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VII Congreso Internacional de Diseño e Ingeniería Naval

CREATING A RULE FRAMEWORK FOR THE GREEN REVOLUTION IN SHIPPING INDUSTRY

Internal & territorial waters

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Challenge

Initial stage

To avoid pollution:

Waste management (oil, waters, garbage), hull antifouling, prevention of oil spillage and leakage, refrigerants, fire-extinguishing media and limitation of nitrogen oxide (NOx) and sulphur oxide (SOx)

- BV notation "Cleanship" – or "Cleanvessel"
- Identification of all hazardous material (Cf. IMO 2009 Hong Kong convention): BV notation "Green passport"
- Connection to shore installation for energy supply: external high voltage electrical power supply in port

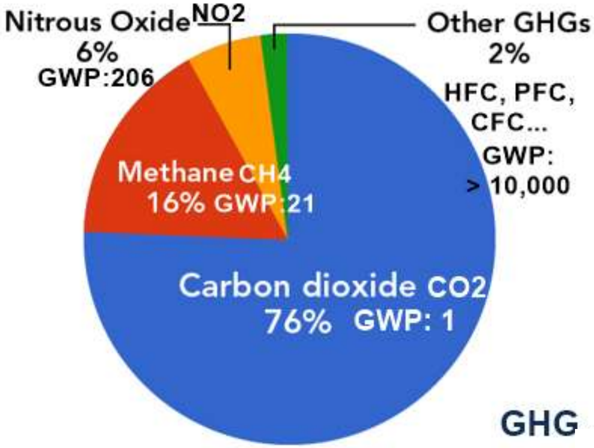
SUSTAINABLE DEVELOPMENT

< 2°C

IMO ambitions

Green house gases

GWP: global warming potential



-40%
CO_2
by 2030

-70%
CO_2
by 2050

-50%
GHG
by 2050

*as compared to 2008

Challenge

Many options: it can start with optimization in hull forms, propellers and coating, and a panel of combinable solutions, but they remain behind the path to meet the goals

Decarbonization implies leaving fossil-based energy within the complete chain, well-to-wake, and not solely from tank-to-wake. Zero-carbon fuel must be produced from sustainable processes

Wind power, solar power, hydro-energy, geothermal energy, bioenergy.

Energy storage is among the key topics.

Challenge

The shipping industry is doing its part by developing new technologies that use green energy.

Energy source and its associated technologies presents new risks.

Need for solutions for existing ships, while deciding how to build future vessels.

Technologies move forward faster than regulations. Technical challenges become regulatory challenges: administrations are urged to provide the shipbuilders with appropriate requirements for design, manufacturing and equipment, notably for vessels operated in internal and domestic waters which are not strictly covered by the international conventions.

Challenge

Overview of the main alternative fuels and their related technologies

- Summarize the majors risks and obstacles
- Classification rules that may offer a suitable support in designing, constructing and obtaining suitable licences to operate

Panel from common LNG solutions, via “start-up” fuels, to less developed options such as hydrogen and ammonia.

- Carbon fuels: LNG, LPG, Methanol/Ethanol
- Carbon neutral: biofuels/biomethane, synthetic methane, green methanol
- Zero carbon: green hydrogen, green ammonia

Possible matters & fuels

Possible matters & fuels

Natural gas: hydrocarbon mixture, mainly methane (CH_4) for more than 95%. It is mainly from fossil origin.

Almost neither SOx nor particulate matter emissions. Low NOx and GHG emissions.

LNG is stored at -162°C (1 bar) or -130°C (10 bars). Boil-off: 0.15 to 0.4 % of its amount per day. If compressed (CNG), the pressure is 200 to 250 bar.

