4rth Korean-Hellenic
Maritime Cooperation Forum

Improving the energy efficiency of trading ships

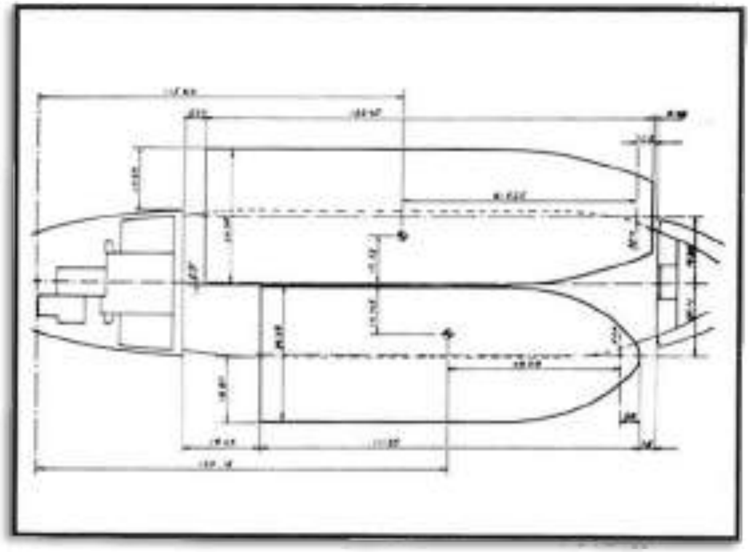
Stavros Hatzigrigoris

Posidonia Ποσειδώνια
The International Shipping Exhibition

5 June 2024

The first major project

The dry tow heavy lift ship



Final positioning of Marianna II on the deck of Sibig Venture

Severing, transporting, reconstructing M/T Marianna II

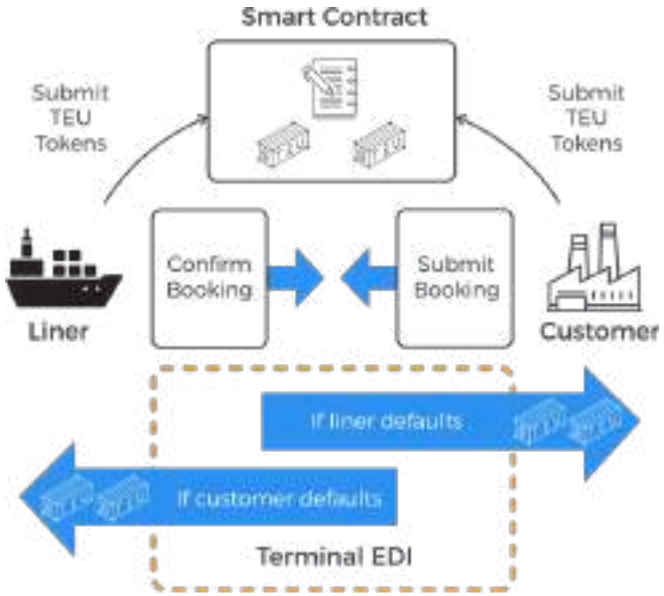
- *Sep 1988* — Exploded, almost cut in 2, declared as CTL
- *Dec 1989* — Departed from Piraeus as heavy lift cargo (24100 mt)
- *Feb 1989* — Arrived at Hyundai Mipo Dockyard in Korea
- *June 1989* — Redelivered to her owners

At full speed to Korea

Completion of loading

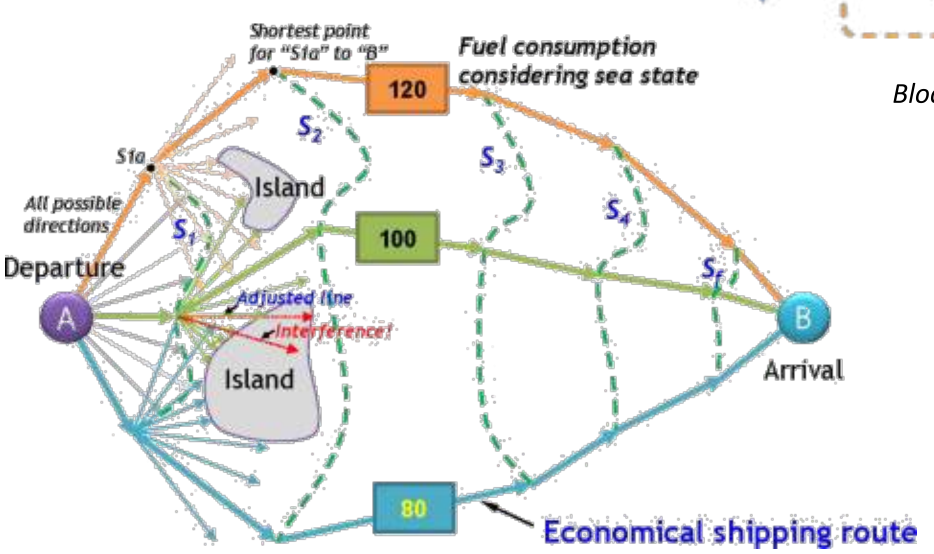
Digitalization

- Artificial intelligence (AI)
- Machine Learning (ML)
- Internet of Things (IoT)
- Blockchain
- Digital Twins
- Weather Routing



Blockchain in shipping

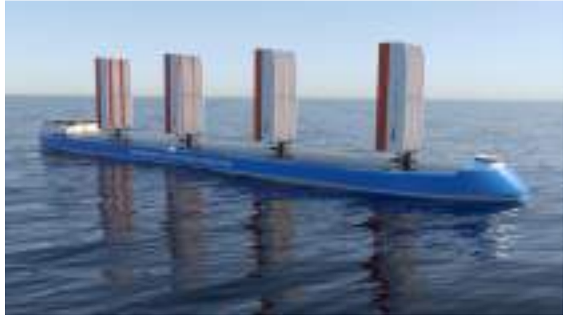
Digital Twins



Weather Routing

Emission and CII Monitoring

Wind Assisted Propulsion (WAP) Technologies



Rigid Wing Sails

Flettner Rotor

Flettner Rotors *(Magnus effect)*: tall, cylindrical rotors mounted vertically on a ship's deck. It is the most common application with CAPEX = 3M$ - 6M$

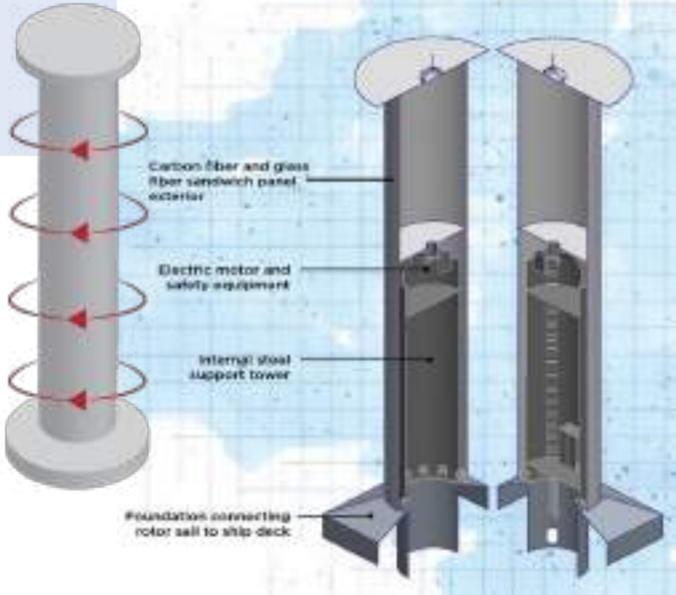
Suction Wing Sails *(thrust mainly from Airfoil's lift force):* vertical non-rotating wings shaped as adjustable airfoils. Internal vents and fans suck air from the low pressure side increasing ΔP and thrust.

Towing Kite *(thrust mainly from drag force):* large kite-like device deployed from bow.

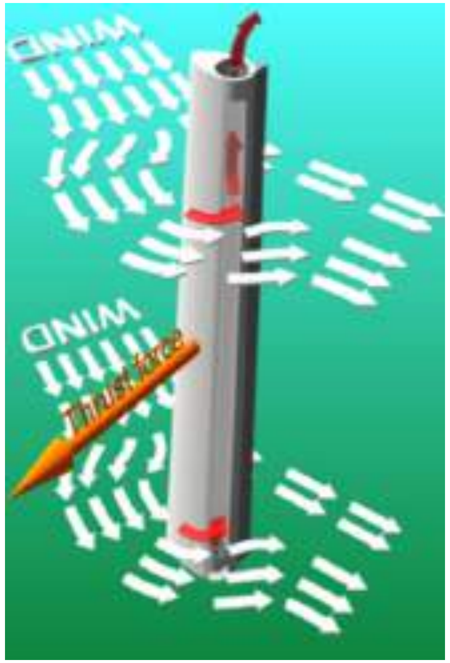
Rigid Wing Sails *(Variable-camber, both drag & lift);* are comprised of a fixed, rigid structure to maintain a consistent aerodynamic shape.

Soft Wing Sails *(Variable-camber, both drag & lift):* combine the benefits of soft sails and rigid wing sails.

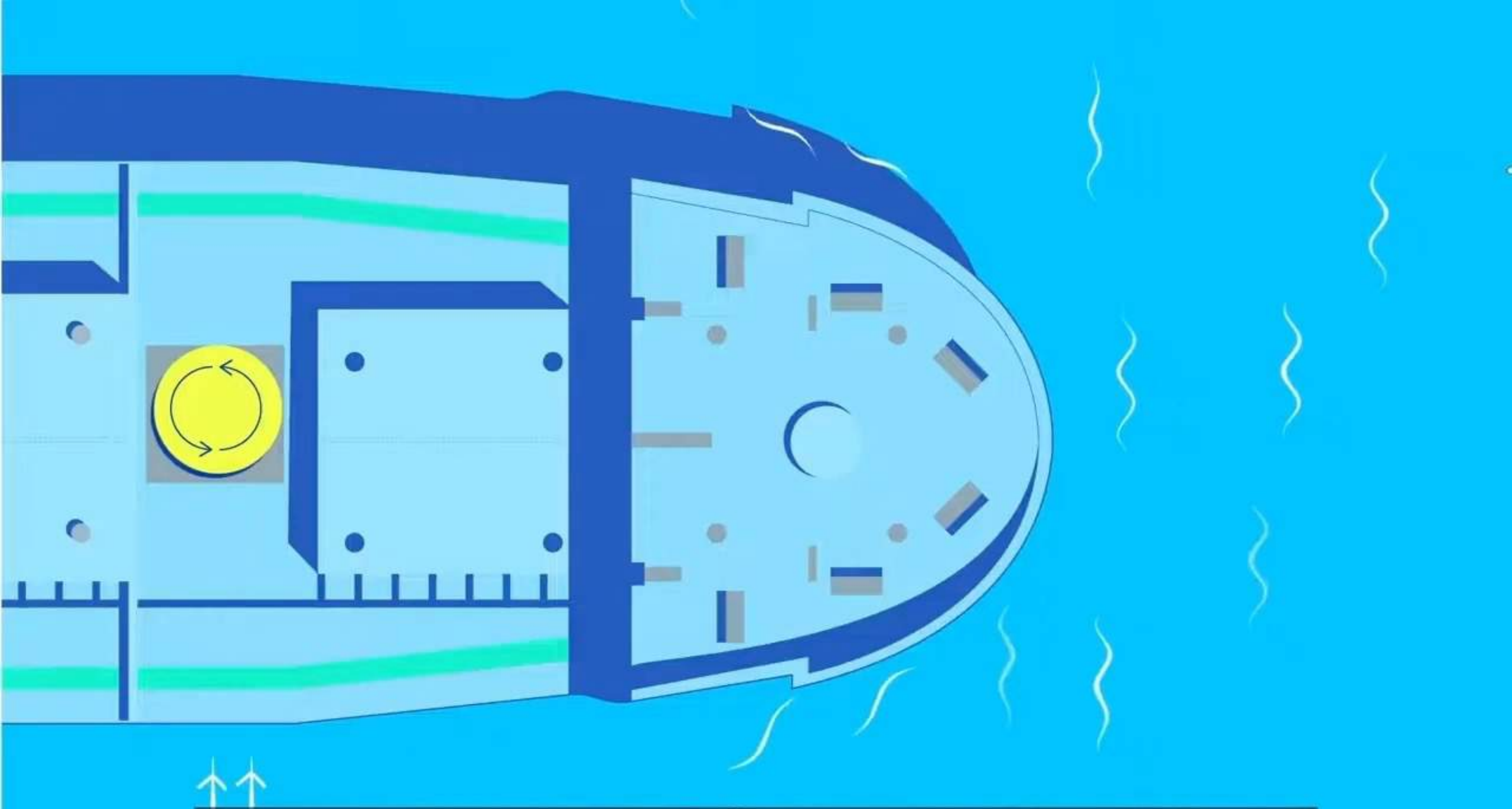
Soft Sails *(both drag & lift):* derived from the traditional yacht sails and they are typically consist of multiple freestanding, rotating masts, each carrying series of individual sails.



