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Seafarers' Section
Maritime Safety Committee

Safety dynamics of ship's energy sources

The transport industry is focusing on alternative energy sources due to a rise in public willingness and the need to partake in global efforts to reduce harmful emissions. The United Nations Sustainable Development Goals (UN SDGs) have driven political pressure across all sectors including maritime. The International Maritime Organization (IMO), the technical agency under the UN developing safety and security standards for the maritime industry, has also pledged its commitment to decarbonise shipping in an effort to contribute to this united worldwide endeavour.

For decades, the maritime industry has dealt with widely available carbon-based fuels which are operated under normal temperature and pressure.

For the maritime industry, the visions and strategies for environmental protection have been developed and include the use of alternative energy sources. Taking into account the fact that there is more than one type of energy source on a ship for safeguarding propulsion and manoeuvring, especially during emergency operations, it is an urgent safety matter to have a clear understanding of the differences amongst energy sources used. This is a historic transition where numerous uncertainties and risk may emerge.

These developments require further consideration for the safety of the human element, in particular seafarers, who are involved and affected across the whole sector in this transition. The need for safety assurances, proper training, and familiarisation must be recognised and implemented to guarantee that all personnel are able to return back home safe.

Seafarers, firefighting personnel, search and rescue personnel, pilots, dockers, bunkering handling personnel and tugboat personnel are directly and indirectly affected and involved in on-the-job operations throughout this transition.

Companies, authorities, suppliers, protection and indemnity insurance providers, and recognised organisations including unions are to ensure the safety of those mentioned above.

Maritime education and training institutes, medical practitioners, and security enforcing bodies are to ensure safety and security culture is firmly embedded in the whole system.

For all stakeholders, appropriate competencies and establishing a safety culture are essential for health and safety for both humans and the environment.

Introducing a new type of energy source encompasses the entire life cycle from manufacturing, transporting, bunkering, storage, and energy processing onboard.

To protect human lives in this transition, it is necessary to have a clear vision of the safety dynamics associated with each energy source and propulsion, manoeuvring and operation technologies. This can be accomplished by acquiring the correct knowledge about the energy sources being used and obtaining the proper competencies necessary for the whole operation, including emergency circumstances. Competencies must therefore include knowledge of operations that may include, inter alia, extreme temperatures and pressures, toxicity, corrosiveness and high voltage, all of which can inflict harm and/or accidents.

The purpose of this document is to highlight the imminent need to put in place measures for those involved in direct on-the-job operations and provide recommendations to close the safety and competency gaps that may exist.

When introducing alternative energy sources, the following are crucial:

- A robust training scheme that guarantees the highest level of safety culture;
- appropriate training that covers communication, Risk & Hazard analysis, operation and emergency situations;
- knowledge about construction and design and relevant regulations;
- adequate fire detection and fire-fighting equipment;
- availability of proper lifesaving appliances; and
- provisions of adequate personal protection equipment for all personnel.

Reading guidance

1. Fuels, energy sources and technologies contained in this document:

- Hydrogen
- Ammonia
- Low Sulphur Heavy Fuel Oil (LSHFO)
- Marine Gasoline Oil (MGO)
- Biofuel
- Liquefied Natural Gas (LNG)
- Liquefied Petroleum Gas (LPG)
- Liquefied Ethylene Gas (LEG)
- Ethanol
- Methanol
- Lithium - ion Battery
- Fusion Energy – Thorium Molten salt Reactor
- Fuel cell (as technology)
- Exhaust Gas Cleaning System "Scrubbers" (as technology)

2. Following tables:

- Identify technical characteristics of fuels and energy sources which produce less emissions;
- Identify hazards related to safety and health and operation, including bunkering and storage;
- Identify safety and health issues for lives and cargo on board related to construction and design of a ship; and
- Recommendations to close the safety gap.

