Fuel cell integrated energy systems for maritime application

Dr. Dibyendu Roy

25th June 2025

Introduction

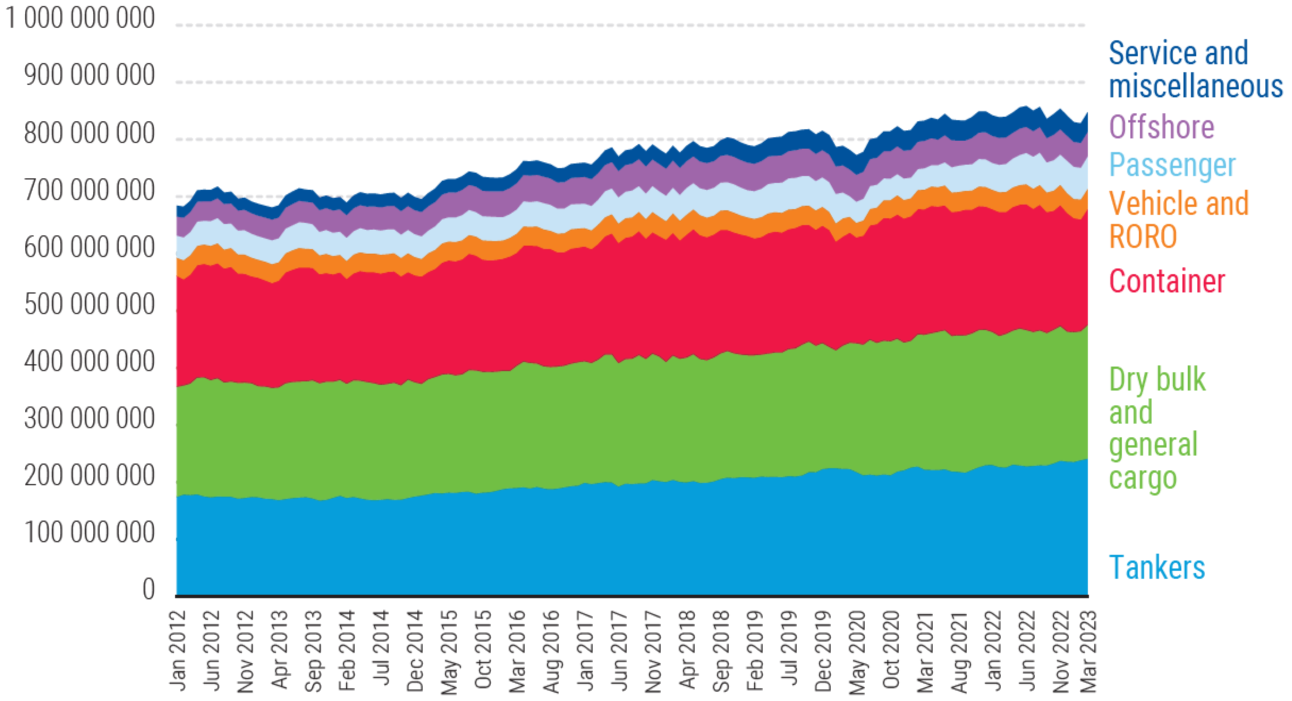
🌍 Maritime transport **accounts for ~3% of global CO_2 emissions**.

🏛 IMO (International Maritime Organization) **targets net-zero emissions by 2050**.

🔥 **Traditional ship propulsion = significant CO_2 emissions.**

🔬 **Need for innovative energy systems to reduce maritime carbon footprint.**

⚡ **Fuel cells as a dual solution: Power generation & emission reduction.**



Total carbon dioxide emissions by vessel types, tons, January 2012—March 2023

Source: UNCTAD, based on data provided by Marine Benchmark, July 2023.

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What are fuel cells?

⚡ Fuel cells convert chemical energy into electricity.

Types of fuel cell: Low temperature (PEMFC) and High temperature (SOFC, MCFC)

🔬 Types investigated for maritime applications:

1. **MCFC (Molten Carbonate Fuel Cell)** – Operates at high temperature, integrates CO_2 capture.

2. **SOFC (Solid Oxide Fuel Cell)** – Operates at high temperature, enhances system efficiency.

✅ **Advantages over traditional marine engines:**

💡 **Higher efficiency**

🌱 **Lower emissions** (less NOx, SOx, and CO_2).

🚢 **Scalable** for various ship sizes.

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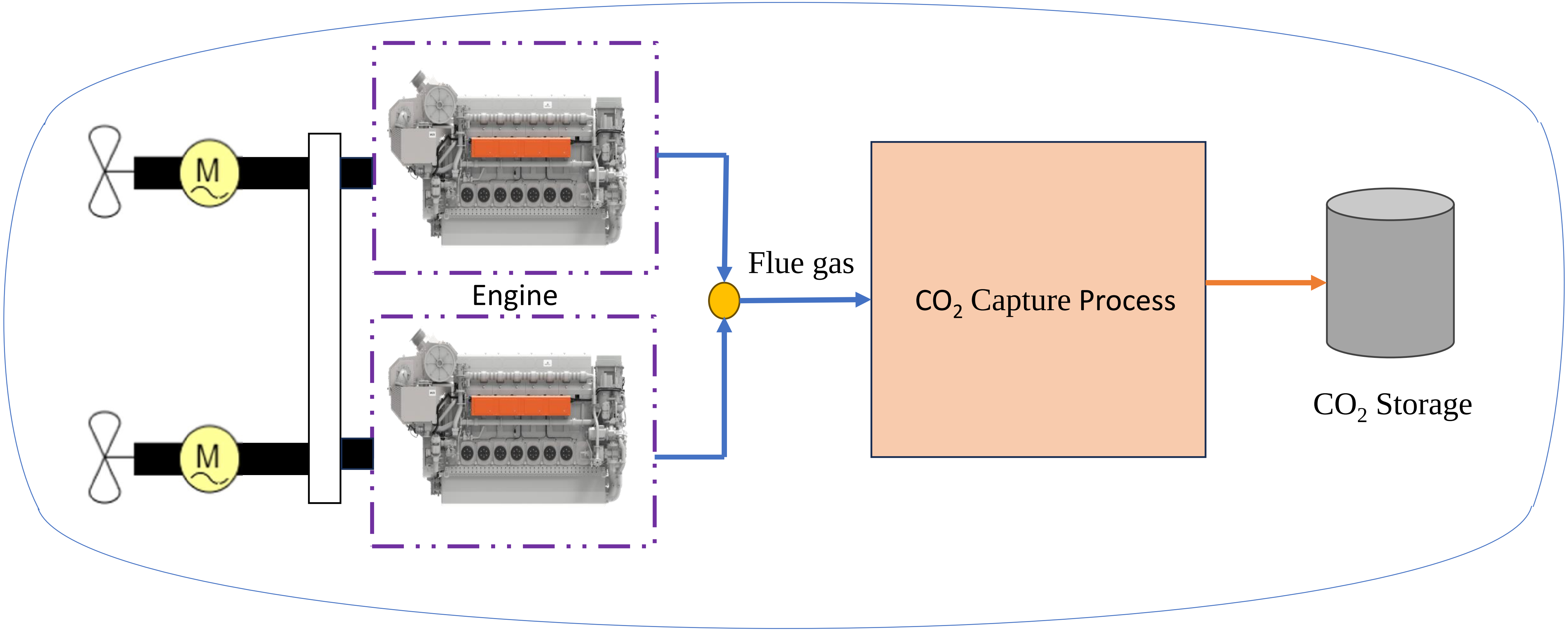
Onboard CO_2 capture on a ship



Exhaust gas → CO_2 separation → Liquefaction → Onboard storage.

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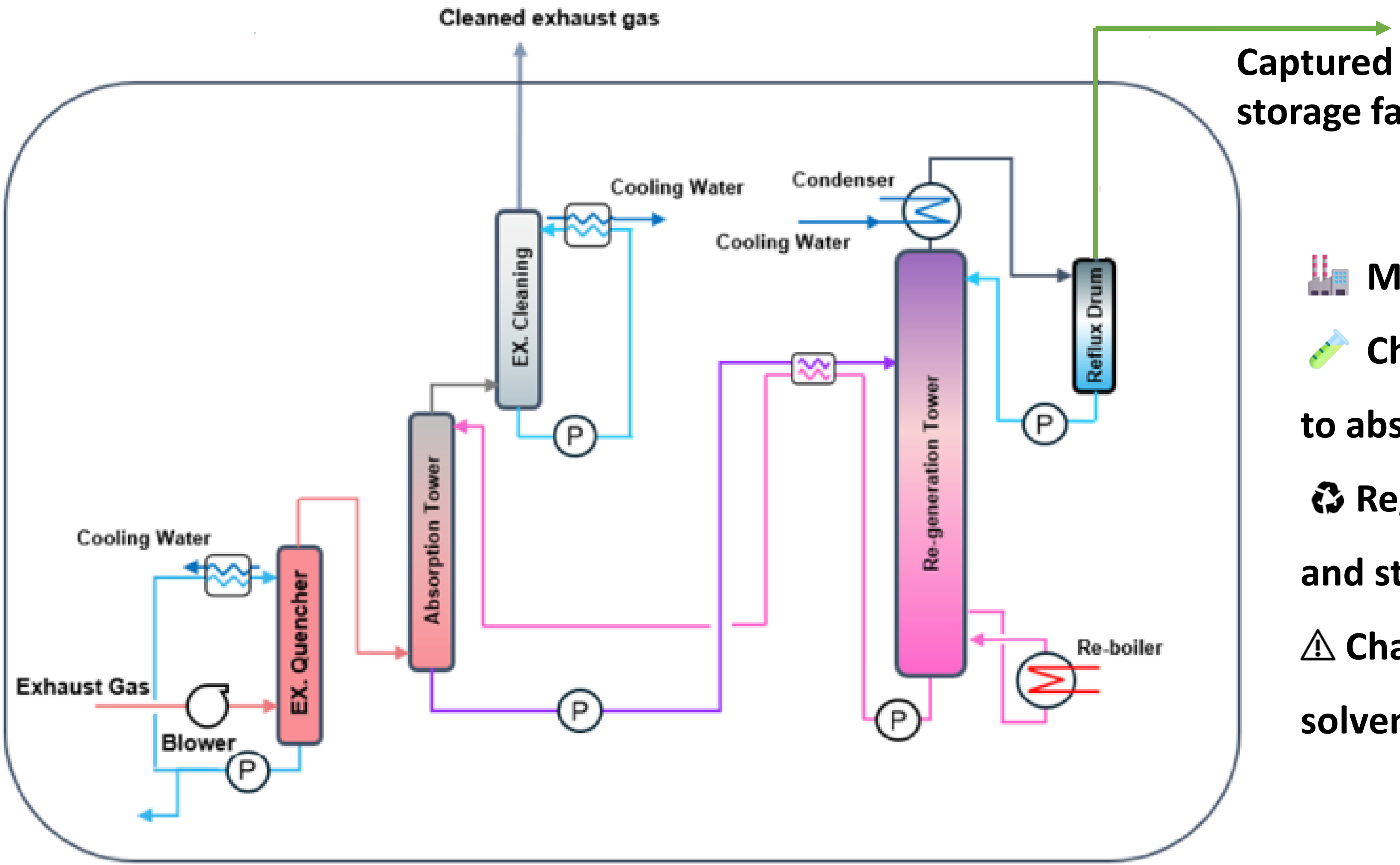
Amine based CO_2 capture process



Captured CO_2 supplied to liquefaction and storage facility

Amine based post-combustion CO_2 capture

- 🏭 Most common CCS method.
- 🧪 Chemical process using amine solvents to absorb CO_2.
- ♻️ Regeneration & storage: CO_2 released and stored onboard.
- ⚠️ Challenges: High energy consumption & solvent degradation.

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How does MCFC operate?

🔬 MCFC generates power + concentrates CO_2 from exhaust.

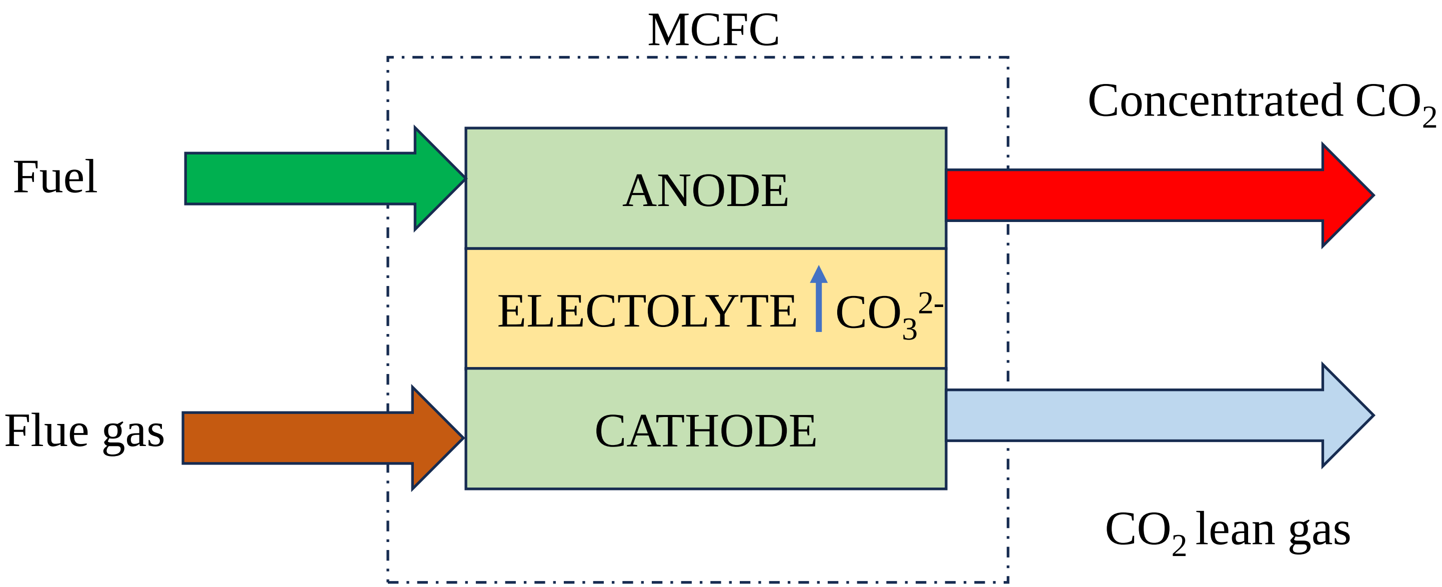
🔥 Uses carbonate ions (CO_3^{2-}) for electrochemical reaction.

🌡 Operates at 600–700°C → integrates well with ship exhaust.

✅ Dual benefits:

•**Electricity generation** for power.

•**CO_2 capture capability** integrated into the process.



Molten carbonate fuel cell

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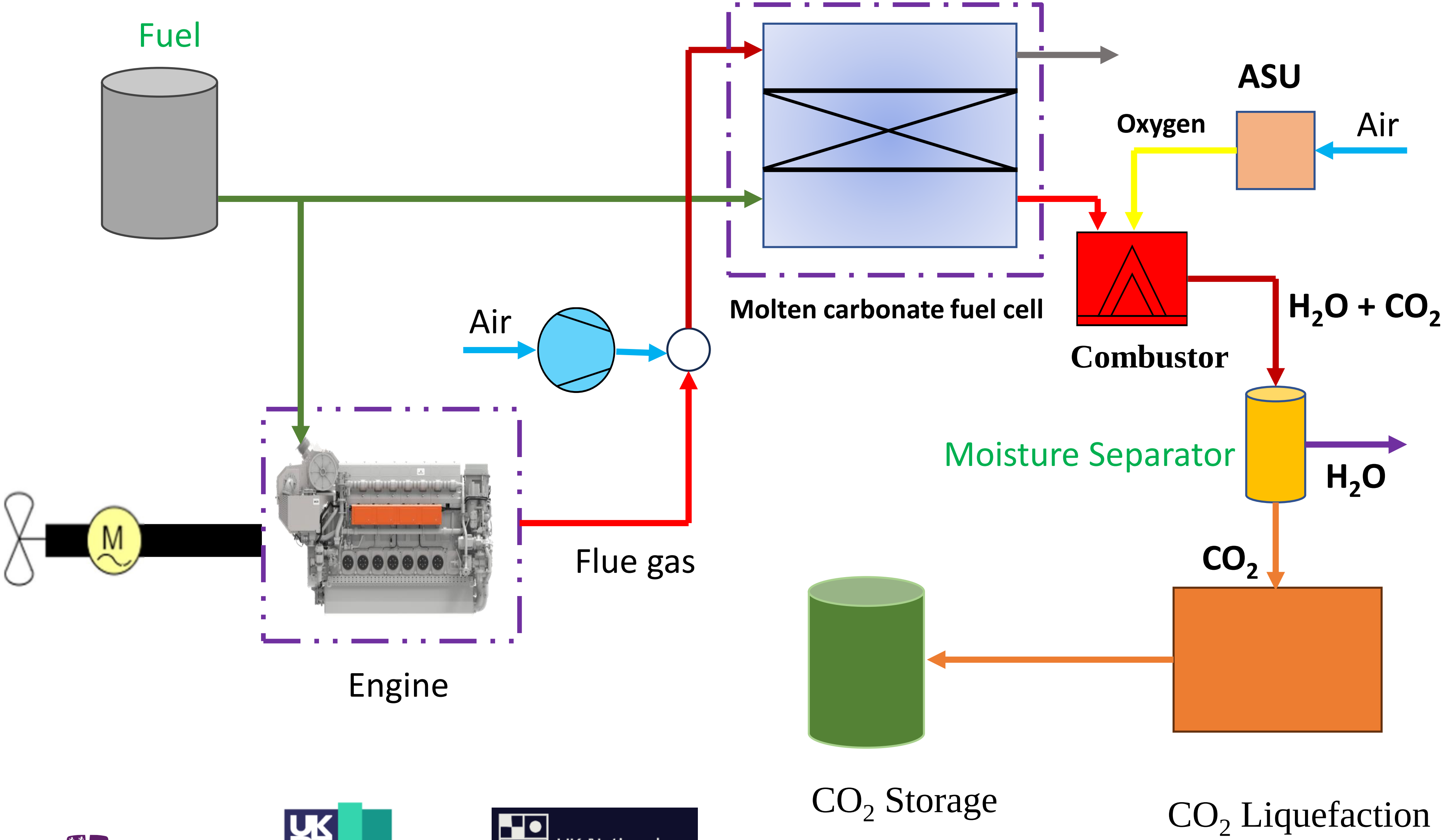
Case study 1 Molten carbonate fuel cell-based power generation system



🔬 **MCFC generates power + captures CO_2, improving overall efficiency.**

⚡ **Integrated system reduces fuel consumption compared to separate systems.**

🏭 **Enhances onboard energy utilization.**

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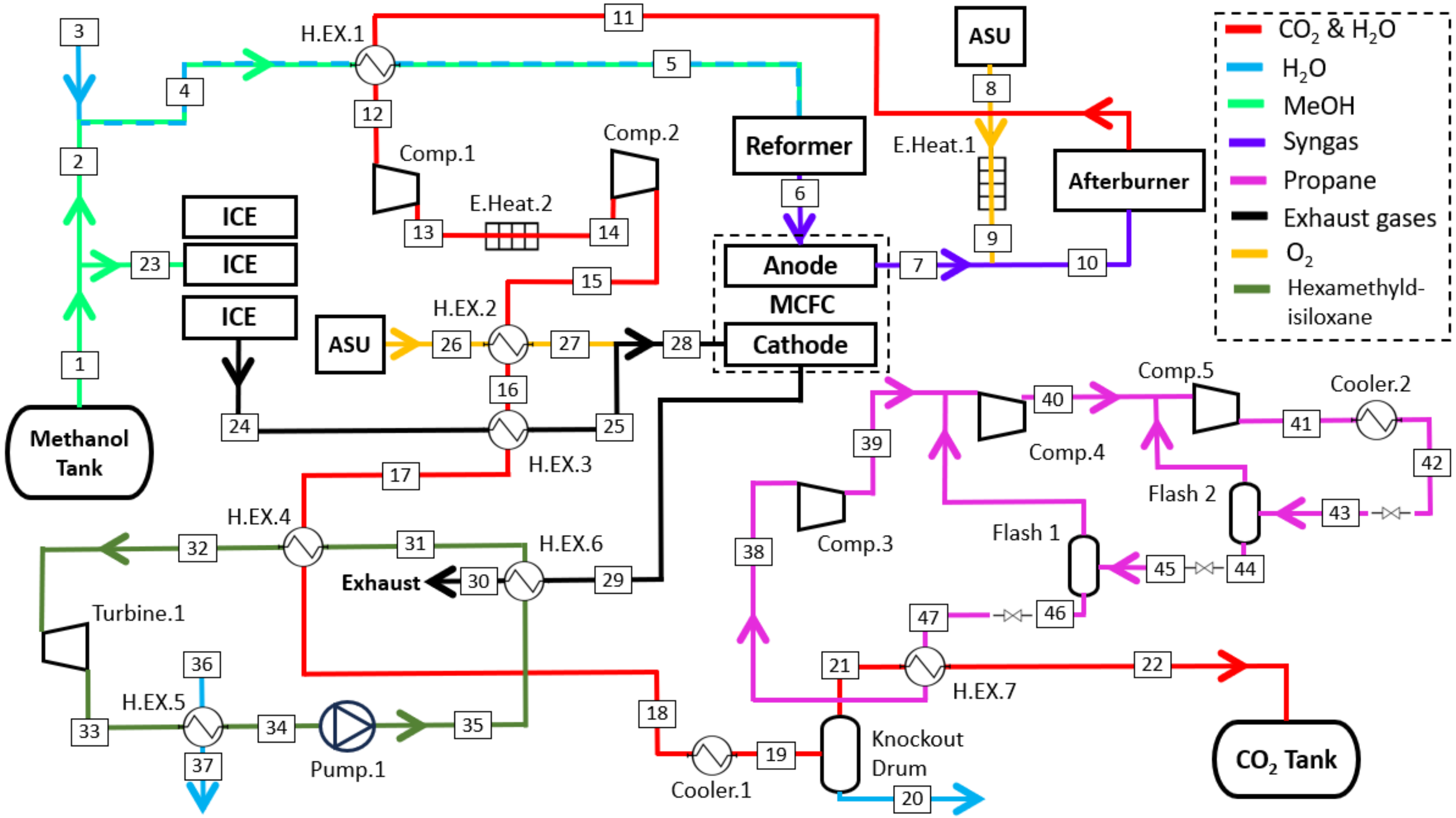
Case study 1: Detailed energy system configuration



Performance metrics at base case

Parameter	Value
$\dot{W}_{ICE}$ (MW)	34
$\dot{W}_{MCFC}$ (MW)	12.75
$\dot{W}_{ORC}$ (MW)	1.88
$\dot{W}_{CCS}$ (MW)	6.44
$\dot{W}_{net}$ (MW)	38
$\dot{Q}_{net}$ (MW)	20.5
η_{ICE} (%)	53
η_{MCFC} (%)	44.1
η_{ORC} (%)	15.9
$\eta_{electrical}$ (%)	49
η_{exergy} (%)	56
CO_2 Captured (%)	93.2
$\dot{m}_{CO_2,emission}$ (kg/s)	0.41
EMI (kg/MWh)	32.1

Source: "*Marine high-temperature fuel cell power and propulsion system with integrated carbon capture: A techno-economic study*", *Roy, et al. 2025, Applied Energy (Under Revision)*"

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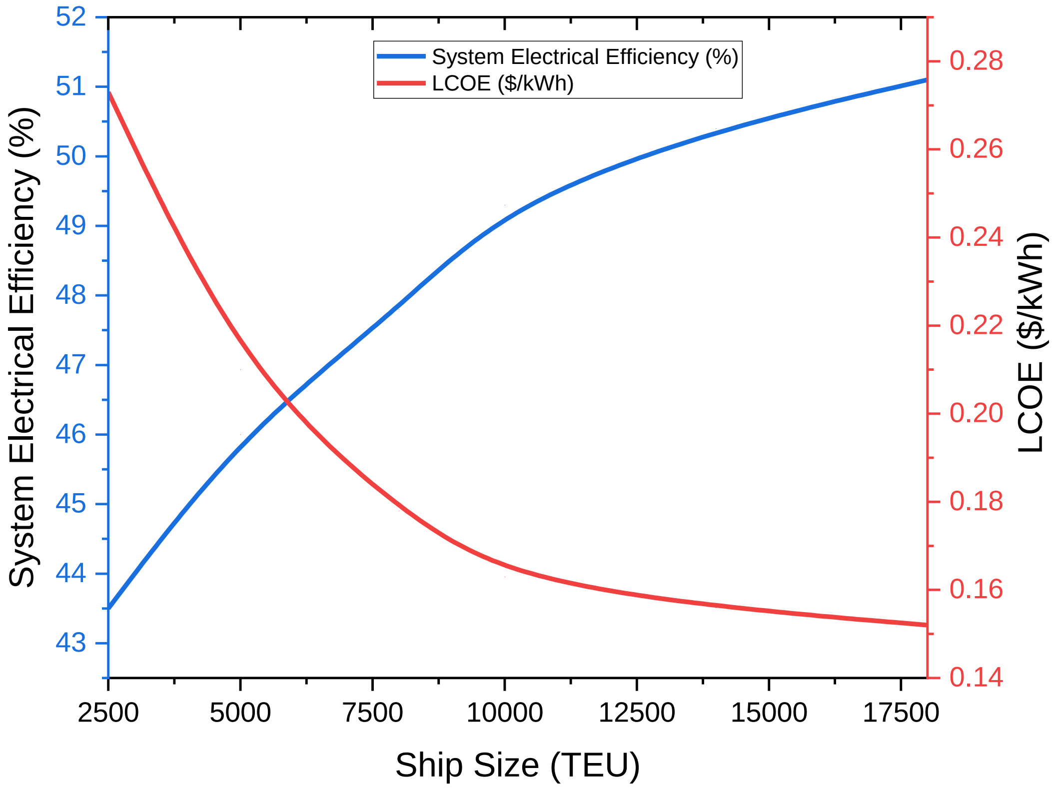
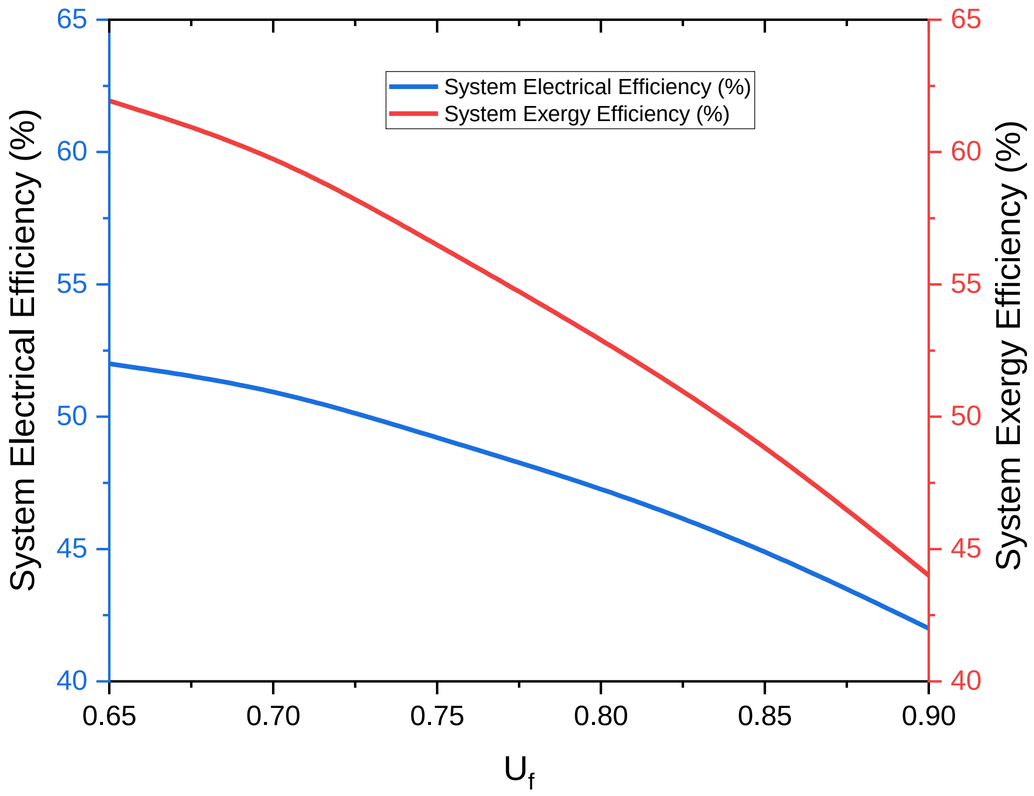
Sensitivity analysis



System electrical efficiency ($\eta_{electrical}$) and LCOE as a function of ship TEU number



System electrical efficiency ($\eta_{electrical}$) and exergy efficiency (η_{exergy}) as a function of U_f

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Summary

Technical Metrics:

- Electrical Efficiency: 49%
- **Exergy Efficiency: 56%**
- CO_2 Capture Rate: 93.2%

Financial Highlights:

- **Levelized Cost of Energy (LCOE): $0.16/kWh**
- Freight reduction cost: $11.55M/year
- Revenue from carbon credits: $12.35M/year

⚠ MCFC accounts for 49% of initial investment (financing challenge).

