CIMAC
INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

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# CIMAC White Paper 4

## Importance of a Well-to-Wake Approach

From the Greenhouse Gas Strategy Group



The first edition of this CIMAC White Paper was approved by the members of the CIMAC Council at its meeting on November 19, 2020.

## Introduction

The switch to sustainable fuels poses the biggest lever to significantly reduce greenhouse gas (GHG) emissions in the shipping sector [1]. The IMO has recognized this by including the development and introduction of (net) zero carbon fuels[1] in the context of proposed long-term measures in the IMO GHG Strategy [2]. In line with that, CIMAC's GHG Strategy Group has also focused on the fuel switch to reduce GHG emissions since its establishment in late 2018. With its White Paper series, CIMAC aims to provide clarification on different aspects of the fuel debate.

The bigger picture of the current alternative fuel debate in maritime shipping and technology pathways of potential future fuels are outlined in CIMAC White Paper 1 "*Production Pathways for Hydrogen with a Zero Carbon Footprint*" [3] and 2 "*Zero and Net Zero Carbon Fuel Options*" [4]. This White Paper builds on White Paper 3 [5] which gives an overview of current and projected maturities and energy intensities of the selected technologies and fuel pathways. The latter are of course only part of a wider range of criteria to assess (net) zero carbon fuels. This White Paper 4 argues why a well-to-wake perspective is essential when assessing alternative fuels and respective policies in maritime shipping.

## Well-to-wake $CO_2$ emissions

Energy efficiency of fuel pathways and respective technology maturities are major factors to consider for assessing upstream GHG emissions and energy consumption. CIMAC White Paper 3 [5] summarizes and consolidates figures on technology readiness levels (TRL) and energy efficiency of fuel pathways from well-to-tank. As excess renewable electricity supply will not be enough in foreseeable future for the large-scale production of (net) zero carbon fuels, the energy mix of electricity system may become crucial.

For evaluating the climate impact of (net) zero carbon fuels, the $CO_2$ or GHG emission footprint is more important than sole process efficiencies. The percentage of renewable energy used to produce these fuels matters. Hence, the energy mix of the electricity or energy system determines the $CO_2$ footprint of the (net) zero carbon fuel. The performance of (net) zero carbon fuels varies heavily depending on the root sources for its hydrogen origin as base component, whether carbon needs to be attached and the heritage of the electrical energy or energy mix used for the (net) zero carbon fuels production. Thus; sometimes its overall GHG-impact is even worse compared to current fossil fuels. Therefore, it is of key importance for fuels produced from renewable electricity that the projects be placed such that there is a high availability of renewables in the electricity mix. For simplicity reasons, we focus in this White Paper on $CO_2$ emissions only.

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[1] In line with terminology of the Getting to Zero Coalition