Flettner Rotor



Suction Wing Sail



The wind in front of the Rotor Sail is accelerated as it's dragged

Wind Atlas (Nov-Feb): Wind speed statistics

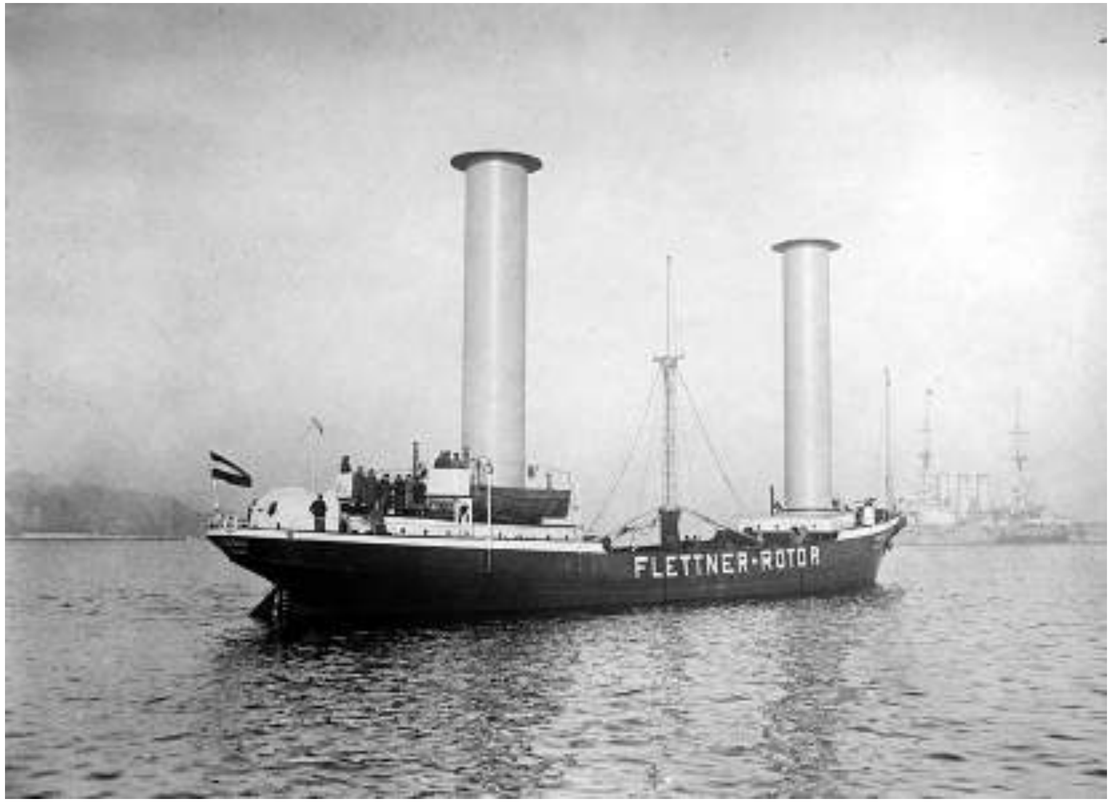
Similar directions for rest of the year

Most common wind direction ⊥ route path Brazil-China
Most common wind direction ‖ route path Brazil-Europe

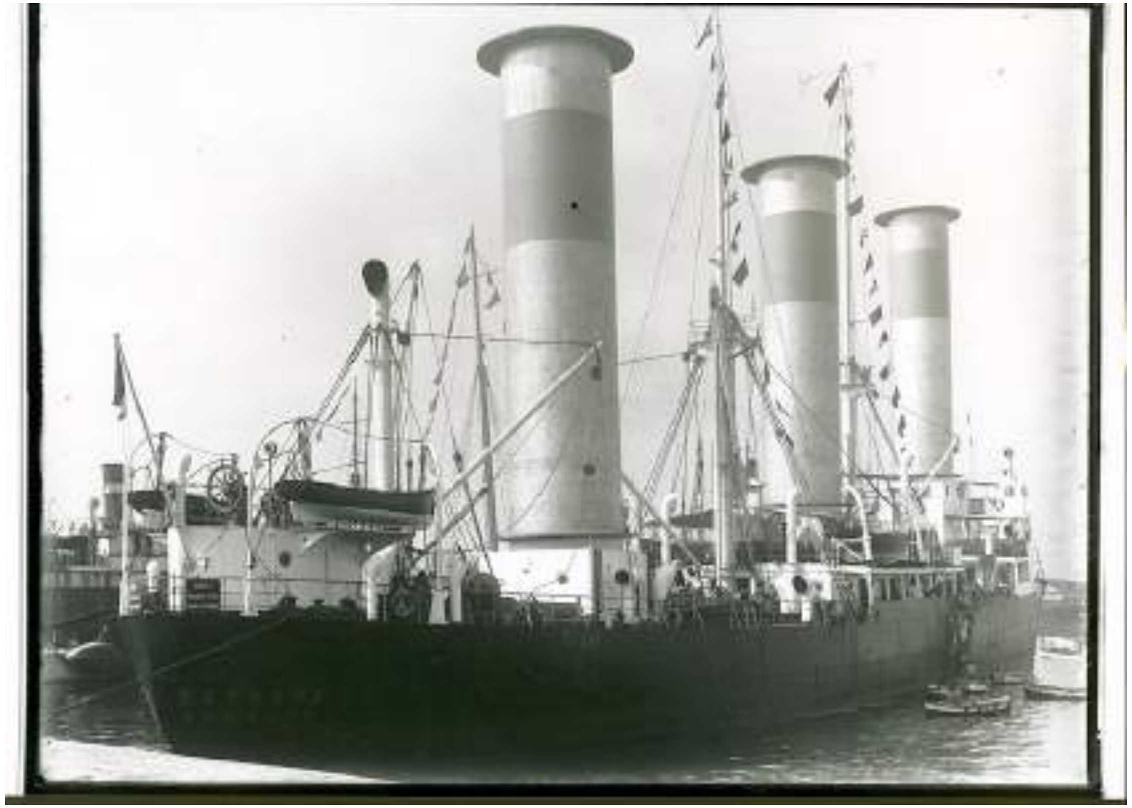
Retrofitting project
Berge Olympus will sail between Brazil and China, a trade route known for having favorable wind conditions.
Expected to save 6 tonnes of fuel per day

Flettner Rotor ships since 1924

The rotor ship *Buckau (1924)*
experimental rotor vessel



The rotor ship *Barbara* (1926)
normal freighter ship



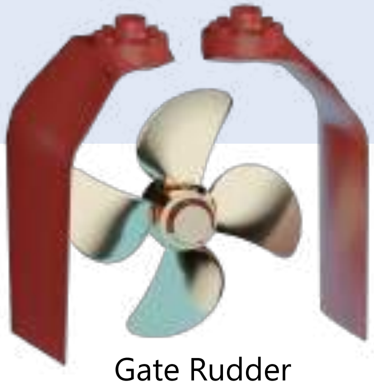
Rudder Design

Rudder bulb / Costa bulb

Integrated propeller and rudder

Becker Rudder

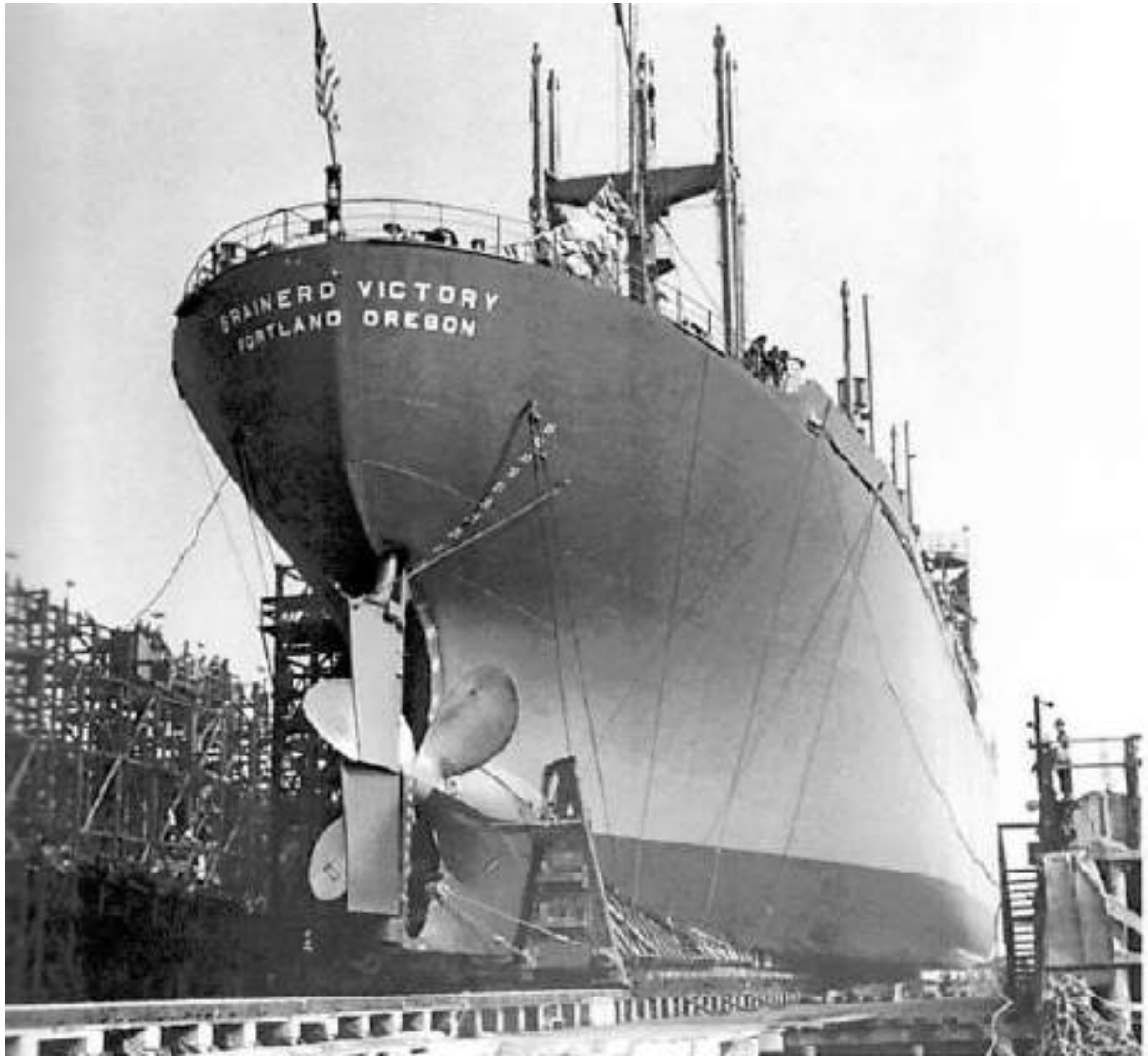
- **Gate Rudder** consists of two asymmetrical rudders placed in parallel either side of the propeller instead of placing behind the propeller
- **Twisted Rudder** is a type of full-spade rudder with upper and lower sides that are designed asymmetrically to consider the wake inlet angle of the propellers.
- **Becker Rudder** is a multi-section rudder; the hinged aft section gives the rudder an extra control surface, enhancing maneuverability with small effect on efficiency.
- **Rudder bulb / Costa bulb** consists of a bulb attached on the rudder in line with the propeller resulting to smoother inflow to the rudder.
- **Integrated propeller and rudder**, where the propeller is directly mounted to the rudder.



Gate Rudder

Twisted Rudder

Twisted rudder (1940s Victory ships)



Left: Final preparations before the launch of the *Brainerd Victory*. Note 19ft diameter propeller and rudder with twisted trailing edge to improve steering.

Propeller Design

Kappel propeller

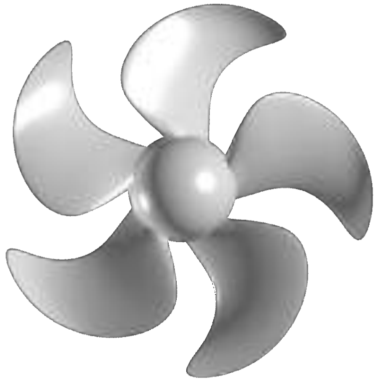
CLT propeller

NPT propeller

- **Kappel propeller** has blades curved towards the suction side in especially towards the blade tip.
- **Contracted Loaded Tip (CLT) propeller**, has end plates at the blade tips.
- **New Profile Technology (NPT) propeller,** designed with special blade sections
- **High skew propeller**, with skew angle more than 25 degrees.
- **Controllable-Pitch (CPP) Propeller,** blades that can rotate relative to the hub.
- **Sharrow Propeller**, consisting of a loop blade design.
- **ABB Dynafin™** composed of rotating vertical blades, mimicking a whale tale motion.

ABB Dynafin™

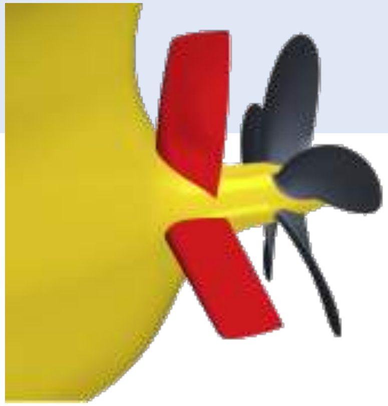
Sharrow Propeller



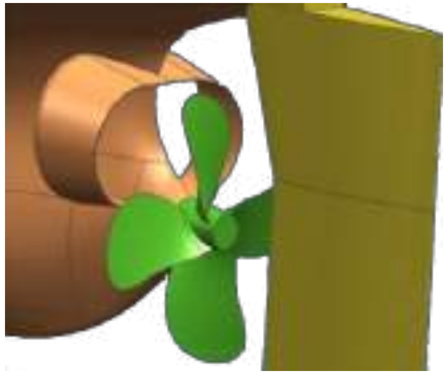
High skew propeller

CPP propeller

Devices for propeller efficiency



Pre-swirl stator

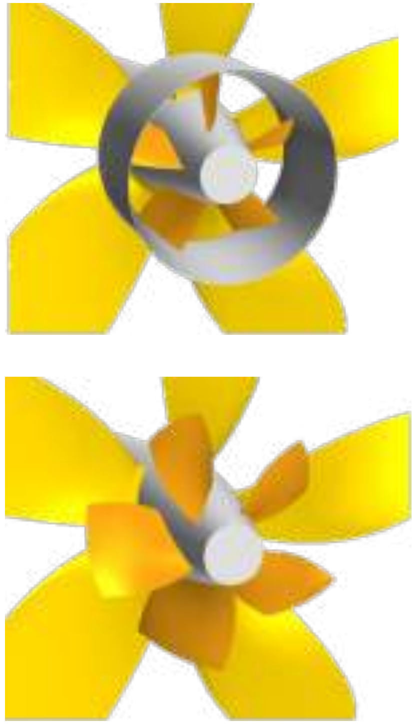


Schneekluth
Wake Equalizing Duct

Becker / Mewis duct

- **Propeller boss cap fins (PBCF)** consists of a propeller boss fitted with short blades inclined to convert hub vortex energy into additional torque and thrust.
- **Becker / Mewis duct** consists of a wake equalizing duct combined with an integrated pre-swirl fin system positioned ahead of the propeller.
- **Schneekluth Wake Equalizing Duct** consists of two nozzle-shaped halfring ducts installed on both sides of the stern ahead of the propeller.
- **Pre-swirl stator** consists of multiple curved fins and a ring attached to the ship's hull, ahead of the propeller.
- **Propeller nozzle** is a circular casing enclosing the propeller which increases the thrust at low speeds.