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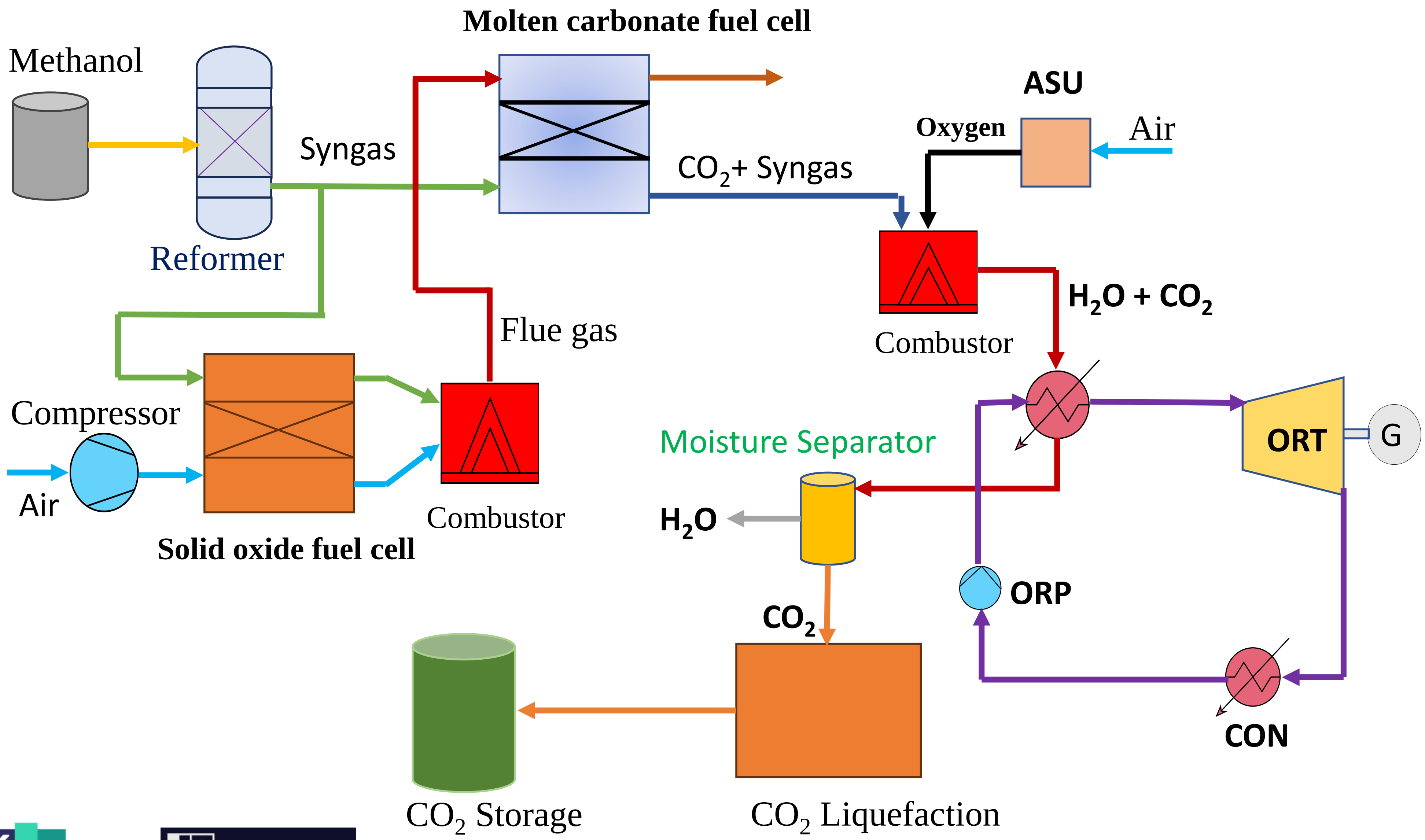
Case study 2 Solid Oxide Fuel Cells (SOFCs) Integration with MCFC

How does SOFC improve the system?

- Operates at 600–1000°C.
- Possibility of internal reforming of fuels.
- Fuel flexible.
- High efficiency compared to MCFC alone.
- Waste heat recovery option.
- SOFC + MCFC hybrid system provides better power density.

Case study 2 SOFC-MCFC based energy system



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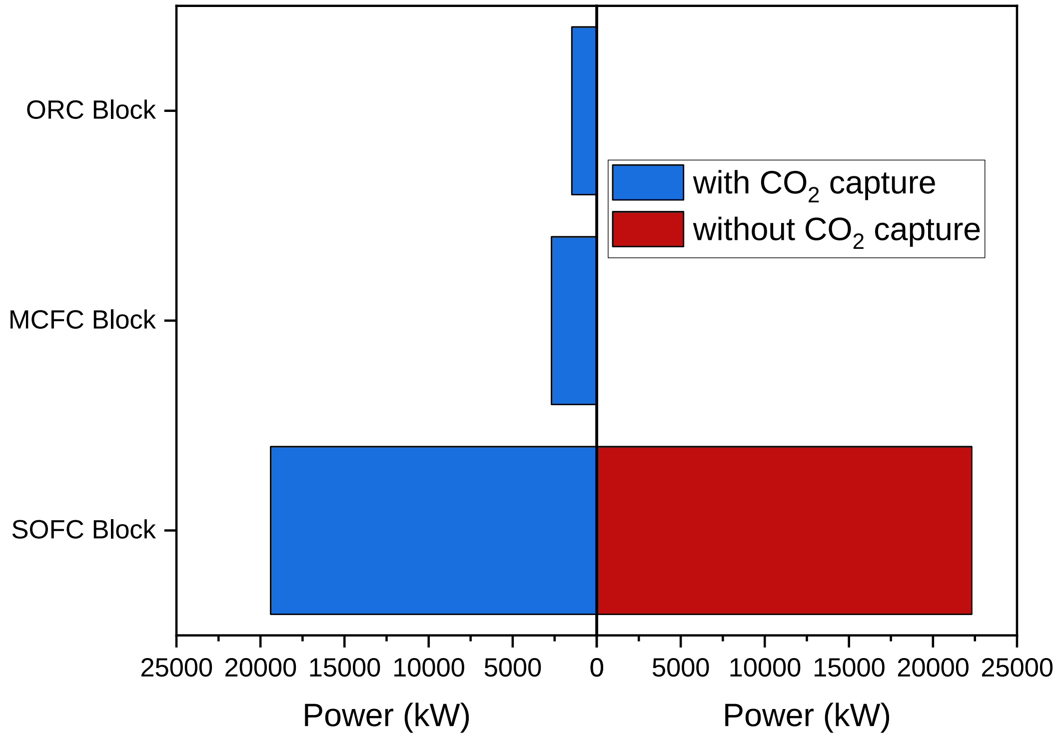
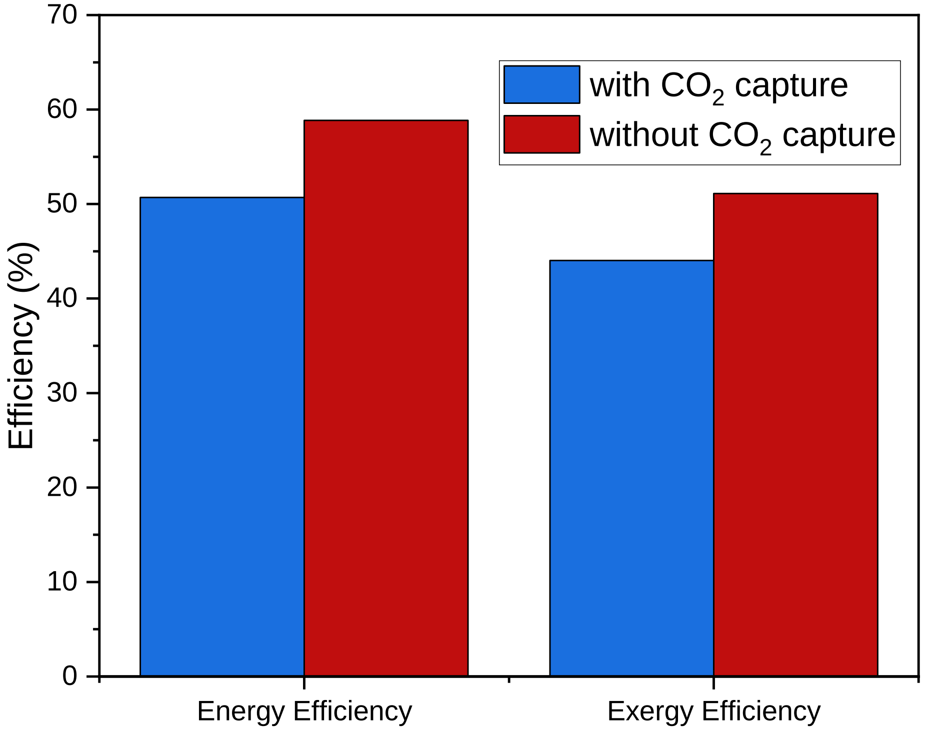
Performance Comparison (With vs Without CO_2 Capture)



Power output for "with" and "without" CO_2 capture scenarios



Energy and exergy efficiencies for "with" and "without" CO_2 capture scenarios

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Conclusions

✅ **Key takeaways:**

- Fuel cell integration improves overall efficiency.
- MCFC technology has potential to remove CO_2 emissions effectively.
- Future expansion could lead to fully decarbonized ships.

⚠**Challenges:**

- **Fuel cell durability** in harsh maritime conditions.
- Storage limitations for liquefied CO_2 on long voyages.
- **Integration with existing ship architecture.**

Ongoing:

- Detailed studies specifically related to sizing details of onboard storage.
- Techno-economic-environment analysis comparing various fuel types.

thank you

ABB POWER AND PROPULSION

Chris Poyner

Head of Shore Power, ABB Marine & Ports

ENGINEERED
TO OUTRUN

ABB in Numbers

ABB is a technology leader in electrification and automation

~110,000
employees

$1.5 bn
R&D investment

$32.9 bn
revenues

>170
manufacturing sites globally

78%
reduction in scope 1 and 2 GHG emissions since 2019

18.1%
operational EBITA margin

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ABB Purpose

We enable a **more sustainable** and **resource-efficient future** with our technology leadership in **electrification** and **automation**

- Creating success
- Addressing world's energy challenges
- Transforming industries
- Embedding sustainability
- Leading with technology

Interesting facts about ABB

We know frequency converters and have twice broken records!

ABB delivered a 100MVA frequency converter for the Grimsel 2 pumped storage power plant in Switzerland.

ABB delivered a 101 MW variable speed drive for a 135,000hp synchronous motor for a NASA wind tunnel, setting a new world record for size and power.

The giant fan generates wind velocities in excess of Mach 1

Interesting facts about ABB

We contribute to cutting edge research

ABB sensors are being used Nancy Grace Roman Space Telescope, NASA’s future space observatory which is due to launch in 2027 in search of other earth-like worlds.

Interesting facts about ABB

We have solutions on Mars

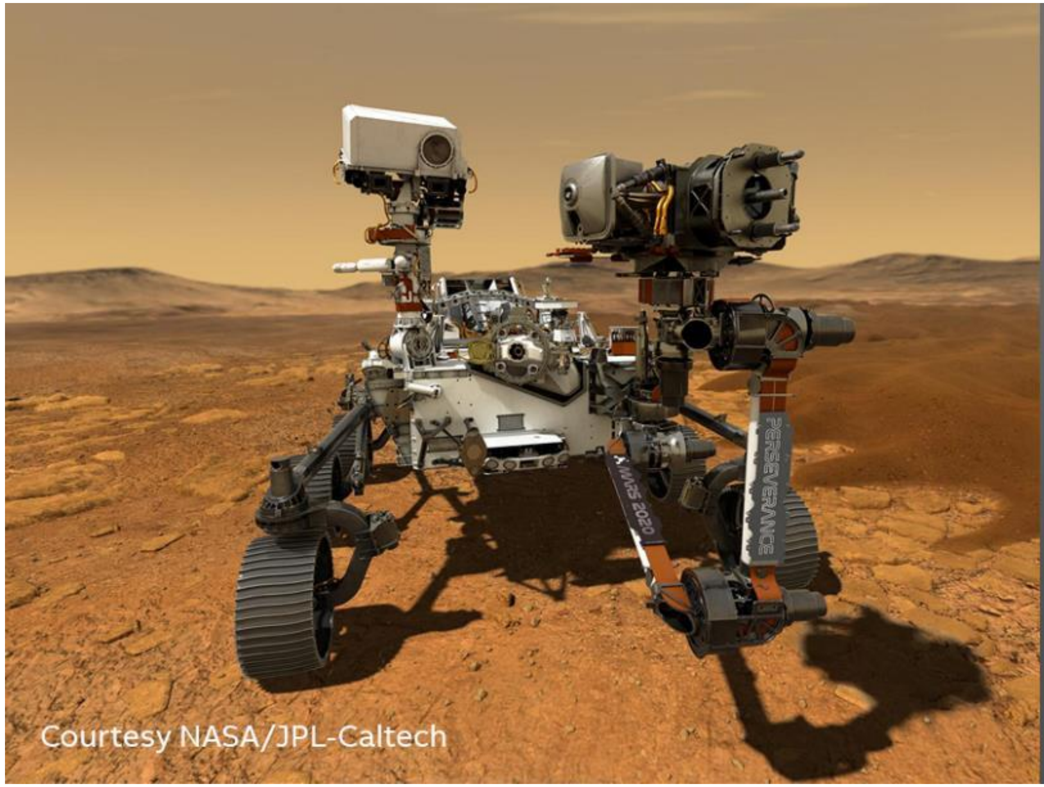


ABB owns Ty-Rap, the cable tie brand originally invented in 1958 to group cables in Boeing airplanes.

- 30 billion Ty-Rap cable ties have been produced
- Laid end-to-end, that is enough to stretch from earth to the Moon and back more than a dozen times.
- Ty-Rap cable ties used on the Mars Rover
    - Made of Tefzel ETFE resins
    - High durability and resistance to chemicals, UV and extreme temperatures
    - Have to absorb 2,000 times more radiation than standard nylon

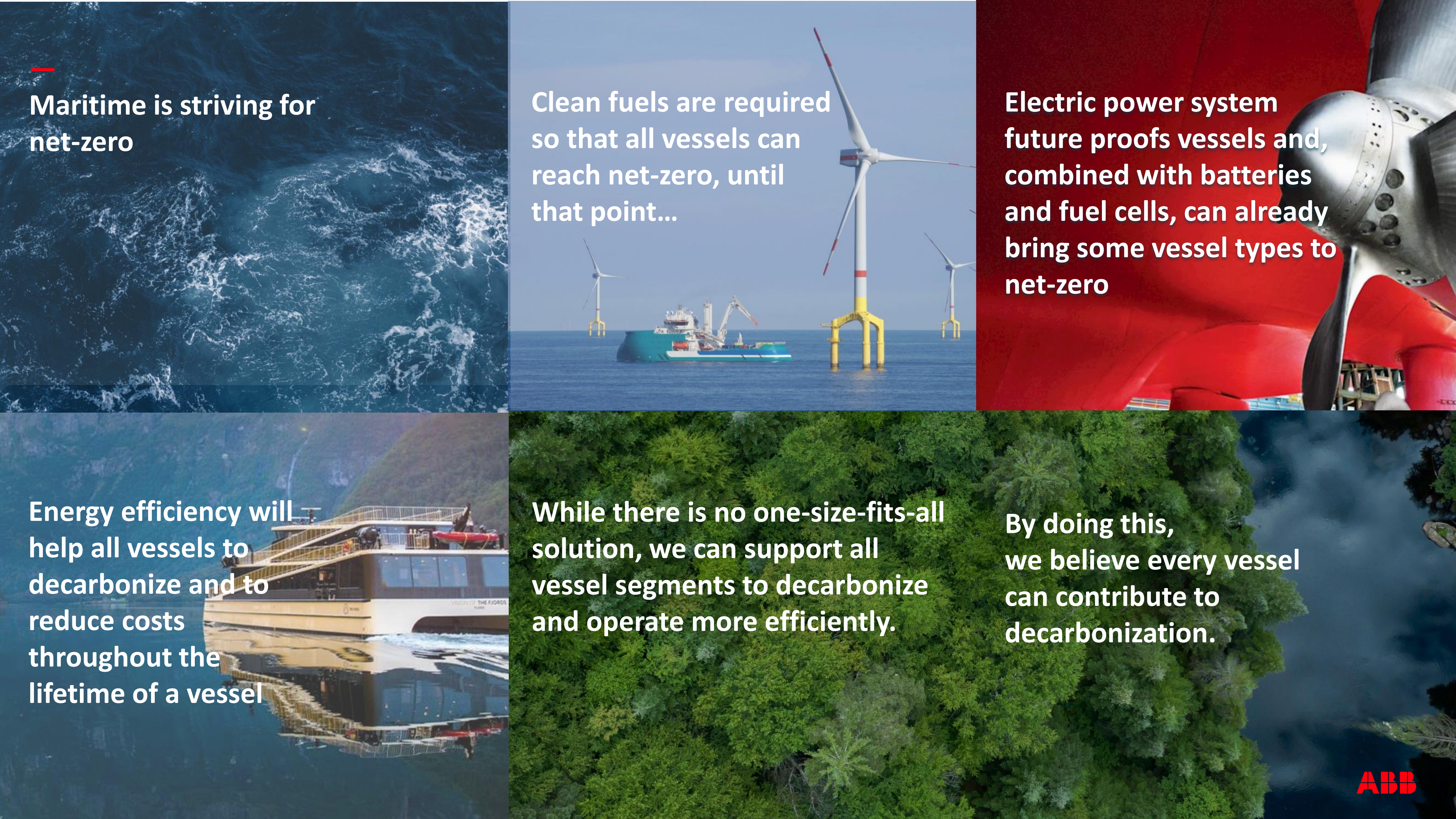
ABB

But what do these all have in common?

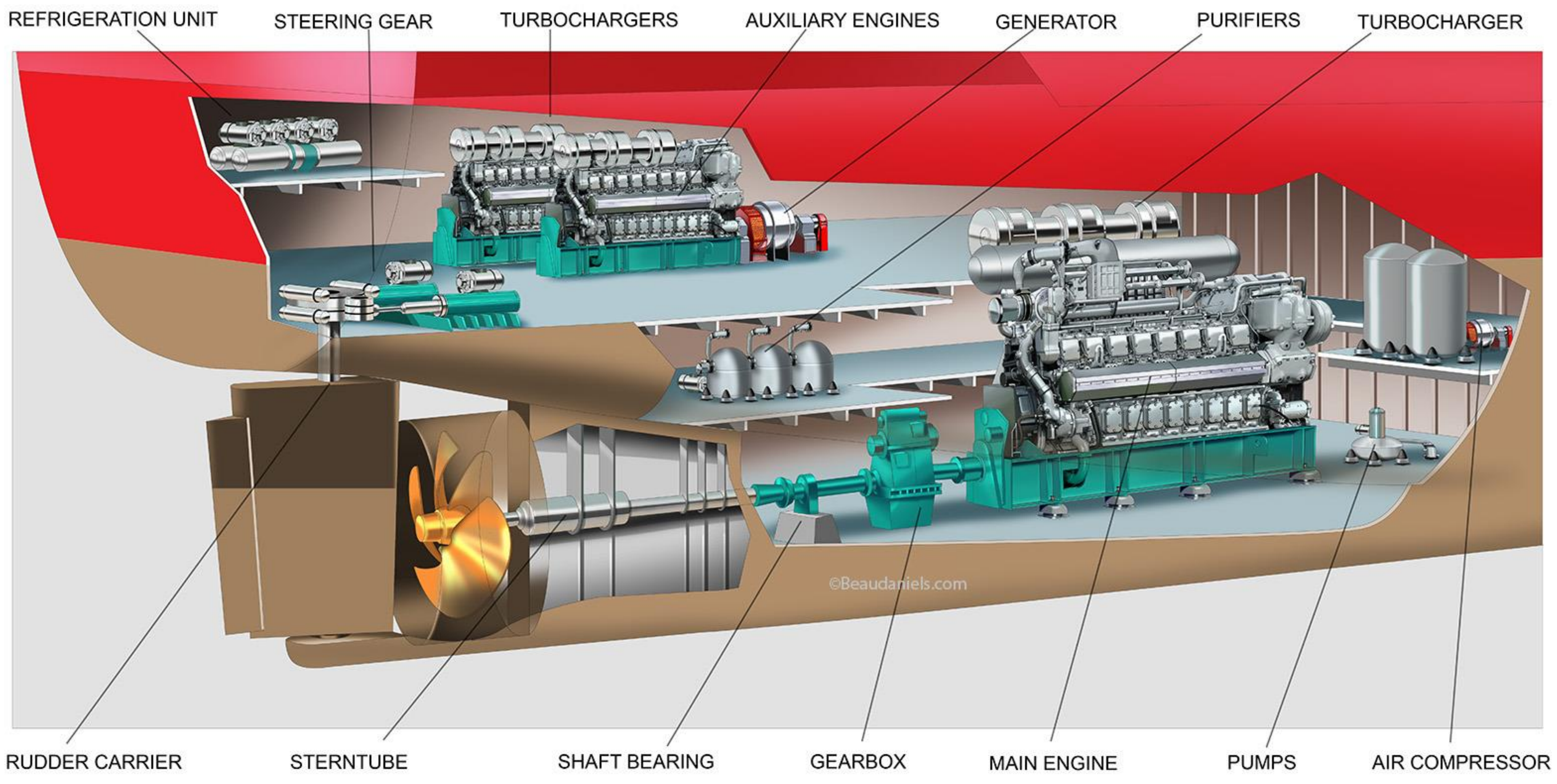
It is possible to solving extraordinary challenges by using ordinary solutions, and Maritime is no different!

Every vessel can contribute to decarbonization.

One size does not fit all. Wherever you are with your decarbonization journey, we help you focus on the most feasible next step.

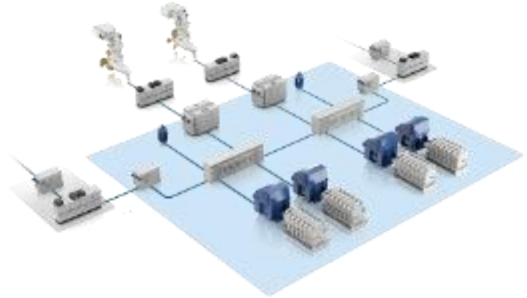

Maritime is striving for net-zero
Clean fuels are required so that all vessels can reach net-zero, until that point…
Electric power system future proofs vessels and, combined with batteries and fuel cells, can already bring some vessel types to net-zero
Energy efficiency will help all vessels to decarbonize and to reduce costs throughout the lifetime of a vessel
While there is no one-size-fits-all solution, we can support all vessel segments to decarbonize and operate more efficiently.
By doing this, we believe every vessel can contribute to decarbonization.