The main hazards are:

- Jet fire: leak with high pressure can form a jet flow, if the gas is lit at the leakage split, then the jet fire happens.
- Rapid phase transition: LNG vaporizes violently upon coming in contact with water. No combustion, but a huge amount of energy transferred in the form of heat.
- Cryogenic temperature: steel structure exposed at cryogenic temperature would risk brittle fracture with no prior apparent plastic deformation

Possible matters & fuels

Petroleum gas: flammable mixture of hydrocarbon gases, propane (C_3H_8) and butane (C_4H_{10}).

LPG is heavier than air therefore it tends to settle in low spots.

Using LPG as a fuel can lower emission to air compared to conventional fuels, GHG, sulphur and NOx but LPG releases more CO_2 per unit of energy than natural gas (fossil fuel).

Safety aspects:

- risk of fire and explosion after vaporization of LPG into a gaseous state
- risk of asphyxiation induced by high concentrations of LPG since it displaces the oxygen in the air.

Possible matters & fuels

Methanol: organic chemical compound of the alcohols group of substances - CH_3OH

Soluble in water and biodegradable.

Flashpoint: 12°C. High octane ratio (114)

Reduced levels of CO_2 emissions, eliminates SOx emissions and limits particulate matter

Safety aspects:

- React violently with oxygen.
- Flammable
- Toxic

Possible matters & fuels

Biofuels: form of energy derived from the harvesting and processing of different types of biomass, including waste, charcoal, wood, fishery and agricultural products.

Reduce emissions of GHG such as methane and ozone precursors

1st generation: organic materials grown for fuel production purposes

2nd generation: by-products of other biomaterials

3rd generation: come from microorganisms such as algae.

Possible matters & fuels

Hydrogen: the most plentiful in the universe but scarcely in natural condition

Highest energy density

Hydrogen produces zero CO_2

Storage and transportation are real challenges:

Either high pressure (700 bar or more) or liquefaction at -253°C. The process uses energy that may consume up to one third of the gas energy.

Solid storage: currently limited

Easily flammable. Wide range of explosivity and low energy of ignition.

Possible matters & fuels

Ammonia: compound of nitrogen and hydrogen, NH_3

Zero CO_2 emissions

Ammonia can either be pressurised (10 bars) or liquefied at -33°C

It ignites and burns poorly

Narrow flammability range

Much lower energy density

It requires three times the space

Toxicity and caustic properties: careful storage and handling.

It is also flammable and corrosive.

Storage characteristics

	Mass energy density LHV (MJ/kg)	Volumetric energy density LHV (GJ/m³)	Storage pressure (bar)	Storage temperature (°C)	Relative tank volume (without insulation)
Marine Gasoil (reference)	42.8	36.6	1	20	1
LNG	50.0	23.4	1	-162	1.6
LPG	46.1	26	17	20	1.4
Methanol	19.9	15.8	1	20	2.4
Liquefied H_2	120	8.5	1	-253	4.3
Compressed H_2	120	7.5	700	20	4.9
Ammonia	18.6	12.7	1 10	-34 20	2.9

Safety issues - Summary

	Fire / explosion	Pressure	Toxicity	Corrosivity	Cryogeny
LNG	X	X			X
CNG	X	X			
LPG	X				X
CH2	X	X			
LH2	X				X
Ammonia	X		X	X	
Methanol	X		X		

Technologies

Technologies

Regulations are not yet ready for all technical options. Furthermore, regulations usually set the suitable technical arrangements, but they don't provide the constructive dispositions for manufacturing, notably material, components of equipment and tests, and assembling on board.

The classification rules are providing the constructive requirements about each fuel. They refer to the main rule books, NR467 and NR217. Both are linked to NR216 which provide the requirements about materials and welding. The requirements for approval of equipment in hull and machinery are given in the Rule book NR266, complete with NR544 for pure inland navigation vessels. Additionally, the Rule note NR320 settles the certification scheme.

The initial conditions for approval of any system must be maintained once it is in service. The classification rules settle the periodical inspections as well as the scope of survey.

