Climate neutrality for 1.3 billion cars and trucks: it won't work without e-fuels

Introduction

Around 2050, there will be about ten billion people on earth, two billion more than today. For this reason alone, the demand for energy will continue to rise. Global Energy Solutions (GES) addresses the question of whether and, if so, how these ten billion people will be able to live in freedom and prosperity. This is a core concern of the Sustainable Development Goals (SDGs), which are also comprising other goals, such as overcoming poverty, preserving biodiversity and stabilising the climate system. Our climate protection considerations are based in particular on the avoidance costs of CO_2: How much does it cost to save, avoid or remove one tonne of CO_2 from the atmosphere? Ultimately, we always think globally. It is crucial to rapidly reduce the concentration of CO_2 (and of other climate gases) in the atmosphere - in particular to prevent the ecosystems from crossing tipping points and thus a climate catastrophe. GES considers itself as a technology and results open think tank. One focus of our work is on renewably produced fuels (re-fuels). These include biomass-based fuels (bio-fuels) and electricity-based (e-fuels). It is already foreseeable that e-fuels will play a decisive role in solving climate and energy issues.

What are e-fuels?

E-fuels are renewably produced fuels that can be generated with the help of electricity and used like fossil fuels. The production process of e-fuels is called "power-to-X". "Power" stands for electricity, "X" for petrol, diesel or paraffin. E-fuels can be cost-effectively stored, transported and blended with fossil fuels to ultimately replace them. The existing energy and mobility infrastructure can continue to be used. This includes pipelines, tankers, petrol stations, as well as aircraft, ships and, last but not least, the world's existing fleet of cars and trucks. Many existing heating systems can also be operated with renewable energy sources. A global energy turnaround that would involve "doing everything from scratch" appears beyond all reality.

A universal building block of any green energy transition is hydrogen, which can be burnt without emissions. However, its transport over long distances is costly. This is where e-fuels come into play, as electricity-based carbon-hydrogen or nitrogen-hydrogen compounds. Ammonia, for example, contains no carbon. It is well suited as an energy carrier, also as a fuel for ships. Ammonia becomes liquid at minus 33 °C degrees, so it has to be cooled for transport. The nitrogen oxides produced during the combustion of ammonia must be removed catalytically, which is state of the art. Conventionally produced ammonia (mostly from natural gas) is a basic raw material in the chemical and fertiliser industries. However, the future belongs to "green" ammonia produced with renewable electricity from hydrogen and atmospheric nitrogen. GES considers the production of e-fuels - with the exception of ammonia - from blue hydrogen to be of little use. In such a case, CO_2 would first be captured (through CCS) to be added back from another source. This makes little sense.

Methanol is one of the most produced organic chemicals, with over 100 million tonnes per year, so far almost exclusively from fossil sources. Methanol can be burned directly in engines in certain percentages without the need for major adaptations. In China, M15 is widely used, i.e. a 15-percent admixture of (fossil-produced) methanol to petrol. Unlike ammonia, methanol exists in liquid form under standard room temperature and pressure. To fuel conventional vehicles, it can be processed into "petroleum-like" petrol, diesel or paraffin. This is also state of the art. Regenerative methanol is produced from hydrogen and CO_2. In order to make methanol climate-neutral, the CO_2 released during combustion must be recycled or stored. An intermediate step is the multiple use of CO_2 by capturing it from a fossil-fueled point source, e.g. a coal-fired power plant, and further using it for methanol.

Among the renewably produced fuels, there are not only e-fuels but also biomass-based fuels (e.g. from maize or from waste such as straw, liquid manure or waste wood), in short: bio-fuels. Both groups of materials can be produced in a climate-neutral way. Bio-fuels are comparable to e-fuels in their application and properties and will be dealt with by GES in a separate position paper.

Who needs e-fuels?

