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Abstract. This article shows the necessity of solving the substitution of fossil fuels differently for each region. In Europe, the focus is currently on the CO2 neutrality of energies. Besides these ecological reasons, however, security of supply and costs are becoming more important. Various renewable fuels exist. On the one hand, these are bio-oil (biodiesel) or bio-ethanol. On the other hand, "green" electricity from wind, water and solar power is very popular. The electricity is used directly in battery vehicles or the electricity is converted to green hydrogen, green methane down to synthetic gasoline (e-fuels). In addition to carbon emissions, the energy availability and the costs are very important. A good example is the use of bio-ethanol in Brazil. Alcohol fuels have been in use in Brazil for decades because of availability and the selling price. In sunny or windy regions, the production of green hydrogen is interesting. The green hydrogen can be used directly for aircraft engines, combustion engines or fuel cells. As Porsche is demonstrating in Chile it is possible to transfer hydrogen into regenerative gasoline (e-fuels). In addition to these considerations, political aspects are important. The direct use of solar and wind power in passenger cars is very popular in the EU. There are more and more battery electric vehicles (BEV) in the market. BEVs have the best possible efficiency. Renewable electricity is stored in batteries with little loss and the electric motors are highly efficient. Fluctuations in solar and wind power are very problematic. A major problem is that the battery capacities are too small to compensate these fluctuations. Furthermore, the costs of the batteries are immense. For this reason, BEVs are subsidized by state funds. Currently, the sales figures of BEV are decreasing. One reason for this are lower state subsidies. This shows the importance of economic aspects as well. The operating energies of the future will be diverse. This paper shows that the nearby exclusive focus on BEV in Europe is globally not purposeful. Depending on the region and social acceptancce, there will be different types of conventional and "green" energies side by side. Aircraft engines, internal combustion engines and fuel cells run on fossil fuels and regenerative substitutes. The direct use of green electricity in battery vehicles will increase.

Keywords: Alternative fuels, e-fuels, bio ethanol, bio hydrogen, bio diesel, power to gas, power to liquid

1. INTRODUCTION

The increasing world population leads to an unprecedented global energy demand. Sunlight, stored in the earth millions of years ago, is presently the most important source of energy. These energies are oil, coal and gas, which cover 80% of the global energy demand in 2020, (BGR 2022). By the way, approximately 3 million years of sunlight storage are necessary to produce the world energy demand of only one year. Three million years of production time compared to one year of usage time is an alternative view of the 1.5 ºC global warming limit.

In the fight against energy consumption and simultaneous to reduce CO2 emissions, engineers do two things. On the one hand, the technicians improve the efficiency of the machines and systems. Of course, engineers has always been experts to optimize efficiency and save resources. On the other hand, there is the increasing realization that efficiency alone is not the only need. Energy availability and the ability to store energy, especially renewable energies, are becoming increasingly important.

Renewable energies, the so-called regenerative energies, are increasingly replacing fossil fuels worldwide. This article shows the status of energy supply for passenger cars, aircrafts and ships but also the necessity of solving the substitution of fossil fuels differently for each region of the world. In Europe, the focus is currently on the CO2 neutrality of energies. This focus primarily takes into account ecological or climate-neutral goals. As already mentioned above, the ecological arguments are not the only determining reasons. Security of supply and last but not least the costs are important criteria as well.
It does not matter whether the reason is sustainability, security of supply or costs: the rate of renewable energy is increasing worldwide, Figure 1. This means that fossil fuels are relevant also in 2050. Depending on the future scenario (STEPS, APS, NZE), there will be a need for fossil energies worldwide either in 2050. The Stated Policies Scenario (STEPS) shows the development implied by today’s political attitudes in general. The Announced Pledges Scenario (APS) entails that, among other things, all the ambitious targets promised by governments will be fully successful and on time. The net zero emissions scenario (NZE) is the most ambitious forecast and takes previously into account, that the 1.5°C target is completely practicable.

2. CURRENT ENERGY SOURCES OF MOBILE DRIVE SYSTEMS

The following chapter gives an overview of the energy sources of today’s land, water and air vehicles. The aviation industry presents a particularly interesting situation because aircrafts must be light and often travel long distances flights (distances > 3000 km). Regenerative produced aviation fuel, the so-called SAF (Sustainable Aviation Fuel), currently plays no proper role. SAF or bio-kerosene only has a small share of ca. 0.1% worldwide, (Witt, 2022). This is very similar in the EU with minor 0.5% use of SAF, (Spiegel, 2022). Energy from hydrogen and batteries is even less common than SAF fuels.

