Application of Steam Reformer in Ship Propulsion

RINA

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ΕΛΛΗΝΙΚΟ ΙΝΣΤΙΤΟΥΤΟ ΝΑΥΤΙΚΗΣ ΤΕΧΝΟΛΟΓΙΑΣ
ΙΔΡΥΘΗΚΕ ΤΟ 1972

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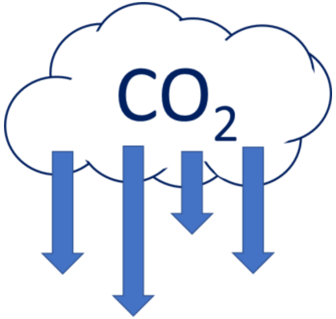
The need for green fuels

CO_2 emissions = (how much fuel we burn) * (what type of fuel we burn)

$$(CO_2) = \frac{MT_{fuel}}{hour} * \frac{MT_{CO2}}{MT_{fuel}}$$



Availability and cost are key concerns

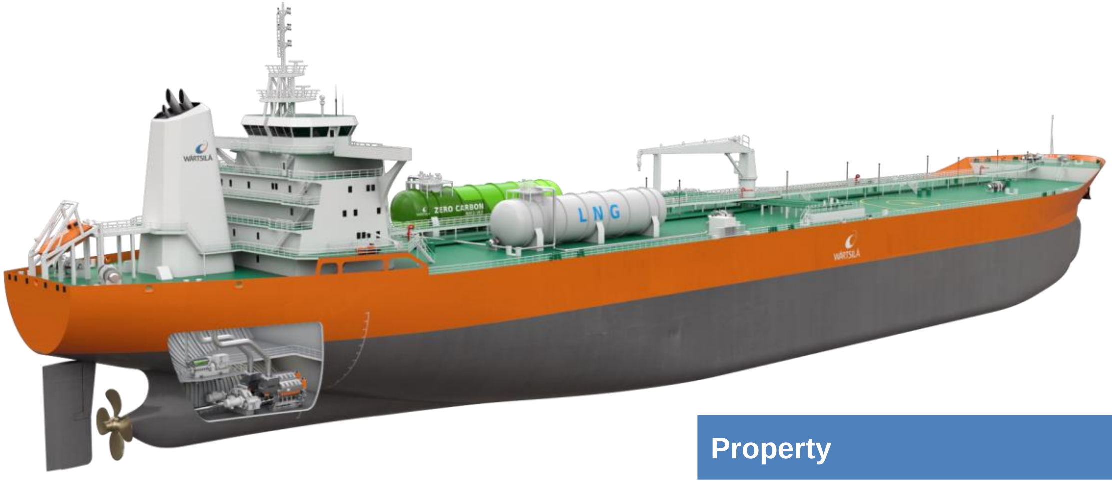
In the past :

Min Fuel consumption for a given transport work

In the future :

Min Fuel **COST** for a **required CO2 reduction** & a given transport work

Improvement of combustion with H2

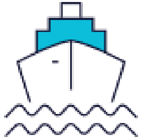


LNG fueled → Hydrogen ready

Property	H_2	NG	HNG
Limits of flammability in air, (vol %)	4-75	5-15	5-35
Burning velocity in NTP air (cm/s)	325	45	110
Quenching gap in NTP air (cm)	0.064	0.203	0.152
Diffusivity in air (cm^2/s)	0.63	0.2	0.31

Hydrogen as fuel

BENEFITS	CHALLENGES
No SOx, PM, CO_2 emissions	▪ Very small production globally ▪ No distribution & bunker infrastructure ▪ Very low energy density (1/2.5 of LNG) , very big tank ▪ Great energy loss for liquefaction ▪ Liquid phase temperature interval is only 13^{o}C; Insulation of LH2 tanks is critical ▪ Material challenges , at very low cryogenic temperatures ▪ Little storage time, not very suitable for long voyages



We cannot realistically anticipate that we can solve the problems around production, transportation, delivery and storage of hydrogen.

