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DEVELOPMENT OF A SAFETY REGULATORY FRAMEWORK TO SUPPORT THE REDUCTION OF GHG EMISSIONS FROM SHIPS USING NEW TECHNOLOGIES AND ALTERNATIVE FUELS

Report of the Correspondence Group

Submitted by the United States

SUMMARY

Executive summary:	This document provides the report of the Correspondence Group on Development of a Safety Regulatory Framework to Support the Reduction of GHG Emissions from Ships Using New Technologies and Alternative Fuels.
Strategic direction, if applicable:	3
Output:	3.8
Action to be taken:	Paragraph 16
Related documents:	MSC 107/20, MSC 107/17/21, MSC 107/17/24, MSC 107/WP.10 and MSC 105/2/2

Background

1 The Maritime Safety Committee, at its 107th session, agreed to include in its biennial agenda, a new output for the development of a safety regulatory framework for the reduction of GHG emissions from ships. In order to progress the work under this new output intersessionally, the Committee agreed to establish the Correspondence Group on Development of a Safety Regulatory Framework to Support the Reduction of GHG Emissions from Ships Using New Technologies and Alternative Fuels (the Group).

List of participants

2 Representatives from the following Member States participated in the Group:

AUSTRALIA
BELGIUM
BRAZIL
CANADA
CHINA
COOK ISLANDS

DENMARK
FINLAND
FRANCE
GERMANY
GREECE
INDIA
ITALY
JAPAN
LIBERIA
MARSHALL ISLANDS
NETHERLANDS (KINGDOM OF THE)
NORWAY
REPUBLIC OF KOREA
RUSSIAN FEDERATION
SWITZERLAND
UNITED KINGDOM
UNITED STATES

as well as observers from the following intergovernmental organization:

EUROPEAN COMMISSION (EC)

and observers from the following non-governmental organizations:

INTERNATIONAL CHAMBER OF SHIPPING (ICS)
INTERNATIONAL UNION OF MARINE INSURANCE (IUMI)
INTERNATIONAL ASSOCIATION OF CLASSIFICATION SOCIETIES (IACS)
OIL COMPANIES INTERNATIONAL MARINE FORUM (OCIMF)
CESA
SOCIETY OF INTERNATIONAL GAS TANKER AND TERMINAL OPERATORS LTD. (SIGTTO)
CRUISE LINES INTERNATIONAL ASSOCIATION (CLIA)
INTERNATIONAL ASSOCIATION OF DRY CARGO SHIPOWNERS (INTERCARGO)
THE EUROPEAN ASSOCIATION OF INTERNAL COMBUSTION ENGINE MANUFACTURERS (EUROMOT)
WORLD NUCLEAR TRANSPORT INSTITUTE (WNTI)
ROYAL INSTITUTION OF NAVAL ARCHITECTS (RINA)
INTERNATIONAL BUNKER INDUSTRY ASSOCIATION (IBIA)
INTERNATIONAL TRANSPORT WORKERS' FEDERATION (ITF)
SOCIETY FOR GAS AS A MARINE FUEL LTD. (SGMF)
INTERNATIONAL WINDSHIP ASSOCIATION (IWSA)

Terms of reference

3 The Committee instructed the Group to:

.1 identify and update a list of fuels and technologies which will assist international shipping to support the reduction of GHG emissions from ships using new technologies and alternative fuels;

.2 conduct an assessment for each identified fuel and new technologies (e.g. the state of knowledge of risks and the technical considerations of solutions, hazards and risks, risk control measures) in sub-paragraph .1 in relation to persons, ships (new built and converted) and applicable operations for these, from e.g. projects applying alternative design and approval process where permitted;

.3 based on the outcomes of .1 and .2 above, develop a record for safety obstacles and gaps in the current IMO instruments that may impede the use of the alternative fuel or new technology; and

.4 submit a written report to MSC 108.

Work plan

4 The Group carried out work under the terms of reference (ToR) in three rounds, including an informal virtual kick-off meeting held just before the close of round 1.

5 A summary list of fuels and technologies was developed under ToR 1. The format used for this list was adapted from annex 2 to document MSC 107/17/24 (IACS), as recommended by the Working Group on Fuel Oil Safety established at MSC 107 (MSC 107/WP.10).

6 An annex was developed to capture more detailed information about each fuel and technology collected during the assessment in ToR 2, and to document safety obstacles and gaps identified under ToR 3.

Use of IMO space to facilitate CG communication and collaboration

7 There were some technical difficulties early on in forming the Group and in communicating with all the members who wished to participate. In order to facilitate better coordination and communication, an IMO space was created for work carried out by the Group. This proved an invaluable resource as a central, easily accessible location for collecting and distributing members' input during each Group's round and will serve as a convenient location for storing references and other resources for future work under this output.

List of alternative fuels and new technologies to support the reduction of GHG emissions from ships (ToR 1)

8 The Group embarked on developing a list of fuels and technologies to support the reduction of GHG emissions from ships by using the fuels and technologies discussed in document MSC 107/17/21 (Belgium et al.), as a starting point. The list also included the fuels and technologies that the CCC Sub-Committee had recently developed interim guidelines for (methyl/ethyl alcohol fuels, LPG as fuel, and fuel cell installations) and also the fuels it is in the process of developing guidelines for (hydrogen fuel, ammonia fuel, and low-flashpoint oil fuels).

9 In further refining the list of fuels and technologies, and recognizing that this list is neither exhaustive nor limiting, the following considerations were discussed and agreed upon:

.1 it was agreed by all that "biofuels" should be included in the list of alternative fuels, however, most of the Group was of the view that a general entry for biofuels was not sufficient to capture the necessary detail, and that specific biofuel types should be listed distinctly to capture and address their different risk profiles, gaps and roadblocks. This approach and the list of biofuels can be further refined as work progresses under this output;

.2 it was generally agreed by the Group that fuels should not be separately listed based on how they are produced unless that distinction presents unique safety issues that need to be addressed, for example from risks posed by the inclusion of added components or impurities in the fuel. With that in mind, fuels labelled in such a way as to distinguish how they were produced, such as bio-methane, e-methane, or PtX hydrogen, have not been individually listed as it is assumed that hazards, regulatory gaps and roadblocks arising from their use on board would be the same regardless of how they were produced;

.3 a few comments were made in round 1 that certain fuels and technologies such as LNG and nuclear power are not really "new" since there are already existing regulatory frameworks in place to address them. However, it is understood that some of these "existing" fuels and technologies are now being considered with broader application, or in new ways to facilitate strategies for reducing GHG emissions. In addition, existing technologies may be advancing in ways not anticipated by the current regulatory frameworks in place. To address this, some fuels and technologies that are "existing" and already have regulatory frameworks in place have been included in order to provide a comprehensive review of gaps and roadblocks envisioned by this new output;

.4 it was agreed that fuel blends or mixtures should be included in the list of fuels, and that the regulatory framework for each of these mixtures may vary based on the blended proportions. However, many members raised concerns that at this point we should not focus on identifying all possible mixtures as this could be a very long list and consume too much of the Group's time and effort. Furthermore, it was mentioned that in many cases, mixtures could be covered by a risk assessment without the need to develop additional guidelines for the mixture, considering the existing guidelines for the respective fuels. Therefore, a line item has been included as a place holder for the future need to develop a regulatory framework for addressing fuel mixtures, and a place to record overarching gaps and roadblocks;

.5 the Group recognized that hydrogen and natural gas can be stored as fuel under different physical conditions (i.e., compressed gas, compressed liquid, or cryogenic liquid), or by using new technologies such as metal hydride storage systems, all of which pose their own unique safety risks. So far, the safety codes and guidelines being developed by IMO, such as the IGF Code and the *Interim Guidelines for the Safety of Ships Using Hydrogen as Fuel*, typically address storage methods and the associated safety risks within the context of each fuel. When asked whether the fuels hydrogen and natural gas should be listed without regard to their means of storage, or treated as separate fuels based on the conditions under which they are stored, a majority commented that they preferred the first approach, however there were many comments on the need for capturing the unique safety aspects of different storage methods. To address this, the current proposed summary list shows separate entries for each fuel along with its storage condition. By contrast, the annex lists each fuel without regard to storage condition, but provides room to discuss the different storage methods in the broader context of the fuel. Since this list is flexible, it can be decided to change the approach at a later point if needed;

.6 regarding wind propulsion, it has been noted that the IMO *Guidelines on life cycle GHG intensity of marine fuels* (resolution MEPC.376(80)) include the wind energy in the fuel list (as No. 128) in their appendix 1. For the time being wind energy has not been characterized on the proposed list as an alternative fuel, but it may be prudent to do so in the future if it is determined that analysing wind energy as a fuel would help in identifying and addressing regulatory gaps and roadblocks;

.7 the list of new technologies was also updated based on round 2 input, with several additional technologies now included, and an adjustment in subcategory titles;

.8 there were several comments proposing that the "fuel storage" subcategory should be removed from the list of new technologies, and that fuel storage should be addressed under specific alternative fuels instead (for example hydrogen stored as metal hydride). At this stage, the proposed list keeps storage systems listed as technologies with the understanding that they will also be discussed/addressed under the specific fuels where they are used. The rationale for doing this is that at this early point in our work it may be easier to identify gaps and roadblocks with the storage systems separated out this way. As work progresses under this output, it may become apparent whether a different approach should be taken;

.9 a few comments in round 1 suggested that nuclear power has been addressed through regulations in SOLAS for decades and should not really be considered a new technology. However, an overwhelming majority agreed that it should be included, as shipboard nuclear power is advancing in ways that are not addressed in the current regulatory frameworks which only cover one specific type of nuclear reactor combined with steam turbines;

.10 one member proposed in round 3, that internal combustion engines, gas turbines and boilers under development for new fuels should be added under power conversion systems. While these may not be considered new technologies, their adaptation for use with alternative fuels may pose challenges that should be considered under this framework. This could potentially be done by addressing them as separate "power conversion" items under new technologies, or, alternatively, they could be addressed under the sections dealing with individual alternative fuels. Due to time constraints the proposal was not discussed by the Group and, therefore, these items were not added to the proposed list. However, it is a topic that does have bearing under this output and should be considered further moving forward; and

.11 a comment was made that the question of whether the definition of carbon capture systems is limited to Carbon Capture and Storage (CCS) systems or if it also captures methane abatement and other carbon capture and utilization technologies, needs to be clarified. The intent of the way it is listed, "Carbon Capture Systems (CCS, CCU)", is to include all relevant carbon capture and utilization technologies. To further address this concern, abatement technologies meant to address different emissions are now listed separately under the subcategory of Emissions Control and Reduction.

10 The final summary list of alternative fuels and new technologies is included as annex 1.

Assessment for each identified fuel and new technology (ToR 2) and Record for safety obstacles and gaps (ToR 3)

11 During round 1, members of the Group were asked to provide relevant references, of which they were aware, that provide a level of background and detail to support the assessments under ToR 2 for any of the fuels or technologies being considered. Those references have been compiled and saved on IMO Space for easy reference during the course of the Group's work, as well as for use by potential future correspondence or working groups formed under this output going forward.

12 Similarly, members were asked during round 1 to provide a listing of vessel projects (newbuild and/or conversions) in which any of the fuels or technologies being considered have been used, with the idea that, as work progresses under this output, lessons learned from these projects may be used to inform the assessments and identify gaps and roadblocks. A list of projects that were provided by members has been compiled and saved on the IMO Space site for easy reference during the course of the Group's work, as well as for use by potential future correspondence or working groups formed under this output going forward.