There is no way around e-fuels in the decarbonisation of aviation in the foreseeable future. Batteries are too heavy and the use of hydrogen is still under development. The addition of Sustainable Aviation Fuels (SAF), on the other hand, brings immediate relief for the climate. Accordingly, the EU Parliament is calling for an initial SAF quota of 2 percent by 2025 and as much as 85 percent by 2050.

In shipping, too, there is no alternative to e-fuels in sight. The promising candidates in the race for the ship propulsion of the future are ammonia and methanol, and as an intermediate step LNG instead of heavy fuel oil. Ammonia can be used directly in appropriately designed ship engines. It does not contain any carbon, but it is toxic and during combustion nitrogen oxides are produced, for which exhaust gas purification is needed. Green ammonia is currently booming; probably the largest production plant is being built in Neom in Saudi Arabia. Methanol, on the other hand, contains carbon that would have to be recirculated, but is otherwise considered environmentally friendly and easier to handle. Waterfront Shipping, the shipping company of the largest methanol producer Methanex, has been operating seven methanol-powered ships for several years. The largest shipping company in the world, Maersk from Denmark, has recently ordered eight container freighters with a capacity of about 16,000 standard containers each with methanol propulsion. The Norwegian supply ship Viking Energy will be the first ship worldwide to be equipped with ammonia propulsion (via fuel cell). The Japanese shipping company Mitsui O.S.K. Lines is also working on ammonia-powered sea-going vessels. However, the use of ammonia for ship propulsion still requires several years of development work.

For vehicles, there are alternatives to e-fuels, first and foremost battery electric vehicles (BEVs). Leading car manufacturers have committed themselves to this technology, for example Volkswagen. Moreover, electric mobility is heavily subsidised in many countries. With electric cars, apart from particulate matter, there are no local emissions, which is particularly advantageous in cities. Electromobility is likely to catch on in parts of the world. Questions remain: What will power millions of trucks as batteries appear too heavy for long distances? Where will the large amounts of green traction current come from? What about the charging infrastructure and upgrading the grid to transport the huge amounts of electricity? Who in the world can afford electric cars, and who cannot? Last but not least: What happens to the existing, and still rising, fleet of over 1.3 billion combustion vehicles in the world?

Emissions from the existing fleet account for 12 percent (7 percent cars, 5 percent buses and trucks) of global CO_2 emissions and are above 5 billion tonnes of CO_2 per year. In addition, shipping and aviation each account for 2 percent of CO_2 emissions. This results in a total of 16 percent for the transport sector. The figures show in particular the great importance of vehicles with combustion engines in the climate debate: their emissions are higher by a factor of 3 than those of ships and aircraft together.

From 2035, only new cars that do not emit greenhouse gases are to be sold in the European Union. Electric cars are set, but the use of e-fuels is also being examined. Openness to technology is important, especially for the European automotive industry, which also has to position itself globally. Because this much is clear: a complete and worldwide electrification of cars and trucks is unrealistic. For example, building a charging infrastructure and the necessary power grid is simply unthinkable on a continent like Africa, where 600 million people still have no access to electricity. Financial support for the purchase of an electric vehicle, as is done in Germany, for example, is not an option given the poverty of African countries. The reality is that many end-of-life vehicles from rich countries are shipped to Africa, where they continue to be driven until it is no longer possible. Moreover, the population in Africa will double again by 2050, to 2.5 billion people. At the same time, construction is taking place on a gigantic scale. This requires transport capacities, robust, strong and cheap trucks or construction vehicles. Should an African free trade zone become reality, the UN expects, for example, another 2.4 million trucks in Africa by 2030. Railway lines are also often not electrified in emerging and developing countries. In all these cases, e-fuels can help.

Are e-fuels climate neutral?