Awareness is key for risk assessment

Methanol

Methanol Fueled Ship
Same cost with LNG
CO2 reduction 8% compared to 24% of LNG

Labelling according Regulation (EC) No 1272/2008

Pictogram	
Signal word	Danger
Hazard statement(s)	
H225	Highly flammable liquid and vapor.
H301 + H311 + H331	Toxic if swallowed, in contact with skin or if inhaled.
H370	Causes damage to organs (Eyes, Central nervous system).

Ammonia

Toxicity of ammonia
5 ppm : the smell is detectable
100 ppm : highly intense irritation after 30 min
2500 ppm : fatal in approximately 30 minutes
5000 ppm : produce rapid respiratory arrest

Labelling according Regulation (EC) No 1272/2008

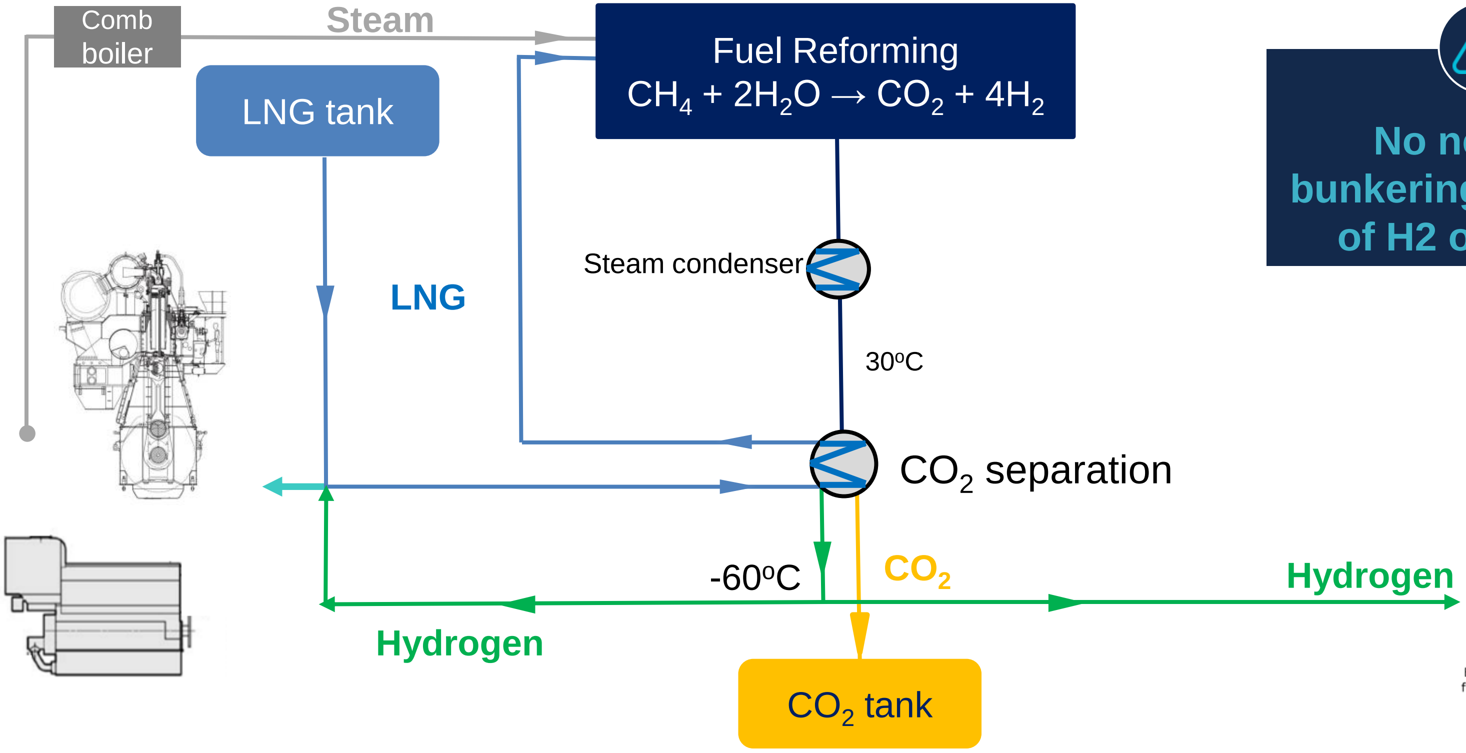
Pictogram	
Signal word	Danger
Hazard statement(s)	
H280	Contains gas under pressure; may explode if heated.
H314	Causes severe skin burns and eye damage.
H331	Toxic if inhaled.
H410	Very toxic to aquatic life with long lasting effects.

