PROSPECTS FOR CARBON-NEUTRAL MARITIME FUELS PRODUCTION IN BRAZIL

Preliminary report for the Brazilian Navy

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The international shipping industry has set ambitious targets for reducing greenhouse gas emissions from the sector. The strategy defined by the International Maritime Organization (IMO) proposes a quantitative reduction in carbon intensity and GHG emissions, which includes, for instance, a 50% reduction in GHG emissions by 2050 compared to 2008 levels (ICCT, 2018). To achieve this target, the sector is looking at potentially carbon neutral fuels from renewable energy sources. Several alternatives can be considered, such as distilled biofuels, bio-LNG, bio-alcohols, hydrogen, ammonia and the so-called electrofuels.

Maritime transport is the backbone of World trade and globalization. It is the most efficient way to promote the medium- and long-distance trade around the World. Despite the cargo containerization process observed in the past decades, long-haul shipping still focuses on the transportation of mineral and agricultural commodities, such as coal, oil, soybeans and wheat (UNCTAD 2019). Thus, while the trade of higher value-added products (typically containerized) is concentrated on the Asia-North America and Asia-Europe routes, the major part of the sea trade is associated with the supply of raw materials by countries of the global south. These are typically low value-added products sold in bulk and transported on large vessels (UNCTAD 2019).

In this context, Brazilian foreign trade is strongly based on primary products and low added value commodities. The main Brazilian products exported to the international market are iron ore, soybeans, crude oil and sugar. On a mass basis, these four products account for more than three-quarters of Brazilian exports, while their combined value represents only a quarter of the country's exports, as illustrated in Figure 1 (Schaeffer et al. 2018). Furthermore, Brazil has an unfavorable geographical location when it comes to international trade and its main exports´ destinations. Far from East Asia, Europe and the United States, and with no direct access to the Pacific Ocean, the country must deal with longer travel times, in addition to higher fuel costs and carbon intensities (Schaeffer et al. 2018).

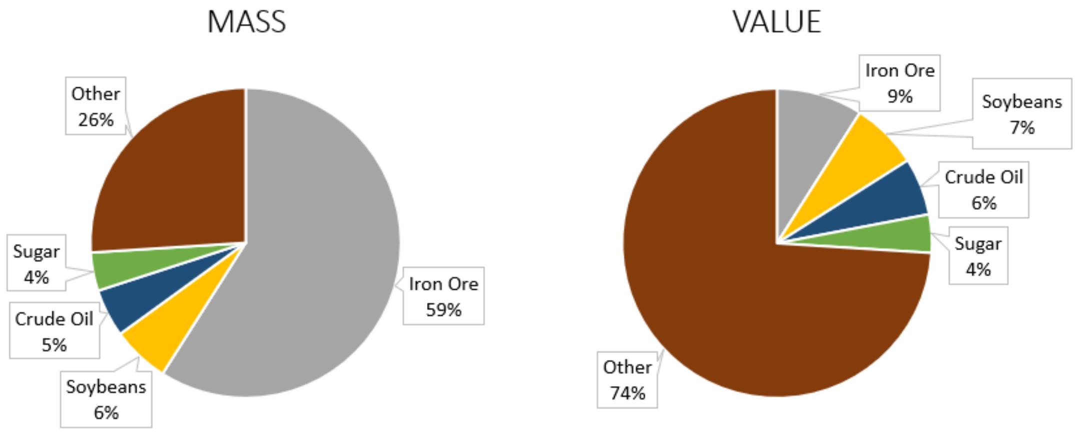

Figure 1: Share of the four main Brazilian export goods in terms of mass and value in the period from 2001 to 2018.
Source: Schaeffer et al., 2018

Deep-sea shipping mostly includes large, ocean-going vessels covering long routes and often without a regular schedule (except for container ships). Vessels operating in long-distance transportation require fuel that is globally available and has a good energy density in order to maximize the space available for cargo transport over long distances. In this sense, the choice of mitigation measures to the shipping sector should be carefully evaluated given the impacts they might have on international trade.

From a techno-economic perspective, various potentially carbon neutral marine fuel options from renewable energy sources could serve as a medium- to long-term alternative to the oil products currently used for propulsion of ships. From a strictly technological point of view, the possibilities are diverse, ranging from the direct use of vegetable oils to the production of synthetic fuels from hydrogen (H_2) and recycled carbon dioxide (CO_2). Figures 2, 3 and 4 present all the pathways considered in this study, from feedstocks to final energy carriers and their possible applications as marine fuels.