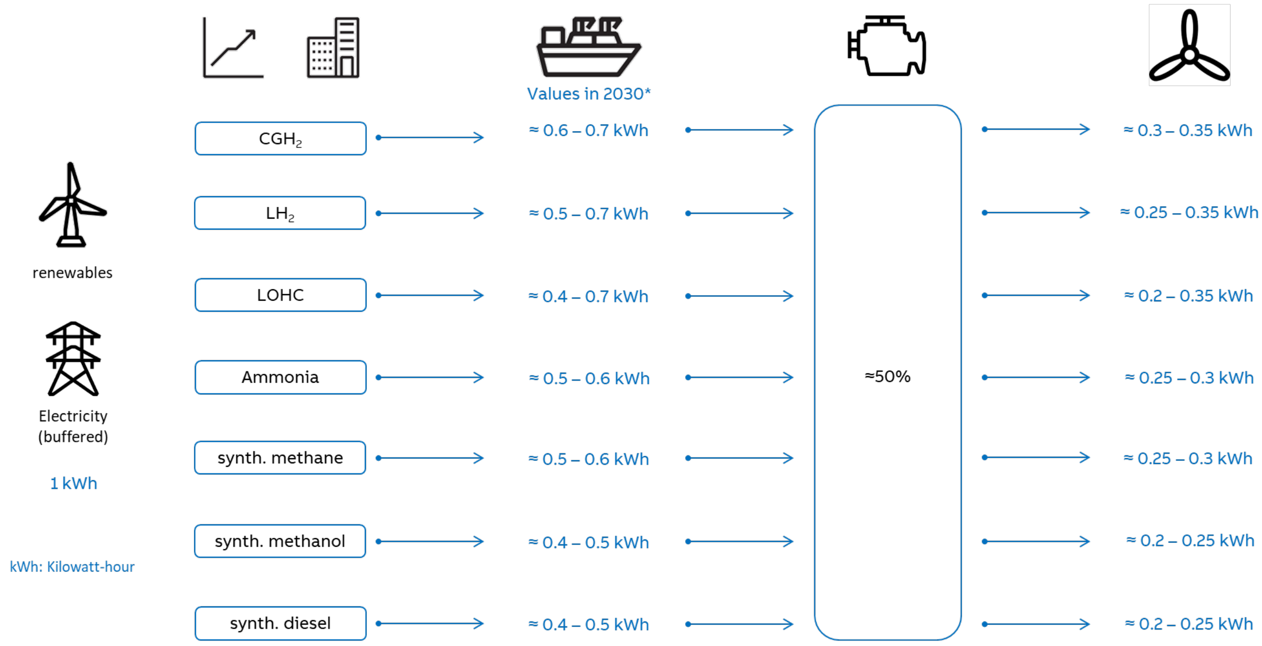


Fig. 1: Energy consumption “well” to “wake”

Figure 1 shows values for each (net) zero carbon fuel starting from one kWh input of energy (buffered electricity), along the production, storage onboard and conversion to mechanical energy at the vessels` propeller. This figure is based on the energy efficiency of the different fuel pathways of White Paper 3 [5] and assumes a constant efficiency of 50% for the ship machinery.

Figure 2 illustrates the footprint dependency on the energy mix of the electricity used for fuel production. A comparison is made between fossil-based conventional diesel and (net) zero carbon fuels regarding their $CO_2$ footprints. Burning marine diesel oil or heavy-fuel oil releases around 630 g $CO_2$/kWh, of which around 530 g $CO_2$/kWh stem from the fuel combustion itself (tank-to wake) [6], while the rest is emitted upstream [7, averaged for MDO/HFO]. To match this value (net) zero carbon fuels, depending on their pathway efficiency must not have a higher g $CO_2$/kWh “well” input of 125 to 220 g $CO_2$/kWh. To achieve a $CO_2$ reduction of 70% requires an electricity mix with approximately 40 – 65 g $CO_2$/kWh in the “well” emissions side. Such low values are currently achieved only in very few production locations globally (e.g. Norway [10] with 18.9 g $CO_2$/kWh in 2018).