Propeller nozzle



Propeller boss cap
fins (PBCF)

Hull Optimization

CAPEX

100k$ - 300k$

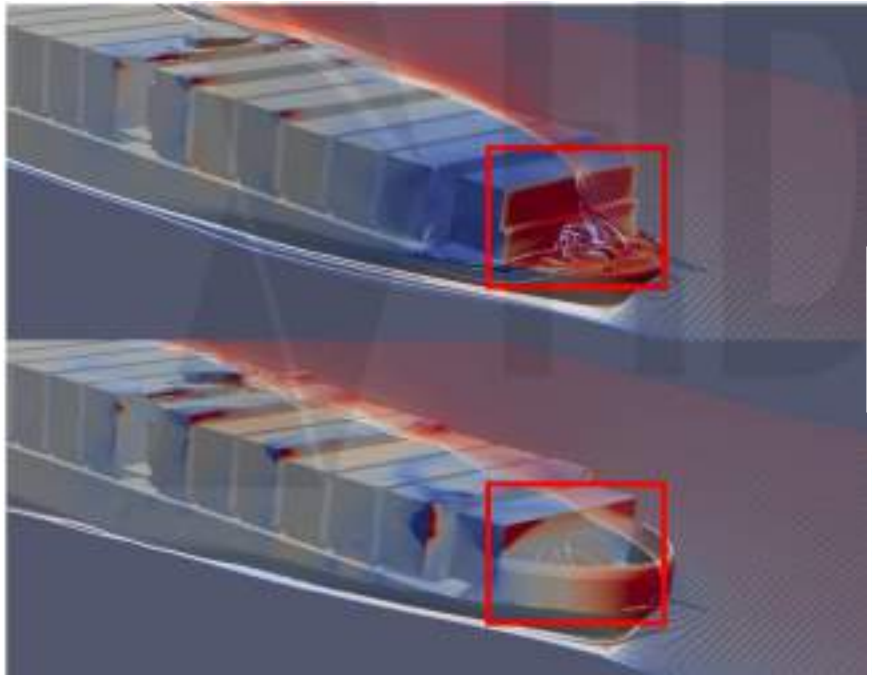
Bulbous bow retrofit

Bulbous bow is optimized for the new operating profile provided by the ship owner. Use optimization tools and CFD programs to search for different shapes of bulbous bows and use optimization algorithms to generate the optimal shape.

Wind cover (containerships)

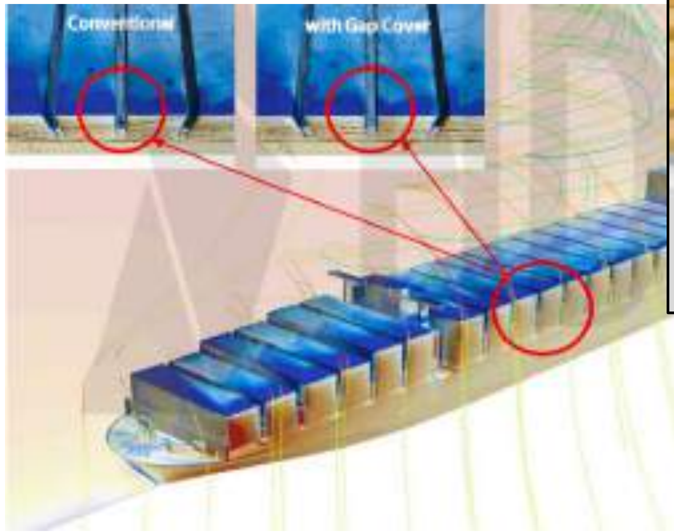
- Wind Cover **(up to 1% net savings for containerships and LNG carriers)**

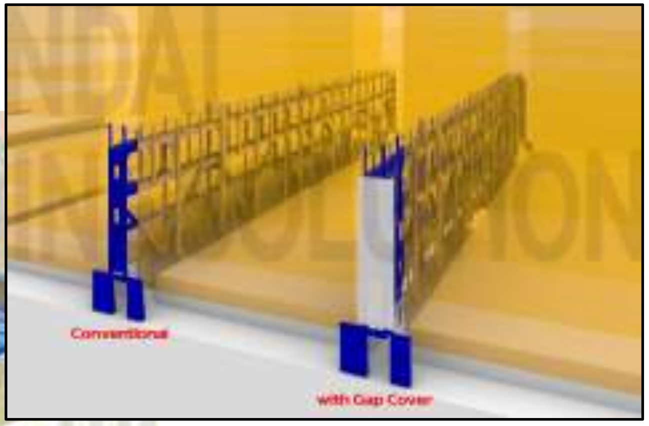
Air resistance normally represents about 2% of the total resistance, however, for loaded container ships in head wind, it can reduce up to 10%.



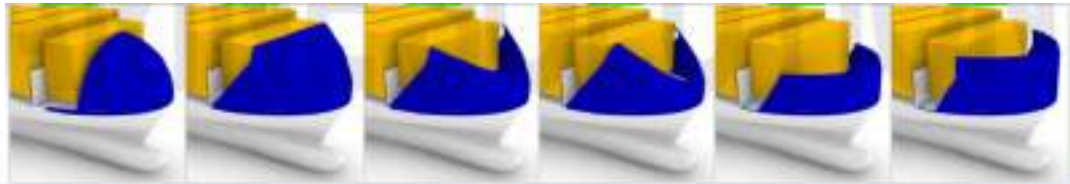
- SGC (Side Gap Cover) in containerships

(~0.5% net savings)





Typical Lashing bridge configuration

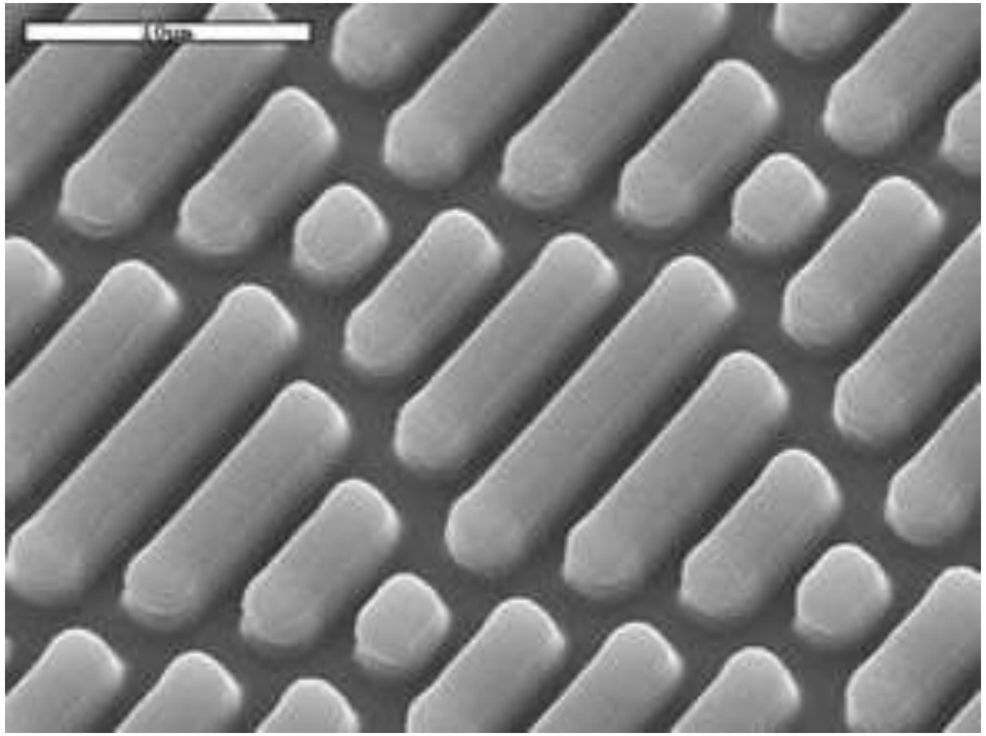


Case	1	2	3	4	5	6
Wind resistance reduction rate	Abt. 10%	Abt. 13%	Abt. 11%	Abt. 12%	Abt. 11%	Abt. 12%

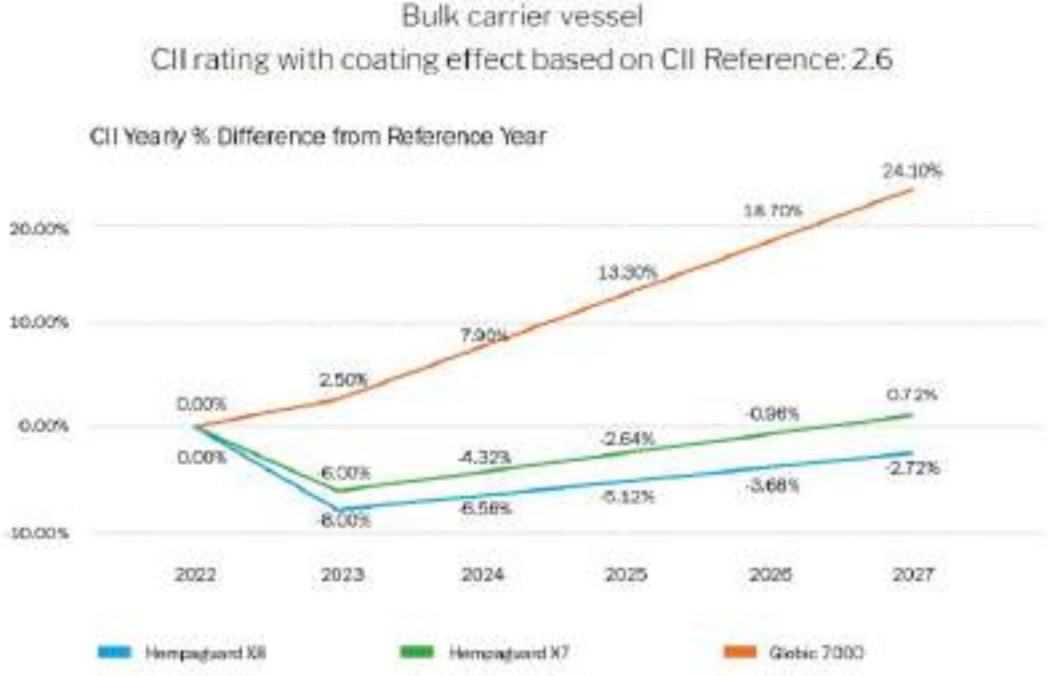
Coatings

- Shark Skin Coating

Composed of tiny scale-like elements that can actually flex in and out to impede growth. In the future it could replace conventional antifouling coatings



- Silicon coatings > biocidal copper coatings
- Full blast > Spot blast



BootTop, Vertical Bottom & Flat Bottom	2022	2023	2024	2025	2026	2027
Full blast • Hempaguard X8	2.55 (C)	2.35 (C)	2.39 (C)	2.42 (C)	2.46 (D)	2.5 (D)
Full blast • Hempaguard X7	2.55 (C)	2.4 (C)	2.44 (C)	2.49 (D)	2.53 (D)	2.57 (D)
Spot blast • Globic 7000	2.55 (C)	2.62 (D)	2.76 (D)	[illegible]	[illegible]	[illegible]

Assumptions: Same trade every year, 3:1 Power to Speed Relationship

by HEMPEL

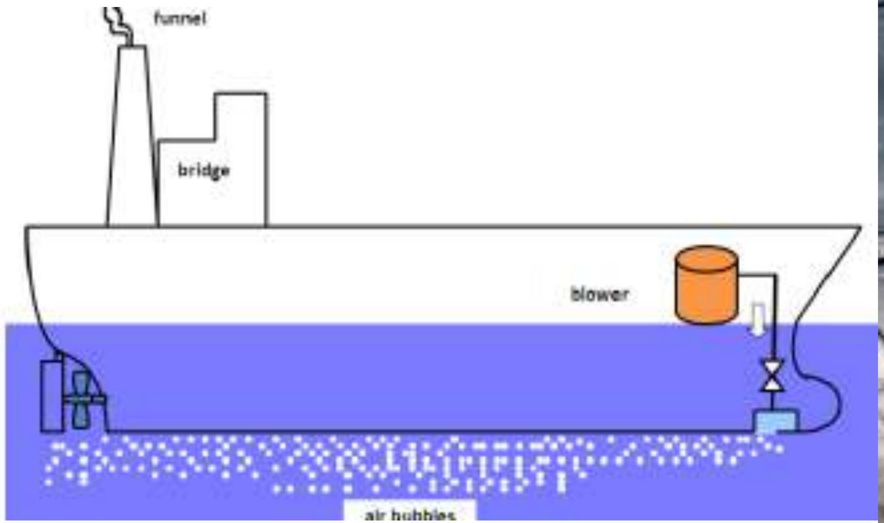
Air lubrication System (ALS)

CAPEX

3.5M$ - 4M$

Up to **9%** net savings

Air lubrication reduces the drag force on the wetted surfaces of the hull due to the lower viscosity of air compared to water (it reduces the friction resistance of the FOB).