13 The Group developed a format for an "annex" that will support the summary list of fuels and technologies developed under ToR 1 and will provide a consistent method of recording the assessments conducted for each fuel and technology on the summary list. This "annex" to the summary list is included as annex 2.

14 As a starting point for conducting an assessment of each fuel and technology (ToR 2), and identifying gaps and roadblocks (ToR 3), the Group agreed to fill in appropriate sections of the annex using existing references where this work has already been carried out to some extent, recognizing that subsequent work will be needed under this output to validate, and then to add to the annex.

.1 a related IMO document, cited in the MSC 107 proposal for the current output the Group, is working under is document MSC 105/2/2 (IACS) on the development of safety requirements at the needed pace and detail to support the achievement of a decarbonization goal. This document offers views and comments on the risks posed by several alternative fuels and new technologies under consideration by the maritime industry. Information in this reference has been used to initially populate "description" and "risks/hazards" fields in the annex for those fuels and technologies that are discussed in the document;

.2 as a starting point for the "description" fields for many of the other fuels and technologies, text has been filled in based on information taken from two of the reference sources identified in round 1:

.1 MEPC 80/INF.10 – Report on the study on the readiness and availability of low – and zero-carbon ship technology and marine fuels; and

.2 European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon; and

.3 as a starting point for the "existing guidance documents/standards" fields for many of the fuels and technologies, information has been filled in based on results from the "Regulatory Mapping Exercise" under the IMO Project Green Voyage 2050, as reported in document MEPC 80/INF.17. The report referenced can be downloaded from the following link: https://greenvoyage2050.imo.org/. This uses a color-coded system for mapping the regulatory readiness of various alternative fuels.

Table 1: Colour coding system used for the regulatory mapping
Low: Indicates the absence of related marine standards, regulations and/or interim/final guidelines with required work yet to start
Medium: Indicates the availability of work in progress or approved (waiting for adoption) related marine standards, regulations and/or approved interim/final guidelines
High: Indicates the availability of related marine standards, adopted regulations and/or adopted interim/final guidelines

15 Under round 3, the Group was asked to provide proposed text and specific input for the annex on each of the listed alternative fuels and new technologies included. This input has been added to appropriate sections in the annex along with the information provided from references as discussed in paragraph 14. This was done recognizing that there was not sufficient time for the Group to review and to comment, thoroughly, on the text provided so far for the annex, and that subsequent work will be needed under this output to validate all the input and references provided.

Action requested of the Committee

16 The Committee is invited to approve the report in general and, in particular, to:

.1 note the discussion on the development of a list of alternative fuels and new technologies to support the reduction of GHG emissions from ships (paragraphs 8 to 10, and annex 1); and

.2 note the progress made in conducting an assessment for each identified fuel and new technology, and developing a record for safety obstacles and gaps, including the need for additional work in validating and adding to the information provided so far (paragraphs 11 to 15, and annex 2).

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ANNEX 1

LIST OF ALTERNATIVE FUELS AND TECHNOLOGIES

Alternative Fuel	Technical background, hazards, and risks to ship/shoreside (in annex)	Instruments causing barriers	Gaps in the regulations	IMO organ(s) with associated competence
Liquid Fuels				
Biodiesel - *fatty-acid methyl ester (FAME)*				
Bio-oils (from thermochemical pathways) - *hydrothermal liquefaction (HTL) fuel* - *pyrolysis fuel*				
Methanol/Ethanol - *methyl/ethyl alcohol fuels*				
Renewable Diesel - *hydrotreated vegetable oil (HVO)*				
Synthetic Diesel - *Fischer-Tropsch (FT) diesel*				
Liquefied & Compressed Gaseous Fuels				
Ammonia				
Dimethyl Ether (DME)				
Ethane				
Hydrogen - *compressed*				
Hydrogen - *liquid*				
Hydrogen - *metal hydride*				
Methane/Natural Gas - *compressed/CNG*				
Methane/Natural Gas - *liquefied/LNG*				

Alternative Fuel	Technical background, hazards, and risks to ship/shoreside (in annex)	Instruments causing barriers	Gaps in the regulations	IMO organ(s) with associated competence
Propane/Butane (LPG)				
Fuel Blends/Mixtures *(e.g. hydrogen - natural gas)*	A regulatory framework should be developed for mixing fuels to address the safety risks of any fuel mixture. This could take the form of a risk assessment where the properties of each individual component of the mixture would have to be considered in addition to the risks associated with the mixture.			
New Technology				
Power Conversion Systems				
Fuel Cells				
Fuel Reforming				
Nuclear Power				
Solar Power				
Wind Power/Propulsion				
Fuel/Energy Storage (storage also addressed within fuel categories)				
Lithium-Ion Batteries				
Other Battery Technologies				
High-Pressure Composite Cylinders				
Metal Hydrides				
Liquid Organic Hydrogen Carrier (LOHC)				

Alternative Fuel	Technical background, hazards, and risks to ship/shoreside (in annex)	Instruments causing barriers	Gaps in the regulations	IMO organ(s) with associated competence
Improved Efficiency				
Air Lubrication				
Foils				
Low-Friction Antifouling Paints				
Hull Form Optimization				
Optimal Routing				
Propeller Optimization and Propulsion Improving Devices	(e.g. stern ducts, wake equalizing ducts (WED), pre-swirl ducts (PSD), pre-swirl stators (PSS), vortex generator fins (VGF), propeller boss cap fins (PBCF), rudder bulbs in combination with propeller caps, twisted rudders, etc)			
Waste Heat Recovery				
Emissions Control & Reduction				
Ammonia Abatement				
CO2 Abatement - *onboard carbon capture systems (OCCS, OCCU)*				
Methane Abatement				
N2O Abatement				
Onshore Power Supply / Cold Ironing				

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ANNEX 2

DETAILS ON ALTERNATIVE FUELS AND TECHNOLOGIES

Liquid Fuels

Biodiesel
- fatty-acid methyl ester (FAME)
Description:
Fatty acid methyl ester (FAME) • Fatty acid methyl ester is the most common type of biodiesel (mainly used in the road-transport sector). It is produced from bio-oil (triglycerides) and methanol or ethanol, using a transesterification (chemical-conversion) process, as indicated in Figure 2. Glycerol and water are by-products of this process (IEA Bioenergy, 2017; Ecofys, 2012). • The biomass feedstocks most commonly used to produce FAME in Europe are rapeseed oil, palm oil and used cooking oil. Other feedstocks include soybean (common in the U.S. and South America), corn and coconut (common in the Pacific Islands). Animal-based greases and fats, such as tallow and poultry litter, also are used (IEA Bioenergy, 2017). Algae, a widely available potential feedstock, can be used to produce FAME through a transesterification process, but the lipids would need to be removed from the algal biomass beforehand (IEABioenergy, 2017). • For diesel engines, FAME is a more suitable fuel than plant oils (see the section on straight vegetable oil [SVO]below). It can be used as a replacement fuel for marine diesel oil and MGO in diesel engines, but this may require engine modifications and approval from the engine manufacturer. • FAME can be considered a drop-in biofuel which can replace up to a certain percentage of a fossil fuel oils. FAME has been used in blends of up to 30% with fossil fuel oil, requiring little or no engine modifications (IEA Bioenergy,2017). (from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon)
Physical/Chemical properties
Risks/Hazards
• Oxidation, corrosion, long-term storage issues, risk of microbial growth, degradation and formation of solid deposits. • Posing risk for fuel system blockage and clogged filters, formation of sediments or other insoluble compounds in tanks - potentially degrading fuel quality. • FAME may not be compatible with certain materials and elastomers. Rust and metals like copper, brass, bronze, lead, tin, and zinc can expedite degradation, resulting in the formation of sediments. • FAME's risk is overall lower due to having a higher ignition temperature. See: (European Maritime Safety Agency (2023), Safe Bunkering of Biofuels, EMSA, Lisbon) (Correspondence Group input)

Existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates oil fuels with flashpoint > 60°C **Medium regulatory readiness level** SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively. • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover low-flashpoint fuel oil. Development of draft interim guidelines for the use of oil fuels with a flashpoint between 52°C and 60°C are currently under consideration. (from MEPC 80/INF.17)
Gaps
• Distinct cold flow properties – need to address correction of temperature during bunkering/fuel transfer. • Cleaning of fuel transferring equipment and storage tanks onboard - maintenance. (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Bio-oils (from thermochemical pathways)
- pyrolysis fuel - hydrothermal liquefaction (HTL) fuel
Description:
Pyrolysis oil • Pyrolysis oil is a bio-oil or biocrude made through a pyrolysis process. In the process, biomass feedstock is heated at high temperature (typically between 300° and 650°C) for a few seconds, in the absence of oxygen. Instead of being combusted, the feedstock decomposes into combustible gases and charcoal. Some gases condense to form pyrolysis oil. There are different processes, which produce different combinations of gases, pyrolysis oil and charcoal. The share of pyrolysis oil is typically 60% to 70%. • Two main types of production processes are slow pyrolysis and fast pyrolysis. In slow pyrolysis, low heating rates and temperatures of 500° to 600°C lead to a high yield of char and a lower production volume of bio-oil (10 to 15weight % [wt]). In fast pyrolysis, biomass is rapidly heated to 400° to 600 °C in an inert atmosphere with a high nitrogen content at ambient pressure. In this type of process, the bio-oil yield is much higher, with a liquid product yield of about 70 wt%, a water content of 15 to 30 wt%, and an oxygen content of 35 to 40 wt%. Fast pyrolysis also can be achieved by using a catalyst (catalytic fast pyrolysis), which improves the quality of the pyrolysis oil, or in the presence of pure hydrogen at higher pressure (hydropyrolysis), which enhances dehydration of the bio-oil and reduces carbon loss and coke formation (Nami, et al., 2021).

- The common feedstocks for producing pyrolysis oil are lignocellulosic and other energy crops. The biomass fed into the reactor must be milled and have a moisture content below 10%, which may require pre-treatment (IEABioenergy, 2017).
- The physical and chemical properties of pyrolysis oil depend to a large degree on the used biomass feedstock and process conditions, notably temperature, pressure, heating rate and residence time. The elemental composition resembles that of used biomass (Nami, et al., 2021).
- Pyrolysis oil therefore has a poor compatibility with existing marine engines (ICCT, 2020). It is not a drop-in fuel, and its use would require marine engines and fuel systems to be modified or replaced. Pyrolysis oil has different characteristics than vegetable or petroleum oils; it is acidic and corrosive. Because the viscosity of pyrolysis oil increases during storage (which may lead to incomplete combustion and the particle deposits, causing engine damage), it should not be stored for more than a few months (Ecofys, 2012). Also, the water content increases over time, which leads to phase-separation phenomena (Nami, et al., 2021). Marine engines are often equipped with heaters and coolers to perform online control of the viscosity of the fuel, and this system also can be used for pyrolysis oil. Pyrolysis oil is expected to have a lower calorific value than MDO (due to the high oxygen content of 35 to 50 wt%), so the fuel-oil supply system, which includes pumps, pipes, fuel boosters and fuel injectors, needs to be expanded to a higher capacity.
- Pyrolysis oil has a high polarity, which makes it immiscible with fossil oils. However, it can be blended with emulsion biofuels to increase thermal efficiency and reduce the output of particulate matter from engines. But given its problematic features, such as high viscosity and corrosiveness, pyrolysis oil should be processed further to make it suitable for use in fuel engines. For example, a catalytic-upgrading process can improve its fuel characteristics and stability enough to produce a drop-in fuel. This process involves hydrogenation (often called "hydroprocessing") and produces a 'hydrogenated pyrolysis oil' that may be suitable for diesel engines (IEA Bioenergy, 2017).

