Ship emissions 2023, 2030, 2050 and beyond.

ΕΛ.Ι.Ν.Τ
9 JUNE 2022
Stavros Hatzigrigoris

The doomsday clock

Every year since 1947, the Bulleting of the Atomic scientists, a-non profit organization consisting of scientists and scholars including 15 Nobel laureates, decides whether the events of the previous year pushed humanity closer to or further from destruction (00:00 - Midnight) and set the so-called "doomsday clock".

"Humanity now faces two simultaneous existential threats, either of which would be the cause for extreme concern and immediate attention. These major threats nuclear weapons *and* climate change *were exacerbated this past year by the increased use of information warfare to undermine democracy around the world, amplifying risk from these and other threats and putting the future of civilization in extraordinary danger."*

Source: Bulletin of Atomic Scientists

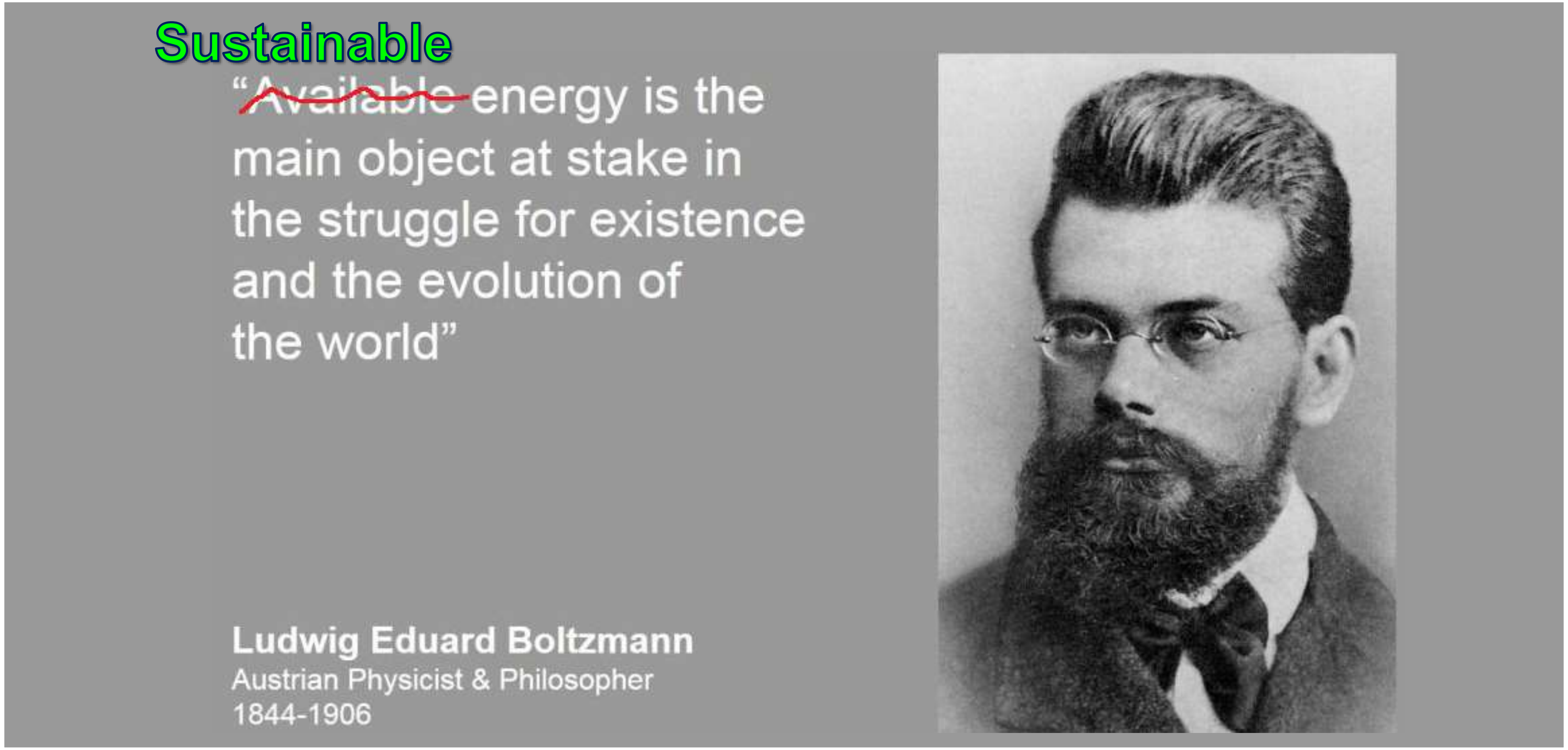
The doomsday clock over history

1953	1991	2019	2022
The U.S. tests its first hydrogen bomb in November 1952.	The Cold War ends, U.S. and Russia reduce nuclear arsenals.	Lack of progress on nuclear risks and the dangers of climate change.	War in Ukraine, nuclear risks and the dangers of climate change.
			
2 mins to midnight	17 mins to midnight	2 mins to midnight	100 sec to midnight

Source: Bulletin of Atomic Scientists

A famous Austrian physicist once said…

If Mr. Boltzmann lived in the 21st century, he would probably rephrase his famous saying …



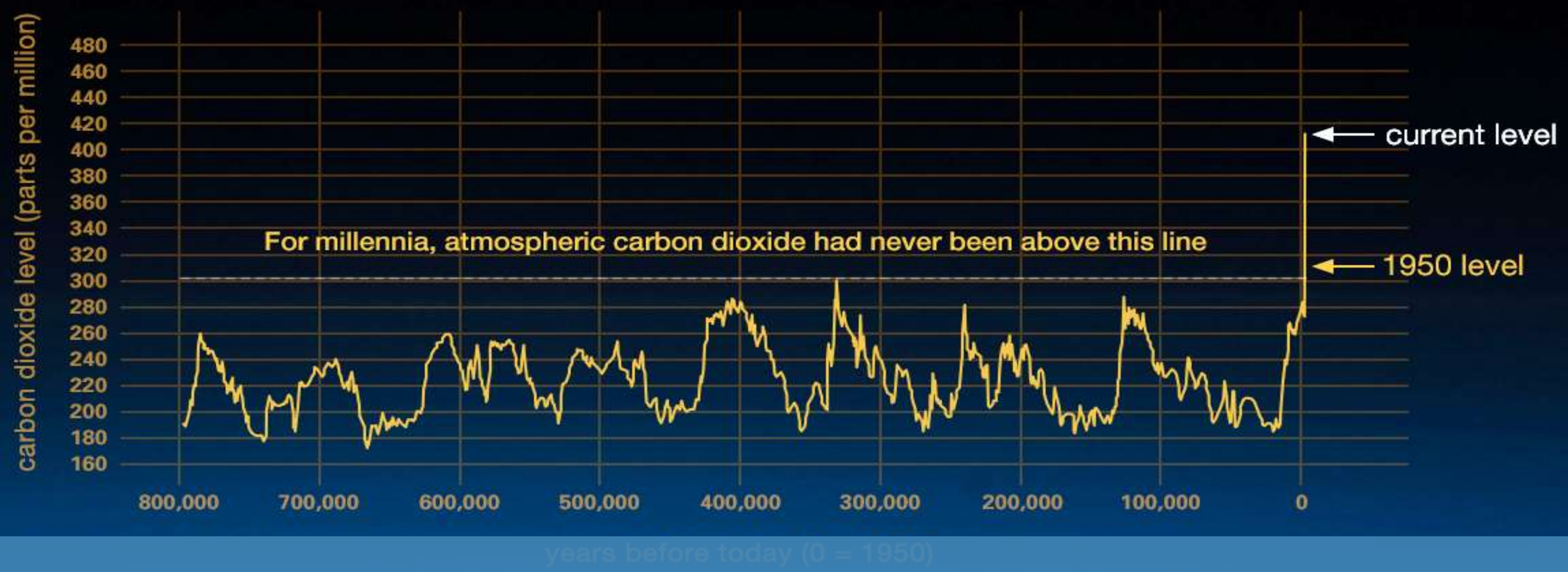
The world at a turning point

- Even if, in 2022, the word confronts a geopolitical crisis (war in Ukraine) we must not neglect the impact of climate change on our planet.
- Governments, industries and financial institutions continue to invest on decarbonization to accelerate net-zero emissions and achieve the Paris Agreement goals.
- Shipping must achieve reduction of the annual greenhouse gas emissions by at least 50% by 2050 compared to 2008.

Safeguarding our planet and people: A call for climate action at Davos 2022

Climate action needs to be taken now to stay within the 1.5 °C Paris Agreement target. Image: World Economic Forum