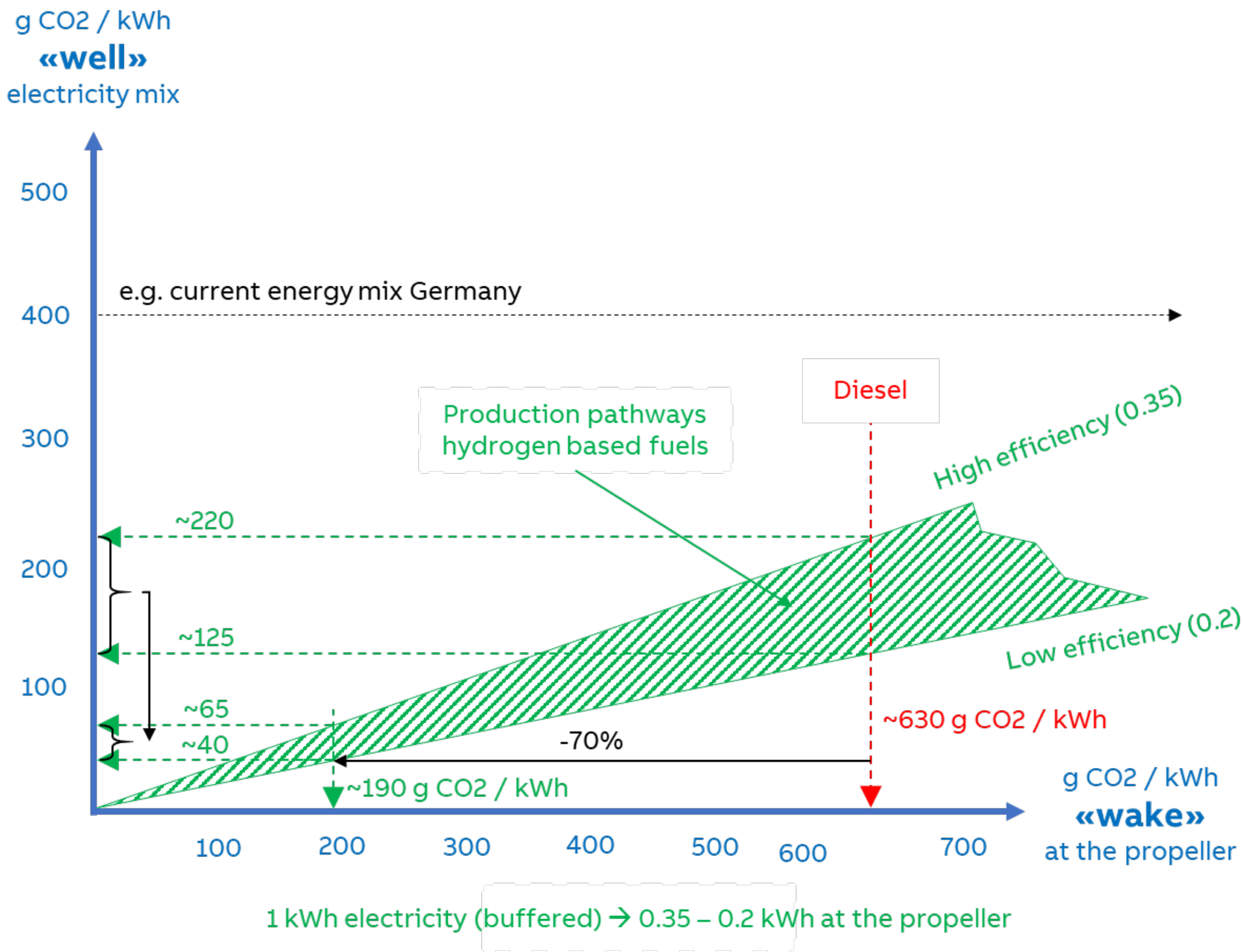


Fig 2: $CO_2$ emissions at "wake" resulting from $CO_2$ emission at "well"

Considering the current $CO_2$ impact of the German energy mix to be around 400 g $CO_2$/kWh [8], it is obvious that a net positive climate impact of (net) zero carbon fuels (compared to current fossil fuels) is only feasible with an increasingly fossil-free electricity power generation.

With the current $CO_2$ footprint of electricity mix still being high in most locations, another pathway for hydrogen production with low net-carbon footprint comes into play. The utmost of current hydrogen production is based on steam-methane reforming (SMR), illustrated in Figure 3: Natural gas is reduced to hydrogen and carbon by a water-gas shift reaction. The carbon is released in the form of $CO_2$. A subsequent state-of-the-art carbon capture process would manage to remove up to 90% of the $CO_2$ in the flue gas, which finally could be sequestrated in e.g. depleted natural gas reservoirs. A study from the IEA [9] outlines a feasible carbon capture process with 90% of $CO_2$ removal (designated as Case 3 in [9]) with an additional energy demand of 11.5% per energy content of the required feedstock. The operation of the SMR process including CCS consumes in total 28% on top of the net energy content of the feedstock. The SMR process itself converts natural gas as feedstock into hydrogen and needs around 16.5% relative to the feedstock to operate the process. This results in process related $CO_2$ emission of 286.3 g$CO_2$/kWh hydrogen. Thus, the overall process of SMR including CCS, where 90% of the CCS processes would remain as $CO_2$ impact for the final hydrogen, i.e. releasing about 28.6 g $CO_2$/kWh hydrogen (Figure 3).

