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TOWARDS ZERO EMISSION: ARE E-FUELS A PROMISING OPTION?

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RESEARCH ARTICLE

ABSTRACT: Today modern, exhaust gas treated engines exhibit almost zero emissions locally. Action is needed exclusively with regard to the conservation of fossil resources and reducing CO_2, both of which are closely related. For a technology-neutral approach, starting with renewable primary energies, the diverse conversion, storage, energy distribution and refueling concepts must be examined in particular with regard to their availability or investment requirements. The Power-to-Liquids approach, i.e. the use of renewable liquid fuels (so-called "e-fuels"), reveals enormous potential, which should be raised in parallel with the electro-mobility that is politically propagated as a "magic bullet".

KEY WORDS: zero emission, greenhouse gases, local emissions, e-fuels, electromobility

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KA NULTOJ EMISIJI: DA LI SU E-GORIVA OPCIJA KOJA OBEĆAVA?

REZIME: Danas savremeni motori, sa tretiranim izduvnim gasovima, pokazuju skoro nultu emisiju lokalno. Akcije su potrebne isključivo u pogledu očuvanja fosilnih resursa i smanjenja CO_2, koji su usko povezani. Za tehnološki neutralni pristup, počevši od obnovljivih primarnih energija, moraju se ispitati različiti koncepti konverzije, skladištenja, distribucije energije i punjenja gorivom, posebno s obzirom na njihovu dostupnost ili zahteve za ulaganjem. Pristup napajanju tečnošću, odnosno upotreba obnovljivih tečnih goriva (tzv. „E-goriva“), otkriva ogroman potencijal, koji bi trebalo podizati paralelno sa elektromobilnošću koja se politički propagira kao „magični metak“.

KLJUČNE REČI: nulta emisija, gasovi staklene bašte, lokalne emisije, e-goriva, elektromobilnost

TOWARDS ZERO EMISSION: ARE E-FUELS A PROMISING OPTION?

Ralph Pütz

1. INTRODUCTION

Both the global population and energy demand double roughly every 40 years. Fossil resources are constantly dwindling, first oil, then natural gas and, after a few centuries, even coal. Whether the so-called “peak oil” has already happened or is still to come is irrelevant – what is certain is that a gap in the supply of energy will arise, which must be filled by renewable energy sources. In addition, in the course of the climate protection conferences in Paris 2015, Marrakesh 2016, Bonn 2017 and Katowice 2018 the European Union (EU) set itself ambitious targets for reducing greenhouse gas emissions. The aim is to achieve climate neutrality within the framework of the "European Green Deal" by 2050. On 16.09.2020, the President of the European Commission announced an intermediate goal for 2030of a further tightening of the greenhouse gases (GHG) reduction from 40% to 55% in comparison to the base year1990. This requires an ambitious CO2 reduction strategy, in particular for the road traffic sector since this sector –unlike local pollutant emissions – generally fails to achieve lower CO2 levels despite ever more efficient engines due to its continuous growth (see Figure 1). Nevertheless, the entire transportation sector globally is responsible for only around 14% of GHG (see Figure 2), yet it remains a political focus. In the energy policy debate on targeted drive and fuel concepts electromobility is seen and promoted almost exclusively as a sustainable option. This ignores the fact that modern internal combustion engines of stages Euro VI (for commercial vehicles) and Euro 6d (for passenger cars) are already at a local near-zero emission level and only renewable fuels are needed to achieve a highly significant reduction in greenhouse gas emissions. In the context of the further expansion of wind power and photovoltaic systems, so-called e-fuels are gaining in importance as climate-neutral liquid fuels with high energy density since the existing vehicle technology can be maintained along with distribution and refuelling infrastructures.

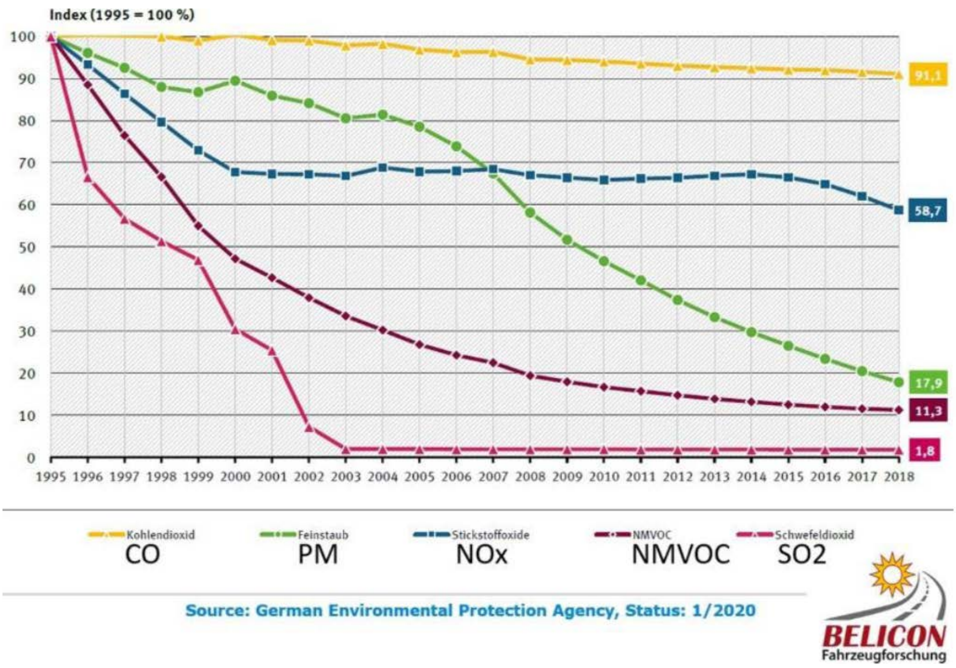

Figure 1 Specific local and global Emissions of the German Passenger Car Fleet (1990-2018)

