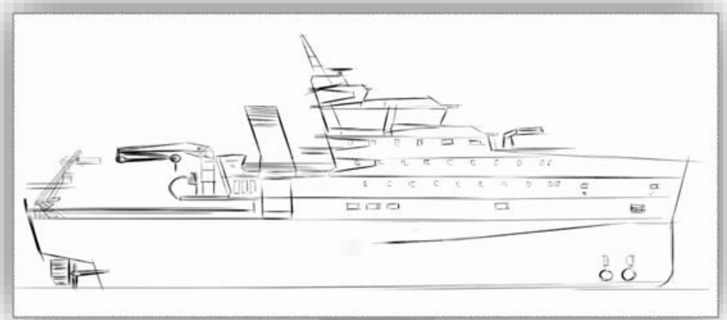
New Spanish research vessel: a diesel-LNG hybrid approach

R.V. Odón de Buen

5th - 7th of September 2022

Motivation

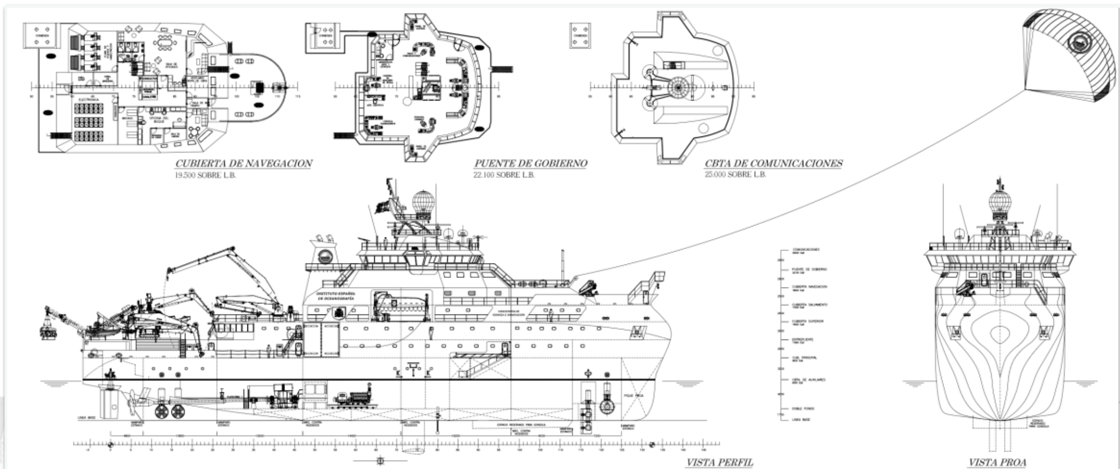


Guidelines from Science Ministry

- **Designed accordingly needs of the whole fleet**
- **Multidisciplinary**
- **Low Exploitation Costs**
- **Low Carbon Footprint**

Low Carbon Footprint

- **Navigation Aids (Kites or Rigid Sails)**



2008 Initial Design

- **Renewable energies**

2018 Technical Specifications

Battery Pack && Solar Panels.
2 hours autonomy for "cleaning sampling", stays in port, aid to generating sets … (> 700 Kwh)

Energy Recovery System (winches)

2020 Approach

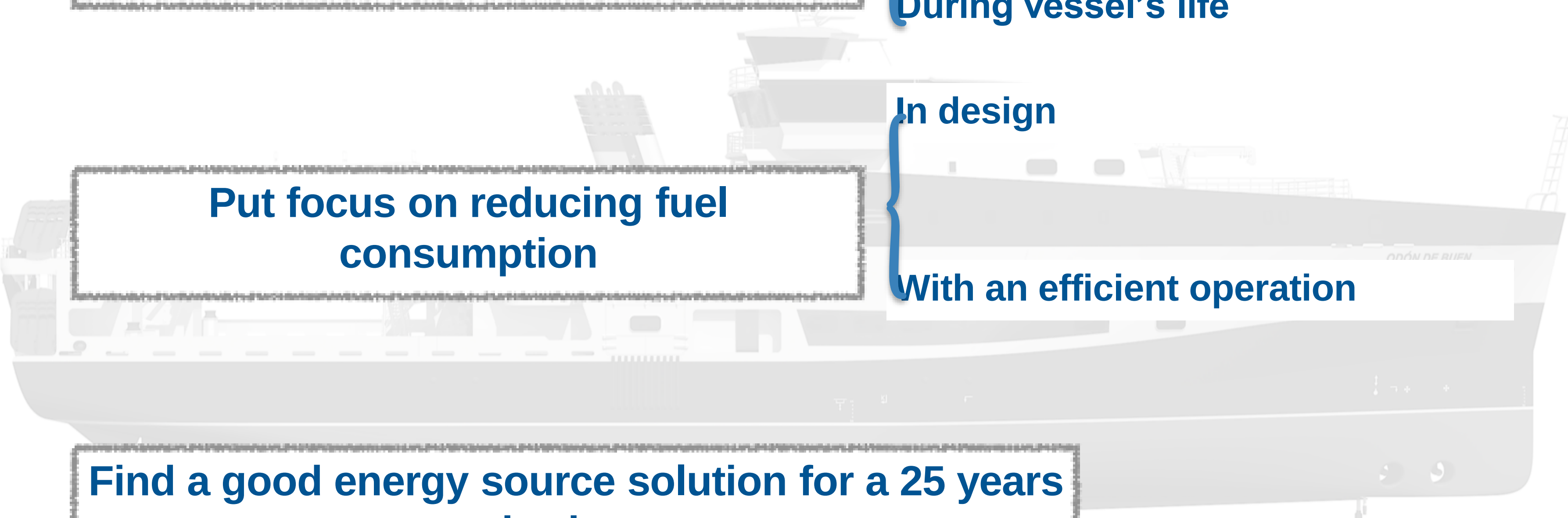
Find a way to estimate the Vessel's Carbon Footprint

- In design
- During vessel's life

Put focus on reducing fuel consumption

- In design
- With an efficient operation

Find a good energy source solution for a 25 years horizon



Estimation of Carbon Footprint

Energy Efficiency Design Index (EEDI)

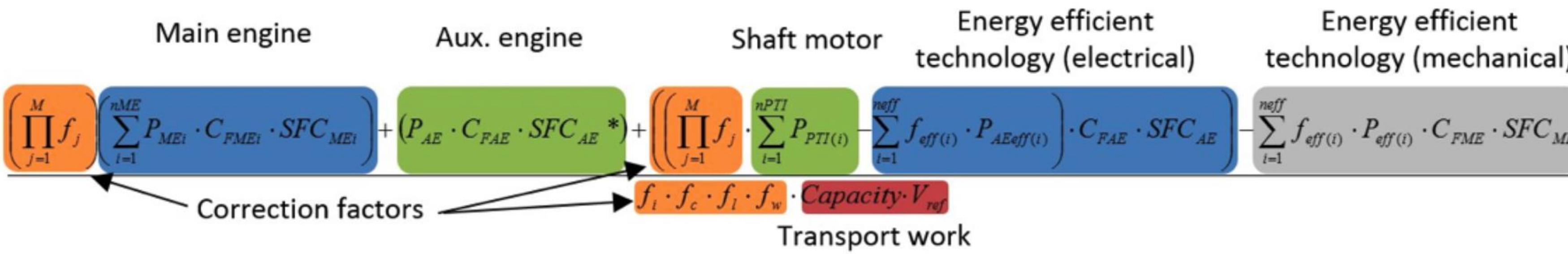
The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI.