How vessels traditionally generate energy

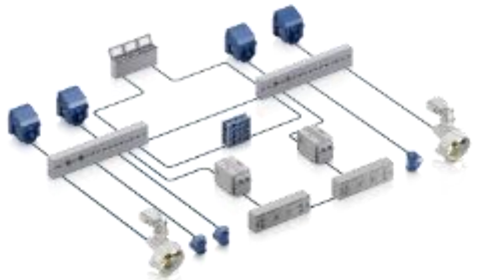


Electric propulsion is a future-proof concept

Electric power and propulsion systems as a backbone of electric and hybrid vessels



Up to 10% reduced fuel consumption with AC solutions



Up to 27% reduced fuel consumption with DC solutions

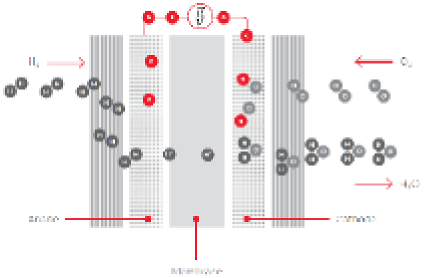
Azipod® electric propulsion

Additional 10% increased energy efficiency with Azipod® electric propulsion

Energy storage

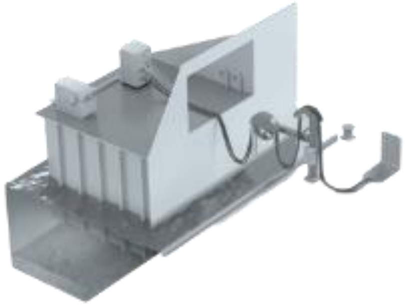
Hybrid or fully electric operation with stored energy and charging solutions

Fuel cells



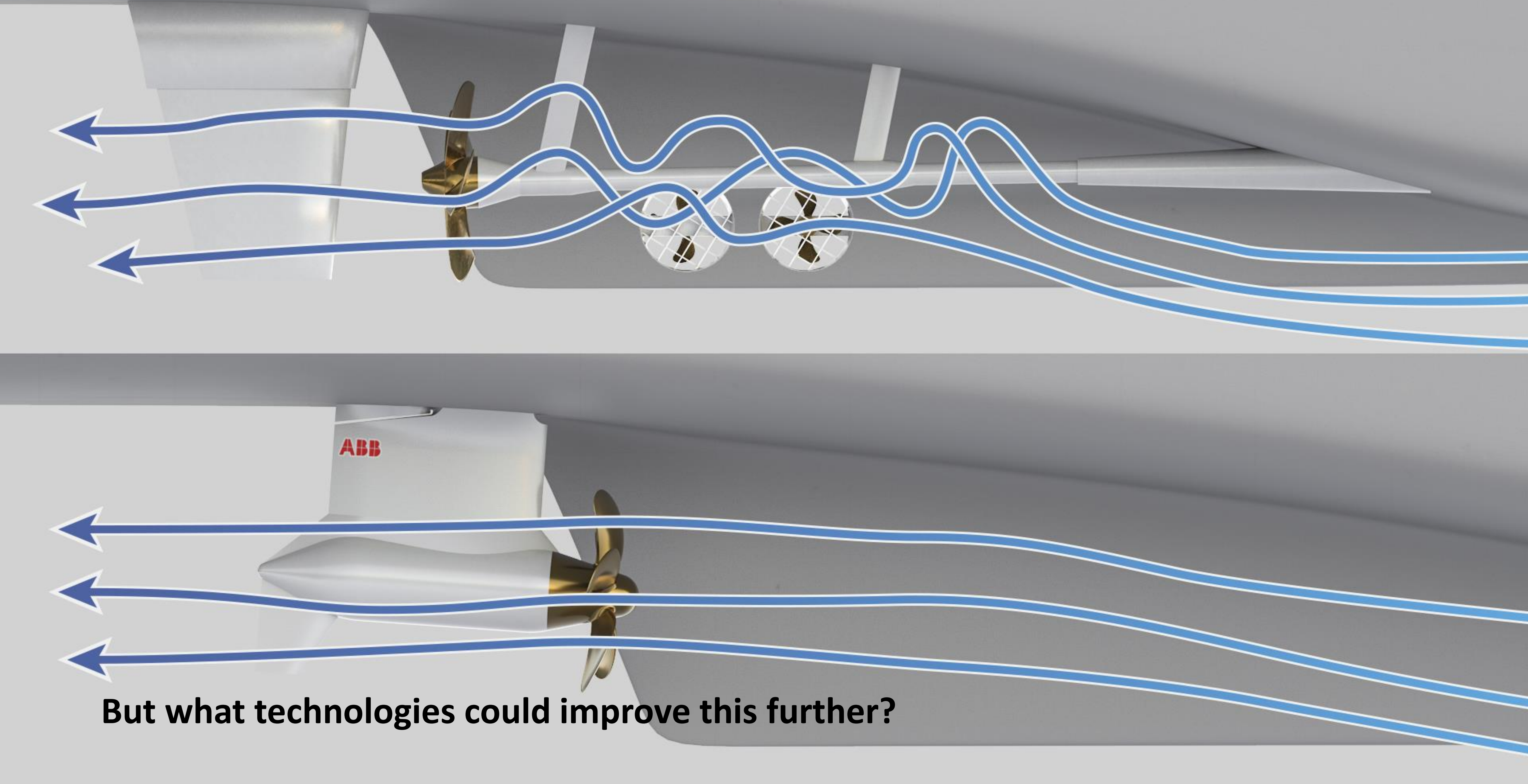
Zero-emission operation with hydrogen fuel cell power system

Shore connection



98% greenhouse gas emissions eliminated in port call

Azipod offers higher efficiencies when compared to traditional propulsion



But what technologies could improve this further?

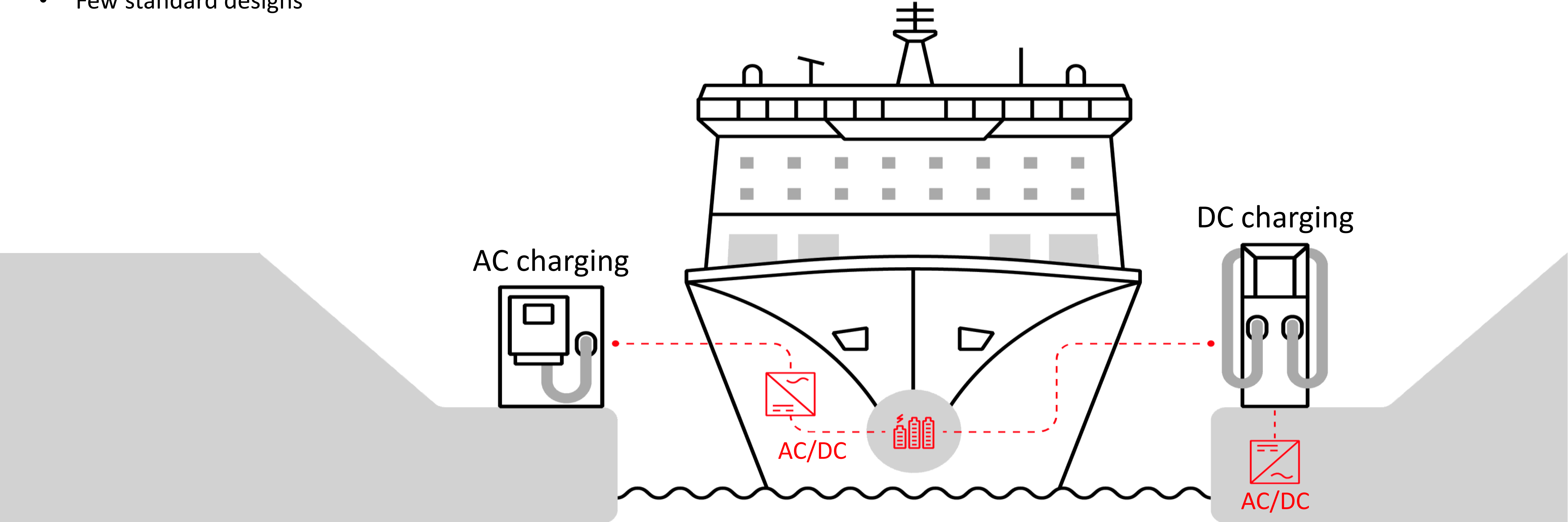
Every Port can contribute to decarbonization

Shore Charging

Shore charging offers sustainable sailing

Typical Characteristics:

- AC or DC Voltage to vessel
- Power demand dependent upon vessel type
- Solutions are generally bespoke to the vessel (with the exception of MCS)
- Few standard designs



How to charge

Data source: Alternative Fuels Insight by DNV/MBF 2024-03-01

Auckland Ferries

Auckland Transport's Mission Electric:

Auckland Transport is expected to become the largest electric ferry fleet operator in the Southern Hemisphere by 2030.

Overall Project Scope:

- 4 all-electric and hybrid-electric ferries are under construction.
- Charging Systems

ABB Scope:

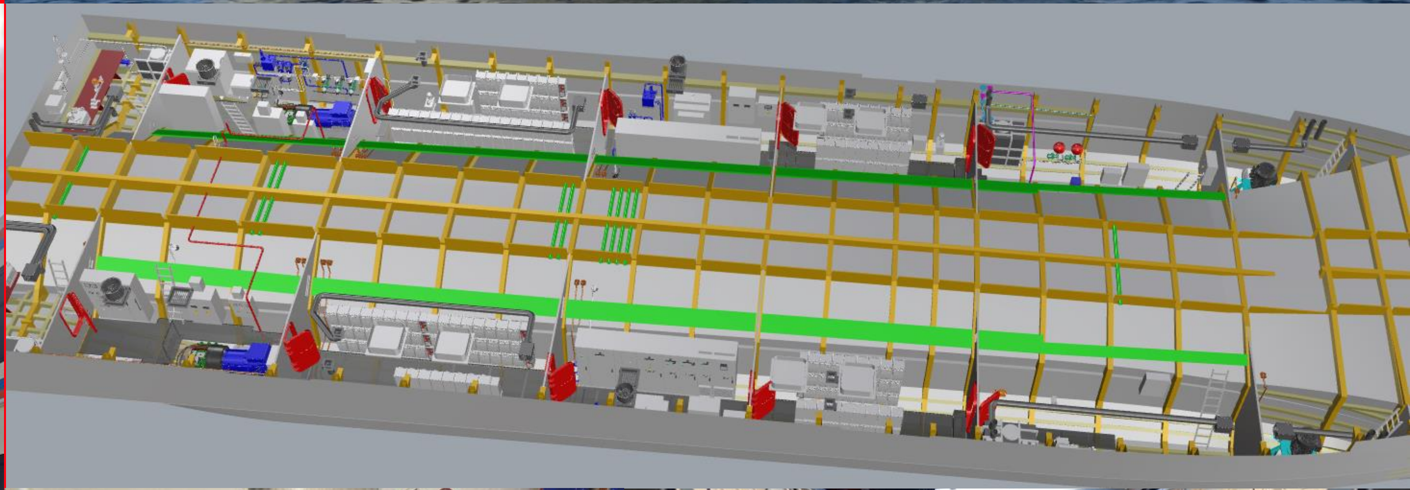
- 5 charging systems
- 2 plugs per system @1.65MW each
- Level 3 MCS
- 720-1000Vdc

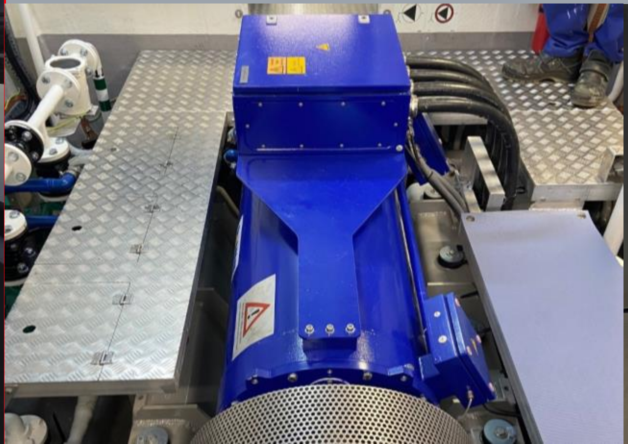
Lisbon Ferries

- **10 fully electric vessels owned by** Transtejo (Tagus River Ferry Company)
- Vessels delivered by Gondan shipbuilding in Spain
- 2200kW DC Charging
- 540 passengers

Operating on three routes:

1. **Cais do Sodre – Cacilhas**
    - 5min crossing
    - 27,000 roundtrips/year
2. **Cais do Sodre – Sexial**
    - 19min crossing
    - 7,900 roundtrips/year
3. **Cais do Sodre – Montijo**
    - 30min crossing
    - 6,900 roundtrips/year

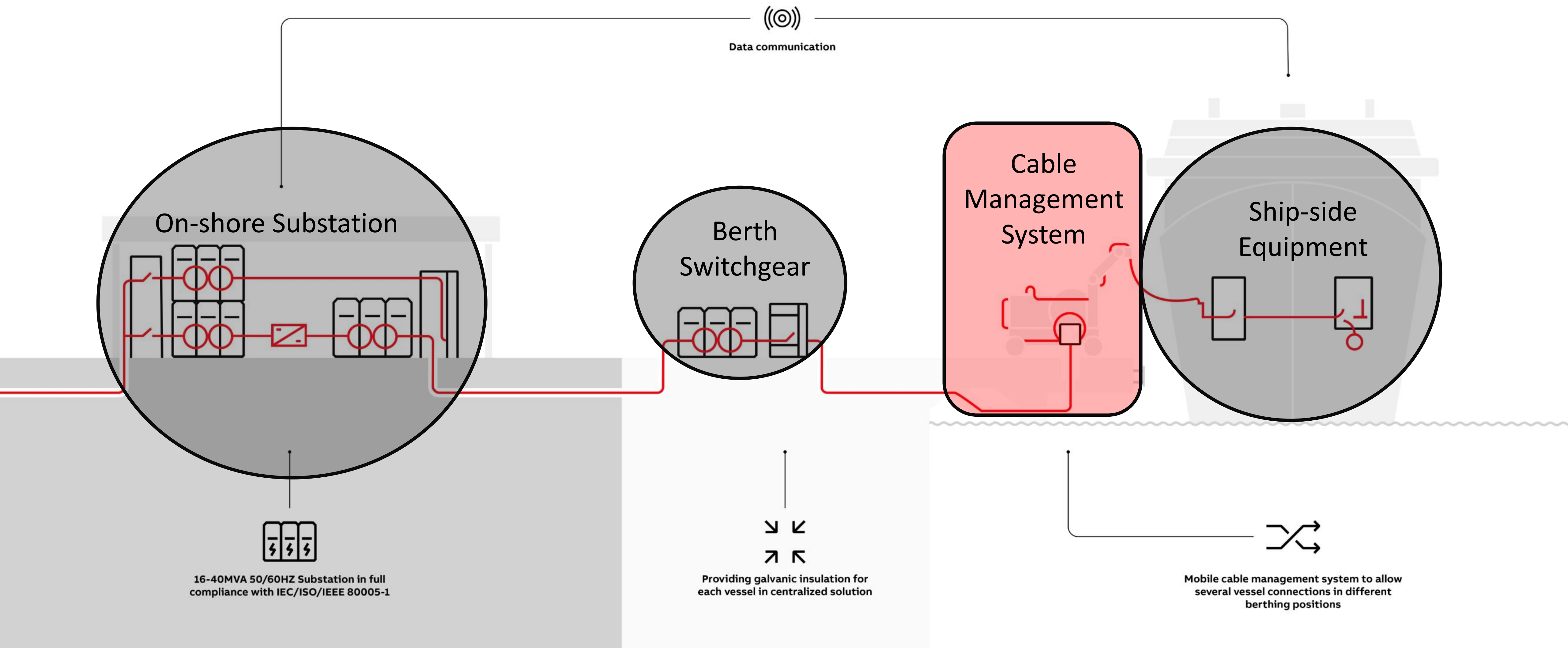




Lisbon Fast Ferries

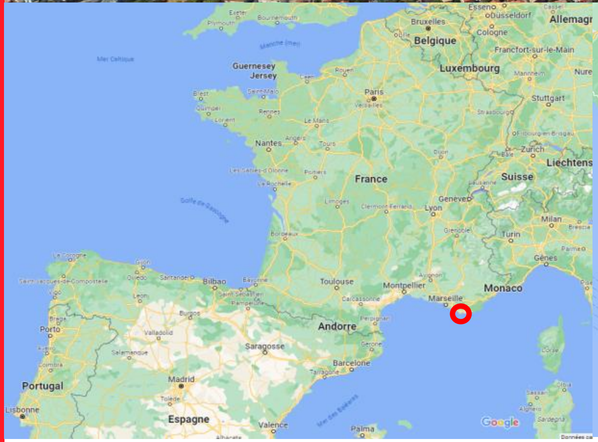
Shore Power

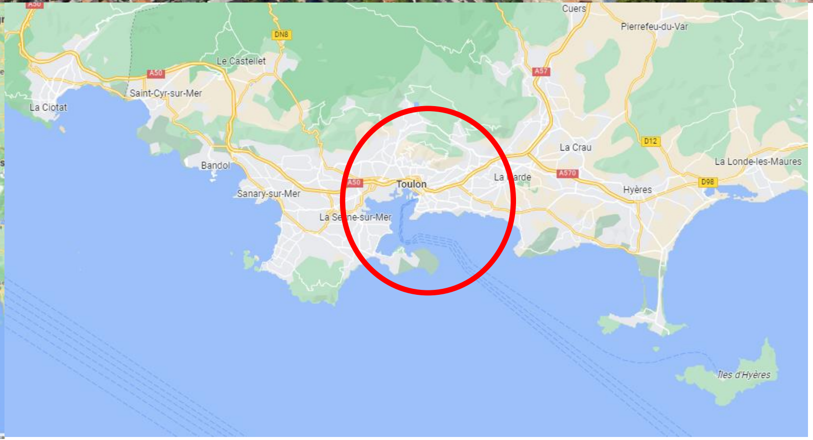
Shore Power offers plug-in sustainability



Worked Example
The Port of Toulon

Mediterranean port with 180,000 people living in close proximity





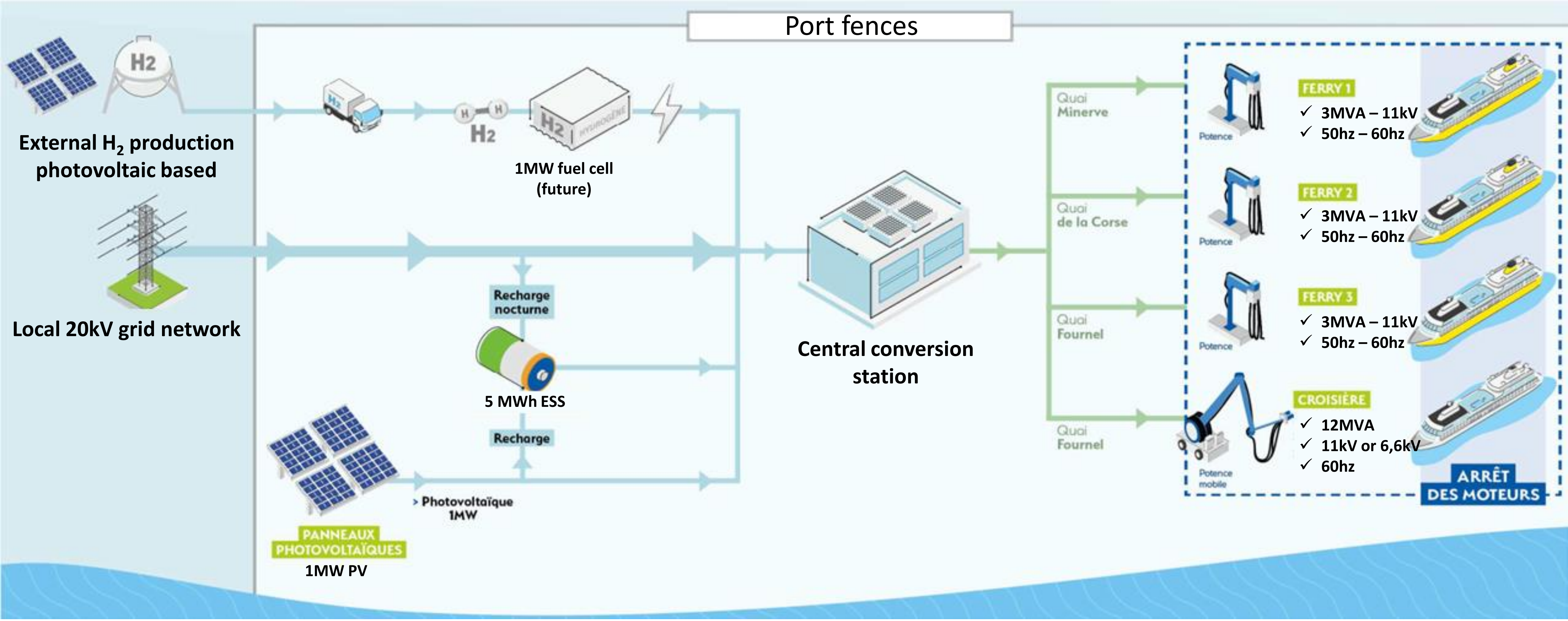
Customer Objectives

Project constrains and specifications

- ✓ Possibility to connect 3 Ferries at one time, or 2 Ferries plus 1 Cruise vessel
- ✓ 50hz and 60hz up to 3 MVA for ferries
- ✓ 11kV and 6,6kV up to 12MVA for cruises
- ✓ Very limited available space for the project
- ✓ 3MVA Peak shaving (9->6MVA) with 3 ferries connected
- ✓ Power Factor >0,92 at grid side
- ✓ Integration of 1 MW photovoltaic power
- ✓ System ready for 1MW Fuel-cell connection

Energy Hub design

The overall solution



Purpose Built Substation

Main Electrical Building

Dimensions: **36m x 11m x 6m**
Total Footprint: **400m²**

- 4 technical rooms
- 1 complete roof top for HVAC

Purpose Built Substation

Cruise berth switchgear (12MVA) and Stepdown transformers (dry type)

Purpose Built Substation

Ferry berth switchgear and battery energy storage

Cable Management System

Cruise cable management system and connection boxes

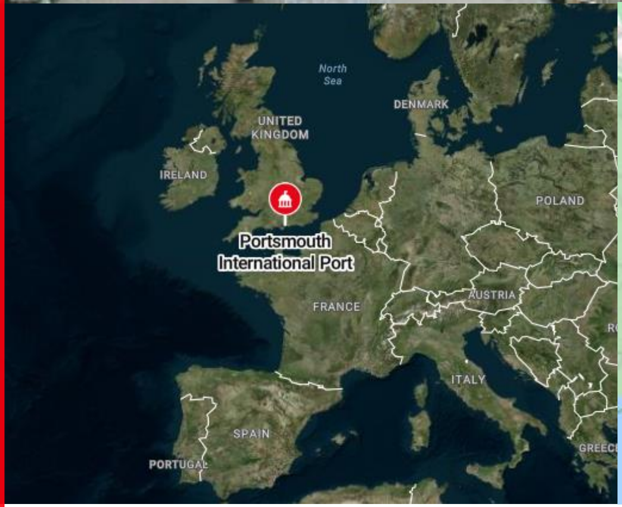
How to integrate PV with limited space

Photovoltaic shades for waiting traffic

—

Worked Example Portsmouth International Port

Portsmouth International Port, also known as Portsmouth Continental Ferry Port, is the harbour authority for the city of Portsmouth, Hampshire, located on the south coast of Great Britain



Funded by UK Government

SEACHANGE

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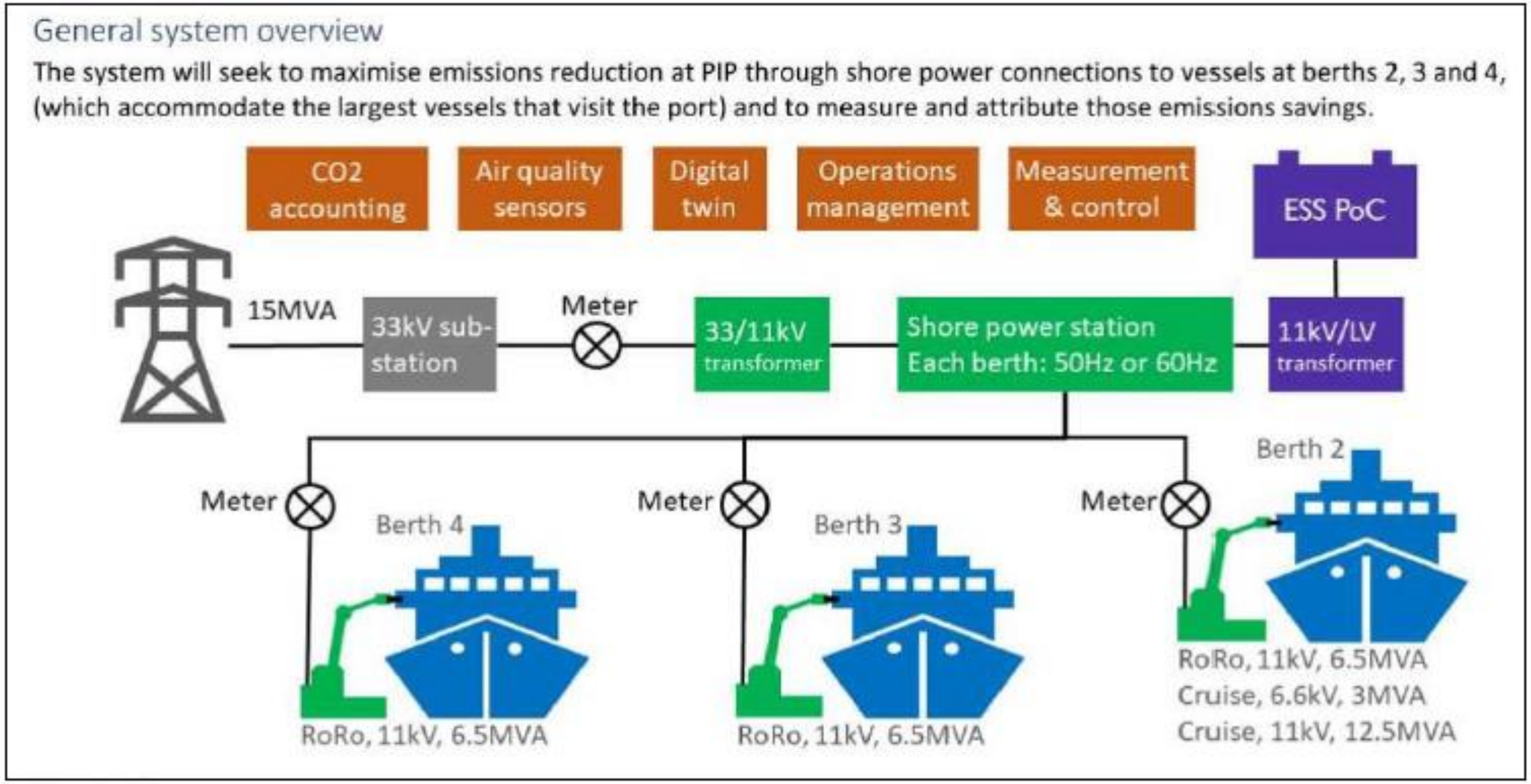
Project Overview