Climate change

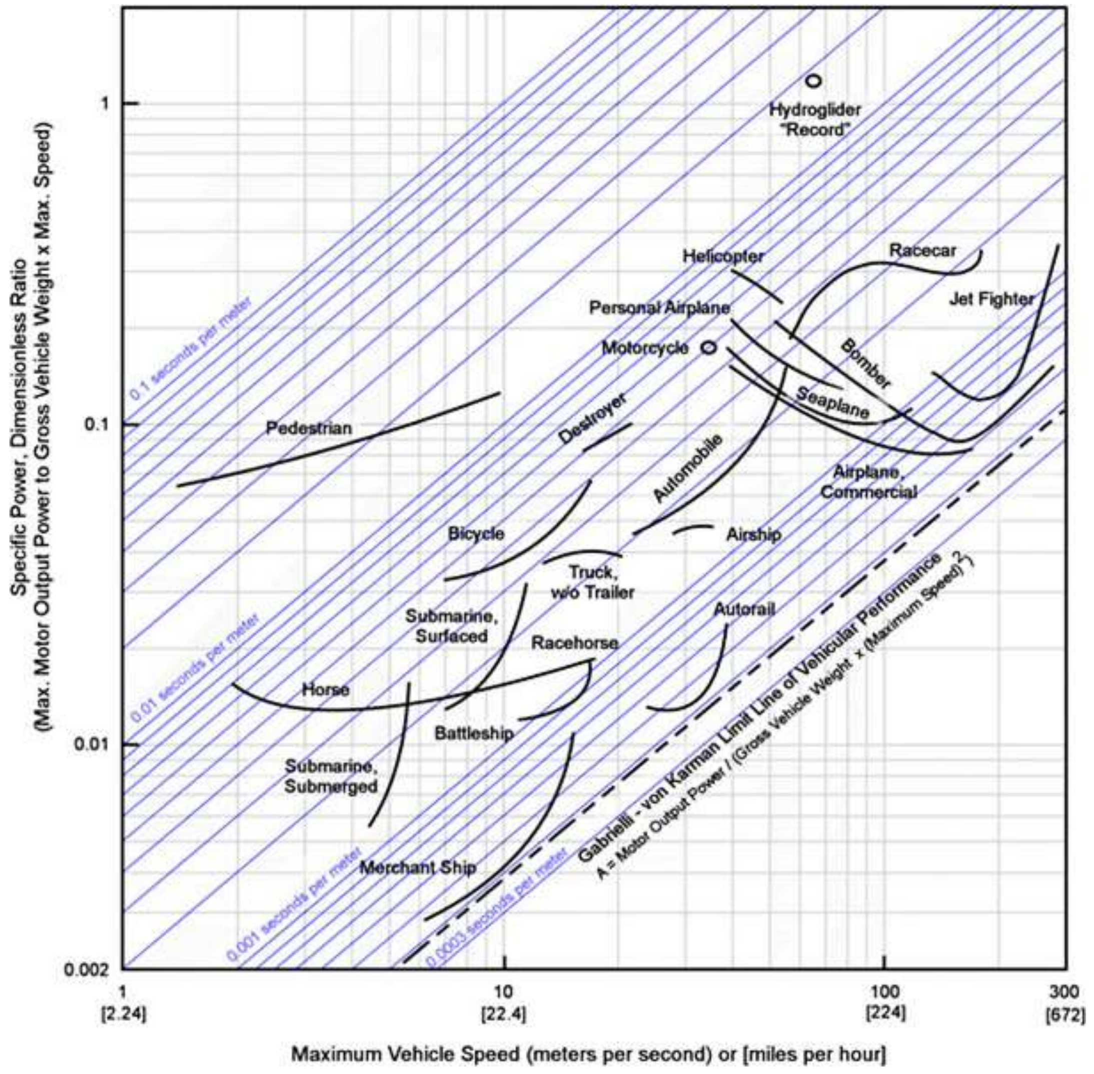


The graph shared by NASA depicting the carbon dioxide levels in the atmosphere over the last 800,000 years is rather disturbing.

Climate change and the shipping community

Shipping is considered as one of the major contributors to the stability of the world economy

- 72 years ago, two famous aeronautical engineers, Gabrielli and Von Karman, studied the efficiency of different transport modes and produced the famous Gabrielli-Von Karman graph.
- It was proven that marine transport is the most efficient means of transport.
- Even though shipping contributes approximately 2.5% in the global greenhouse emissions; we should do our best for a greener future.



Climate change and the shipping community

SOx Emissions

- IMO has set a global limit for sulphur in fuel oil to be used on board ships of 0.50% m/m (mass by mass) from 1 January 2020 onwards.
- Operators have the following five - widely discussed - options for sailing in global waters from the 1st of January 2020 and onwards:
  - Operate on MGO.
  - Operate on 0.5% low sulphur fuel oils (VLSHFO- produced by blending or refining).
  - Operate a dual fuel engine on LNG.
  - Continue operation on high sulphur fuels and install an exhaust gas scrubber.
  - Use alternative fuels such as biofuels, hydrogen etc.

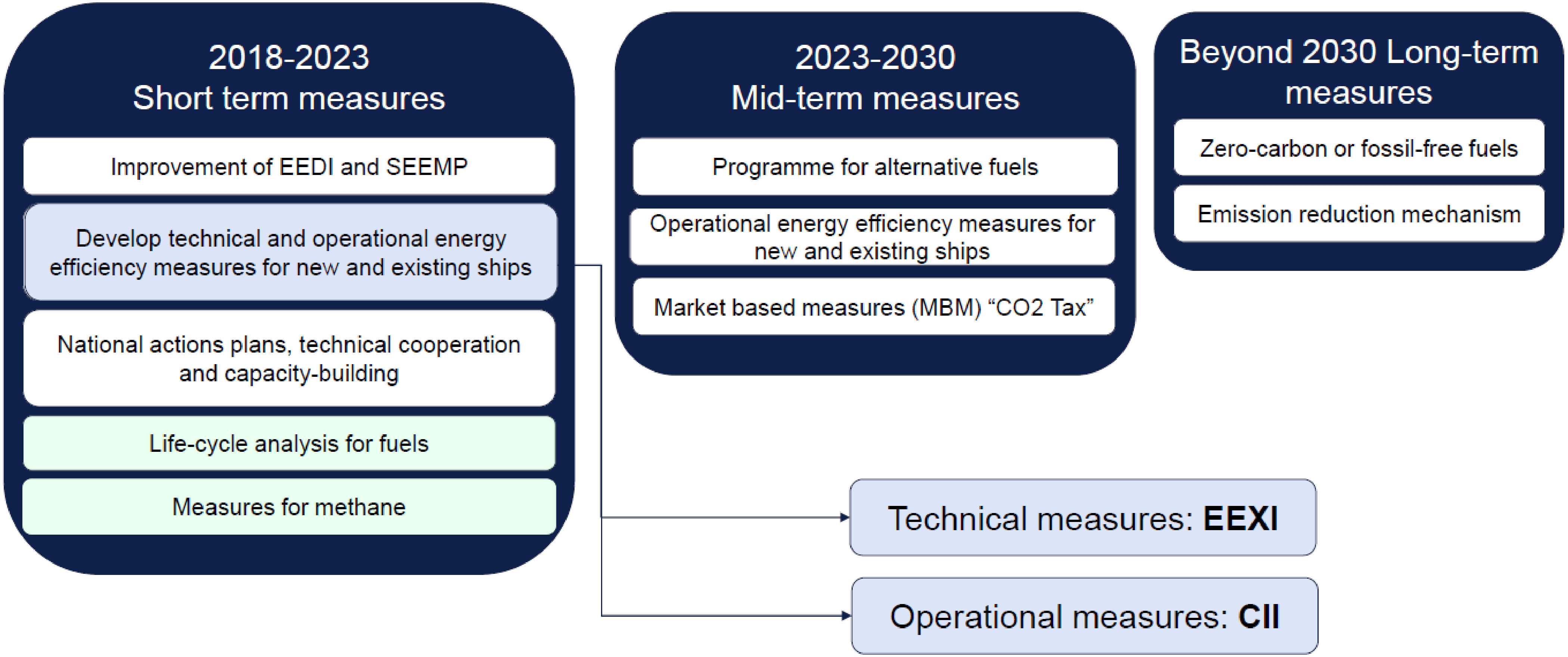
Climate change and the shipping community

NOx Emissions

- Not a recto-active requirement.
- Vessels constructed (keel laid) on or after the 1st of January 2021 have to comply with the Tier III emission limits in the US NECA and Northern Europe / Baltic Sea NECAs as well.
- Future NECAS (Japan, China and the Mediterranean are being discussed)
- Options to comply:
  - Selective catalytic reduction system (High-pressure or low pressure)
  - Exhaust gas recirculation
  - Use gas as fuel (problematic if not fully approved by the USCG)
  - Water emulsion.
  - Classify the engines for NECA areas.

Climate change and the shipping community

Greenhouse Gas emissions



Energy Efficiency Design Index (EEDI)

- EEDI is the ratio of the ship's CO2 emissions divided by the product of the ship's deadweight and speed as measured in trial conditions at 75% of installed power and at scantling draft.

- EEDI= $\frac{P*sfc*Cf}{DWT*v}$ gCO2/ton*mile

Where: P= Power in kw, sfc = specific fuel consumption in g/kWh, Cf = Non-dimensional conversion factor between fuel consumption and CO2 emission, DWT = deadweight at scantling draft in tons , v = ship's speed in nautical miles per hour.

- The EEDI is verified by the Class Society during the sea trials of new built vessels.
- The EEDI gave incentive to shipbuilders, designers, for more efficient ships.
- Reduction of EEDI can be achieved by the reduction of service speed, since the effect of power is greater than the effect of speed.
- Reduction of EEDI can be achieved by increase in deadweight, however there are physical limitations.
- The EEDI has sparked controversy in the shipbuilding community.

$$\text{EEDI} = \frac{\text{Impact to environment}}{\text{Benefit for society}}$$

$$\text{EEDI} = \frac{CO_2\ \text{Emission}}{\text{Transport Work}}$$

Energy Efficiency Design Index (EEDI)

TITANIC (1909)

EEDI= 55.41
g CO2/ton-mile

EUROPE (2002)

EEDI= 2.18
g CO2/ton-mile

STEAM LNG SHIP (2005)

EEDI= 12.18
g CO2/ton-mile

MEGI LNG SHIP (2018)

EEDI= 3.56
g CO2/ton-mile

Required EEDI (Phase 1)= 6.019 gCO2/ton-mile

Already 60% of the required EEDI level

LIBERTY SHIPS (1945)

EEDI= 24.45
g CO2/ton-mile

CRUDE OIL TANKER (2005)

EEDI= 2.53
g CO2/ton-mile

DFDE LNG SHIP (2013)

EEDI= 5.93 g CO2/ton-mile

CRUDE OIL TANKER (2018)

EEDI= 2.12
g CO2/ton-mile

Required EEDI (Phase 1) = 2.26 gCO2/ton-mile

EEDI Evolution

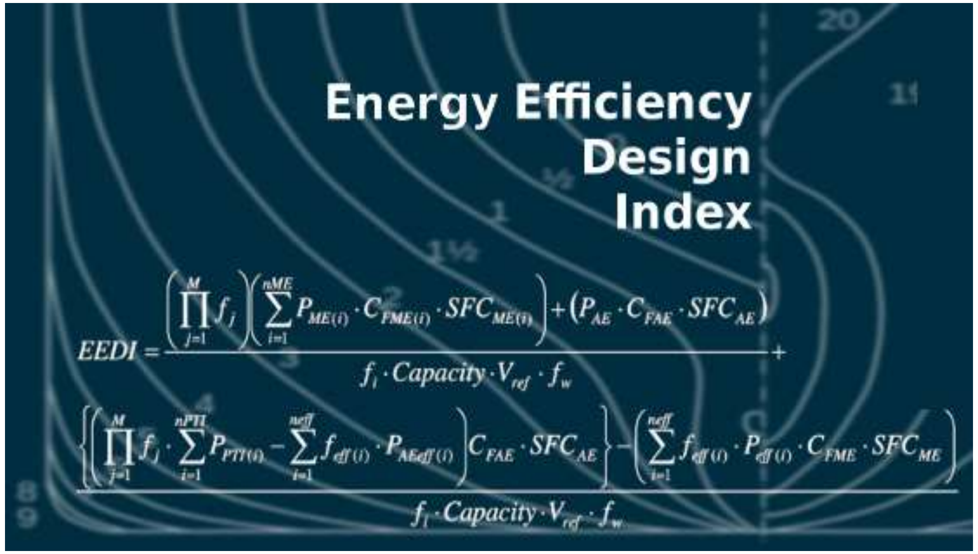
Vessel	Year of Built	EEDI	Improvement of EEDI Based on “Titanic”	Required EEDI
Titanic	1909	55.41	-	-
Liberty Ships (2,710 total)	1941-1945	24.45	44%	-
Europe (ULCC)	2002	2.18	4%	-
Steam LNG SHIP HN 2228	2005	12.18	22%	-
DFDE LNG SHIP HN2288	2013	5.93	11%	-
MEGI LNG SHIP HN 2458	2018	3.56	6%	6.02
CRUDE OIL TANKER HN 5262	2005	2.53	5%	-
CRUDE OIL TANKER HN 5442	2018	2.14	4%	2.26