Hydrothermal Liquefaction (HTL) biocrude

- HTL biocrude is a crude-like bio-oil that is produced from biomass using hydrothermal liquefaction technology. The production process uses temperatures between 250° and 550°C, with pressures of5-25 MPa for 20 to 60 minutes. Catalysts are used to maximize production yields. The water becomes either subcritical or supercritical and acts as a solvent, reactant, and catalyst during the process. The oxygen in the biomass is removed through dehydration or decarboxylation (IEA Bioenergy, 2017).
- Unlike the pyrolysis process, HTL can process wet biomass. Non-processed agricultural residues and lignocellulosic biomass are ideal feedstocks because they offer a mix of carbohydrates and low-lignin content to reduce the risk of charring. Algae also can be used as a feedstock.
- HTL biocrude has poor compatibility with existing marine engines and is not considered a drop-in fuel. But it may be used in engines in blends with residual fuels. Alternatively, HTL biocrude can be further upgraded, most likely via hydroprocessing, to produce a drop-in MGO or MDO (ICCT, 2020; IEA Bioenergy, 2017; Ramirez, et al., 2015).

  (from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon)

Physical/chemical properties
Risks/hazards
Existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates oil fuels with flashpoint > 60°C **Medium regulatory readiness level** SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover low-flashpoint fuel oil. Development of draft interim guidelines for the use of oil fuels with a flashpoint between 52°C and 60°C are currently under consideration. (from MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Methanol/Ethanol
- methyl/ethyl alcohol fuels
Description:
Bio-alcohols • Bio-alcohols are a group of liquid biofuels that can be produced from a range of feedstocks and production pathways. The most relevant bio-alcohols to the marine sector are bio-methanol and bioethanol, both of which can be used to replace distillates. It is acknowledged that methanol or bio-methanol produced from natural gas or biomass, respectively, requires marine engines that are specifically designed or converted to operate on methanol, as well as the relevant fuel-storage tanks and fuel-supply systems. **Bioethanol** • Bioethanol is produced by fermenting sugar and starch crops (glucose-based feedstocks) such as wheat, sugar cane and maize or algae. This type of bioethanol is often referred to as "first-generation" bioethanol. First-generation refers to biofuels from food crops, but also to the conversion pathway. The term "conventional bioethanol" is used as well. As the different meanings of these definitions are often used, it is recommended to mention both the fuel and the feedstock. • The three main steps used to produce bioethanol through cellulosic ethanol conversion of lignocellulosic biomass are pre-treatment, hydrolysis and fermentation. Pre-treatment extracts the carbohydrates from the biomass. • Hydrolysis of cellulose and hemi-cellulose produces sugars, which are then fermented. There are different types of hydrolysis (including enzymatic hydrolysis,

the use of acids and treatment with hot water or steam) each with their own advantages and disadvantages.

- In the hydrolysis process, lignin is a residual product that can be used in gasification or solvolysis to produce another biofuel, such as solvolysis oil (Ecofys, 2012; IEA Bioenergy, 2017).
- Bioethanol also can be produced from lignocellulosic and algal biomass, using innovative production technologies (Devarapalli & Atiyeh, 2015) Bioethanol from lignocellulosic and algal biomass is often referred to as "second generation" or "advanced" bioethanol, as these new production pathways that came after the pathways for bioethanol from sugars and starches. In EU policy "advanced" refers to the feedstocks, but sometimes it also refers to the more advanced conversion technology.
- Bio-ethanol could be used as a drop-in fuel for maritime shipping, but as with bio-methanol (in the following section), it will require that the engine, the fuel-containment and fuel-supply systems are designed to operate on ethanol. Although 2-stroke and 4-stroke marine engines operating on methanol are currently in service, there is insufficient information available about the use of ethanol on marine engines. Engine designers are already considering the development of such engines and it is very likely that these will become available in the near future. A 2-stroke engine designer has already communicated that is likely that their methanol dual-fuel engine, which is currently in service, will also be able to operate on ethanol with just a few changes to its control system.

Bio-methanol

- Bio-methanol is produced through the gasification of biomass and a synthesis of the resulting syngas to methanol (Ecofys, 2012). In the synthesis step, syngas is pressurized and converted to methanol in the presence of a metal catalyst, followed by the removal of water and impurities. The methanol conversion is done at high pressure and low temperatures (50-100 bar and 220-275°C, in the catalyst of copper and zinc oxides on alumina) (IEABioenergy, 2017).
- Lignocellulosic biomass can be used as a feedstock in combination with thermal gasification, wet biomass in combination with supercritical water gasification (see the description on LBM in 2.1.2.4).
- Alternatively, bio-methanol may be produced from bio-methane via reforming, with or without the addition of low-carbon hydrogen. *(Correspondence Group input)*
- A limited amount of bio-methanol can be blended with marine diesel for use in marine engines (Paulauskiene, et al., 2019). It also could be used at higher percentages in adapted or multi-fuel engines, or as a 100% methanol fuel in direct-methanol fuel cells.
- Large bore 2-stroke or 4-stroke engines using methanol and equipped with separate injection systems for fuel oil and methanol, i.e. dual-fuel (DF) engines, can typically burn methanol containing a percentage of water. Methanol mixes easily with water and this is a known technique for reducing NOx emissions in internal combustion engines, whether as direct injected water, humidification of intake air or by emulsifying or mixing it with the fuel. It is possible to burn a fuel solution using more than 50% water in some of these engine designs.
- However, using a water in methanol solution will result in a fuel penalty during combustion, as it costs energy to heat up the water. Furthermore, the energy used to supply or produce the fresh water on board - by freshwater generators, for example - needs to be considered.
- Further, it should be considered that diluting methanol with water further decreases the calorific value of methanol, which is already low. The calorific value

of methanol per unit weight is roughly half the calorific value of conventional marine fuels. (Correspondence Group input) • Some engine designs, using a mix of up to 50% water with 50% methanol, can reduce NOx emissions to IMO Tier III levels; these engines are already in operation in chemical carriers burning methanol as a fuel (Prevljak, 2021) (MAN ES, 2022) (Mayer, 2019). (from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon) • Can be used as a hydrogen carrier (natural hydrogen content) and can be reformed into hydrogen at low temperatures to supply fuel cell power system. (Correspondence Group input) ***Technical background:*** • Assessment of compatibility with existing engines: • Reformer for hydrogen consumer use (fuel cells) • Low inflammability; • Miscible in water; • Double walled pipes; • Infrared detectors; • Injection system; • Segregation, tightness of pipes and tanks; • Ventilation; • Storage space; and • Cooler required (but not cryogeny). (Correspondence Group input)
Physical/chemical properties
Stored at ambient pressure and temperature (Correspondence Group input)
Risks/hazards
• Toxicity, explosion, corrosion; Invisible flame. SAFETY *(BV white paper)* • Toxicity as a liquid and as vapour • Flammability (flashpoint <60°C) • Explosivity - Invisible flames without smoke - methanol-water mixture of at least 25% methanol is still capable of burning - Methanol vapor cloud can be heavier than air if colder or lighter if warmer (density in air 1.11) - Can be corrosive to some metals and alloys such as aluminium, copper, nickel, titanium, cast iron - Swelling of plastics and rubber materials - The alcohol-resistant foam type should be used for methanol/ethanol fires - High odour threshold – by the time a person detects it an acute IDHL exposure may have occurred (Correspondence Group input)

Existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover methanol as fuel but **MSC.1/Circ.1621** *Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel* has been developed. **Marine standards in progress** (Methanol) Marine standards in progress **ISO/AWI 6583** "Specification of methanol as a fuel for marine applications" is under development. Currently, the IMPCA[1] Methanol reference specification and ASTM[2] D1152 standards are used when specifying methanol quality. **No marine standards available** (Ethanol) No marine standards available (from MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Renewable Diesel
- hydrotreated vegetable oil (HVO)
Description:
Hydrotreated vegetable oil (HVO) • HVO, is also known as renewable diesel or hydrotreated esters and fatty acids. To produce HVO, feedstocks undergo a process of hydrotreatment and refining, usually in the presence of a catalyst where it is compared to FAME production. In the two-stage hydrotreatment process, hydrogen is first deoxygenated and the double bonds in the hydrogen molecules are saturated to form alkanes. In the second stage, the alkanes are isomerised and cracked. • HVO can be produced from vegetable oils used for cooking oil (UCO) and animal fats (AF), or from the algal lipids extracted from algae. • UCO and AF supply chains operate in accordance with the principles of the circular economy, allowing waste and by-products otherwise destined for disposal to be converted into products with high added value. • Due to hydrotreatment during production, a process similar to fossil-refinery practices, the fuel oils are more similar to petroleum diesel than to FAME. This results in higher quality of fuel that is typically produced meeting diesel fuel standards such as EN 590 and ASTM D975. • Pure HVO is considered a drop-in fuel, and can replace fossil diesel oil in most of the available marine engines (ICCT, 2020).

(from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon)

- Can be used as drop-in, mixed with other hydrocarbon-only diesels such as MGO and can be mixed with FAME.
  (Correspondence Group input)

Physical/chemical properties

HVO is a hydrocarbon free of oxygen, sulphur and aromatic compounds, and has chemical-physical properties similar to those of conventional diesel fuel, from which it differs due to a lower density and a high cetane number. Its hydrocarbon nature makes it usable in mixture with marine diesel even at high percentages, and it can be used pure in engines validated for its use.
It is a natively "drop in" fuel. Since it is not hygroscopic and does not contain oxygen, it does not facilitate the formation of bacterial loads which, giving rise to sludge and deposits, can clog the filters of the fuel system.

The energy density of HVO (equal to 44 MJ/kg) is very similar to that of fossil diesel oil and therefore, for its use, adjustments to the storage systems on board ships are not necessary.
As required by the ISO 8217 regulation currently in force, the HVO as such can be used to replace the fossil bunker only by agreement between the seller and the user.

According to the conventional criterion of Directive (EU) 2018/2001 "REDII", the reduction of CO_2eq emissions from HVO along the logistics-production chain varies between 65% and 90%, compared to the reference fossil mix (i.e. 94g CO_2eq/MJ), depending on the raw materials used for its production.
(Correspondence Group input)

Risks/hazards

- Flammability: Similar safety measures and hazards when compared with MGO
- The oxidation stability of HVO is generally comparable to that of conventional petroleum diesel, indicating similar storage durations.
- HVO can be regarded as possessing materials compatibility equivalent to that of conventional petroleum diesels with respect to components, tanks, and materials present in storage, transfer, and handling equipment (Neste, 2020).
- Filter clogging is not reported as an issue with pure HVO; however, it may arise when blended with high levels of FAME. Microbial growth poses a comparable risk for both HVO and fossil diesels, necessitating no additional precautions (Neste, 2020).
- Prolonged exposure may lead to skin dryness or cracking and irritation. Inhalation of vapour, mist, or fumes may cause irritation to the nose, mouth, and respiratory tract. Under normal conditions, vapour inhalation is not a concern due to low vapour pressure. However, entering confined or poorly ventilated spaces contaminated with vapour, mist, or fumes without proper respiratory protective equipment and adherence to a safe work system is extremely hazardous (BP, 2023).

