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reFuels as necessary building block of a GHG-neutral mobility

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ABSTRACT

Talking to politicians, the future will be 100% electric. A rough overview of the development of vehicle sales, the size of the fleet and its rates of change shows that additional technologies are needed to achieve the climate targets demanded by the countries in Paris.Syntetic fuels from renewable sources (reFuels) enable a much faster greenhouse gas reduction than any fleet conversion. The paper provides an overview of the current situation with a special focus on the European situation.

REFUELS AS ELEMENT OF GHG NEUTRAL MOBILITY

Reducing greenhouse gases is a global endeavor. To make the global target controllable, it is broken down into continent- or country-specific sub-targets. Countries, in turn, consider sectoral sub-targets, which are usually optimized only for themselves. In the case of mobility in particular, there is a close link between the energy, industry and mobility sectors themselves. Life cycle assessments show the corresponding sensitivities and thus the need for cross-sectoral approaches. If we take into account the remaining budget available to the planet for climate research, there is the additional aspect that the time frame for all measures to be taken is very limited.

Therefore, it is important to use all possible measures (battery electric vehicles, fuel cell vehicles, and renewable fuels) and not exclude any. By leveraging the existing vehicle fleet and energy distribution infrastructure, renewable fuels have a much faster impact, making them a key lever to achieve the internationally agreed Paris targets.

CHALLENGES IN MOBILITY GRENHOUSE GAS REDUCTION

EXISTING FLEET

The global level of motorization is rising and has not yet reached a steady state. While the number of vehicles is increasing only slightly in the highly industrialized countries, the emerging markets have much greater potential.

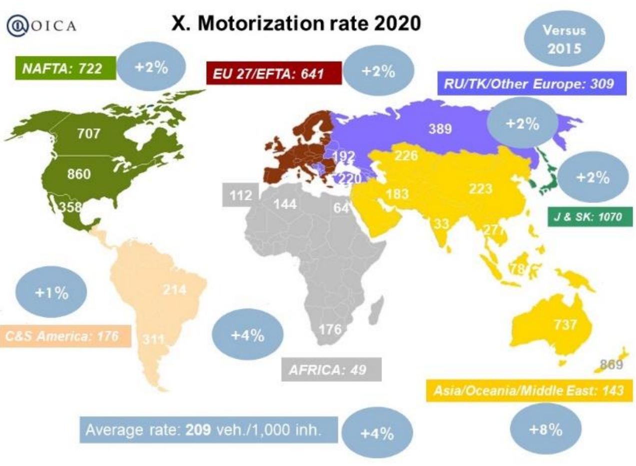

Figure 1: motorization rates world perspective [1]

The fleet structure is determined by the available energy supply and the main uses. Europe, for example, is based on oil imports and dominated by trucking and individual passenger transport, both of which have a comparable share of gasoline and diesel fuel. Brazil, on the other hand, has high ethanol capacity, resulting in a higher market share for flex fuel (including E85).

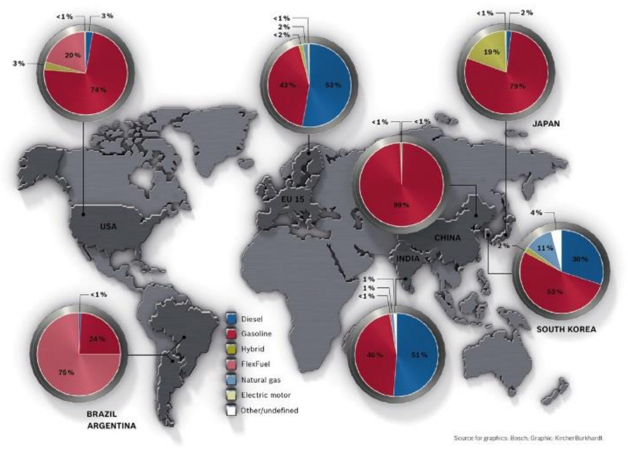

Figure 2: world map of vehicle energy supply (2014) [2]

DEVELOPMENT OF BATTER ELECTRIC FLEET ON A GLOBAL BASE

Every consulting firm in the industry is forecasting a sharp increase in battery electric vehicle (EV) sales, and these studies are mostly optimistic to drive change management among their clients.