The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship

[..] the Shipyard will demonstrate the EEDI of the submitted design and will include it in the ship's technical report as a characteristic thereof, although, given the non-existence of standard reference values for oceanographic ships, it will not be a reason for evaluating the offers submitted.

Its calculation and value will be taken only at an informative and descriptive level of the ship.

Energy Efficiency Design Index (EEDI)



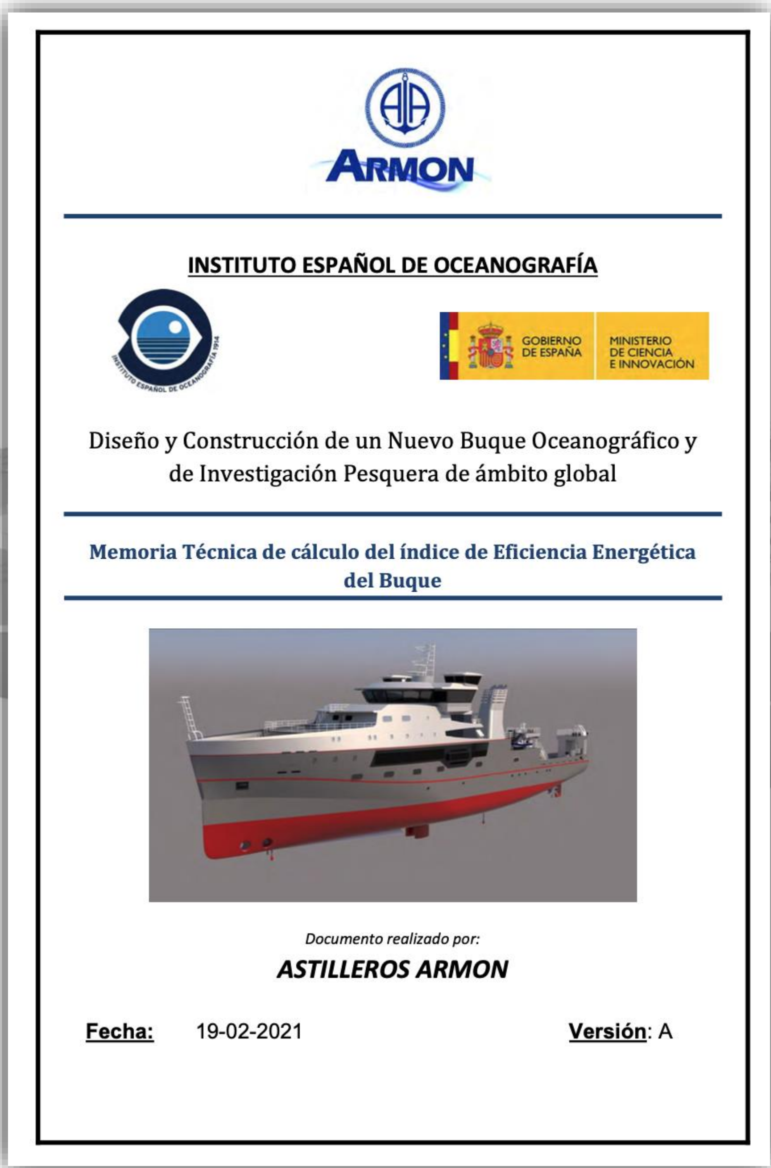
The top line of the EEDI formula can be divided into four key parts:

1. CO_2 emissions due to propulsion power, PME + PPTI
2. CO_2 emissions due to auxiliary power, PAE
3. CO_2 emissions reduction through energy efficient technologies reducing the auxiliary power by generating electricity for normal maximum sea load, PAEeff. Examples include waste heat recovery and photovoltaic power generation.
4. CO_2 emission reduction through energy efficient technologies reducing the propulsion power, Peff. Examples include air lubrication systems and wind propulsion systems.

The bottom line of EEDI formula consists of capacity and reference speed Vref, which represent the transport work capacity of the vessel.

Energy Efficiency Design Index (EEDI)

Estimation of Carbon Footprint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INSTITUTO ESPAÑOL DE OCEANOGRAFÍA

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN

Diseño y Construcción de un Nuevo Buque Oceanográfico y de Investigación Pesquera de ámbito global

Memoria Técnica de cálculo del índice de Eficiencia Energética del Buque

Documento realizado por:

ASTILLEROS ARMON

Fecha: 19-02-2021 **Versión**: A

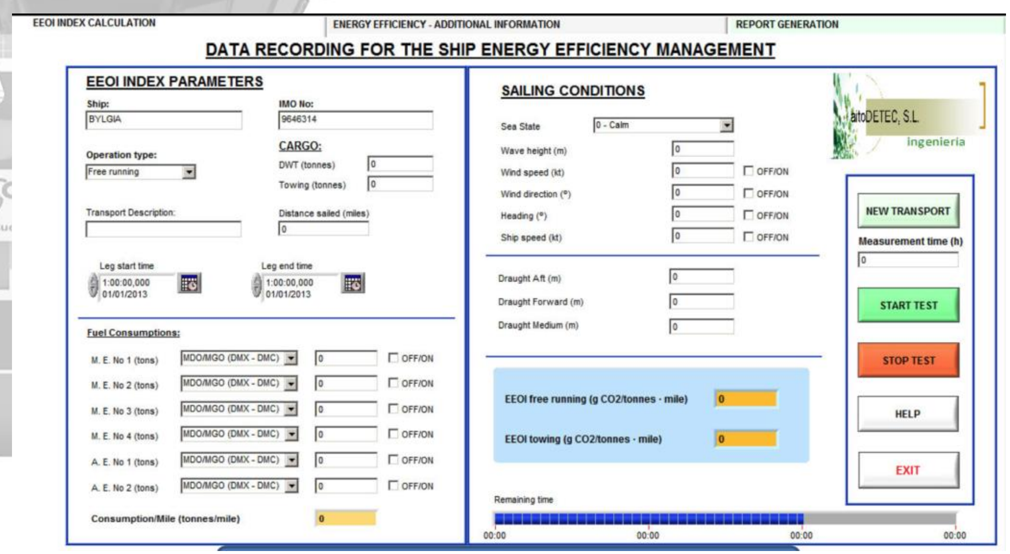
$$EEDI = \frac{186829{,}65 \left[kW * {}^{g_{fuel}}/_{kWh} * {}^{g_{CO_2}}/_{g_{fuel}}\right]}{6478{,}38 \left[tonne * knotical \frac{miles}{hour}\right]} = 28{,}838 \frac{g_{CO_2}}{tonne * knotical\ miles}$$