See: (European Maritime Safety Agency (2023), Safe Bunkering of Biofuels, EMSA, Lisbon)
(Correspondence Group input)

Existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates oil fuels with flashpoint > 60°C **Medium regulatory readiness level** SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover low-flashpoint fuel oil. Development of draft interim guidelines for the use of oil fuels with a flashpoint between 52°C and 60°C are currently under consideration. (from MEPC 80/INF.17) The reference technical specifications for HVO marine use are the EN 15940 standard Automotive fuels - Paraffinic diesel obtained by synthesis or hydrotreatment and the ISO 8217 standard "Petroleum products - Fuels (class F) - Specifications of marine fuels." (Correspondence Group input)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees
Synthetic Diesel
- Fischer-Tropsch (FT) diesel
Description
Fischer-Tropsch (FT) diesel • FT diesel is produced by means of applying Fischer-Tröpsch synthesis to synthesis gas. Routes to manufacture synthesis gas from biomass comprise biomass gasification, currently touted as the most economical route, reforming of bio-methane and reverse water-gas shift (reacting hydrogen with CO_2). • In gasification, biomass processing produces a synthesis gas (syngas), which is mainly a combination of hydrogen and carbon monoxide. The process takes place at a high temperature (around 900°C) and pressure, and with a low proportion of oxygen and/or steam-to-gas. It decomposes the biomass into its basic components (CO, H2 and CO2). The gas is then cleaned to remove soot and tar (IEA Bioenergy, 2017). In the FT synthesis process, the syngas reacts over a catalyst and forms carbon chains (CC) of various lengths. • Various biomass feedstocks can be used, including agricultural residues and lignocellulosic (woody) biomass. Types of lignocellulosic biomass include forestry residues, quick-growing woody crops such as miscanthus and willow, and agricultural residues such as corn stover and wheat straw. • FT diesel is a drop-in fuel that can be used 'neat' (i.e. it can fully replace fossil diesel), or can be blended with fossil diesel up to a high percentage without engine modifications (ICCT, 2020). *(from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon) and (Correspondence Group input)*

Physical/chemical properties
Risks/hazards
• The auto-ignition temperature of FT-diesel is given as 208 °C, compared to >250 °C for MGO. This must be considered wherever heated surfaces may be in contact with FT-diesel. Class rules for ship design typically use equipment surface temperatures of 220°C as a cut-off point for insulation requirements. • FT-diesel can be regarded as possessing materials compatibility equivalent with that of fossil MGO. • FT-diesel is thought to exhibit similar properties as fossil diesel with respect to safe handling and toxicity. • FT-diesel is thought to exhibit similar properties as fossil diesel with respect to miscibility and contaminants. • FT-diesel is chemically stable and has a high oxidation stability, not needing anti-oxidant additives as is required by some FAME biodiesels (Bezergianni & Dimitriadis, 2013). See: (European Maritime Safety Agency (2023), Safe Bunkering of Biofuels, EMSA, Lisbon) (Correspondence Group input)
existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates oil fuels with flashpoint > 60°C **Medium regulatory readiness level** SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover low-flashpoint fuel oil. Development of draft interim guidelines for the use of oil fuels with a flashpoint between 52°C and 60°C are currently under consideration. (from document MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Liquefied & Compressed Gaseous Fuels

Ammonia
Description
• Ammonia may be used as fuel for fuel cells, internal combustion engines, gas turbines or boilers, with different technology readiness levels. Ammonia is gaseous at the atmospheric pressure and temperature above -33.3°C, and, according to the literature, the equilibrium points between gas and liquid occur at: 10.25 bar at 25°C; 11.67 bar at 30°C; 15.56 bar at 40°C; 20.34 bar at 50°C. • Therefore, practically ammonia may be stored in a liquified form, either by cooling, pressurization or a combination of both. Gaseous ammonia is much lighter than air (0.696 g/m3 vs 1.225 kg/m3). • Ammonia is soluble in water (340 g/l at 25°C) and creates an alkaline solution (pH 11.3 for 1M solution corresponding to about 17 g ammonia per litre of water). It is highly toxic to humans and, according to the National Institute for Occupational Safety and Health (NIOSH), the Recommended Exposure Limit (REL) for ammonia is 25 ppm (averaged over an 8-hour workday), with a maximum allowable Short Term Exposure Level (STEL) of 35 ppm during any 15-minute period in the day, and an IDLH (Immediately Dangerous to Life and Health) value of 300 ppm. • Ammonia is hard to ignite (minimum ignition energy is generally estimated to be in the range of 12-50 mJ, vs hydrogen with only 0.016 mJ), has low flame speed (0.07 m/s), and low flame temperature. Such properties, together with the possible dependence of the flashpoint on the method used to determine it (e.g. ISO 1523, ISO 2719, ISO 2592, ISO 3679, ISO 13736), have introduced uncertainty in determining its flashpoint (reported with different values between 11°C and 650°C). However, being a combustible gas at standard conditions, most of the methods and definitions for flashpoint are not applicable. • Irrespective of the above, it is consolidated knowledge that ammonia may create explosive atmosphere when its concentration in the air is between 15% (LEL) and 28% (UEL). Therefore, it appears that, regardless of the definition of low flash point fuel given in SOLAS regulation II-1/2.30, precautions should be taken in respect of the possible formation of both toxic and explosive atmosphere for its safe use as a fuel. Ammonia is corrosive to some materials, especially copper and its alloys. (from document MSC 105/2/2). ***Technical background:*** - Material compatibility for corrosion; - Segregation, tightness of pipes and tanks; - Ventilation/ equipment to treat ammonia vapours (scrubbers, oxidizers); - Engines not available. (Correspondence Group input)
Physical/chemical properties
Risks/hazards
• toxic effects, both for shipboard and nearby personnel, in case of release (also noting that ammonia is toxic to marine life); • explosion; • frost bite (when ammonia is stored or handled at low temperature); and • corrosion. (from MSC 105/2/2)

Toxicity, explosion, corrosion;
- Invisible flame; and
Noxious for environment (vapour).

SAFETY *(BV white paper)*

- Highly toxic to humans
- Lighter than air when dry, ammonia vapor heavier than air in wet/humid conditions
- Corrosive

  - Main hazard = toxicity
  - Experience from IGC ships carrying NH3 to be used, including ship/shore interface + STS
  - Engine development ongoing (delivery of two stroke engines end 2024)

AREA	HAZARDS
Chemical	Toxicity Short-term Exposure Limit (STEL – 15 min) Values:50 ppm
	Corrosiveness and stress corrosion cracking (relevant for carbon steels and copper-zinc alloys.
	Explosivity and flammability
Bunkering	Ammonia vapor leak Liquid ammonia leak – hose failure/ loading arm
Navigation	Vessel collision leading to NH3 leak and fuel tank damage Grounding leading to NH3 leak and fuel tank damage
Fuel Storage	Ammonia vapour leak Liquid ammonia leak
Fuel preparation/handling system	Liquid ammonia leak Structure damage
Fuel Management system	Over-pressurisation of tank Overfilling of tank
Engine room	Ammonia leak Exhaust explosion Ammonia vapour release in secondary systems
Accommodation	Internal fire External fire Ammonia leakage in accommodation
External risk	Dropped objects Cargo fire

(Correspondence Group input)

Existing guidance documents/standards

Medium regulatory readiness level

SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through

- SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively
- SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455**

IGC Code identifies ammonia as a toxic product and prohibits toxic cargo to be used as a fuel.
The IGF Code does not cover ammonia as fuel. Draft interim guidelines for the safety of ships using ammonia as fuel are currently under development.

No marine standards available

No marine standards available
(from document MEPC 80/INF.17)

ISO standards related to ammonia from land-based industry

Document	Title
ISO 5771:2008	Rubber hoses and hose assemblies for transferring anhydrous ammonia
ISO 7103:1982	Liquefied anhydrous ammonia for industrial use – Sampling – Taking a laboratory sample
ISO 7105:1985	Liquefied anhydrous ammonia for industrial use – Determination of water content – Karl Fischer method
ISO 7106:1985	Liquefied anhydrous ammonia for industrial use – Determination of oil content – Gravimetric and infra-red spectrometric methods
ISO 7108:1985	Ammonia solution for industrial use – Determination of ammonia content – Titrimetric method
ISO 6957:1988	Copper alloys – Ammonia test for stress corrosion resistance
ISO 7179:2016	Stationary source emissions – Determination of the mass concentration of ammonia in flue gas – Performance characteristics of automated measuring systems
ISO 1877:2019	Stationary source emissions – Determination of the mass concentration of ammonia – Manual method

ISO standards related to natural gas as marine fuel

Document	Title
ISO 23306:2020	Specification of liquefied natural gas as a fuel for marine applications
ISO 21593:2019	Ships and marine technology – Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas
ISO 20159:2021	Ships and marine technology – Specification for bunkering of liquefied natural gas fuelled vessels
ISO/TS 8683:2021	Guidelines for safety and risk assessment of LNG fuel bunkering operations

European Regulations and Guidance Documents

Document	Title
ATEX 94/9/EC	Equipment Directive - Equipment and protective systems intended for use in potentially explosive atmospheres

ATEX 99/92/EC	Workplace Directive - Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres
EN 378	Refrigerating systems and heat pumps. Safety and environmental requirements. Basic requirements, definitions, classification and selection criteria
EN 60079	Explosive atmospheres. Electrical installations inspection and maintenance

See also:
Latest News - Potential of Ammonia as Fuel in Shipping [updated] - EMSA - European Maritime Safety Agency (europa.eu)
(Correspondence Group input)

Gaps

- IGC 16.9.2 – Ammonia carriers will not be able to use ammonia as fuel until IGC code amends for toxic cargo as fuel
- Development of guidelines

From CCC 9-INF.16 by IACS

- Ammonia is a low-flashpoint fuel, IGF Code applies.
- Ammonia fuel definition and specifications should be developed. Cooperation with ISO would help set standards.
- The risk assessment of ammonia fuel should address all relevant hazards. The toxicity of ammonia is a health risk to individuals onboard, however, the flammability and explosivity hazards should also be considered.
- ESD machinery space is not accepted for ammonia. Gas-safe machinery concept will be followed.
- Arrangements to maintain or treat ammonia in case discharge overboard is prohibited should be developed. Dedicated holding tanks, ammonia treatment systems and other options to be considered for the guidelines.
- Ammonia may be stored under high pressure and ambient temperature condition. The limitation of MARVS of type C tank should be modified accordingly. Currently, the IGF code allows MARVS up to 1.0 MPa.
- Storage of ammonia fuel in gaseous form may not be considered.
- Materials, welding, and post-weld heat treatment requirements should be developed considering the corrosive characteristics and stress corrosion cracking property of ammonia. IGC code chapter 17.12 can be consulted for this reason.
- PRVs vent outlets distances should be further investigated and supported by gas dispersion analysis and risk assessment.
- As anhydrous ammonia may react with carbon dioxide, inert gas using combustion gases is limited for purging and gas-free applications.
- Safety measures are to be developed to prevent the vapour generation during bunkering. Design the system with a vapour return line to be considered.
- Unburnt ammonia emissions, returns from engines, fuel supply systems should not be vented to atmosphere during normal operation. Options to mitigate this should be offered in the guidelines (ammonia treatments systems e.g. knock-out drum, gas absorber and/or holding tanks).
- Toxic area classification (similar to the hazardous areas) is defined.
- Increased ventilation rates (catastrophe ventilation) in the event of gas detection in enclosed spaces is introduced.