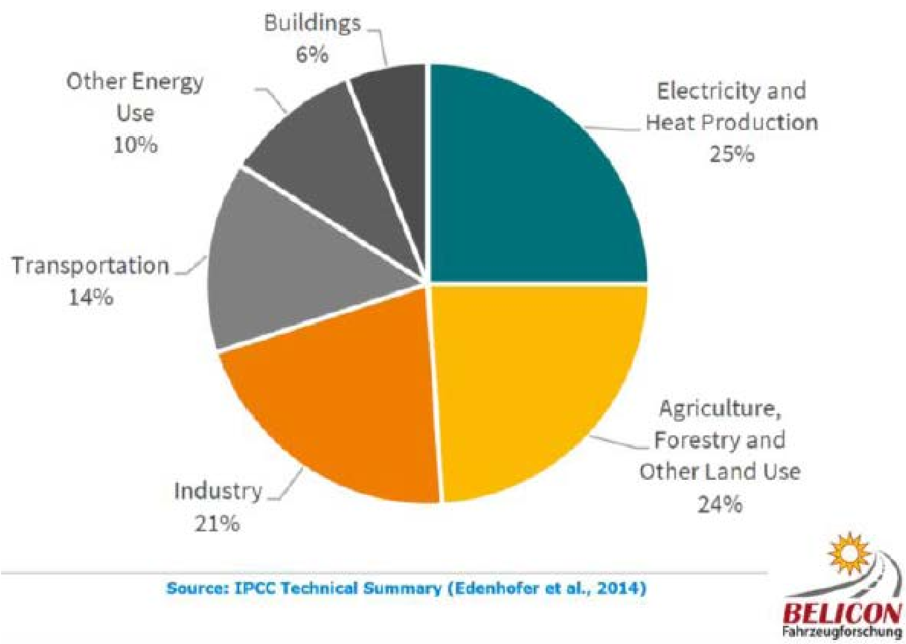

Figure 2 Global Greenhouse Gase Emissions by Sector (2010)

2. SYSTEMS APPROACH INDISPENSABLE FOR AN OBJECTIVE EVALUATION

For a comprehensive ecological and economic evaluation of vehicle fleets of different power drives and fuel types all stations of the lifecycle of transport systems must be included in the analysis, namely:

- Vehicle production (Cradle-to-Gate; CtG) and, if applicable, recovery/disposal,
- Fuel availability (Well-to-Tank; WtT),
- Driving mode (Tank-to-Wheel; TtW) and
- Maintenance.

since the isolated view of only looking at the actual driving operation – as in the relevant EU directives on road vehicles (e.g. the new "Clean Vehicles Directive" in the public transport (PT) bus sector, adopted in June 2019) –can lead to completely false conclusions. Only in this way can targeted solutions be identified for transport systems with both low local and global emissions and increased energy efficiency and reduced noise in the context of a holistic ecological integrity (see Figure 3 for example PT bus). This approach can be further developed for an entire transport company (see Figure 4). When analysing the emissions the main localised effective criteria include particle and nitrogen oxide emissions and the main global criteria primarily include CO_2 emissions or CO_2-equivalents whose effects on the determination of external costs can be summarised as an ecological profile of a drive technology. In the economic analysis the focus is on „vehicle costs“ which consist of capital services, fuel/energy costs and maintenance costs for fleet operators, supplemented by the costs of the energy supply infrastructure.

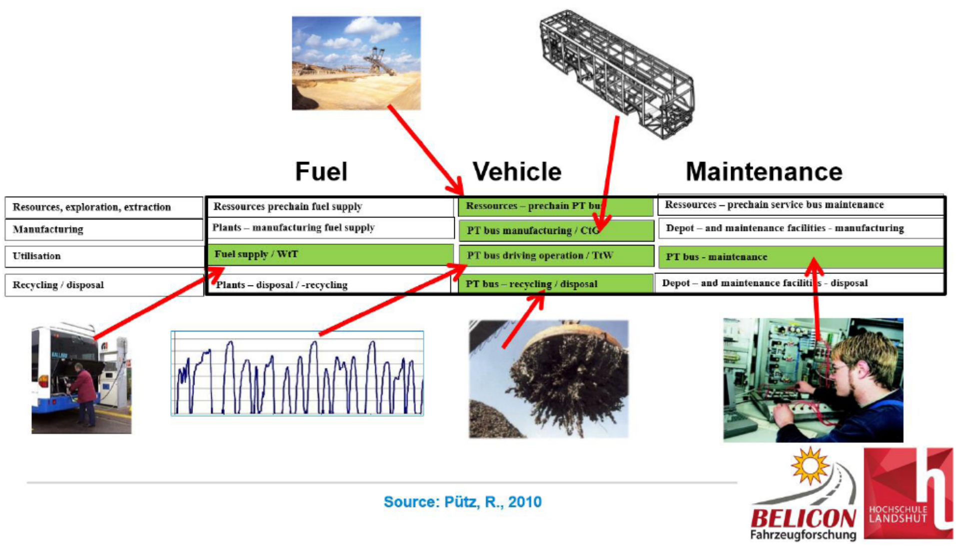

Figure 3 Ecological Systems Approach with Subsystems (example: PT Bus)