The expected EV sales are 8.5 million vehicles in 2025 and 26 million vehicles in 2030, which would lead to a 28% share of electric vehicles in 2030 [3,4]. Another study assumes an 8% EV share in the fleet in 2030 [5], but ~40% EV share in 2040. The iea net-zero scenario [6] even calls for a 40% EV fleet share in 2030.

All developments are below the European Union's 55% GHG reduction plan.

LIMITING FACTS

The European policy framework separates GHG emissions between vehicle production-related emissions (industrial sector), energy well-to-tank emissions (energy sector and/or industrial sector), and tank-to-wheel emissions. As a result of this approach, battery electric vehicles (EVs) are considered zero-emission vehicles. As a result, the automotive industry is heavily focused on driving EV sales.

Shipping companies are dominated by total cost of ownership strategies. They must balance higher vehicle costs, high electricity costs on the one hand, and lower Scope 2 emissions on the other. Similar to private vehicle users, battery prices limit interest in e-vehicles, even with high government financial support. Another important influencing factor is the limited range of a given battery storage, which in turn leads to corresponding costs.

<u>Minerals</u>

Since battery electric vehicles and fuel cell vehicles, as well as all other strategies based on electricity from renewable sources, are material-intensive, the demand for some critical minerals is increasing sharply.

The European Union has established a list of critical minerals since 2011 and updates this list every three years [7].

As a result of this increasing limiting factor, the European Union has introduced a battery passport that regulates the content of recycled material in batteries. Calculations show that the material supply will be a key factor for the ramp-up rate [8].

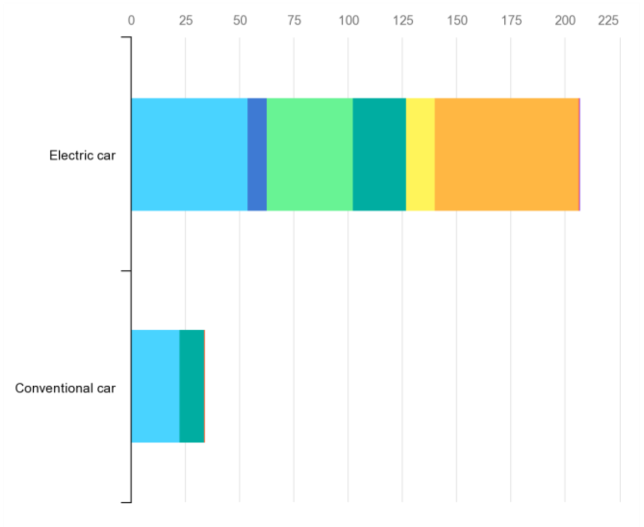

Figure 3: raw material needs for different powertrains [8]

<u>Electrical supply</u>

Battery-powered electric vehicles require a corresponding charging infrastructure. In most countries, the power grid must be adapted in parallel in two ways.

On the one hand, the power supply network must be converted from a centralized power system with larger power plants (e.g. fossil coal-fired power plants or nuclear power plants) to a decentralized network with distributed smaller plants that use energy from renewable sources. Optimistic and progressive approaches, as proposed in the Climate Neutral Germany 2045 scenario, show that there will still be a fossil gas share in the power supply in 2040.

On the other hand, the local infrastructure must be adapted to the higher power consumption requirements. Heat exchangers for home heating and vehicle charging stations are additional loads that can exceed the standard connected load between 14.5 kW and 27.6 kW. At the street or neighborhood level, cable distribution cabinets and the existing wiring harness are the limiting factors and would need to be replaced for higher penetration of electrical loads. Adjusting them to accommodate the planned electrification transition will cause a large amount of adjustment and construction, resulting in a potential time delay.