Consumo Total	***0,2690***	$\boldsymbol{m^3/_h}$
Consumo a 14 nudos	*0,7618*	$m^3/_h$
Consumo a 10 nudos	*0,2688*	$m^3/_h$
Consumo a 7 nudos	*0,1348*	$m^3/_h$
Consumo a 2 nudos	*0,0755*	$m^3/_h$

Management System for an efficient vessel navigation conditions

Ship Efficiency Management Plan: permanent monitoring of consumption and mechanical and energy parameters of the vessel.

- Control and management of consumption in real time
- Ability to detect possible deviations in the combustion processes
- Identification of elements to optimise performance, consumption and mechanical efficiency
- Identification of possible deviations from equipment manufacturing protocols
- Establishment of the optimal navigation speed for the different scientific scenarios
- Generation of historical energy and mechanical efficiency

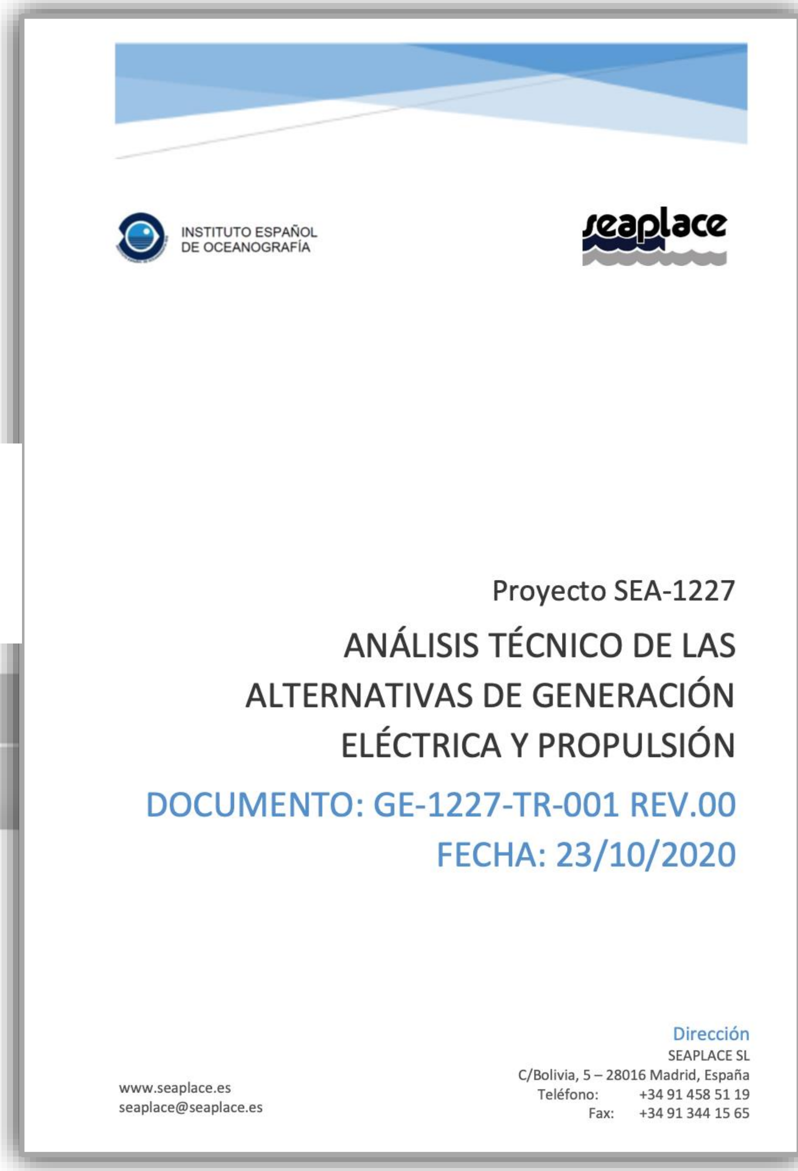


In addition, the system will be able to calculate the EEOI adapted for an Oceanographic vessel where the load is not the fundamental parameter. The EEOI is defined as the mass ratio of CO2 (M) emitted per unit of transport carried out.

Alternatives for Energy Generation

2020

STATE OF THE ART: TECHNICAL ANALYSIS OF ELECTRICAL GENERATION AND PROPULSION ALTERNATIVES



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Proyecto SEA-1227

ANÁLISIS TÉCNICO DE LAS ALTERNATIVAS DE GENERACIÓN ELÉCTRICA Y PROPULSIÓN

DOCUMENTO: GE-1227-TR-001 REV.00

FECHA: 23/10/2020

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REQUIREMENTS COMPLIANCE MATRIX

	Noise and vibrations (ICES CRR 209)	Autonomy 45 days	Minimize CO2 emissions	NOX Treatment Systems	Horizon 2050 emissions (IMO)	Maximize space on board	Availability	Crew comfort (noises, odours)	Crew comfort (noises, odours)	Easy operation	Total
Weight factor	*1*	*1*	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	
LNG	2	2	2	3	2	2	3	2	2	2	29
Hybrid & Bateries	2	3	2	2	2	1	3	2	2	2	27
Fuel Cells	3	1	3	2	3	1	1	3	1	1	27
Biofuel	1	3	3	1	1	3	2	1	3	3	26
NH3	2	2	3	1	3	1	1	1	2	1	24
Diesel	1	3	1	1	1	3	3	1	3	3	23

1	Low
2	Medium
3	High

Considerations:

- The alternatives have been evaluated with values from 1 to 3, according to the relative advantage or di

- A higher weight (2) has been attributed to the requirements related to the reduction of emissions.