Technologies

Thermal engines: LNG

Greater numbers of LNG-powered vessels are being built

LNG poses the challenge of methane slip, caused by incomplete LNG combustion

There are three types of engines

- ❑ Spark ignited lean burn engine (Otto cycle): low pressure gas supply, 4 to 5 bar. The gas is injected in the air charge to the cylinder where the mixture is compressed and ignited by a spark.
- ❑ Diesel ignited dual fuel engine (Combined Otto/Diesel cycle): low NOx emissions. The diesel-ignited LNG engine is the first type used in the marine industry. It runs with low pressure gas supply, 4 to 5 bar.
- ❑ High pressure direct injection engine (Diesel cycle): its high fuel flexibility and very high-power density are attractive. Combustion is very complete but with higher NOx emissions. Currently, its use in the marine industry is still limited.

Technologies

Thermal engines: LNG

The IMO regulations are the SOLAS Convention and the IGF Code.

NR529: class notations “gasfuel” (or “dualfuel”). Risk analysis: design of machinery spaces.

There are two alternative systems:

a) Gas safe machinery spaces: arrangements is such that the spaces are considered gas safe under normal as well as abnormal conditions.

b) ESD protected machinery spaces: arrangements are such that the space itself acts as the pipe enclosure required by IGC Code. In abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery must be automatically executed.

NR529: Gas supply system - Storage tanks - Ventilation system - Electrical systems - Gas detection

Technologies

Thermal engines: LPG

LPG is supplied to the engine at a pressure of 50 bar. To achieve a full atomization of the LPG when leaving the injection valves nozzles, 600-bar injection pressure is necessary

Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) system is necessary to fulfil the IMO NOx emission limits.

The IMO regulation is the IGF Code: alternative design

Rule note NI647:

- Risk assessment
- NR529 for material and design of LNG piping systems also apply to LPG.
  - Regulations for bilge systems and drainage arrangements
  - Drip trays
  - Venting arrangements
  - Secondary enclosure for LPG fuel piping
  - Electrical installations

Technologies

Thermal engines: methanol

Methanol can be used in spark-ignition engines.

Low calorific value: consumption would increase.

Due to formation of acidic products during combustion, the wearing of valves, valve seats, and cylinders might be higher than with hydrocarbon burning

Methanol can be mixed with ordinary fuel: mixture of methanol (70%) and diesel (30%).

IMO interim guideline MSC.1/Circ.1621

NR670:

- Cofferdams surrounding fuel tanks
- Ventilation of void spaces
- Fuel containment system, tank segregation

Technologies

Thermal engines: biofuels

They can provide a workable entry point into carbon-neutral shipping.

Biofuel-specific technical challenges such as oxidation stability, cold flow properties, and the risk of microbial growth.

Mixing traditional carbon fuels with biofuels or synthetic fuels, known as “drop-in” fuels.

The regulations are those applicable to the original matter (diesel, LNG, …).

Class: type approval certificates to be reconfirmed

Technologies

Thermal engines: Hydrogen

Can be injected, pure or mixed with diesel. Usual internal combustion engine but stronger design.

The energy efficiency is slightly less than classic engines. The proportion of hydrogen would decrease proportionally the direct emission of CO_2 but it would increase the NOx emission due to higher burning temperature

Three main types of hydrogen engines:

- ❑ Direct cylinder injection: the fuel-air mixture inside the combustion cylinder after the air intake valve is closed. Maximum output can be 15% higher than diesel engine (but NOx emission).
- ❑ Central injection or Carburetted System: fuel-air mixture during the intake stroke. Same system as gasoil engine. More subject to irregular combustion due to pre-ignition and backfire. Power is 85% of that of diesel engine.
- ❑ Port injection: it injects fuel directly into the intake manifold at each intake port. Air is injected separately at the beginning of the intake stroke. The risk of premature ignition is reduced. Same power as carburetted engine.

If engine is designed for about twice as much air as required for complete combustion, NOx is reduced to near zero, but the power output is about 50% of gasoil engine.

Technologies

Thermal engines: Hydrogen

One of the most flammable products when mixed with air even in small amounts.

