

Options for climate-neutral mobility in 2050

What if...?

Road transport is to become independent of fossil fuels. But how will this be implemented, and what will it cost? Focusing on three scenarios, the “Defossilizing the Transportation Sector” study conducted by the Research Association for Combustion Engines (FVV) provides a basis for informed discussion.

Text: Johannes Winterhagen

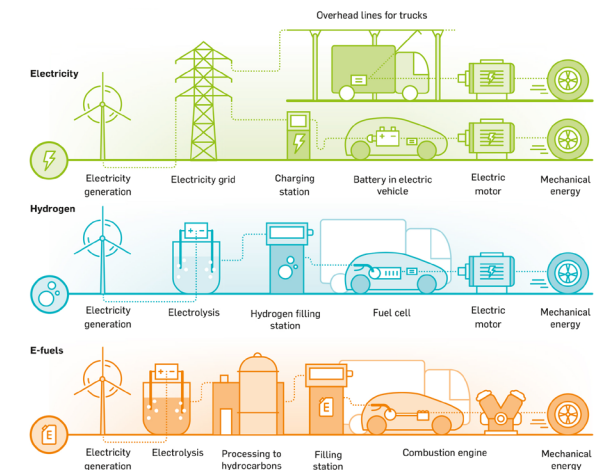
To ensure the global average temperature does not increase by more than two degrees Celsius by the end of the 21st century, current scientific research has shown that a total of 1100 billion tonnes of CO₂* can still enter the atmosphere – not a huge amount considering that current annual emissions total more than 40 billion tonnes. As such, the transport sector, which is currently still almost completely dependent on fossil fuels, is facing a huge challenge. While it should continue to provide prosperity, it must also become climate-neutral in a relatively short time.

Three paths, one destination

In the foreseeable future, electricity generated primarily from solar and wind energy will be available as a climate-neutral energy source. There are three paths which enable this electricity to be utilized in road transport.

- The electricity is distributed across a charging infrastructure, stored directly in batteries in vehicles and converted to kinetic energy via an electric drivetrain.
- Hydrogen is generated from the electricity via electrolysis, which in turn generates electricity for the electric powertrain in a fuel cell on board the vehicle.
- The hydrogen is enriched with carbon through chemical processing, resulting in the generation of gaseous or liquid fuels that can be used in combustion engines.

In the “Defossilizing the Transportation Sector” study, a working group at FVV analysed the three paths that are technically feasible with regard to the economic costs to be expected. At times, over 40 experts from different sectors were involved in precisely calculating the engineering basis for these costs – such as the efficiency of specific powertrains or possible loads in the power grid. To keep results comparable, the working group decided to solely analyse scenarios in which a single energy source could cover 100% of the demand. The required amount of kinetic energy in road transport – i.e. the energy at the wheel – was kept consistent at 143 terawatt hours per year for all three scenarios.



The electric pathway

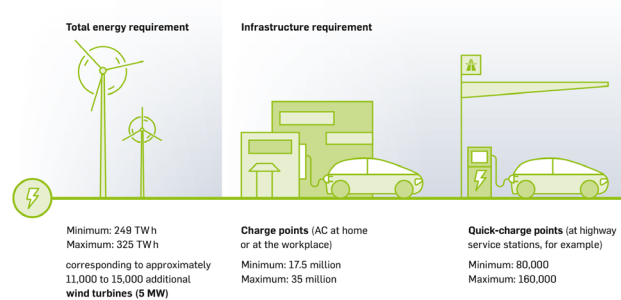
No surprise here: the direct use of electrical energy results in the greatest efficiency. As such, only between 249 and 325 terawatt hours of electricity must be generated in order to maintain our current level of mobility. This equates to the average annual yield of 11,000 to 15,000 offshore wind turbines in the 5 megawatt class in the North Sea. However, it does not take into consideration the energy required to heat the interior – energy which is generated as waste heat in combustion engine applications. Experts in the FVV working group also assume that the availability of charge electricity during dark periods (times without sun radiation and wind) can only be ensured in a cli-

Options for climate-neutral mobility in 2050

What if...?

mate-neutral manner via reconversion of sustainably generated energy sources (e.g. synthetic methane in a gas power plant).