Effect of EEDI – Norway Estimate

- **Effect of EEDI**: IMO prediction for EEDI back in 2012 was as follows: The introduction of the EEDI for all new ships will mean that between 45 and 50 million tonnes of CO2 will be removed from the atmosphere annually by 2020, compared with “business as usual” and depending on the growth in world trade. For 2030, the reduction will be between 180 and 240 million tonnes annually from the introduction of the EEDI.

- The 4th IMO GHG study will indicate the effect of EEDI. However, the latest estimation by Norway: Approximately 1,100-1,200 vessels were delivered per year between 2015 and 2017 with mandatory EEDI levels, which is 60% of the total number of vessels delivered and **emitting about 90% of the total emissions** from all new builds per year.

- The current EEDI requirements are estimated to reduce carbon intensity on ships contracted:
  by 15% from 2013 to 2015;
  by 25% from 2015 to 2020;
  by 25% from 2020 to 2025; and
  by 35% from 2025 onwards.
  The total impact is lower as the scope of required EEDI is 90% of the total emissions (as mentioned above).



Energy Efficiency Existing Ship Index (EEXI)

- Short term IMO technical measure for GHG reduction
- Entry into force on first annual, intermediate or renewal IAPP survey or the initial IEE survey on or after 1 January 2023
- The calculation of Vref can be challenging
- Options to comply:
    - Engine power limitation (EPL)
    - Shaft power limitation (SHaPoLi)
    - Operation on LNG or other alternative fuels
    - Retrofit of energy saving devices/technology

$$\text{Attained EEXI} \leq \text{Required EEXI} = \left(1 - \frac{y}{100}\right) \bullet \text{EEDI Reference line value}$$

Ship type	Required EEXI*
Bulk carrier	Δ15-20% by size
Tanker	Δ15-20% by size
Container	Δ20-50% by size
General cargo	Δ30%
Gas carrier	Δ20-30% by size
LNG carrier	Δ30%
Reefer	Δ15%
Combination carrier	Δ20%
Ro-ro cargo / ro-pax	Δ5%
Ro-ro (vehicle)	Δ15%
Cruise ship	Δ30%

Carbon Intensity Indicator (CII)

- Short term IMO operational measure for GHG reduction
- For the first time, ships are ranked.
- Ranking is based on grams of CO2 emitted per cargo-carrying capacity and nautical mile (CO2 emissions)
- BIMCO is working on a “CII” clause for charter parties
- Updated guidelines expected after MEPC78 in June 2022.
- IMO recommends operators to maintain ratings above C, on their ships:
- Options to comply:
  - Speed reduction. Commercial parties will eventually be involved.
  - Transport chain optimization
  - Operation on LNG or other alternative fuels

$$\text{CII} = \frac{\text{Annual fuel consumption} \cdot \text{CO}_2\text{ factor}}{\text{Annual distance travelled} \cdot \text{Capacity}} \cdot \text{Correction factors}$$

To be developed

Year	Reduction factor (Z%) for the CII relative to the 2019 reference line
2023	5 %
2024	7 %
2025	9 %
2026	11 %
2027-2030	To be decided

Impact of the EEXI and CII on the world fleet

EEXI

Percent of vessels requiring improvement to become **EEXI compliant**

Bulk Carriers	87%	Sample 11,179 vessels
Containerships	88%	Sample 5,080 vessels
Tankers	85%	Sample 9,546 vessels
Gas Carriers	95%	Sample 1,705 vessels

CII

Percent of vessels requiring an operational change or improvement by 2030 to stay within A, B or C for CII

Bulk Carriers	82%	Sample 1,377 Vessels
Containerships	78%	Sample 731 Vessels
Tankers	70%	Sample of 1,110 Vessels
Gas Carriers	80%	Sample 128 Vessels
LNG Carriers	54%	Sample 98 Vessels

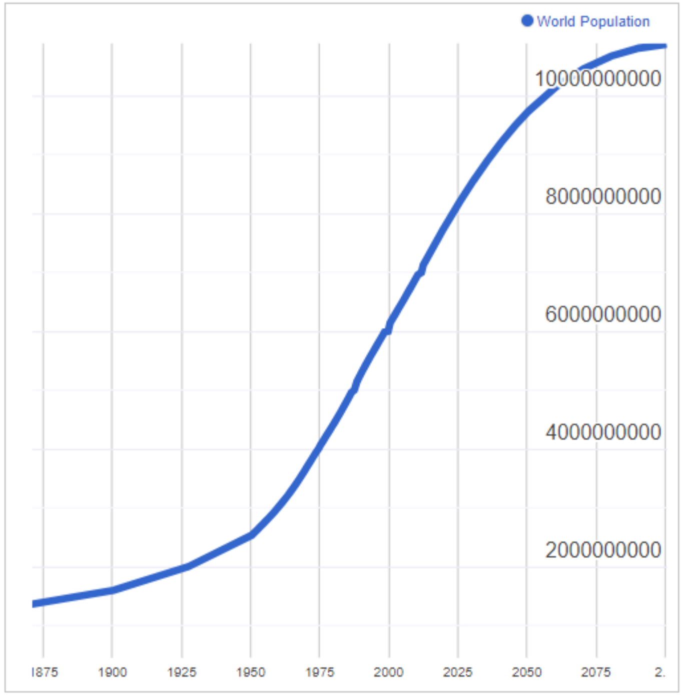
Source: ABS

Prospects of the future – Growth population

GROWTH IN POPULATION BY 2050 (%)						
REGION	POPULATION 2022	WORLD SHARE 2022	POPULATION 2050	WORLD SHARE 2050		PERCENTAGE GROWTH
ASIA	4,715,149,573	59.34%	5,290,263,118	54.34%	-5.00%	12.20%
AFRICA	1,400,601,232	17.63%	2,489,275,458	25.57%	7.94%	77.73%
EUROPE	748,487,540	9.42%	710,486,313	7.30%	-2.12%	-5.08%
LATIN AMERICA AND THE CARIBBEAN	664,865,774	8.37%	762,432,366	7.83%	-0.54%	14.67%
NORTHERN AMERICA	373,113,453	4.70%	425,200,368	4.37%	-0.33%	13.96%
OCEANIA	43,700,882	0.55%	57,376,367	0.59%	0.04%	31.29%
TOTAL	7,945,918,454		9,735,033,990			22.52%

Data originated by Worldometers.info

World Population:
Past, Present, and Future



Prospects of the future – Growth of Seaborne trade

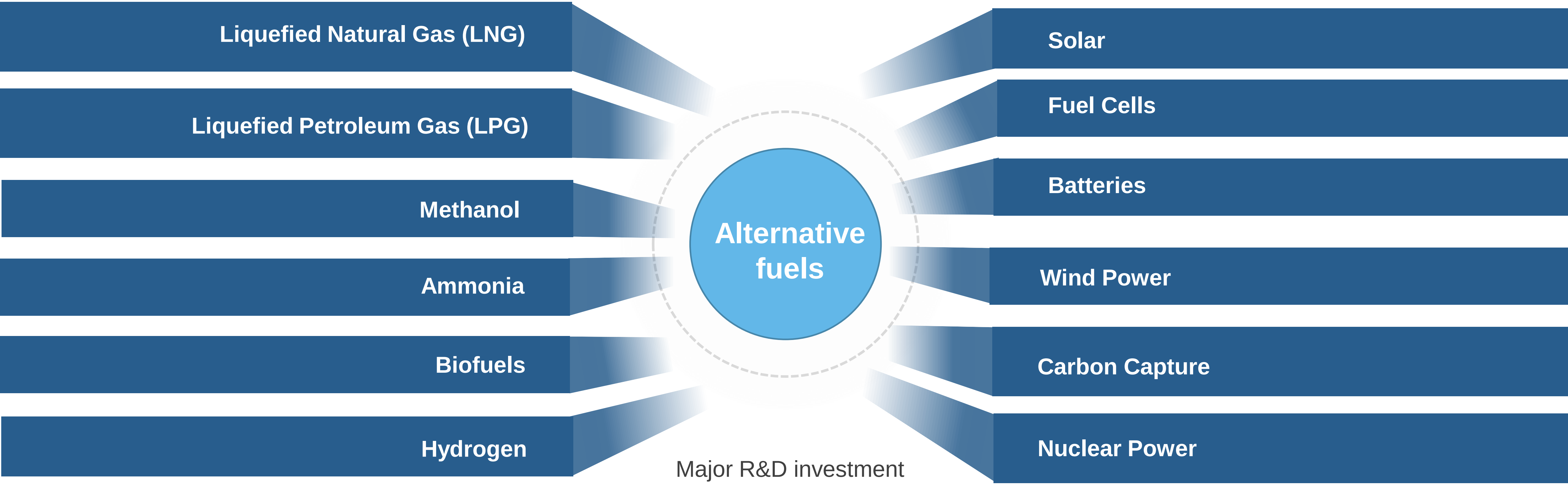
SEABORNE-TRADE DEMAND GROWTH ASSUMPTIONS FOR THE LOW-GROWTH SCENARIOS					
SCENARIO	ASSUMPTIONS	ANNUAL CHANGE		TOTAL CHANGE	
		2020–2030	2031–2040	2041–2050	2020–2050
LOW-GROWTH DNV GL ETO	TANK	-0.60%	-0.70%	-1.40%	-21.80%
	BULK	1.30%	0.90%	-1.40%	8.30%
	CONTAINER	2.50%	2.20%	1.20%	73.40%
	GAS	7.50%	5.80%	2.50%	327.60%
	OTHER CARGO	1.30%	1.00%	0.30%	28.70%
	NON-CARGO	2.60%	2.60%	2.10%	94.70%
	TOTAL GROWTH	**1.40%**	**1.20%**	**-0.30%**	**24.90%**