RISK MATRIX

	Engineering Project			Technological risk				
	Engineering Integration	Impact on the distribution of spaces	Mature regulatory framework (SSCC Rules, IMO standards)	On-board installation	Evolution of technology (obsolescence)	Safety on board	Solution Maturity	Total Risk
Diesel	1	1	1	1	1	1	1	7
Biofuel	1	1	2	1	1	1	1	8
Hybrid & Bateries	1	3	1	1	1	1	1	9
LNG	2	2	1	2	1	2	1	11
NH3	3	2	3	3	3	3	3	20
Fuel Cells	3	3	3	3	3	3	3	21

1	Low
2	Medium
3	High

Considerations:
-The alternatives have been evaluated with values from 1 to 3, according to the relative risk of each one compared to the rest of the solutions.

Working lines to be included in Tender Tech. Specs.

- **Use of LNG with Diesel on an Hybrid solution (Around 10 days of “cleanner” operation)**
- **Fuel consumption criteria for evaluation of the different offers**
- **Inclusion of Energy Efficiency Design Index estimated by shipyard as a reference (not to be considered as a evaluation criteria)**
- **Supply a system for an efficient navigation**

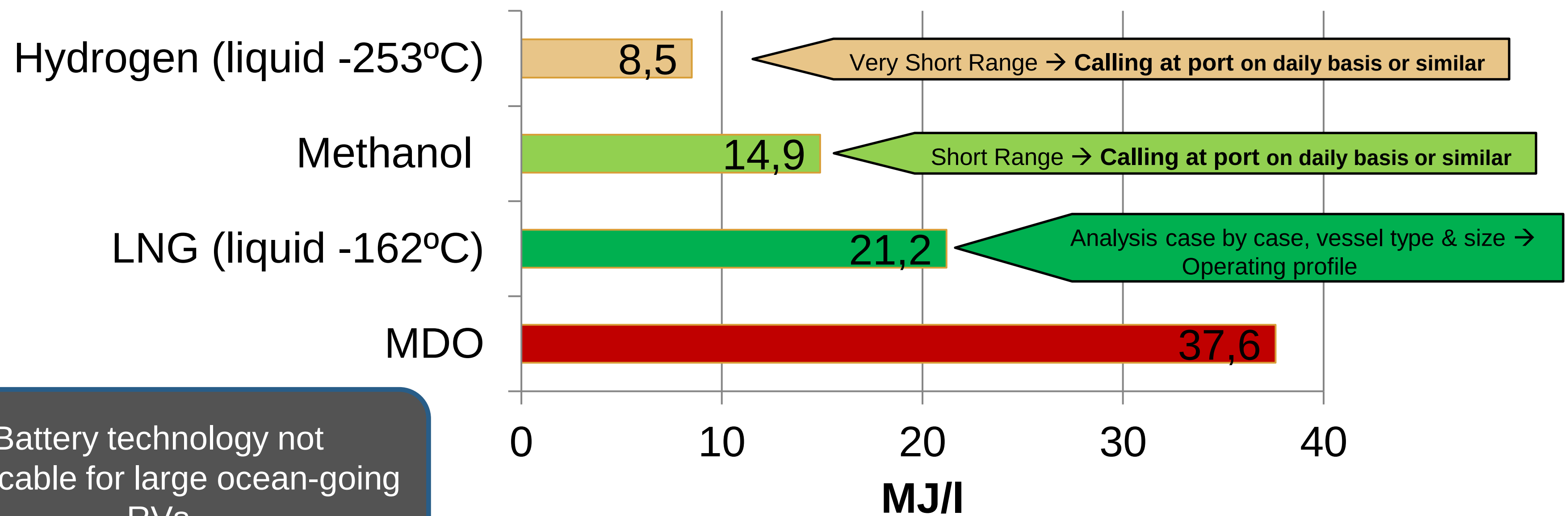
FEASIBILITY ANALYSIS OF LNG IMPLEMENTATION AS FUEL

DECISION MAKING

The choice for a dual Diesel-LNG was made based on a mix of strategic and practical considerations

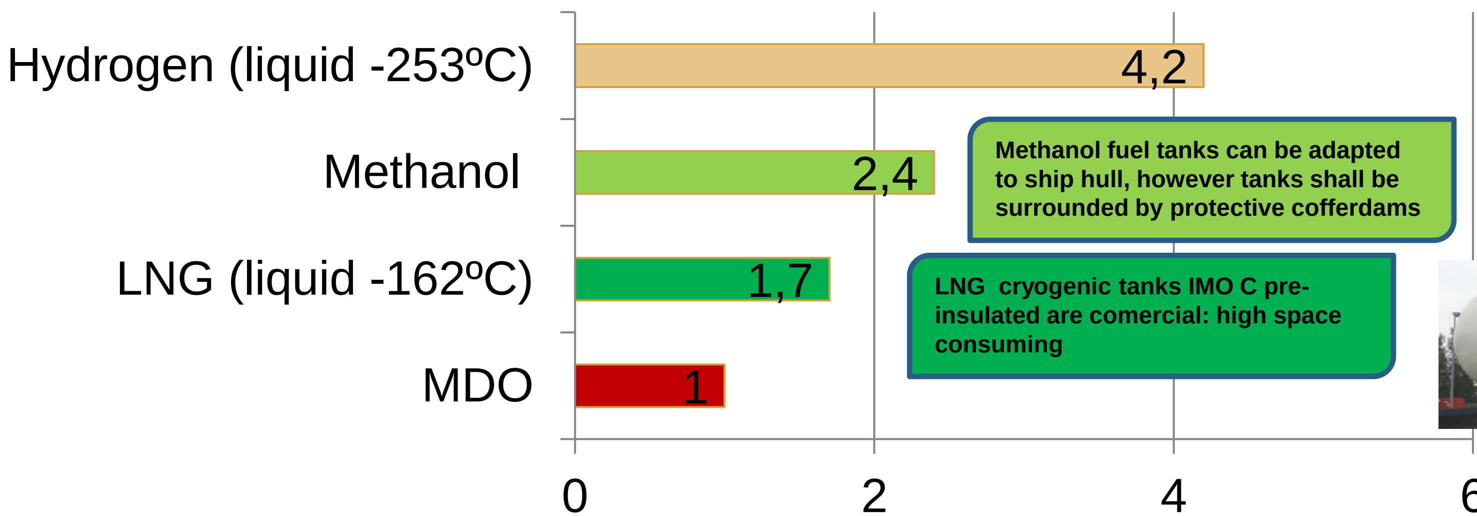
- ✓ Fuel Efficiency/ship operational profile.
- ✓ Sustainability
- ✓ Environmental drivers: Air pollution and Greenhouse gases: the **Methane slip problem.**
- ✓ Other alternative fuels considered.
- ✓ LNG-Fuelled Vessels; Current OVERVIEW and FORECAST
- ✓ LNG Tanks arrangement into a Research vessel
- ✓ Financial drivers & Conclusions