Project Scope

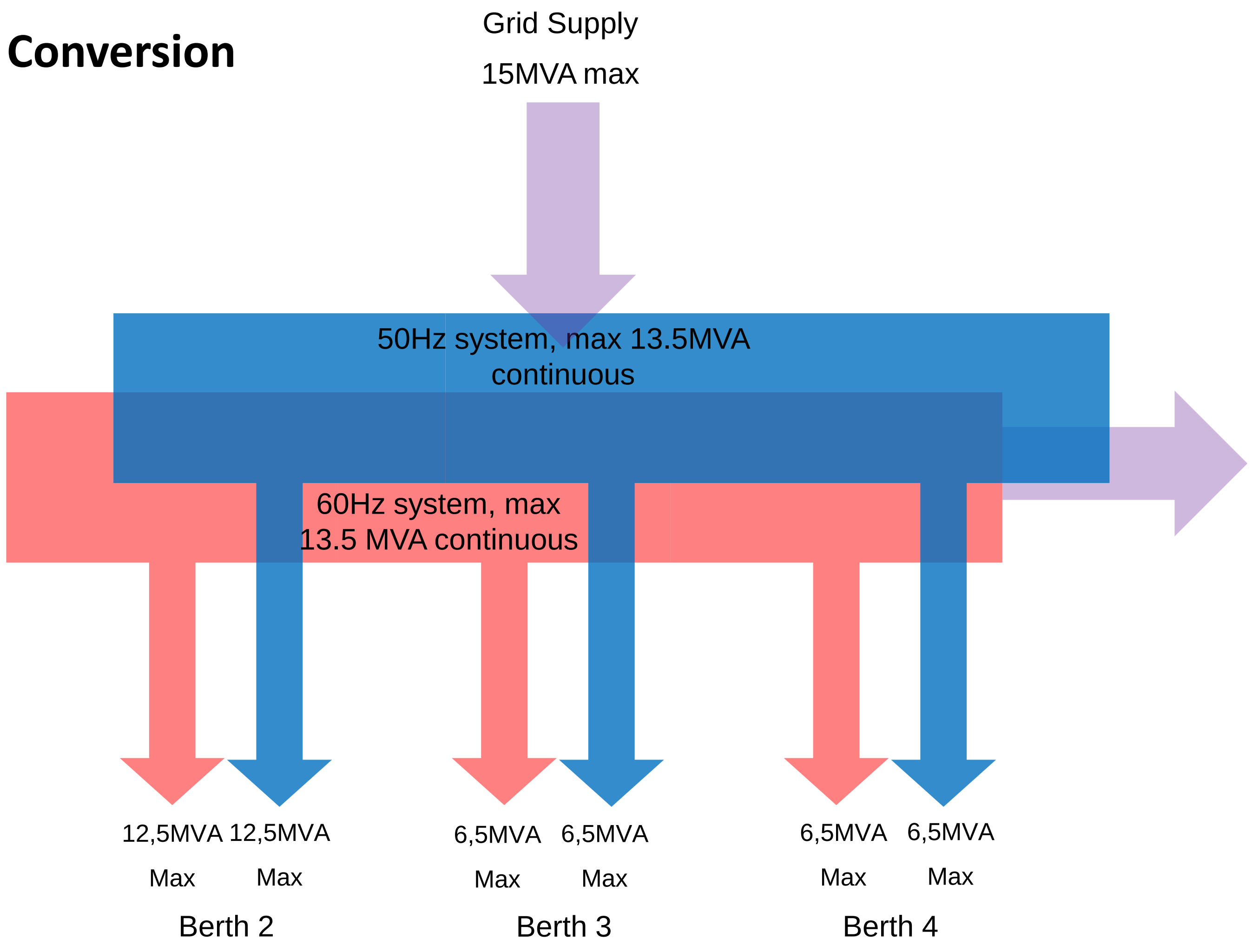


Portsmouth Shore Supply

Portsmouth International Port

Portsmouth Shore Supply

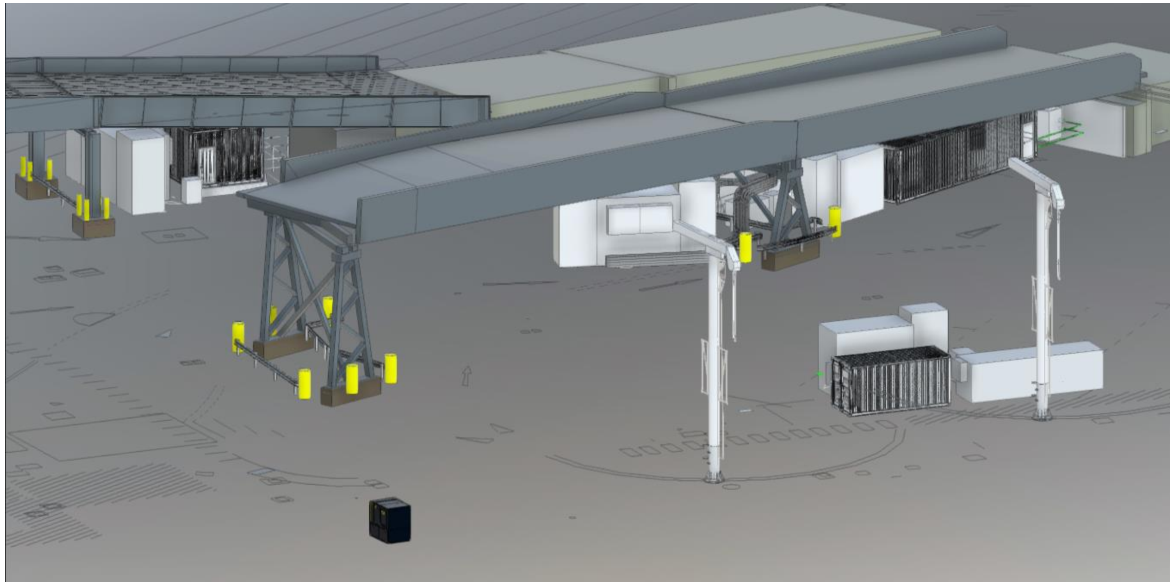
Centralised Frequency Conversion



- ESS Battery
- Auxiliary Power
- System losses
- Starting consumer margin

Portsmouth Shore Supply

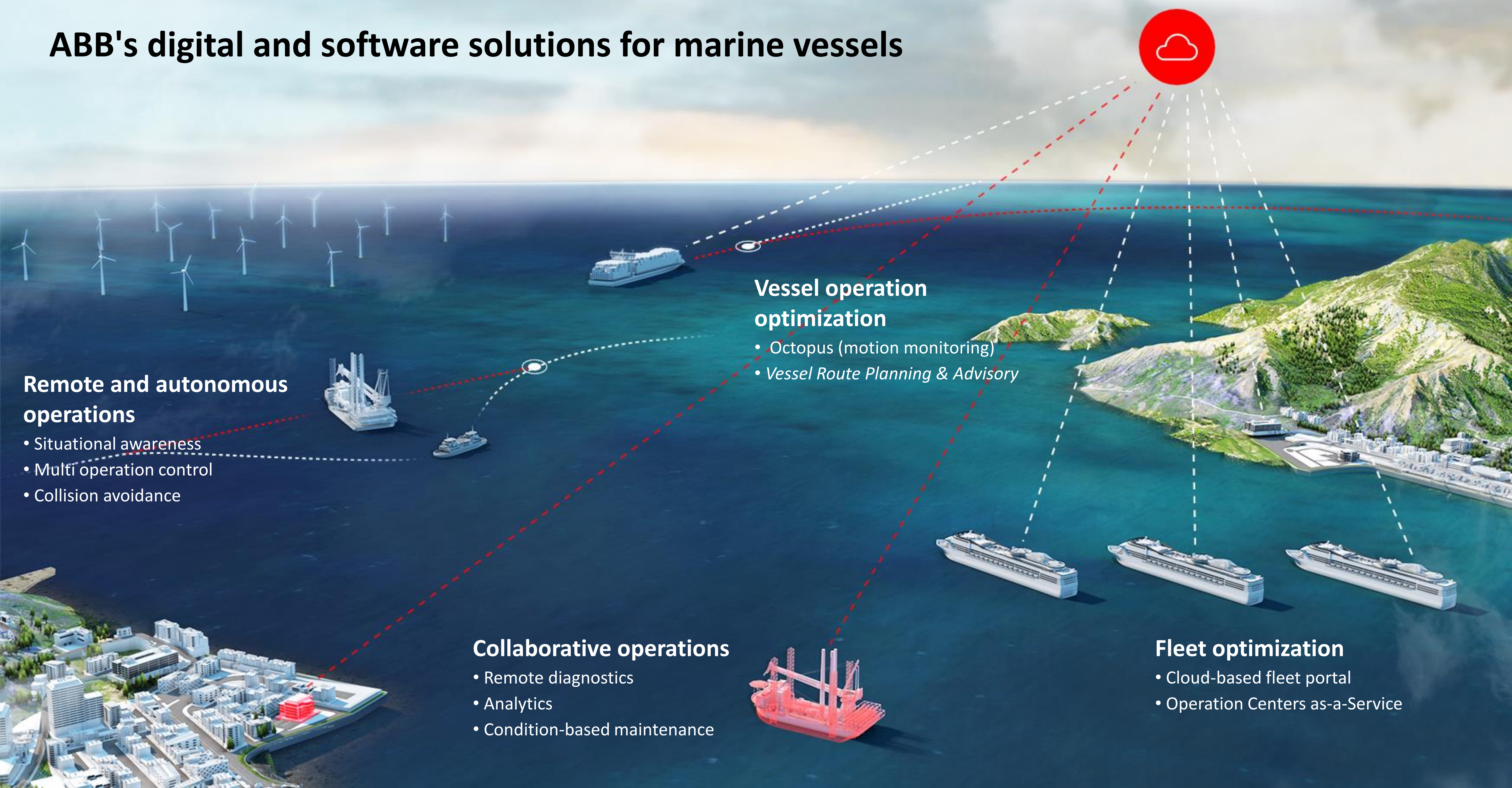
Equipment location

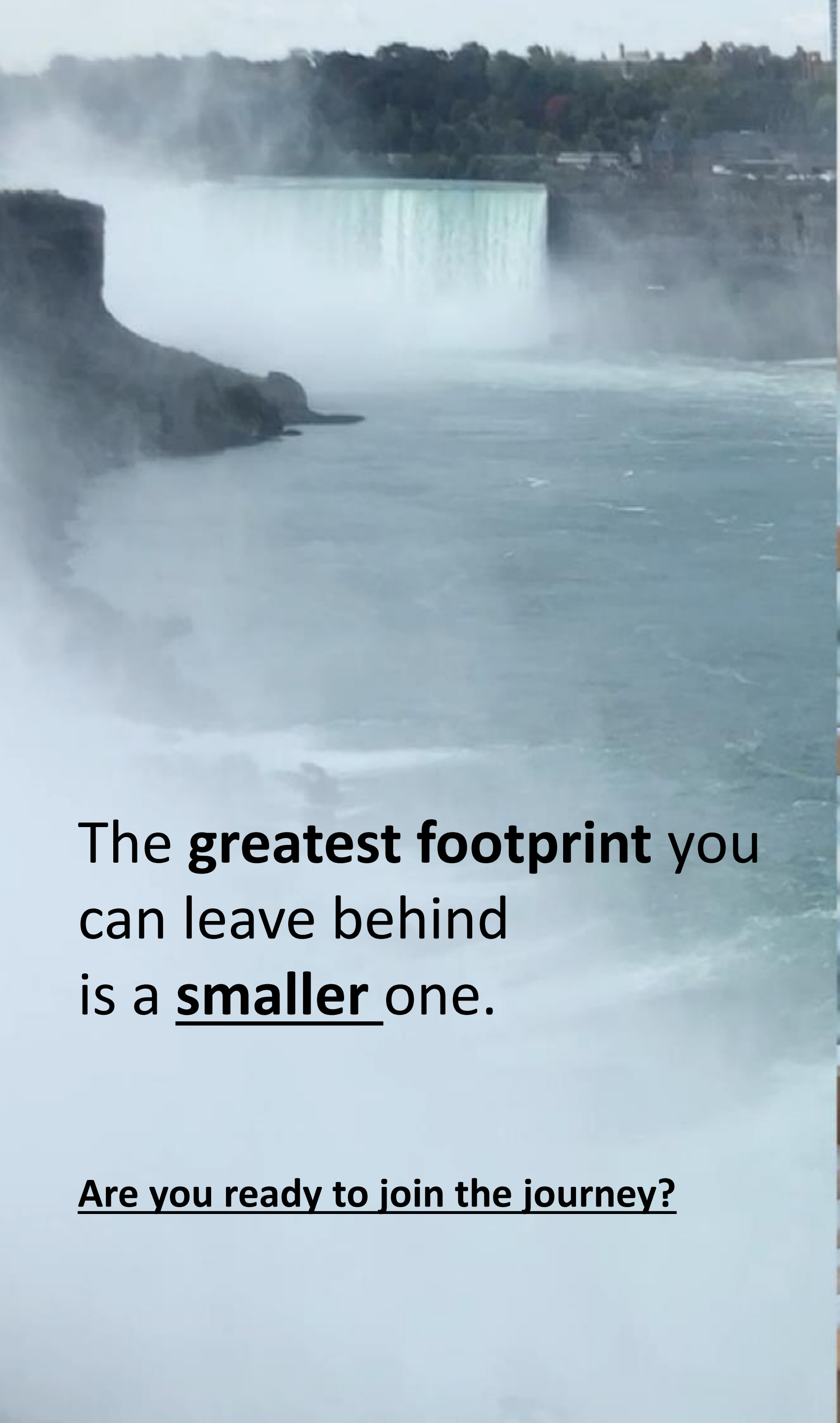


Portsmouth Shore Supply

Connecting multiple vessels

ABB's digital and software solutions for marine vessels





The **greatest footprint** you
can leave behind
is a **smaller** one.

Are you ready to join the journey?

Contacts

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Vessel Design, Efficiency & Innovation in Action of Theme 4 at Newcastle University

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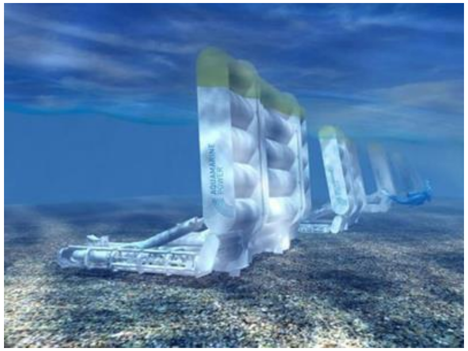
Outlines

Newcastle University

- Introduction
- Physics-informed AI technology in energy efficiency optimization
    - Dynamic application in Wind-assisted Ship Propulsion
    - Quasi-static application in optimization of propulsive efficiency
- Hydrogen engine onboard sea trial



Introduction

Research conducted in Newcastle University Team of Clean Maritime Hub

1) Propose novel methods in achieving CO_2 reduction and energy saving for shipping industry.
2) Overcome challenges by employing AI in this field.
3) Sea Trial of hydrogen engine onboard practice.

- The Role of Propulsion System in Emission Reduction – Quasi-static

- Wind Assisted Ship Propulsion - dynamic

- How to employ AI technology?

- First successful hydrogen engine onboard sea trial in The UK

Outlines

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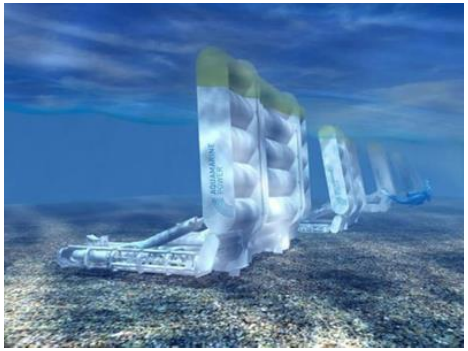


Dynamic Physics-informed AI technology

○ Dynamic application in Wind Assisted Ship Propulsion

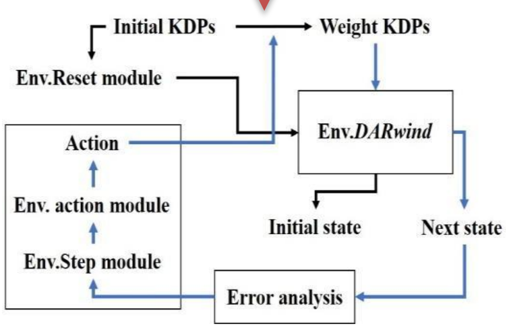
Purpose

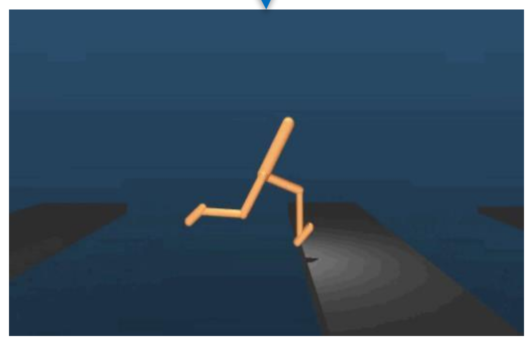
- Energy saving and CO_2 emission reduction by the employment of wings installed onboard.
- How to employ AI technology to optimize the energy consumption? Application of novel SADA method.

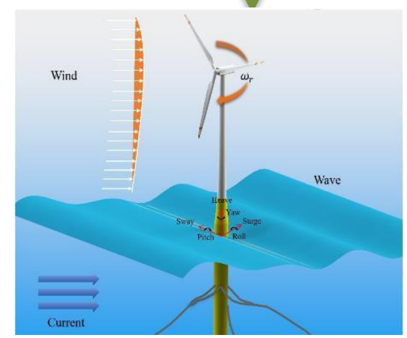
Dynamic Physics-informed AI technology

☐ *SADA*: an AI-based method developed in Newcastle University

Software-in-the-loop combined **A**rtificial intelligence method for **D**ynamic response **A**nalysis of FOWTs







☐ Contents

- ***A physic-informed mathematical model and programme*** (Coupled aero-hydro-servo-elastic in-house program, *DARwind*)
- ***Machine Learning*** (Reinforcement Learning: *DDPG* algorithms)
- ***KDPs*** (Key Disciplinary Parameters)

- Peng Chen, Chunjiang Jia, Chong Ng, Zhiqiang Hu. Application of SADA method on full-scale measurement data for dynamic responses prediction of Hywind floating wind turbines. Ocean Engineering 239 (2021) 109814

Dynamic Physics-informed AI technology

Newcastle University

Application of SADA method in Wind Assisted Ship Propulsion model

- Theoretical model

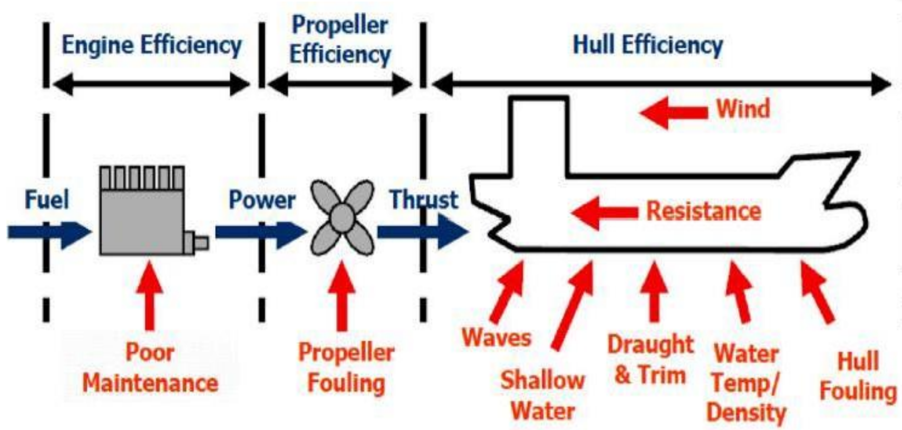
Engine thrust = Total resistance − Wind thrust

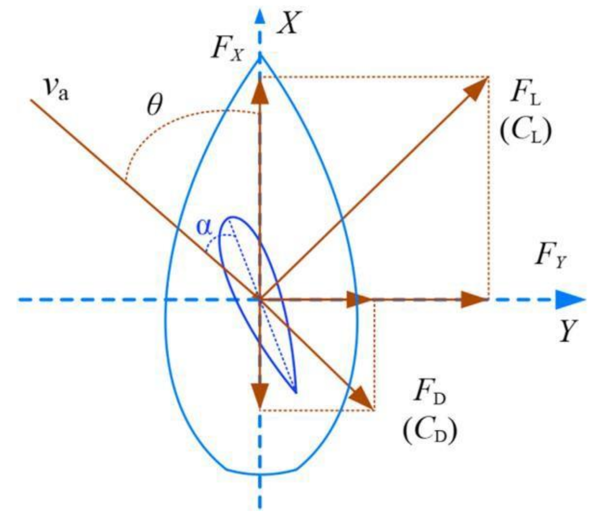
- Hydrostatic drag + atmospheric drag

$$R = R_s + R_A$$

$$R_s = R_t + \Delta R_t = (R_f + R_r)(1 + K_t)$$

$$R_A = K_1 \times C_A \times \frac{1}{2} \times \rho_A \times A_V \times V_r^{\ 2}$$





- Wind-induced forces on the wings :

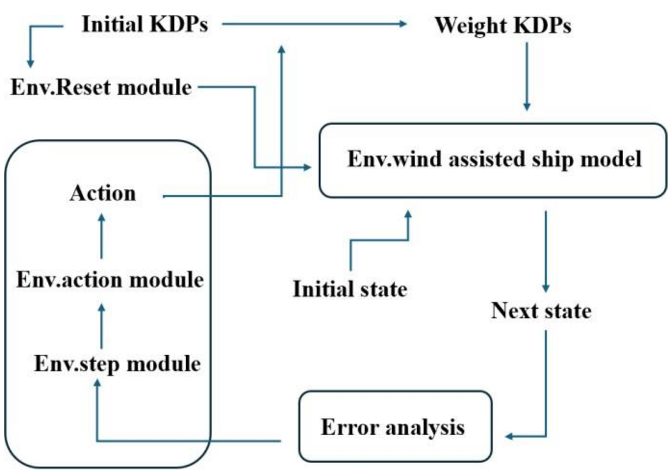
$$T_w = F_L \times \sin\beta - F_D \times \cos\beta$$

$$F_L = C_L \times \left(\frac{1}{2} \times \rho_A \times S \times V_r^{\ 2}\right)$$

$$F_D = C_D \times \left(\frac{1}{2} \times \rho_A \times S \times V_r^{\ 2}\right)$$

Dynamic Physics-informed AI technology

SADA method application



1) Choose KDPs;

2) Run initial propulsion prediction;

3) Error assessment;

4) The deep neural network/ Gaussian distribution to give action that is adjusting the KDPs;

5) Run propulsion prediction by agent to obtain new states.

KDPs selection

No.	Name	Code	Unit	Action	Bound
1	Correct ship velocity	CorrVship	(m/s)	0.05	[-1, 1]
2	Ship length	L	(m/s)	0.1	[320, 330]
3	Ship breadth	B	(m)	0.05	[55, 65]
4	Ship draft	T	(m)	0.05	[18, 22]
5	Wetted area coefficient	C_WetArea		0.01	[1.5, 2]
6	Kinematic viscosity	Nu	(m**2/s)	0.01	[1, 1.5]
7	Roughness height	Ks	(m)	0.05	[0.1, 1.5]
8	Wind wing breath	Bwind	(m)	0.5	[14.0, 15.5]
9	Correct Wind angle	CorrTheta	(Deg)	0.5	[-10, 10]
10	Correct wind velocity	CorrVwind	(m/s)	0.01	[-1, 1]
11	Main engine efficiency	Eta		0.001	[0.8, 1]
12	Specific fuel oil consumption	SFOC	(g/kWh)	0.5	[180, 220]
[illegible]	[illegible]			[illegible]	[illegible]

Dynamic Physics-informed AI technology

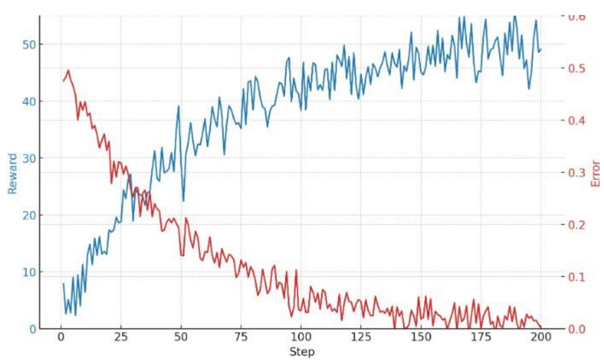
○ Training with real-time data

- **Training cases**

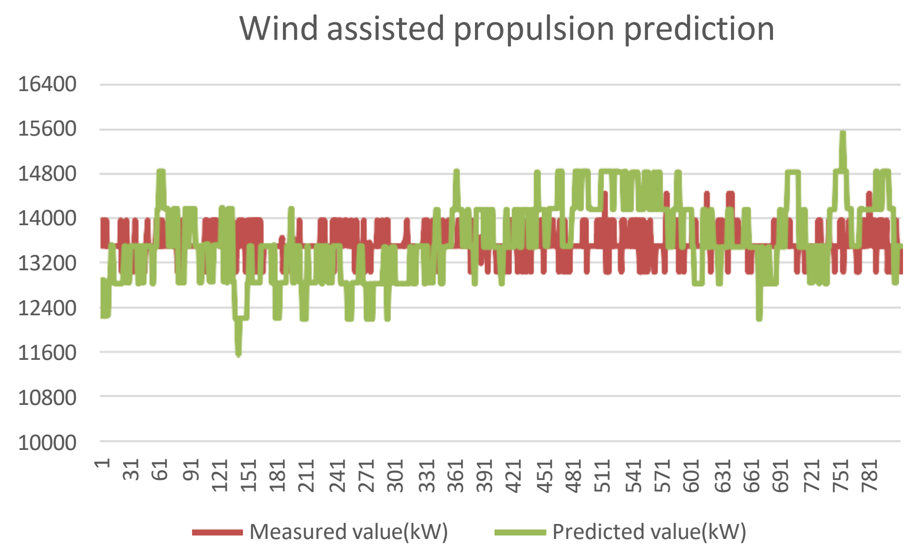
Case No.	Date
1	2023-1-27T00.00.00+2023-1-27T02.13.00
2	2023-1-27T02.14.00+2023-1-27T04.27.00
3	2023-1-27T04.28.00+2023-1-27T06.41.00
4	2023-1-27T06.42.00+2023-1-27T08.55.00
5	2023-1-27T08.56.00+2023-1-27T11.09.00
6	2023-1-27T11.10.00+2023-1-27T13.23.00
7	2023-1-27T13.24.00+2023-1-27T15.37.00
8	2023-1-27T15.37.00+2023-1-27T17.50.00

- **Prediction cases**

Case No.	Date
1	2023-1-27T17.51.00+2023-1-27T20.04.00
2	2023-1-27T20.05.00+2023-1-27T22.18.00



○ Comparison and Prediction

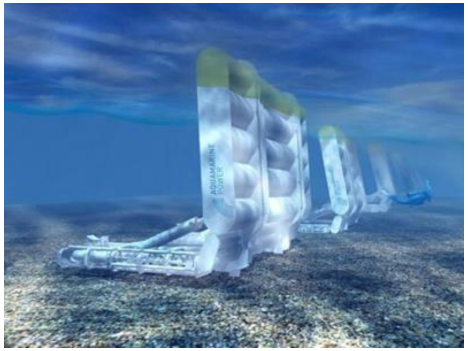


- **The AI trained ship propulsion model is smart and can be used to predict energy consumption considering wind-assisting effect with better accuracy.**

'Application of an AI-based SADA Method in the Prediction of Propulsion Performance and Energy-Saving Optimization for Wind-Assisted Propulsion Vessels', will be published in *International Conference of Ships and Offshore Structures* in Gothenburg, Sweden, September 2025.

Outlines

- Introduction
- Physics-informed AI technology in energy efficiency optimization
    - Dynamic application in Wind-assisted Ship Propulsion
    - Quasi-static application in optimization of propulsive efficiency
- Hydrogen engine onboard sea trial

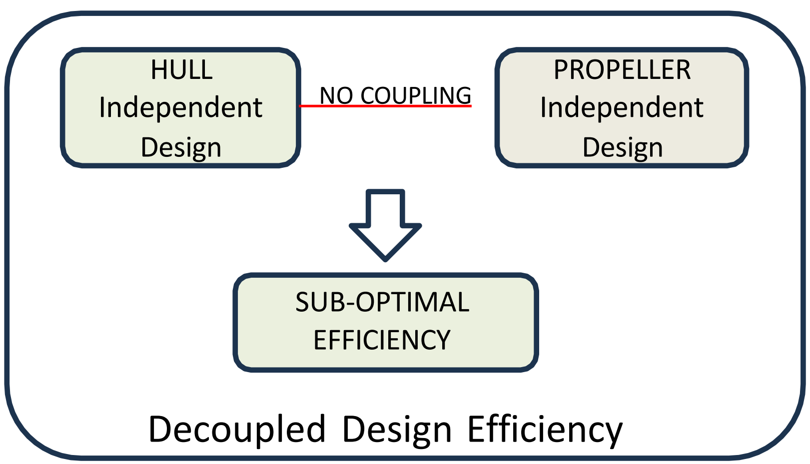



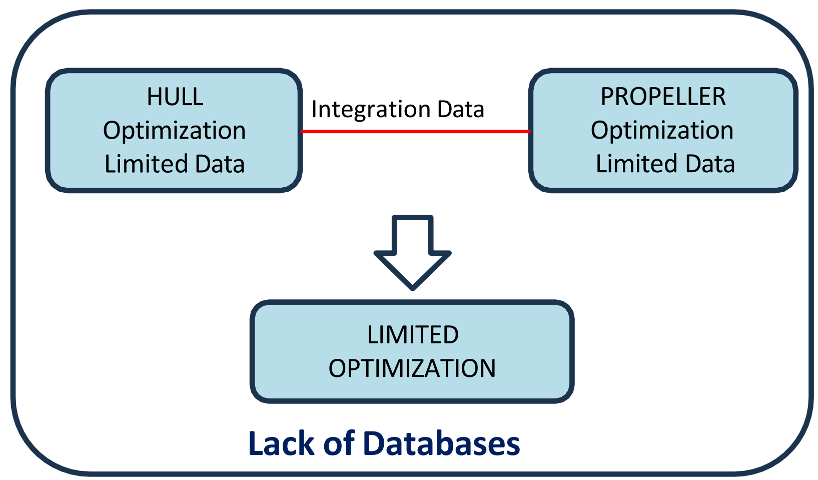

Quasi-static Physics-informed AI Tech

○ **Design optimization considering interactions between Ship hull and propellor**

Challenges

1) Exiting ship design optimizes hull and propeller separately, failing to capture complex hull-propeller hydrodynamic interactions and limiting achievable efficiency gains.
2) Ship propulsion optimization faces severe data scarcity. Limited experimental datasets published.
3) Unaffordable cost for large amount of high-fidelity hydrodynamic analysis via CFD.





