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CIMAC White Paper 2

Zero and Net Zero Carbon Fuel Options

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 21, 2019.

Introduction

There are a number of pathways for the shipping industry to achieve the 2050 emission reduction targets of the Initial IMO GHG Strategy[1]. Besides other technical and operational energy efficiency measures, employing zero carbon or net zero carbon fuels[2] seems the only way to achieve the GHG reduction level aimed for in the long-term[3]. Hydrogen with a net zero or zero carbon footprint is the starting product for these fuels. Different production pathways of hydrogen have been outlined in the CIMAC white paper "*The Need for Hydrogen with a Zero Carbon Footprint*"[4]. The final products are ranging from net zero carbon fuels like synthetic methanol containing carbon from renewable sources (e.g. from biomass combustion) up to zero carbon fuels which are carbon-free like ammonia.

A (non-exhaustive) overview of potential pathways is shown in Figure 1. The pathways vary in their energy intensity and need for resources. Apart from hydrogen, other zero and net zero carbon fuels can be generated with further conversion steps and by adding nitrogen or carbon.

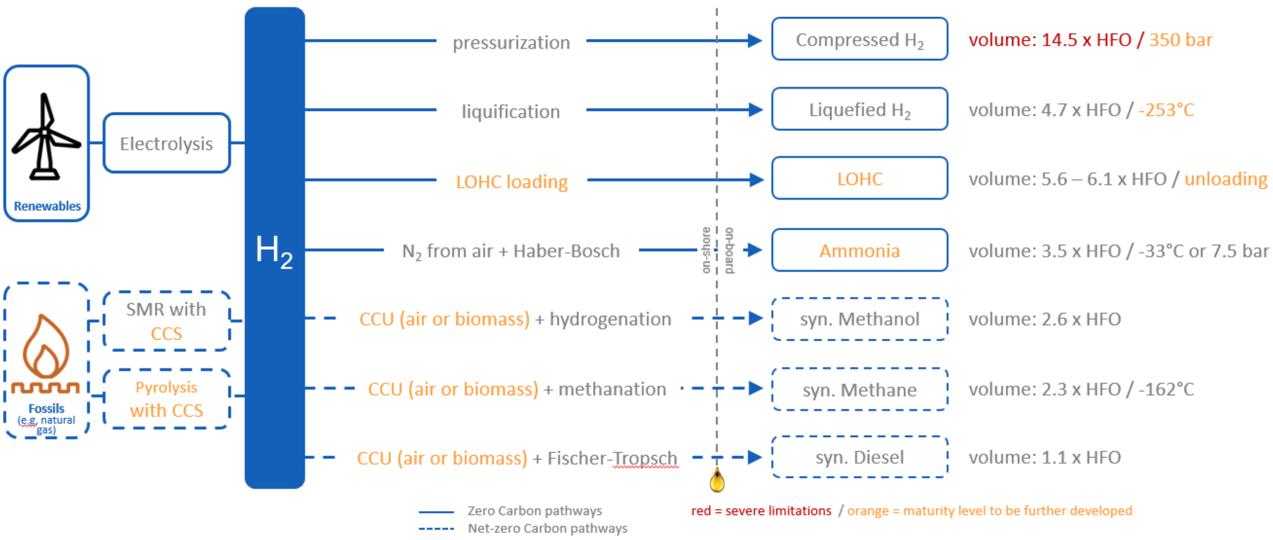

Figure 1: (Net) Zero carbon fuel production pathways (non-exhaustive); fossil pathways as transitional technologies; CCS= Carbon Capture and Storage; CCU= Carbon Capture and Utilization; SMR= Steam Methane Reforming (Source: ABB, 2020)

Hydrogen

Production of hydrogen (H_2) based on zero carbon energy sources requires less processing steps than synthetic fuels based on carbon like synthetic diesel. Hydrogen originating from an electrolysis process typically has pressure levels of less than 30 bars and cannot be transported further in large amounts in this form other than in pipelines due to the low

[1] Resolution MEPC.304(72)
[2] As outlined by the *Getting to Zero Coalition* which CIMAC is supporting.
[3] DNVGL (2019) – Maritime Forecast to 2050, p.34
[4] CIMAC White Paper 1 (2020) – Production Pathways for Hydrogen with a Zero Carbon Footprint

energy density. Otherwise, hydrogen can be transported either pressurized, liquefied or via bonding to a liquid (e.g. liquid organic hydrogen carrier (LOHC)). Large volumes and storage requirements (Figure 1) as well as safety issues pose a challenge to the application of hydrogen as a fuel which might limit its practical uptake. A legislative framework governing the use of hydrogen as a fuel for shipping is yet to be developed, as is the fuel distribution network.