1.- Fuel Efficiency: Energy Content per Volume



Battery technology not practicable for large ocean-going RVs

Range: Fuel tank size relative to MGO

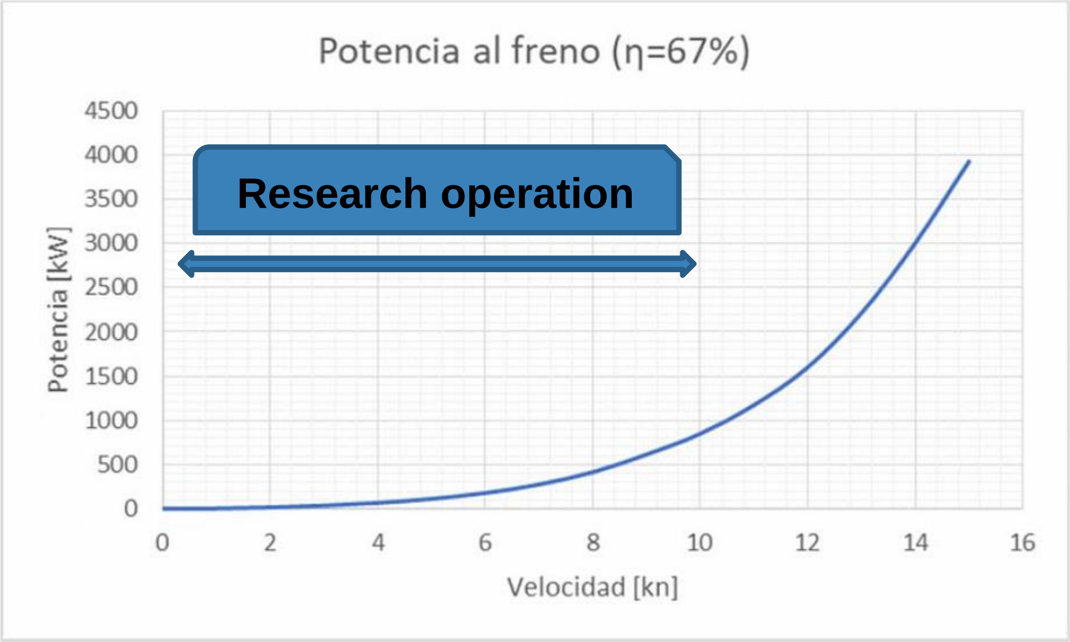


FEASIBILITY ANALYSIS OF LNG IMPLEMENTATION AS FUEL

A DIESEL-LNG hybrid approach

SHIP OPERATIONAL PROFILE

BOMAG for IEO: Global Research Vessel with a range over 45 days



Decision making, the use of Dual fuel gen-sets:

1.- MDO for transit, higher speeds and areas far away from the coast

2.- Lower emissions fuel for:

a.- Approach to port

b.- At least 10 days of Research operation with speeds below 10 kn. Environmentally sensible areas like Antartida or Mediterraneum sea

Sustainability: Electric Vehicle Battery facts

A typical Lithium-ion battery of 500 kg is approx. composed by:

- ✓ 12 kg of lithium: 12000 kg of brine needed to manufacture it.
- ✓ 30 kg of nickel: 2500 kg of raw material
- ✓ 22 kg of manganese
- ✓ 15 kg of cobalt: 15000 kg of raw material
- ✓ 100 kg of cupper: 12000 kg raw material
- ✓ 200 kg of aluminum
- ✓ Plastic + steel

TOTAL= 250.000 kg of material extracted from the Earth,s crust.

A DIESEL-LNG hybrid approach

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ENVIRONMENTAL DRIVERS: GAS EMISSIONS

- ✓ Local emissions of Sox and Nox and Particulate Matter impacting human health
- ✓ GHG emissions with associated global warming impact

	Emission type	Pure LNG reduction potential compared to MDO 1% S	How
Respiratory	SO_x	~100 %	No sulfur in LNG
Carcinogen	Particulate matter	~100 %	No black carbon source from LNG
Ozone	NO_x	85-90 %	Better combustion performance
Green House Gas	CO_2	20 – 25 %	Higher energy content in fuel per weight