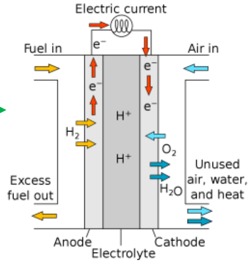
The challenge with new fuels

	Energy content (MJ/kg)	Annual consumption (mill Tonnes)	Annual production (mil Tonnes)	Traded volume (mil Tonnes)
Fuel Oil	41	300		
Ammonia	18.6	**661 (equiv)**	**250**	**25**
Methanol	19.9	**618 (equiv)**	**115**	**15**

Needed increase	Production	Trade
Ammonia	x 2.5	x 26
Methanol	x 5.5	x 55

Steam Methane Reforming





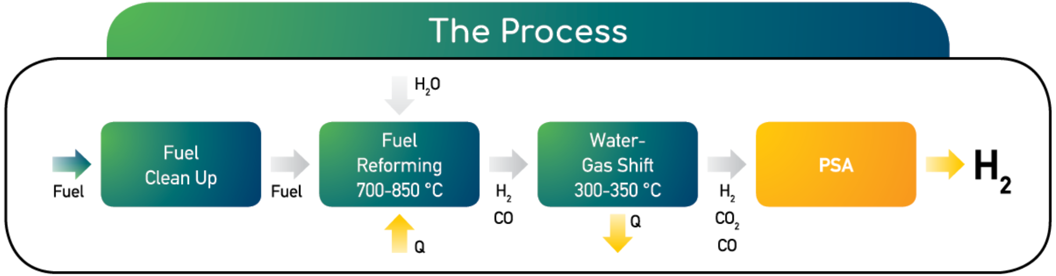
No need for bunkering & storage of H2 on board!