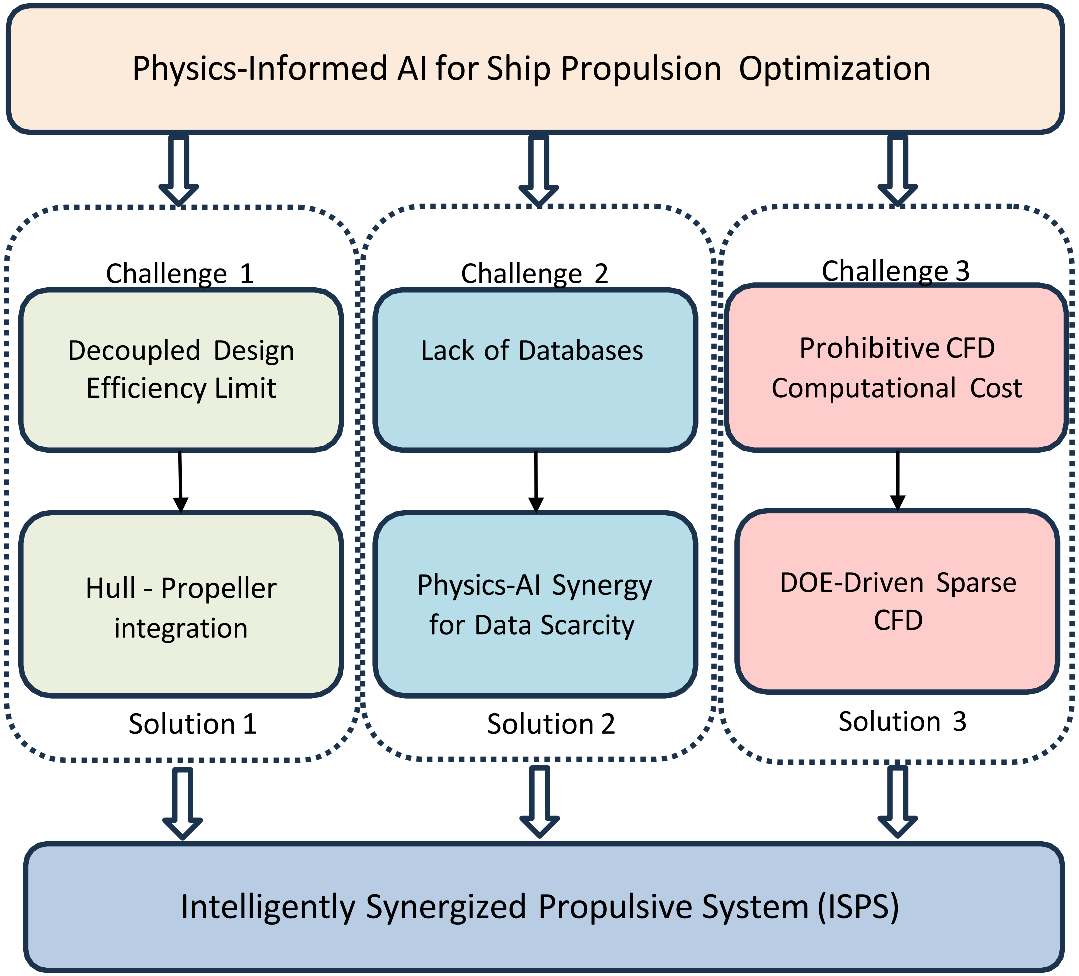
Quasi-static Physics-informed AI Tech

Newcastle University

Research aim

This research develops the Intelligently Synergized Propulsive System (ISPS), a physics-informed AI framework addressing the three critical challenges to achieve substantial propulsion efficiency improvements in ship design.

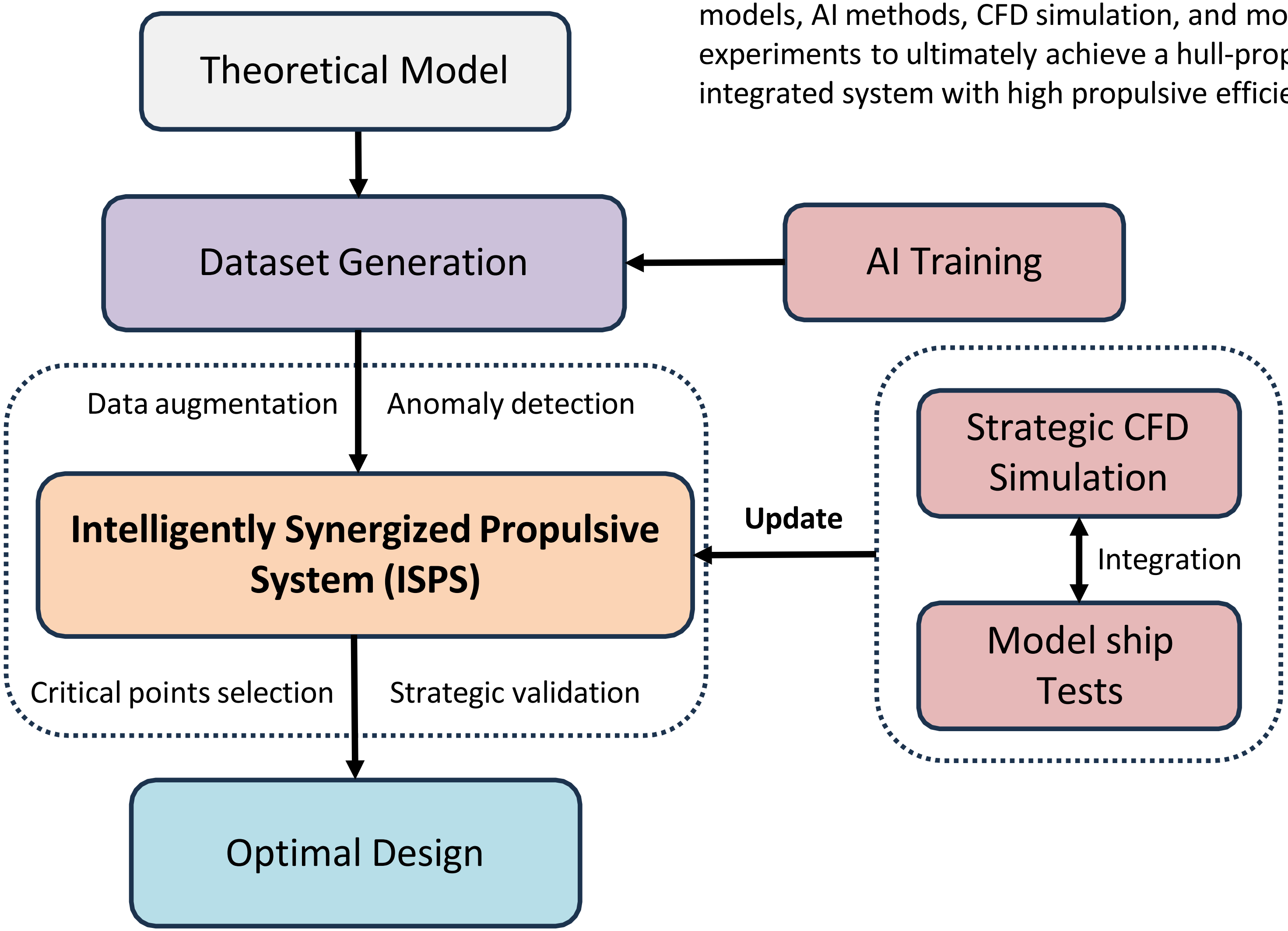
- **Solutions to challenges in ISPS method**



Quasi-static Physics-informed AI Tech

ISPS framework

This research will establish the ISPS through theoretical models, AI methods, CFD simulation, and model experiments to ultimately achieve a hull-propeller integrated system with high propulsive efficiency.



Quasi-static Physics-informed AI Tech

Newcastle University

Theoretical models building

$$R_t = R_w + R_f$$

$$\mathbf{T} = Z\int_{r_h}^{R}\left[F_i \cos\beta_i - F_v \sin\beta_i\right]dr\left(\hat{e}_a\right)$$

$$\eta_H = \frac{1-t}{1-\omega}$$

$$R_w = \frac{A\rho g^2}{\pi U^2}\int_1^{\infty}\left(I^2 + J^2\right) * \frac{\lambda^2}{\sqrt{\lambda^2 - 1}}d\lambda$$

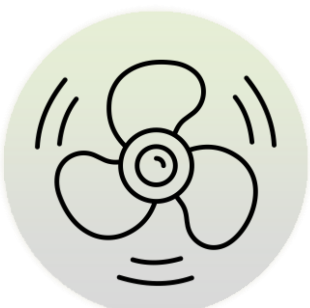
$$\mathbf{Q} = Z\int_{r_h}^{R}\left[F_i \sin\beta_i + F_v \cos\beta_i\right]rdr\left(-\hat{e}_a\right)$$

$$\eta_R = 0.9922 - 0.05908A_E / A_O + 0.07424\left(C_P - 0.0225lcb\right)$$

$$R_f = \frac{1}{2}C_f \rho U^2 A_{ws}$$

$$\eta_0 = \frac{TV_s}{Q\omega}$$

Resistance



Propeller Efficiency

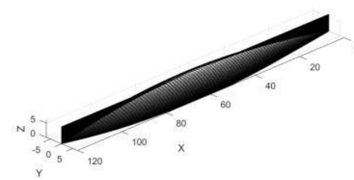
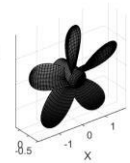
Interaction Effect

- Theoretical models is the foundation for AI tech application.
- An in-house programme will be built based on these theoretical models.

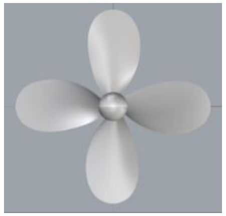
Quasi-static Physics-informed AI Tech

○ CFD simulations

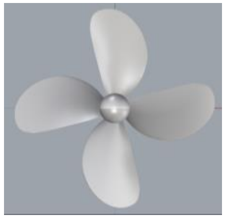
- KCS containership as reference ship.
- Preliminary CFD simulations.
- StarCCM+

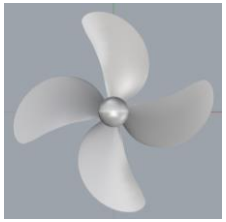
Propeller Skew:



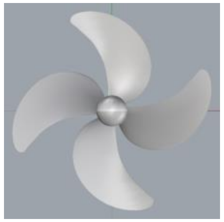
0 Deg.



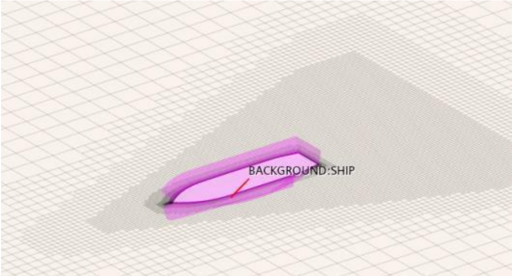
16 Deg.



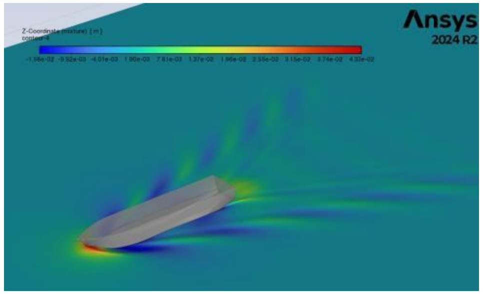
32 Deg.



48 Deg.

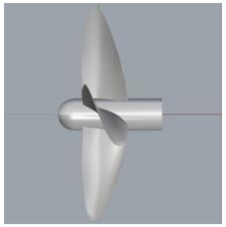


CFD model

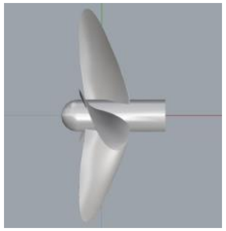


Wave elevation

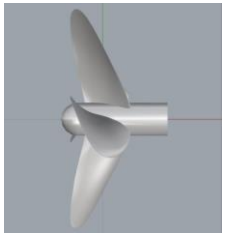
Propeller Rake:



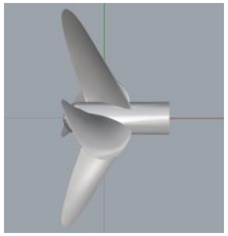
0 Deg.



6 Deg.



12 Deg.



18 Deg.

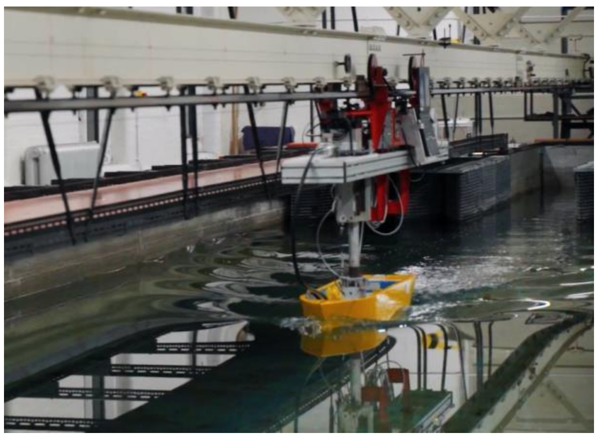
Model scale Exp. Vs CFD

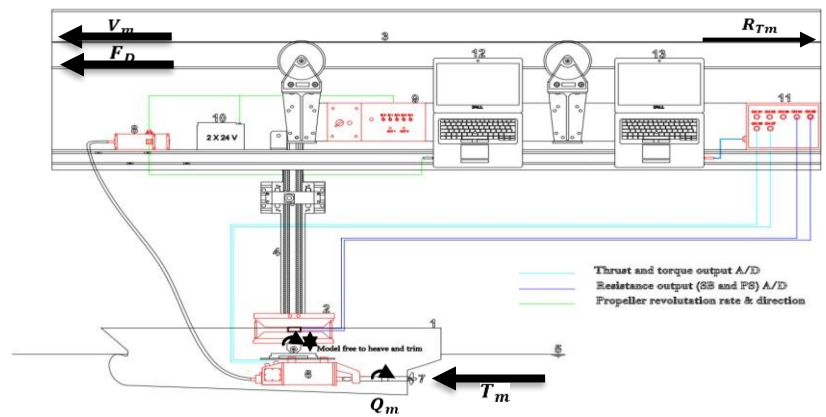
V_s [kts]	Fn [-]	V_m [m/s]	R_T Exp. [N]	R_T CFD. [N]
5.164	0.158	0.598	1.045	1.029
6.060	0.186	0.697	1.303	1.375
6.886	0.211	0.796	1.719	1.795
7.798	0.239	0.897	2.302	2.332
8.590	0.263	0.988	2.838	2.872
9.537	0.292	1.097	4.671	4.310

Quasi-static Physics-informed AI Tech

○ Towing tank experiment

- Preliminary experiments have been conducted at Newcastle University.
- A KCS containership model has been selected as reference ship.





Towing Tank of Hydrodynamics Lab at Newcastle University

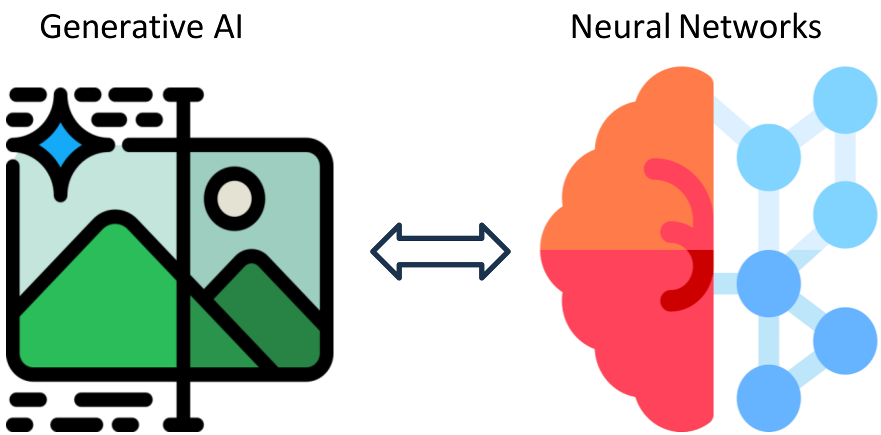
Propeller model

Ship model (containership)

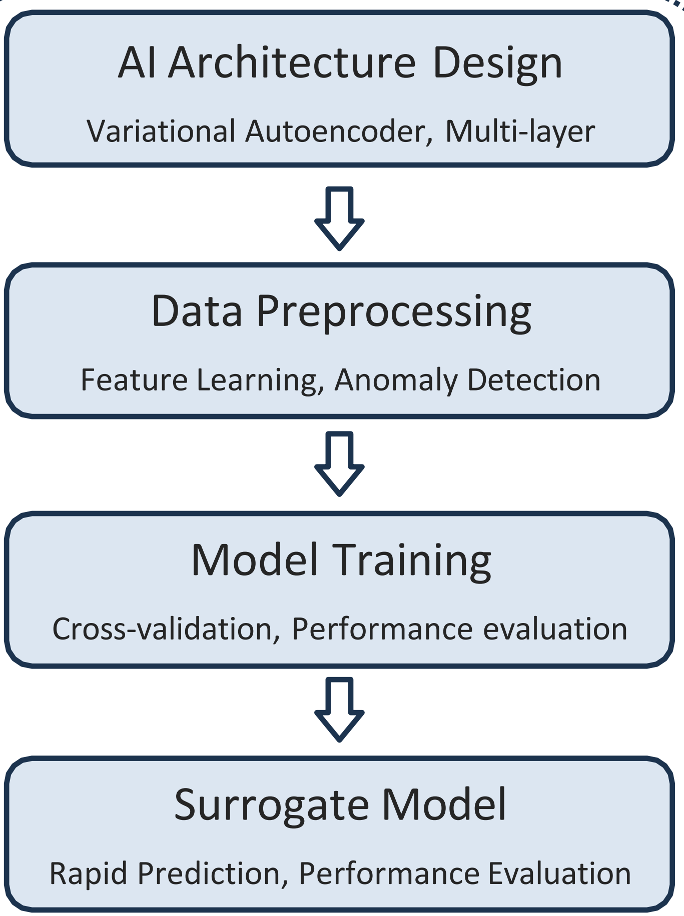
Quasi-static Physics-informed AI Tech

Newcastle University

○ AI technology application



During this process, generative AI and neural networks will be used.



- Using Variational Autoencoder methods to optimize the dataset and establish surrogate models through data training.
- The surrogate models will be useful and reliable tools for ship design optimization.

Outlines

- Introduction
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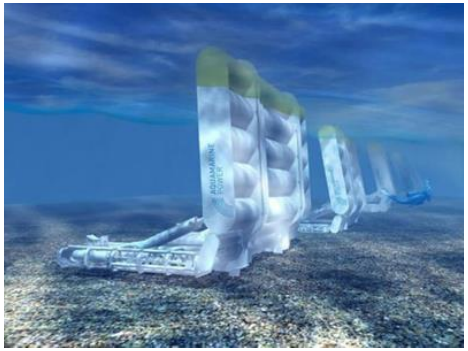
    - Dynamic application in Wind-assisted Ship Propulsion
    - Quasi-static application in optimization of propulsive efficiency
- Hydrogen engine onboard sea trial


Hydrogen engine onboard testing

Newcastle University

- **A collaborative research with Innovate UK project.**

Aim:

Develop, test and deploy an innovative propulsion unit using battery with hydrogen as range extender on a UK certified Crew Transfer Vessel (CTV), The Princess Royal to achieve Net Zero Emissions (NZE).

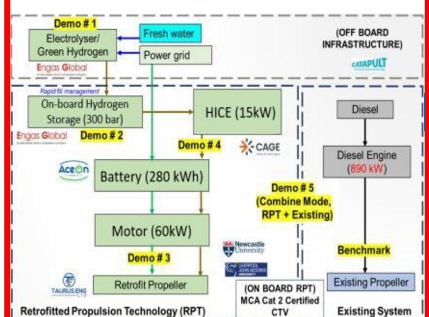
Objectives (overcome identified barriers):

- Design onshore recharging and hydrogen production infrastructures
- Integrate Retrofittable Propulsion Technology (RPT) on CTV.
- Demonstrate RPT applicability and market scalability.
- Platform for real-time data-monitoring for sea-trials (Port-of-Blyth and Blyth-Wind farms).
- Evaluate impact of RPT on vessel emissions reduction and human factor.

Hydrogen engine onboard testing

Newcastle University

Vessel Name	The Princess Royal
Ship Type	Working Boat
Length Overall	18.88 m
Beam	7.3 m



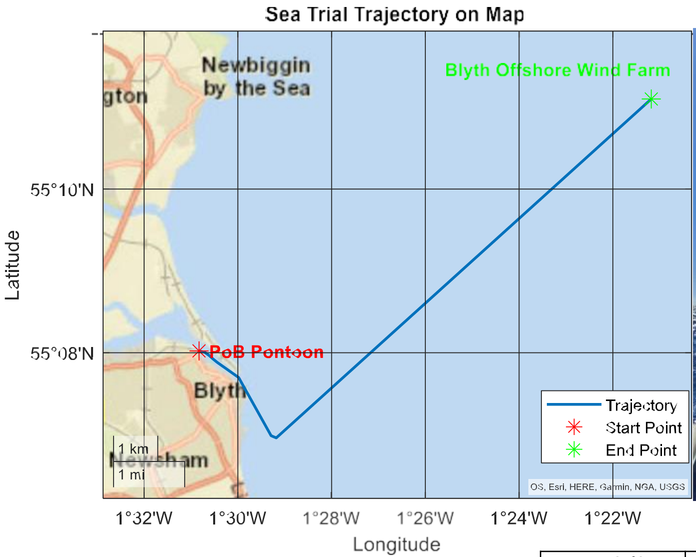
Stability Assessment

Modification

Certification: Working at Sea

Risk Assessment, Mitigation Plans and User Manual: Retrofitted System

Hydrogen engine onboard testing



Scenario: CTV Operation to Blyth Wind Farm

- Data Collection

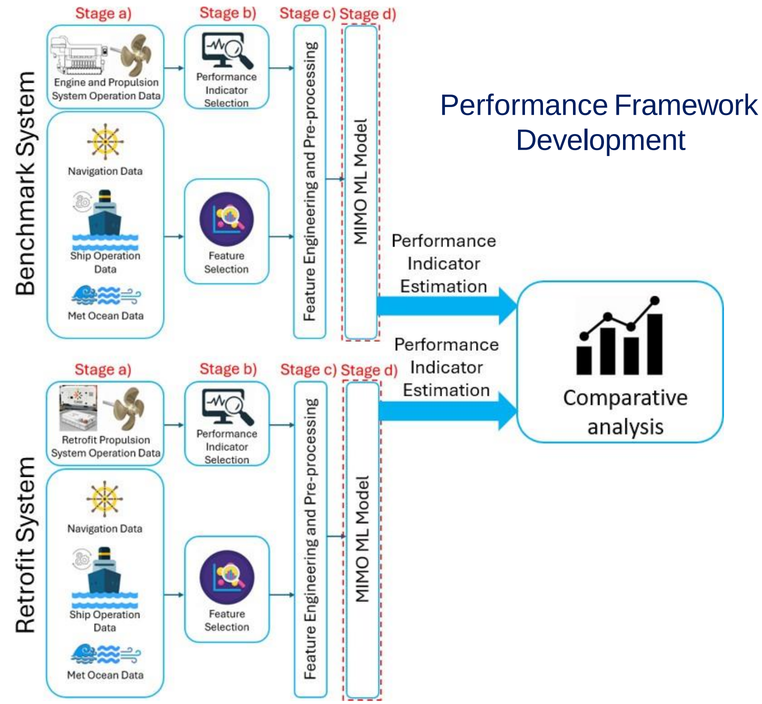
- Real-time Data Monitoring

Date: 07/04	Mode	COG	Speed	Apparent Wind		Motor		Battery1		Battery2		Water Depth
Timestamp	Mode	COG	SOG	Speed	Bear	RPM	Power	Bat1 SOC%	Bat1 Power	Bat2 SOC%	Bat2 Power	
[hh:mm:ss]	EV1/EV2/HY1/HY2	[deg]	[kt]	[kt]	[deg]	[RPM]	[%]	[%]	[kW]	[%]	[kW]	[m]
10:37	EV2	104	4	17.2	60	2022	40	71	0	80		10.9
10:38	EV2	85	4.5	16.8	73	2502	71	71	0	80	57	12.2
10:39	EV2	73	4.8	17.2	86	2478	69	71	0	79	56	14.7
10:40	EV2	64	5	15.3	94	2504	70	71	0	78	56	16.2
10:41	EV2	63	5.1	15.7	98	2505	71	71	0	77	56	17.4
10:42	EV2	58	5.1	16.2	102	2504	69	71	0	77	56	17.4
10:43	EV2	54	5.3	16.6	103	2504	70	71	0	76	55	19
10:44	EV2	60	4.9	15.7	102	2498	69	71	0	75	56	18.7
10:45	EV2	63	5.2	16.3	99	2506	70	71	0	75	56	19
10:46	EV2	61	5	16.6	99	2504	70	71	0	74	56	21.5
10:47	EV2	64	5.1	15.3	97	2505	71	71	0	74	55	25.8
10:48	EV2	62	5.1	16	96	2505	70	71	0	73	56	30.4
10:49	EV2	61	5	16.2	98	2505	70	71	0	72	55	31.6
10:50	EV2	64	5.1	18.9	92	2505	71	71	0	72	56	32.6
10:51	EV2	67	5.3	16.3	100	2505	71	71	0	71	56	32.7
10:52	EV2	65	5	17.2	98	2503	72	71	0	71	56	33.8
10:53	EV2	52	5.2	16.7	105	2503	71	71	0	70	56	34.4
10:54	EV2	67	5.3	14.8	98	2502	70	71	0	69	56	34.9
10:55	EV2	71	5.1	16.7	95	2506	71	71	0	68	56	35.5
10:56	EV2	74	4.7	16.5	91	2515	54	71	0	67	57	35.6
10:57	EV2	75	5.1	16.5	95	2503	72	71	0	67	56	36.5
10:58	EV2	67	5.3	16.1	101	2504	71	71	0	66	56	36.5
10:59	EV2	63	5.1	14.5	101	2504	72	71	0	65	56	37.7
11:00	EV2	60	5.2	15.6	101	2505	72	71	0	65	56	37.7
11:01	EV2	60	5.3	15.8	105	2506	72	71	0	64	57	38.3
11:02	EV2	58	5.2	14.3	110	2506	71	71	0	64	55	38.7

Hydrogen engine onboard testing

Technical summary

- CTV sea trial conducted: a typical route to Blyth Wind Farm.
- Based on sea trial data, the CO_2 emissions of the retrofitted propulsion system were compared against those of the benchmark diesel system.
- With a carbon intensity of 124 g CO_2/kWh and 92.5% grid efficiency, the retrofitted system consumes approximately 0.023 tonnes of CO_2 per roundtrip and 4.784 tonnes annually.