Ship Type	Typical Operational Speed [kts]	Typical Operational Draught [m]	Flat of Bottom as a % of total WSA	Expected Net Silverstream© System Performance
Tanker & Bulk Carrier	13 - 15	13 - 20	35% - 50%	**4% - 6 %**
Containership >9000 TEU	20 - 23	14 - 16	25% - 30%	**4% - 6.5%**
LNG Carrier	16 - 18	9 - 12	35% - 42%	**6% - 9%**
Cruise Vessel	18 - 20	8 - 9	20% - 30%	**4% - 7%**
Large RoRo	18 - 22	7 - 8	26% - 32%	**5% - 7%**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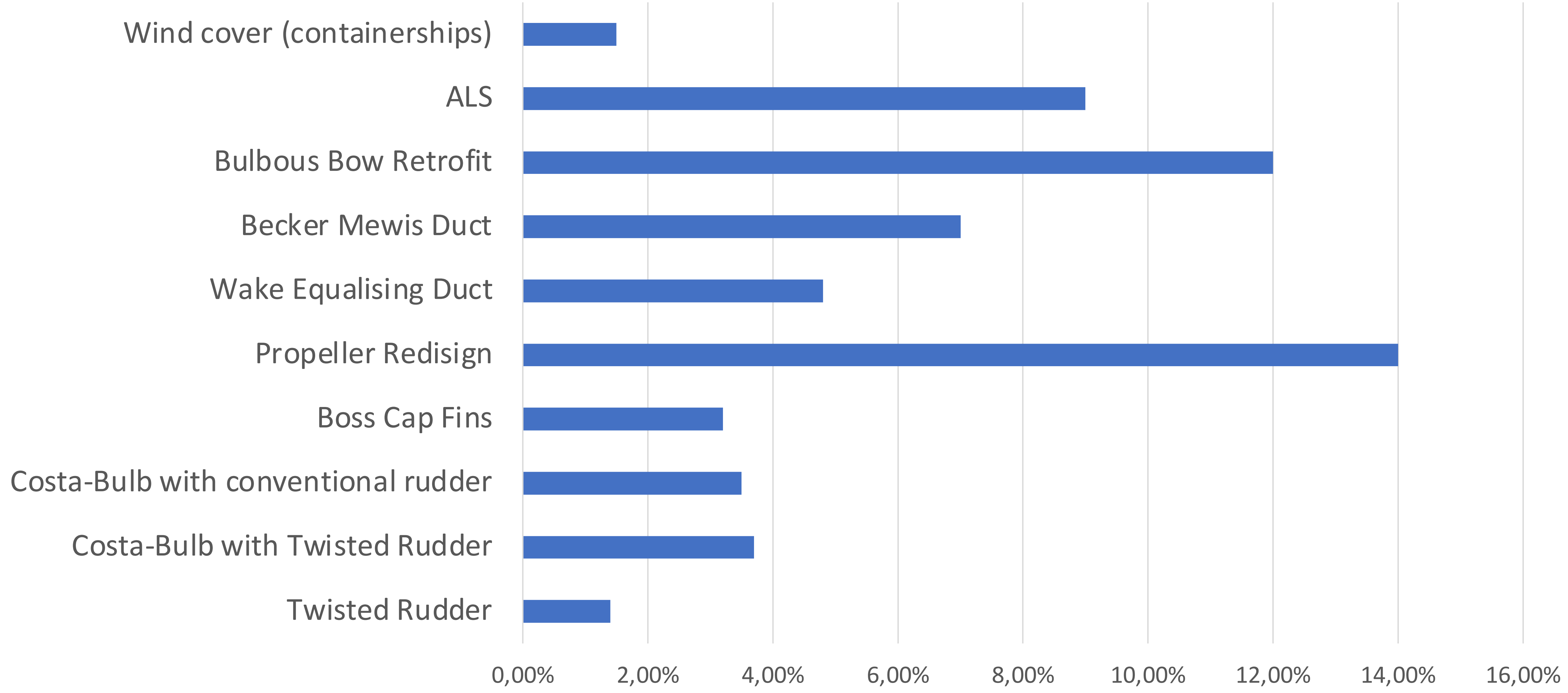
Hydrodynamics & Aerodynamics
Maximum power savings



Engine Part Load Optimization (De-rating)

From **2%** to **10%** CO_2 reduction

From design, the vessel engine and propeller are both designed and optimized for a given operational and maximum speed. If the vessel true speed is generally lower than originally optimized for, derating of the main engine and propeller may be considered. …not favored by engine makers

ROI = 2-3 years
6-7 mo project
<1 mo DD

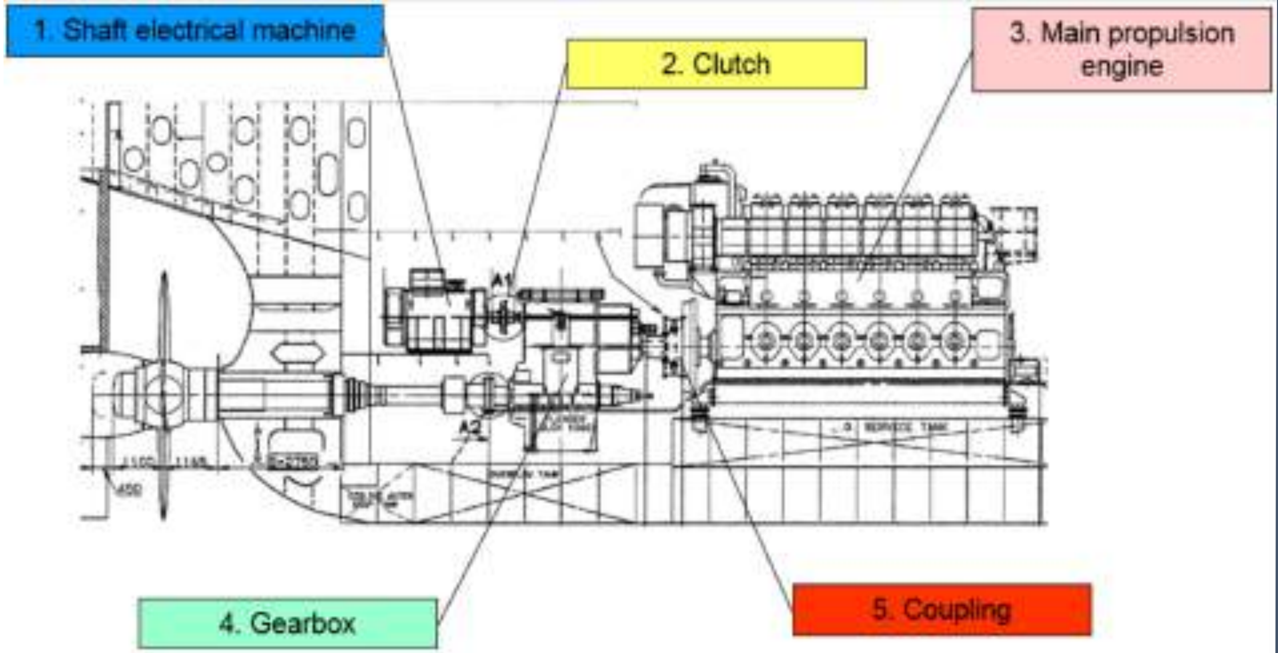
Part- and low load	**T/C Cut-Out**	Fuel savings up to 6 g/kWh	T/C Cut-out
	ECT	Fuel savings up to 3 g/kWh	Electric Turbo Compounding
	VTA (or VGT)	Fuel savings up to 5 g/kWh	Variable Turbine Angle
	EGB	Fuel savings up to 5 g/kWh	Exhaust Gas Bypass
	HPT	Fuel savings up to 5 g/kWh	High-pressure tuning
High load	**TCS-PTG**	Fuel savings up to 7 g/kWh	Turbo Compound Systems with Power Turbine and Generator

Shaft Generators (S/G)

Saves up to **20%** of original GE consumption

Improved efficiency for electricity generation (due to the higher efficiency of main engine compared to auxiliary ones). Decreased fuel, lubrication and maintenance costs

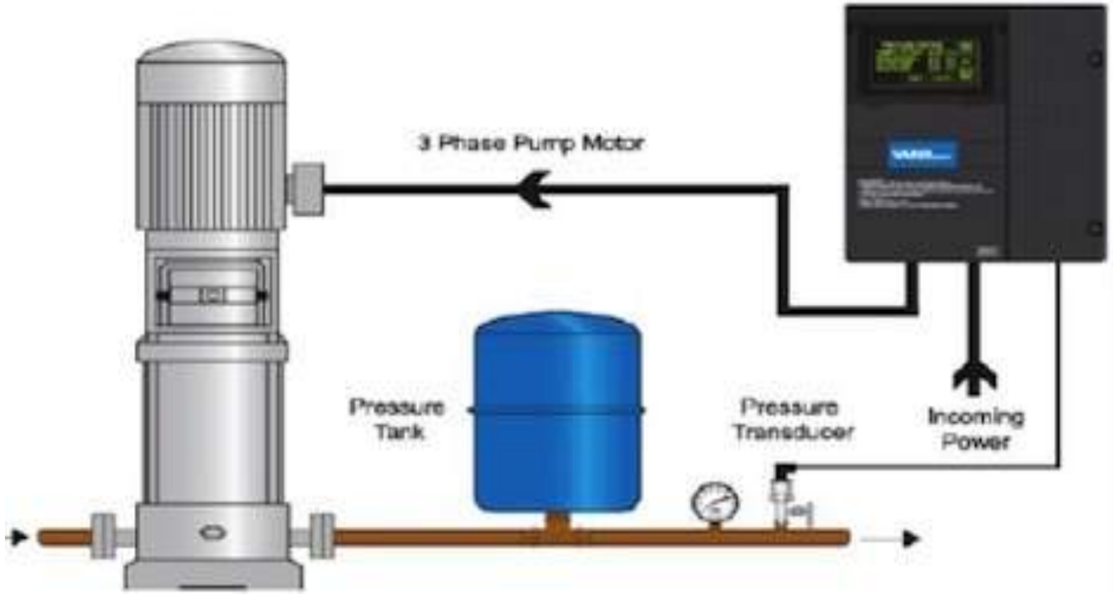
2 MONTHS RETROFIT
CAPEX = 3.5M$ - 4M$



VFD

Up to **1%** CO2 reduction

Fans and pumps often operate binarily, (either off or operating at full capacity). Instead these can be dynamically operated depending on the real requirements. *Applications e.x. cranes, winches, bow thrusters, ventilation, pumps, compressors, OW separators, S/G*

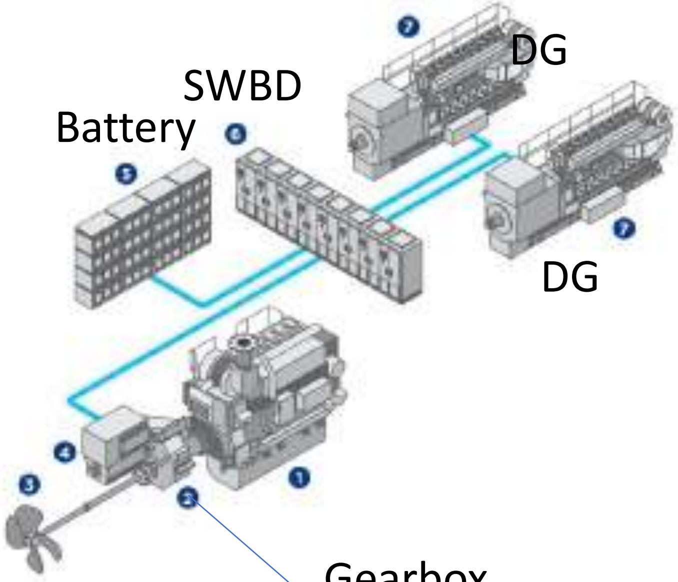


LED lighting (~1%)

Lighting systems	Lamp type	System power [kW]	Electrical energy consumption [kWh/year]
Existing lighting	FL	16.6	119 674
	IL	6.1	5 160
	MFL	21.3	90 034
	Total	44.1	214 868
LED lighting	LED	17.9	100 810

Batteries

Incorporating a battery as a "spinning reserve" ensures continuous operation with a single engine, maintaining redundancy and improving power generation efficiency during peak loads.



Shore Power AMP

California

Initial year	Vessel type
2023	Container, refrigerated cargo and passenger
2025	Roll-on roll-off
2025	Tanker (only LA & Long Beach)
2027	All Tankers

FuelEU

From 2030:
Containerships required to utilize cold ironing when at berth >2 hours in a TEN-T port.
From 2035:
In all AMP supported ports

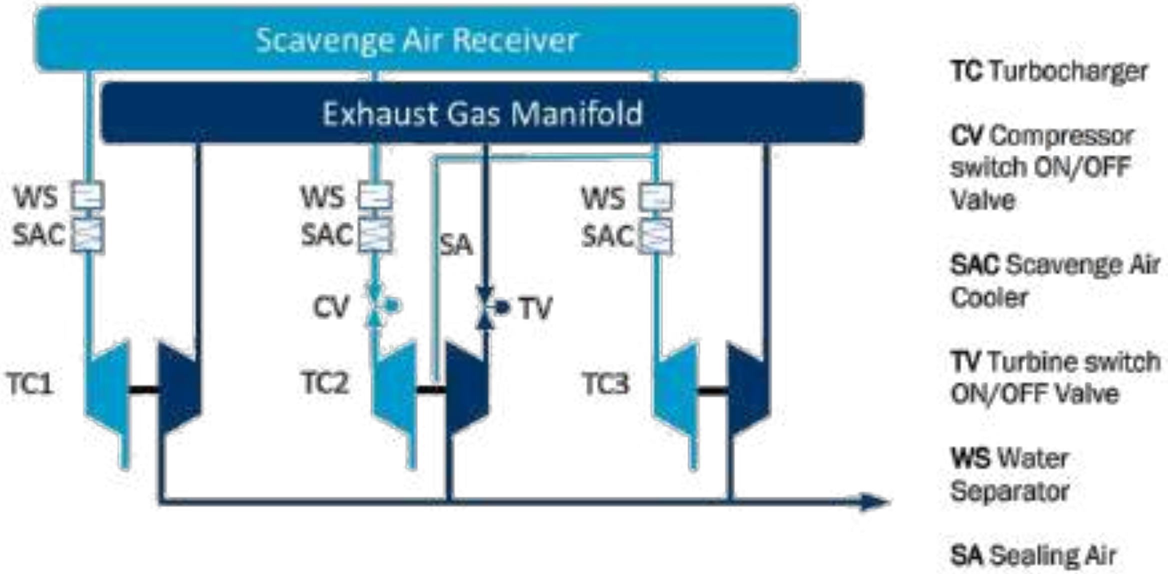
Main Engine Upgrades

- **PMI VIT** (Performance Measuring Indicator Variable Injection Timing), with 9% fuel savings.
- **PMI ACCo** (Performance Measuring Indicator Adaptive Cylinder Control) with fuel savings of 1 to 3.5 g/kWH
- **EcoCam** enables efficient slow steaming with operational flexibility for mechanical engines, with fuel savings of 2-6 g/kWh.
- **EcoNozzle** with fuel savings of 2 to 7 g/kWh.