3. This document does not contain renewable energy sources, such as solar and wind power.

4. Energy efficiency comparison:

- Combustion engine is about 35 %
- Steam turbine is about 50 %

5. Glossaries:

- *Flash point* is the lowest temperature at which vapours above a volatile combustible substance ignite in air when exposed to flame.
- *Explosive limits* means specify the concentration range (% has been used in this document) of a material in air which will burn or explode in the presence of an ignition source. There are two types of explosive limits: lower explosive limit (LEL) and upper explosive limit (UEL).
- Differences between liquid and gas and terms used, such as storage temperature and vapour temperature.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Hydrogen	Storage temperature -253°C; Storage pressure 700 Bar; Boiling point -252.8°C; Flash point -252.8°C; Energy density 142.0 MJ/kg	Needs 6 to 10 times more storage space, few bunkering ports available; Storage tank and fuel cell shall be on the highest point on the ship where natural ventilation is possible; Structural fire protection (insulation towards neighbouring spaces); H_2 detection system; Pressure regulating unit(s) and a relief system; Fire safety system; Emergency shutdown system	Virtually zero exhaust emissions; To produce 1 kg H_2 48 kWh needed; Transporting of H_2 conducted by carbon-based fuel	High fire and explosion risk due to low flashpoint and extremely high pressure; Explosive/flammability limits 4–75%	Bunkering possess needs high level of caution for safety of all personnel; If inhaled; - In small concentrations, it can cause headache, nausea, irritation in skin and eye, convulsions; - high concentration, can cause asphyxiation	**Operation** - Knowledge gaps: More testing needed on the safety aspects of handling, storage and bunkering; - Safety: H_2's unique properties make it very different from natural gas; - Fuel system: Use in its pure form when possible; - Framework: The Alternative Design process is currently the best approach; - Implementation: Scaling up H_2 operations will be a challenge; **International regulations** Amendment to IGF Code Crew safety training /competency requirements; Amendments to STCW, focusing on ships specific trainings and familiarisation,

						medical treatment and first aid competence; Alignment SOLAS and MARPOL VI for safe operation of H_2 fuelled engines.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Ammonia	Storage temperature -30 °C; Vapour pressure (45°C) 18 Bar; Boiling point -33,4 °C; Flash point 132°C; Energy density 22.5 MJ/kg	Needs 4 times more storage space, few bunkering ports available; Must be stored in a tightly closed tank in a well-ventilated place, protected from heat sources, separately from oxidizing agents; Installations, equipment, tanks and pipelines must be made of approved materials; Explosion/corrosive-proof electrical equipment must be used in construction; Well-marked escape routes; Enough numbers of shelters, including bridge and engine control room, must be there and remained safe from ammonia;	Actual effectiveness is depending on how ammonia is produced by using what, n.b. synthetic or natural ammonia (7.8-12MWh/ton); In case of a fire or high temperature, nitrogen oxides (NO_x) are formed	Explosive limits 15–33.6%; Fire hazard: -Ammonia gas mixed with air can ignite; -Fuel tank may explode on heating due to overpressure;	Extremely corrosive and toxic; Depending on individuals, even very small concentration from 5ppm can cause irritating to the eyes, nose, throat and respiratory system failure, which result crew unable to carry out work	**<u>Operation</u>** -Be alert with extreme corrosiveness and toxicity of this fuel at all times; - Safe fuel/pilot fuel preparation and treatment; -Follow established routines for all handling of ammonia and use of personal protective equipment (PPE); - Have emergency preparedness for handling minor injuries, equipment and routines for first aid; -Wash ammonia away immediately if contacted on any body part; -Robust overview of where the gas will/can go in the event of a leakage or discharge **<u>Fire-fighting measures</u>** -Do not try to extinguish fire in burning gas;

		Gas/vapour detector (s) that provide early warning of leakage; Fire safety system; Emergency shutdown system				-Try to stop the gas leak if this can be done without risk otherwise, let the gas burn; -Extinguish ambient fire with carbon dioxide (CO_2), powder, sand or foam. Do not use water jet; -Keep unauthorized persons away from the dangerous area; -Ventilate well **<u>International regulations</u>** Amendments to STCW, focusing on ships specific trainings and familiarisation, medical treatment and first aid competence; Alignment SOLAS and MARPOL VI for safe operation of H_2 fuelled engines

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Low Sulphur Heavy Fuel Oil (LSHFO)	Room temperature; Atmospheric pressure; Flash point 61°C; Energy density 41 MJ/kg	Same as Heavy Fuel Oil (HFO), but in addition, chemical tank and pumps are needed from the traditional construction. The chemical tank and pumps must be more secured and ventilated.	Reduce the emission of Sulphur Oxides (SO_x); The sulphur replacement used are toxic chemicals and micro plastic; If not removed from the marine environment, any remaining oil will take a long time to break down and become small sources of long-term chronic ecotoxicity.	Same as Heavy Fuel Oil (HFO); Potential risks associated to the leakage of chemicals, replacing sulphur, are not known, yet	Toxic chemical additives, replacing sulphur, are harmful to both machinery and humans, requiring more maintenance; The oil is toxic as one of its major components will be a mixture of (as much as 30-50%) aromatic polyaromatic hydrocarbons (PAHS) of various sorts, all of which are highly acutely and chronically toxic to humans and marine life.	**Operation** Ensure all crew to be familiar with accurate safety data sheets, in particular PPE section **International regulatory provisions** Recognise SOLAS regulation II-2/4 related to oil fuel parameters other than flashpoint, "*Oil fuel delivered to and used on board ships shall not jeopardize the safety of ships or adversely affect the performance of the machinery or be harmful to personnel.*"; Develop measures to prevent and handle criminalisation; Ensure to introduce prevention and handling of criminalisation in hazard and risk assessment; Use IMO Guidelines for sampling procedures for oil fuel,