SEABORNE-TRADE DEMAND GROWTH ASSUMPTIONS FOR THE HIGH-GROWTH SCENARIOS					
SCENARIO	ASSUMPTIONS	ANNUAL CHANGE		TOTAL CHANGE	
		2020–2030	2031–2040	2041–2050	2020–2050
HIGH-GROWTH RCP2.6, SSP 4	TANK	-3.60%	-3.20%	0.00%	-52.00%
	BULK	3.60%	3.70%	3.90%	211.00%
	CONTAINER	5.10%	5.10%	5.10%	367.00%
	GAS	3.60%	3.60%	3.60%	198.00%
	OTHER CARGO	4.20%	4.20%	4.20%	258.00%
	NON-CARGO	3.60%	3.60%	3.60%	198.00%
	TOTAL GROWTH	**2.60%**	**3.50%**	**4.00%**	**179.00%**

Prospects of the future – GDP Growth

GDP GROWTH COMPARED TO PREVIOUS YEAR (%)												
REGION	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	**Total**
ADVANCED ECONOMIES	1.76%	2.46%	2.25%	1.74%	-4.54%	5.20%	4.54%	2.17%	1.72%	1.61%	1.59%	**22.16%**
EURO AREA	1.86%	2.63%	1.85%	1.50%	-6.34%	5.04%	4.35%	1.98%	1.58%	1.42%	1.38%	**18.17%**
EUROPEAN UNION	2.09%	3.02%	2.26%	1.95%	-5.88%	5.10%	4.44%	2.29%	1.88%	1.72%	1.66%	**22.08%**
EMERGING MARKET AND DEVELOPING ECONOMIES	4.48%	4.77%	4.58%	3.67%	-2.07%	6.38%	5.15%	4.65%	4.51%	4.44%	4.39%	**55.02%**
ASEAN-5	5.14%	5.48%	5.37%	4.89%	-3.40%	2.95%	5.85%	6.04%	5.58%	5.41%	5.36%	**60.43%**
LATIN AMERICA AND THE CARIBBEAN	-0.60%	1.35%	1.19%	0.15%	-7.02%	6.34%	3.05%	2.54%	2.35%	2.37%	2.41%	**14.45%**
MIDDLE EAST AND CENTRAL ASIA	4.56%	2.48%	2.17%	1.48%	-2.79%	4.11%	4.07%	3.79%	3.64%	3.62%	3.68%	**35.23%**
SUB-SAHARAN AFRICA	1.49%	2.95%	3.28%	3.13%	-1.66%	3.70%	3.80%	4.10%	4.04%	4.12%	4.18%	**38.40%**

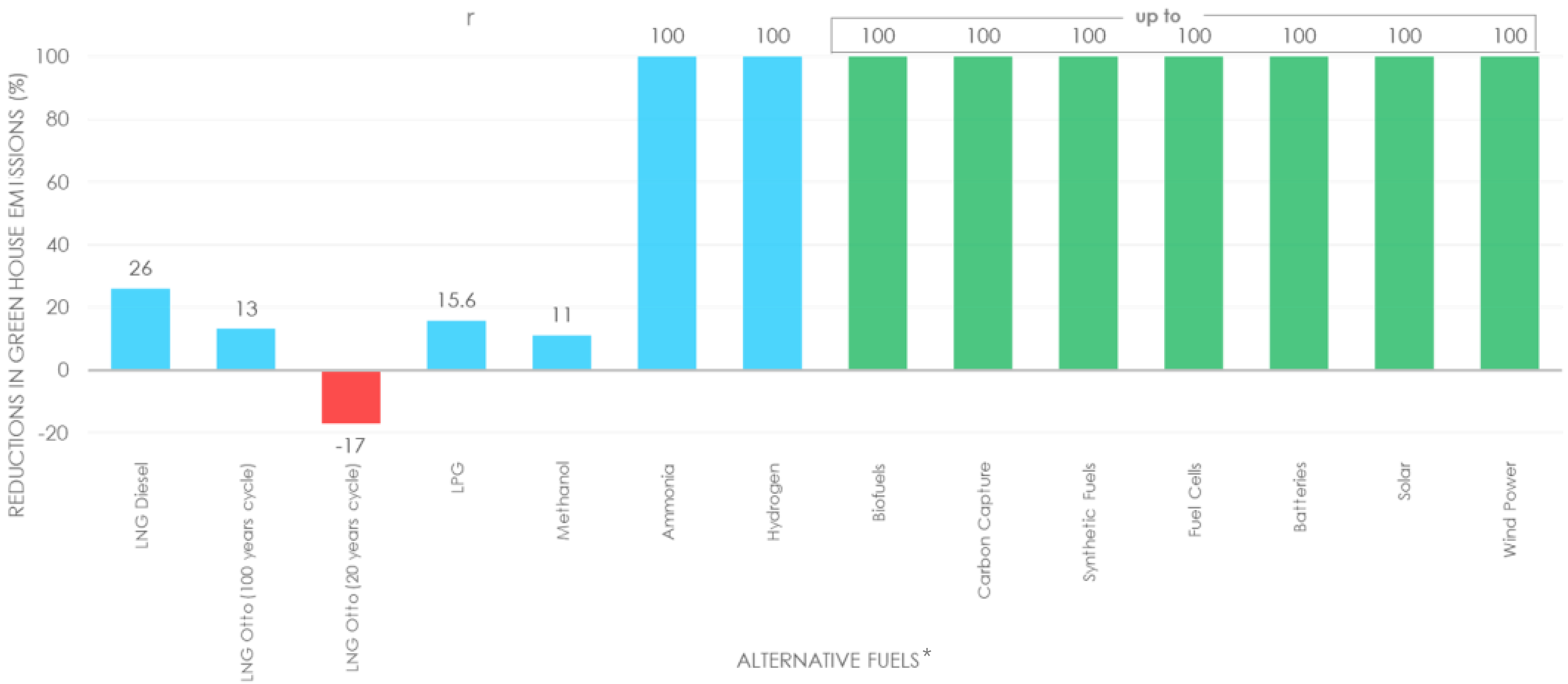
Alternative Fuels: a long-term solution?



Major R&D investment and effort is required. Novel propulsion technologies will have to be explored

Alternative Fuels: a long-term solution?

Still to be agreed based on the methane GWP (25 or 83)



**All figures refer to the tank-to-wake approach*

Alternative Fuels: a long-term solution?

Fuel / Technology	Fuel production	Fuel storage logistics bunkering	Installation	Propulsion system	Onboard safety & fuel management	Zero carbon emission target
Fossil Fuels						
LNG						
LPG						
Methanol						
mmonia						
Hydrogen						
Biofuels						
Nuclear						
Fuel Cells						

Existing technology	
Partly available / In progress	
A long way to go	

Alternative Fuels: a long-term solution?

Fuel	Energy Density (MJ/lt)	Volume Comparison HFO	CO_2 (kg CO_2 / kWh)	CO_2 (kg CO_2 / kWh) reduction compared to HFO
Heavy Fuel Oil (HFO)	38.2		0.2700	
Liquefied Natural Gas (LNG)	21.6	1.85	0.2061	26%
Liquefied Petroleum Gas (LPG)	24.88	1.62	0.2353	15.6%
Methanol	15.7	2.54	0.2486	11%
Ethane	26.13	1.47	0.2295	Up to 20%
Ammonia	15.7	2.55	0	100%
Biofuels	15.9 – 35.7	0.9 – 1.1	0.14 – 0.16	50%
Hydrogen	9.2	4.33	0.06	75.6%
Synthetic Fuels	F-T: 36.2	0.76		Up to 100%
Solar		N/A	Down to 0	Up to 100%
Fuel Cells		N/A		Up to 100%
Batteries	0.9 – 2.63	N/A	Down to 0	Up to 100%
Wind Power	?	N/A	Down to 0	Up to 100%
Carbon Capture	N/A	N/A		Up 90%
Nuclear Power	79,390,000 MJ/kg		0	Up to 100%

Alternative Fuels: a long-term solution?

Liquefied Natural Gas (LNG)

M/T Eagle Valence (2022), one of the first dual fuel VLCCs

Liquefied Natural Gas (LNG)

- **Benefits:**
  - Multiple marine engine technologies available
  - Cleanest-burning fossil fuel currently available, currently, at a large scale
  - Reduces NOx, eliminates most SOx and particulate
  - Available experience on gas fuel handling systems, dual fuel engines and dual fuel boilers, arising from LNG carriers
  - OPEX benefits due to “cleaner combustion”
- **Challenges:**
  - Does not meet GHG targets for 2030 or 2050 alone but must be combined with other technologies. It can be considered as an interim solution.
  - Limited bunkering infrastructure and regulations.
  - Relatively high CAPEX.
  - Methane slip in some engines (Otto cycle). This may result in a moderate decrease of GHG (100 years) or even to an increase (20 years).
  - Low temperature, boil-off, flammability and related safety considerations. Bunkering procedures require crew training / expertise.
  - A lot of promotion lately for LNG.

Alternative Fuels: a long-term solution?

Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG)

- **Benefits:**
  - Marine engine technology is available
- **Challenges:**
  - Limited bunkering infrastructure, although existing network of LPG terminals and carriers could be reconfigured to supply bunkers.
  - Easier storage and handling than LNG.
  - Low temperature, boil-off, flammability and related safety considerations.
  - Easy to apply on LPG carriers.

Alternative Fuels: a long-term solution?

Methanol

Stena Germanica RoPAX Ferry

Methanol

- **Benefits:**
  - Available worldwide?
  - Currently commercially produced from natural gas, but can be also produced from renewable sources such as biomass which is a GHG-neutral process
- **Challenges:**
  - Energy intensive production.
  - Limited experience in shipping with operating methanol-fueled marine engines.
  - Methanol is corrosive which will require redesign of some engine parts, use of additives or specialty coatings.
  - Lack of regulatory guidance.
  - Several hazards associated with storage and transport (acutely toxic, corrosive, flammable, and heavier than air meaning leaks would tend to accumulate in bilges or low sections of a space).