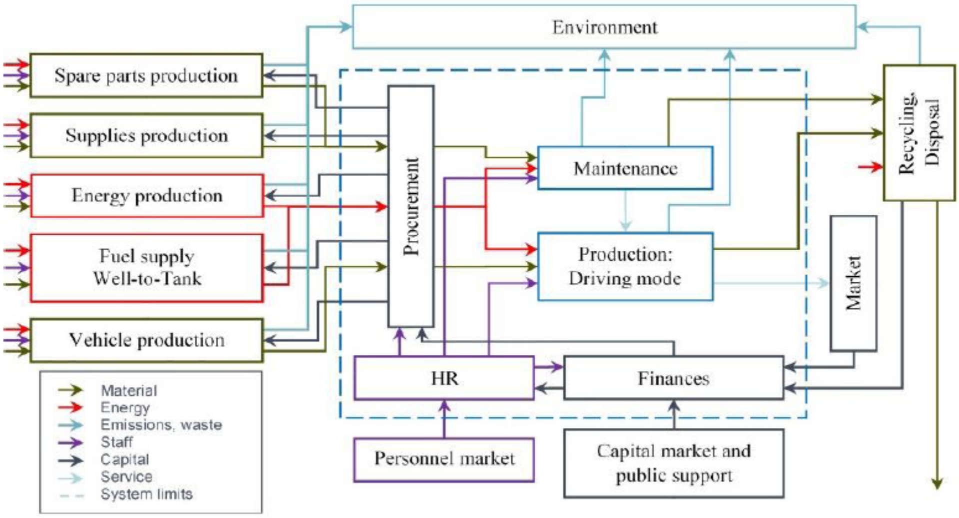

Figure 4 Ecological-economical Model for the complex System "Transport Company" and its Subsystems

3. NEAR-ZERO LOCAL EMISSION WITH EURO VI/6D COMBUSTION ENGINES

The local pollutant emissions of modern, exhaust-gas after-treated Euro VI/6d combustion engines are already accepted as uncritical. Figure 5 shows the measured values from the real operation of articulated PT buses in urban traffic with 'stop-and-go operation' for a flat line. On the left, the emission ratio of a Euro V and, on the right, a Euro VI articulated bus are shown respectively. The profiles of the exhaust gas temperatures shown in green are almost identical. The Euro V articulated bus shown on the left generates high NO emissions after the cold start, which settle down after less than 10 minutes. The Euro VI articulated bus shown on the right emits lower emissions than the operation-ready Euro V articulated bus even at cold start. With the Euro VI articulated bus shown on the right, nitrogen oxide emissions are already at ambient air level after just 10 minutes due to effective SCR exhaust gas after-treatment! Figure 6 shows in detail the particulate emissions in the ambient air and after particulate filters in a Euro-6d-passenger car, which clearly show that the intake air contains more particles than the exhaust gas and is thus actually cleaned in the process. This means that there will be no so-called "diesel crisis" if the exhaust gas after-treatment systems available as standard are used. Today the only need for action is with regard to the use of renewable fuels to significantly reduce globally effective emissions (GHG) and to conserve fossil resources.

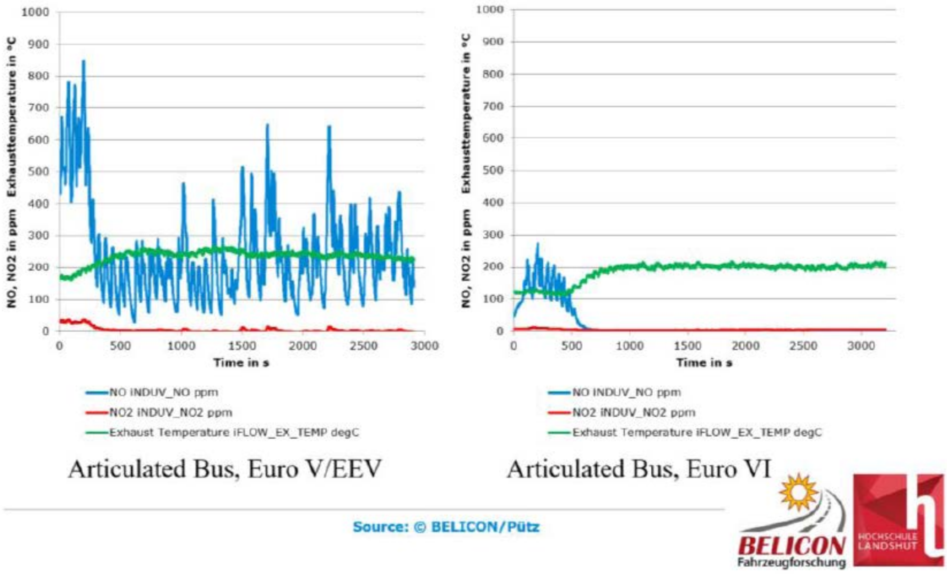

Figure 5 Comparison of NOx Emissions in Euro V/EEV and Euro VI articulated Diesel Buses