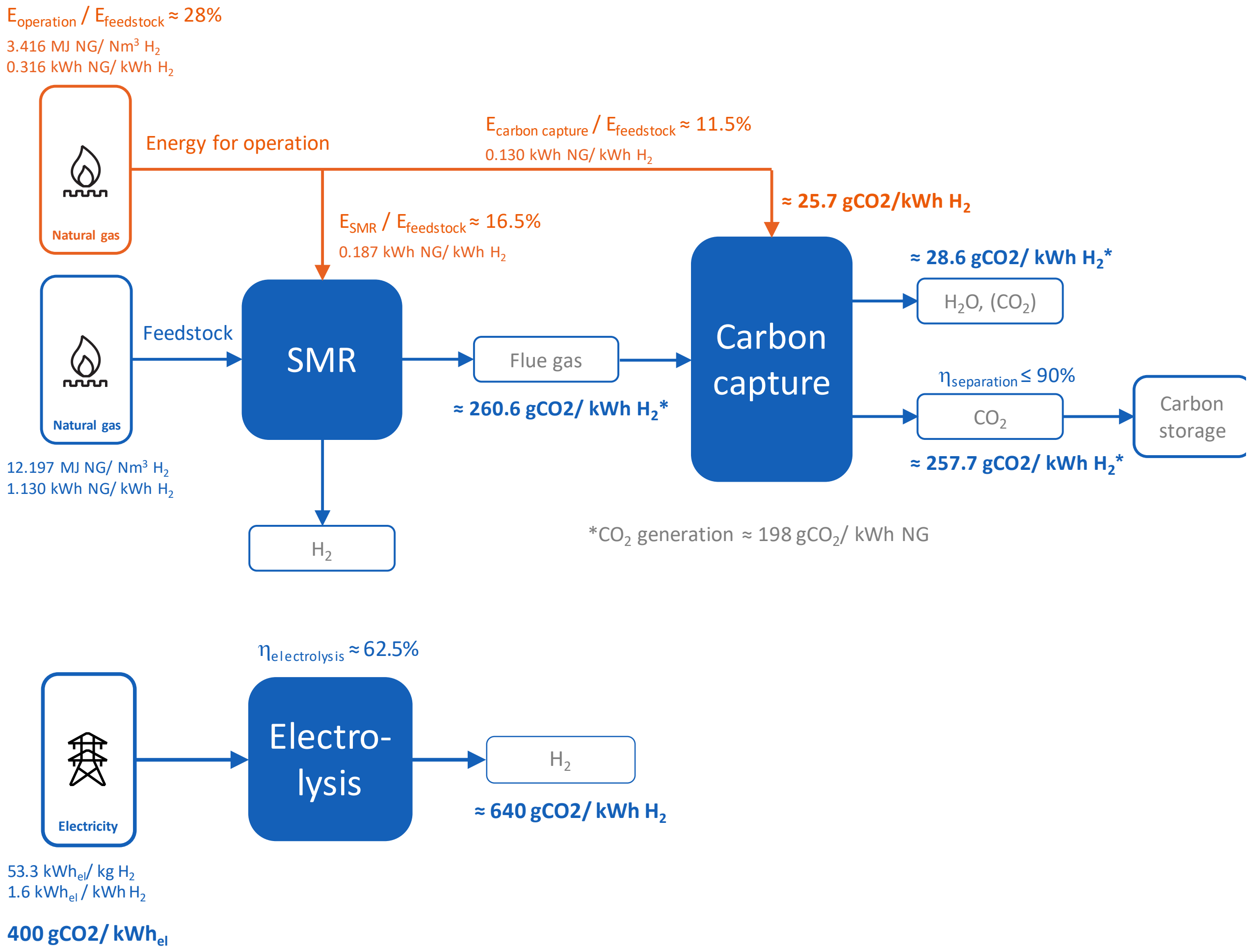


Fig 3: CO2 emissions from SMR with carbon capture vs. electrolysis with grid energy mix

For the electrolysis of 1 kg of hydrogen at an efficiency of 62.5% [5] a power consumption of 53.3 kWh/kg is required. With an energy mix of 400 g $CO_2$/kWhel this would result in $CO_2$ emission of 640 g CO2/kWh hydrogen.

With the extension of current SMR technology with CCS an improvement of almost 96% in $CO_2$ emissions could be achieved. As shown in Figure 4, the hydrogen produced through SMR + CCS is equivalent in $CO_2$ emissions as with electrolysis with an electricity mix with 18 g $CO_2$/$kWh_{el}$. (~18(eq.))

Generation of hydrogen is only the first step in the preparation of a fuel ready for use onboard a ship. In figure 2, wherein the bandwidth of the total $CO_2$ emissions from different fuel options in engine applications is displayed in relation to the $CO_2$ generation from the electricity mix, a comparative range for steam methane reforming with carbon capture can be added. Calculating with the aforementioned $CO_2$ emission of 18 g $CO_2$/$kWh_{el}$ for hydrogen production with electrolysis at an efficiency of 62.5% the lower end of the estimated bandwidth of the $CO_2$ generation of the entire fuel process chain arrives at 50 g $CO_2$/kWh and the upper end at 90 g $CO_2$/kWh.