• Water mist system or other water-based safety system in ventilation system to bind to toxic ammonia gas in the event of a leak is introduced. • Ammonia detection levels should be defined. Alarms and safety functions need to be established on these. • Requirements for gas dispersion analysis and risk assessment to be included for toxic areas definition. (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees
MSC & CCC

Dimethyl Ether (DME)
Description
Dimethyl ether (DME) • DME can be produced by the gasification of biomass, followed by catalytic-fuel synthesis. During the gasification process, biomass is broken down into syngas, which can be used to produce DME directly, or the gas can be first converted to methanol as an intermediate product, followed by methanol dehydration (Ecofys, 2012; IEA Bioenergy, 2017). • Thanks to gasification technology, virtually all types of biomass feedstock can be used; lignocellulosic biomass via thermal gasification and wet biomass feedstocks via super critical water gasification (see the description on liquefied biomethane (LBM) in 2.1.2.4). • DME can be used as part of a blend with MGO or MDO after limited engine modifications, although the percentage blend is understood to be rather low and is thus self-limiting in terms of CO2 reduction when considered as a drop-in fuel. However, DME may be used with LPG where it can be considered a drop-in fuel, though blending percentages above 30% still need to be verified and additional storage tanks and fuel-supply systems will be needed. To use DME as a 'neat' fuel requires dedicated engines (ICCT, 2020). (from European Maritime Safety Agency (2022), Update on potential of biofuels in shipping, EMSA, Lisbon) • DME may be used as a fuel for internal combustion engines, gas turbines or boilers with varying technology readiness levels. • In the case of DME, the high oxygen content, together with the absence of C–C bonds in the molecules, causes a practically smokeless combustion, which is one of the most important advantages of DME. DME is not affected by hazardous contaminants like sulphur and vanadium. Major benefits from this fuel are the large reduction of CO2 and NOX emissions and the absence of SOX emissions. (from MSC 105/2/2)
Physical/chemical properties
Risks/hazards
• low lubricity; • high reactivity and corrosiveness; and • toxicity. (from MSC 105/2/2)

• Extremely flammable gas, necessitating precautions to avoid heat, hot surfaces, sparks, open flames, and other ignition sources. • Contaminated clothing poses a fire hazard and should be handled accordingly. • Heavy vapour, white cloud that may travel along the ground or water surface, posing a risk of distant ignition. • Since DME is normally stored as a liquefied gas at pressure, in case of leakage, ignitable vapours will be created. • Higher temperatures are needed for DME to auto-ignite when compared to MGO. • DME has low kinematic viscosity when compared to MGO which may lead to leakage problems with the fuel supply system. • The solvent properties of DME pose a risk of degrading rubber and elastomer seals, which may necessitate their replacement. • DME, when released as a liquid, poses a low-temperature exposure hazard. The rapid release of pressurized gases (i.e. liquefied), may cause frost burns due to evaporative cooling. See: (European Maritime Safety Agency (2023), Safe Bunkering of Biofuels, EMSA, Lisbon) (Correspondence Group input)
Existing guidance documents/standards
Low regulatory readiness level SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** No specific requirements or guidelines available for dimethyl ether (DME) as fuel. The IGC Code identifies DME as a toxic product and prohibits toxic cargo to be used as a fuel. **No marine standards available** No marine standards available (from MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Ethane
Description
Physical/chemical properties
Risks/hazards
Existing guidance documents/standards
Low regulatory readiness level

SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** No specific requirements or guidelines available for ethane as fuel. **No marine standards available** No marine standards available (from document MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Hydrogen
- (compressed/liquid/metal hydride) - including e-hydrogen
Description
• Hydrogen may be used as fuel for fuel cells, reciprocating internal combustion engines, gas turbines or boilers, but these technologies are still under development. Hydrogen is gaseous at atmospheric pressure and at temperature above -253°C. Hydrogen may be liquified only at temperature below its critical temperature (about -240°C). Gaseous hydrogen at ambient conditions is much lighter than air (0.08988 g/m3 vs 1.225 kg/m3). • Hydrogen is very easy to ignite (minimum ignition energy of only 0.016 mJ) and shows the unusual property that the expansion is exothermal (hydrogen is heated by expansion). The flammability/explosivity range of hydrogen in the air is very wide, between 4% (LEL) and 74% (UEL). Hydrogen is typically stored as a compressed gas, or in a liquified form by cooling, or may be stored in metal hydrides at ambient temperature and little pressure (values depending on the specific metal). • Hydrogen, in contact with certain metals, may cause their embrittlement. In case of some steels operating at elevated temperatures (typically above 400°C) in hydrogen-rich atmosphere, a phenomenon named High Temperature Hydrogen Attack (HTHA) needs to be taken into consideration as well. • As most materials (metals and polymers) are permeable to hydrogen, hydrogen diffusion in metallic materials is difficult to grasp owing to the non-uniform compositions and material structures; further research would be necessary to enable safe application of hydrogen in future ship propulsion as well as energy storage and conversion machinery. • In case of liquefied hydrogen, the low temperatures may cause condensation of air on exposed parts of the containment system, with a possibility of localized oxygen enrichment due to the condensation from the atmosphere. (from MSC 105/2/2), (also see annexes to CCC 9/INF.17).

Some relevant properties

Flammability limit (vol%)	4.1-74.8	very broad (compared to other gases)
Detonation limit (vol%)	18.3-59.0	very broad ‘’
Min ignition energy (mJ)	0.017	very low ‘’
Laminar burning velocity (cm/s)	270	very high ‘’
Autoignition temperature C	585	as other gas

(Correspondence Group input)

Physical/chemical properties

Risks/hazards

- leak due to permeability of materials;
- fire and explosion;
- frost bite;
- material embrittlement; and
- oxygen enrichment.

(from MSC 105/2/2), (also see annexes to document CCC 9/INF.17).

AREA	HAZARDS
Chemical	• Physiological (suffocation, asphyxiation, and respiratory problems - frostbite, hypothermia for LH2), • Physical (embrittlement, failures, and phase change), • Chemical (fire, explosion) • Extremely low electro-conductivity rate - flow and agitation of hydrogen generate electrostatic charge that might trigger the spark, • Propensity for leakage of compressed hydrogen (smallest molecule), • LH2 leak can create solidified air creating conditions for detonation. Regassified air is oxygen rich creating conditions for explosion. • LH2 leak turns into cold vapour that if in contact with a hotter liquid create a Rapid Phase Transition explosion. • The product of combustion of hydrogen exhaust (Smoke) is water vapour – not dangerous
Bunkering	• Hydrogen release or leak • hydrogen release or leak – hose failure/ loading arm
Navigation	• Vessel collision or grounding leading to tank rupture/damage and so to hydrogen leak/release • Grounding leading to hydrogen leak and fuel tank damage
Fuel Storage	• Hydrogen release or leak

Fuel preparation/handling system	• Hydrogen release or leak • Structure damage
Fuel Management system	• Over-pressurisation of tank
Vent System	• Internal Deflagration/detonation • Local Leakage • Over pressurisation of protected system
Engine room	• Ammonia leak • Exhaust explosion • Hydrogen vapour release in secondary systems
Accommodation	• Internal fire • External fire • Hydrogen migration accommodation
External risk	• Dropped objects • Cargo fire

(Correspondence Group input)

Existing guidance documents/standards

Medium regulatory readiness level

SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through

- SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively
- SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455**

  The IGF Code does not cover hydrogen as fuel. Resolution MSC.420(97) provides interim recommendations for carriage of liquid hydrogen in bulk. Draft interim guidelines for the safety of ships using hydrogen as fuel are currently under development.

No marine standards available

ISO 14687:2019 "Hydrogen fuel quality – Product specification"
(from document MEPC 80/INF.17)

See also:
Publications - Potential of hydrogen as fuel for shipping - EMSA - European Maritime Safety Agency (europa.eu)
(Correspondence Group input)

Gaps

Development of guidelines (expected to be finalized at CCC 10)
(Correspondence Group input)

Roadblocks

Recommendations for IMO action

Relevant IMO Committees/Sub-Committees

Methane/Natural Gas
- (compressed/CNG; liquefied/LNG) - including bio-methane, and e-methane
Description
• Methane may be used as marine fuel both in compressed form or, most commonly, in liquid state. To keep methane liquified at ambient pressure, the storage temperature must be kept below -161,5°C. • Liquified methane has a high calorific value per unit weight: ~50 MJ/kg, higher than conventional marine fuels (typically 35-40 MJ/kg). • Methane may also be used in compressed form • The most common source of methane is natural gas, from which a methane-rich gas can be obtained after purification. This is a fossil methane source. Albeit a fossil fuel, the methane molecule contains four hydrogen atoms and methane is considered an attractive fuel in the interim because its combustion produces less CO_2 per unit energy released than conventional marine fuels. • Alternatively, methane can be extracted from the product of anaerobic digestion of decomposable waste (biogas) and landfill gas (renewable natural gas) or it can be manufactured by reacting CO_2 with low-carbon hydrogen (e-methane). These are renewable forms of methane and the CO_2 generated from these molecules is regarded as climate neutral. Furthermore, the production of biogas and renewable natural gas supports improved waste management practice, and it is therefore beneficial for reducing emissions of methane to the atmosphere from waste decomposition. • Methane production through all the known processes and on-board use may also be associated with emissions of methane to the atmosphere. Considering that methane is a greenhouse gas with an effect on climate far greater than CO_2 (~28 times on a 100-years' time perspective and more than 80 on a 20-years' time perspective), utmost care must be exercised to eliminate these emissions at all steps of the supply chain. (Correspondence Group input)
Physical/chemical properties
Gaseous at ambient conditions. Liquid at -161.5°C Lower calorific value: 50 MJ/kg
Risks/hazards
Existing guidance documents/standards
High regulatory readiness level SOLAS Chapter II regulates methane (CNG) as fuel through SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and the IGF Code. **Marine standards available** **ISO 23306:2020** "Specification of liquefied natural gas as a fuel for marine applications" (from document MEPC 80/INF.17)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Propane/Butane (LPG)
Description
• LPG may be used as a fuel for internal combustion engine, gas turbines or boilers with varying technology readiness level. LPG is considered to be a clean, energy efficient and portable fuel at an affordable price and possess the advantage of being readily available worldwide. • LPG is a mixture of propane and butane, meaning that in case of leakage, vapours will accumulate in the lower portion of the surrounding area. LPG is a preferred fuel choice of LPG carriers. • LPG is portable and easy to handle; it can be stored in pressurized tanks; it is easily accessible across all terminals in the world and is more environmentally friendly than other fossil fuels. LPG can offer shorter payback periods, lower investment costs and lower sensitivity to fuel price scenarios. • The LPG quality is particularly jeopardized during the transshipment processes, when this fuel may be exposed to contamination by other substances like water and sulphur compounds. The contaminants present in LPG may cause corrosion of the structural materials being in contact with this fuel. The solid products of the corrosion process are mechanical contaminants, which may cause damage to system components. (from MSC 105/2/2)
Physical/chemical properties
Risks/hazards
• fire and explosion; • toxic effects; • contamination; and • corrosion. (from document MSC 105/2/2) - Main hazard = flammability - Experience from IGC ships carrying LPG to be used, including ship/shore interface + STS - Two stroke engines with LPG fuel already proven technology for several years (Correspondence Group input)
Existing guidance documents/standards
Medium regulatory readiness level SOLAS Chapter II regulates low-flashpoint fuels (< 60°C) through • SOLAS Ch II-1 Part G (low-flashpoint liquid fuel or gas) and IGF Code; alternatively • SOLAS Ch II-1 Part F (Alternative design and arrangement) – **MSC.1/Circ.1212/Rev.1** and **MSC.1/Circ.1455** The IGF Code does not cover LPG as fuel. Draft interim guidelines for the safety of ships using LPG fuels have been finalized and are expected to be adopted by MSC 107 in June 2023.