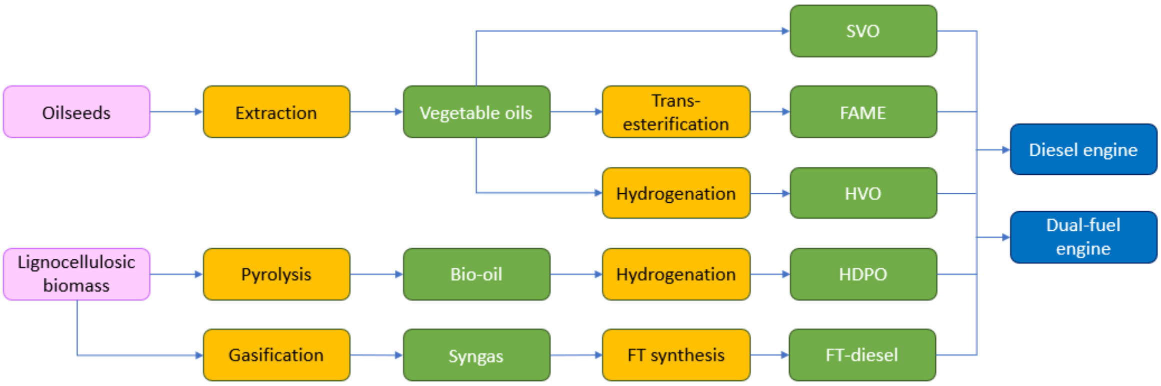

Figure 2: Potential carbon neutral fuels (group 1 - distilled biofuels).

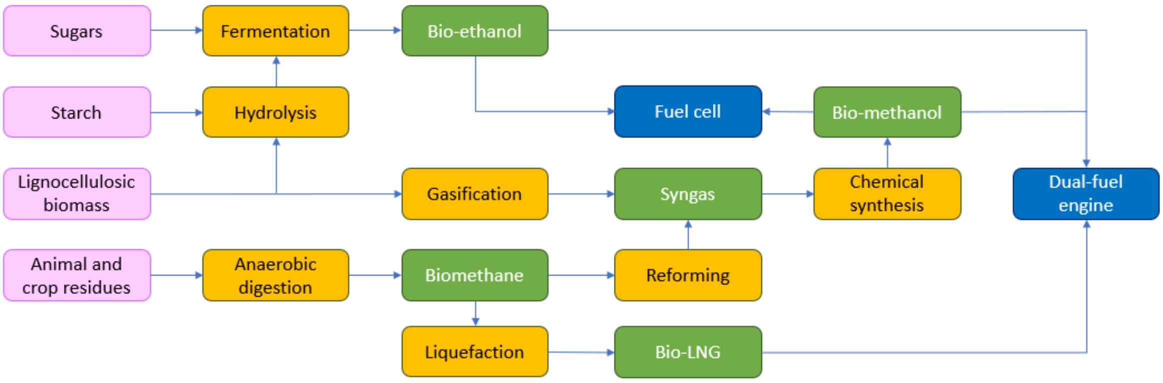

Figure 3: Potential carbon neutral fuels (group 2 – alcohols and liquefied gases).