An effective and promising CO_2 reduction solution for achieving UK national Net Zero target.

VIP visit; across Tyne Bridge

Thank you

Carisbrooke Shipping Innovation
25th June 2025
Liverpool

Capt. Simon Merritt

Senior Fleet Manager

Capt. Simon Merritt began his maritime career with Carisbrooke Shipping 36 years ago, quickly rising through the ranks to become Master at just 23 years old. Over the years, he has taken on key roles, including Project Manager for newbuilds in China and Technical Director for the fleet in Germany.

For the past 15 years, Capt. Merritt has overseen all technical aspects of Carisbrooke's fleet, managing projects, innovations, and the introduction of new vessels, while ensuring the safety and operational efficiency of the fleet in service.

Carisbrooke Shipping Ltd

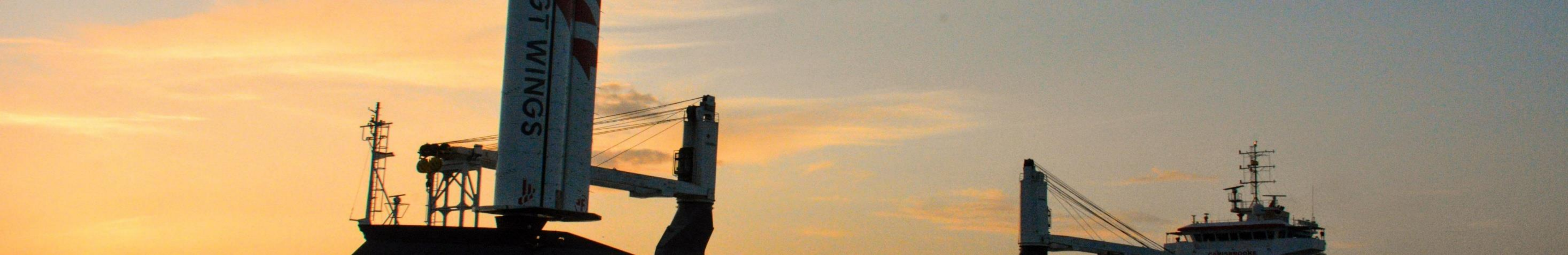
Carisbrooke Shipping owns and operates a fleet of over 20 modern dry cargo and multi-purpose vessels from offices in Cowes, UK.

Founded in 1969 on the Isle of Wight all key aspects of ship management are covered in house, including technical and safety management, crewing and financial administration.

The average age of our fleet is currently 14 years old, with an excellent safety record, efficient designs and numerous innovative technologies. Our vessels trade worldwide and are operated by highly-trained, multinational crews.

Our vessels are all classed as general cargo carrying a multitude of dry bulk cargoes, project cargoes, heavy lifts, dangerous goods, forest products both within the holds or on deck. A number of our vessels are fitted with tween decks and cargo cranes servicing more remote locations.

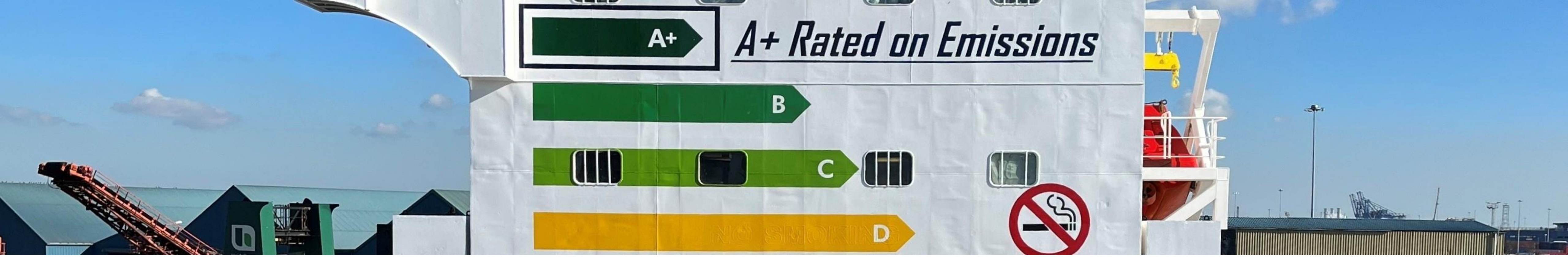
As with most companies the size and makeup of our fleet has evolved over the years led mainly by supply and demand or steel prices. We currently have 3 vessels under construction and plan a fleet renewal process in the coming few years.



Carisbrooke/GT Green Technologies AirWing™

- Funded 70% by Innovate UK under CMDC 4 (£3.69 million total cost)
- Installation of a 20m vertical wing onboard Vectis Progress in Hull February 2025.
- Annual fuel saving based on actual annual voyages performed 8.3% (conservative).
- Designed by ex-Formula 1 & America's Cup team aerodynamicists.
- Class requirements are to withstand 100 knots of wind with safety factor of 20%.
- Lift is achieved with wind 30 degrees off the bow.
- Non-folding prototype to avoid complications, can be adapted later.
- Challenges with design, class reviews, structural reinforcement and delivery in short project window.

Wind has been harnessed for centuries; we need to adapt our design to suit modern vessel operations.



Challenges and Statistics

- Bridge visibility, Navigation lights, Radar blind sector, Stability, Underdeck structure, Manoeuvrability.
- Underdeck structure added 7.7t, pedestal 8.4t, AirWing 37t, electrical systems 3.0t – total 56.1t
- Designed, built, approved, assembled, installed, commissioned and tested within 12 months.
- Installation of forward sidelights, navigational cameras, moved forward mast, forward radar.
- Installation was done in house with MMS Shipyard installing the pre-fabricated steel section.
- When the AirWing was installed we had to conduct new lightship survey and inclining test.
- Ongoing validation of data will continue but initial results are very promising.

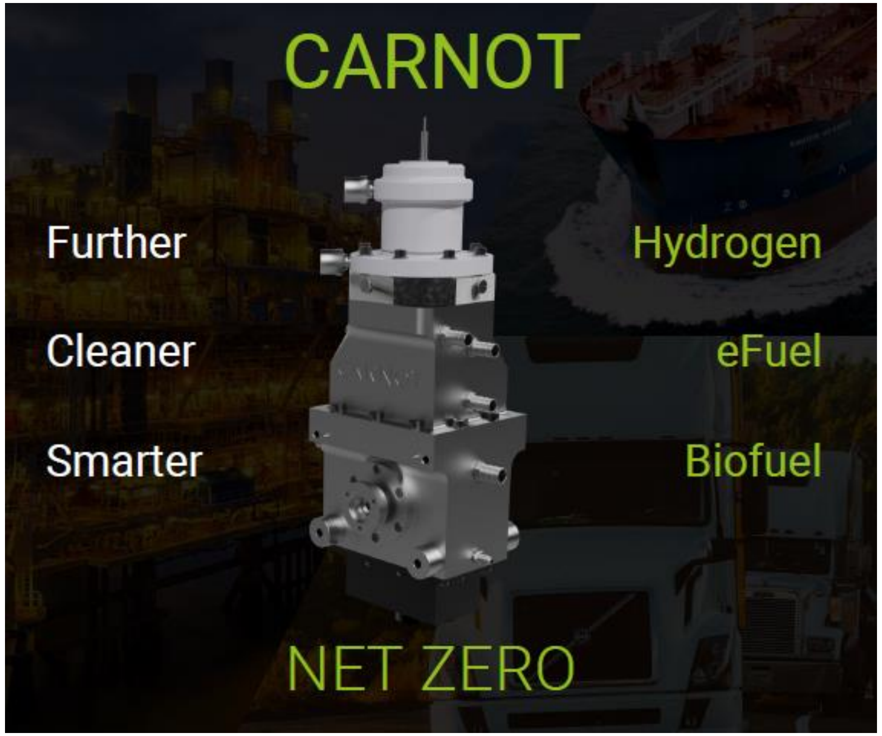

GT WINGS
VECTIS PROGRESS

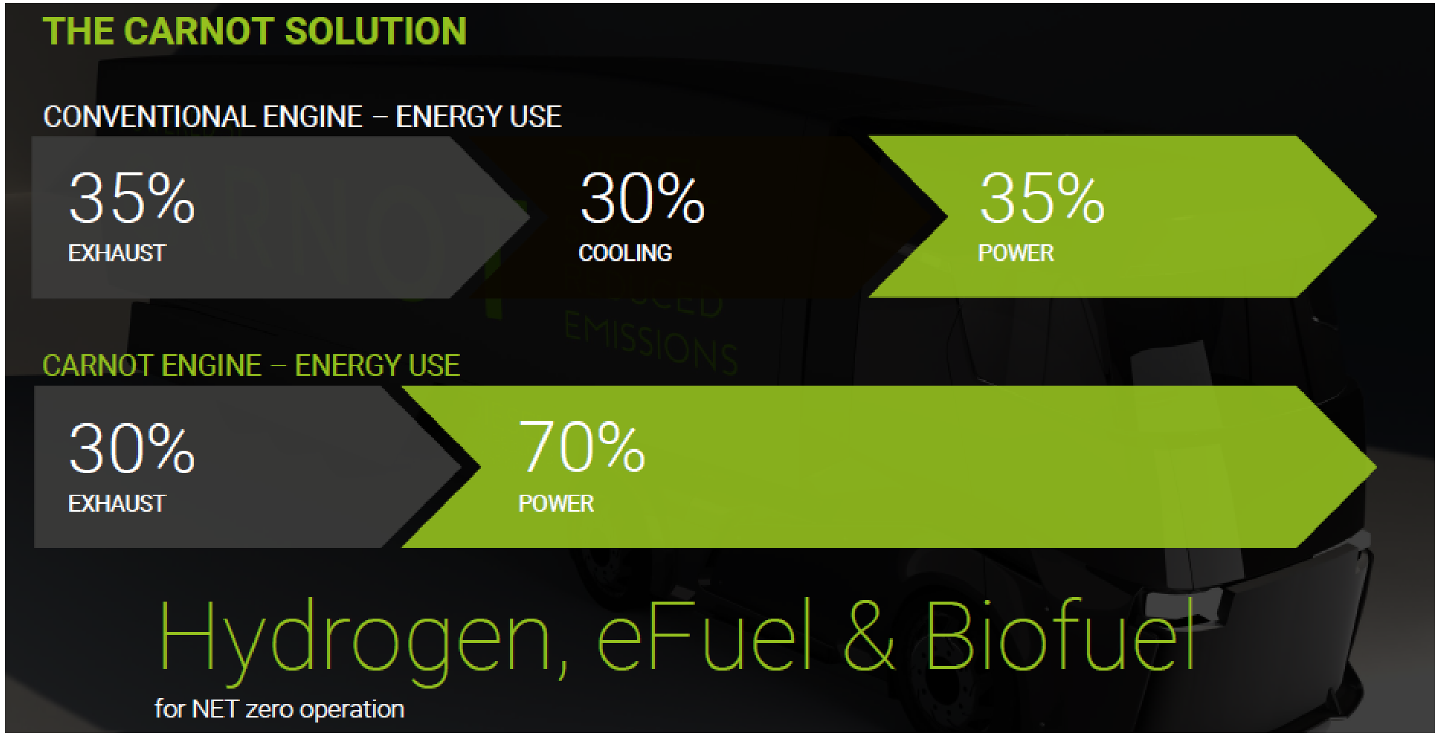
Carnot High Efficiency Hydrogen Combustion Engine Demonstrator

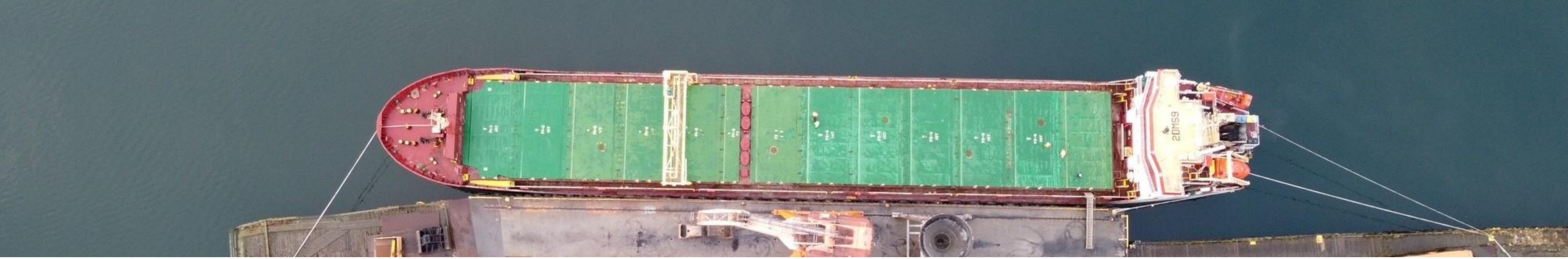
CARNOT

- Installation of a 50kW prototype hydrogen engine onboard MV Kathy C Q3 2025.
- Funded by Innovate UK under CMDC 3 (funding £2.28 million).
- Zero carbon emissions when burning hydrogen.
- No cooling system to engine as components can withstand extremely high temperatures.
- 70% thermal efficiency against the most efficient engines currently in production with 50 - 55%.
- Oil cannot be used to lubricate as it will vaporise, (self-lubricating Inconel materials).
- Engine, safety & control systems plus battery buffer in a standard 20ft container on deck.
- Hydrogen fuel storage system in a 10ft container on deck at 250 bar (approx. 250kg H_2).
- Regulations for H_2 systems in their infancy, first MCA H_2 approved training in April, no experience at sea (yet).
- Sailing between Belfast & Avonmouth to prove the concept (engagement with all parties).
- Testing of the prototype engines on diesel & H_2 has been ongoing for many months.

https://carnot.egnyte.com/dl/kGdFm48wZN


CARNOT
Further
Cleaner
Smarter
Hydrogen
eFuel
Biofuel
NET ZERO


THE CARNOT SOLUTION
CONVENTIONAL ENGINE – ENERGY USE
35%
EXHAUST
30%
COOLING
35%
POWER
CARNOT ENGINE – ENERGY USE
30%
EXHAUST
70%
POWER
Hydrogen, eFuel & Biofuel
for NET zero operation



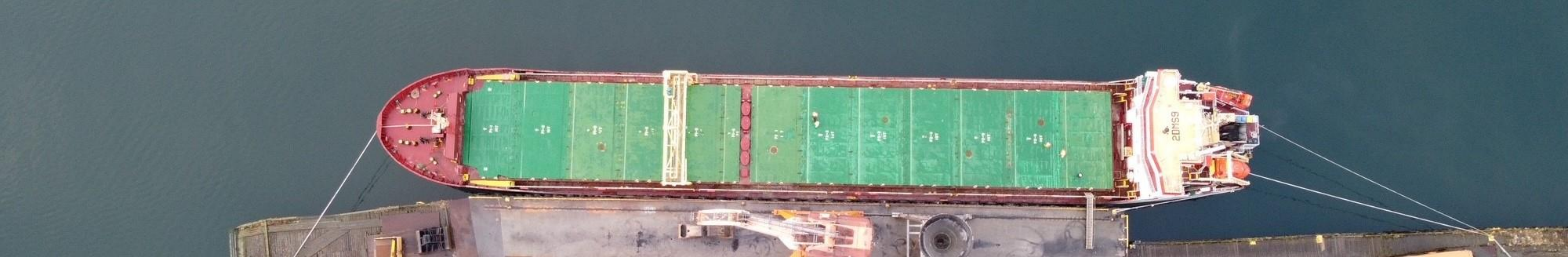
Dispelling the myth

Everyone knows of the Hindenburg disaster where a hydrogen airship was engulfed in flames when docking during 1937 with significant loss of life – we have all seen the famous news headlines.

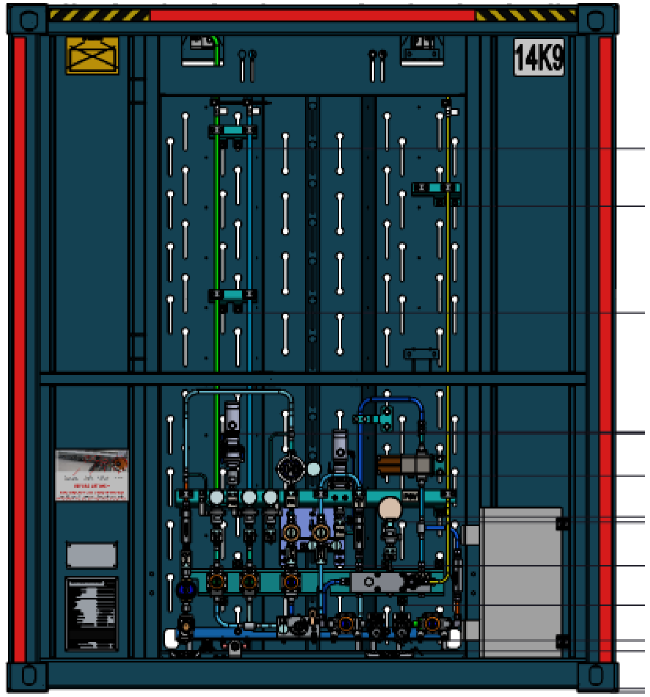
Detailed studies from NASA and others have shown that the Hindenburg disaster was likely exacerbated, but not caused, by hydrogen. It was probably caused by static electricity following a collision with the docking station which led the huge hydrogen filled air ship to catch alight.

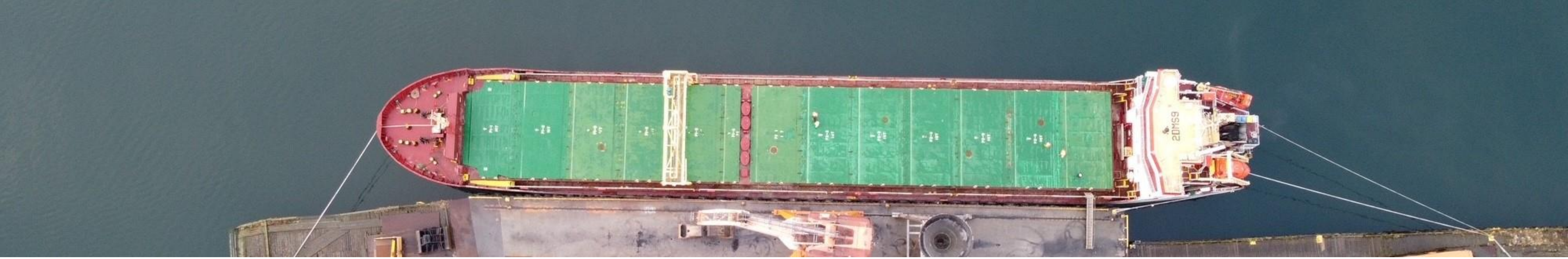
But did you also know her sister ship *Graf Zeppelin*:

- **Flew more than a million miles,**
- **Nearly a decade on hydrogen without incident,**
- **Made 590 flights, including first circumnavigation of the world by an airship,**
- **First nonstop crossing of the Pacific Ocean by air,**
- **Visited Arctic and numerous other remote regions,**
- **Provided first commercial transatlantic passenger service.**



H2 storage & plant layout



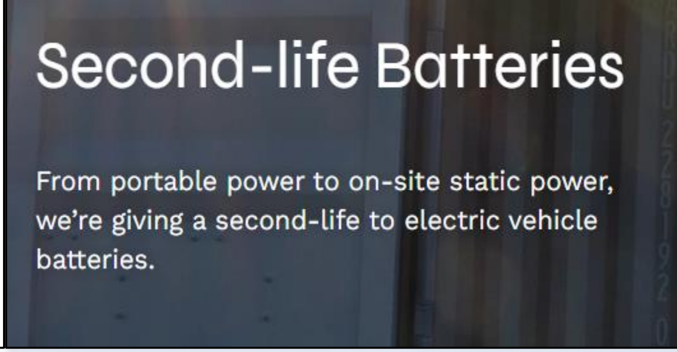


Progress so far

One prototype engine being tested at Carnot Engines facility for diesel.
One prototype engine being tested at Brunel university for hydrogen.
Approval in Principle (AiP) received from BV.
Fuel storage system delivered and undergoing BV approvals.
Plant container being fitted out ready for engine and ancillary installations.
Key personnel attended TFF, IGF basic, IGF advanced and MCA H2 training.

Lots of work lies ahead but preparations are in place to test our prototype engine onboard a vessel later this year paving the way for future trials. We anticipate scaling up to replace one engine at a time in our new builds currently designed as diesel electric.

There is a lot of interest and potential investment based on successful outcome, even without hydrogen this engine has potential to cut emissions by 30%.



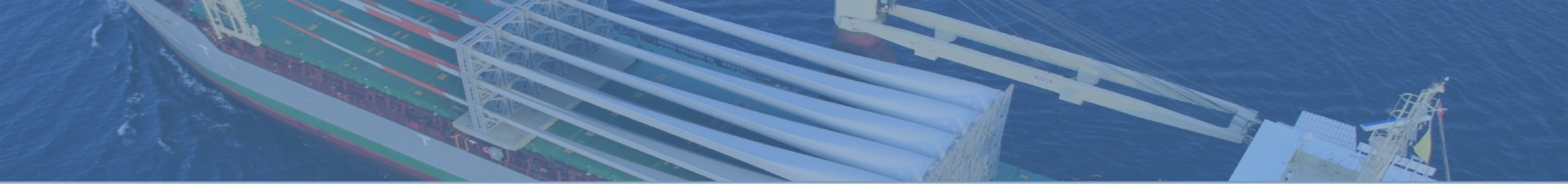
Cold-ironing and power-bank recycling

‘Cold Ironing’ systems were designed and incorporated onboard eight of our newbuilds 12 years ago; however, finding a port that provided a shore power connection to general cargo terminals remains a challenge.

As the technology advanced, we found a partner in the port of Antwerp and conducted trials with an innovative company which converts used non-recyclable EV batteries into a large containerised power bank which was placed on the quay allowing us to run cold in port.

During a port call at Zuidnatie Terminal (Antwerp) between 10th – 13th September 2023 we teamed up with Zenobe for our first cold ironing trials. We were able to take power from a battery bank on the quay which enabled us to switch off the ship’s generators for 3 days and power the vessel almost exclusively from the batteries – there was also a backup shore generator for the first trials which was a local port requirement.

We have since upgraded the cold ironing facility onboard UAL Harrier with the learnings from the first trials enabling synchronisation, so we do not need to blackout the ship during power transfer. We hope to make a second trial soon with a larger battery pack charged by solar panels and windmills located on the quay for real zero emission cold ironing.

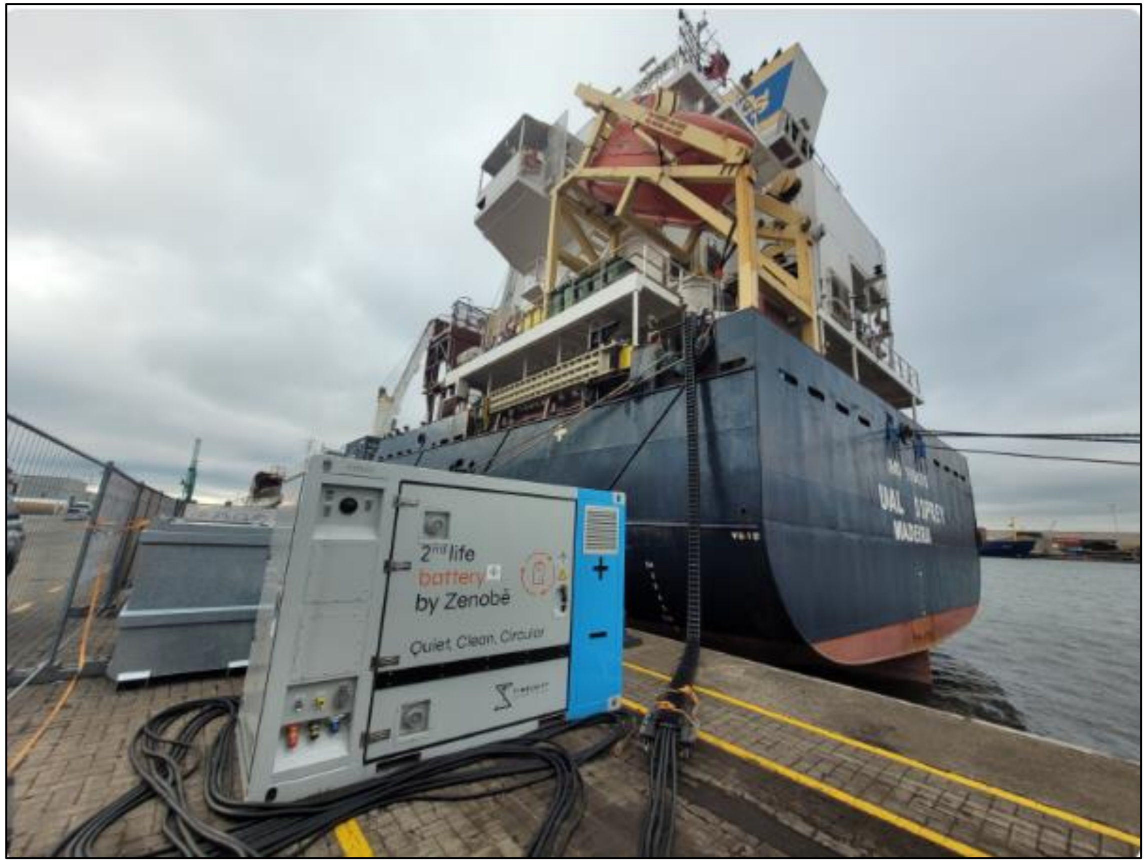


Benefits

Reduced emissions in port areas.
Lower machinery noise onboard and in port.
Lower engine running hours, lower running costs ($4.5/h).
Lower Lub Oil consumption.
Ancillary equipment can be switched off, lower loads.
More comfortable environment onboard the vessel.
Maintenance can be conducted on those engines.