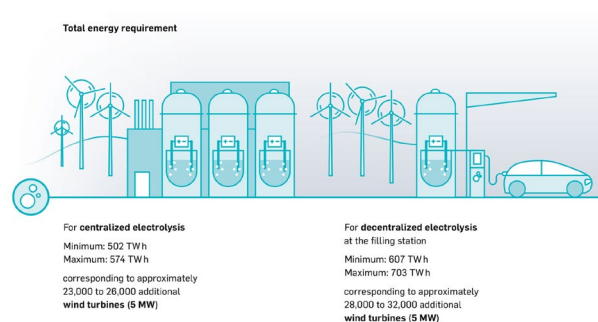
The economic investment required for a 100% electric scenario is determined by the infrastructure for electricity distribution and charging. The core question for the distribution networks is how far time-controlled charging can compensate for the network expansion. The investment requirements for car traffic are between 0 and 77 billion euros. This is joined by costs for the required AC charge points at home and at work, as well as the quick charge stations on motorways. Experts expect to see a hybrid solution for lorries which combines overhead power lines on motorways with high-performance batteries for all other routes. The infrastructure required here will cost up to 21 billion euros.



The electric pathway

The hydrogen pathway

Bigger means more efficient. This applies both to engines and to electrolysis systems in which sun and wind energy are used to manufacture hydrogen. However, alongside the large-scale manufacturing analysed in the study, a local hydrogen generation structure was also observed, for which the “transport costs” are mainly generated through the expansion of the electricity networks. Initial findings showed that the efficiency advantages of centralised generation are significant. The electricity requirements are between 502 and 574 terawatt hours, which can increase up to 703 terawatt hours in a local structure. Furthermore, decentralised (local) generation requires the corresponding expansion of the electricity network, which can cost up to 90 billion euros.



The hydrogen pathway

According to experts, between 5,000 and 10,000 hydrogen filling stations, each with eight filling points, should be sufficient to guarantee complete mobility with fuel cell vehicles in Germany. Investment costs of more than three million euros are to be expected for a single filling station with eight filling points, each capable of charging at least six vehicles per hour.

The synthetic fuels pathway

There is no such thing as ‘the’ synthetic fuel. As there are multiple methods available to enrich regeneratively created hydrogen with carbon, the experts from the FVV working group analysed a total of seven fuels in eight scenarios. An important factor for overall efficiency beyond the manufacturing process is how the carbon is generated. In the long term, the only conceivable method in a climate-neutral world is to separate it from the air, which requires additional energy and costs. In a transitional period, however, using CO₂ from industrial processes is a viable option. The study shows that synthetic methane can be produced with an efficiency of 65% in this manner. The worst overall efficiency is found in the production of OME when coupled to CO₂ separation from the air, at just 31%. In the best-case scenario, this results in additional required electricity generation of 625 terawatt hours – a figure which is 2.5 times higher than the electricity require-

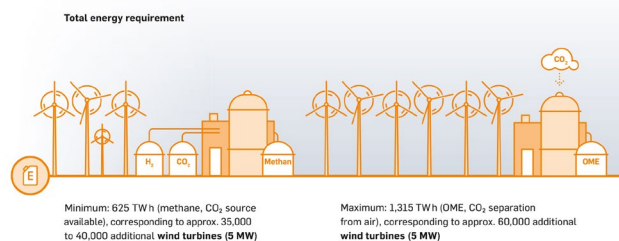
Options for climate-neutral mobility in 2050

What if...?

ments in the purely electric scenario.

The combustion engine as an energy converter has a decisive impact on the energy balance of synthetic fuels. The study was based on the fuel consumption from the best current passenger car and truck engines. Further potential for improvement – such as the “admixing” of electricity in hybrid powertrains – was not considered..

Navigation aid



The synthetic fuels pathway

In reality, 100% scenarios are neither useful nor desirable. The results from the FVV study, which are sound from an engineering standpoint, provide different indicators for the design of future energy and traffic policies, as well as the respective research funding. The most important findings from the study include the following:

1. Cost equilibrium between the energy sources

Taking the least expensive scenario as the basis in each case, the route-related mobility costs are almost equal as long as cost parity can be achieved between a passenger car with a combustion engine (diesel), battery-electric drive and fuel cells. The minimum costs in the electric scenario are 29.4 cents per kilometre, while the best value achieved by hydrogen is 29.9 cents per kilometre. The least expensive synthetic fuel is synthetic methane at 28.4 cents per kilometre.