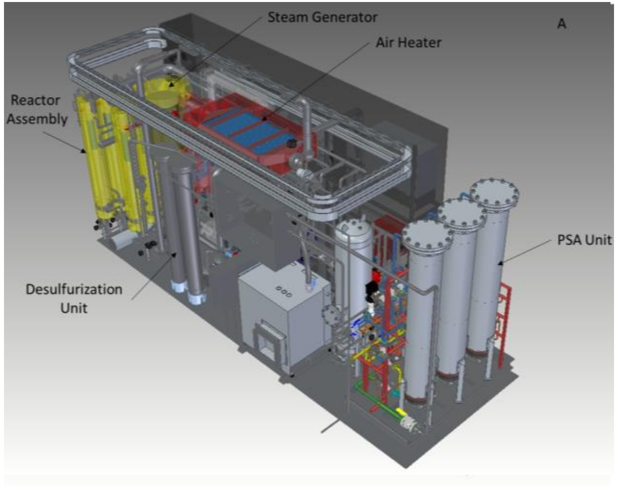
Hydrogen is a safer fuel

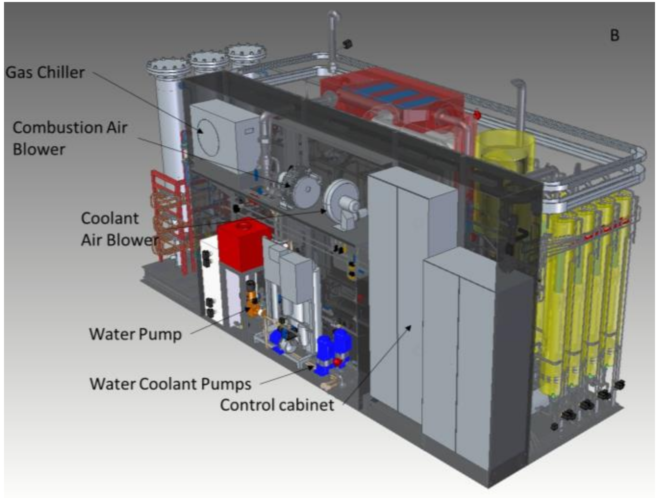
Property	Unit	Safe fuel/less hazard, when parameter is :	Gasoline	Methane	Hydrogen
Density	kg/m3	Low	4.4	0.65	0.084
Diffusion coefficient in air	cm2/sec	High	0.05	0.16	0.61
Specific heat at const. P	J/gK	High	1.2	2.22	14.89
Ignition limits in air	vol %	Narrow range	1.0-7.0	5.0-17.0	4.0-75.0
Ignition energy in air	mJ	High	0.24	0.29	0.02
Ignition temperature	deg.C	High	228-471	540	585
Flame temperature in air	deg.C	Low	2,197	1,875	2,045
Explosion energy	gTNT/kJ	Low	0.25	0.19	0.17
Flame emissivity	%	Low	34-43	25-33	17-25

- **The risk of hydrogen explosion is minimal**.
- Although hydrogen can burn in low concentrations, an explosion of hydrogen is very difficult to occur,
- It blazes with little heat radiation, therefore only things immediately next to the flame would burn.

Onboard Hydrogen Generators







COP27 : Solutions for carbon intensive industries

- Cement, iron and steel, and chemicals / petrochemicals industries are the most significant industrial CO_2 emitters, accounting for about 25% of total CO_2 emissions globally and 66% of the industrial sector.

- The decarbonization of these industries is a top priority

- The solutions presented fall into two categories:
  - *Technology-based solutions* : **carbon capture utilization and storage (CCUS)**; hydrogen; industrial energy efficiency; nuclear power and heat; electrification coupled with increased renewables
  - Concept-based solutions : Circular Carbon Economy (CCE) and Industrial Clusters approach.

It is reasonable that shipping shares solution with other industries (CCUS)

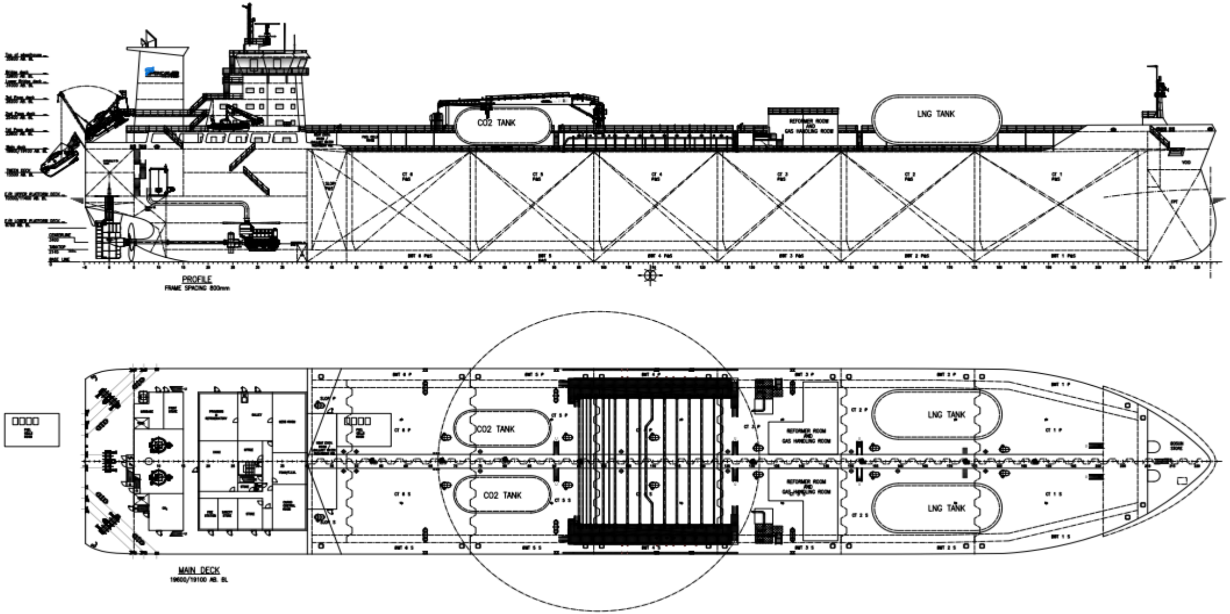
Scalable fuel cell system based on marine certified modules