Ships have the advantage that they are able to transport large masses and volumes. They are therefore predestined to transport heavy batteries. However, this is not the case, as 98.8% of ships worldwide use conventional propulsion systems, (DNV, 2022), Figure 2. There is almost no alternative to combustion engines. This engine use heavy fuel oil, petrol and fossil gas. In addition, LNG (Liquefied Natural Gas), LPG (Liquefied Petroleum Gas) and methane gas are mostly fossil energies and supply the modified combustion engines. Hybrid drives are an efficiency-optimized combination of internal combustion engines and electric motors. Accordingly, almost all current ships run with ICI-based drives.
The situation is different with passenger cars. The use of these vehicles is more diverse, because private individuals buy their passenger cars often for emotional reasons. Nevertheless, the economy and operating costs are also very important for private individuals and are ultimately decisive for the purchase. According to (ABB, 2021), in 2021, around 95% of all new passenger car registrations worldwide had an internal combustion engine (ICE) or an electrified internal combustion engine as a hybrid drive (HEV, PHEV, MHEV); only 4.1% of the vehicles had been new battery electric vehicles (BEVs).

Of course, BEVs have the best possible efficiency. 1 joule of thermal energy (from gas, gasoline or ethanol) is not comparable to 1 joule of mechanical or electrical work. As an example, solar modules are not able to convert sunlight into electricity without losses; commercial systems currently achieve < 25% efficiency. The advantages and disadvantages of BEV are subject of discussion later on.

The popularity of ICE drives is regional. A good example is the use of bio-ethanol in Brazil. Alcohol fuels have been in use in Brazil for decades because of the availability and the selling price. It is a well-known fact that the replacement of fossil gasoline has taken place very successfully and has a share of more than 2/3. In Brazil, renewable fuel consumption is growing steadily, reaching a level of 412 thousand barrels of oil equivalent per day, (BP, 2022). This corresponds to approx. 65.5 million litres of diesel fuel per day.

The situation in the EU is different. For 2021, 9.1% BEVs are newly registered, less than 3% of the vehicles are using alternative fuels (including LNG and ethanol), (ACEA, 2022). Unlike in Brazil, the EU massively intervenes in the market with state subsidies. In 2022, new BEVs in Germany received a subsidy premium of up to €9,000 or ca. $9,800 (€3,000 manufacturer, €6,000 state subsidy). From 2023, the subsidy will only reach up to €4,500 or ca. $4,900 in total. Whether BEV sales will continue to grow exponentially is a matter of controversial discussion, also due to falling subsidy premiums.

2. PROSPECTIVE ENERGY SOURCES OF MOBILE DRIVE SYSTEMS

As previously discussed, aircrafts use fossil kerosene almost exclusively, there are only little shares of SAF existing. In addition, battery-powered flying is not feasible on large aircrafts and long distances due to the energy density and the batteries weight, (Hartbrich, I., 2021). That is the reason why the EU is introducing a quota for SAF (Sustainable Aviation Fuel). The minimum share of SAF fuel must be 2% in 2025, 5% in 2030 and 63% in 2050 (European Parliament, 2023), Figure 3. One of the most important manufacturing companies for SAF is Neste, which is producing ca. 100,000 tonnes per year. By the way, the SAF annual consumption in Germany is ca. 7,000,000 tonnes per year. It becomes obvious that fully regenerative aviation is difficult with SAF alone. Another solution are hydrogen-powered aircrafts. Well-known manufacturers such as Airbus are working on new types of hydrogen aircrafts. An example of this is the conversion of the A380 to hydrogen engines. In the next years, there will be a testing of a prototype, but a possible series production only after 2030. In summary, this means that fossil fuels will continue to be important in aerospace industry for decades.

![Figure 3](image-url)
or battery drives do not change that much. In others words: 0.02% of the worldwide newly ordered ships will have a battery or hybrid drive.

![NUMBER OF SHIPS](image)

Figure 4. Current number of ships and newly ordered ships worldwide, June 2022, (DNV, 2022)

The Figure 5 shows a hybrid drive from Rolls-Royce, which weaves a marine diesel engine from MTU. A clever combination of the combustion engine and the generator increases the efficiency of the system. The hybrid system consists of a mechanical decoupling of the combustion engine from the ship's propeller. As a result, the ICE runs constantly at the best consumption point.