Ammonia

Ammonia's molecular structure incorporates three hydrogen molecules and is thus a carbon-free hydrogen carrier with a lower volume than hydrogen itself; nevertheless, ammonia is highly toxic. For the ammonia synthesis, nitrogen (N_2) is captured from the air as it is the primary gas in the atmosphere (78%). The Haber-Bosch process is today the only process to synthesize ammonia on an industrial scale. The process produces ammonia in a high-pressure catalytic reactor and has a high energy demand. However, less energy intensive alternatives are under development (e.g. solid-state-ammonia-synthesis)[5]. Being carbon-free, ammonia's ability to be a zero carbon fuel depends solely on renewable electricity and a carbon-free hydrogen production pathway. A legislative framework for the use of ammonia as a fuel for shipping is also yet to be developed as well as the fuel distribution network.

Carbon-based synthetic fuels

Carbon-based synthetic fuels can be produced by adding carbon dioxide (CO_2) from renewable sources, via direct air capture (DAC) or from biomass. DAC currently requires a significant amount of energy[6] and is not available on an industrial scale yet, whereas CO_2 from biogenic point sources (like biogas facilities) is already available. As the latter would not be able to supply CO_2 in sufficient amounts for a large-scale production of net zero carbon fuels, investments and upscaling of DAC are needed. With different technologies and materials under development, the range for cost estimations is wide, but it is expected that the process may be more cost-effective in future[7], e.g. through heat recovery from other processes[8].

Depending on the desired synthetic fuel type, CO_2 needs to be added either directly or by converting it into carbon monoxide (CO) first (e.g. through water-gas shift reaction (WGSR)). These carbon-based synthetic fuels can be gaseous like methane or liquid like methanol or diesel. The relevant synthesizing processes are (Figure 1):

- Methanation
- Fischer-Tropsch process
- Methanol synthesis

Depending on the process further refining steps are needed.

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[5] Garagounis et al. (2014)
[6] According to Climeworks, DAC process takes up more than 50% of the thermal energy of the final fuel (e.g. diesel)
[7] Brynolf et al. (2018) - Electrofuels for the transport sector: A review of production costs
[8] Fasihi et al. (2019) – Techno-economic assessment of CO_2 direct air capture plants

Methane can be synthesized via chemical/catalytic or biological methanation. The latter one works with microorganisms (archaea) in a bioreactor (methanogenesis) while the first one is using the “Sabatier” reaction with a catalyst like nickel which is widely used.

The Fischer-Tropsch consists of several chemical reactions converting a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. Metal catalysts, high temperatures and pressures are needed to produce syncrude (C_xH_y) which can be refined to the desired product like diesel. The process with the WGSR technology is very exothermic and the resulting heat could be used for high-temperature electrolysis or DAC[8].

Methanol synthesis is a known, globally used industrial process consisting of three main steps (production of syngas, production of crude-methanol and conditioning). Industrial standard are copper-zincoxide-alumina catalysts. Research is under way looking into a direct methanol synthesis eliminating the step of producing syngas[9].

Maritime and other sectors

Synthesis and conditioning vary for these (net) zero carbon fuels and thus have a direct impact on the cost of each final synthetic fuel because additional energy consumption for fuel production requires additional upfront investment and different pathways require different infrastructures. Even though the convenience level increases with each processing step because a synthetic (carbon-based) fuel increasingly resembles current fossil fuels, prices for these highly processed fuels might be higher. However, estimations for future prices come with high uncertainty and vary depending on the system boundaries considered (e.g. pure fuel production cost vs. inclusion of infrastructure cost).

(Net) Zero carbon fuels will find application not only in maritime, but also in other transport sectors and energy-demanding industries. On one hand, competition for (net) zero carbon fuels and for the so far limited renewable electricity can be expected. On the other hand, demand in various industries can be a benefit due to scale effects and a higher willingness-to-pay in other sectors. In general, (net) zero carbon fuels are a cross-sectoral issue because sectors and industries become increasingly interlinked throughout the whole energy transition and regarding the production of hydrogen and derived fuels.

In the maritime sector, the applicability of the different (net) zero carbon fuel types and the application of different propulsion systems (electrification, fuel cell, hybridization, internal combustion engines) will vary for different ship types. Deep-sea shipping has fewer options compared to the short-sea segment[10]. With the ability to combust all these hydrogen-based fuels, the internal combustion engine is likely to remain the most energy-efficient, reliable and cost-effective solution for shipping – complemented by other propulsion options. Up until now, it is not possible to project with certainty which (net) zero carbon fuel type will be dominant in shipping in the future as there is a multitude of factors to consider (e.g. price, infrastructure, bunkering implications and drop-in capability).

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[9] Hobohm et al. (2018) – Status und Perspektiven Flüssiger Energieträger in der Energiewende
[10] DNVGL (2019) – Maritime Forecast to 2050

Imprint

CIMAC e. V.
Lyoner Strasse 18
60528 Frankfurt
Germany

President: Prof. Dr. Donghan, Jin
Secretary General: Peter Müller-Baum

Phone +49 69 6603-1567
E-mail: info@cimac.com

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