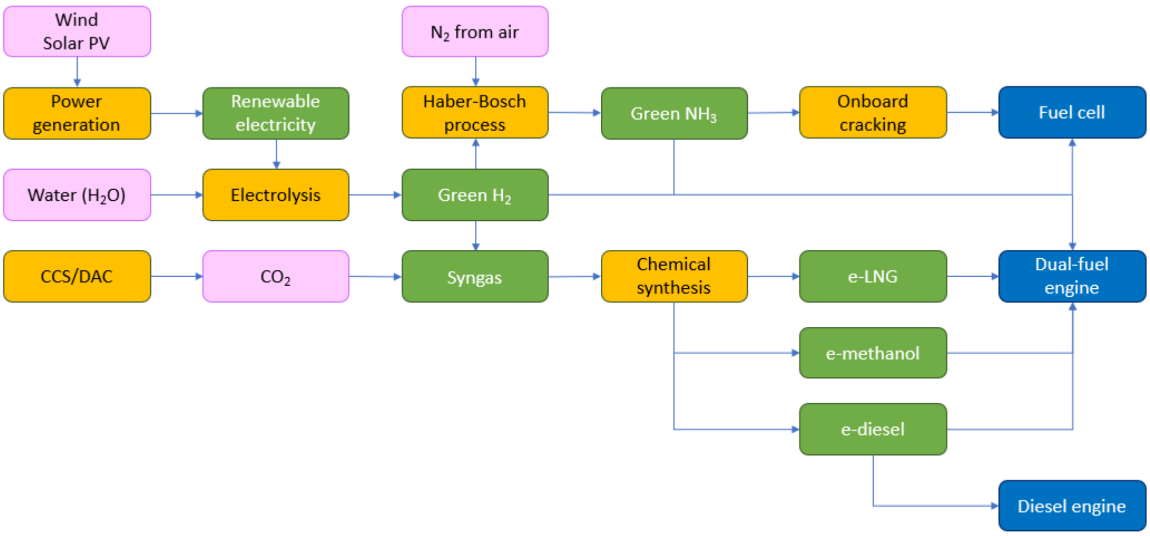

Figure 4: Potential carbon neutral fuels (group 3 – hydrogen, ammonia and electrofuels).

Brazil can be considered a potential producer of marine biofuels (biobunkers) given the high availability of biomass resources and the long experience in liquid biofuel production in the country. In addition, the significant share of renewable energy sources and the low emission factor of the Brazilian power grid would facilitate the production of green hydrogen, green ammonia and electrofuels.

In order to perform a preliminary assessment of the operational, commercial and sustainable aspects of various alternative fuels for the Brazilian deep-sea shipping transportation, a set of criteria were developed. This analysis is critical for assessing potential advantages and adverse side effects of these various alternatives, so as, and facilitate the selection of the most suitable available options. The performance of the alternatives in each criterion is determined by a scale from 1 to 5, where 1 means "Very Bad" and 5 "Very Good". Similarly, this assessment makes use of a color scale for presentation purposes (Table 1). Table 2 presents the results obtained for the different alternatives assessed here, based on the selected set of criteria.

Table 1: Classification of various fuel alternatives in terms of their different scores.

Score	Color scale	Description
1		Very Bad
2		Bad
3		Neutral
4		Good
5		Very Good

Table 2: Evaluation of the fuel alternatives according to the criteria defined.

	SVO	FAME	HVO	HDPO	FT-diesel	Bio-LNG	Bio-CH_3OH	Bio-C_2H_5OH	Green H_2	Green NH_3	e-diesel	e-LNG	e-CH_3OH
Availability	yellow	yellow	yellow	yellow	yellow	orange	pale green	green	yellow	yellow	red	red	red
Applicability	light green	yellow	green	green	green	yellow	pale green	orange	red	orange	green	yellow	pale green
Technology Readiness	green	green	green	orange	yellow	green	pale green	yellow	yellow	orange	yellow	orange	orange
Energy Density	green	green	green	green	green	yellow	orange	yellow	red	orange	green	yellow	orange
Economic	light green	green	light green	yellow	yellow	light green	green	green	red	orange	red	red	red
Safety	green	green	green	yellow	green	yellow	yellow	light green	orange	orange	green	yellow	yellow
Standards	yellow	light green	light green	light green	light green	light green	green	green	red	red	light green	light green	green
Local Sustainability	light green	light green	light green	light green	green	green	light green	light green	yellow	yellow	yellow	yellow	yellow
Global Sustainability	yellow	yellow	yellow	light green	green	yellow	pale green	orange	green	green	green	pale green	green

SVO = Straight Vegetable Oil; FAME = Fatty Acid Methyl Ester (biodiesel); HVO = Hydrotreated Vegetable Oil; HDPO = Hydrotreated Pyrolysis Oil; FT-diesel = Fischer-Tropsch diesel (synthetic diesel); Bio-LNG = liquefied biomethane; Bio-CH_3OH = biomethanol; Bio-C_2H_5OH = bioethanol; Green H_2 = renewable-based hydrogen; Green NH_3 = renewable-based ammonia; e-diesel = electrodiesel; e-LNG = electromethane; e-CH_3OH = electromethanol (e-fuels: fuels produced from H_2 and CO_2 using renewable electricity)

Straight Vegetable Oil (SVO)

Besides being a drop-in alternative, SVO has the advantage of both a high technological maturity and an energy density to replace heavy fuel oil (HFO). Depending on operational conditions, SVO should be pre-heated prior to the injection in diesel engines. However, the current utilization in the food industry and for biodiesel production may affect its availability. Also, sustainability issues may hamper its utilization as a maritime fuel, especially if produced from oil crops such as soybeans and palm.