![Figure 5: Illustration of a modern Rolls-Royce / MTU Hybrid Drive (in blue: heavy diesel engine and generator; in grey: electric machine and the ship's propeller), (Rockenstein, S., 2023)](image)

Passenger cars are of particular interest, because the drives are subject to a high level of publicity. In the EU, the requirements for the emission limit are increasing, so that the engines have almost no pollutant emissions anymore. In addition to that, the vehicle test cycles intensifies due to higher accelerations and top speeds. This is super positioned, because at the same time the vehicle masses are becoming heavier and heavier, Figure 6.

![Figure 6: Illustration of a modern Rolls-Royce / MTU Hybrid Drive (in blue: heavy diesel engine and generator; in grey: electric machine and the ship's propeller), (Rockenstein, S., 2023)](image)
As seen in the previous chapter internal combustion engines are common around the world and BEVs are only slowly replacing ICE vehicles. There are different market shares of new BEV, e.g. 4.1% worldwide (ABB, 2021) compared to 9.1% in the EU for 2021 (ACEA, 2022). In addition, the vehicles achieve a long service life. The average lifespan of all vehicles in the EU in 2021 was around 12 years, (ACEA, 2023). This means that the vehicles can easily reach a lifetime of 20 years. Therefore, it is very welcome that automotive companies as BMW or Mazda are consistently developing the internal combustion engine further (Wetzel, K.; et al., 2023), (Schäfer, P, 2023).

Nevertheless, most scientists agree that even in 2040 a large number of new vehicles with combustion engines (ICE) or electrified combustion engines (HEV, PHEV) will enter the worldwide markets. Figure 7 visualizes this for the EU, USA and China markets very clear. The chart shows the proportion of new cars in the market. Considering the long service life, it becomes clear that only the use of alternative fuels can reduce the CO2 emissions of this fleet.

### 3. REGENERATIVE FUELS AND BATTERY ELECTRIC VEHICLES

Are hybrid drives, internal combustion engines or aircraft turbines CO2-neutral? The question is wrong itself because the answers depends on the used fuel.

Of course, BEVs have the best possible efficiency. The reason for that is the energy status of electricity in comparison to caloric energy. The electricity stored in the batteries is powerful secondary energy or in other words “pure Exergy”. If the electricity from wind, hydroelectric or photovoltaic power plants flows directly into batteries, BEVs have a high level of efficiency. If the electrical power comes from gas, coal or oil power plants, the efficiency of the BEVs are often lower than that of ICE cars. Two issues are important here. One is efficiency and the other is the ability to store energy. Electrical energy cannot be stored in large quantities because the capacity of the batteries is limited. This is critical because wind, hydro and solar power is highly fluctuating or so-called volatile. There must be a way to store and transport regenerative
energy in large quantities. One answer is the conversion of electricity into gasiform energies (power to gas PtG, hydrogen or methane) or liquid energies (power to liquid PtL, synthetic fuels). Figure 8 shows the losses caused by the use of PtG and PtL fuels in FC (fuel cells) or in ICE. Of course, it is possible to use the PtG hydrogen in hydrogen-ICE drives instead of in FC. The losses, seen in Figure 7, are the price of the storage and transportability of the electric energy.

PtG and PtL is the transformation of electricity into easily storable media. These methods are at the beginning of industrial mass production and are among the biofuels of the 2nd generation. The ambitious goals of the Porsche Company in Patagonia in Chile is an example of this technology, see Figure 9. The vision is the production of 11.4 million liters of synthetic gasoline per day by 2030 (Winterhagen, J., 2023). In addition to the PtL and PtG strategy, there are developments to exchange biomass in gases or liquids. These BtG and BtL fuels are also energies of the 2nd generation, which uses the complete plant and not just the fat and sugar content of the plants.

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Figure 8. Energy consumption for a car journey of 100 km depending on the energy conversion system (BMU, 2023)

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Figure 9. Left: HIF pilot plant in cooperation with Porsche AG. Right: Board members Barbara Frenkel and Michael Steiner filling up a Porsche with e-fuel (Porsche, 2023)

In the meantime, the regenerative fuels of the 1st generation are used on a large industrial scale. Vegetable fats or fat waste is hydrogenated or is transesterified and turned into bio diesel (HVO, FAME) or bio kerosene (SAF). Another
process is the fermentation and distillation of plants. Brazil is very successful in producing ethanol from sugar cane. The country produces 65 million litres of oil equivalent every day.