						in particular: facilitate reporting of confirmed cases to IMO; actions against and report oil fuel oil suppliers that have been found to deliver oil fuel that does not comply with minimum IMO flashpoint requirements; Note that the flashpoint of the actual fuel batch when bunkering must be provided in the bunker delivery note

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Marine Gasoline Oil (MGO)	Room temperature; Atmospheric pressure; Flash point 65°C; Energy density 45.3 MJ/kg	Same as Heavy Fuel Oil (HFO)	Toxic to aquatic life with long lasting effects due to toxic chemical additives	Upper/Lower Flammable Limits UEL: 7.0% LEL: 0.6%	May be fatal if swallowed; Harmful if inhaled; Causes skin irritation if exposed; Suspected of causing cancer; May cause damage to organs through prolonged or repeated exposure	Ensure PPE protocols in safety data sheet: - Eye/face protection; -Skin protection, in particular hand protection; - Respiratory protection; -Thermal hazards protective clothing in emergency

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Biofuel	Room temperature; Atmospheric pressure; Flash point 150°C; Energy density 38 MJ/kg	The recommended rate to be mixed with other fossil fuels is 10% biofuel. Therefore, equivalent construction and design applied as fossil fuels; Needs changes to fuel storage, handling, treatment (water) arrangements and engines.	100% biofuel does not produce sulphur or aromatics, but still emits greenhouse gases (GHG) such as carbon dioxide (CO_2); Impact on the amount of food production remains concern.	Same as MGO	Same as MGO	**Operation** Be aware of toxic chemical additives used for fuel treatment process. Ensure PPE protocols in safety data sheet: -Eye/face; chemical protective glasses or goggles or face shields to prevent skin and eye contact especially caused from splashing; -Air-supplied respirator; -Air-purifying respirator

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Liquefied Natural Gas (LNG)	Storage temperature - 162°C; Atmospheric pressure; Vapour pressure 0.01bar; Flash point - 188°C; Energy density 55.0 MJ/kg; Colourless and odourless; High risk of "roll over"	Bunkering infrastructure is continually improving, with fuel already available in most major shipping hubs; Storage tanks on deck and evacuation valve with pipe high above the ship's highest point; Require gas tight rooms, sniffers, double pipes, enclosed engine room and special isolated tanks; -Structural fire protection (insulation towards neighbouring spaces); Pressure regulating unit(s) and a relief system; Fire safety system; Emergency shutdown system	Zero SO_x emission; 30% less CO_2 than fuel oil; Less NO_x emissions; Not emitting soot, dust or fumes; Produces insignificant amounts of sulphur dioxide (SO_2), mercury, and other particulates compared to other fuels; However, releases methane (CH_4), which is the dominant component in natural gas, and is 20 times more dangerous CO_2; CH_4 reacts in the atmosphere and forms, among other things, tropospheric ozone which is harmful to both living health and the environment	Highly flammable and explosive; Rapid flame propagation, large mass burning rate about 2 times more than gasoline; High flame temperature, so the burning is of strong radiant heat; Easy to form large area of fire, with characteristics of recrudescence, re-explosion and difficult to put out.	Bunkering prosses is very hazardous; Cryogenic freeze burns, embrittlement of metals and micro plastics and confined spaces hazards	**<u>International regulations</u>** Advocate effective implementation of the IGF Code training requirements, i.e. bunkering processes, onboard familiarisation and training, handling of PPE and first aid competence; Advocate optimal use of simulator training.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Liquefied Petroleum Gas (LPG)	Storage temperature -42°C; Atmospheric pressure; Vapour pressure (27°C) 6.4 bar; Flash point -104°C; Energy density 47.2 MJ/kg; Colourless, but you can smell; If spilt on water, it will float on the surface before vaporising; The gas or vapour is at least 1.5 times as dense as air and does not disperse easily	It will sink to the lowest possible level in a ship construction structure and may accumulate in cellars, pits, drains or other depressions; Structural fire protection (insulation towards neighbouring spaces); Fire safety systems; Emergency shutdown system	Reduces SO_x emissions by 97% and lowers NO_x emissions by around 20%, compared with HFO or VLSFO; Considered easier and safer to handle when protecting soil and water from harmful toxic substances, in case of accidental leaks or accidents at sea	Fire and explosion hazard if stored or used incorrectly; Forms flammable mixtures with air in concentrations between approximately 1.8% and 9.5%; If enters into a confined space and is ignited, an explosion could result; In case of a fire, it may overheat and rupture violently giving an intensely hot fireball and may project pieces of the vessel over considerable distances	Irritation and freezing if liquid enter or exposed to skin; Eye irritation from vapour; If inhaled, may cause irritation to respiratory tract; Moderate exposure may cause headaches or dizziness; Elevated exposure may cause unconsciousness and respiratory arrest by diluting the oxygen concentration in air below the level necessary to support life; May affect the heart and nervous system.	**International regulations** Advocate effective implementation of the IGF Code training requirements, i.e. bunkering processes, onboard familiarisation and training, handling of PPE and first aid competence; Advocate optimal use of simulator training.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Liquefied Ethylene Gas (LEG)	Atmospheric pressure; Flash point -136,6 °C; Energy density 20 MJ/kg; Autoignition temperature 490°C	Same as LNG/LPG	Similar to LNG	Same as LNG/LPG flammable limits LEL 2.7 % UEL 36 %	Same as LNG/LPG	Same as LNG/LPG

