minute fuelling rate for filling 4 to 6 kilograms (or 8.8 pounds to 13.2) of onboard storage of hydrogen at about 1 kilogram per minute. 1 kg of hydrogen will allow you to travel 97 to 100 km. At that 10-minute rate, Class A fuel-cell trucks (very large truck) would have enough hydrogen fuel stored to travel within a 1,100- to 1,600-km range (source **hydrogen-central.com**).

At the end of 2021, about 730 HRSs were dispensing fuel at 350 and/or 700 bars to 880 heavy-duty trucks, 3,600 medium-duty trucks, 4,700 buses and around 42,000 cars (source IEA). Over 4,600 HRSs would need to be installed by 2030 in the NZE Scenario to support the growing fleet of heavy-duty fuel cell trucks, assuming an average nameplate capacity of over 2.5 tonnes per day (source IEA). At the end of 2022, 814 hydrogen refuelling stations were in operation worldwide. Concrete plans are already in place for 315 additional refuelling station locations. Europe had 254 hydrogen stations at year end, 105 of which are in Germany. France is still second in Europe with 44 operating stations, followed by the UK (source **hydrogen-central.com**). The Netherlands has 10-15 HRSs depending on the source.

The costs to build a Hydrogen Refuelling Station depends on how the hydrogen is delivered (gas, liquid or produced onsite). The former is the cheapest HRS while the latter is the most expensive one. The exact costs vary widely. The lead-time is often several years. According to the **International Council of Clean Transportation** the average costs at-the-pump price for onsite renewable hydrogen was11 euros per kg in 2020. This is a mid-level scenario and this includes the hydrogen production cost and the fuelling station cost. A light duty vehicle needs between 4-6 kg hydrogen so this will translate into 44-66 euro. The costs would be 7 euros in 2030 and 5 euros in 2050. The optimistic scenario has of course lower prices. The EU aims for a price of green hydrogen below 2 euros per kg by 2030.

Efficiency challenge

Fuel cell battery electric vehicles are less efficient than battery electric vehicles. According to McKinsey the efficiency of a fuel cell battery electric vehicle is 50% while that of a battery electric vehicle 75-85%. The efficiency of a battery electric vehicle is defined by how much electricity a car uses to travel a set distance. Another study shows an even larger difference. According to other sources the overall efficiency rate of an battery electric car is between 70-90% while that of a hydrogen car 25-30% is. 45% of the energy is already lost during the production of hydrogen through electrolysis. Of the remaining 55% another 55% is lost when converting hydrogen into electricity within the vehicle. This is based on the use of renewable electricity.

Limited supply of low-emission hydrogen

Today the production of hydrogen is primary based on fossil fuel technologies. Low emission production represented less than 1% of total hydrogen production. Low emission hydrogen is hydrogen produced via electricity and hydrogen produced via fossil fuels with CCUS. According to IEA in the net zero scenario low-emission hydrogen production accounts for 95 Mt, more than half of global hydrogen production by 2030.

Challenges for ICE vehicles fuelled by synthetic fuels

Internal combustion engine vehicles fuelled with synthetic fuels

There are several ways to reduce emissions from vehicles. In the previous sections we discussed the use of zero emission vehicles: battery electric or fuel cell electric vehicles. In this section we focus on the use of synthetic fuels in vehicles with internal combustion engines. Synthetic fuels could be blended with fossil fuels or replace fossil fuels. The current fuelling infrastructure could be used. But synthetic fuels also have challenges as we explain below. We mainly focus on e-fuels.

Total cost of ownership and price challenge

The total costs of ownership for the internal combustion engine car fuelled by synthetic fuels appears to be higher than a battery electric car. Taking the total cost of ownership (TCO) into account, running a car on e-fuels over five years will cost a driver EUR 10,000 more than running a battery electric car. High e-fuel costs will also make running second-hand cars on e-petrol around EUR 10,000 more expensive over the same timeframe (source **Transport & Environment**). But the price estimates for a litre of e-fuels vary widely. This is because the views of different stakeholders are far apart. On the one hand the eFuel Alliance says that the production costs for one litre of eFuel in 2025 with a 4% blending rate with conventional fuels are estimated to be between EUR 1.61 and EUR 1.99. By 2050 they may decrease from anywhere between EUR 0.70 to EUR 1.33 per litre of eFuel with a 100% blending rate. Some are even more optimistic. On the other side of the spectrum are the estimates of the ICCT or Internal Council on Clean Transportation. It states that significant volumes of renewable e-fuels won't be made for less than 3 or 4 Euros per litre in 2030 (source **ICCT**). No one's making e-fuel at commercial scale today, but doing so would probably cost around $7 a litre, according to Stephanie Searle, director of ICCT's Fuels Program. So to make e-fuels a viable solution from price point of view, prices have to come down significantly. A lower price will also result in a lower cost of ownership.