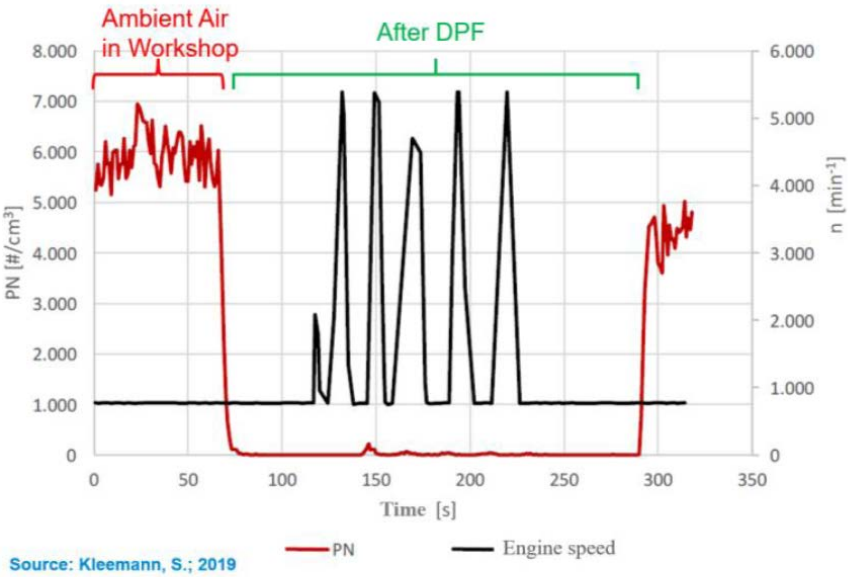

Figure 6 Particulate Emission of a Euro 6d Diesel Car before/after Diesel Particulate Filter (DPF)

Irrespective of the above-mentioned facts, the EU Clean Vehicles Directive defines “emission-free vehicles” as only those vehicles with no local emissions and without direct CO_2 emissions. A coal-powered electric bus with obvious higher CO_2 intensity would thus be viewed misleadingly as “emission-free” whereas a much cleaner diesel bus would be excluded by politically limited procurement quotas, despite it demonstrating integrated ecological advantages compared to an electric bus, even with an average German electricity mix (see Figures 7 and 8). Under the EU Clean Vehicles Directive, on the other hand, buses with highly sophisticated diesel engines would still be permitted as "clean" vehicles in the medium term if they are operated using sustainable biofuels or synthetic fuels (xtL fuels). Thus, in addition to the E-fuels (Power-to-Liquids) produced from renewable electricity, GtL (gas-to-liquids; from natural gas) and even CtL (coal-to-liquids; from coal) would be permissible, the latter regardless of its high CO_2 intensity and subsequent significant deterioration of the CO_2 balance compared to fossil diesel fuel. In doing so, the options for diesel powered vehicles in conjunction with GtL and natural gas power with fossil natural gas defined in the Clean Vehicles Directive as „clean“ offer no ecological advantage compared to the Euro VI diesel propulsion system with conventional EN590 diesel fuel. Thus, it is clear that the EU Clean Vehicles Directive is in need of immediate amendment in order to objectively assess the actual – system-related – ecological relations. In conjunction with E-fuels (Power-to-Liquids) the ecological objectives of Euro-VI-6d vehicles with regard to both local as well as global emissions would already be achieved and would thus be definitely feasible for the entire conventional vehicle fleet where a quantum leap could be made in the reduction of GHG emissions. In addition, the use of full-hybrid diesel buses (which according to the EU Clean Vehicles Directive are only declared as "clean" in the form of plug-in hybrids)with e-fuels would provide timely ecological improvements.

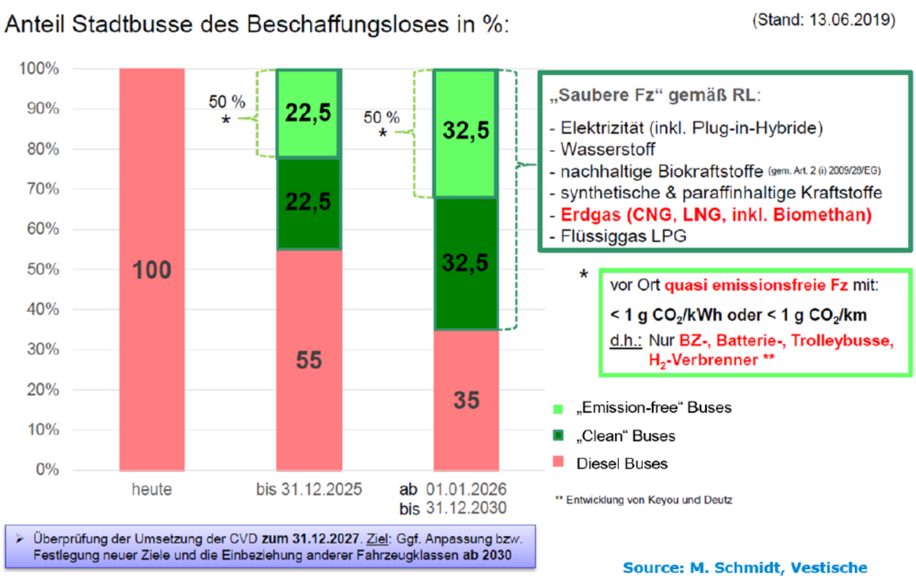

Figure 7 Fixed Quotas for the Tendering of new PT Buses over Time acc. to EU Clean Vehicles Directive