Methane slip reduction challenge

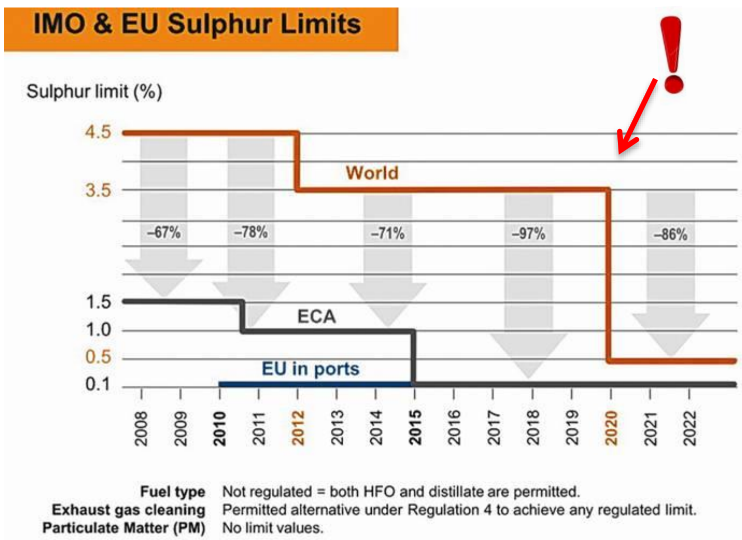
14% for 4-stroke engines

A DIESEL-LNG hybrid approach

ENVIRONMENTAL DRIVERS

✓ IMO Emission Control Areas, ECA – New MARPOL Annex VI

- Not only ECAs: also EU regulations in EU ports



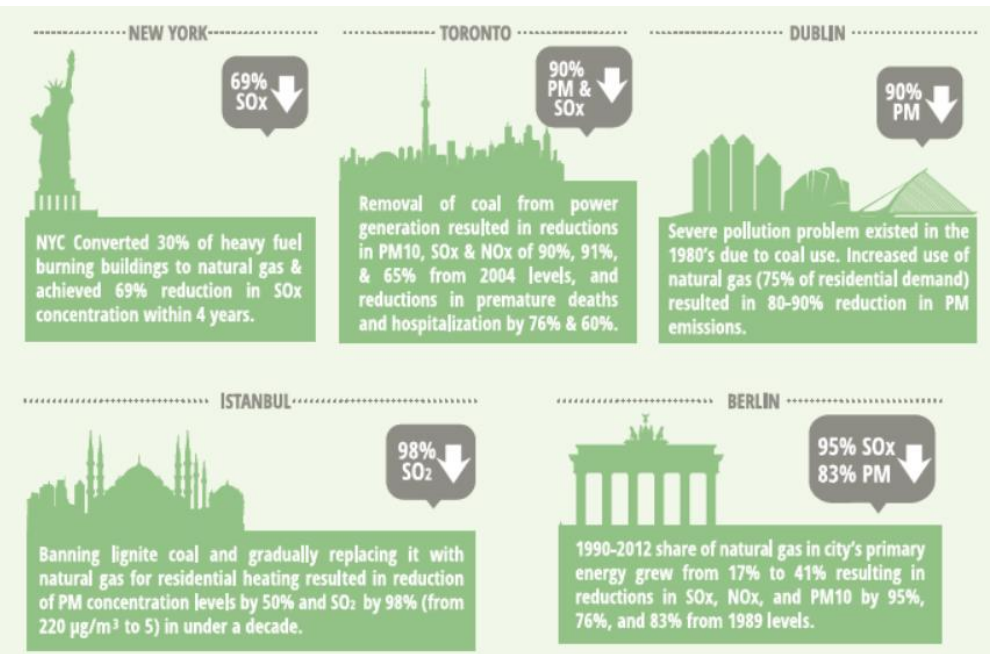
Otions for NOx removal!:

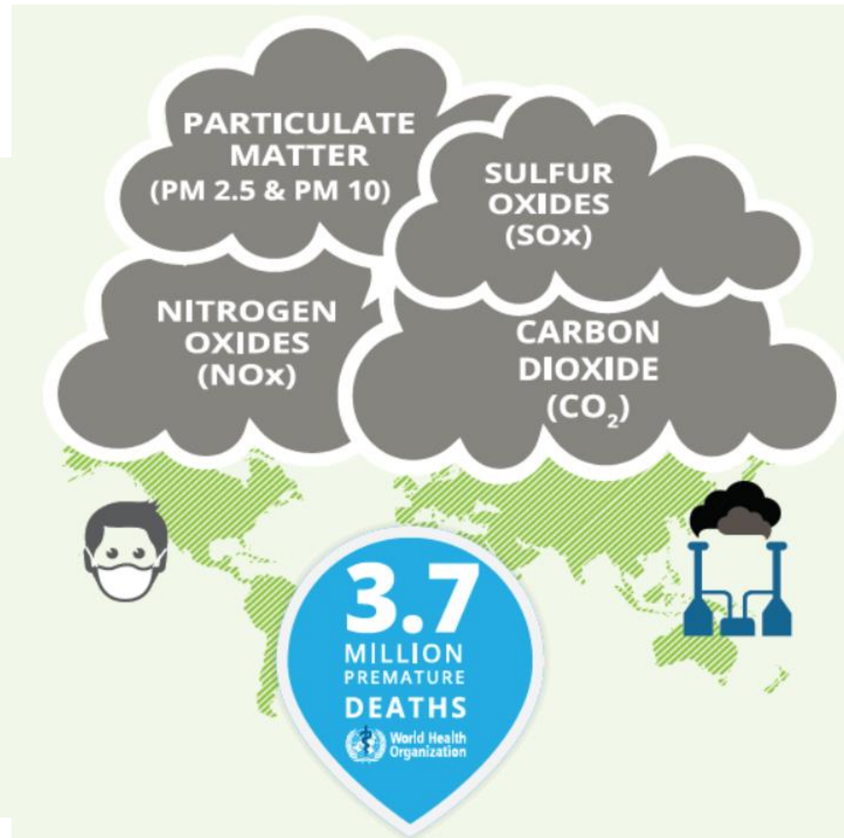
- ❑ **LNG as fuel**
- ❑ **SCR for exhaust gas purification**

Otions for SOx removal!:

- ❑ **LNG as fuel**
- ❑ **HFO+Scrubbers for exhaust gas purification**
- ❑ **Low sulphur fuel,** Limited Global Capacity of destilation → **MGO/ price increase expected !**

ENVIRONMENTAL DRIVERS





ENVIRONMENTAL DRIVERS

Methane slip is the unburned methane from engines.

Reasons

Due to dead volume in form of crevices or cracks between cylinder unit components.

Incomplete combustion in form of quenching at the coldest part of the combustion chamber when running lean.

Main problems:

- ❖ CH_4 is more warming than CO_2.
- ❖ Engines has the most leakiest.

ENVIRONMENTAL DRIVERS

SOLUTIONS

50%

Over the last decade, improvements to engine design and electronic controls have already realized a 50 percent reduction in methane slip.

70%

Solutions such as aftertreatment with an oxidation catalyst can further reduce methane slip by up to 70 percent.

Under development

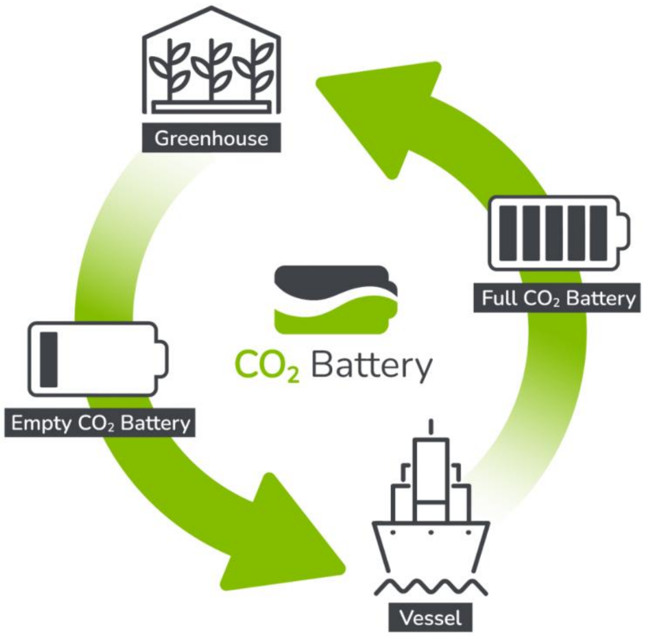
90%

Direct gas injection technology has a potential methane slip reduction of up to 90 percent.