Low temperature may generate embrittlement. Inert gas and constituents of air may come to liquefaction and solidification.

Storage: IMO MSC.420(97)

Class: guideline NI547. Containment and use of hydrogen.

Non-metallic piping carrying hydrogen gas may accumulate electrostatic charge along its exterior surface. This may be achieved by specifying pipe material with sufficient conductivity, or by limiting gas flow velocity below values where electrostatic charge might accumulate

Hydrogen equipment should be purged before and after using hydrogen. Inerting should be performed, with inert gas that cannot freeze

Technologies

Thermal engines: Ammonia

Combustion could lead to higher NOx emissions unless controlled by after-treatment

Challenges embrace toxicity, corrosiveness, slow ignition, and NOx emissions.

Volume and weight of storage is an issue. Cryogenic storage would be considered safer.

To limit NOx: Exhaust Gas Recirculation (EGR) and Selective Catalytic Reduction (SCR).

Quick corrosion of nickel and copper found in seals, gaskets, valves, and electrical components, and most elastomers once exposed to ammonia,.

Engine very similar to diesel engines could use small quantities of ammonia as a drop-in fuel.

Technologies

Thermal engines: Ammonia

IGF Code does not cover ammonia in detail: alternative design approach is required.

Class Rules: NR671

- Prevention of leakages
- Prevent corrosion: selection of materials
- Containment system (same approach as IGC/IGF Codes)
- Venting management
- Leakage management: double barrier concept (double wall piping), dilution through water and emergency ventilation

Technologies

Fuel cells

Convert chemical energy from hydrogen into electrical energy as direct current. This electrochemical reaction occurs between hydrogen and oxygen from air with efficiency range between 35 and 55% and it emits only heat and water.

The main advantages of fuel cells compared to thermal engines are:

- High efficiency: between 40 and 50% (instead of 20% or 30%)
- No pollutant emission, no GHG (NOx, CO2), no SOx
- Modular (number of cells for voltage and surface of cells for intensity)

Different types of fuel cells. Use of hydrogen, LNG, methanol.

There is no regulation yet providing suitable requirements for fuel cells.

NI 547: notation “Hydrogencell”. Certification of equipment and materials. All requirements from the classification Rule books relating to specific fuels such as LNG, hydrogen and methanol, must be met.

Types of fuel cell

Type	AFC	DMFC	PEMFC	SOFC	MCFC	PAFC
Name	Alkaline fuel cell	Direct methanol fuel cell	Proton exchange membrane fuel cell	Solid oxide fuel cell	Molten carbonate fuel cell	Phosphoric acid fuel cell
Electrolyte	Liquid potash	Solid polymer	Solid polymer	Solid ceramic	Liquid Molten salt	Liquid Phosphoric acid
Temperature (°C)	70	80 to 130	70 to 160	600 to 1,000	600 to 650	160 to 210
Power (kW)	10 to 100	25 to 5	0 to 200	0 to 200	10 to 500	100 to 400
Combustible	Hydrogen Ammonia	Methanol	Hydrogen	Hydrogen LNG Methanol	Hydrogen LNG Methanol	Hydrogen LNG Methanol
Electrical efficiency (%)	50 to 70	40	30 to 45	50 to 60	40 to 60	40
Lifetime (h)	4,000 to 8,000	4,000	2,000 to 20,000	3,000 to 50,000	20,000 to 50,000	20,000 to 50,000
Starting time	Minute	Minute	Minute	> 10 h	10.	1 to 3 h

Technologies

Batteries

Energy is required to produce electricity used for battery charging

Battery system may be the suitable option for small coastal ships and inland vessels using full electric propulsion.