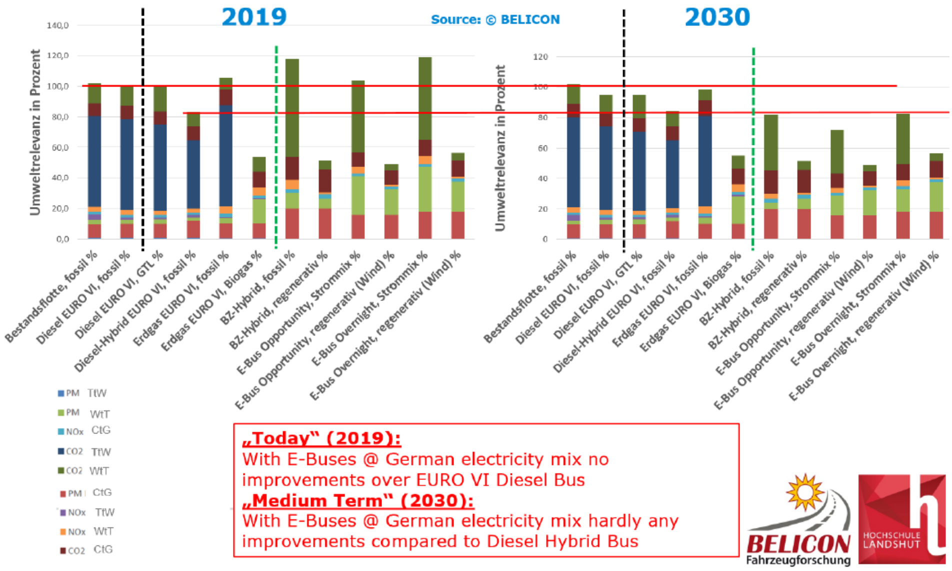

Figure 8 System-related Environmental Relevance of an exemplary Bus Fleet 2019 and 2030

The overall economic evaluation (including infrastructure) for PT buses is shown in Figure 9 on the time horizon of 'today' with a normal depreciation period of 9 years. Without taking into account the abundant public start-up funding for electric buses and their infrastructure, the options for electromobility are still currently way behind being economically viable. For an economic evaluation of the 'medium term' the forecast development of fuel prices is assumed, which includes investment costs for electromobility as well as the forecast, significant cost degression of the energy stores but still, however, has a replacement battery over the 12 (up to 17) years of operational use for PT buses (used from new). Today it can be assumed that the expected lifespan of the batteries with average public transport use barely lasts a 'half bus life' (ranges from 5 to 7 years). Likewise, for fuel cell technology, there is a similar significant cost depreciation assumed in the 'medium term'. It is evident that, in the 'medium term' electro buses– in particular due to ever increasing energy prices for fossil fuels (diesel and natural gas) as well as the reduction in battery and fuel cell costs and despite increasing electricity prices, will draw even closer to becoming as economics conventional drives. The economic viability of established, clean concepts with combustion engines will, however, not be achievable even in the medium term with the options for electromobility for most public transport operator circumstances. With today's dominant li-ion battery technology in the medium term, the operation of electric buses like buses with internal combustion engines – in other words, Overnight Charger – can only be possible with highly significant additional costs of over 50 percent due to the high investment costs, even without taking into account investments in the infrastructure. The Opportunity Charger will – without consideration of additional infrastructure costs – be about 20% more expensive compared to diesel technology. If the energy consumption for heating/ventilation/air conditioning (HVAC) and thus the range in winter as well as the reduced passenger capacity due to the battery mass of the overnight charger for e-buses are considered in depth, then the cost balance for e buses worsens due to the maintenance of operation of necessary additional vehicles (see Figure 10). This shows that the input of e-fuels in combustion engines also demonstrates significant economic advantages.