2. Acquisition costs dominate overall costs

From a purchasing standpoint, the total costs alone are decisive. These comprise many factors not considered in the study, such as taxes and insurance premiums. When the usual depreciation is applied, the acquisition costs and not the price for energy sources dominate the total costs. When converted to individu-

al users, the costs for the establishment and expansion of the infrastructure are almost negligible for synthetic fuels, but not when battery-electric vehicles are used.

3. Significant investment required

From an economic standpoint, however, significant investments are required. They vary from 270 billion euros for the least expensive scenario (synthetic methane) to at least 360 billion euros for 100% electric, and at least 380 billion euros for 100% hydrogen. The calculations are based on the year 2050, with costs being significantly higher in the beginning. The greatest risks are found for the hydrogen scenario with decentralised generation.

	1 Investment costs for electricity generation	2 Investment costs for fuel production	3 Investment costs for infrastructure	4 Cumulative additional vehicle costs (20 years)
100% electric	€ 110–260 bn	0	€ 40–200 bn	€ 160–770 bn (car) € 50–90 bn (truck)
100% hydrogen	€ 90–340 bn (central) € 270–570 bn (local)	€ 70–90 bn (central) € 60–70 bn (local)	€ 20–40 bn (central) € 20–130 bn (local)	€ 160–850 bn (car) € 40–125 bn (truck)
100% e-fuels	€ 140–780 bn	€ 100–250 bn	€ 0–6 bn	€ 0–230 bn

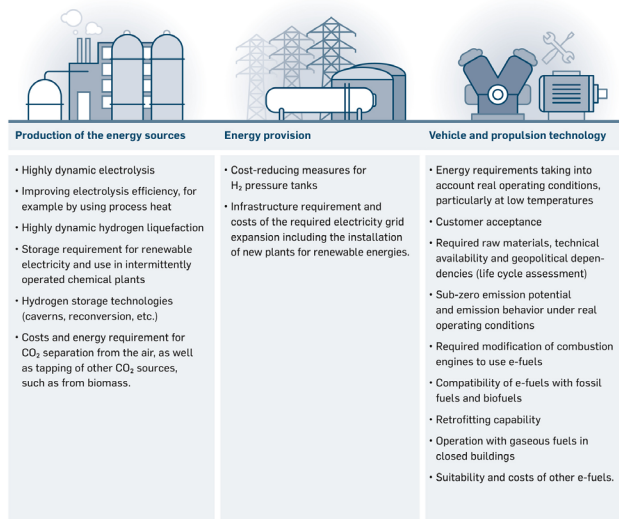
Investment requirements

Options for climate-neutral mobility in 2050

What if...?

4. Technology-neutral research is useful

The experts involved in the study calculated the costs and efficiency based on the technology available today. However, as the work progressed, it became apparent that there is significant potential for further development in several areas, such as the efficiency of electrolytic hydrogen generation during fluctuating electricity loads. However, as the economic optimum will probably only be achieved through hybrid scenarios, it would appear sensible to promote research which is open to a wide range of technologies.



5. Technology-neutral legislation would make sense

According to the experts, the key to developing energy paths for a largely greenhouse gas-neutral and environmentally friendly transportation system lies in energy generation, not in the vehicle itself. Finding the best powertrain mix, with which individual mobility requirements can be fulfilled in passenger and goods transport, requires technology-neutral conditions. Legislators in Germany and Europe should therefore ensure that the industry has enough room for a wide variety of innovations.

** Note: To improve comprehensibility, this text refers solely to CO₂. As other gases also increase the greenhouse effect, their impact on the climate is generally converted to CO₂ equivalents.*

FVV | What if...?

Research Association for Combustion Engines (FVV) eV
 Lyoner Strasse 18
 60528 Frankfurt / M., Germany
 T +49 69 6603 1876
 F +49 69 6603 2876
 smieja@fvv-net.de

→ www.primemovers.de/en | Science

→ Copyright: FVV