No marine standards available No marine standards available (from MEPC 80/INF.17)
Gaps
- Update of IGC/IGF code - Development of guidelines (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Fuel Mixtures
(e.g. hydrogen - natural gas)
Description
A regulatory framework should be developed for mixing fuels to address the safety risks of any fuel mixture. This could take the form of a risk assessment where the properties of each individual component of the mixture would have to be considered in addition to the risks associated with the mixture.
Physical/chemical properties
Risks/hazards
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO committees/sub-committees

Power Conversion Systems

Fuel Cells
Description
Fuel cell technologies may take until the late-2030s to reach full commercial maturity: • Hydrogen fuel cells are already being piloted and commercial operations are expected in the late 2020s, at least for smaller vessels. The key challenges are scaling up the power output, ensuring reliability for sustained operation, fuel storage/handling and regulatory maturity. • Liquid organic hydrogen carrier (LOHC) technology provides higher density hydrogen storage. Though more recently developed, it is also forecast to commercialize over similar timescales as hydrogen fuel cells, i.e. forecast to be used in commercial operations later this decade.

• Methane and methanol fuel cells are forecast to begin commercial operation around 2030 and take a decade to fully mature. Methanol and methane can either be used directly in some fuel cells or reformed on board to produce hydrogen first. Development of both technologies is forecast to be similar. Vessels using methane/methanol for propulsion with engines may provide an opportunity to accelerate commercialization of methane/methanol fuel cells through use for auxiliary power. • The first vessels to pilot using ammonia directly in fuel cells are expected in the late 2020s. Onboard cracking of ammonia into hydrogen is forecast to commercialize earlier, however. Cracking into hydrogen allows a wider choice of fuel cell types but adds complexity. The full commercialization of ammonia fuel cell technologies for propulsion is unclear because it depends on how its efficiency, cost, and robustness compares with ammonia engines. (from document MEPC 80/INF.10) • Main fuel cell technologies foreseen for marine applications Low Temperature Proton Exchange Membrane Fuel Cell (LT-PEM) High Temperature Proton Exchange Membrane Fuel cells (HT-PEM) Solid Oxide Fuel Cell (SOFC) (Correspondence Group input)
Risks/hazards
Existing guidance documents/standards
• Interim guidelines for the safety of ships using fuel cell power installations June 2022 (msc.1/circ.1647) • Ships using fuel cell – nr 547 dt r01 e – January 2022 • Handbook for hydrogen-fuelled vessels – dnv marhysafe jdp phase 1 –1st edition (2021-06) • Hydrogen-fuelled ships- nr678-November 2023 (Correspondence Group input)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Fuel Reforming
Description
Risks/hazards
Existing guidance documents/standards
Gaps

Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Nuclear Power
Description
• The use of nuclear power generation in the industry since the middle of the 20th century, including merchant shipping and the Navy, has shown a very high safety standard, however, due to the severity and reach of possible incidents, which may also have the potential to cause long term damage, it may raise social concerns. • The risks connected with the use of nuclear power generation are related to the physical and chemical properties of the materials used and the reaction taking place. • Current research into new types of reactors (molten salt reactors, gas cooled reactors and liquid-metal cooled reactors) are considering further safety improvements by reducing the potential severity of incidents, although existing pressurized water reactors (PWR) currently in use on many ships have proven their reliability over many years of successful operation. • In general, however, the potential risks connected with the use of nuclear power generation and disposal of spent fuel may be summarized as: - radiation; - contamination; - loss of control; - explosion; and - complexity of decommissioning. • Noting the above-listed potential risks and a general interest shown in this solution, it is noted that resolution A.491(XII) adopted the Code of Safety for Nuclear Merchant Ships as a guide to Administrations on the internationally accepted safety standards for the design, construction, operation, maintenance, inspection, salvage, and disposal of nuclear merchant ships. Given its adoption in 1981, it may be beneficial and timely to consider updating it. • A separate and significant challenge is related to the role of a human in the "nuclear propulsion systems control loop" due to potentially having great influence on risks related to nuclear technology implementation in ship propulsion system design, construction, and operation, as well as all maintenance and decommissioning issues. That said, for alleviation of possible hazards associated with the human factor, the number of crew persons servicing the nuclear power plant propulsion on existing ships is significantly larger compared to ordinary ship propulsion. (document MSC 105/2/2) Nuclear energy is the only energy source which is released without combustion, and nuclear reactors therefore, do not emit greenhouse gases when operating. Nuclear energy provides a clean and reliable energy source and is a significant part of the world energy mix. The use of nuclear power generation in the shipping industry since the middle of the 20th century, including merchant shipping and Navy, has shown a very high safety standard. No fatalities and few injuries have been recorded from radioactive releases in oceangoing vessels. Classification Societies are working to write new class rules and

standards for nuclear powered ships and the marine and nuclear insurance industries will come together to create a commercial insurance framework for new nuclear maritime solutions.

The nuclear industry has benefitted from more than 70 years of operational experience which has been used to provide continuous improvements and enhancements to the safety aspects of nuclear reactors.

New reactor designs are now being built. Molten Salt Reactors, where the fuel and coolant are combined as a liquid, making a melt-down impossible. Gas cooled and Liquid-metal cooled reactors, where water is replaced as a coolant, avoids the risk of a hydrogen explosion in the event of a meltdown. All these new designs are based on the fundamental "Defence in Depth" principle for the prevention and mitigation of potential initiating events and applying inherently passive safety systems providing further safety enhancement. The application of new reactor technology to maritime is expected to play a major part towards net zero goals.

Resolution A.491(XII) adopted the Code of Safety for Nuclear Merchant Ships as a guide to Administrations on the internationally accepted safety standards for the design, construction, operation, maintenance, inspection, salvage, and disposal of nuclear merchant ships. Since it was adopted in 1981, the nuclear industry has made significant progress, and the code urgently needs a revision for modern nuclear solutions to be considered.
(Correspondence Group input)

Risks/hazards

• radiation;
• contamination;
• loss of control;
• explosion; and
• complexity of decommissioning.
(from document MSC 105/2/2)

Nuclear power is associated with Low-Probability – High Consequence, LPHC, type of risk, despite much evidence to the contrary. The fatality count from Three Mile Island (zero), Chernobyl (around 30), and Fukushima (one) pales in comparison to the regular number of deaths in other parts of the energy industry.

The commercial nuclear industry has safety as its top priority, with a risk-informed approach in the design process, implementing Defense in Depth and Safety by Design principles. The risk of radiation exposure to the workers, the public and the environment is mitigated by design in all licensed nuclear reactors – during operation and accident scenarios.

Preventing the unplanned release of radioactive materials during operation of nuclear reactors is an integral and required part of the design process and ensures compliance with the highest international standards. The release of high levels of radioactivity during accident conditions are also prevented and mitigated as part of the safety analysis and design process through use of shielding and containment. It is noted that some advanced, innovative designs are set to operate at low pressure, ensuring that the potential for radioactive release to the atmosphere is almost eliminated by design.

In addition, security risks and hazards associated with proliferation are addressed by an appropriate security infrastructure and culture, strict Materials Control & Accountability (MCA) and passive measures.
(Correspondence Group input)

Existing guidance documents/standards
Medium regulatory readiness level • The IAEA is the world´s centre of cooperation in the nuclear field. IAEA Safety Standards represent international consensus on best international practices to achieve a high level of safety. The wide international consensus is achieved through a rigorous development process. They are used by Member States as a reference for review of national standards, by regulatory authorities and by the nuclear industry. • SOLAS Chapter VIII provides the general framework for the application of SOLAS to nuclear ships. • Resolution A491 (XII) *Code of Safety for Nuclear Merchant Ships* was developed in 1981 and requires updates to meet current standards. As the Code adequately regulates conventional nuclear reactor installations, but falls short in regulating advanced and modern designs, it can be debated whether the Code is of Medium or High regulatory readiness level. Because of the work required to update the Code, WNTI has classified the regulatory readiness level as Medium. Resolution A.491(XII) adopted the *Code of Safety for Nuclear Merchant Ships* as a guide to Administrations on the internationally accepted safety standards for the design, construction, operation, maintenance, inspection, salvage, and disposal of nuclear merchant ships. Given its adoption in 1981, it may be beneficial and timely to consider updating it. (Correspondence Group input)
Gaps
To accommodate new marine-appropriate nuclear energy solutions, the Code must be made technology agnostic. The Code must also be brought up to date to reflect the current IAEA nuclear safety, security, and safeguards standards. An expert group convened by WNTI has prepared a complete gap analysis which identifies the sections of the Code that require updates for it to be consistent with the IAEA Standards as they would apply to nuclear-powered merchant ships. WNTI will be making the entire gap analysis available to all Member States of both IMO and the IAEA, and is willing to host sessions with Member States to review the full gap analysis, providing further empirical and scientific evidence to assist with its use to review the Code. (Correspondence Group input)
Roadblocks
The Code is specific to earlier designs of Pressurized Water Reactors (PWRs) directly driving the propellers. In the intervening time, the progress in the design of Small Modular Reactors (SMRs), the advent of new nuclear technologies and the development of the All-Electric-Ship concept have created the potential for the successful application of different nuclear technologies to seagoing vessels. These integrated designs are smaller, incorporate inherent passive safety features, and can operate at power for longer periods without refuelling. However, most of those new nuclear technologies are not covered by the existing Code, which also needs to be updated to reflect the current IAEA safety, security, and safeguards standards. The knowledge in this field is deep and WNTI sees no roadblocks to a successful revision of the Code. (Correspondence Group input)

Recommendations for IMO action
To coordinate a thorough revision of Resolution A491 (XII) Code of Safety for Nuclear Merchant Ships as is required by Clause 1.6 of that Code. (Correspondence Group input)
Relevant IMO Committees/Sub-Committees
MSC should be the coordinating organ and decide which other committees and sub-committees should be involved. It looks highly likely that the SDC Sub-Committee will have the competence for work needed to update Resolution A.491, The Code of Safety for *Nuclear* Merchant Ships. MSC may also decide that other committees and sub-committees will need to be involved with various aspects. (Correspondence Group input)

Solar Power
Description
Solar panels, a fully mature technology on land, have been demonstrated on-board and are expected to develop commercially later this decade. However, their use is expected to be limited by practical constraints, so the extent of their possible commercialization is unclear. (from document MEPC 80/INF.10)
Risks/hazards
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Wind Power/Propulsion [alternative 1]
WAPS – Wind Assisted Propulsion System
Description
Flettner rotors, which are now in use providing wind assistance on several vessels operating commercially, with commercial development expected to accelerate into the 2030s. Towing kites and rigid sails have achieved pilot demonstrations, and commercial operation is expected by 2025. However, not all wind assistance technologies are suited to all vessel types, so until their practicality and effectiveness has been more widely demonstrated, their commercialization paths are unclear. (Wind propulsion assistance technologies are considered as energy reduction technologies to reduce demand on using fuel for propulsion.) (from document MEPC 80/INF.10)

Risks/hazards
• For a WAPS with a rotating unit, the static vs rotating heeling moment needs to be considered for vessel stability. • Impact in vessel's manoeuvrability. • Navigational hazards – obstruction to visibility, navigation lighting, radar blind spots. • Impact of adverse weather – lightning strikes, strong winds, ice accumulation, waves resulting in motions out of the vessel's design limits. • Vibrations and noise. • Efficiency of fire suppression systems to fight fire in the WAPS. • Impact on the availability of mooring system and equipment when multiple WAPS are installed on deck on forepart of ship. (from EMSA Study on the Potential of Wind-Assistance Propulsion for Shipping)
Existing guidance documents/standards
Report including HAZID exercises for the rotor sails, ventofoils and sail concepts and detailed regulatory gap analysis is available from EMSA's Study on the Potential of Wind-Assistance Propulsion for Shipping (Publications - Potential of wind-assisted propulsion for shipping - EMSA - European Maritime Safety Agency (europa.eu)) (Correspondence Group input)
Gaps
• Currently, there are only regulations for static stability and there is no regulation to consider the rotating heeling moment. Need to investigate if the present criteria in the IMO Code on Intact Stability and IMO's second generation of stability criteria and if the damage stability criteria for all ships should be adapted to ships with WAPS. • Contribution of WAPS to EEDI/EEXI not addressed in current regulations. • Need to investigate if the present criteria in the IMO Standards for Ship Manoeuvrability are applicable to ships with WAPS. • Address the need to develop specific guidelines for the navigation safety of ships with WAPS to be used to compensate the larger blind spots that are caused. (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Wind Power/Propulsion [alternative 2]
Description
The propelling of a ship through the direct harnessing of wind energy via a 'wind engine' or other device/design aspect Definitions : 1. Primary wind powered ship: a ship which is designed to maintain service speed the majority of time using wind propulsion only. [a ship which is designed to use primarily the wind propulsion and the engine as a complementary propulsion.]