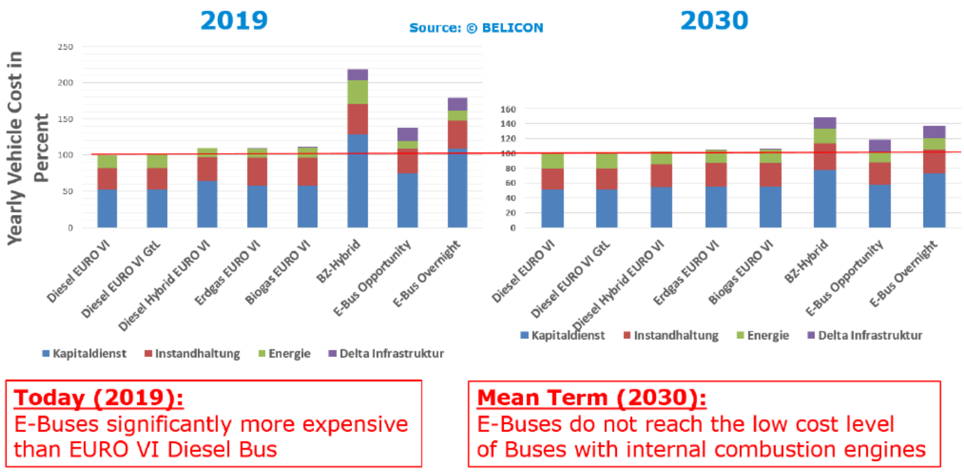

Figure 9 Relative Vehicle Cost of an examplary PT Bus Fleet in 2019 and 2030 - without Subsidies

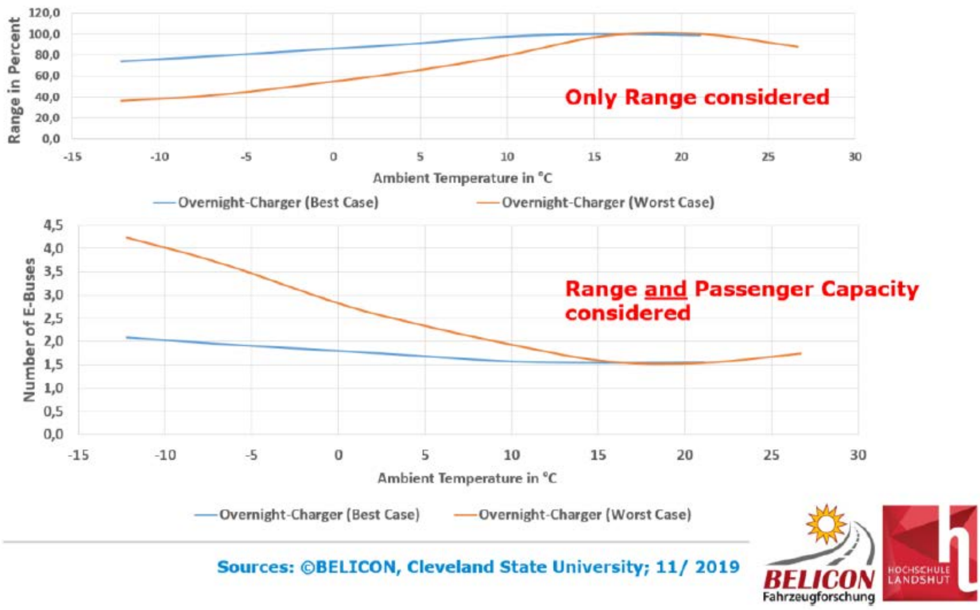

Figure 10 Range depending on ambient Temperature and Passenger Capacity of Overnight-Charger E-Buses

Since the further development of electromobility in the passenger car sector is also considered as a driver for the cost reduction of electric mobility in regular buses, the assessment of FEV Aachen (2017) for the period up to 2030shown in Figure 11 should be given. According to this, by 2030 in the EU only 20% of new vehicles in the passenger car and light commercial vehicle sectors will not have a combustion engine. Battery powered vehicles will make up19% and fuel cell vehicles only 1% of new vehicles. Nevertheless, 91% of new vehicles should have an electric powertrain, which demonstrates the increasing importance of (plug-in) hybridization of combustion engines. The mild hybrids account for the biggest proportion of new vehicles at 51%. This development once again demonstrates the enormous potential of e-fuels.