RENEWABLE FUELS AND THE CARBON BUDGET

GREENHOUSE GAS BUDGET AS DRIVER

The international agreements on the Paris targets envisage global warming to 2°C. As a result, highly industrialized countries in particular will have to limit their greenhouse gas emissions very quickly. Carbon dioxide has an average atmospheric residence time of over 100 years and its effects are therefore cumulative. The so-called carbon-budget describes the cumulative global greenhouse gas emissions to meet the Paris Agreement targets. The 2018 IPCC report estimates this to be 420 Gt CO_{2eq}[9]. Any delay in an activity will therefore intensify the necessary reduction rate.

The European Union is responding to this situation by launching the Fit for 55 initiative with resulting regulations in various sectors. The German government has legally stipulated in its "Federal Climate Protection Act" [10] that it will achieve climate neutrality in 2045.

Given the limited potential to reduce greenhouse gas emissions in mobility in the short term, additional measures such as the introduction of renewable fuels are urgently needed. This approach is reinforced by the fact that a conversion of the fleet stock would take more than ten years due to the average useful life of vehicles in Europe. For example, the German passenger car fleet is 48.8 million vehicles at the beginning of 2023. Even with a €10,000 government subsidy, new registrations of battery-electric vehicles will remain in the 16% range, leaving well over 30 million combustion vehicles in 2030.

reFuels have to to combine two major requests:

a) The have to be CO_2-negative
b) They have to meet the standard fuel norms

Compliance with standard fuel standards for gasoline or diesel fuel allows use in all existing vehicles and in the existing fuel distribution infrastructure. For synthetic diesel fuels, there is a small deviation due to the use of paraffinic diesel fuel. Fischer-Tropsch e-fuel diesel fuel or hydrogenated vegetable oil (HVO) both yield paraffinic diesel fuel. Their density (765-800 kg/m^3) is defined in EN15940 and is lower than the values of the European diesel standard EN590 (820-845 kg/m^3)[11]. Since paraffinic diesel has been specified since 2012 [12], its parameters and criteria are the basis for almost all current vehicles and can be used in the fleet.

FAST RAMPUP OF REFUELS

We have defined the synthetic word reFuels, which is a combination of the words regenerative and fuels, to summarize all regenerative-based fuels that remain in the fuel standards discussed above. The discussion of multiple fuel pathways that discuss synthetic fuels in a neither loses the speed we can achieve if we use all pathways and add them up to increase reFuels quickly.

All fuels require carbon from the atmosphere, either directly by capture from the air or indirectly via biogenic residues and waste. On the other hand, they require hydrogen, which is synthesized in an electrolysis process or also comes from biogenic waste. In the case of synthetic e-fuels, we need to ramp up energy from renewable sources, electrolysers and fuel synthesis - Foscher-Tropsch or methanation and methanol-to-X (gasoline, diesel and cerosene) - in parallel. In the case of fuels based on residual and waste materials, only the ramp-up of fuel synthesis determines the achievable ramp-up rate.

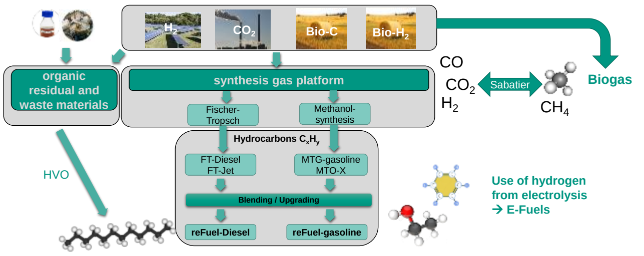

Figure 4: reFuels synthesis pathes

This characteristic of being available today is accompanied by the fact that their actual resources are limited and several potential feedstocks are in conflict with food supply chains. Therefore, the European legislation for the introduction of renewable energy (RED II) [13] follows a deployment plan with increasing requirements for GHG mitigation potentials for new installations over the years. These GHG mitigation potentials are calculated in terms of indirect land use changes, and as an example, phasing out the use of palm oil as a feedstock leads to a stop in its use for petroleum refineries in 2023.

The life cycle assessments we have calculated show the potential of about 90% CO2 reduction using known feedstocks and range-specific European electricity. In summary, fuels from biogenic residues and wastes enable an immediate ramp-up of fuels and thus an immediate CO_2 reduction, but are limited from a global perspective.