Efficiency challenge

E-fuels are the least efficient technology for road transport. According to ICCT 48% of the energy from renewable electricity is lost in the conversion to liquid fuels. To compound the problem, according to various studies 70% of the energy in those fuels will be lost when they are combusted in internal combustion engines. All together the total efficiency for the e-fuels pathway for road transport is around 16%. This compares to a 72% efficiency for a battery electric car where the battery is charged by solar panels. Third, manufacturing e-fuels is very expensive and energy-intensive. Using e-fuels in an internal combustion car requires about five times more renewable electricity that running a battery-electric vehicle, according to a paper in the Nature Climate Change journal.

The zero-emissions challenge

Synthetic fuels could be low carbon or carbon neutral. Low carbon fuels could emit up to 90% less CO2 during the life cycle than fossil fuels but this depends of what feedstock is used and the blend-in rates. Carbon-neutral fuels are fuels where during the production process the carbon is captured from the atmosphere and the same carbon is released during burning the fuel. However, the production process also needs to be done with renewable energy to qualify them as green. Are they also net zero greenhouse gas emissions? This is not the case. Cars powered by synthetic fuel emit as much poisonous nitrogen oxides (NOx) as fossil fuel engines, independent emissions testing shows. In a laboratory, research organisation IFP Energies Nouvelles compared for Transport & Environment the emissions from a car using petrol and three different blends of e-petrol. The car running on e-petrol emits equally high levels of toxic NOx as standard E10 (source **Transport & environment**).

Availability challenge

The availability of e-fuels is limited. This is because there is currently limited production capacity of e-fuels. Of course this can be built but this takes time. The eFuel Alliance sees gradually increasing synthetic admixture to conventional fossil fuels rather than an immediate swap. This would alleviate the slow initial supply, but the expectation is for just 4% admixture by 2025, 12% by 2030, and only 100% by 2050. Low levels of production mean that e-Fuels will only be able to cover around 2% of the EU's vehicle fleet by 2035, a new study concludes; just 5 million cars out of the EU's fleet of 287 million could fully run on synthetic fuel in 2035 (source Transport & Environment).

Conclusions

Which technology is viable or suitable for which subsector in road mobility? Lithium-ion batteries are a viable solution for personal cars, vans and city buses but less so for heavy duty vehicles (because of weight, range, infrastructure and grid adjustments). But the investments in infrastructure and grid adjustments are crucial. Lithium-ion technology is more efficient than fuel cells fuelled by hydrogen. Fuel cells fuelled with hydrogen are a viable solution for heavy duty vehicles. But the infrastructure is the main challenge.

Meanwhile synthetic fuels can be used in all subsectors of mobility (with internal combustion engines). While existing infrastructure and engines of fossil fuels can be used, e-fuels need to be produced from renewable energy in order to qualify as green. In addition it can partly solve some of the challenges with battery electric vehicles and fuel cell electric vehicles. However synthetic fuels are the least efficient technology, manufacture is very expensive and energy-intensive, are only available in limited quantities and not all synthetic fuels are carbon neutral or zero-carbon. Despite this the they could play an important role in the transition to reduce emissions. If future technological developments result in a less expensive, less energy-intensive mass-production of synthetic fuels and improve the efficiency of synthetic fuels, they could be used on a wider scale and also in cars.

So there are numerous challenges to the technologies/solutions to reduce emissions by road transport as indicated above. Therefore reaching the ambitious European and Dutch targets may prove to be difficult. It is a chicken and egg story. Without the infrastructure (battery electric and fuel cell electric vehicles) and/or substantial production (synthetic fuels) vehicles will not be able to reduce the needed emissions.

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