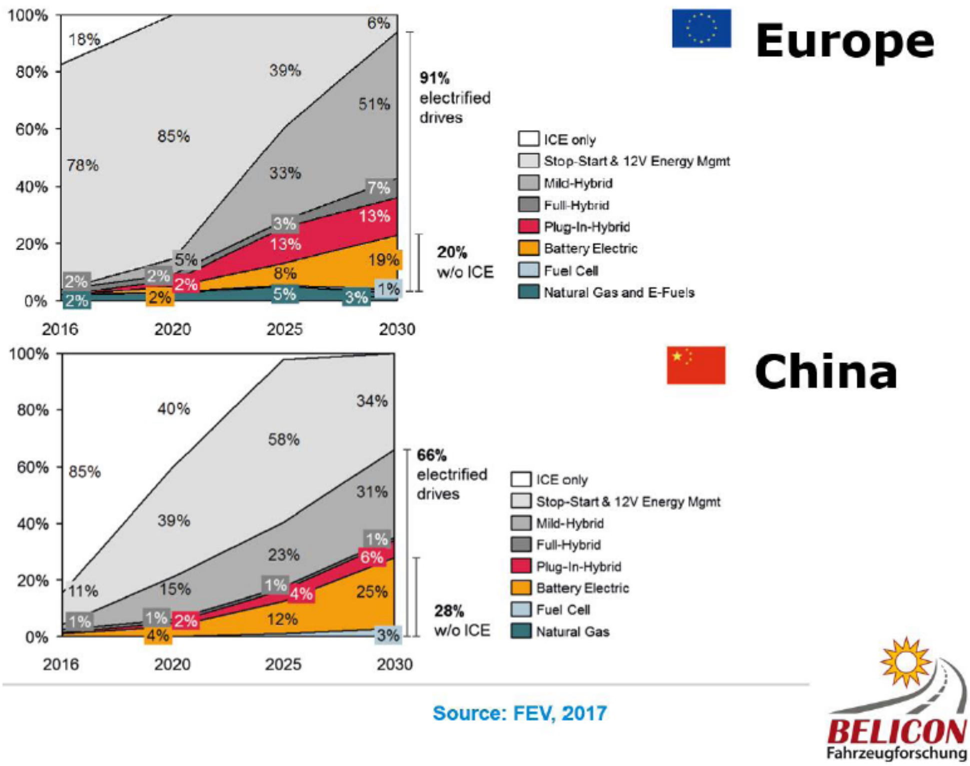

Figure 11 New Passenger Cars till 2030: Increasing electrification of the powertrain with ICE

4. E-FUELS AND THEIR POTENTIAL AGAINST E-MOBILITY

E-Fuels are climate-neutral liquid fuels that are generated by renewable electricity (solar, wind, hydropower) via hydrogen from water electrolysis and CO2 (for example from ambient air or from conventional power plants) with the help of the Fischer-Tropsch synthesis. The decisive advantages of e-fuels are their high energy density and compatibility with existing distribution and tanking infrastructure for conventional liquid fuels, but primarily also that they are produced in sun and wind-rich areas of the earth, so that the construction of wind and solar energy in areas with relatively little renewable energy (like Germany) is not required. According to the EU, for example, it would be possible to establish a strategic implementation of e-fuel production in southern Europe, which could also render obsolete the long disputed, unsustainable ‘donor/recipient countries’ finance systems in the long term and would strengthen the economy in southern

EU regions. In addition, the tankers which bring the new fuels to the market could likewise be powered by e-fuels. Although electromobility has advantages in terms of energy efficiency compared to the "internal combustion engine + e-fuel" approach (see Figure 12), this does not play a role in the excessive availability of renewable energy.

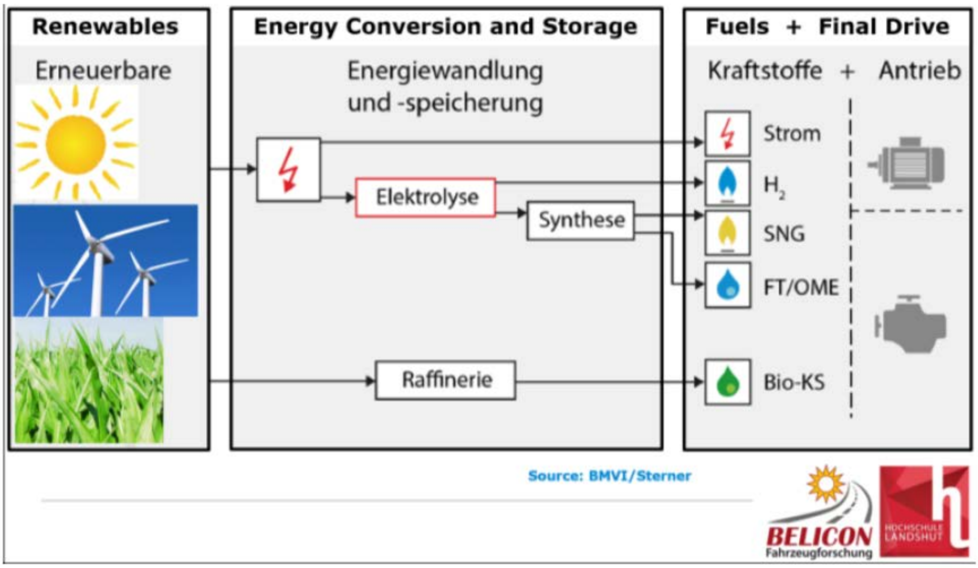

Figure 12 Electrolysis as central Element of Power-to Liquids

As shown above, the local pollutant emissions from modern combustion engines are already negligible so that subsequently only the influence on global emissions (GHG) should be considered. Since a complete substitution of diesel fuel by e-fuels cannot be expected in the medium term, the potential for reducing CO_2 should be depicted for the ‘long term’ time horizon (2040) with a 70% mixture of fossil diesel fuel compared with electric vehicles (primarily with renewable electricity) using the example of a medium sized car as shown in Figure 13. An integrated balancing of global emissions shows that, even in the long term (2040), the approach of combustion engine + e-fuels/diesel blend does not reveal any ecological disadvantages compared with electric battery vehicles primarily powered by renewable electricity; however, there are significant advantages to the vehicle costs. The e-fuel production is currently being set up on an industrial scale (for example, pilot plant in Australia) and is expected to achieve a production price of €1 per litre in the medium term, which is marketable in terms of transportation costs and profit compared to an expected diesel price of €1.70 per litre in the medium term. In the context of being technology-neutral other leading options must also be accredited in addition to electromobility. Thus, the German Energy Agency (DENA) anticipates in the long term a parallel, equal existence of electrical and non-electrical final energy applications within the framework of scenarios for combined energy and power transitions, whose proportional representation in this respect is still completely open (see Figure 14).