There are three ways to achieve climate-neutral e-fuels. Firstly, if the CO_2 used is extracted from the air by means of Direct Air Capture (DAC) (removal). Secondly, if the CO_2 is of biogenic origin, for example from a wood chip or biogas plant. In these two cases, the CO_2 comes directly (DAC) or indirectly (in the case of biomass through natural photosynthesis) from the atmosphere (removal). A closed carbon cycle is created because only as much CO_2 is released again as was previously captured. Thirdly, if the CO_2 used for the e-fuels comes from coal-fired power plants, steel mills, cement plants or other fossil point sources (reduction). In this case, the carbon must be compensated for complete climate neutrality via nature-based solutions (reforestation, humus formation in agriculture) or via direct air capture with subsequent storage of the CO_2, also in the form of mineralisation. Clean accounting is necessary for this.

The atmosphere contains CO_2 only in small quantities (currently 420 parts per million). Whereas in point sources, for example at the smokestack of a coal-fired power plant, it is present in high concentrations, around 10 per cent or above, i.e. more than 200 times higher in relation to the atmosphere. This is why CO_2 from point sources is also significantly cheaper as a raw material for e-fuels. However, the costs for nature-based solutions or the final storage of the CO_2 are to be added to ensure climate neutrality.

More than 80 per cent of the energy used worldwide (still) comes from fossil sources. Amongst these emissions from coal-fired power plants (around 10 billion tonnes per year) are of outstanding importance. Overall, people will continue to use fossil fuels for a very long time. If we want to solve the climate problem and enable the developing and newly industrialised countries to achieve the development that is demanded and granted, we cannot disregard the fossil sources of CO_2 - but must make them as harmless as possible (CCS) or use them (CCU). And time is of the essence. Nature-based solutions have a special significance in this context.

There is another option to produce e-fuels, namely with CO_2 from fossil point sources without compensation. In this case, the e-fuel would not be climate-neutral. But emissions would be reduced by about 50 percent because the CO2 would be used twice, once in the power plant, another time in the vehicle. E-fuel would replace petrol, diesel or paraffin from fossil sources. This process could be seen as a first step leading to a significant reduction in CO_2 emissions.

Do pollutants arise during the combustion of e-fuels?

Yes, for example nitrogen oxides when ammonia is burnt, which have to be captured by a denitrification system. However, methanol-based e-fuels allow better combustion than fossil fuels because a short-chain hydrocarbon such as methanol burns particularly cleanly. An admixture of 15 percent methanol to petrol (M15) leads to a more than 30 percent reduction of unburned hydrocarbons in the exhaust gas. Generally speaking, modern combustion engines are much cleaner than they were 10 or 20 years ago. This applies to residual hydrocarbons, carbon monoxide, sulphur dioxide and nitrogen oxides. And according to figures from Robert Bosch, further optimisation is possible. One issue that affects electric cars just as much as vehicles with combustion engines is particulate matter, for example from abrasion of brakes. Electric cars are particularly affected because they are heavier, due to the battery. It is possible to further reduce pollutant emissions, but one should weigh the cost issue and the limitedness of financial resources against the improvements that can be achieved.

How efficient are e-fuels?

Fossil fuels are converted into kinetic energy in a car with a combustion engine with a technical efficiency of 25 to 40 percent. The electricity refuelled by the electric car, on the other hand, is used with an efficiency of 60 to 80 per cent. However, this isolated view (tank to wheel) is misleading. What is decisive are the emissions and costs per kilometer driven or tonne transported.

Therefore, a holistic system comparison of electric cars must also take into account electricity generation, battery production, transport, conversion, storage and the construction of the charging and filling station infrastructure.

In the case of e-fuels, the following must be considered: in addition to process efficiency and the production of the fuel, the possible operating hours of the wind or solar plants also play an important role in terms of economic efficiency. In general, the higher the full load hours achieved, the more suitable a location is for renewable power generation. Therefore, coastal locations along the earth's sunbelt are often particularly attractive because they can use wind energy in addition to solar energy. The electricity yield of PV systems in sun deserts is two to three times higher than in Central Europe. This is a massive inefficiency, but it is usually ignored in the discussion. In the end, and viewed holistically, the economic efficiency of electric cars and internal combustion vehicles amounts to similar ratios in an international comparison.