Scalable from 200 kW to MW-scale

- PEMFC systems built in cabinets and certified by fuel cell suppliers
- Cabinets can be organized in lineups or back-to-back installation
- Pre-engineered skid mounting enables standardized interfaces
- Container arrangement allows for on-deck installations
- Solutions suitable for newbuild or retrofit projects

IMAGES: Ballard, PowerCell Sweden

Actual vessel



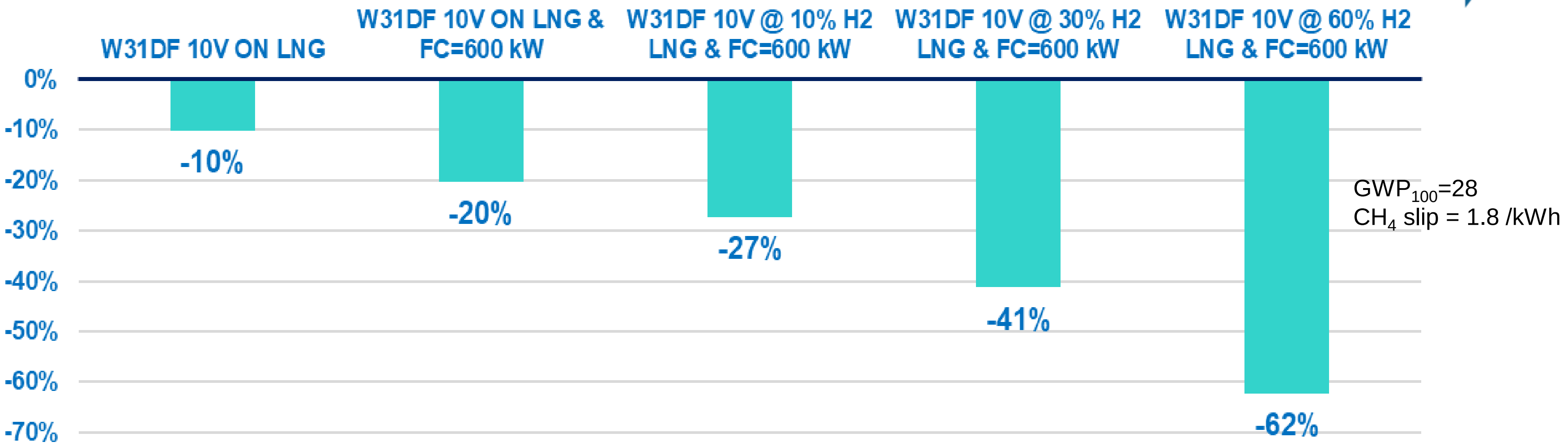
MAIN PARTICULARS

Length over all	183.00 m
Length between pp	177.00 m
Breadth mld	32.20 m
Depth mld	19.10 m
Draught design	11.00 m
Draught scantling	13.30 m
Deadweight at design draught	36 800 tonnes
Deadweight at scantling draught	48 500 tonnes
Cargo capacity	54 300 m^3
LNG tanks	1 450 m^3
CO2 tanks	1 400 m^3
Technical FW tanks	350 m^3
Domestic FW tanks	275 m^3
Water ballast abt	21 000m^3
Cargo pumps	12 x 600 m^3/h
Ballast pumps	2 x 750 m^3/h
Accommoodation	23 + 6 pers
High voltage shore power	6,6 kV
Service speed	13.0 knots