2. Wind assisted ship: a motor ship which is adapted such that in favourable wind conditions, the propulsive power to maintain service speed is reduced from using wind powered technology. [a motor vessel equipped with a wind powered technology as a complementary propulsion.]

3. Wind powered ship: Primary Wind Powered Ships and Wind Assisted Ships [A ship without engine]

(Correspondence Group input)

Risks/hazards

Extended analysis of HAZIDS undertaken as part of EMSA Wind propulsion report pages 114 to 120, along with case studies. https://www.emsa.europa.eu/publications/reports/item/5078-potential-of-wind-assisted-propulsion-for-shipping.html

- For a WAPS with a rotating unit, the static vs rotating heeling moment needs to be considered for vessel stability.
- Impact in vessel's manoeuvrability.
- Strong impact on air draught.
- Navigational hazards – obstruction to visibility, navigation lighting, radar blind spots.
- Impact of adverse weather – lightning strikes, strong winds, ice accumulation, waves resulting in motions out of the vessel's design limits.
- Vibrations and noise.
- Efficiency of fire suppression systems to fight fire in the WAPS.
- Impact on the availability of mooring system and equipment when multiple WAPS are installed on deck on forepart of ship.
- (EMSA Study on the Potential of Wind-Assistance Propulsion for Shipping)

(Correspondence Group input)

Existing guidance documents/standards

- MEPC.1/Circ.896 – 14 December 2021 – Guidance on treatment of innovative energy efficiency
- Technologies for calculation and verification of the attained EEDI and EEXI https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf

Classification documents: These all deal with risk and safety issues

Bureau Veritas Guidelines: https://erules.veristar.com/dy/data/bv/pdf/206-NR_2024-01.pdf

ClassNK Guidelines are downloadable from www.classnk.com

DNV Guidelines: https://www.dnv.com/news/dnv-rules-for-ships-july-2022-edition-227477

ABS Wind Propulsion Guidelines (2022)
https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/315-requirements-for-wind-assisted-propulsion-system-installation/315-wind-asisted-propulsion-reqts-july22.pdf

Lloyds Register Guidelines: https://www.lr.org/en/knowledge/lloyds-register-rules/guidance-notes/guidance-notes-for-flettner-rotor-approval/
https://www.lr.org/en/knowledge/lloyds-register-rules/guidance-notes/guidance-notes-for-masts-spars-and-standing-rigging/

China Ship Classification Society (2023): Guidelines for Survey of Marine Wind-Rotor Assisted Propulsion System 2023 https://www.ccs.org.cn/ccswzen/file/download?fileid=202301300953804120 (Correspondence Group input)
Gaps
Gap analysis available in document MEPC 81/INF.39 – safety details taken from EMSA Wind propulsion report pages 73 to 109 of the annex. https://www.emsa.europa.eu/publications/reports/item/5078-potential-of-wind-assisted-propulsion-for-shipping.html The major concerns related to wind propulsion for shipping are related to vessel's stability and manoeuvrability, change in air-draft, operational and navigational obstructions, obstruction in cargo loading/unloading (e.g. for bulk carriers), impact of adverse weather, ice accumulation, fire and lightning protection, noise and vibrations, system and component failures, maintenance. The issues described above may require further studies for better understanding of the risks as well as for defining the necessary safeguards that will need to be implemented to prevent or mitigate the major hazards. Based on the Hazard Identification (HAZID) studies, preventive and mitigative safeguards as well as recommendations for various ship types are presented, which may help to inform prescriptive requirements and develop inherently safer designs and arrangements. While some safeguards are regulatory requirements, many of these are considered additional safeguards due to the inherent risks of wind propulsion. Overall, the studies did not identify any major risk that cannot be resolved. (Correspondence Group input)
Roadblocks
For the shipping industry, wind propulsion is not a new technology. To facilitate its wider uptake on commercial vessels some additional safeguards need to be considered, while wind propulsion systems reliability and availability may need to be further improved for the maximum potential benefit to be realized. No major roadblocks to implementation and all substantial barriers have been identified and no issues have been identified that are unsolvable. (Correspondence Group input)
Recommendations for IMO action
The need to incorporate both wind-assist and primary wind applications across IMO regulation is identified in the attached documents and in the EMSA report. This integration of wind propulsion into decarbonization pathways more broadly is also evident in all IMO committees/Sub-Committees (Correspondence Group input)
Relevant IMO Committees/Sub-Committees

Fuel/Energy Storage

Lithium-ion Batteries	
Description	
Risks/hazards	
AREA	**HAZARD**
Cells, Module, packs	• Internal cell failure causing thermal runaway. Temperature control for cells and modules is not adequate.

	• Means to prevent or mitigate internal short circuits, mechanical and electrical hazards are not implemented. • Means to manage the thermal runaway propagation are not provided. • A battery fire generates several dangerous gases such as hydrogen fluoride, hydrogen chloride, lithium oxide, carbon monoxide
UPS	Configuration and available uninterruptible power supply is not able to maintain the functioning of the BESS's essential safety functions (i.e. Battery Management System, fire and explosion control systems and Battery Thermal Management System of the battery enclosure)
Converters Inverters-Charges	Converters and inverters-chargers do not operate as an integrated system, not providing for electrical protection and parameters within the range and tolerances of the BESS. Use out of operational tolerances and consequent system failures are not reported.
Battery Management System	Overcharge and over discharge are uncontrolled. High temperature during charging and discharging operations is not monitored and no measures implemented in case of overtemperature. BMS is not protected from unscheduled power interruptions.
Comms	Communication protocol fails to deliver, where needed, alarms and alerts messages. Communication protocols are compromised for the failure of a single node of the network.
Energy Management System	Continuous assessment of power and energy available to the ship becomes unavailable. Alarms and alerts are not reported. Cyber resilience is not ensured
Battery Space	Mechanical impact damaging the battery space. Battery gassing, fire and/or explosion originating inside the battery space. Water ingress, leakages, and condensation in the battery space. External factors to the BESS determining unsafe conditions inside the battery space (such as fires, outside temperature). Overall degradation of the system and its performances due to environmental conditions.

Fire safety	BESS generated fires due to thermal runaway: Electrical fire – overcharging/discharging or low temperature causing dendritic growth, lithium plating causing short circuits (leading to thermal runaway and fire). Thermal fire – over temperature causing the electrolyte decomposition or melting separator (leading to thermal runaway and fire). Mechanical fire – events that can lead to penetration of the enclosure of the battery/cell (such as drop of objects, ship's collision, grounding, maintenance errors) causing short circuits, (leading to thermal runaway and fire). Internal short circuit – failure of the separator due manufacturing fault or any of the above conditions Detection – thermal runaway is not detected at early stage and no consequential fire safety measures are taken. Extinguishment Re-ignition of the fire in the battery space. Extinguishing means are not able to reach the fire. Extinguishing means generate explosive, toxic and/or corrosive chemical compounds.

(Correspondence Group input)

Existing guidance documents/standards

EMSA Guidance on the Safety of Battery Energy Storage Systems - Ship Safety Standards - Battery Energy Storage Systems (BESS) - EMSA - European Maritime Safety Agency (europa.eu)

Various ISO standards such as BS EN 62619 and 62620
Class rules (e.g. BV NR467, part C)
(Correspondence Group input)

Gaps

- Batteries not considered as main source of power in SOLAS – requirements for the battery space left out of regulations

(Correspondence Group input)

Roadblocks

- Continuous technological development makes it difficult to draw up requirements for batteries that may become obsolete in a short period of time.

(Correspondence Group input)

Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

High-pressure Composite Cylinders
Description
Multi-element gas containers (MEGC) are becoming the standard for the transport of compressed hydrogen or natural gas. They usually consist of spirally wound fiberglass cylinders with or without plastic or metal liner, although steel cylinders are also encountered. A multitude of suppliers is available, most comply with ADR/IMDG regulations but still under development for hydrogen as fuel storage tank to comply with IGF Code requirements because of strong constraints compare to road transport (ADR). (Correspondence Group input)
Risks/hazards
Fire/explosion • Low resistance to fire • High velocity venting constraints • Swapping operations • Extent hazardous areas due to very high pressure of hydrogen (Correspondence Group input)
Existing guidance documents/standards
ISO 11120, PED, ADR, IMDG Various ISO standards (e.g. 11119-2) (Correspondence Group input)
Gaps
MEGC's approved for IMDG / ADR should be allowed for use on board of ships. This should be taken into account when developing Regulations (Correspondence Group input)
Roadblocks
Due to lack of maritime guidelines and standard, risk analysis process is a long process with a need of demonstration when it comes to risk evaluation and mitigation measures (Correspondence Group input)
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Metal Hydrides
Description
Thanks to metal bounds, metal hydrides can store hydrogen in metal powder. The absorption of hydrogen by hydrides is an exothermic process, which releases heat. The desorption of hydrogen from hybrids is an endothermic process that creates cold. The thermal management is a key parameter in the process. Reversibility of these processes allows to reuse the metal powder for hydrogen storage almost indefinitely.