E-fuels have an advantage. In terms of climate, they have an immediate effect - the higher the admixture to conventional fuels, the better. Electric cars, on the other hand, start with a heavy mortgage, because the production of the battery is extremely energy-intensive, generating considerable CO_2 emissions. In addition, the production conditions of the traction current and the associated emissions play an important role. Electromobility also requires critical raw materials such as lithium or cobalt. And in the long term, it will definitely be necessary to set up a recycling chain for the batteries. In contrast, the use of e-fuels saves the enormous costs of converting the infrastructure and replacing the existing vehicle fleet. That, too, is efficiency!

Ultimately, the decisive factor is the avoidance costs, i.e. the amount of money that has to be invested in plants and their operation in order to avoid one tonne of CO_2. Measured against this, e-fuels are definitely competitive. It is not the technical efficiency that matters, but the economic efficiency: how much fuel can be produced at what cost.

How expensive are e-fuels?

The biggest cost in generating e-fuels is the low-CO_2 electricity needed to produce hydrogen. Technical progress is helping here. In recent years, the cost of photovoltaic systems has dropped significantly. A kilowatt hour of electricity generated in solar deserts costs at best about 1 to 2 cents. However, these low prices for low-CO_2 electricity from solar and also wind power plants can only be achieved in suitable places on earth - no chance in Central Europe.

Another cost factor for the production of methanol is CO_2. One tonne captured at a cement plant costs about 70 euros. In contrast, a tonne produced with direct air capture is currently about ten times as expensive. In the long term, these costs can perhaps be halved. For the foreseeable future, one should therefore rely on fossil (point) sources in many cases and combine them as comprehensively as possible with nature-based solutions.

Currently, e-fuel costs about twice as much as a comparable amount of energy fossil fuel. But with larger production volumes, good location conditions and falling electricity prices, fuels produced in this way can become significantly cheaper than they are today. However, this requires billions of dollars of investment in production facilities. Optimistic forecasts assume that costs for e-fuels of 1 to 2 euros per liter are achievable, excluding taxes. Transport costs only account for a few cents of this.

When will it happen? Studies that analyse the price development of green hydrogen can serve as a point of reference. According to these studies, green hydrogen (which today costs around 5 US dollars per kilogram) could be competitive with fossil hydrogen (1.5 to 2 US dollars per kilogram; 2021 prices) around the year 2030.

Are there enough e-fuels?

Those who want to buy e-fuels at the moment are usually disappointed. There are only small pilot plants for research and development. Compared to conventional fuels, prices are therefore still high. The Haru Oni e-fuel project in southern Chile, which is probably the most advanced, will start (test) operation at the end of 2022. If e-fuels are to make a contribution to solving the climate crisis, production capacities would have to be expanded enormously in the next 10 to 20 years with major investments.

The global energy demand of shipping and air transport is considerable, that of road transport even much greater: a total of about 28,000 terrawatt hours per year - almost all of it oil-based so far. If one wanted to meet this demand with renewable energy, one would first need low-CO_2 electricity and then - mostly via electrolysis - green hydrogen.

The Fraunhofer Institute has examined the potential for the production of electrolysis hydrogen from a global perspective. In the PTX Atlas, the institute calculates a possible production volume of 109,000 terrawatt hours outside Europe. If questions of investment security and infrastructure are taken into account, the production potential is reduced to about 69,000 terrawatt hours of hydrogen.

A sample calculation by GES shows that this could be quite sufficient in the future. We assume a demand for 32,000 terawatt hours of low-CO_2 electricity in 2040 to produce sufficient quantities of e-fuels. With an electrolyser capacity of 8000 gigawatt-hours, half of which (4000 hours per year) is utilised, 3.4 billion tonnes of methanol can be produced (together with the input of 4.7 billion tonnes of CO_2) - and from this in turn 1.7 billion tonnes of (methanol-) petrol. This would be more than enough for 1.3 billion vehicles with internal combustion engines (with a demand of about 1 tonne of fuel per vehicle and year).