Propulsion options

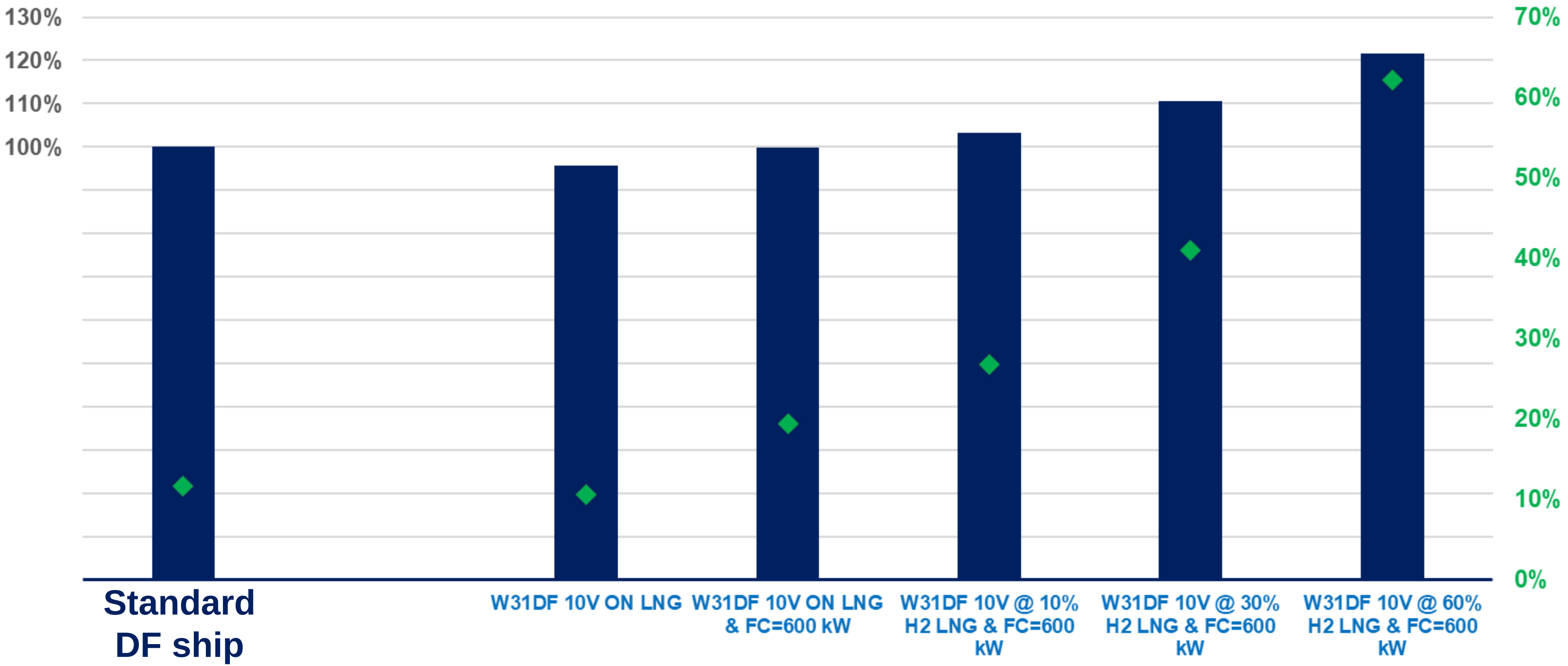
	Conventional	Engines Only	Hybrid 4 stroke	Hybrid 2 stroke
No. Engines	1	2	1	1
Type	2 stroke	4 stroke	4 stroke	2 stroke
	6G50ME-C10.5-HPSCR	Wartsila 31DF, 2 x 8V	Wartsila 31DF, 10V	5G50ME-C9.6-GI Gas Std.
MCR	10,320 kW	8V = 4,800 kW	6,000 kW	8,600 kW
		8V = 4,800 kW	6,000 kW	
SMCR	7,240 kW	Same as MCR	Same as MCR	6,840 kW
Generators	3 x 650 kW	600 kW	N/A	1 x 1,200 kW
PTO/PTI	N/A	2 x 1,500 kW	2,000 kW	1 x 3,000 kW
Fuel Cells	N/A	N/A	800 kW	3,000 kW
Less kW purchased		**17%**	**45%**	**20%**
Propeller	FPP	CPP	CPP	FPP