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Ethanol	Room temperature; Atmospheric pressure; Flash point 14°C; Energy density 19.9 MJ/kg; Colourless, flammable liquid	Needs 2.5 times more storage space, few bunkering ports available.	Clean-burning, no sulphur, can be produced from renewable feedstocks; Dissolve readily in water, biodegradable, and does not bioaccumulate; Not rated as toxic to aquatic organisms; Particulate emissions very low; Lower NO_x emissions than conventional fuels, depend on the combustion concept and temperature; Very small amount of SO_x emissions depending on the pilot fuel	Extremely flammable liquid and vapour; A polar solvent that is completely miscible in water; Heavier than air and has a wider flammable range than gasoline; LEL 3.3 % UEL 19 %; Still flammable liquid in solutions as dilute as 20% and at the temperature of 10°C	Fatal if swallowed; Suspected of causing blood cancer if repeated over-exposure by inhalation and/or skin contact occurs; May cause damage to liver, kidneys and nervous system by repeated or prolonged inhalation or skin contact; Causes eye irritation; Can be absorbed through skin and repeated or prolonged skin contact can cause irritation and dermatitis.	**<u>International regulations</u>** Advocate effective implementation of the IGF Code training requirements. Consider possible amendments to STCW, i.e. onboard familiarisation and training, handling of PPE, first aid competence and on ships specific trainings

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Methanol	Room temperature Atmospheric pressure Flash point 12.8°C Energy density 31.1 MJ/kg Colourless, flammable liquids; The simplest of alcohols and is widely used in the chemical industry.	Needs 2.5 times more storage space, few bunkering ports available; Structural fire protection; Fire safety systems; Emergency shutdown system	Emissions from combustion in diesel engines are low compared to conventional fuel oils with no aftertreatment; Dissolve readily in water, biodegradable, and does not bioaccumulate; Not rated as toxic to aquatic organisms	Extreme danger of starting fire; Highly flammable in both liquid or gaseous forms; Gaseous methanol molecules can travel quite a distance. This could potentially spread fires in other places; Methanol containers can explode if not sufficiently insulated or protected; When in contact with a platinum-blank catalyst, methanol can also ignite.	Toxic; May cause birth defects of the central nervous system; Chronic poisoning from repeated exposure to vapor may produce inflammation of the eye (conjunctivitis), recurrent headaches, giddiness, insomnia, stomach disturbances, and visual failure.	**Operation** Use spark-proof tools and explosion-proof equipment; Exhaust ventilation or other engineering controls must be provided; Ensure adequate ventilation. **International regulations** Advocate effective implementation of the IGF Code training requirements; Consider possible amendments to STCW, i.e. onboard familiarisation and training, handling of PPE, medical treatment, first aid competence and on ships specific trainings