But there is still a long way until then. The necessary plants still have to be built, especially electrolysers to produce hydrogen from electricity. Competing electrolysis technologies have various advantages and disadvantages. One possible bottleneck for the expansion of PEM electrolysis, for example, is a shortage of raw materials such as iridium and platinum. Both precious metals are largely corrosion-resistant and therefore excellently suited for the technology. In addition, there are numerous obstacles to scaling up the production of hydrogen: high electricity prices or the EU requirements to use 100 per cent green electricity. But also the availability of raw materials for production plants, a possibly low utilisation of the plants, insufficient quantities of water for electrolysis (especially cooling water), government regulations, transport costs, and the cross-border development and financing of complex novel business models. Only if these problems can be tackled simultaneously the ramp-up can succeed.

However, the ramp-up of electromobility also poses considerable problems. So far, electric vehicles are essentially niche products. If the share of the vehicle fleet is to be significantly increased, a new infrastructure must be created: for example, more charging points, as well as efficient and "smart" electricity grids. After all, very few customers have a PV system on the roof and a battery in the basement. Especially the new renewables, wind and solar power, are very volatile. And electricity can only be stored to a very limited extent. When the wind doesn't blow and the sun doesn't shine, backup power plants have to step in: the more electric cars, the more backup. In Germany, for example, you quickly reach the necessary reserve capacity which corresponds to the entire power plant capacity of today. Nationwide electromobility, even in rich countries like Germany, is therefore not only expensive, but also quickly comes up against technical and logistical limits.

The situation is different with e-fuels. By their very nature, they are chemical electricity storage devices (liquid electricity), and they are also easy to handle. A canister of petrol or e-fuel in the garage can already be helpful. In short, the storage function of e-fuels brings security of supply and stability to the energy system of the future. No different than fuel oil, petrol and diesel do today.

How can CO_2 from e-fuels be offset?

The natural carbon cycle includes not only CO_2 sinks in the oceans, but also on land. Forests, bogs, mangroves and the humus layer of the soil are part of it. Nature-based Solutions work according to this model of nature. When degraded areas in the tropics - of which there are 1 billion hectares alone - are reforested, carbon is stored in the biomass of the forest that is created again. When a tree is felled and burnt, the CO_2 stored (temporarily) in the wood escapes back into the atmosphere. When humus is formed in agriculture, carbon is stored over much longer periods of time. These connections and approaches are well researched. Scientists assume that there is a storage potential on the planet with Nature-based Solutions of about 10 billion tonnes of CO_2. In short, the approach works - if it is done seriously. Polemics such as "greenwashing" and "selling indulgences" are not only misleading in this context, they are wrong.

Nature-based solutions also work in practice. In 2018, the German Federal Ministry for Economic Cooperation and Development (BMZ) founded the Alliance for Development and Climate, now an independent foundation. The Alliance now has more than 800 supporters: Municipalities, federal states, sports clubs and, last but not least, large companies such as Deutsche Bank, Munich Re and SAP, but also Bosch, which as an industrial company has been climate neutral since 2020, and the world's largest logistics service provider in the field of sea freight, Kühne+Nagel. Among other things, they all focus on reforestation and forest conservation. In a voluntary market with certificates.

But the truth is also that the global forest areas as a whole are currently not carbon sinks, but sources! This is essentially due to the large-scale destruction of (rain) forest. The reason for the destruction of nature is almost always economic. Only economic means, in short: money, can help against this.

And this is where e-fuels come into play. The example calculation above talks about 4.7 billion CO_2 needed to supply the global fleet of cars and trucks with e-fuels. If one wanted to compensate for this amount of carbon and assumed a CO_2 price of 50 euros per tonne, one would arrive at an amount of 235 billion euros per year. This would make a liter of e-fuel less than 15 cents more expensive. In some cases, climate levies for the fuel would even be eliminated, for example in Europe.