![Diagram showing CO2 equivalent (in Tonnen) for different vehicle types](image)

Figure 10. Distance-related CO2 emissions based on the Golf class. ADAC study from December 2022 (ADAC, 2023)

Just looking at the emissions of the vehicles, but not at the emissions from their production, is not enough. Figure 10 shows the calculated CO2 equivalent for both, the production and the operation, of a typical medium-sized vehicle in Europe. ICE cars based on bio methane achieve better values than BEV does, that run by the current electricity mix of conventional and renewable power. The CO2 intensive production of the BEVs has a break-even point of around 75,000 km in comparison to a methane based ICE cars, if the BEVs are powered by 100% regenerative electricity.

(Koç, H, 2015) comes to a similar analysis, which calculates a breakeven point of a Golf 7 TDI with an e-Golf at around 90,000 km. However, the CO2-intensive production of the batteries and the current electricity mix are decisive for the calculations.

The effect of costs on purchasing decisions is not the focus of this technical paper. Still, the impact is big. As already mentioned, from January 2023 there is a significantly lower state premium for BEVs in Germany. In December 2022, 104,325 new BEVs entered the German roads (KBA, 07/2023). In January 2023, only 18,136 new BEVs entered the German market (KBA, 07/2023). This is an indication of the high influence of costs.

4. INDIVIDUAL PROJECTS AND EYE-CATCHERS

With all drive-systems, there are always individual projects that usually serve demonstration or advertising purposes. These special forms of drives can offer a glimpse or inspiration of the future. Instead of individual projects, there are also small series. The two-seat Tesla Roadstar in 2008 is an example of a limited lot production vehicle that transformed the market.

Interesting special projects exits in the shipping industry. An example is the nuclear-powered general-purpose ship "Thor" by the Norwegian company Ulstein. The 148m vessel is emission-free and uses a thorium liquid reactor for self-propelling. Furthermore, the ship is able to act as a mobile power plant. Other companies and research institutes are also
working on salt reactors, such as Bill Gates with the small power plant "Terra Power". China is also planning a pilot plant for 2024.

Figure 11. The visionary ship "Thor" is powered by a thorium salt reactor, runs emission-free and works as a floating power plant or as a research station. (Ulstein, 2023)

In addition to these futuristic projects, there are specific individual projects and small series. One sample is the battery ferry between Rodby in Denmark and Puttgarden in Germany. From 2024, the battery ferry will drive the 18.5 km long trip 12 times a day (Heumer, W., 2023). The new ship is flexible because, in addition to battery operation, there are also diesel generators on board for charging with fossil fuels.

5. CONCLUSIONS

The current ships and the newly ordered ships on the seven seas almost exclusively run on fossil fuels. The service life of these ships is well over 20 years (Hapag-Lloyd, 2023), so that they will need fuel for many decades in the future. Aircrafts are using fossil fuels either and the share of other gasolines is currently marginal. The substitution by SAF fuel is just beginning. Like ships, aircraft have long life expectancies. In the case of passenger cars, there are signs of increased sales of BEVs. However, this incensement is greatly determined by the world region. Even in 2035, there will still be significant new registrations of ICE or HEV vehicles that have a long lifetime ahead of them. That is why the research and large-scale series production of alternative fuels is important.

On the other hand, the efficiency and CO2 emissions of BEVs are unsurpassed if they are not charged by e.g. coal-fired power plants. The problem, however, is the storage of large amounts of renewable electrical energy. Synthetically produced gases and liquids (PtG and PtL) are ideal here. These forms of energy have a low overall efficiency, but they are able to supply existing vehicles, ships and aircrafts. Biofuels of the 1st generation (biodiesel, bio kerosene, alcohol petrol) are of great importance today and tomorrow. 2nd generation fuels such as PtG and PtL will also become more significance in the future.

In the present text, only examples indicate that new technologies must also be economically useful. The great success of bioethanol in Brazil, even without large state support programs, is an example. Another example is the high sales of BEVs in Germany in 2022, which are noticeably smaller in 2023 after the reduction of state premiums.

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