Alternative Fuels: a long-term solution?

Ammonia

C-Job Naval Architects concept design

Ammonia

- **Benefits:**
  - Ammonia is carbon-free and, when synthesized from renewable power sources, its production can also be a carbon-free process (green ammonia)
  - Engine technology for ammonia as a fuel has been widely used on land, although development for marine engines is in early stages
- **Challenges:**
  - While combustion of ammonia offers considerable reductions in GHG emissions, production of ammonia can produce significant emissions.
  - Selective catalytic reduction systems (SCR) or equivalent measures would be needed to manage NOx emissions.
  - At the moment, ammonia as fuel is not economically feasible for shipping.
  - Infrastructure exists for the fertilization industry, but not the marine industry.
  - Major onboard modifications would be required for use on ships.
  - When used for internal combustion engines ammonia produces water, nitrogen, unburned ammonia and NOx. Managing combustion by products will be a key environmental challenge.
  - Toxic and corrosive, flammable in vapor phase.
  - Must be stored at low temperature or under pressure with boil-off considered.

Alternative Fuels: a long-term solution?

Two-stroke ammonia engine development by MAN ES

2019 – Pre-study

- ✓ NH3 combustibility investigation.

2020 – Project kick-off

- ✓ 4T50ME-X test engine received as platform for the Ammonia engine development.
- ✓ HAZID workshop on engine concept.
- ✓ Combustion chamber 1st evaluation.

2021 – Engine concept R&D

- Engine basic concept defined based on R&D and simulations.
- Ammonia fuel supply & Auxiliary systems specified and established in RCC.

2022 – Engine combustion and emission

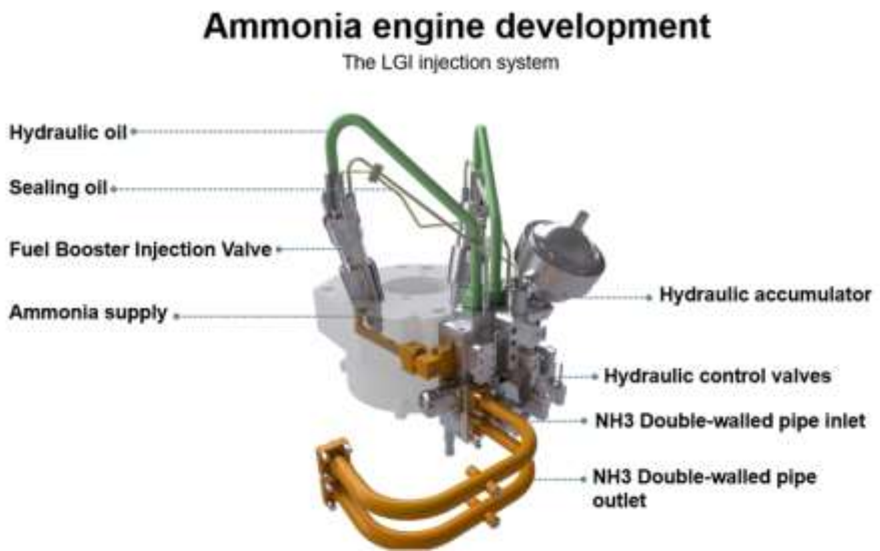
- 1st engine confirmation at Research Centre Copenhagen (RCC).
- Specification of emission after-treatment done.

2023 – Full scale engine test

- Full scale engine test at RCC evaluated for 1st commercial design.

2024 – 1st engine delivery to yard

- Ammonia engine in engine programme.
- 1st ammonia fueled engine delivered to yard.



Alternative Fuels: a long-term solution?

Biofuels

Biofuels

- **Benefits:**
  - Carbon-neutral energy

- **Challenges:**
  - Potential to reduce available farmland earmarked for normal food production.
  - May not be cleaner than distillate fuels in terms of NOx, SOx and particulate matters.
  - Minimal experience and data.
  - Biofuels tend to oxidize and degrade in storage, producing in some cases highly corrosive hydrogen sulphide. They are susceptible to microbial growth.
  - Fuel lubricity, conductivity and corrosion are problematic.
  - High acidity causing increased wear on engine components.
  - High cost.

Alternative Fuels: a long-term solution?

Hydrogen

Energy Observer

Hydrogen

➢ **Benefits:**

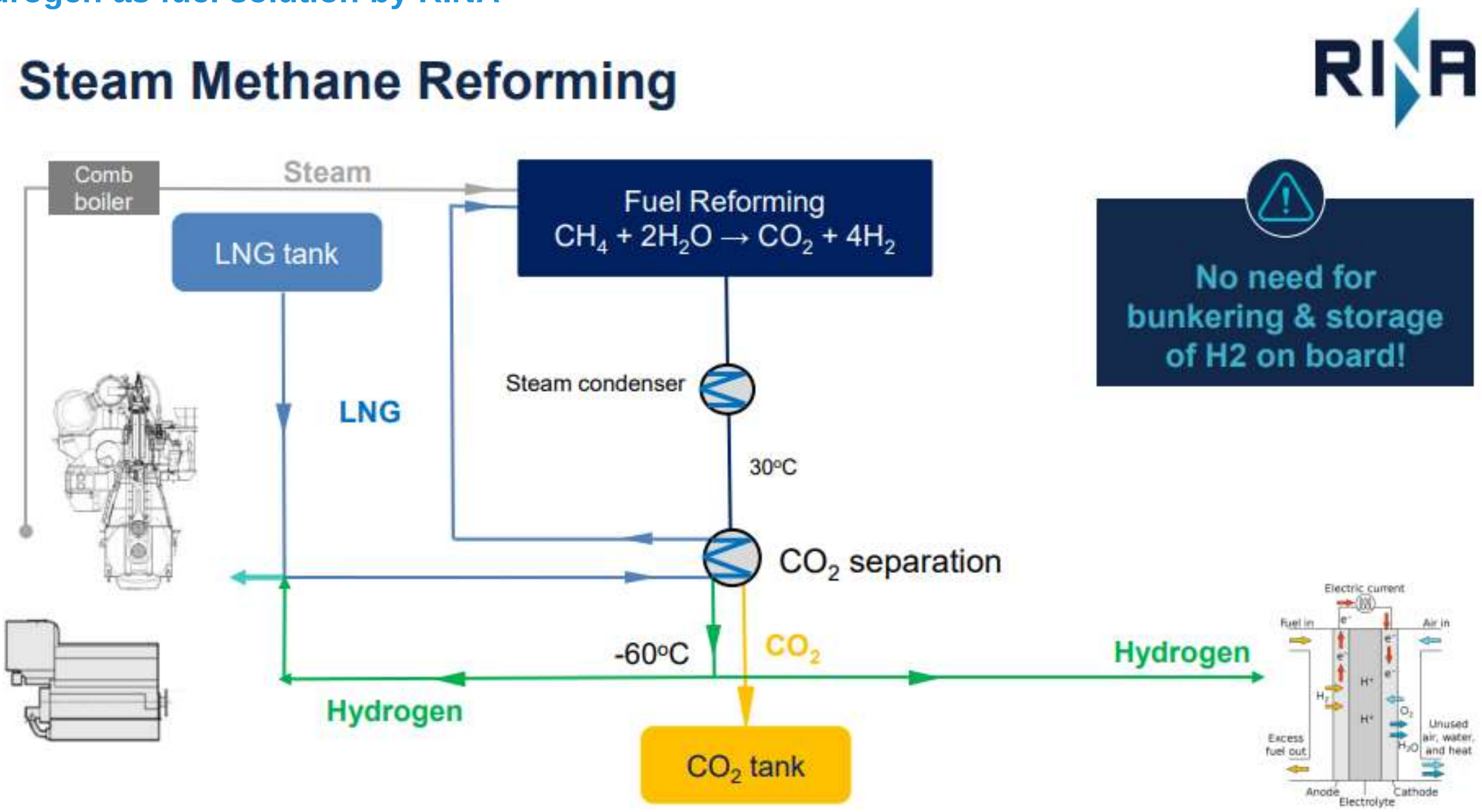
- Cleanest marine fuel currently available in terms of NOx, Sox and Particulate matter
- When produced by renewable energy, it has almost zero GHG emissions

➢ **Challenges:**

- Hydrogen production is very energy intensive, expensive and not available at scale.
- Storage and handling is a major issue.
- Low efficiency in internal combustion engines.
- Hydrogen is stored as a compressed gas or liquid and advancements in storage technology are key to its greater adoption.
- It is prone to leaking due to small molecular size, and leakage in enclosed spaces can quickly cause asphyxiation. It is also flammable.
- Less than 25% of energy content if compared with fossil fuels.

Alternative Fuels: a long-term solution?

Hydrogen as fuel solution by RINA



Alternative Fuels: a long-term solution?

Synthetic Fuels

FT synthetic fuel and conventional fuel

Synthetic Fuels

- **Benefits:**
  - Carbon-neutral
  - Modifications required to existing vessel equipment and systems for using them would be minimal
- **Challenges:**
  - Manufacturing process is expensive and energy/labor-intensive.
- **History:**
  - Were used by the German army during WW II.

Alternative Fuels: a long-term solution?

Solar

Eco Marine Power (EMP) + concept project

Solar

- **Benefits:**
  - Renewable energy
  - Technology is available, although so far mainly applied on yachts / sailing vessels with only very few commercial applications
- **Challenges:**
  - Limited applicability in areas with insufficient sunshine.
  - Adverse environmental conditions such as humidity, shading, corrosion (including from salt deposits on panels) are issues.
  - Space requirements and weight.
  - Storage of the energy (batteries) will increase the cost.

Alternative Fuels: a long-term solution?

Fuel Cells

Type 212A –
German and Italian Navy

Fuel Cells

- **Benefits:**
  - Have been successfully deployed on naval submarines
- **Challenges:**
  - High capital costs.
  - High weight (though generally lighter than comparable battery systems).
  - Complex support and control systems.
  - Toxic exposure, asphyxiation and explosion risks from fuels.
  - Bunkering infrastructure needs to be developed.
  - Significant storage capacity for hydrogen and methanol.
  - Fuel input needs to be renewable to maximize emissions savings.
  - Lack of regulations.
  - Fast advancing technology. Hyundai are now selling in the US a fuel cells car.