If all vehicles with combustion engines were to be supplied with e-fuels in this way, every second coal-fired power plant in the world could be made climate neutral by means of CCU. This would work best if the methanol production were located close to the coal-fired power plant, thus reducing transport costs. The 235 billion euros mentioned above, which the rich countries would have to raise for the most part, would help the emerging and developing countries enormously, not only in saving the rainforest, but also in many other SDG goals, such as education or gender equality. And all this for 15 cents per liter. These 15 cents would also be the benchmark for the alternative solution path via direct air capture and storage of CO_2, for example in underground gas storage facilities or through mineralisation.

Conclusion

Mobility is a basic human need and an important prerequisite for value creation. In developing and emerging countries in particular, there is a great need to catch up over the coming decades. The mobility of people and goods will therefore increase, if only because of the growing number of people. It is therefore foreseeable that the current stock of 1.3 billion cars and commercial vehicles will continue to increase. The same applies to the use of aircraft and ships.

In order to achieve global climate neutrality, the emissions caused by the human need for transport must be made as climate neutral as possible. From today's perspective, aircraft and ships seem predestined for e-fuels. For the foreseeable future, alternative solutions that are economically viable are not apparent for them. This may be different in the future, as technical progress continues.

But the crucial question is: What will become of cars and trucks, and what will become of the huge existing fleet? Today, CO_2 emissions from this sector are about three times as high as those from shipping and aviation combined. That is why solutions for these sectors are so important; it is the only way to achieve a solution to the global climate problem at all.

Electric cars are already well developed, both in terms of technology and business models. E-fuels, on the other hand, are just starting to ramp up. Both approaches have their strengths; electric mobility scores points in inner-city traffic, for example.

The widespread introduction of electric mobility is already a challenge in rich countries. For developing countries, a significant share of electric cars is hardly conceivable. This may be different for e-scooters, which are often seen in India and China. Basically, it is impossible to electrify the global fleet of cars and trucks; already the limited availability of raw materials for the batteries is the reason why this is not possible.

And this is where e-fuels come into play. Mankind needs all sensible approaches to solve the climate problem, including mobility. The advantages are obvious: use of the existing infrastructure, easy handling and storage of energy and thus stabilisation of the future energy system. That is why GES advocates the greatest possible openness to technology.

It is scientifically proven that e-fuels can be produced on a large scale, that enough renewable energy, sufficient land and resources are available. The difficulties of ramping up e-fuels lie elsewhere: in the expansion of production capacities, for example of electrolysers, in the provision of capital, in the design of global supply chains, especially with emerging and developing countries, in regulation that recognises the climate neutrality of e-fuels and exempts them from climate levies, and last but not least in the financing of avoidance and compensation of CO_2, i.e.: CCUS and nature-based solutions.

A liter of e-fuel would become about 15 cents more expensive through the consistent application of nature-based solutions. And even if the rich North were to bear a large part of the costs, the expenditure would be remarkably low - measured against the task of the century to save the climate. We need an effective and rapid reduction of CO_2 (and other greenhouse gases) in the atmosphere. The goal is Net Zero.

Ultimately, we are talking about an energy transition on a global scale and e-fuels are an important building block in this process. The transition will take several decades. GES is convinced that it is feasible. However, the right steps have to be taken today. For e-fuels this means:

- Overcoming mental obstacles. In Germany, this mainly concerns CO_2 capture, i.e. CCS and CCU.
- Support the technology and business models of e-fuels. We not only need a hydrogen strategy, but also an e-fuel strategy.
- Recognise e-fuels as climate-neutral - and thus exempt them from the climate levy.
- Introduce a substantial blending quota of e-fuels also for cars and trucks - in order to accelerate the ramp-up.