Biodiesel

Biodiesel’s energy density and technological maturity comprise its largest advantages as a marine fuel. Also, its consolidated market and distribution chain enhance its economic feasibility, at least in the near-term. Notwithstanding, the fuel low stability and the possibility of water contamination hinder its utilization as a drop-in alternative. Furthermore, biodiesel’s current utilization in road transport and some of its sustainability issues regarding an oil-crop-based biofuel reduce its attractiveness to the shipping sector.

Hydrotreated vegetable oils (HVO)

HVO represents a drop-in alternative to replace fossil maritime fuels. Its high energy density, its current production at commercial scales and the growth forecast for the upcoming years make it an interesting alternative to replace fossil fuels. However, sustainability issues regarding oil crop-based biofuels may compromise its availability. Further, the high quality of HVO may make it a more suitable alternative for use in the aviation sector.

HDPO

HDPO is also a drop-in alternative produced from lignocellulosic biomass, which is a largely available resource throughout the World. The high energy density of HDPO makes it a suitable option to replace fossil fuels in ocean-going vessels. Although the technology is not mature yet, new conversion facilities are under construction. Finally, concerns regarding its low flash point and high costs may become a barrier for its use as a maritime fuel.

Fischer–Tropsch diesel (FT diesel)

FT-diesel is another drop-in alternative that uses residual biomass as feedstock. The fuel’s high energy density and mitigation potential makes it an interesting alternative to replace fossil fuels in long-distance shipping. However, up until now at least, the technology has been demonstrated at a pilot-scale but is not commercially available yet, which may affect its availability. Moreover, as a high quality and costly alternative, it may be better suited for the aviation sector, whose fuel is highly priced.

Bio-LNG

Bio-LNG represents a biofuel alternative that is not suitable for diesel engines that represent the major part of the world shipping fleet. LNG vessels are already in operation and some scenarios forecasts indicate their growth for the upcoming years. Bio-LNG's development is mostly limited by the availability of bunkering facilities around the World. Also, the technological processes to produce Bio-LNG are fully developed. However, Bio-LNG has a lower energy density in volumetric basis than distillate fuels, which means that it requires more space to be stored in ships. Also, bunkering costs represent an economic challenge for its use as maritime fuel. Nonetheless, the existence of standards for gaseous maritime fuels and the potential reduction in GHG and air pollutant emissions makes Bio-LNG an attractive alternative for fossil maritime fuels.

Green Hydrogen

Hydrogen (H_2) use in fuel cells is the main alternative for its utilization for ship propulsion, but the adaptation of internal combustion engines (ICEs) needs to be considered. Its use as a fuel does not generate direct GHG emissions or air pollution. Nevertheless, green H_2 has relevant disadvantages as a maritime fuel. In addition of being highly flammable, producing an invisible flame and of having a very low volumetric energy density, the fuel also has high production, storage, transport and bunkering costs. Also, it is not compatible with the existing fleet, and as such H_2 would be preferentially used in fuel cells. Technological readiness is also an issue, especially when produced from intermittent renewable energy sources. Moreover, the existing infrastructure is completely based on non-renewable energy and the production via electrolysis puts extra pressure on water resources, indicating its current lack of feedstock and infrastructure for its production and use. On the other hand, remaining global solar and wind energy potentials are vast, which would be a plus for green hydrogen production and use in the future.

Green Ammonia

Green ammonia is potentially a carbon neutral fuel (reduction of at least 95% in life cycle GHG emissions) that also leads to significant reductions in air pollutants (except for NO_x). It could be used as a maritime fuel in internal combustion engines or in fuel cells (either directly or as an energy carrier for H_2) and both pathways face technological and technical challenges. The use of pure NH_3 in ICEs, for instance, is hindered by its combustion properties[1]. Alternatively, it could be used as a support fuel, such as green H_2, biomethanol or biogas. In the case of fuel cells, an onboard plant would be required to crack the NH_3 molecules and produce H_2. To this end, high-temperature fuel cells, which are not fully developed, would be required. Thus, NH_3 is not a mature technology yet (especially in terms of its use as a fuel) and has low applicability to the existing fleet. Energy density is also a problem given that NH_3 requires a volume three times higher than a conventional bunker fuel. Due to the high cost of electrolysis, its economic performance is also weak, with levelized energy costs around two times those of distillate biofuels. Finally, although NH_3 is safe from a flammability perspective, it is corrosive and highly toxic, harnessing its operational safety.