Alternative Fuels: a long-term solution?

Batteries

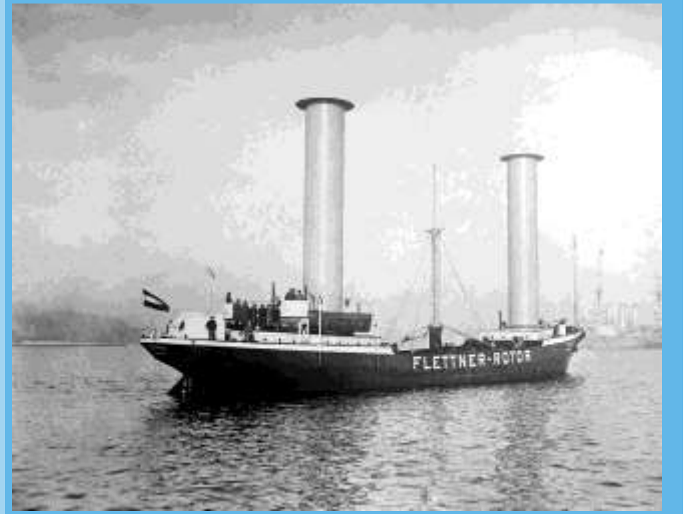
Seacor retrofit projects on PSVs

Batteries

- **Benefits:**
  - Applications of technology already exist on short-range vessels
  - High efficiency of electric propulsion systems
  - Available class / regulatory guidance
- **Challenges:**
  - High capital cost.
  - Weight and space requirements.
  - New technology for distributing direct current may need to be introduced to the electric propulsion system to integrate the battery with any renewable energy and help the prime mover operate efficiently. This may require a complete redesign of some equipment.
  - When power and battery recharging are supplied at port, shore side infrastructure may need to be upgraded.
  - Fast advancing technology. Production of batteries is not environmentally friendly

Alternative Fuels: a long-term solution?

Wind Power



Buckau (1924)

Wind Power

- **Benefits:**
  - Renewable energy
  - Available technology

- **Challenges:**
  - Performance dependent on external factors such as the force and the direction of the wind.
  - Require high maintenance, and availability of components for repair may be an issue.
  - Operational considerations (such as air draft or the need to secure systems in storms) should be considered.
  - The Flettner rotors can work for a wide range of wind directions. Average contribution to propulsion power +/- 10%.

Alternative Fuels: a long-term solution?

Nuclear Power

USS Nautilus (1954)

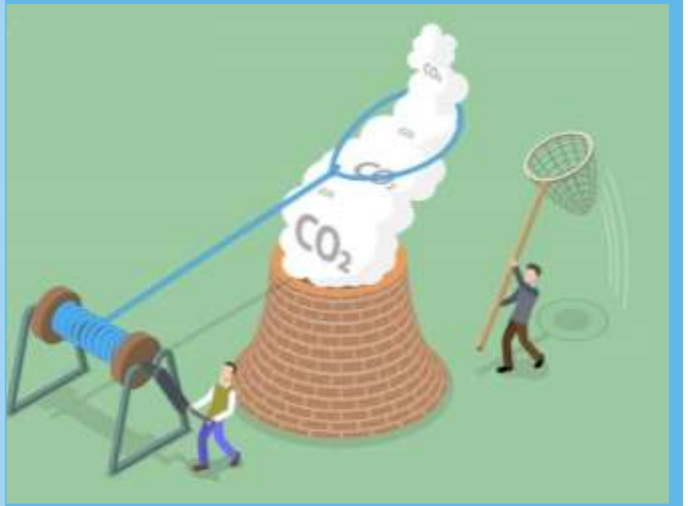
Nuclear Power

- **Benefits:**
  - Zero GHG emissions
  - Very high Fuel to Power ratio
  - No space needed for bunkering
  - Well-established propulsion in military vessels and the Savannah

- **Challenges:**
  - High CAPEX & OPEX. To be evaluated against total lifetime costs.
  - Uranium supply is expected to last for 30-60 years
  - Management of nuclear wastes: Some radioactive species, which may be lethal to living species, have lifetime longer than 1,000,000 years. Suggestions for their disposal is either Ocean floor or vaults of 1 km below Earth's surface have been made. In 1973, the Royal Swedish Academy of Sciences emphasized the need for these wastes isolations to be "fully justified".
  - Political reasons
  - Crew training

Carbon Capture

Carbon Capture



Carbon Capture

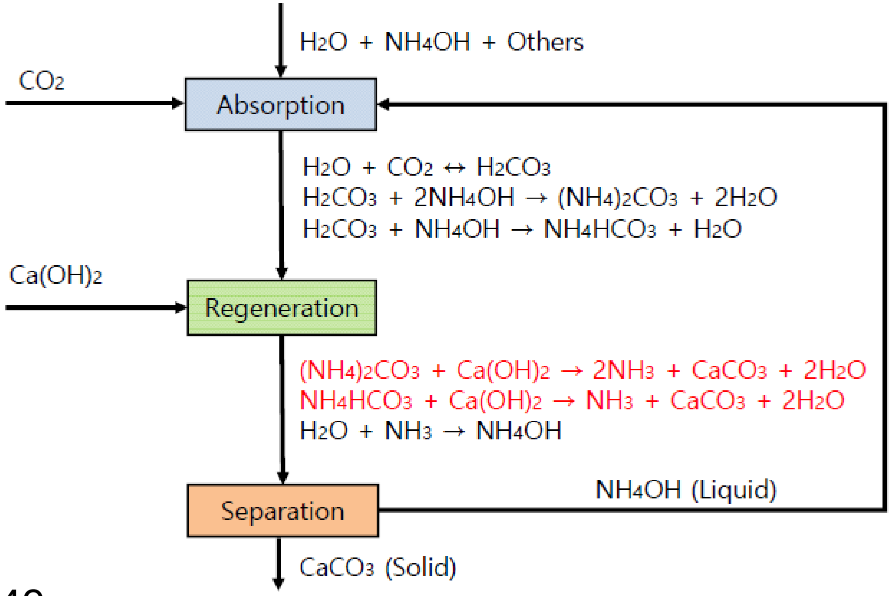
- **Benefits:**
  - Allows for continued use of available carbon-based fuels

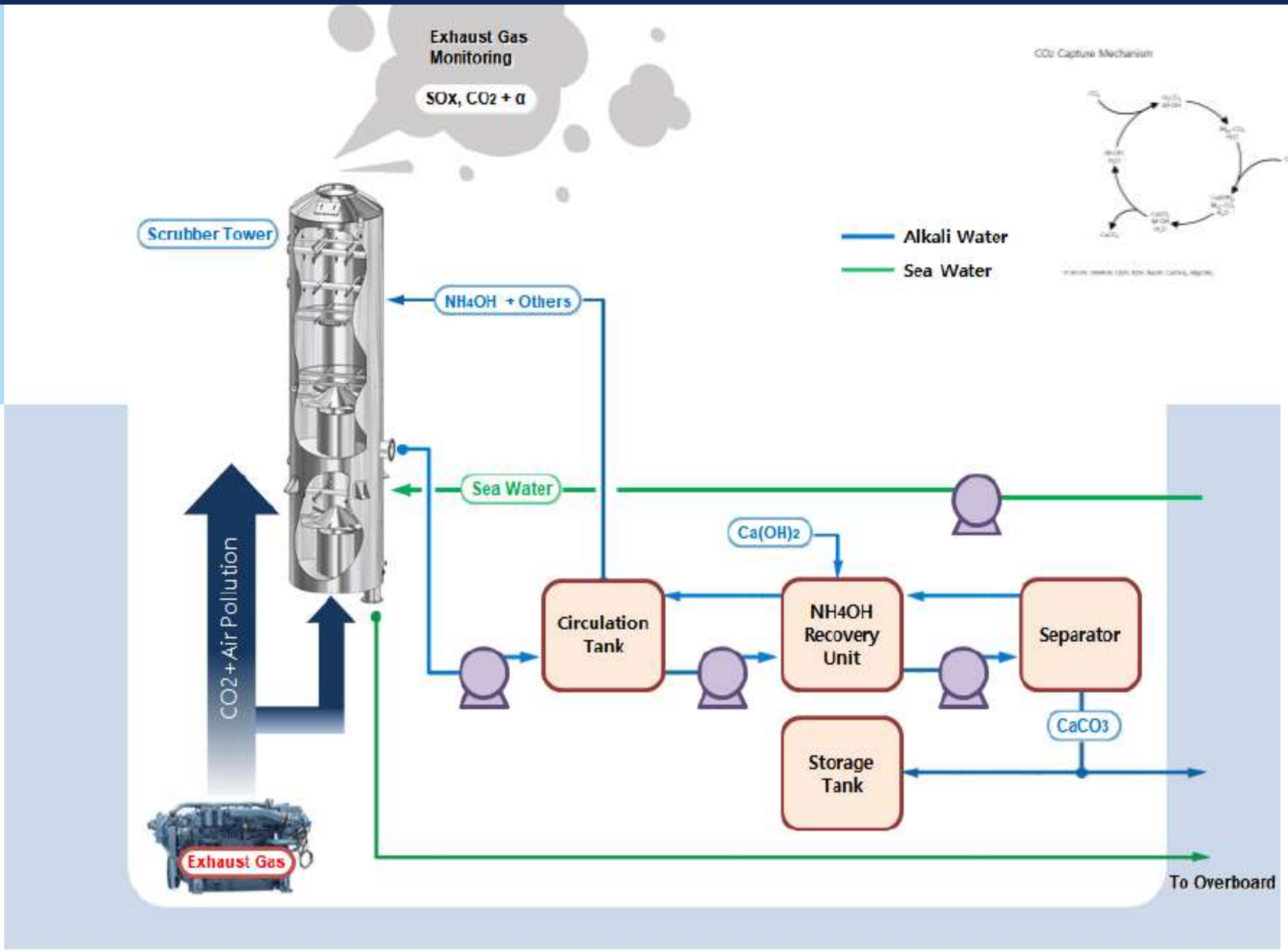
- **Challenges:**
  - The challenge in the marine environment is the handling and storage of any captured CO2 which would require either significant space (if CO2 is stored in vapor form) or significant power (if CO2 is liquefied).
  - CO2 capture equipment may have a very large volume.
  - Widespread application in shore power plants but limited experience in the maritime sector.