Business plan for required CO2 reduction

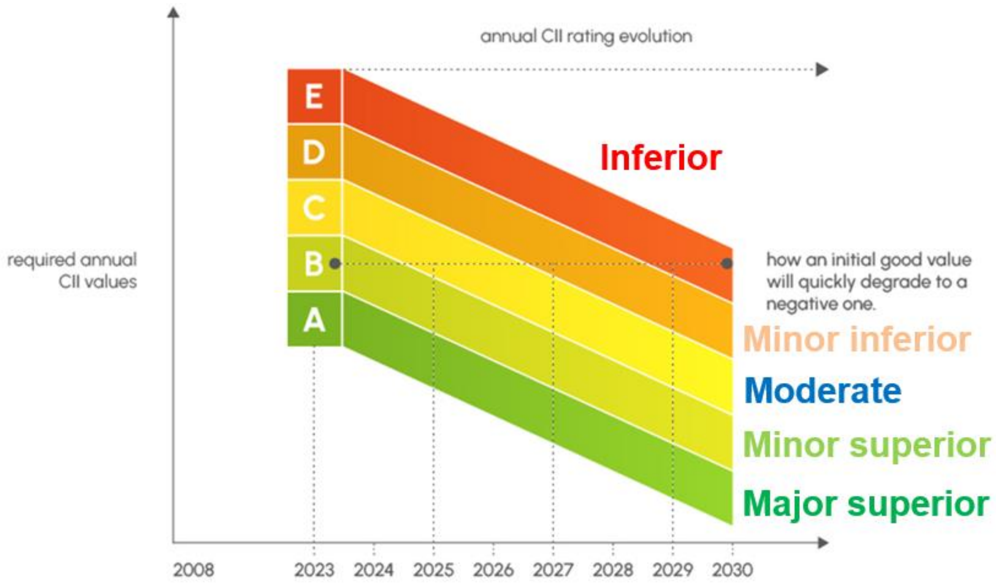


	Year	H2 prod. (kg/h)	LNG tank (m3)	CO2 tank (m3)
Ship Delivery	2025	36	1,298	90
1st Drydock	2030	60	1,336	414
2nd Drydock	2035	107	1,420	628
3rd Drydock	2040	178	1,547	951

The cost for CO2 reduction



CII : required rate of CO_2 reduction



$$Attained\ annual\ CII = f\left(\frac{Annual\ consumed\ fuel\ \times CO_2\ conversion\ factor}{Capacity\ \times annual\ distance\ travelled}\right)$$

The importance of CII

			2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
Z=70%	2 Stroke	Fuel Oil	B	B	C	C	C	C	C	D	D	D	D	E	E	E	E	E	E	E	E	E	E
Z=100%	2 Stroke	Fuel Oil	B	B	C	C	C	D	D	D	E	E	E	E	E	E	E	E	E	E	E	E	E
Z=70%	2 Stroke	LNG	A	A	A	A	A	B	B	B	C	C	C	C	C	D	D	E	E	E	E	E	E
Z=100%	2 Stroke	LNG	A	A	A	A	B	B	C	C	C	D	D	E	E	E	E	E	E	E	E	E	E
Z=70% Z=100%	4 stroke	LNG + FC + H2	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

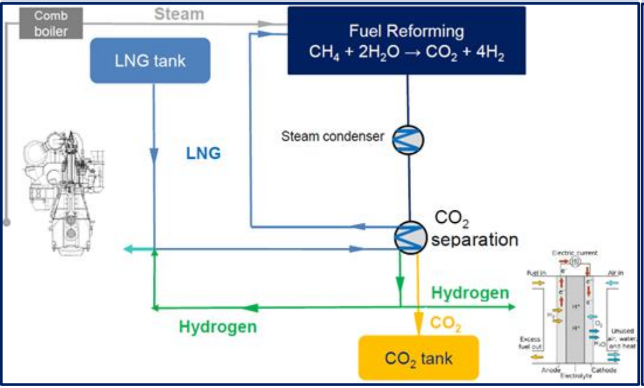
Study for a kamsarmax (82,000 DWT) bulk carrier