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Lithium - ion Battery	Room temperature; Atmospheric pressure; Energy density 0.5 MJ/kg	Every battery cell shall be certified its quality. Energy Management System (EMS) and Battery Management System (BMS) should be tested for interoperability, system communication, surveillance, and security systems; The battery compartment must consider the marine environment, such as moisture, salinity, vibration and electromagnetic radiation; The battery compartment must also consider high voltage systems, cooling and ventilation during normal and emergency operations; Barriers are needed from other dangerous	100% effective for ship emissions for a pure battery powered ship; For hybrid packages, the reduction will be depending on the power system design and voyage profile; The effectiveness varies between a major reduction for ships with large batteries on short sea voyages to minimal reduction for large ships making transoceanic voyages.	Extremely high fire temperature which can melt ship structure; Extreme danger of "Thermal Runaway" and the temperature of flames can be above 1000 °C and melt steel; The gasses produced due to high temperature are extremely toxic and corrosive and can create extreme danger for fire and explosion; Extremely explosive gasses, which can self-ignite, without warning.	Fatal gasses, such as Hydrofluoric acid (Hydrogen Fluoride - HF), produced due to high temperature. **<u>Skin hazard</u>** Absorbed through skin causes nerve, bone and organ damage, which can be fatal; **<u>Eye hazard</u>** High risk of blindness; **<u>Inhalation hazard</u>** - Toxic, lethal concentrations above 200ppm; - Non-lethal doses may cause pulmonary edema. **<u>Ingestion</u>** Toxic and fatal	**<u>Operation</u>** Exercise regularly for manual shutdown in various abnormal conditions such as one natural part of emergency drills; **<u>Fire emergency</u>** - Leave the battery compartment close and monitor the situation outside the compartment; - Disconnect the battery system and make sure the battery cooling system is activated, release extinguishing system use of salt water is banned; - Do not re-enter the battery compartment until the exhaust gas has been vented; - Fire gas should be ventilated in good distance of the ship; - Avoid adding O_2; - Use high voltage and chemical PPE;

		cargo/storage and the effect of extremely high temperatures in case of a fire;				- Never touch batteries as these are conductive. **<u>International Regulations</u>** Ensure effective implementation of the STCW requirements for firefighting as a basic safety training: Ensure effective implementation of the ISM, such as equal level of competences amongst seafarers, fire brigade, rescue team, etc. for the safe operation system, including emergency, in particular communication.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Fusion Energy – Thorium Molten salt Reactor	Reactor temperature 700°C; Vapour pressure; Boiling point 4787°C; Melting point 1750°C; Energy density 79,420,000 MJ/kg; Energy efficiency 50%	The reactor system placed in engine room, with double cooling systems; The reactor system is concealed with 1m thick concrete container; Replacing a combustion engine with the reactor system will reduce the ship's dwt. e.g.6,500dwt off on a 68,220dwt-ship; No need for HFO storage tanks; Bunkering is not needed, but the "stone" with size of an golf ball to be replaced every 10 year	Zero emission to marine environment; No radiation is released outside the concrete container	No risks due to: - A "freeze plug" where a reactor drain-plug is actively cooled to keep the fuel in and the reactor running. If anything goes wrong, the reactor fuel is safely drained, and the reactor stops; - The molten salt intrinsically slows the reaction if it becomes overheated because of its negative temperature coefficient of reactivity.	Normally none	**International regulations** Use existing SOLAS regulations (Ch. VIII); Amendments needed with additions; Ensure effective implementation of the STCW, focusing on ships specific trainings and familiarisation, medical treatment and first aid competences.

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Fuel cell **(as technology)**	Energy efficiency around 60%; An electrochemical cell that converts the chemical energy of a fuel (e.g. H_2). Different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction; Can produce electricity continuously for as long as fuel and oxygen are supplied	Heavy unit; Must be placed on an open space; Stringent evacuation plan required, including shelters for persons	Potentially 100% depending on fuels used and means of producing fuel; Produce water, heat and, depending on the fuels, very small amounts of NO_x and other emissions	Extremely explosive		**Operation** Evacuation plan should be well instructed, including locations of shelters

Energy	Characteristics	Construction & Design	Environmental Effectiveness	Fire and explosion risks	Health and safety issues	Recommendation
Exhaust Gas Cleaning System "Scrubbers" (as technology)	Three types of wet scrubbers exist for removal of SO_x and particulate matter in the exhaust air: -open-loop -closed loop -compact/ hybrid using both open/closed loop	Heavy unit	Potentially 100% depending on fuel used; No fuel penalty; Known as the best solutions for large existing ships, further this technology is considered for Carbon capturing measure, too	Daily maintenance, required to avoid risks, is heavy-labour nature		**Operation** Follow established routines and use of PPE.