The former RED II is a regulation that must be transposed into national law by each EU member state. In addition to the general parts of this directive, there will be at least two technical additions called legislative acts, both of which are still being discussed today. One of these acts deals with the accounting of different CO_2 sources, the other with the boundary conditions for the energy used for fuel synthesis. Briefly summarized, the energy must be renewable, additional, without transmission bottlenecks, and available for fuel synthesis within a defined time frame.

Conventional e-fuels are often debated in terms of their greenhouse gas mitigation potential. In 2018, the reFuels initiative was founded, in which 14 companies and six KIT institutes participate. Within this initiative, several thousand liters of gasoline and diesel fuels were synthesized, successfully tested (reduced raw emissions), and evaluated under multidisciplinary aspects. The results of two exemplary Fischer-Tropsch fuel synthesis processes with direct air separation and cement plant off-gas scrubbing as two different CO_2 sources are shown in Figure 5.

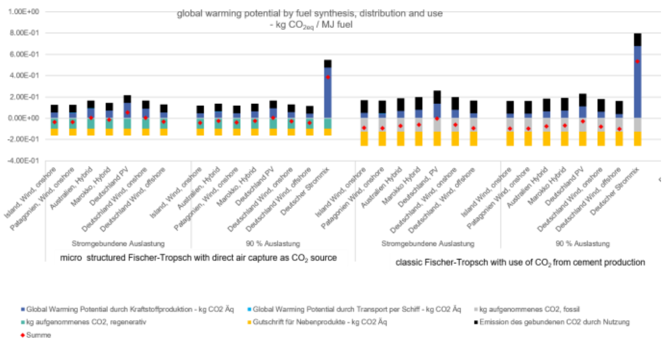

Figure 5: LCA results on greenhouse gas emissions regrading fuel synthesis, distribution and usage [14]

THE RAMP UP OF MANUFACTURING

General discussions are needed on the various aspects of fuel synthesis. In addition to the ecological aspects and the legal framework, business decisions must also be made. The high investment volume usually requires constant framework conditions for 15 to 20 years. Under these specific conditions, different technologies are developed in parallel.

The standard procedure in chemical engineering is a multi-step scaling process. The size of the scaling steps has to be adapted to the processes and their sensitivity to e.g. temperature gradients (Figure 6 shows exemplary scaling steps). Each scaling step in a later phase must be coordinated with process engineering milestones (basic engineering, detail engineering, etc.) and design efforts. For the initial realization, implementation times between 3 and 4 years are discussed for each step. Subsequent realizations will be faster.

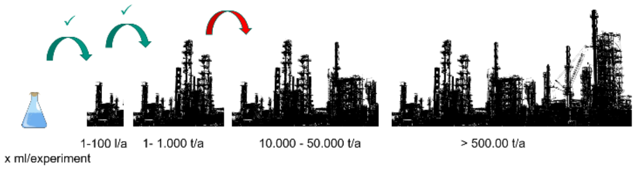

Figure 6: exemplaric schaling steps for chemical process ramp up

In the FVV association, a working group on fuels was set up as part of pre-competitive research to discuss all limiting factors for the introduction of synthetic fuels. The results are summarized in the so-called Fuel Study IVb [14] (which was also presented at this conference) and show the implementation speed of reFuels if there are no political blockades (here with focus on Europe).

The delay between the methanol pathway and the Fischer-Tropsch pathway is caused by the reverse water gas shift reaction process step, which converts CO2 to CO, which is needed as an input to Fischer-Tropsch reactors. This technology has a technology maturity level (TRL) of ~7 and requires additional time to scale up as announced by the industry partners in the above project.