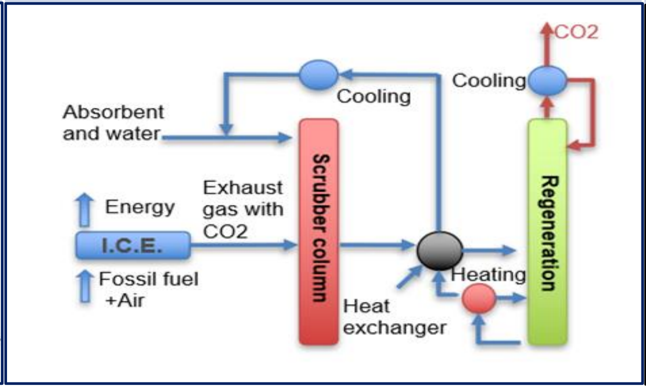
Conclusions:

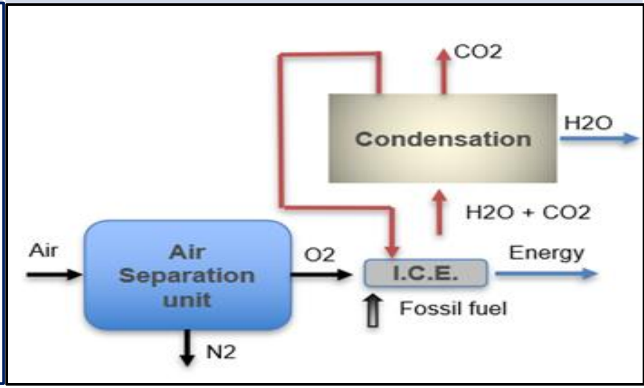
- Waiting for a new fuel to arrive, presents a great risk that may render new ships as stranded assets
- LNG offers a solution for few years more, but being fossil, has also a clear limitation in its use
- Shipping is provided with enough time to prepare, but solutions must be deployed by early 2030's
- New ships can provide carbon credits to existing ones

Carbon capture options

Pre-combustion	Post-combustion	Oxy-fuel
• Steam Methane Reformer • High efficiency of Carbon Capture • No emissions of CH_4 • Very little NO_x and N_2O emissions *<u>RINA proposal</u>*	• Efficiency depends on concentration of CO_2 • Higher cost	• Air separation required • High efficiency of carbon capture • No NO_x and N_2O emissions







Aspects of post combustion capture

- ❖ The process in the absorption tower is sensitive to vibrations

- ❖ Is not a unique technology : It may include a wide range of chemicals and processes with very different costs involved & requirements of logistics
- ❖ Cannot be applied in modular manner : Higher % CO2 capture requires a totally New system. This either limits the penetration of investment in time, or accounts for huge extra capex at ship's price
- ❖ Still undergoes technology development

- ❖ The mass of chemicals needed is enormous : even in case the product $CaCO_3$ can be discharges at sea :
  - Storage demand : ammonia (x1.2), calcium hydroxide (x5.2) (which becomes even bigger due to water solutions) , calcium carbonate (x10)

- ❖ It is important to design the capture system to have a high capture rate for the most frequent engine load.

- ❖ Burning LNG leads to cleaner exhaust gas and lower USD/MT CO2

Conclusions

IMO 2050

Fuel Selection

- No need to wait for zero-carbon fuels
- No need to handle toxic substances
- No need to develop new infrastructures

Technology

- Mature for steam-methane reformers
- Mature for Dual Fuel engines
- Rapidly developing for Fuel Cells
- Eliminates Methane slip

CO2 Storage

- Rapid development has already started
- All evidence points it will be commercially applied in large scale

Extra Cost

- Much less than the cost of any other zero-carbon fuel
- Potential to be totally offset in case of moderate carbon tax
- Improved freight cost per unit of cargo

Thank you for your attention!

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