Carbon Capture

Carbon Capture solutions for ships

- CO2 absorption using Ammonium hydroxide (NH_4OH). (Hi-Air)
- Production of solid Calcium carbonate ($CaCO_3$).
- Easy retrofit for ships equipped with SOx scrubbers.

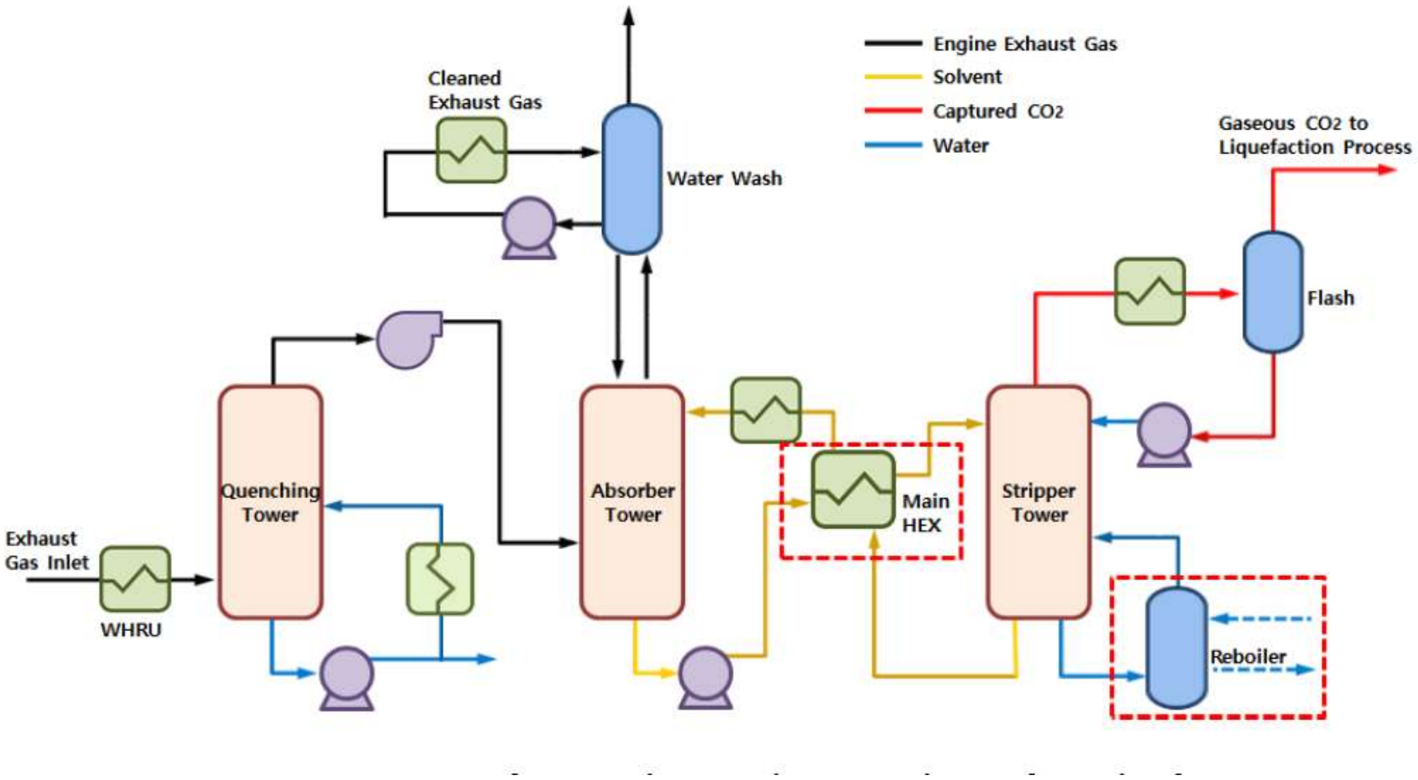




Carbon Capture

Carbon Capture solutions for ships

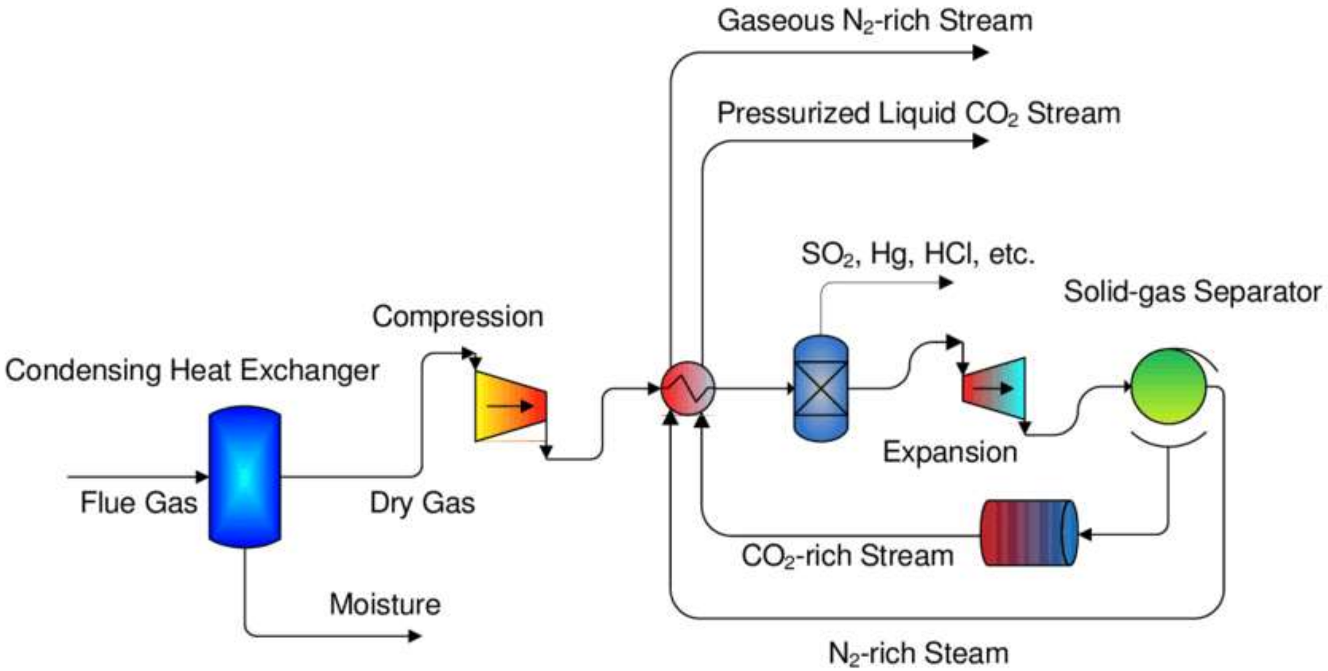
- ➢ CO_2 absorption by liquid amines.
- ➢ Complicated installation



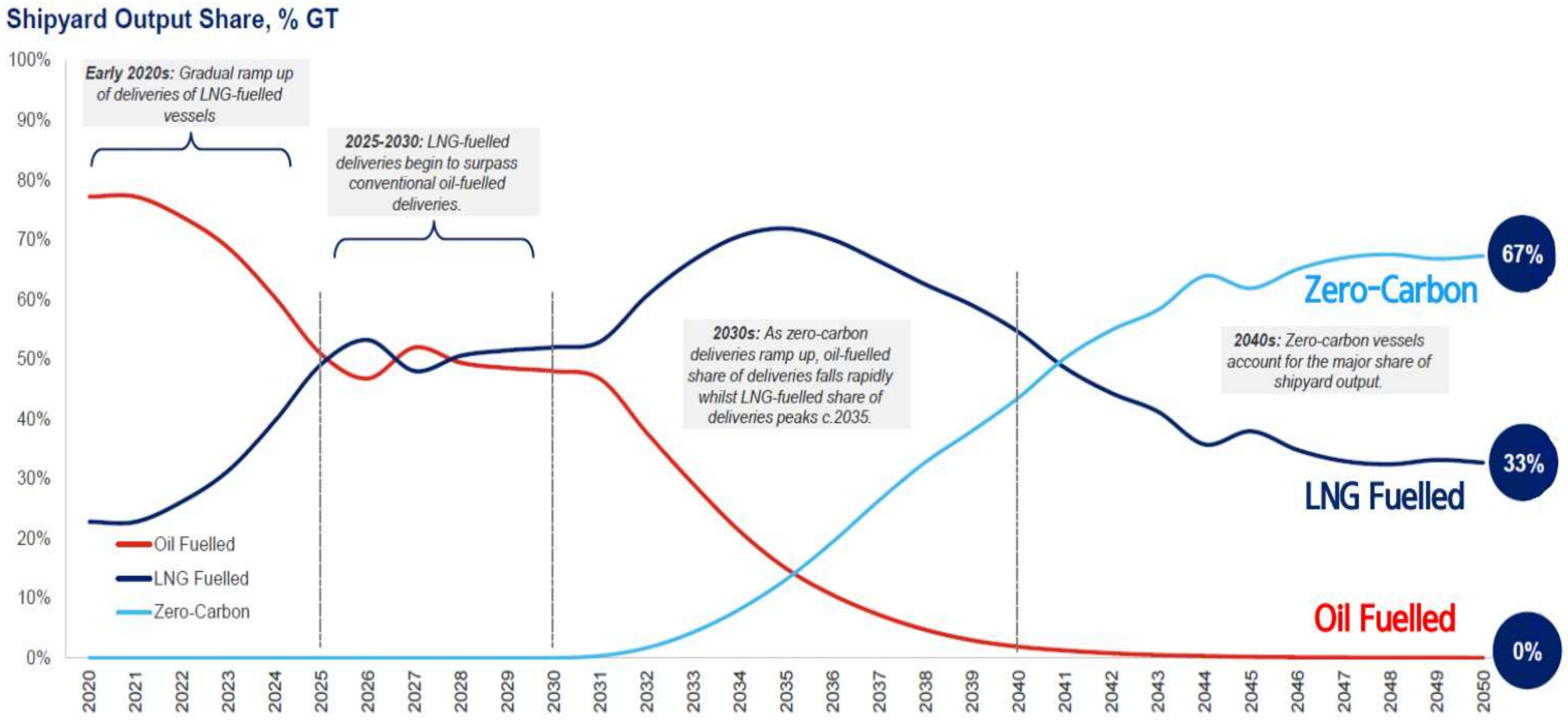
Carbon Capture

Carbon Capture solutions for ships

- CO2 capture using cryogenic technology
- Expensive installation
- Complicated / energy intensive



Alternative Fuels: is LNG as fuel the most pragmatic interim solution?