However, the reduction in $CO_2$ is not only related to CCS, but also to the inherently lower power consumption of SMR in relation to water electrolysis. Even without carbon capture certain fuels based on hydrogen from SMR would end up in lower total $CO_2$ emissions than conventional diesel fuel. An equivalent electrolysis plant with an efficiency of 62.5% would require an energy mix with 163 g $CO_2$/$kWh_{el}$ (~163(eq.) in Figure 4) to be on par in $CO_2$ emissions (~ 465-815 g CO2/kWh) with SMR without carbon capture.

This is most likely valid for the direct use of hydrogen stored as liquid, under pressure or in a LOHC and for ammonia, as they meet the bandwidth between 465 and 630 g$CO_2$/kWh, but not for the synthetic hydrocarbons at the lower end of energy efficiency of their production chain, as they exceed the 630 g$CO_2$/kWh from diesel fuel. Due to the stringency of the IMO ambition levels a significant improvement in the carbon footprint is necessary, such that carbon capture is mandatory to meet them.

Therefore, for a transitional phase, where not enough electricity from regenerative sources is available to produce marine fuels the pathway via steam-methane reforming with carbon capture and storage remains an alternative with very low well-to-wake $CO_2$ emissions.

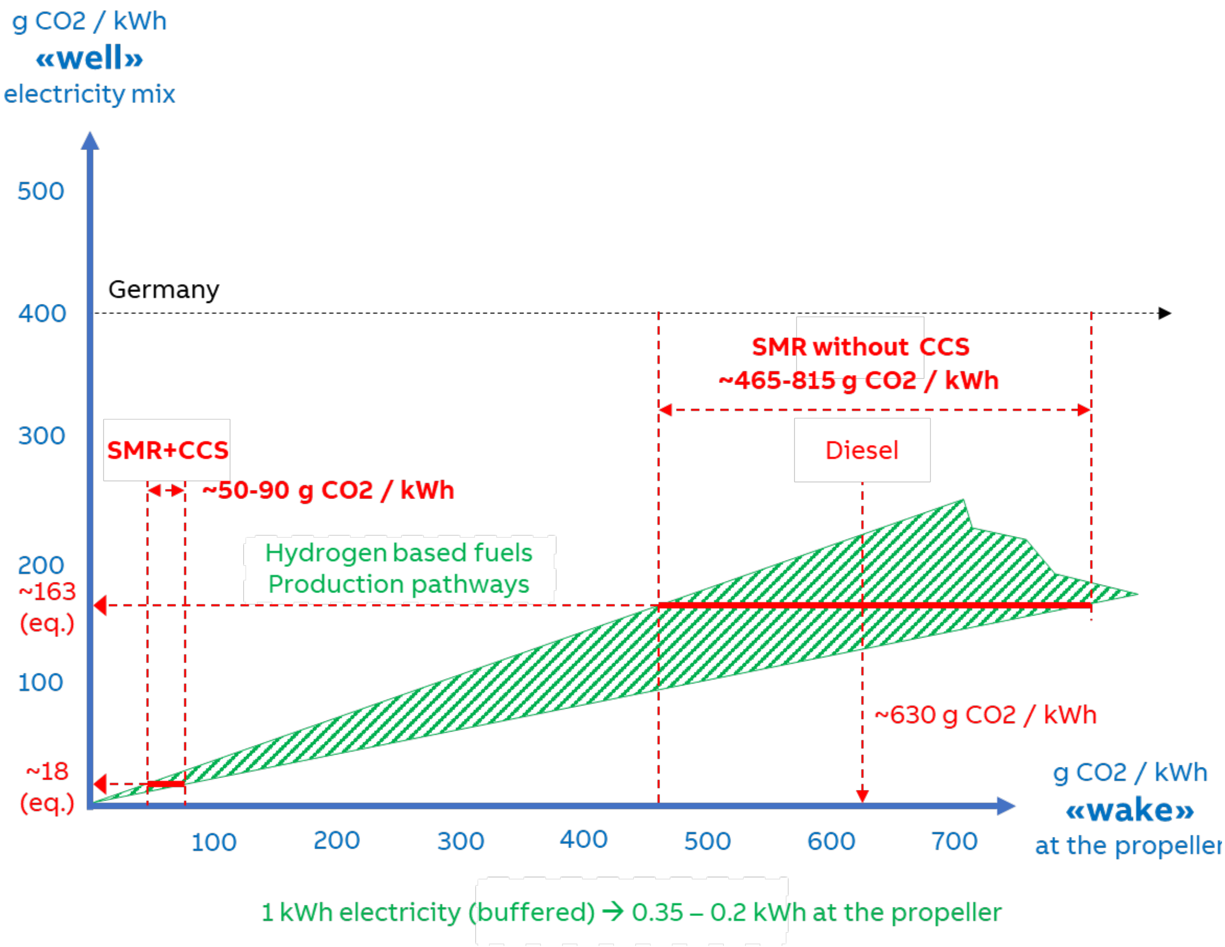


Fig. 4: $CO_2$ emissions at “wake” resulting from $CO_2$ emission at “well”, including SMR+CCS

In context of its Initial GHG Strategy [2], the IMO has initiated discussions on life-cycle-assessment for sustainable alternative fuels as part of the proposed mid- and long-term measures. Discussions on these long-term are yet to take place. However, there have been several submissions to the MEPC and Intersessional GHG meetings (including one from CIMAC, submitted kindly via EUROMOT [ISWG-GHG 7/5/1]), which addresses the necessity to include a well-to-wake approach for the use of future sustainable alternative fuels. Up-until now, the IMO has applied in all its current instruments the tank-to-wake (or tank-to-propeller) concept. However, the need for a whole life-cycle assessment of fuels and its production pathway have reached the IMO and discussions are though increasing on how to account for a well-to-wake perspective on alternative fuels including outside of IMO's typical regulatory scope. It needs to be at least visible for shipowners and operators when bunkering, what upstream emissions are attached to the respective fuel. Transparency would be key to ensure that only fuels enter the maritime market that improve the overall GHG impact. CIMAC supports these discussions to ensure a valid defossilization of maritime fuels.