Biomethanol (Bio-CH_3OH)

Biomethanol can be produced from several feedstocks and relies on a solid existing infrastructure, especially in the case of the biomethane route. It has also a good economic performance, with reasonable production costs in comparison to other low carbon options. Despite of not being a drop-in fuel, methanol has good applicability on the global fleet, given that its use requires minor modifications on existing maritime engines and on bunkering infrastructure, with the possibility of flex-fuel operation. Moreover, biomethanol provides significant air pollution and GHG emissions cutbacks. The main inconvenient related to the use of biomethanol as a maritime fuel is its low energy density, as it requires twice as much space as distillate fuels.

Bioethanol (Bio-C_2H_5OH)

Bioethanol is the most used biofuel in transportation around the world, with the US being the largest producer followed by Brazil. Given its high availability, bioethanol prices are low compared to other biofuels. However, ethanol has not been used as a fuel in large maritime engines. In order to make it a drop-in alternative for diesel engines, it is necessary to increase its cetane number and its lubricating power. Moreover, bioethanol has about half the energy density of diesel, which implies additional fuel storage space. In terms of safety, it can be corrosive to some materials, but it dissolves easily in water, it is biodegradable, and does not bioaccumulate. At the same time, bioethanol mitigates local and global environmental impacts, considering the reduction in aldehydes, SO_x, PMs and CO_2 emissions and, depending on engine characteristics, nitrogen oxides (NO_x) as well.

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[1] Narrow flammability range and low flame speed.

Electrodiesel (e-diesel)

Electrodiesel is the same fuel as FT-diesel in terms of its chemical composition. Thus, it has very good energy density, applicability and safety ratings. Also, from a global sustainability perspective, the e-diesel is a promising fuel, presenting very low or nearly zero life cycle GHG emissions. Its main drawback is the economic aspect. The production of H_2 from intermittent energy sources implies high costs and several technical challenges. Besides, there is another relevant issue regarding feedstock availability, given the fact that CO_2 must come from CCS[2] or DAC[3], which are currently not available in large scales.

Electromethane (e-LNG)

Electromethane is chemically identical to biomethane. Therefore, many of the bio-LNG ratings also apply to e-LNG. Furthermore, similarly to e-diesel, e-LNG has a weak performance in terms of costs and feedstock availability.

Electromethanol (e-CH_3OH)

Electromethanol shares many of the biomethanol ratings because they are equivalent fuels in terms of molecular composition. Similarly to the other e-fuels, e-methanol faces challenges regarding feedstock availability and technological (CO_2 from CCS or DAC) and technology readiness. However, its production costs are quite low when compared to e-diesel and e-LNG, which could be an advantage.

Conclusion

The evaluation and comparison of the different fuel alternatives is useful to identify their main advantages, drawbacks and readiness for application in the long-distance shipping sector. Distillate biofuels seem to be a promising alternative, at least in the near-term, given their high energy density and compatibility with current infrastructure. This is particularly relevant in the case of Brazil, whose international trade profile is characterized by long-distance shipping of low added value products. However, the availability of sustainable biomass and the competition with other sectors may hamper biofuels production for the shipping sector. In this sense, the utilization of biomass residues that are currently not harnessed reduces sustainability concerns

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[2] Carbon Capture and Storage (CCS) is the process of capture, transport and storage of waste CO_2 from different sources (industries, refining, and biomass conversion plants, for example).

[3] Direct air capture (DAC) represents the capture of CO_2 directly from the atmosphere to produce a concentrated stream of CO_2.

and enables the production of bioenergy at large scales. Nonetheless, logistic issues regarding large scale conversion plants could increase biofuels costs and emissions.

In addition, bio-LNG production also reduces concerns regarding the sustainability of biomass sources if it uses residual feedstock to produce biogas. On the other hand, it would be an alternative for the medium- to long-term that may not be suitable for long-distance shipping, given the lack of bunkering infrastructure around the World and its low energy density.

The use of ethanol as a maritime fuel is particularly interesting for Brazil, one of its major global producers. However, its low energy density, the need of additives in the fuel, the risk of corrosion and its current use in road transport reduce its competitiveness to be used in maritime transportation.

Green hydrogen seems to be today a distant alternative for the case of Brazil, especially because of its poor performance in terms of costs, energy density and applicability. Green ammonia, which has slightly better ratings in these criteria, could be an alternative for carrying hydrogen. Alternatively, it could be used in Brazilian cabotage transport. E-fuels are an interesting option from both a technical and a sustainability perspective, but they still face significant challenges in terms of cost, at least in the medium-term.

References