Source: Clarkson's

A few questions to the Clean Shipping Coalition

01

Is the technology available to use any other environmentally friendly fuel than LNG (admitting that LNG is an interim solution) ?

02

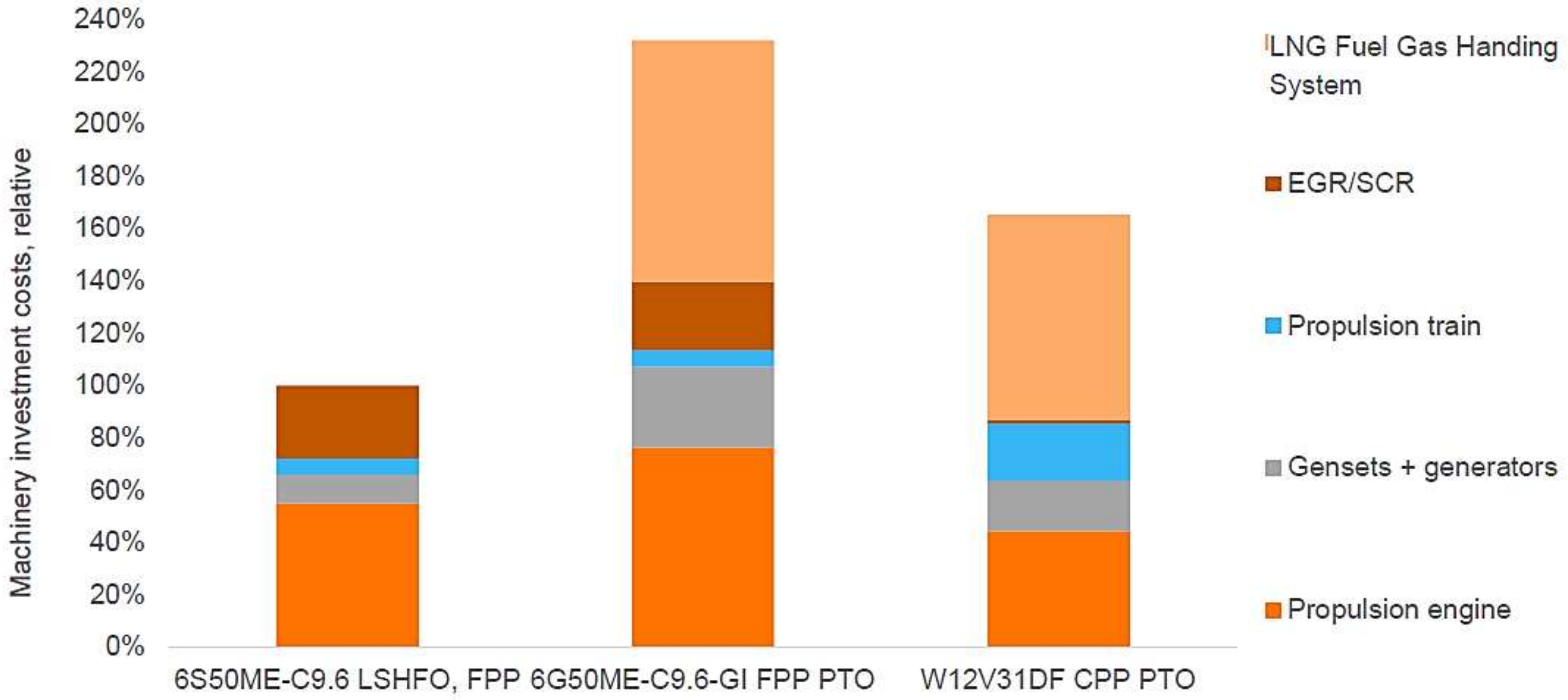
Is LNG lowering:

- ✓ SOx to 0?
- ✓ NOx by 20-30% and by more than 80% for Otto cycle engines; and
- ✓ PM to almost 0?

Green ships of the future

LNG-fueled bulk carrier with shaft generator, solar panels and batteries (under development)

Green ships of the future: the price to pay



Conclusions (way forward)

- Holistic approach for long-lasting, sustainable and safe solutions. New fuels and technologies will have to be adequately studied and tested prior using them in a large-scale onboard ships. (reduction in NOx increases CO2, SOx scrubbers do the same, EEDI – minimum power and shafting issues)
- Research and development for green technologies should be supported by State and green funding.
- Reliability is a top priority for marine equipment on ships that operate thousands of miles away from shore.
- New technology will increase the cost of ships during a period at which the profit margins in shipping are being reduced. New financing schemes may emerge. But at what cost to the independent shipowner?

Conclusions (way forward)

- Universities will have to modernize their curriculum and give incentives to students for fresh and productive ideas. Athens has the potential to become the maritime “Silicon Valley”.

- Marine academies will have to upgrade their standards in order to catch up with the faced-paced technological changes and train the next generation of “tech-savvy” sailors.

- Transparency is becoming a universal requirement.

- It may be the time to “break the tradition” and work together with governments, oil majors, charterers and shipbuilders towards a sustainable shipping industry. Independent shipowners will need to be supported to keep ordering and operating their ships.

Conclusions (way forward)

- History has shown that shipping evolves in short or long cycles (lately longer than shorter) depending on the supply-demand balance

- Today and for the next decades, shipping, will be affected a lot by:
  - Environmental legislation
  - More expensive fuels. More efficient ships will be needed to reduce the transportation costs
  - New technology and digitalization

- Shipmanagement companies may have to modernize their operational practices and adopt a “big-data” digitalization approach for decision making.

Conclusions (way forward)

- Technology will change but we will still need ships with enhanced reliability and maintainability. These are the ships that we will need to build in the next decades. Shore controlled or autonomous ships may come later.

- LNG as a fuel is a technology that exists today and will help in lowering the ships' generated emissions globally.

- The well-to-wake theories need to be discussed. Each one of us should get his house in order. We feel that shipping is losing this game at this moment

Off the press!

European Commission president Ursula von der Leyen (standing) backs nuclear power and natural gas, but will European Parliament lawmakers agree? Photo: European Parliament

EU mulls 'green' label for natural gas and nuclear

Controversial energy forms are set to be included in bloc's classification list of environmentally sustainable economic activities

3 January 2022 10:05 GMT *UPDATED 3 January 2022 10:08 GMT*

Taylor Maritime's Edward Buttery, pictured at Marine Money's Singapore Ship Finance Forum, says ordering ships is a risk for smaller owners in the current climate. Photo: Marine Money

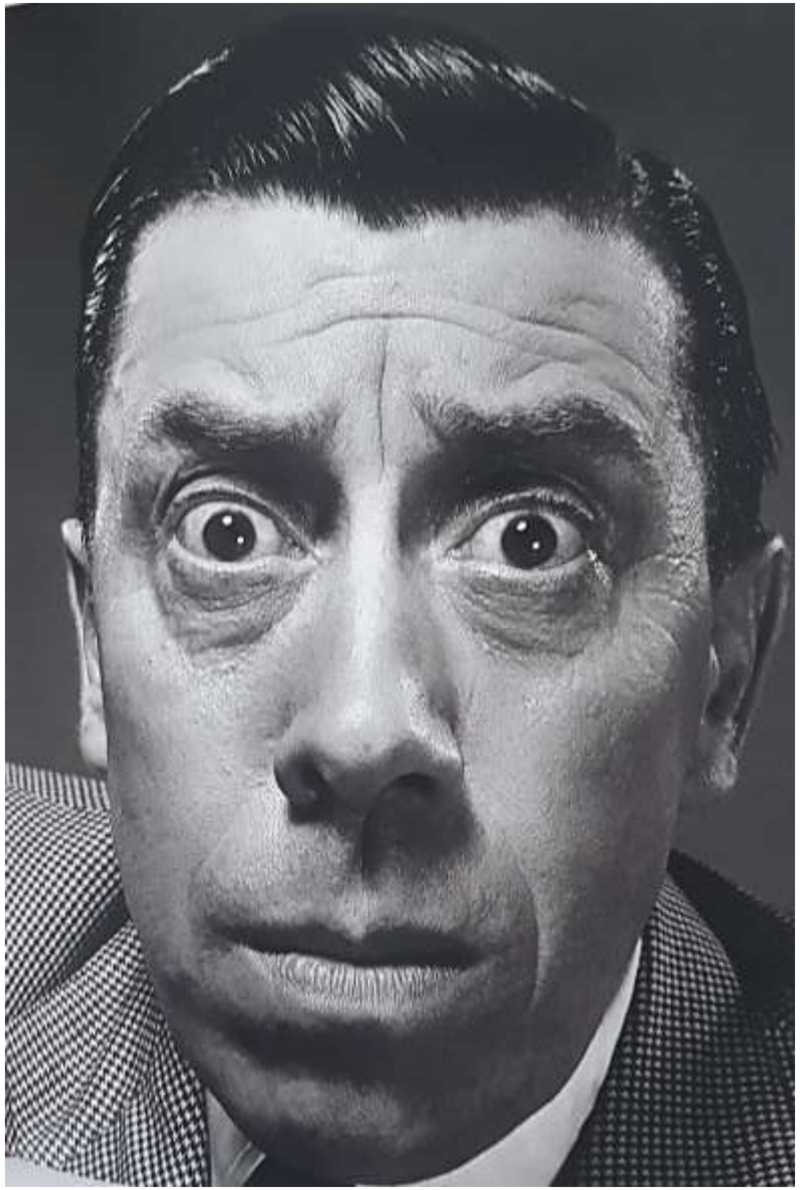
Smaller shipowners sit on the sidelines as decarbonisation debate rages on

Taylor Maritime and Swire Shipping to avoid newbuildings until a clearer picture of pathways emerges

8 April 2022 8:34 GMT *UPDATED 8 April 2022 16:24 GMT*

By Jonathan Boonzaier in Singapore

WHAT WILL BE THE MARITIME FUEL OF THE FUTURE?



DO YOU FEEL THAT OUR GOVERNMENTS ARE PUSHING THE SHORE-BASED INDUSTRIES TO REDUCE EMISSIONS AS HARD AS THEY PUSH THE SHIPPING INDUSTRY?

DO YOU THINK THAT THE SHIPPING INDUSTRY WILL SUPPORT THE WORLD SUSTAINABILITY EFFORT?

Thank you!