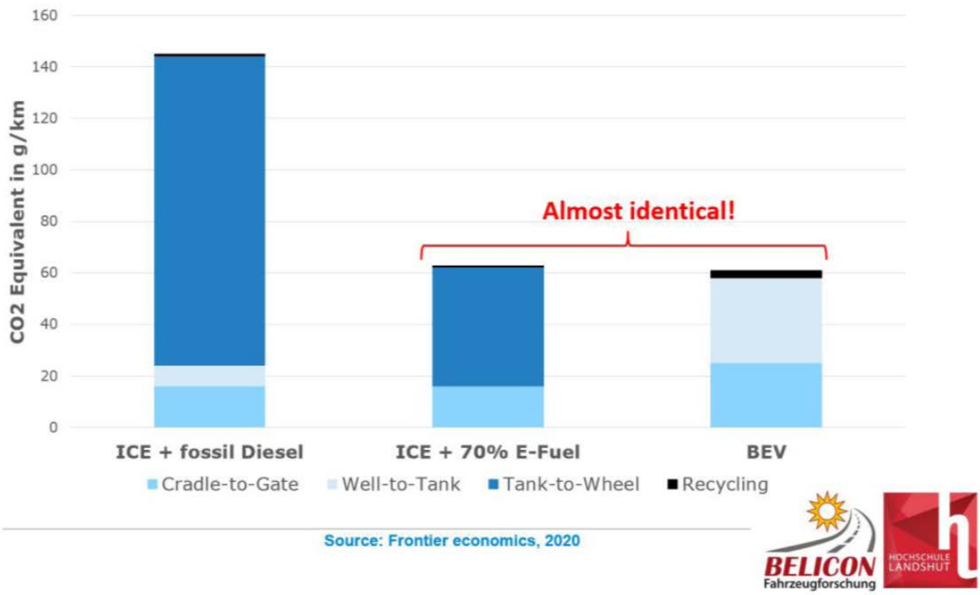

Figure 13 CO_2 Reduction Potential of „ICE w. E-Fuel Blends" vs. Battery-electric Vehicles (Medium Class Car)

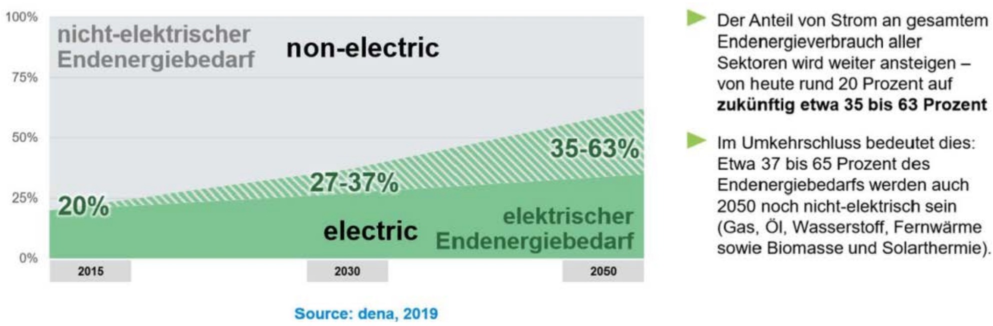

Figure 14 Dena Study: Use of renewable Energies @ end-user over Time

5. CONCLUSIONS

Today there is no need for action for local emission reduction of combustion engines (though Euro 7 is being planned). Action is needed exclusively with regard to the conservation of fossil resources and the reduction of CO_2, both of which are closely related. A technology-open political question should be: How does one get renewable energies (sun, wind, hydro, biomass) to the final drive stage which can not only be an electric motor, but also a highly clean internal combustion engine? For a technology-neutral approach, the diverse conversion, storage, energy distribution and refuelling concepts must be examined, starting with renewable primary energies, in particular with regard to their availability and/or necessary investments. A focus exclusively on vehicle operation (tank-to-wheel) –as in the relevant EU vehicle directives – delivers misleading results. Only a holistic accounting, taking into account all subsystems (cradle-to-gate, well-to-tank, tank-to-wheel, recycling/disposal), provides objective data on the way to a system-related zero emission. Analysis of the approach of “highly clean combustion engine with e-fuel” reveals that the politically motivated, continuous exclusion of the combustion engine with simultaneous ideological propagation of electromobility is an unsustainable strategy, which must be replaced as a matter of urgency with an open mind to technology on the basis of effective regulations in order to avoid economic development failure. The potential of e-fuels in combustion engines can be converted and dismantled nearer the time – initially by mixing with fossil fuels – for the entire existing vehicle fleet (in Germany approximately 65 million vehicles). This will be supported through the use of existing distribution and refuelling system infrastructure, whilst a comprehensive charging infrastructure must be constructed for electromobility. The imminent problem of disposal/recycling inherent in electromobility does not exist for e-fuels. From an economic viewpoint, all alternative drives in the electromobility spectrum are currently – without enormous public funding – far from economic viability. Also, in the medium term, the additional costs of the spectrum options politically defined misleadingly as “emission-free” have not yet reached the level of the highly attractive combustion engine options and, if the energy supply infrastructure is taken into account during the depreciation period, highly significant additional costs are still required. “Many roads lead to Rome” – a target-oriented policy must allow alternative options and the market mechanisms to develop the optimum, subject to effective regulations.

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