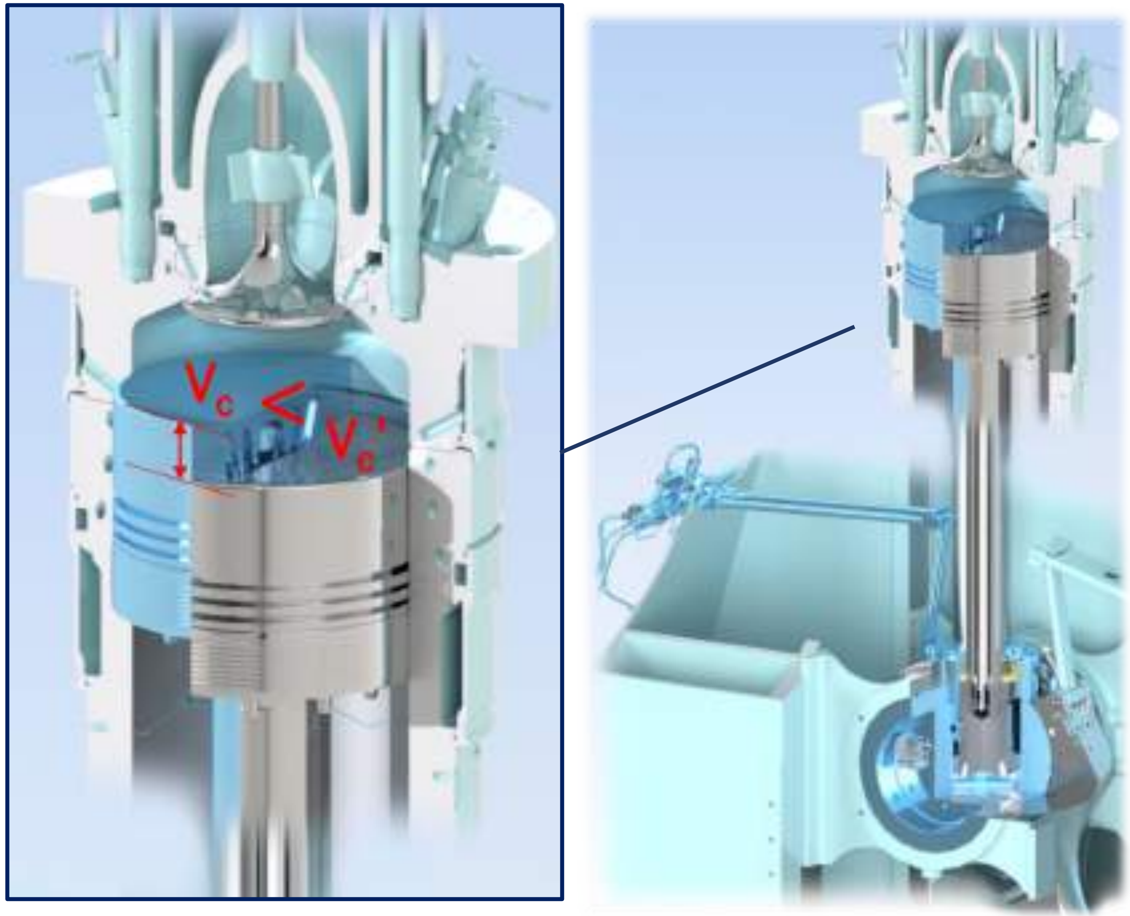
Main Engine Upgrades

WIN GD
Winterthur Gas & Diesel

- **aSTC** (automated Sequential Turbocharging) with fuel savings of up to 5 g/kWh at low engine load.
- Improved combustion efficiency by increasing the cylinder pressure, increasing compression ratio and optimized fuel injection an exhaust valve closing timing



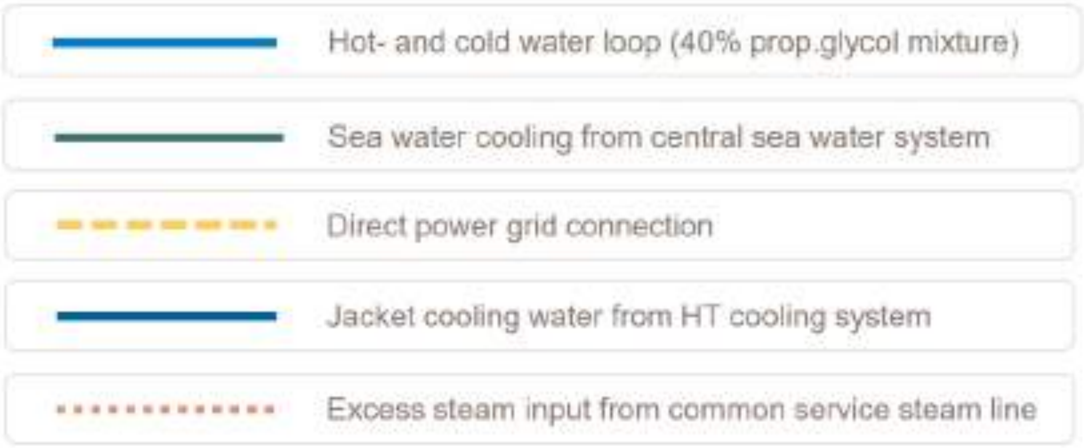
- **VCR** (Variable Compression Ratio) with fuel savings up to 6 g/kWH (for Gas Mode) and 8-12 g/kWh (for Diesel Mode).



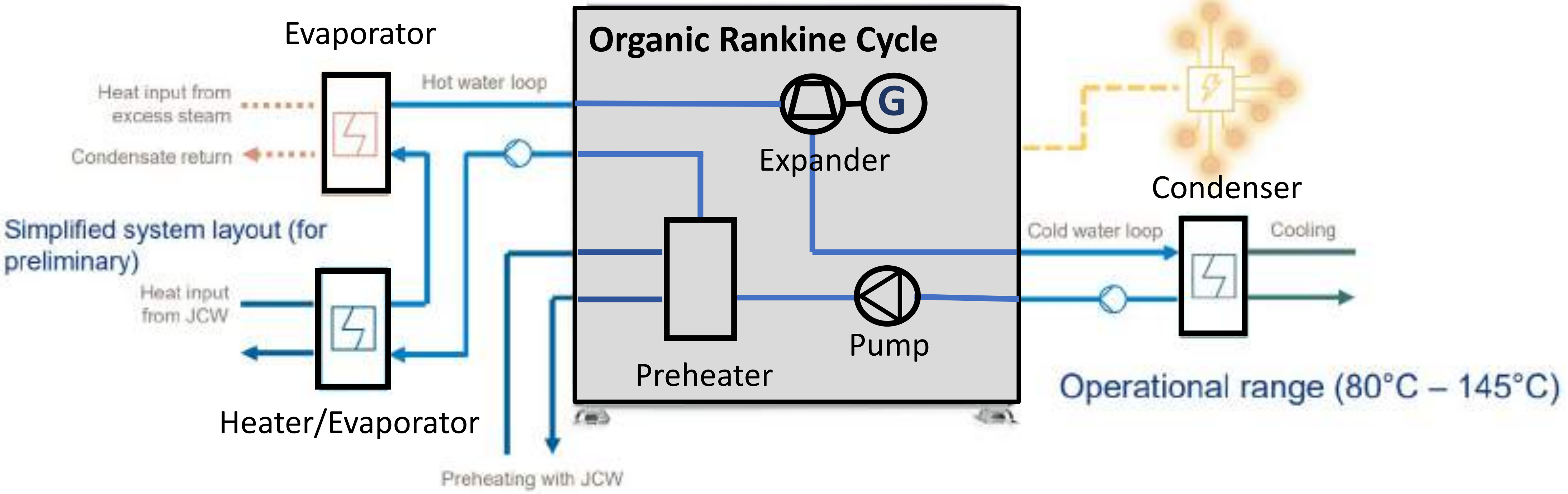
Waste Heat Recovery (WHR)

Up to 500 KW electrical power with no CO_2 generation

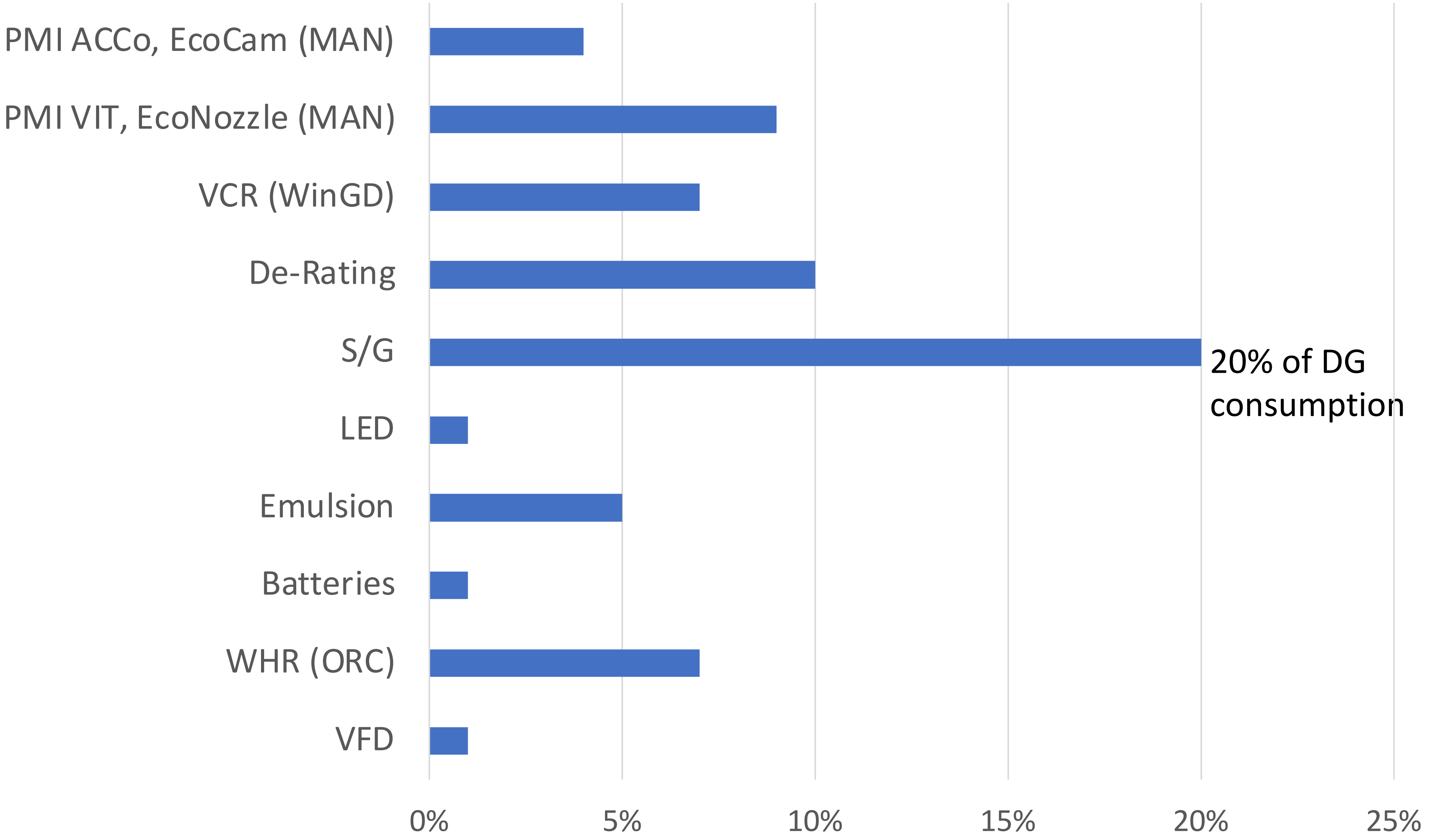
Converting an engine's excess thermal energy into electrical power. This can be achieved by an Organic Rankine Cycle (with working fluid ex. 40% prop. Glycol mixture). The electricity is automatically fed into the ship's grid, reducing demand on the auxiliary engines, so CO_2 ⬇.