Currently used

Control the low loads in the gen-sets by a good selection of generator sets

CO2 CAPTURE IN SHIPS



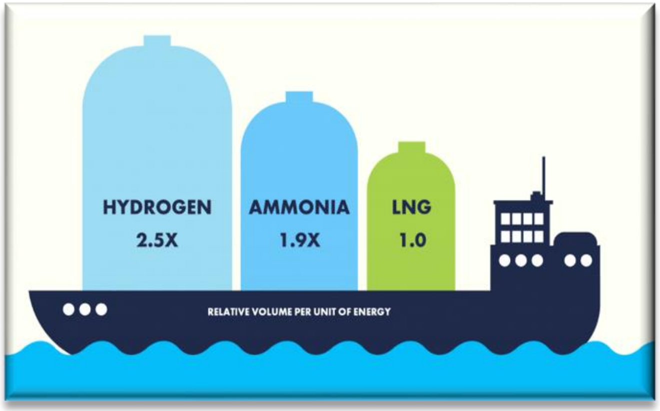
Source:Value Maritime

- ✓ New systems based on filtration technology to remove CO_2 from the vessels exhaust gas.
- ✓ The CO_2 is used to charge CO_2 Battery; an onboard storage facility which can charge and discharge CO_2 infinitely.
- ✓ The charged CO_2 Battery will be offloaded in ports and transported to CO_2 customers who “re-use” the CO_2.
- ✓ After CO_2 discharge, the CO_2 Battery returns to the vessel, to be recharged with CO_2; A 100% circular solution!

OTHER ALTERNATIVES CONSIDERED

ALTERNATIVE HYDROGEN-BASED ENERGY CARRIERS: AMMONIA .

- ✓ Ammonia (NH_3) as a future potential fuel for shipping .
- ✓ Ammonia, sometimes called 'the other hydrogen', is carbon-free.
- ✓ The GHG emissions from production of ammonia depends on the production method. Most of the ammonia produced today derives from natural gas, generatinge larger CO_2 emissions per energy unit.



Ammonia was dismissed due to the lack of proven Technological maturity

OTHER STUDIED ALTERNATIVES

ALTERNATIVE HYDROGEN-BASED ENERGY CARRIERS: METHANOL .

Well-to-wake GHG emissions: The well-to-wake GHG emissions includes emissions from production, transport and storage of each fuel, as well as combustion/conversion to mechanical energy onboard the vessels. The resulting comparative measure of well-to-wake emissions is the mass of CO2 equivalent emissions per unit of shaft output energy

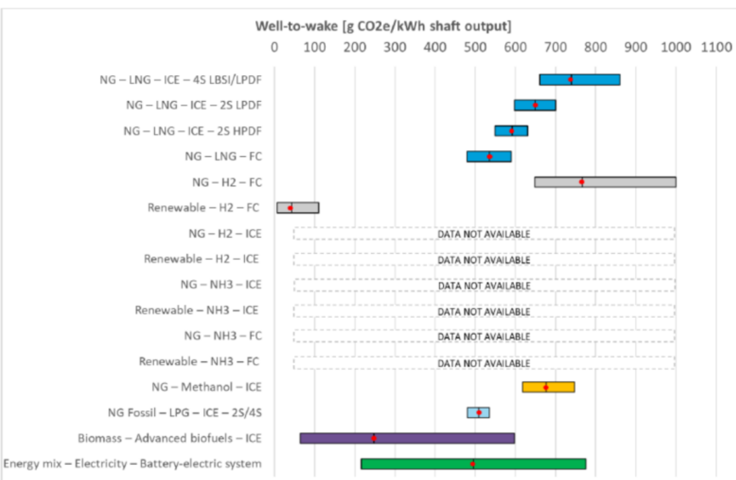


Figure 1-4: Well-to-wake emissions for fuel/technology pathways, taking into account energy content of fuel and system efficiency [g CO2e/kWh shaft output]

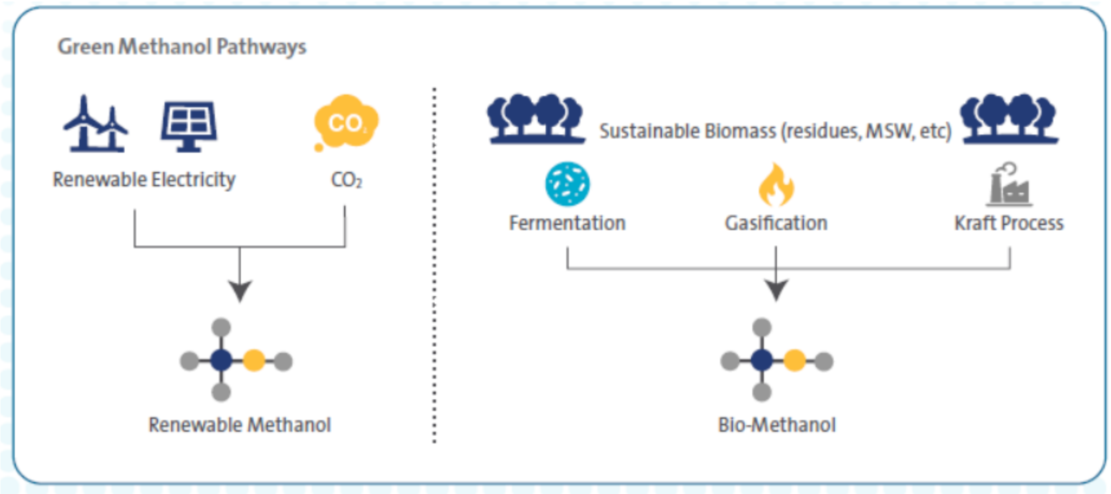
Methanol (not green) has similar g CO2/kwh shaft output to LNG

OTHER ALTERNATIVES CONSIDERED

Green Methanol

Green methanol is one of the most promising carbon neutral fuels for the long-term in a decarbonization scenario

Source: Stena Lines, MAN
Combustion emission reductions when compared to heavy fuel oil



Today Green Methanol production is insignificant and too expensive

OTHER ALTERNATIVES CONSIDERED

Some important facts about Methanol (CH_3OH) onboard a Research Vessel

✓ **ADVANTAGES**

- **Methanol can be transported in liquid form at ambient conditions.**
- **Methanol tanks can be adapted to hull form**
- **Methanol is a good transport driver of hydrogen.**

✓ **CHALLENGES**

- **Methanol has a very low flashpoint: 11ºC, is highly flamable and constitutes a high fire risk.**
- **Methanol provides approximately half the energy per volume compared to oil.**
- **Methanol flames burns at low temperatures with invisible flames in daylight: it can be undetected.**
- **Methanol is toxic and poisonous to humans.**

Needs a well trained crew

The price of synthetic methanol must compete at competitive levels as studies show methanol prices will be higher in comparison with other synthetic fuels.