Lower fuel consumption from ships stock significantly reduces taxes from FuelEU, ETS allowances and the vessels CII rating improves dramatically – especially for vessels trading exclusively in EU or with long durations alongside.

https://www.youtube.com/watch?v=UeoMNEa3L8U

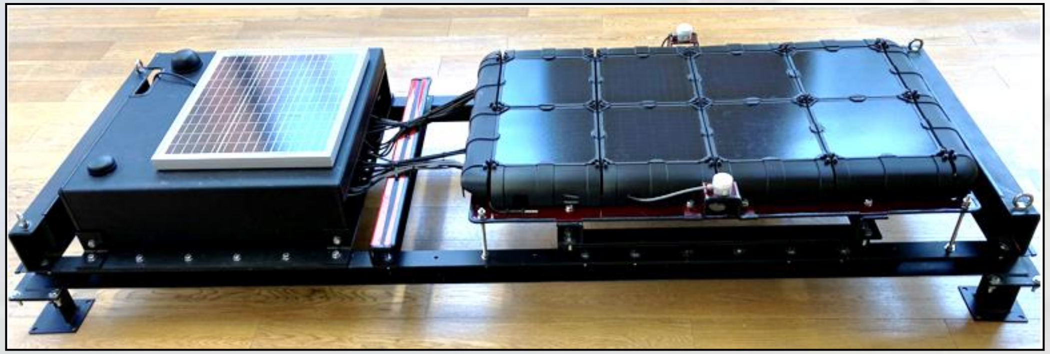


Solar Power Generation

Grafmarine have developed an innovative renewable energy source for the marine industry with their NanoDeck.

NanoDeck creates and stores energy in a single tile, this can be used in large or small arrays to supply ships electrical power. It is designed for retrofit or new build installation onto any flat surface such as vessel superstructures, within ports and marinas to create continuous energy.

The test array was placed on board of one of our 8,500 dwt vessels in Aberdeen in December 2022 for several months on her route to West Africa to gather data under varying light conditions, this was necessary to improve efficiency, the tiles will be produced by recycling fishing gear dumped in the oceans.



graf marine

GRAFMARINE

New Product – Lub Oil Trial (live)

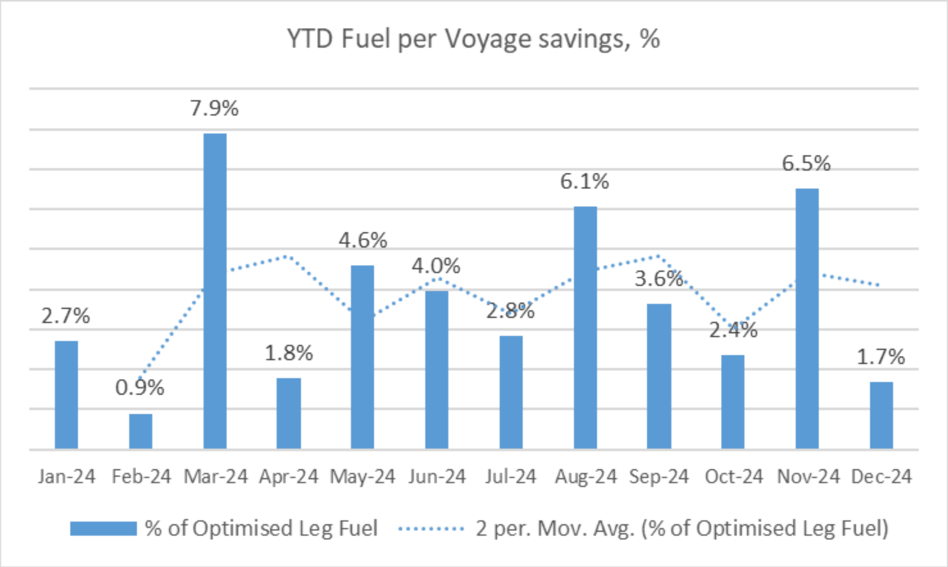
- Aurelia FE with low frictional properties.
- Suitable for all 4 stroke engines BN 20, 30, 40 available.
- Claimed this product will reduce fuel consumption by 3 – 5%.
- Kikki C – Oil being trialled since 23/10/23 (unofficial trials).
- Kimberly C – 2 Mass flow meters installed and building baseline.
- Further vessels planned to join this trial.
- Prior to trials we overhauled 2 complete units.
- Installation of highly accurate flow meters +/- 0.1% accuracy (EUR 10k).
- Regular observations & samples from the vessel to assess condition.
- Risk to owners in case of high wear, failure of components etc.
- With such small savings it's difficult to measure due to numerous variables.

TotalEnergies

Lubmarine

Carisbrooke Shipping Ltd – Fleet Operations Centre

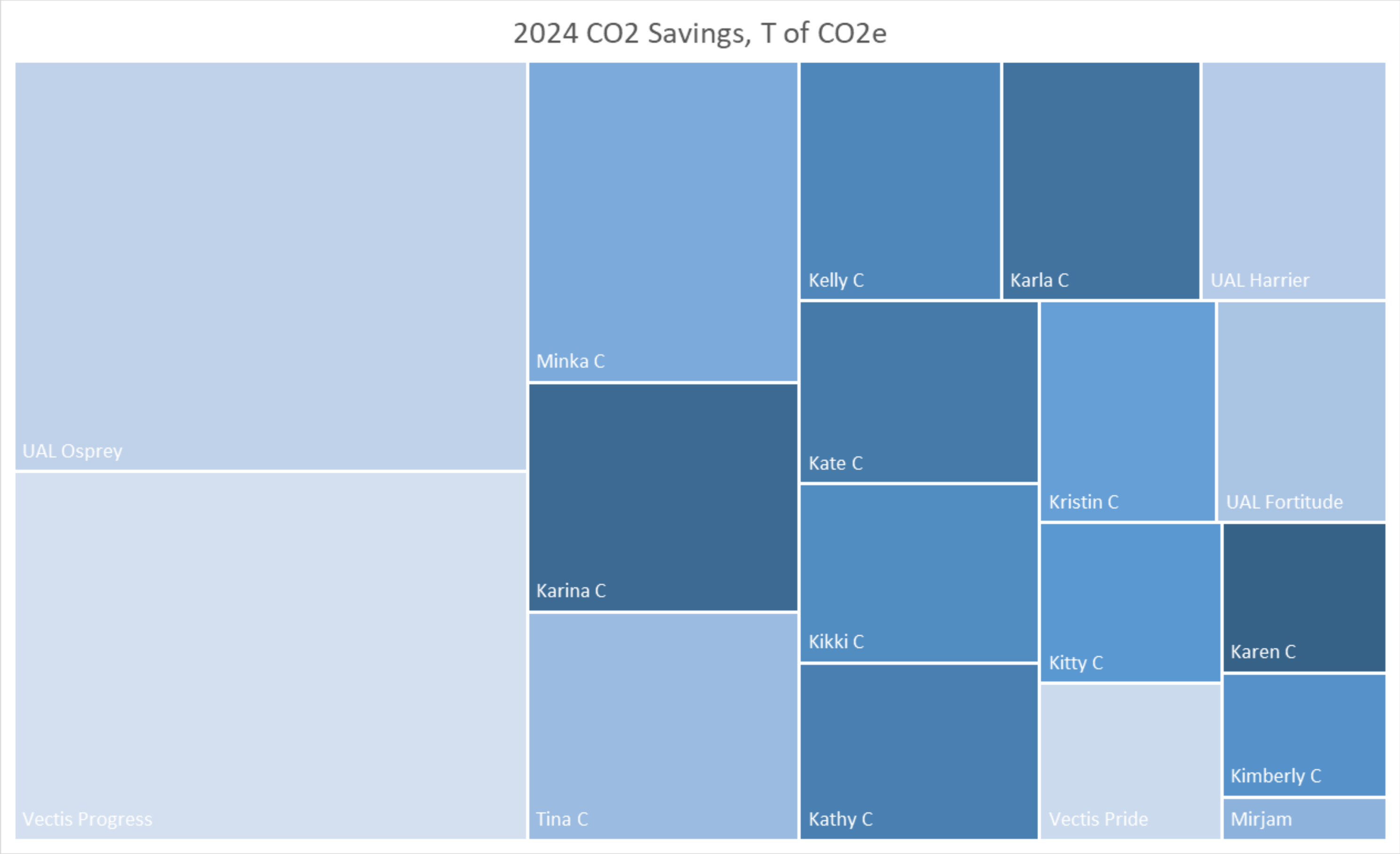
We started to monitor vessel performance 10 years ago and have designed a system to collect accurate, live data from our vessels and to optimise every voyage. Our focus is on Carisbrooke operated vessels, but we have capacity and expertise to advise externally.



- Close monitoring of voyage with live feeds from ships ECDIS.
- Daily meetings to review vessel data, voyage particulars, schedule & line up with the view to develop a single source of truth platform.
- Forward planning for vessels arrival, berth & port conditions.
- Monitor & optimisation of vessel performance.
- Optimisation of cargo intake and vessel trim.
- Optimisation of voyage using weather, tide and currents.
- Monitor of hull and propeller fouling, cleaning of hull can be scheduled.
- Compare sister vessels voyages to suggest improvements.

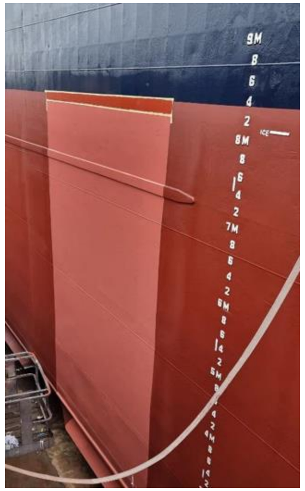
2024 Results

CO2 Emission savings – 838.8 tonnes;
264.4 tonnes of fuel
(5.4% of optimised voyages);
$178.7K in costs.



Underwater coating trials

AQUATERRAS (biocide free self-polishing) coating was applied as a test to Carisbrooke Shipping's MV ONEGO ISLE's vertical sides at Remontowa Shiprepair Yard in 2022 to test performance alongside Carisbrooke's standard conventional SPC antifouling coating and the monitoring is ongoing to be fully assessed in the next dry dock in 2027.



It is well known that underwater roughness can reduce vessel efficiency by 4-5% - however those parameters are extremely difficult to measure in service. We have decided to trial other hard type costings which are ultra smooth but will require more cleaning between docking intervals.

Sea-Speed (silane-siloxane technology) is an ultra hard underwater coating with a smooth finish which marine growth finds it difficult to attach to, easily cleaned and with a 10-year warranty against damage. We have coated one vessel with two more planned this year in dock.

We are also trialling *Intersleek* on another vessel within the fleet.

These coatings and their preparation are extremely expensive – only time will tell whether they are viable.

Biofouling Prediction Modelling Tool

University of Southampton is a part of the Russel Group and has a proven track-record of engaging with the local businesses to find innovative solutions to business challenges and provide a competitive advantage through consultancy or collaboration.

Our project is based around development and testing of the hull bio-fouling predictive tool using the University's National Biofilms Innovation Centre (NBIC) cutting-edge facilities and collaboration with their research team to help to fulfil their program requirements with the real-life operational knowledge. This has recently been delivered and being tested with ten vessels.

Select Historic Data

This tool allows you to analyze the fuel consumption of historic ships voyages and estimate the additional fuel cost due to biofouling.

Vessel: Karina C

Model: XGB

Start Date: 2023-03-01

End Date: 2023-03-31

Voyage ID:

Currency: $ /mt

HFO cost: $569.50

LFO cost: $801.00

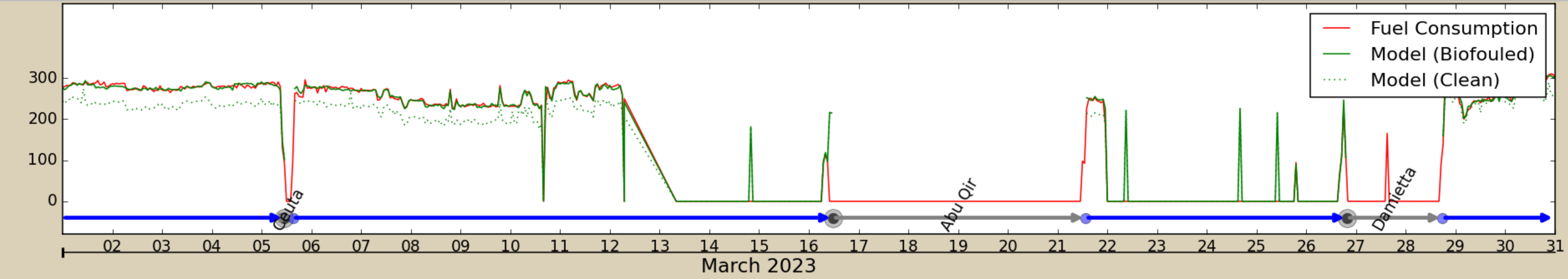
Plot

Karina C

01 Mar 2023 to 31 Mar 2023

Voyage | Speed | Wind | Fuel | Trim | Propellor | Biofouling | Evaluate Model

ID	From port	Since	To port	Till	Cargo (T)	IMRV (kg)	Eefting (kg)	Predict (kg)
263	Fowey	2023-02-28	Ceuta	2023-03-05	6579.0	0.00	29,927.88	29,830.47
263	Ceuta	2023-03-05	Ceuta	2023-03-05	nan	0.00	0.00	0.00
263	Ceuta	2023-03-05	Abu Qir	2023-03-16	6685.0	0.00	41,134.70	41,694.85
263	Abu Qir	2023-03-16	Abu Qir	2023-03-21	nan	0.00	0.00	0.00
264	Abu Qir	2023-03-21	Damietta	2023-03-26	0.0	0.00	2,989.22	3,743.41
264	Damietta	2023-03-26	Damietta	2023-03-28	nan	0.00	0.00	0.00
264	Damietta	2023-03-28	Ceuta	2023-04-07	6213.0	0.00	14,647.29	14,606.06



University of Southampton

Questions?

Thank you for your attention.

University of Nottingham
UK | CHINA | MALAYSIA

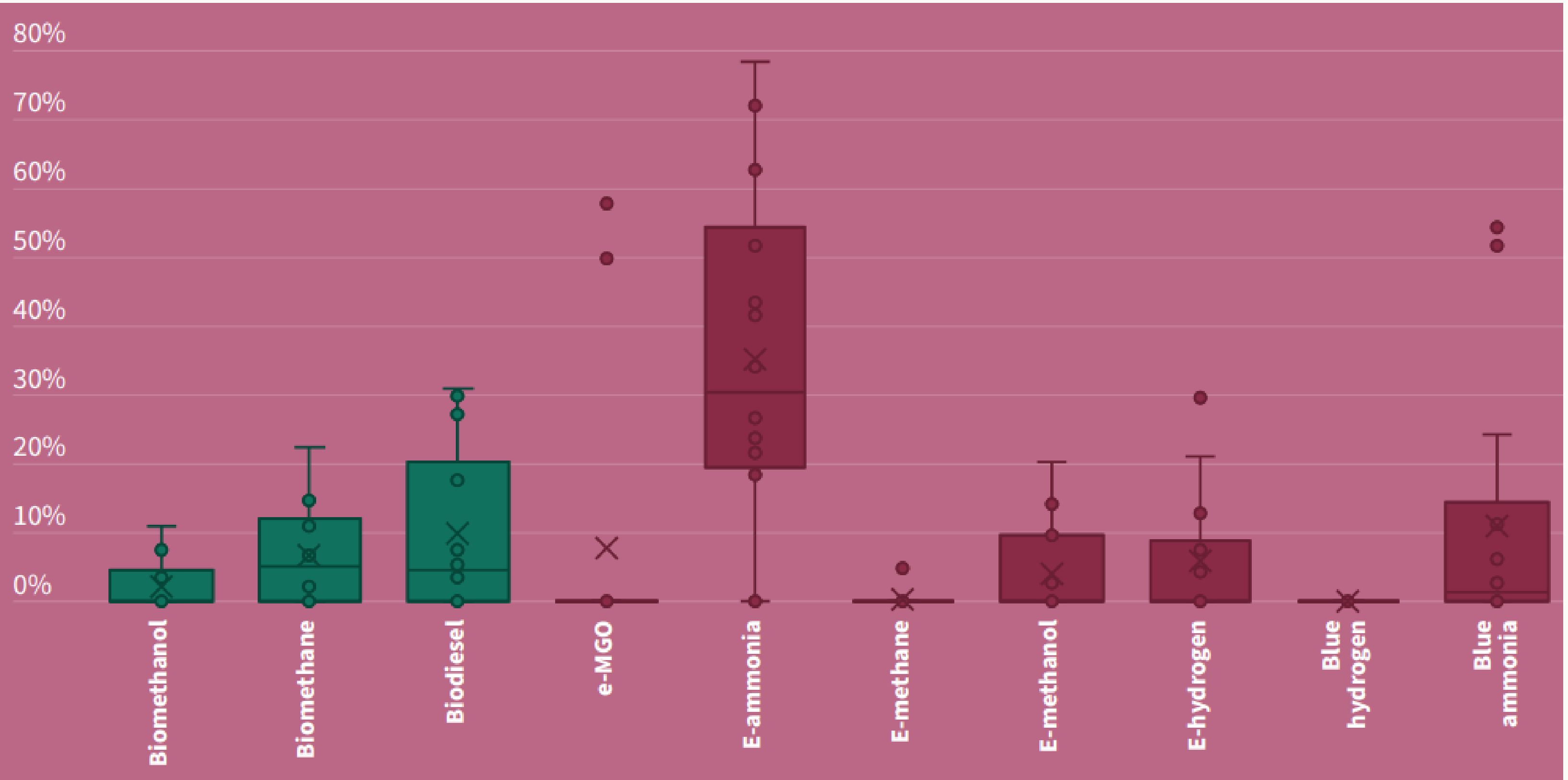
On-board Ammonia Cracking: Enabling Technology for Deep Decarbonisation of Maritime

Prof. Alasdair Cairns

June 2025

Contents

Future Maritime Fuels



E-ammonia is expected to be the most popular maritime fuel in the long term – on average the share of e-ammonia is 35% in 2050. However, there is a large variation across the scenarios because of the different assumptions on future prices and the ability to scale at the required pace given safety challenges.

Ref: "The Future of Maritime Fuels", Lloyds Register 2023

- Green NH_3 is projected to become the dominant marine fuel
- Uncertainty remains around acceptance criteria and environmental impacts
- Dual fuel solutions are already being developed (e.g. Wartsila, MAN, IHI etc.)

Key Fuels - End Use Characteristics

Attribute	Marine Diesel	Liquid Hydrogen	Methanol	Ammonia	Liquid Natural Gas
Energy Density	🟢	🟡	🟡	🟡	🟡
Combustion Characteristics	🟢	🟢	🟢	🟡	🟢
End Use Emissions	🔴	🟢	🟡	🟡	🟡
Safety	🟢	🔴	🟡	🔴	🟢
Technology Readiness Level	🟢	🟡	🟢	🟡	🟢
Ease of Storage	🟢	🔴	🟢	🟢	🟡

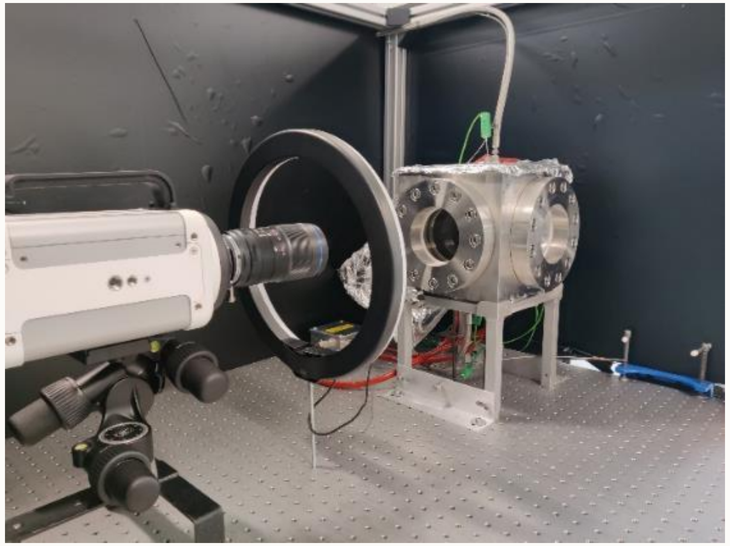
Contents

Nottingham Powertrain Research Centre

- **Our main focus is decarbonised heavy duty engines and fuels**
  - Advanced retrofit technologies
  - **Clean + high thermal efficiency**
  - Live funding portfolio of ~£12M

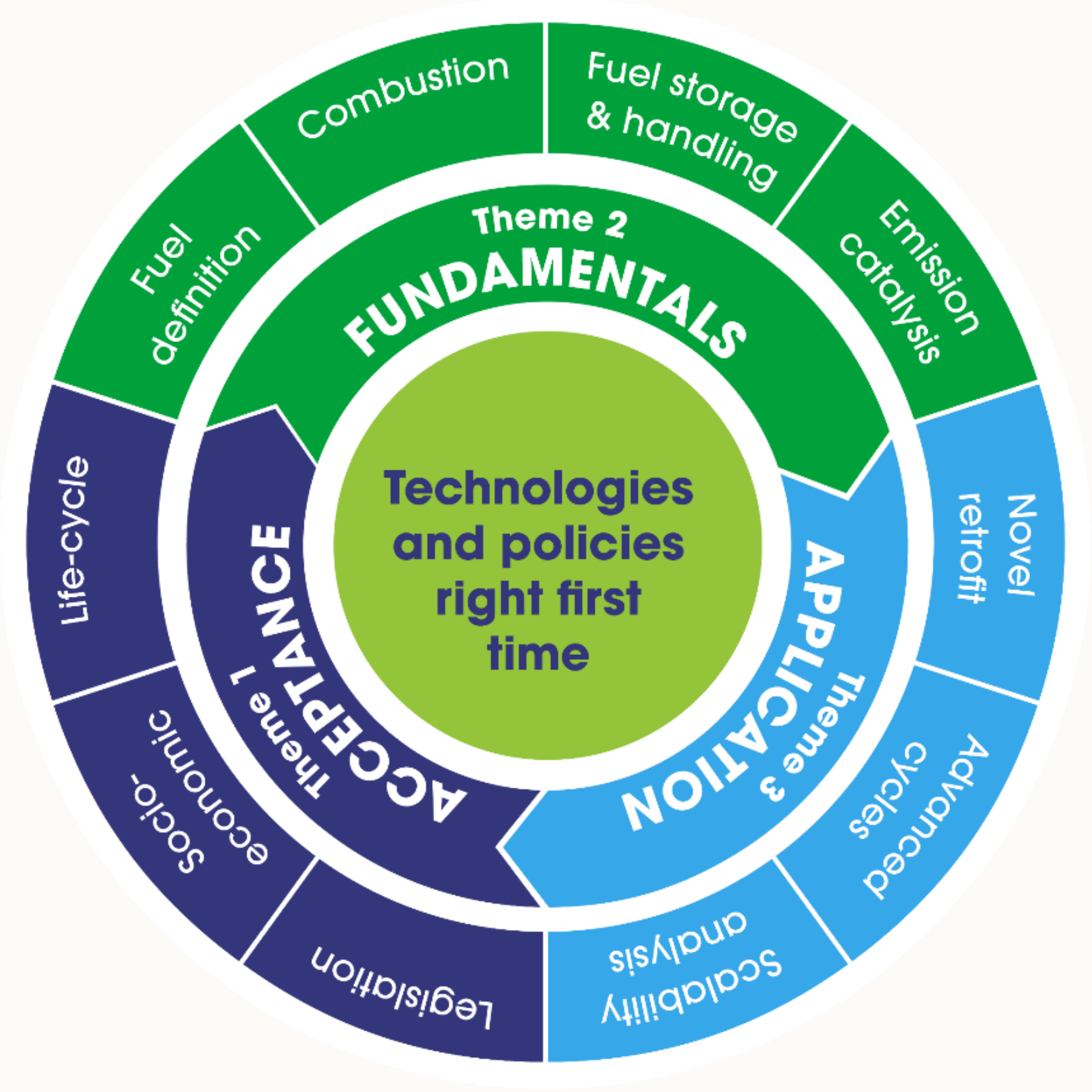
Metal Single Cylinder (Spark/Jet Ignition)

Dual Fuel Multicylinder



Optical Engine & Combustion Rigs

EPSRC “MariNH3” Programme



- Nottingham led 5-year programme (£5.51M funding, £9M cost, 2022-2027)
- Focus is four stroke ammonia fuelled marine engines
- Holistic (and agnostic) approach to understanding future end use of ammonia (beyond large two stroke applications)
- See https://marinh3.ac.uk

Industry & outreach partners

MariNH3

Clean, green ammonia engines for maritime

BMT	BP Shipping	Clean Air Power Ltd	Connected Places Catapult
Coryton Advanced Fuels	Cox Powertrain	Cummins Power Generation Ltd	Dolphin N2
Green Ammonia Working Group	Health & Safety Executive	Hybrid Marine Power Ltd	Infineum UK Ltd

Johnson Matthey	Lloyds Register EMEA	Longitude Engineering	MAHLE Powertrain Ltd
Maritime and Coastguard Agency	Pacific Green Technologies Group	Quantum ES	Ricardo UK
Rolls Royce PLC (UK)	SCE	Westport Fuel Systems	

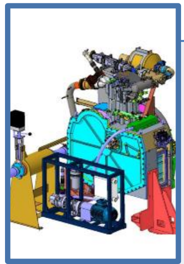
The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
UNIVERSITY OF BIRMINGHAM
University of Brighton
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
Funded by UKRI Engineering and Physical Sciences Research Council

Ammonia Propulsion Major Topics

MariNH3
Clean, green ammonia
engines for maritime

Decarbonisation

Combustion



Scale up

Emissions

Mono-Fuel operation

H_2 production

Cold start

Fuel storage & Preparation

Vessel approval

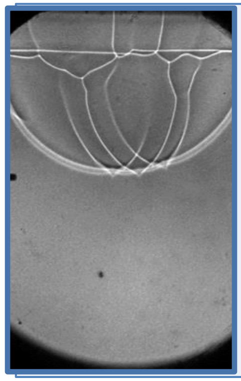
Technology roadmap to enable the adoption of safe, clean, efficient Ammonia ICE

Contents

NH_3 Engine Development Roadmap

Generation 1:

- Retrofit - Dual Fuel
- Diesel fallback
- Carbon Emissions
- Minimum viable combustion



Generation 2:

- Retrofit & New Build - Spark ignition
- Full decarbonisation
- High efficiency
- Clean Tailpipe Emissions

Generation 3:

- New Build - Fully optimised Ammonia
- Bespoke combustion architecture
- Advanced Tech (MAHLE Jet Ignition, Liquid NH_3)

Technology evolution for Ammonia ICE

Ammonia Spark Ignition – Global Warming Potential

- Must consider overall Global Warming Potential (GWP)