C Rate is the current which described how fast the cell is charging or discharging

Challenge: increase the energy density and manage the risk of thermal runaway and explosion. Additional safety measures such as appropriate ventilation, gas detections, protection against leakage and electrostatic hazard, fire protection and fire-extinguishing system

Li-on batteries are preferred for their light weight, high energy density, low rate of self-discharge and low maintenance

Battery management system (BMS): monitors and manages electric and thermal states. It provides communication between the battery system and power management system (PMS)

IEC standards are applicable. Class: NR467 and NR217. For lithium type, a risk analysis covering battery packs, battery compartment and BMS must be submitted.

Technologies

Hybrid systems

They are commonly based on diesel-electric system coupled with battery system.

Hybrid system can be the easiest way in conversion of existing vessels to reduce fuel consumption.

NR467: the additional class notation “Electric Hybrid” may be assigned to ships provided with an Energy Storage System (ESS) used to supply the electric propulsion or the main electrical power distribution system. The ESS aims at assisting the electric propulsion or the main electrical distribution system with the power demand.

“Electric hybrid” is completed with (PM) when the power management mode is available as load smoothing mode, peak shaving mode or enhanced dynamic mode. The notation (PB) is assigned when power backup mode is available and (ZE) when zero emission mode can be chosen.

SUMMARY

Summary

Large panel of solutions but no panacea.

Choice depends on type of vessel and the constraints of the area of operation.

LNG: a step to the right direction for CO_2/GHG reduction with easy switch towards biogas and SNG.

LPG could be a step to ammonia since the technology may be compatible.

Methanol: technically attractive but not economically viable yet. Bio-methanol engines can be adapted from units running on LNG.

Biofuels: an available stepping-stone on the path to decarbonization. Hardly sustainable. A partial solution pending the next stage.

Summary

The regulatory aspect is of major importance. The classification rules cover the new technologies and combination of them.

Possibility to validate a design for possible future conversion: notation “-prepared” (e.g. “Ammonia-prepared”).

Hydrogen: storage remains a technical challenge.

Ammonia: although the safety issues are still challenging, as hydrogen carrier it shows promise.

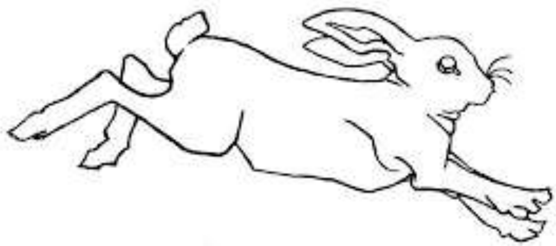
Batteries: an increasingly favoured solution for travelling fixed routes, such as river, estuary and short-sea ferries. Need for improvement of BMS and battery lifetime. Can be combined with fuel cells.

Electrical hybrid: may be a valuable solution for existing vessels, depending on the engine load, more significant during manoeuvres.

Summary

Matter	Efficiency / Interest	Main Risk	Pros & Cons		Regulation	Class Rules
LNG	No SOx Low NOx CO2 reduction	Flammable Cryogenics or high pressure	Experienced	Fossil Methane slip	IGF	NR 529 NI547
LPG	Low SOx	Flammable Leaks	Production	Fossil (CO2) NOx emission	IGF	NI 647
Methanol	No SOx CO2 reduction Few PM	Flammable Toxic	Thermal efficiency	Fuel consumption	IMO interim guideline	NR 670 NI547
Biofuels	Low GHG	Gas: idem LNG	Readiness Compatibility Mixed fuels	Production	Idem	Idem
Hydrogen	Zero carbon	Flammable Cryogenics or high pressure	Energy density	NOx (T.E) Production	No	NI 547
Ammonia	Zero carbon	Flammable Toxic Corrosive	Production Mixed fuels	NOx emission Storage (volume)	IGC (storage) IGF (alternative)	NR 671
Battery	No emission	Thermal runaway	Efficiency Hybrid	Charging	IEC standards	NR 467 NR 217
Fuel cell	No emission	Hydrogen	Efficiency		No	NI 547

Warning!



2021

Nth warning
from IPCC

2030

Almost tomorrow!

2050

Measure the effects

Thank you for your attention