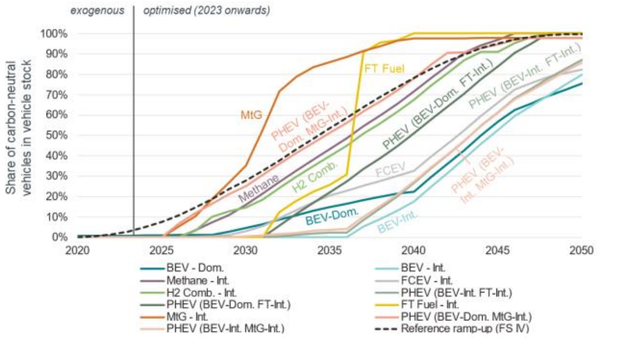

Figure 7: Potential ramp up of green vehicles - comparison of different technology pathes [14]

POTENTIAL OF ENERGY FROM RENEWABLE SOURCES

As a result of the DeV-KopSys project funded by the German government, Fraunhofer IEE has created a world map showing the most interesting positions for converting wind, solar or comparable energy sources into electrical energy and combining them with the next steps of fuel synthesis [16] (see Figure 8). This map gives a good global overview and uses general data and technologies that were known at the time the project started.

In addition to this project, there are other activities that provide more detailed data, such as the Global Wind Atlas and the Global Solar Atlas [17,18], which provide geographically and temporally resolved data. Depending on the location, different hydrogen storage sizes, electrolyzer sizes or other synthesis parameters have to be chosen. In Europe, there are only a few sites with low electricity costs and high availability. Therefore, Europe will have to import intermediate products such as methanol or Fischer-Tropsch crude oil from pyrolysis and process them in existing refineries.

Figure 8: World map of e-Fuels hot spots [16]

Based on the limited local "resources" of wind and solar energy, the potentially high costs of synthetic fuels are discussed in Europe. These discussions neglect the high availability of solar and wind energy resources worldwide.

A summary description of a detailed study is given by Perez et al [19], which compares the increasing demand for electrical energy with the realistically available potentials, as shown in Figure 9.

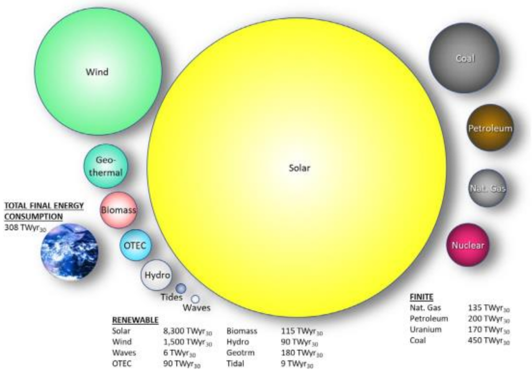

Figure 9: Comparison of 30 years realistic recoverable energy reserves, 30 years world energy consumption and total fossile reserves and by size [18]

The figure clearly shows that we do not have an energy shortage, it is just a question of where and when. Renewable synthetic fuels (reFuels) are a cheap way to store and transport this energy.

Fuel synthesis efficiency is highly dependent on plant size and process integration, and all process optimization must aim to maximize CO_2 reduction to achieve the highest carbon efficiency. As a result of this optimization, energy efficiency will decrease. Using standard components, we expect a Fischer-Tropsch diesel fuel plant or a methanol-based gasoline plant to achieve 43% and 50% energy efficiency, respectively, without any optimization [14]. Using advanced techniques (TRL 7), we measured >60% for the Fischer-Tropsch pathway.

Combined with the energy availability described above, it is now only a question of final product cost and not feasibility. Optimization of product costs is automatic after the ramp-up.

One of the cost optimization potentials lies in the use of existing infrastructure for transportation, storage and final processing of fuels. Redesigning existing refineries is part of current research programs such as REV4FU from the German Federal Ministry of Digitalization and Transport.

Any activity to introduce reFuels will only be driven or slowed by the acceptance of reFuels as part of greenhouse gas reduction. This acceptance will be the basis for regulatory implementation and provide the framework for rapid deployment.

CONCLUSION

reFuels are an existing technology that can lead to significant reductions in greenhouse gas emissions, both in the existing fleet and in new vehicles. Their approach to closing the carbon cycle enables real change in mobility compared to shifting to new challenges and limited minerals on the other side. reFuels allow rapid deployment and are therefore the only way to meet climate targets in time.

Fuels made from biogenic residues and wastes allow immediate ramp-up of fuels and thus immediate CO_2 reductions, but are limited in global terms. Those who do not use them are knowingly emitting greenhouse gas.

Translated with www.DeepL.com/Translator (free version)

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APPENDI