*It can also utilize flue gas wasted heat



Machinery Upgrades: Maximum power savings



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LNG Carriers : RE-Liquefaction

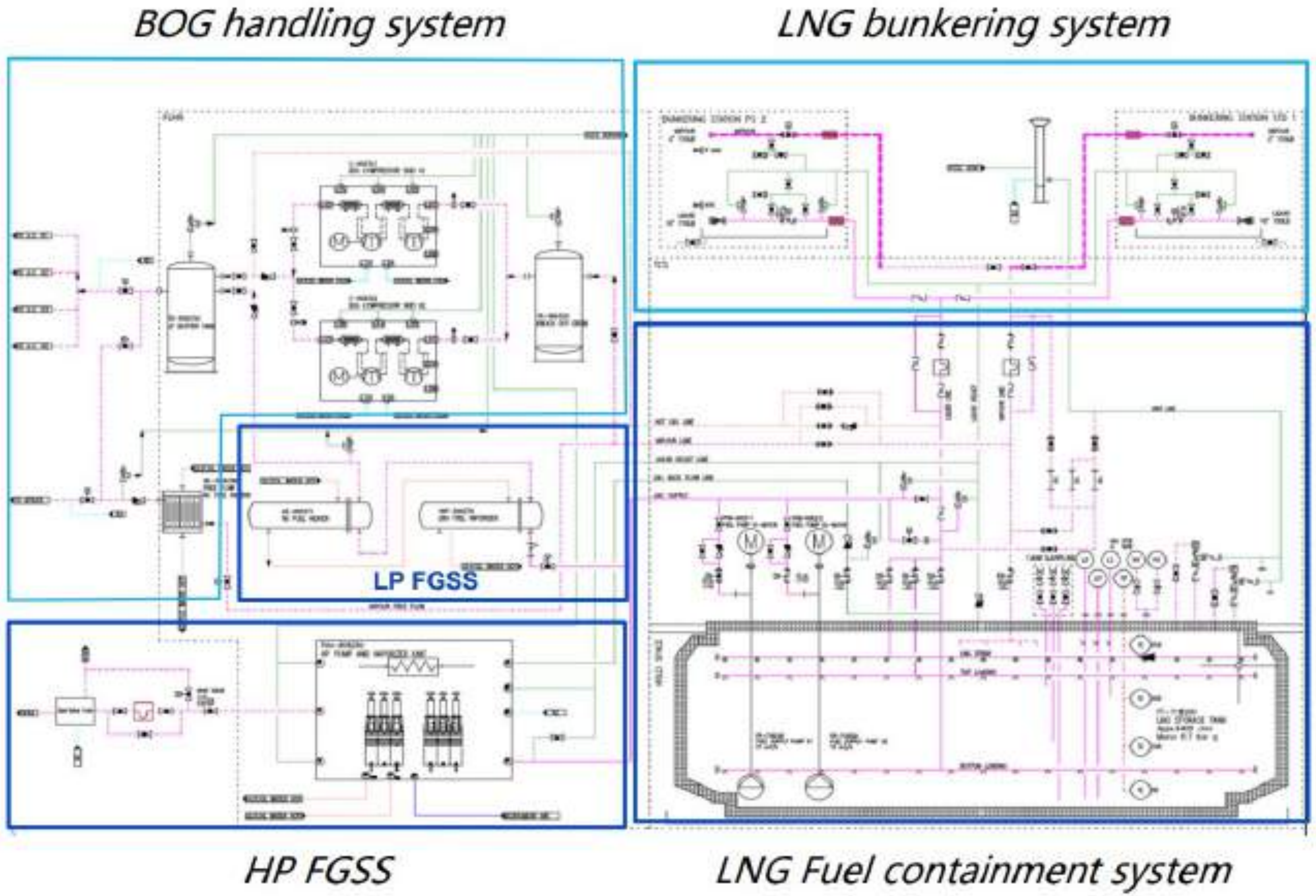
- Payback of abt. 4 years
- <2 mo DD & gas trials

Trend → Re-liquefaction & ALS retrofit

• All the natural BOG generated from cargo tanks is used as fuel due to low propulsion efficiency.

• The need for re-liquefaction and surplus gas management is low.

LNG Carriers : RE-Liquefaction

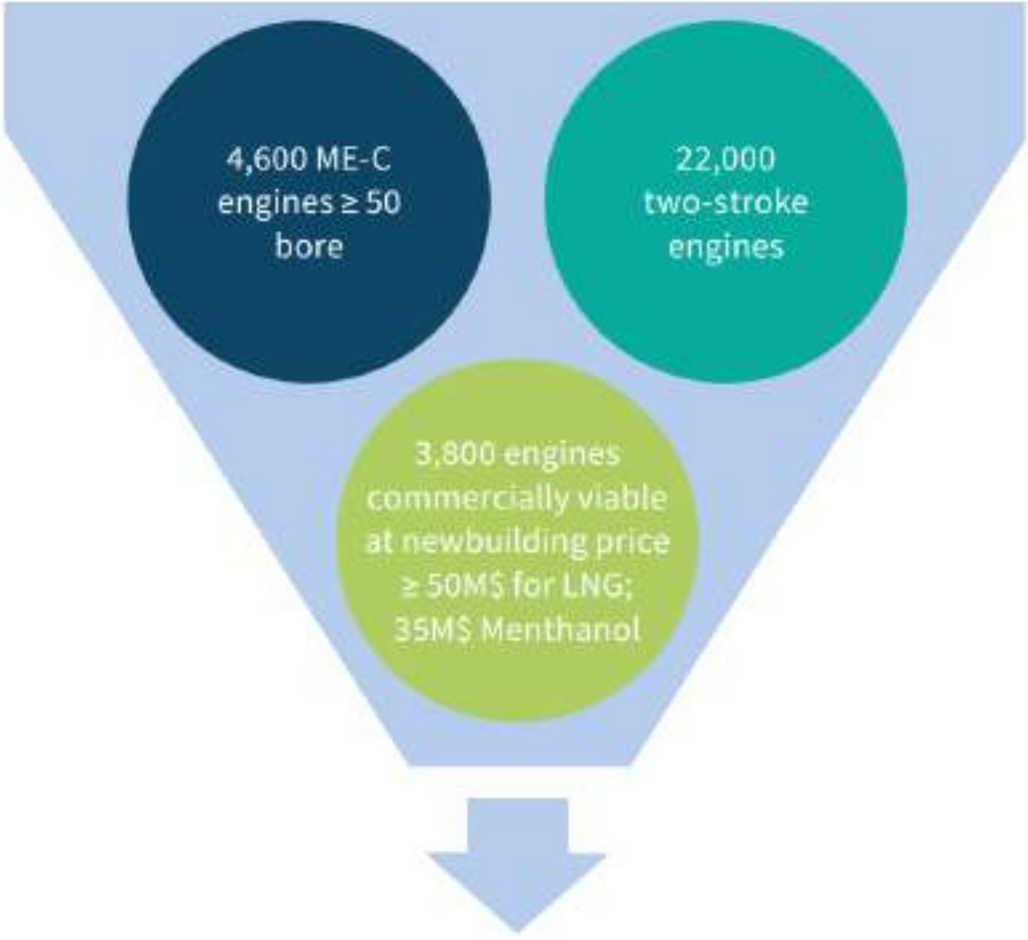


Compliance Solutions

VESSEL AGE	GREEN SOLUTIONS	CII IMPROVEMENT	CAPEX
Under 5 Year	DF Conversion / CCS	HIGH	HIGH
Under 10 Year	Re-liquefaction/ ALS / Rotor Sail / Shaft Generator	MEDIUM	MEDIUM
No Limit	PBCF / Pre Swirl Duct / Bulbous Bow / Propeller Retrofit / Wind Cover / VFD / LED / WHRS / MSS / Coatings	LOW - MEDIUM	LOW

[HMI]

Older ships will not live to experience the final regulations. So, for them it is more profitable to stick to the ESD technologies (discussed so far), achieving 3% - 15% GHG reductions. In contrast **newbuilding and younger ships** will experience the final stage of the regulations, so for them the alternative fuels and Carbon Capture are also considered.



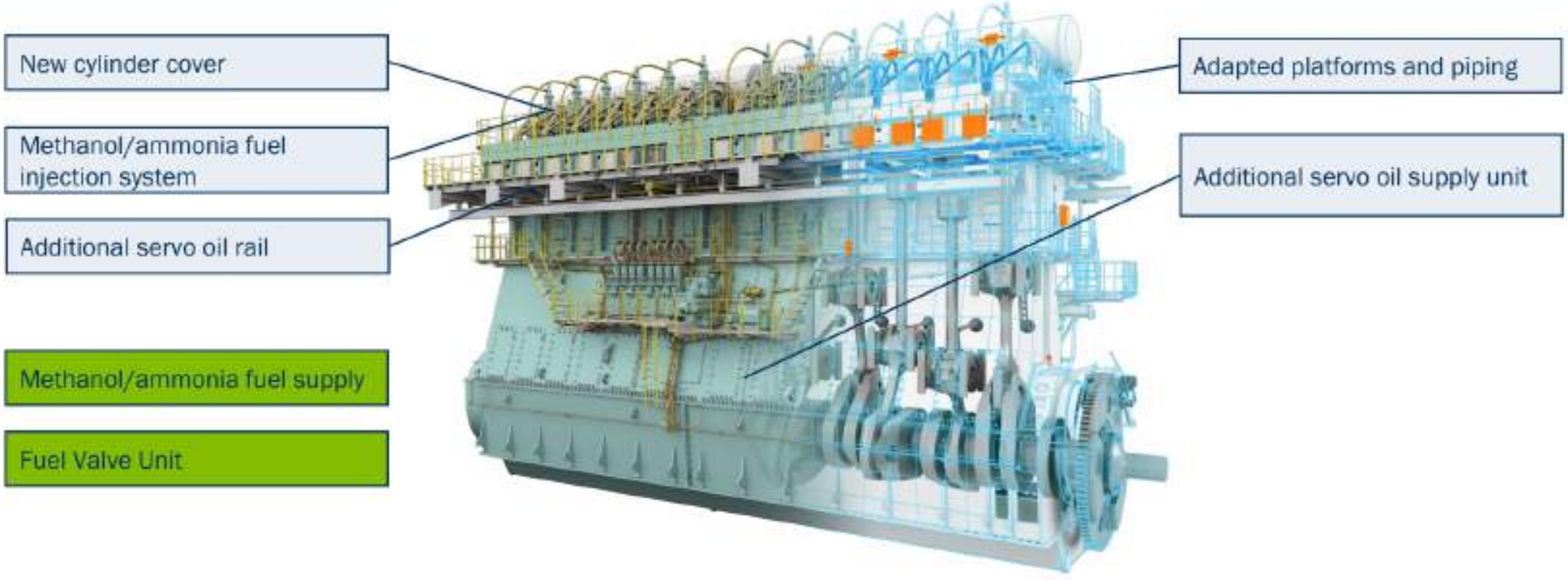
2,500 engines
with matching parent engine test in alternative fuel version!

Dual Fuel (DF) Engines vs Conventional

<u>Concept</u>: conventional diesel engine basis with additional methanol/ ammonia injection system

What changes when burning alternative fuels?
In order to burn alternative fuels (LNG, LPG, MeOH, Ammonia) for marine propulsion, a conventional diesel engine can be used with modifications in the **fuel injection and supply system.**

Ex. below WinGD DF engine differences from conventional:



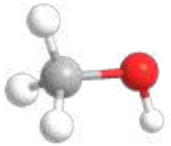
Engine Technology readiness

Alternative fuel / DF Combustion Engines

Key issues to be solved:

LNG: in service

- Methane slip



Methanol: in service since 2016

- No substantial WtW reduction if it is grey methanol

Ammonia: still in research level, but now moving faster

Expected NB engines ~ 2025
Expected retrofits ~ 2026-27

- **Banned from certain Ports!**
- Safety aspects
- Regulatory gaps
- No IMO requirements (only class)
- N20 emissions (Ammonia slip)
- Crew training & maintenance

Hydrogen: still in research level

7 Mar 2024: World-First Hydrogen Test! on a marine two-stroke engine

- Safety aspects, Regulatory gaps
- Hydrogen leakage
- No IMO requirements (class recently)
- Unburn H2 → GHG (Hydrogen slip)
- Crew training & maintenance

Engine Technology readiness

Other alternative fuels:

Key issues to be solved:

b **Biofuels**: in service →

- No technical issues
- Allowed only up to 30% of HFO

s **Synthetic fuels :** still in research level →

- No serious technical issues
- Still under development

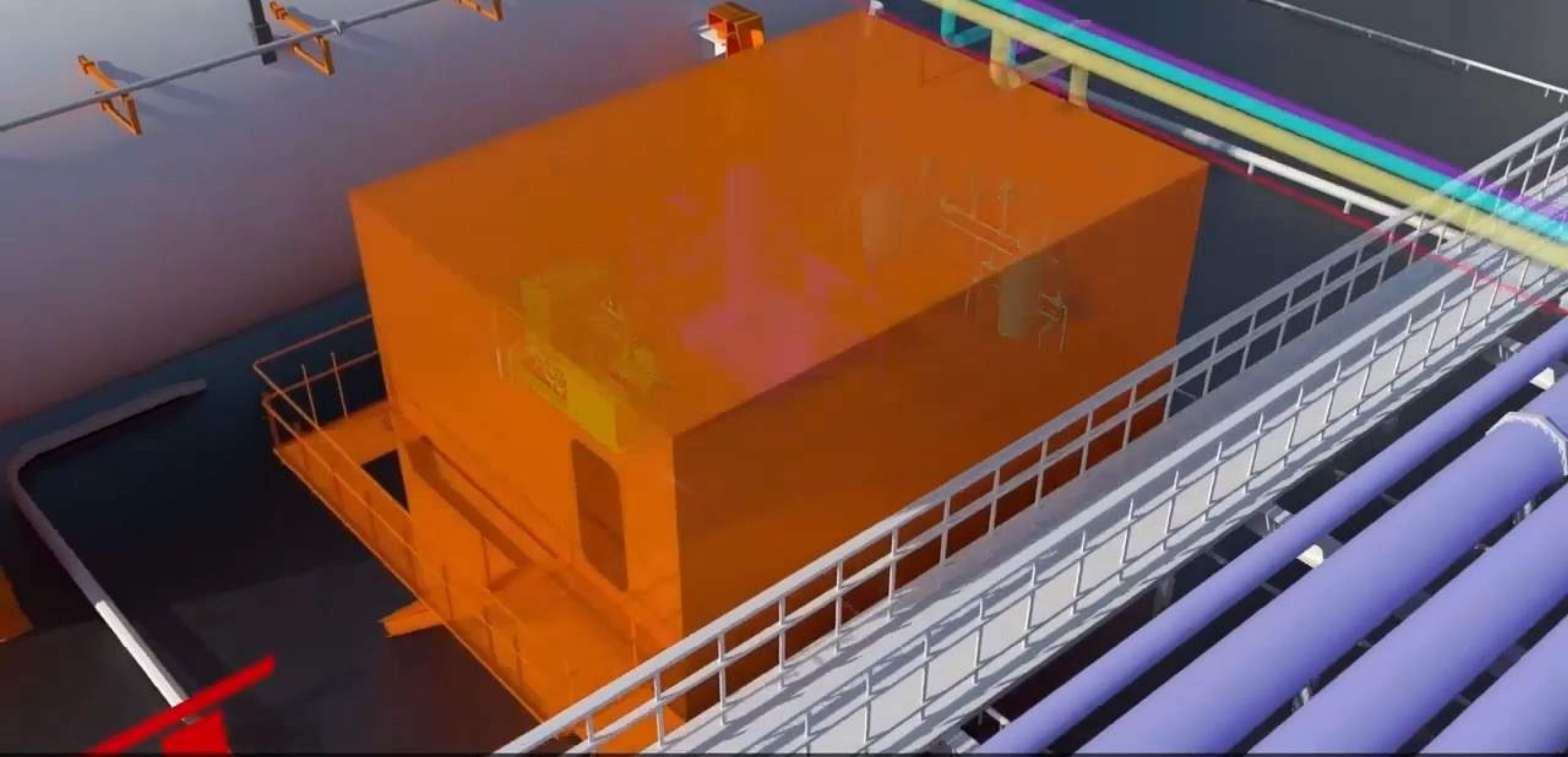
Synthetic fuel is a generic term applied to any manufactured fuel with the approximate composition and comparable specific energy of a natural fuel.

W **WCO Biofuel :** Waste cooking oil (WCO) is a food waste generated domestically and industrially as a result of cooking and frying food using edible vegetable oil.

e **Electrofuels (eFuels) :** Electrofuels are advanced gaseous and liquid fuels normally produced from hydrogen and often captured carbon dioxide (CO2)

p **Pyrolysis oil**, **(bio-crude) :** is a synthetic fuel. It is obtained by heating dried biomass without oxygen in a reactor at a temperature of about 500 °C with subsequent cooling, separation from the aqueous phase and other processes.

Hv **Hydrotreated vegetable oil (HVO) :**is a biofuel made by the hydrocracking or hydrogenation of vegetable oil.



At the same time, the production of FGSS packages also begins
which takes **abt. 36 weeks** for completion and delivery to the work site.

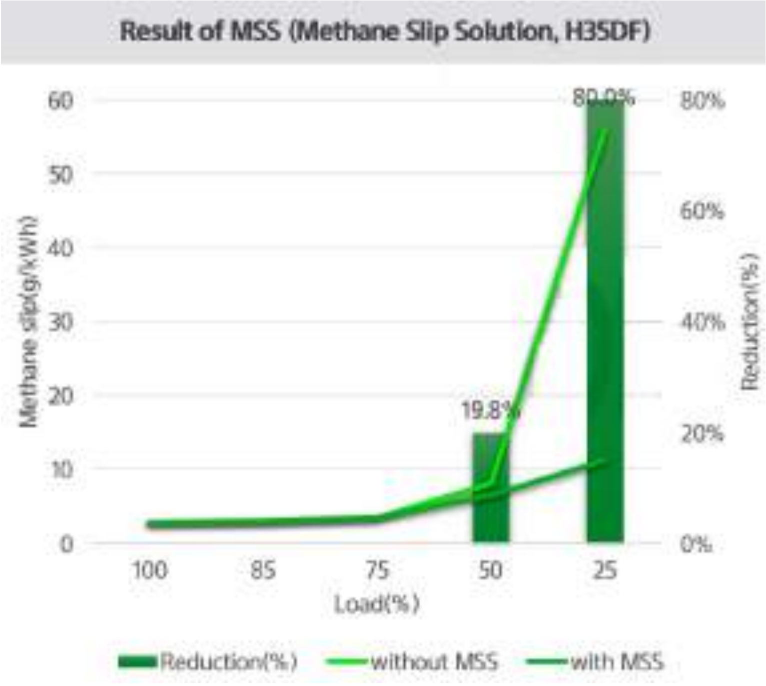
Engine load ↓
MS rate ↑

LNG conversion: **Methane slip**

EU ETS included by 2026

Methane is an extremely powerful GHG. Methane slip (MS) can potentially offset the climate benefits of LNG if not addressed.

LNG consists 90% methane
Some of the methane remains unburned and escapes into the atmosphere because of flame quenching and scavenging losses



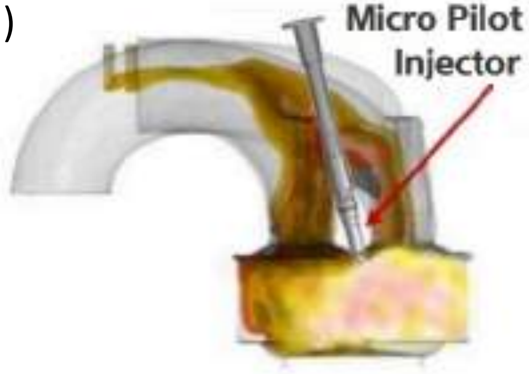
Cylinder Cut-Off (CCO)

Possible solutions (CCO need no physical installations) :

Engine Gas Recirculation (EGR)

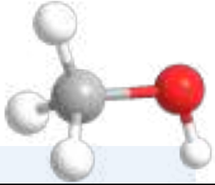
Reduction methane slip by ~ 45 %

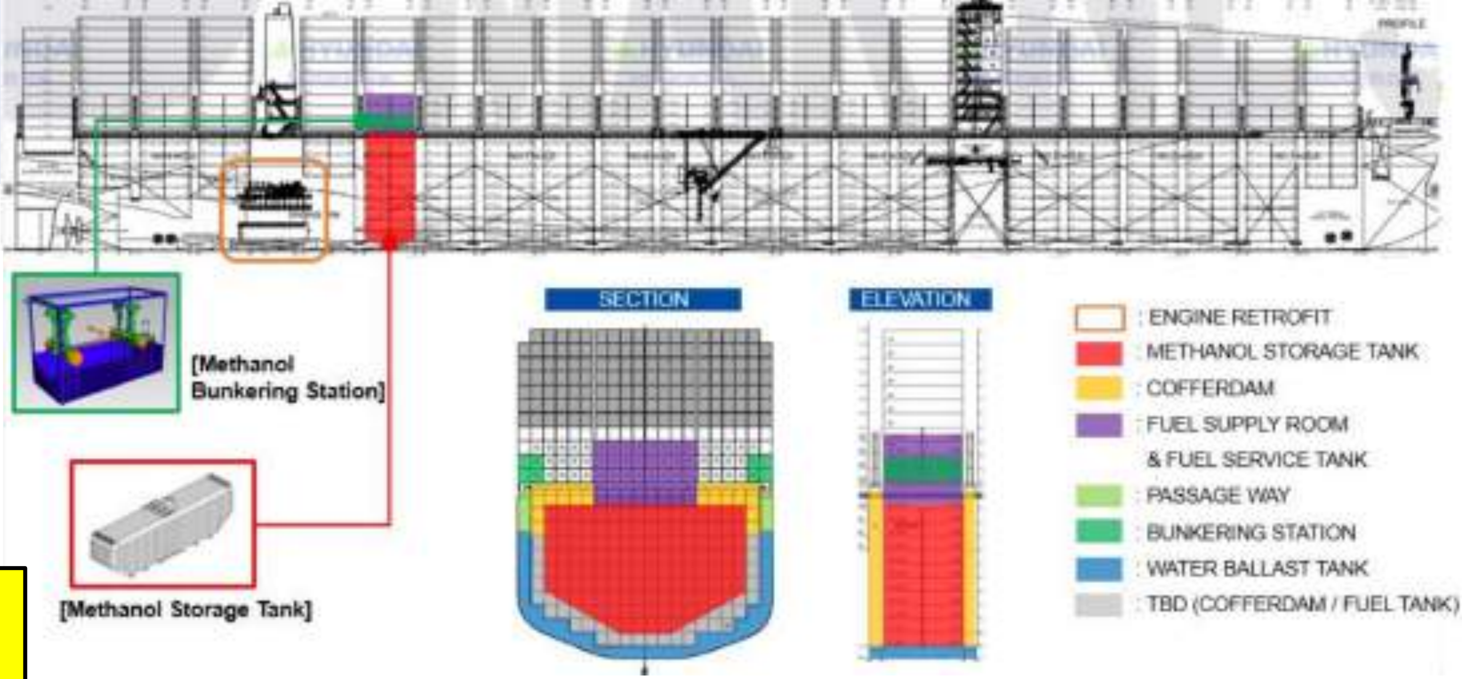
Multi Pilot Injection (MPI)



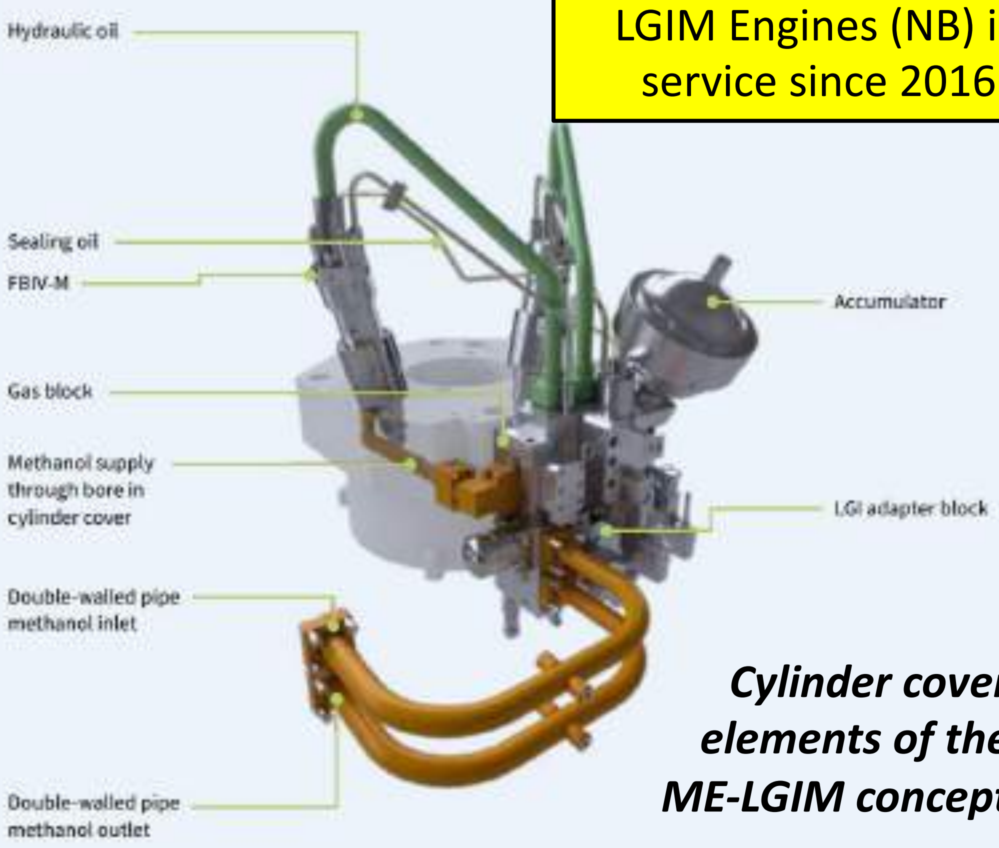
Methanol conversion

- Possible to convert from the existing ME-C type Engine to ME-LGIM
- Added / Replaced LGIM components and the counter parts
- 2 months DD



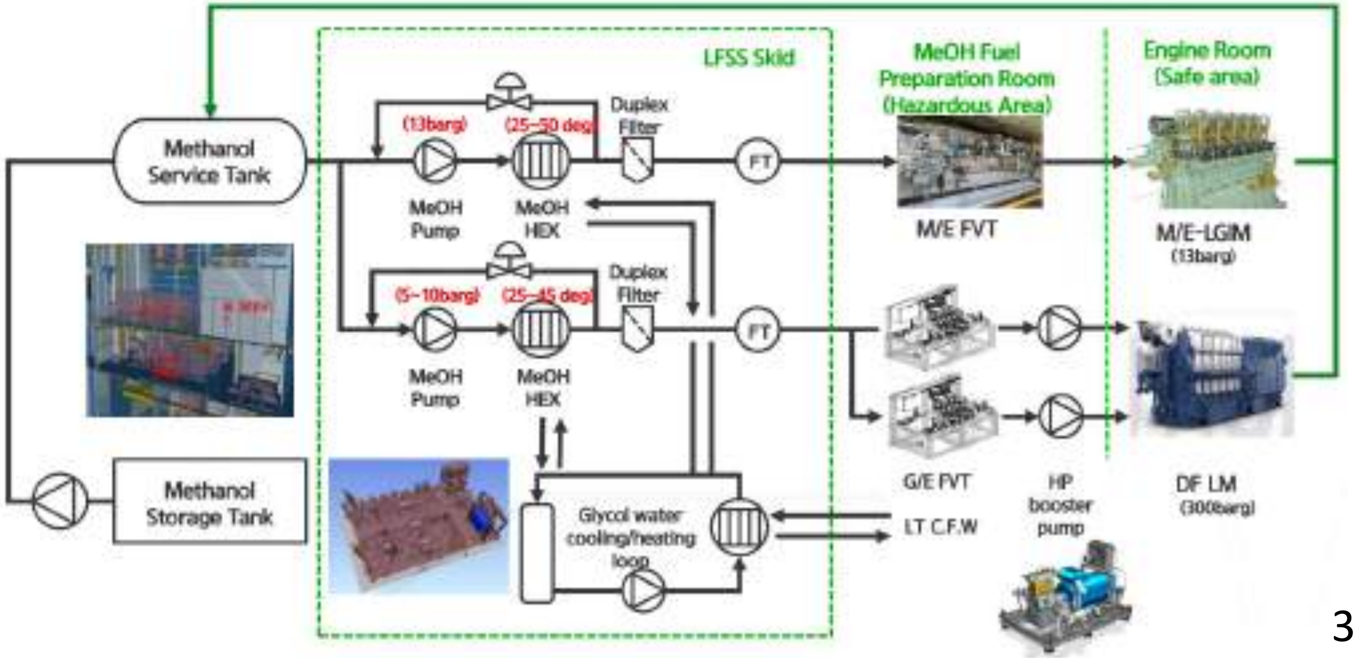


LGIM Engines (NB) in service since 2016

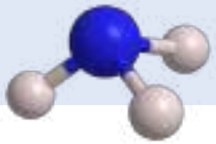


Cylinder cover elements of the ME-LGIM concept

Methanol Fuel Supply System typical configuration:



Ammonia conversion



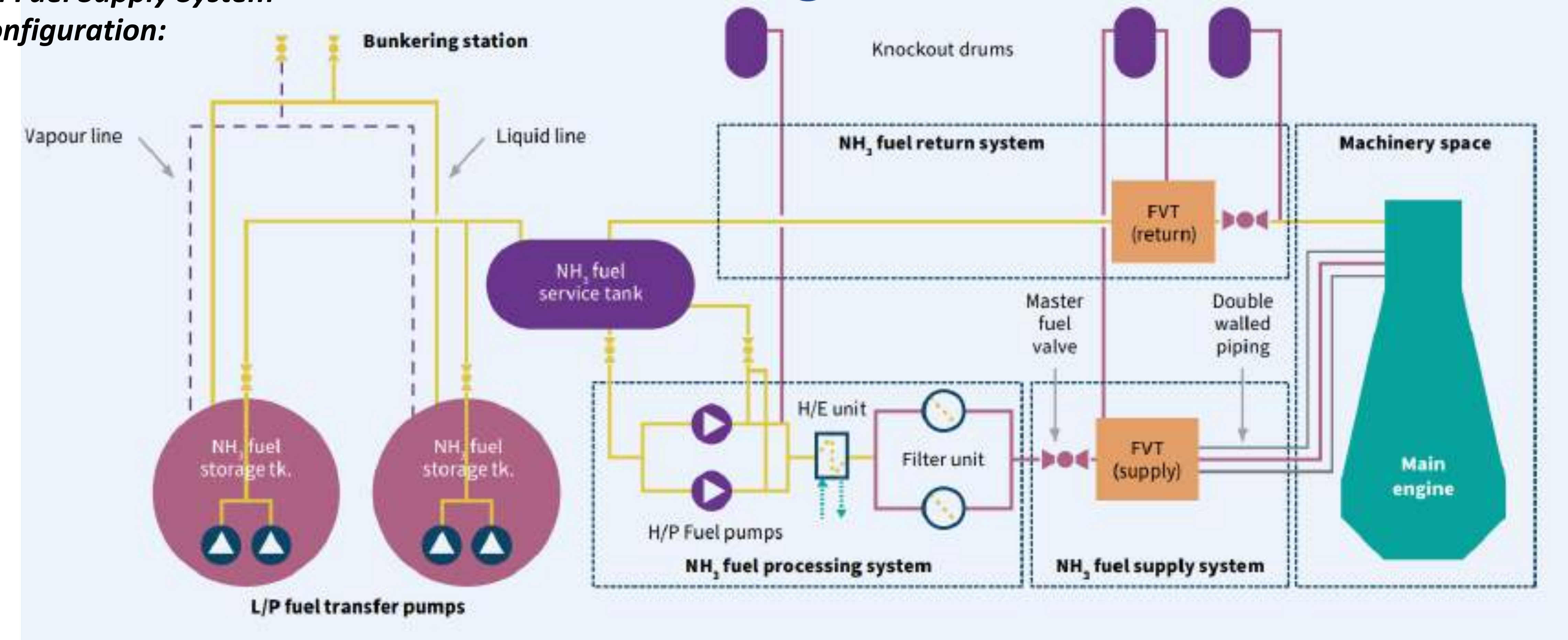
Engine still in research level…
Expected NB engines ~ 2025
Expected retrofits ~ 2026-27

Inert gas
Vapour
purging

ISSUES TO OVERCOME…

- Safety aspects
- Regulatory gaps
- No IMO requirements (only class)
- N20 emissions (Ammonia slip)
- Crew training & maintenance

Ammonia Fuel Supply System typical configuration:



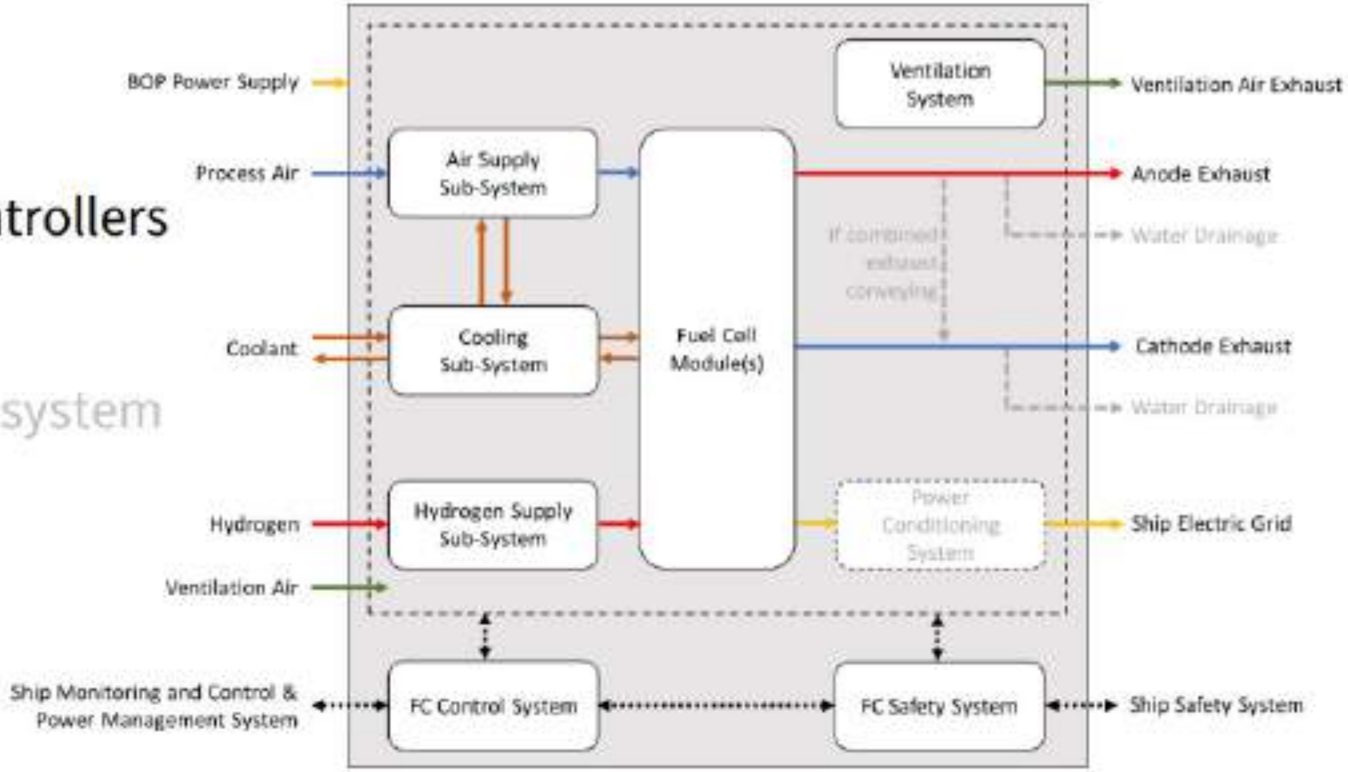
Fuel Cells

Marine Fuel Cell Systems

Official term in the rules: Fuel Cell Power System

- Self-controlled unit, containing
  - ➢ FC module(s)
  - ➢ BOP sub-systems
  - ➢ System & Safety controllers
  - ➢ Ventilation system
  - ➢ Power conditioning system
- Power Range
  - ➢ 100 – 500 kW

Example: Power Cell's 200kW Marine System[1]



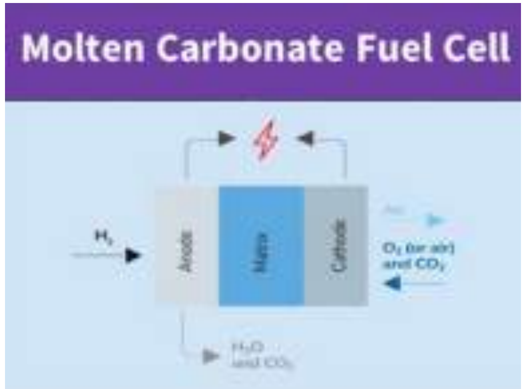
Fuel cell power system schematic including sub-systems

Nuclear propulsion

Hurdles to be overcome:

- IMO resolution to allow nuclear ships to trade in port
- Proof of concept (technical and safety issues)
- Commercial employment of the ships
- Leasing of the reactor
- Lifetime supply of nuclear fuel
- Exchange of the reactor enrichment of the fuel when depleted
- Provision of nuclear reactor operators by the reactor manufacturers
- Back to steam for the engineers of the ships
- Control of operating costs

Onboard Carbon Capture Sys (OCCS)



Chemical Adsorption: CO2 in Exhaust absorbed by chemical solvent

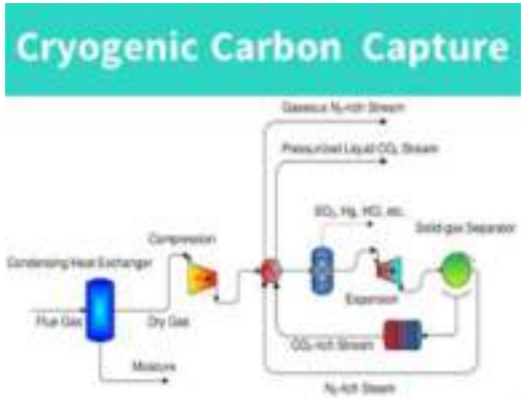
Calcium Looping: The process consists of two main cycles: an air contractor (CO2 capture cycle) and a sorbent regeneration cycle

Membrane Technology: Selective permeation of gases in exhaust through membrane

Cryogenic Carbon Capture: CO2 in exhaust cryogenically cooled with other components separated

Molten Carbonate Fuel Cells: MCFC can operate as a CO2 separator and concentrator while generating power

Pre–Combustion Carbon Capture: The process primarily focuses on methane cracking , capture of carbon in solid form and use of the deriving hydrogen in combustion blending or fuel cells



What are soft skills?

Soft skills are personal attributes that enable an individual to interact effectively with others in a social framework.

- Depend on personality traits.
- Although always existing, they were defined and studied by the western societies from the late 1950’s and onwards.
- Became a “fashion” in the corporate world over the past 20 years.
- Applicable to all professions.
- Developed by the interaction with others.
- Not easily quantifiable.
- Influence the culture.

Pericles's Funeral Oration by Philipp Foltz (1852)

What are soft skills?

Examples of soft skills

Communication	Teamwork	Decision making	Time management	Stress management
Adaptability	Leadership	Persuasion	Openness to critisism	Resilience

What are hard skills?

Hard skills are part of the skillset that an individual is required to have for accomplishing specific tasks.

- Have been the foundation of human societies since the dawn of civilization.
- Crafts and arts.
- Create added value.
- Concrete professional skills.
- Quantifiable.
- Acquired through academic studies or on the job training.
- Require considerable effort.

"The Hunters in the Snow" by Pieter Bruegel the Elder (1565)

What are hard skills?

Examples of hard skills

- Engineering and manufacturing
- Finance and Accounting
- Healthcare and Medical Diagnosis
- Familiarization with new technologies
- Crafts and Arts
- Legal
- Handling and usage of new fuels
- Artificial Intelligence / Machine Learning
- Digitalization
- Computer coding

Soft and hard skills in maritime

- In a world where technological breakthrough tends to take over and automate most of the processes, eliminating the inevitable human error, hard skills seem to gain some ground over soft skills.
- Quoting Stephen Hawking's word, *"The rise of powerful AI will be either the best, or the worst thing, ever to happen to humanity".* In this respect, the need of deep understanding and effectively controlling the new technologies is evident, which compose some of the basic hard skills.

- In shipping, seafarers are required to keep up with the rapid technological growth and develop specific hard skills enabling them to effectively handle and use the newly introduced fuels, operate advanced equipment and ensure the smooth operation of a ship that looks less and less like the traditional ship that they are familiar with.
- Life at sea requires a set of soft skills as well.

Soft and hard skills in maritime

- AI’s effectiveness in accomplishing a task is not affected by how empathetically or compassionately you assign it.
- Decision making is automated in a future of a well-established digitalization.
- However, soft skills are important as well. Effective human communication, critical thinking and leadership will be the ingredients for a brighter future.

Conclusions Soft and hard skills in maritime

Hard skills

Hard skills are the tools that will enable us to understand and master the technology for the benefit of our society. Indeed, the younger generations need to focus on the development of their hard skills, so as to remain competent and relevant.

Soft skills

Soft skills will act as the “governor” that will safeguard the ethical and sensible use of technology.

Thank you
감사합니다