The hydrogen atoms occupy the interstitial sites of the metallic lattice, which enables a good volumetric density. Metal hydrides is stored at low and constant pressure that increase safety. Main advantages are: • High volumetric density • Good safety properties • Long lifetime, no degradation • Density corresponds to compressed hydrogen at approximately 1000 bar(g) • Flow rates can be controlled with temperature • Hazardous area to be considered only on flanges and connections Main disadvantages • Low mass density (Correspondence Group input)
Risks/hazards
Hydrogen leakage, fire, and explosion (Correspondence Group input)
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Liquid Organic Hydrogen Carrier (LOHC)
Description
Liquid organic hydrogen carrier (LOHC) technology provides higher density hydrogen storage. Though more recently developed, it is also forecast to commercialise over similar timescales as hydrogen fuel cells, i.e. forecast to be used in commercial operations later this decade. (MEPC 80/INF.10) Forecast to be used in commercial operations later this decade. (MEPC 80/INF.10) ... For use as a fuel? Or as a cargo? My understanding is that it may never be viable as a fuel. (Correspondence Group input)
Risks/hazards
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Improved Efficiency

Air Lubrication
Description
• Air lubrication also serves to reduce hull friction. Although used on some vessels commercially today, some limitations have meant it has not yet become established. Commercial development is expected to improve its effectiveness and competitiveness by late 2020s, reaching full maturity by 2035. (from document MEPC 80/INF.10) Air lubrication consist of a number of nozzles or mixing chambers that inject air through the hull, creating an air cushion under the bottom and along the sides. Power savings of up to 5-10% have been claimed and/or measured, although 3% is a more practical figure. The system, in its simplest form, consists of a series of nozzles in the forepart of the vessel and a number of small compressors to provide air. In this form, the drawback is that the air bubbles cannot follow the hull when the vessel is rolling. (Correspondence Group input)
Risks/hazards
Extra hull penetrations, each with its risk of leakage
Existing guidance documents/standards
Several industry solutions exist: Air Lubrication System - Wärtsilä (wartsila.com), Air Lubrication System for vessels - DACS - Damen, research has also been carried out: Air lubrication | MARIN (Correspondence Group input)
Gaps
No FSA has been carried out according to our knowledge (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Foils [Hydrodynamic Energy Saving Devices]
Description
Foils are hull appendages that reduce GHG emissions by improving the hydrodynamics of a vessel. Foils may be active or passive and may be retractable. Foils can improve a vessel's hydrodynamics by reducing the wetted surface area, reducing wave motions in a seaway or optimizing trim. The use of foils to improve energy efficiency is experiencing a resurgence – particularly in smaller commercial vessels. Fully supported Hydrofoils have been around since the 1960's, however, there has been recent focus on bow foils that can be translated into larger ships. Bow foils on larger vessels improve seakeeping and reduce wave-added resistance through the thrust force generated by the foil as the vessel heaves and pitches. Foils or suction sails are rigid active sails that operate on the boundary layer effect created by the under pressure in the (wing shaped) foil. How it works: ventifoils, Interreg VB North Sea Region Programme . Fuel savings depend on the number of units installed, and whether the units are fixed (bigger) or containerized (smaller).

Fully lifted hydrofoils are relevant where high speeds are necessary, and ships are lights: • Drag of a foil is directly related to its surface and surface is linked to lift that must be created. The heavier a ship, the greater the drag. • Drag and lift is also related to the square of the speed: a fast ship will need less surface than a slower ship. Bow foils on larger vessels improve seakeeping and reduce wave-added resistance through the thrust force generated by the foil as the vessel heaves and pitches. Bow foils may experience large loads and are limited to ship about 50m long, up to now. However, research studies have shown a potential savings of about 10-20% depending on the sea state. (Correspondence Group input)
Risks/hazards
- Risk of impact damage in keeping with other appendages Demonstration of the saving effect When more than one hydrodynamic saving device is used the saving is generally NOT cumulative. Bridge visibility issues Colreg issues regarding navigation light positions • Risk of collision with sea mammals, driftwood, etc. • Risk of failure of control or retractable mechanisms/algorithms (redundancy needed). (Correspondence Group input)
Existing guidance documents/standards
High regulatory readiness level Foils measure may be implemented under SOLAS IAW the requirements of a classification society (SOLAS II-1 3.1). The requirements of classification societies vary and most have requirements specific for hull appendages. ITTC 7.5-03-02 Series – Resistance and Flow (Correspondence Group input)
Gaps
No regulatory gaps identified.
Roadblocks
No regulatory roadblocks identified.
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees
MSC (Committee) and SDC (Sub-committee) (Correspondence Group input)

Low-friction Antifouling Paints
Description
• Friction-reducing advanced hull coatings are already applied in commercial operation and are expected to reach full maturity before 2030. (from documents MEPC 80/INF.10)

• Low friction paints have no biocide and rely on very smooth surface aspect so that marine life cannot adhere. Negative effects on the environment are limited and since friction is lower, energy consumption is lower as well. • Low-friction paints are in general mainly composed of silicone. (Correspondence Group input)
Risks/hazards
• Dispersion of silicone is the marine environment has not been extensively studied. Some of silicone polymers used are toxic, bioaccumulative, persistent and degrade under UV action. • Recycling of silicone paint does not exist. Difficulty to prove savings due to low-friction paints since this low rugosity is out of the application range of ITTC formulas and CFD software.
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
• Ask suppliers to demonstrate environmental safety of their low friction paints. Adapt ITTC formulas to low rugosity. (Correspondence Group input)
Relevant IMO Committees/Sub-Committees

Hull Form Optimization
Description
For a given ship (displacement, arrangement, GM, propeller diameter), a variety of hull shapes can be created. The main goal of hull form optimization is to find one of the best designs leading to the lowest energy consumption. Two main areas can easily be optimized: bow and stern. Depending on the ship use (speed, manoeuvring capabilities, etc.) a bulb or a straight bow can be selected. Shape of the stern will also have a strong impact on inflow to the propeller. Using CFD and optimization algorithms, it is possible to generate hundreds of hull shapes and to evaluate their performances without spending time and money in towing tanks. Most recent algorithms are able to dig in most promising designs and to refine them. From early hull shape design to as-built hull, up to 20% of energy can be saved. Most of CFD suppliers now offer optimization tools. Hull optimization can also be performed on retrofitted vessels: a route change, a speed change or a draught change may have significant impacts on the performances and a hull optimization for a set of parameters may not be adapted to another set of parameters. (Correspondence Group input)
Risks/hazards
Demonstration of the achieved savings against the claimed. Hull optimization in CFD is theoretical and real numbers must consider welds, anodes, local buckling, etc. An appropriate margin must be considered.

Optimization constraints shall be clearly defined before any work so hull optimization is efficient. (Correspondence Group input)
Existing guidance documents/standards
ITTC 7.5-03-02 Series – Resistance and Flow ITTC 7.5-02-02 Series – Resistance (Correspondence Group input)
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Optimal Routing
Description
Performance studies performed by the naval architect generally consider calm water conditions. However, depending on the weather conditions and ship characteristics (length, speed), various phenomenon may happen, leading to added resistance: slamming, drift, added resistance in wave, windage, excessive heeling. Even if the ship is not fitted with WAPS, routing is useful to save energy since software are able to predict energy consumption for a variety of environmental conditions and are able to consider ETA. Most of the shipping companies use weather routing. It shall be noted that weather routing is essential to take full advantage of WAPS. (Correspondence Group input)
Risks/hazards
No specific risks identified. (Correspondence Group input)
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Propeller Optimization and Propulsion Improving Devices
Description
Propeller optimization measures include propeller design, propeller polishing, propeller retrofitting.

Propulsion improving devices seek to improve the hydrodynamic efficiency of the propeller or the interaction of the propeller with the hull or the rudder. This may be achieved by adding pre-rotation to the propeller Inflow, improving propeller inflow, alleviating flow separation, decreasing eddies after propeller ca or decreasing cavitation caused by propeller-rudder interaction.

Examples of Propulsion improving devices include stern ducts, wake equalizing ducts (WED), pre-swirl ducts (PSD), pre-swirl stators (PSS), vortex generator fins (VGF), propeller boss cap fins (PBCF), rudder bulbs in combination with propeller caps, twisted rudders, etc.)

In general, propeller optimization measures and propulsion improving devices are technologically mature and have received widespread commercial applications. GLoMEEP has been doing work relevant to propellor optimization (Propulsion Improving Devices (PIDs) (imo.org)) including the costs and specific application based on vessel types
(Correspondence Group input)

Risks/hazards

- No specific risk identified.

ITTC 7.5-03-02 Series – Resistance and Flow
ITTC 7.5-02-03 Series – Propulsion
(Correspondence Group input)

Existing guidance documents/standards

High regulatory readiness level
Propeller optimization measure may be implemented under SOLAS IAW the requirements of a classification society (SOLAS II-1 3.1)
The requirements of classification societies vary.
(Correspondence Group input)

Gaps

No regulatory gaps identified.
(Correspondence Group input)

Roadblocks

No regulatory roadblocks identified.
(Correspondence Group input)

Recommendations for IMO action

Relevant IMO Committees/Sub-Committees

MSC (Committee) and SDC (Sub-committee)
(Correspondence Group input)

Waste Heat Recovery

Description

Current text:
"Advanced waste heat recovery systems recover useful energy from low-grade waste engine (or high temperature fuel cell) heat. Although relatively recently developed for maritime use, they are starting to be used in commercial operation, and are forecast to be fully mature in a decade. "
Proposed text:
"Advanced waste heat recovery systems recover useful energy from low-grade waste engine (or high temperature fuel cell) heat. Although relatively recently developed for maritime use, they are starting to be used in commercial operation, and are forecast to be fully mature within ~~a~~ decade. "

Reason: OCR (organic Rankine cycle) has been a mature land-based application for decades and changing it to marine application is uncomplicated. Marine have formally not seen the use for it. Currently there are at least 6 companies selling commercially ready systems, amongst others, Alfa Laval, Climeon, Electratherm, Enogia, Orcan, and Zuccato – systems that have been trialled onboard and are sold with full warranty. It will not take one decade or more for these systems to become "fully mature" as suggested by MEPC.80/INF.10. (Correspondence Group input)
Risks/hazards
Circuit media may be hazardous for humans. Circuit media may have a high greenhouse gas warming potential (GWP) (Correspondence Group input)
Existing guidance documents/standards
Gaps
Circuit media may differ from supplier to supplier. The circuit media would normally circulate in a hermetically enclosed system, avoiding human interfacing and release to the atmosphere. However, it might be prudent to specify hazardous and GWP levels allowed for the circuit media or at least identify which existing regulations such media should adhere to. (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Emissions Control & Reduction

CO2 Abatement
- onboard carbon capture systems (OCCS, OCCU)
Description
• CCS is a technology, by which carbon dioxide is separated from the combustion exhaust stream, liquified by compression or cooling, and stored in containers for separate reuse or sequestration (e.g. in underground geological formation). The separation process may use a variety of technologies, including absorption, membrane gas separation and others. • The risks involved are typically related to the high pressure and oxygen depletion in case of leakage or release of high quantities of CO2 in closed spaces as below: - explosion; - asphyxiation; and - storage of liquid CO2 at cryogenic temperatures. (from document MSC 105/2/2)
Risks/hazards
• explosion; • asphyxiation; and • storage of liquid CO2 at cryogenic temperatures. (from document MSC 105/2/2)
Existing guidance documents/standards

Gaps
No regulation in place (Correspondence Group input)
Roadblocks
Recommendations for IMO action
Relevant IMO committees/sub-committees

Methane abatement
Description
Risks/hazards
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

N2O Abatement
Description
Risks/hazards
Existing guidance documents/standards
Gaps
Roadblocks
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees

Onshore Power Supply / Cold Ironing
Description
• Shore power is transitioning from commercial operation to commercial development for larger vessels, with international standards in place. However, its high capital costs have been difficult to justify without firm

demand, with unclear financial benefit to vessel operators or ports. Favourable policies are starting to be adopted and so it could be widely used (i.e. full maturity) within a decade. (from document MEPC 80/INF.10)
Risks/hazards
Risks during charging related with electrical fire/explosion, occupational incidents/shock/arcing, and blackout
Existing guidance documents/standards
EMSA Guidance on Shore-Side Electricity to Port Authorities and Administrations – Part 2 includes in section 9 an overview of the safety considerations related to onshore power supply. Ship Safety Standards - Shore-Side Electricity (SSE) - EMSA - European Maritime Safety Agency (europa.eu) Various standards such as IEC/IEEE 80005-1:2019 (Correspondence Group input)
Gaps
Roadblocks
Standardization (Correspondence Group input)
Recommendations for IMO action
Relevant IMO Committees/Sub-Committees