HYDROGEN AS ALTERNATIVE FUEL

H2 Storage System

Compressed H2 gas:

350 bar
(~ 24,1 kg/m3)

700 bar
(~ 41,0 kg/m3)

(At ambient temperature)

Liquefied H2:

- 253 ºC, 1-…5 bar
(~ 70,9 kg/m3)

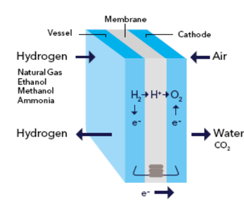
Propulsion & Distribution System

H2 MARINE ENGINE

Dual fuel (higher flexibility)

Spark Ignited

H2 FUEL CELL



PMS
(Power Management System)

Batteries

Consumers

HYDROTUG PROJECT (under construction at ASTILLEROS ARMON SA) (Zeebrugge port)

World's first hydrogen-powered tugboat:

Tractor - Type TUG (< 500 GT):

- LOA .... 30,20 m
- Bmoulded 12,50m
- Bollard Pull .... > 65 TBP
- Speed .... 12,50 knots
- **H2** Capacity .... **405 kg at 350 bar**
- **Dual fuel engines:**
  - 2x ABC-BEHYDRO 12V DZD
  - 2000 KW/engine at 1000 rpm

Expected range (running on H2):

- **8-9 hours**
  (at transit speed of 7-8 knots, > 100 km)

ARMON's Tug in-house design (& CMB for H2 equipment)

A DIESEL-LNG hybrid approach

Financial drivers (Current Fuel Price comparison)

BEFORE UKRAINE WAR CRISIS

Average prices before the war

- IFO 380/180: 9,9/10,7 \$/mmBTU = 380/410 \$/ton
- MGO 0,1% S: 14,3 \$/mmBTU = 580 \$/ton
- Gas TTF (EU Gas): 7,4 \$/mmBTU (lhv)= 341 \$/ton(*)
- Crude oil Brent: 12 \$/mmBTU = 474 \$/t = 65 \$/barrel

- 40 %

**Assumptions:*

- Liquefaction costs have to be added to henry hub price. Today values between 3 and 5 \$/mmBT for liquefaction might be used.
- LNG in Europe competes with pipeline gas therefore only costs of distribution to the ship have to be added to gas price.
- Supply to the ship must be added to fuel costs.

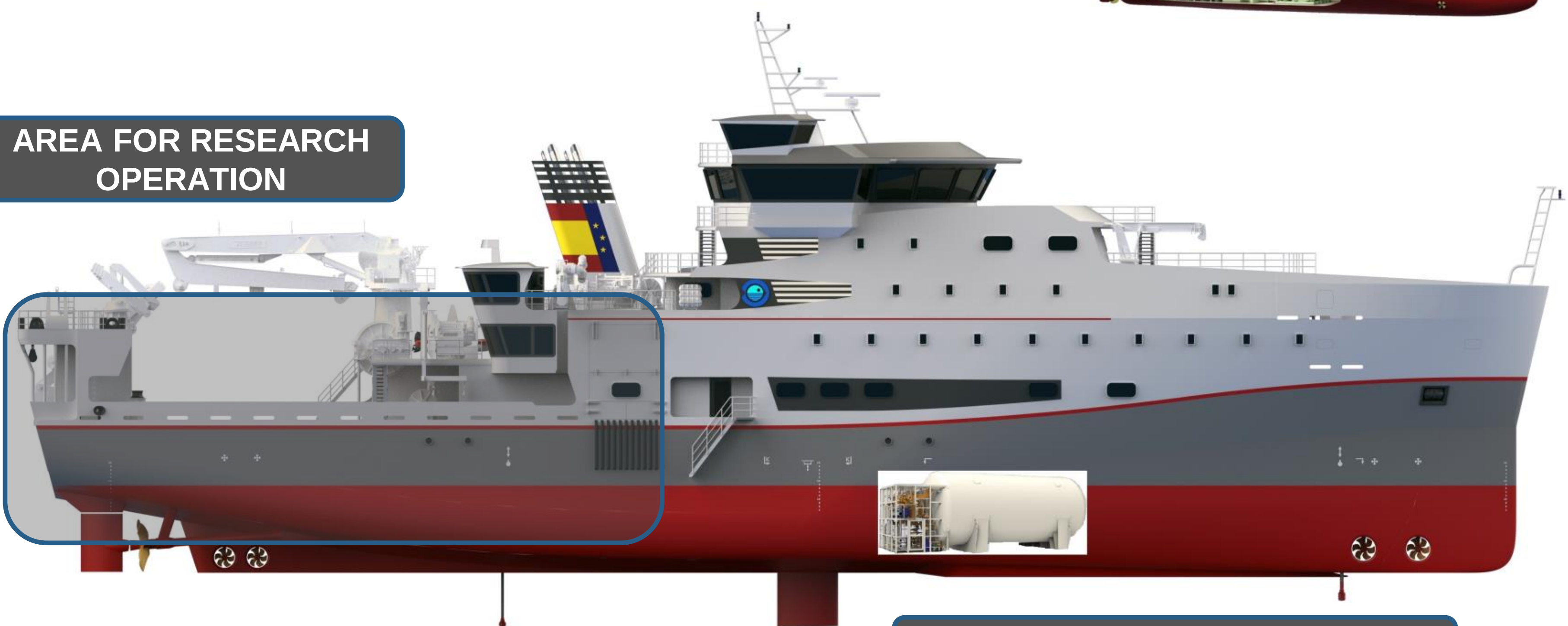
Source: https://www.dnvgl.com/maritime/lng/current-price-development-oil-and-gas.html

¿Why make an feasibility analysis based on LNG as DUAL-FUEL in Research Vessels?

Summarazing:

- ✓ Clear **advantages for the ENVIRONMENT**
- ✓ Fuel gas **BETTER PRICE** (expected)
- ✓ And the **NECESSARY TECHNOLOGY IS AVAILABLE** and has been well proven for many years in methane tankers (which transport LNG and also use it as fuel) with a very **favorable safety records.**

LNG TANKS LOCATION



Conclusions

✓ ADVANTAGES

- **Operational savings → Less OPEX**
  - Less fuel oil consumption
  - LNG cheaper than Fuel Oil
- **Clear environmental advantages**
  - **Less environmental footprint**
  - Share of operation inside ECA
- More LNG suppliers are now entering the market.
- **Other** available **alternatives depending on operation: CNG,** fuel cells on LNG (under development)

✓ CHALLENGES

- **Higher CAPEX →** higher initial investment
- **Loss of cargo space: LNG capacity → range restrictions,** development is ongoing to shift from cylindrical (volume consuming) to hull integrated tanks
- Bunkering infrastructure is still in the early stages
- Fuel costs, still some uncertain
- Competance / Training
- Slight methane slip from engine when running on low load

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THANK YOU!