## Conclusion

The exemplary calculations show that (net) zero carbon fuels require a significant amount of renewable energy in the energy system to have a positive impact compared to conventional fuels. As energy efficiency of all fuel pathways will improve over time, the dependency on the input energy mix for hydrogen generation remains. A full understanding and a correct evaluation of the overall climate impact of (net) zero carbon fuels is only possible with a well-to-wake perspective. The IMO must therefore find ways to integrate this perspective into the regulatory framework making use of the large amount of work already done on Life Cycle Assessments. Otherwise, we risk introducing new fuels while harming the climate instead of effectively reducing GHG emissions.

This White Paper also shows that if the shipping sector plans to use alternative fuels which do not release additional GHG emissions soon, the renewable energy supply needs to be scaled up rapidly and significantly.

- With the current $CO_2$ footprint of electricity mix in Germany and at many locations globally, (net) zero carbon fuels result in increased $CO_2$ emissions compared with the direct use of marine diesel oil. Thus, e-fuels produced from electricity to truly be low-CO2 emissions, projects need to be established at sites where large amount of renewable electricity is available.
- The production of (net) zero carbon fuels based on hydrogen from steam-methane reforming or pyrolysis has the potential to reduce the $CO_2$ footprint significantly in a transition period, it requires CCS facilities to be available.
- Dedicated production sites for (net) zero carbon fuels for marine being fed solely with renewable energy are required. Using electricity out of the public grid would have a negative impact on the global $CO_2$ situation and hence is not a sustainable solution at many locations.

## Sources

[1] DNV-GL (2019) – Maritime Forecast to 2050

[2] Resolution MEPC.304(72)

[3] CIMAC (2020) - White Paper 1: Production Pathways for Hydrogen with a Zero Carbon Footprint

[4] CIMAC (2020) - White Paper 2: Zero and Net Zero Carbon Fuel Options

[5] CIMAC (2020) – White Paper 3: Efficiencies and Maturities of (Net) Zero Carbon Fuel Pathways

[6] EEDI carbon factors for MDO and LFO acc. Resolution MEPC.308(73), LHV for MDO according ISO 3046-1:2002, LHV for HFO acc. EC standard values for emission factors

[7] SINTEF (2020) LNG and Cruise Ships, an Easy Way to Fulfil Regulations – Versus the Need for Reducing GHG Emissions: global values acc. Thinkstep

[8] : IEA (2019), $CO_2$ Emissions from Fuel Combustion 2019, www.iea.org/statistics

[9] IEA (2017) – Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS

[10] Electricity disclosure 2018 - NVE

## Imprint

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