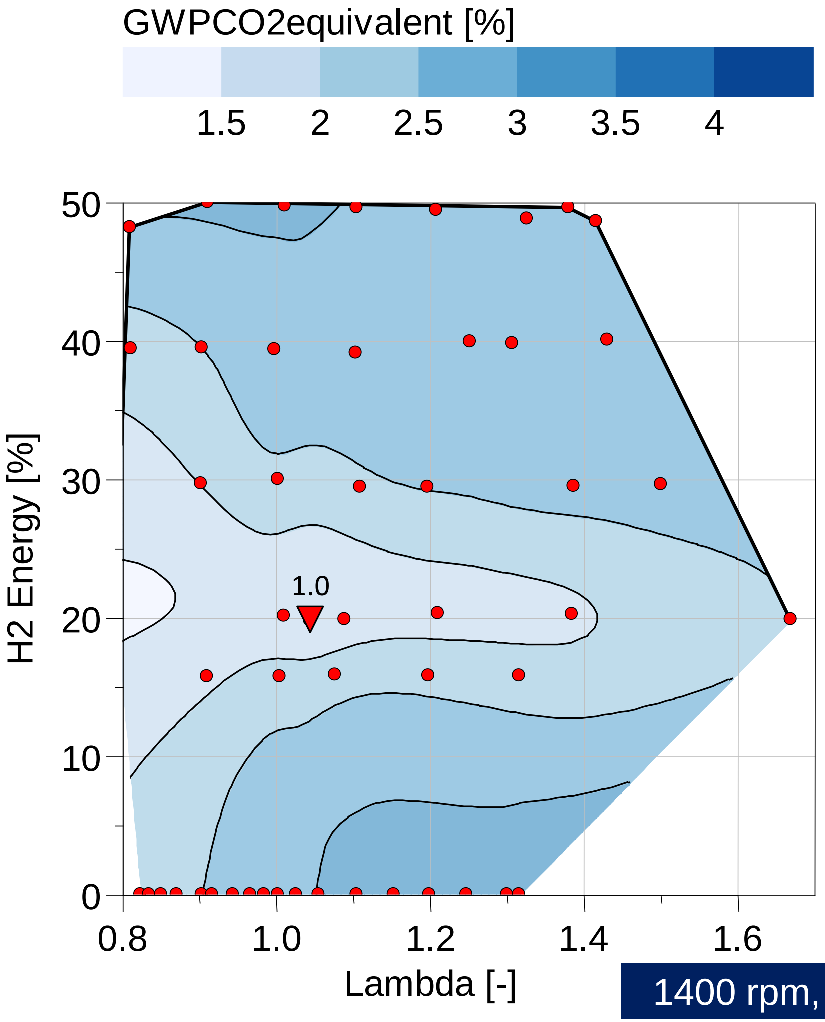
- Useful GWP numbers:

	GWP_{20}	GWP_{100}
– Carbon Dioxide (CO_2)*	1	1
– Hydrogen (H_2)**	35	12
– Natural Gas (CH_4)*	81	29
– Nitrous oxide (N_2O)*	273	273
– Ammonia (NH_3)***	0 – 273	

Status

– GWP whole area map produced (right)

– GWP reduction measured at **85-95%**



1400 rpm, 14 bar IMEP

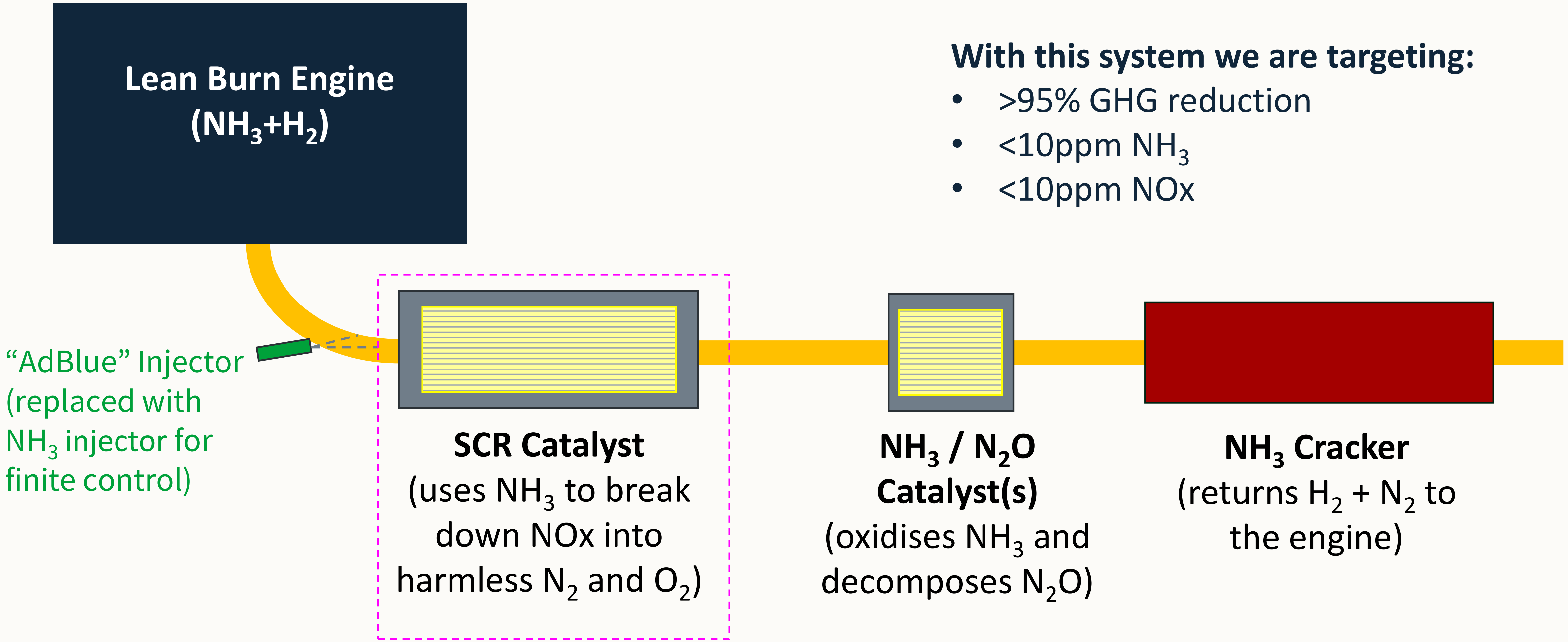
* IPCC Global Warming Potential Values 6th Assessment Report (AR6)
** Sand et al, 2023 doi.org/10.1038/s43247-023-00857-8
*** Ammonium Nitrate decomposition to N_20 as reference for worst case

Diesel ICE GWP reduced by up to 95% using Ammonia – *demonstrated (engine-out), Next with aftertreatment*

Current Focus – Lean Burn Spark Ignition

With this system we are targeting:

- >95% GHG reduction
- <10ppm NH_3
- <10ppm NOx



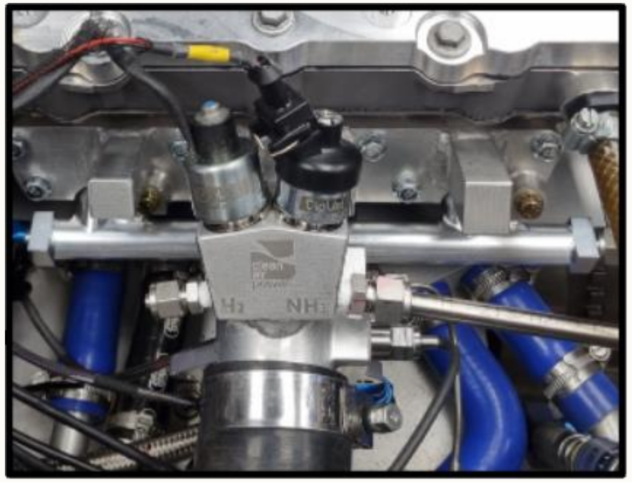
$$\alpha = \frac{NH_3}{NOx} \sim 1$$

Contents

Ammonia Cracking Testing at UoN

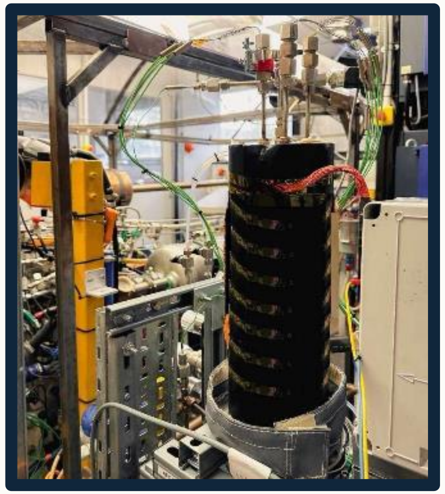
1

- Q2 2024
- Bottled gas
- NH_3 + H_2 Co-firing



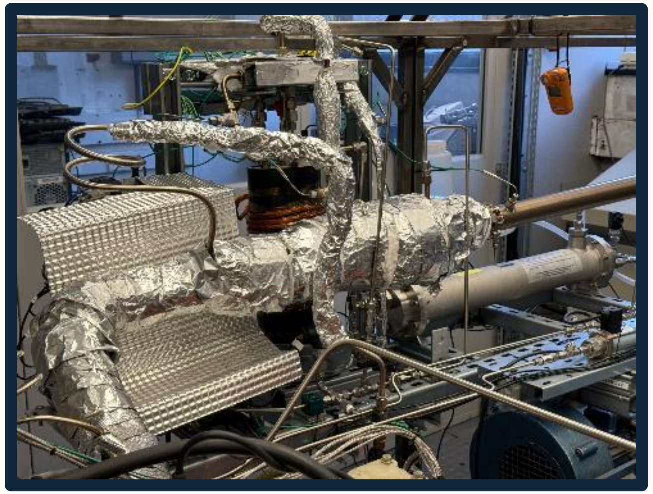
2

- Q3-2024
- Electrically heated cracker

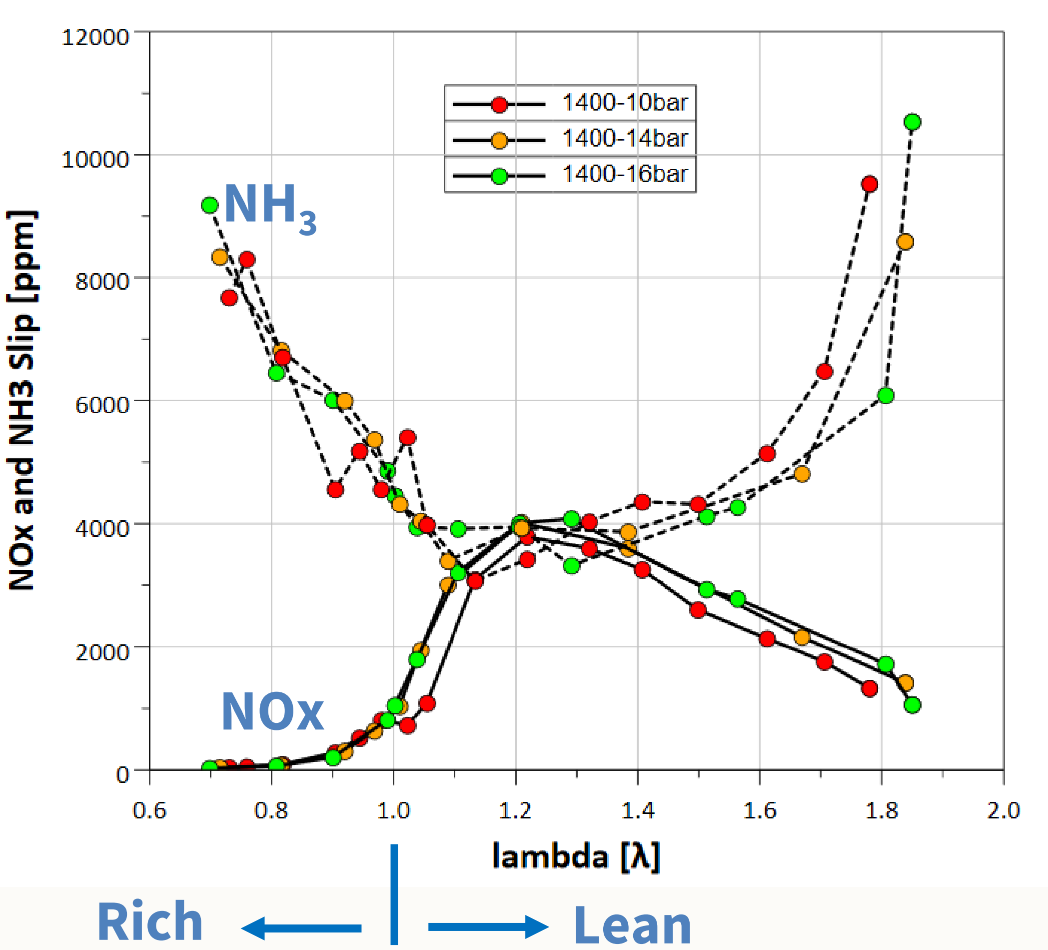


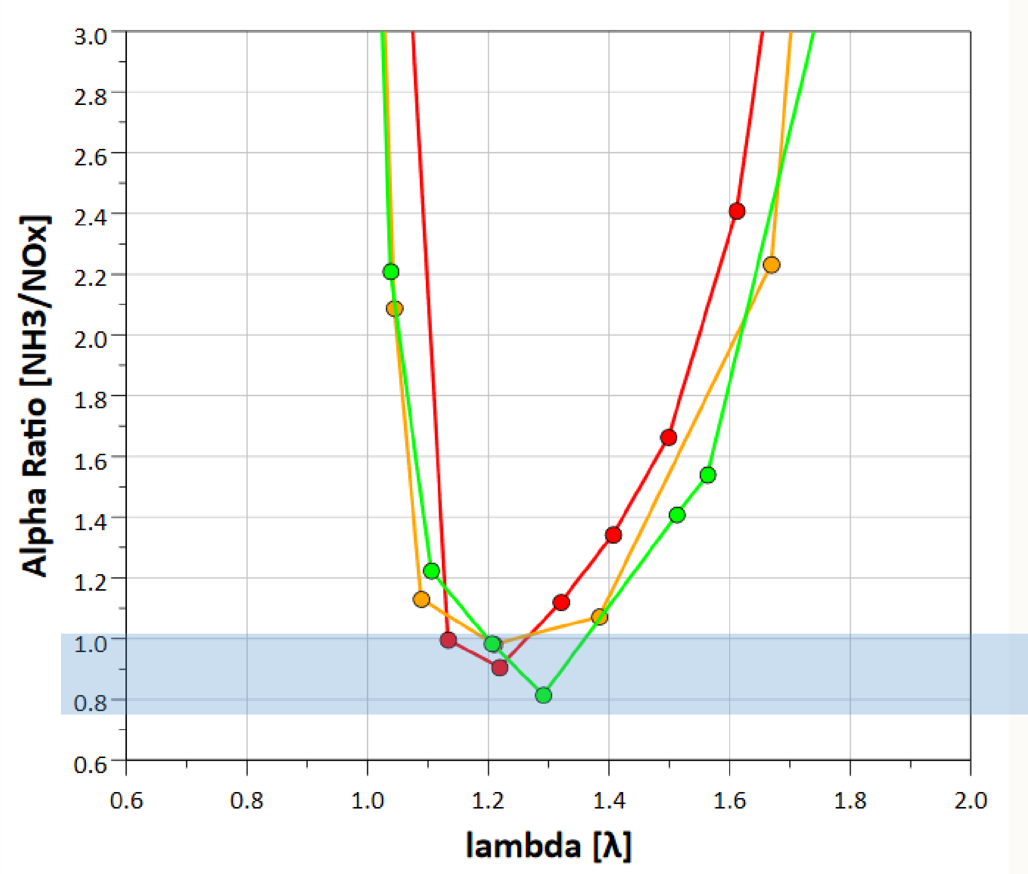
3

- Q1-2025
- Integrated cracker with exhaust heat recovery



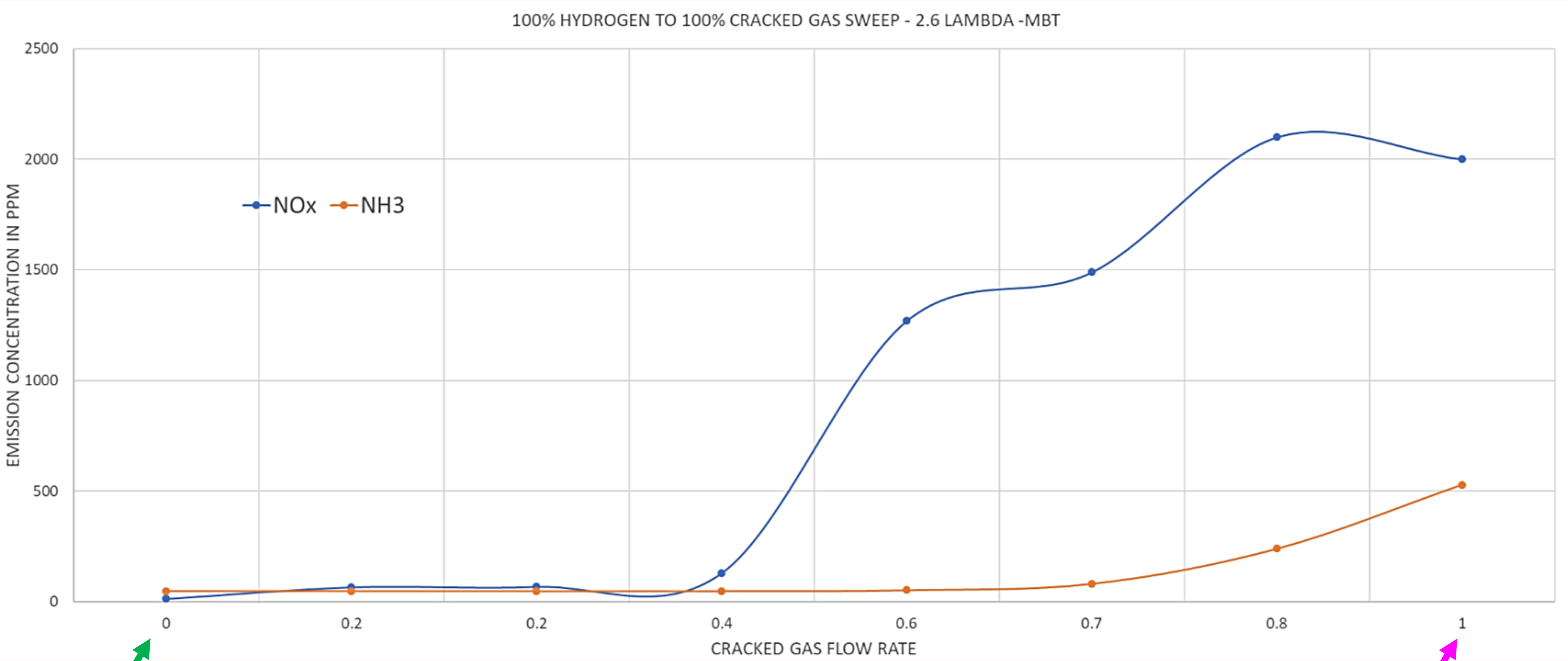
Lean Burn NH3 Operating Strategy (20% H2)





$$\alpha = \frac{NH_3}{NOx} \sim 1$$

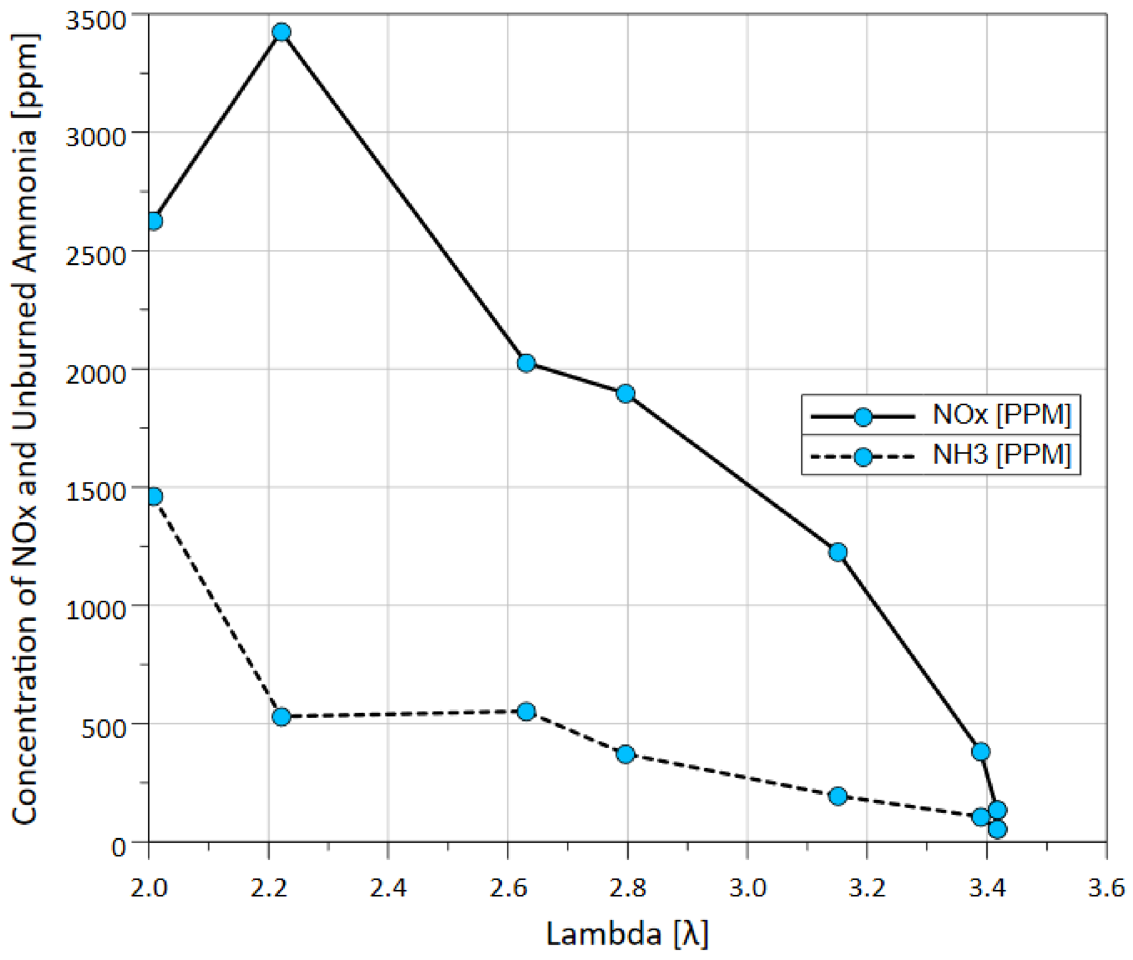
Cracked Gas Substitution Sweep (1400rpm/4bar IMEP)

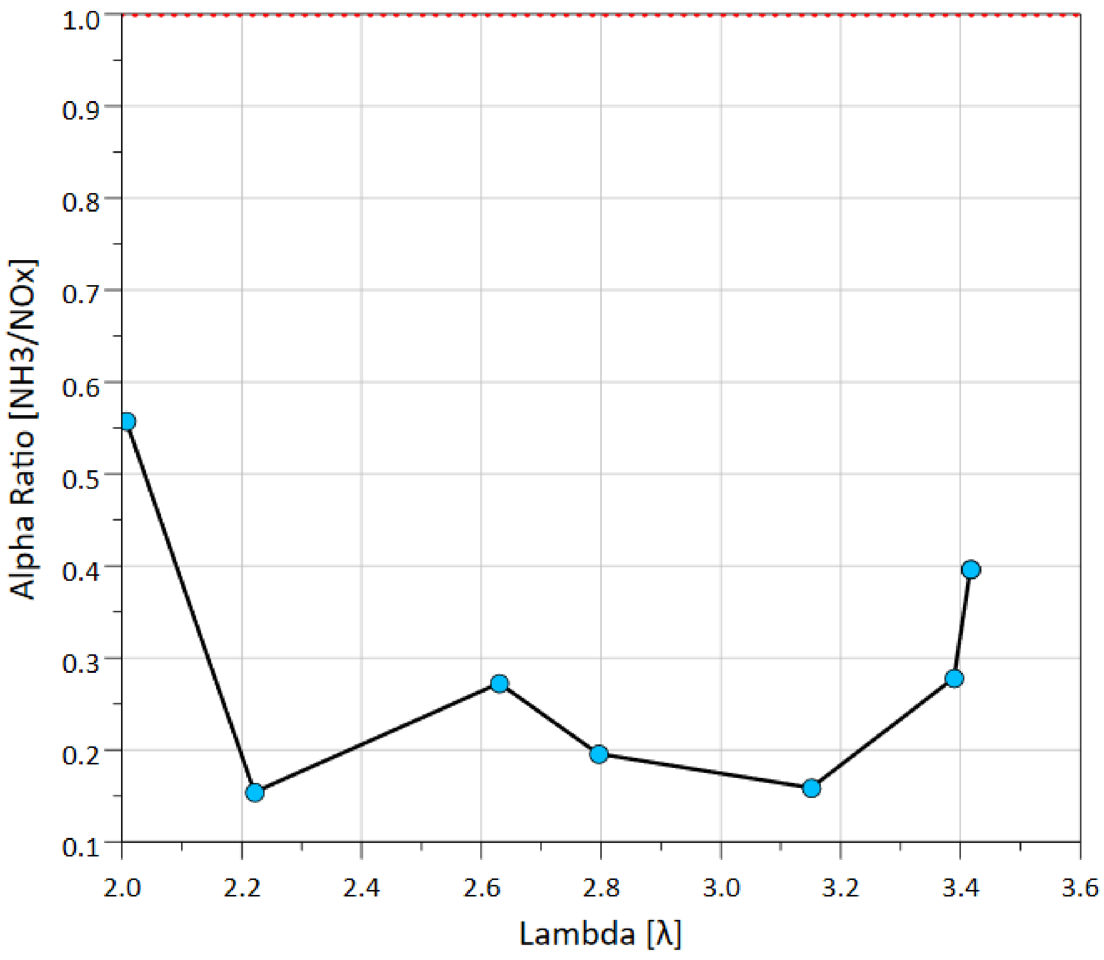


100% H_2

100% cracked gas

100% Cracked Gas (1400rpm, 4 bar IMEP)

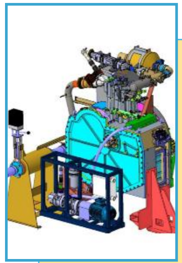




Ammonia Propulsion
Major Topics – Progress Health Check

Decarbonisation


Combustion

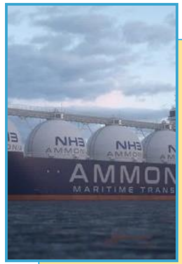

Scale up


Emissions


Mono-Fuel operation


H_2 production


Cold start


Fuel storage & Preparation


Vessel/site approval

Contents

Ammonia Monofuel System Level Demonstration

12-month plan – System Level Demonstration

- CMDC6 “REACT”
  - Follow on from MariNH3
  - Gen 2 engine with clean emissions, cracker and high output
  - Cold start and emissions control
  - Pre-deployment demonstration in lab setting
  - Preparation for power-gen demonstration project

REACT

Retrofitable Emission-free Ammonia Combustion Technology

clean air power | The University of Nottingham | MAHLE Powertrain | AFC Energy | JM

CMDC6 REACT will feed into MariNH3 and the hub, demonstrating clean, efficient, high power NH_3 at a system level

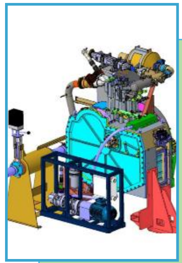
Ammonia Propulsion
Major Topics – Progress Health Check

Decarbonisation

REACT

Combustion

REACT



Scale up

REACT

Emissions

REACT

Mono-Fuel operation

REACT

H_2 production

REACT

Cold start

REACT

Fuel storage & Preparation

REACT

Vessel approval

Roadmap health check shows good progress – *work to do, further R&D needed, but no immovable roadblocks*

Summary

Dual fuel ammonia-ready engines are already emerging

Monofuel is cleaner and can be enabled by ammonia cracking

Cracking can radically simplify the required exhaust emissions after-treatment

Methanol cracking studies are also now underway…….

Thanks for listening!

Marine fuels; past, present and future

David Browbank

Brookes Bell

Agenda

- Introduction to Brookes Bell
- Current marine fuels
- Biofuels
- Alternative fuels
- FuelEU

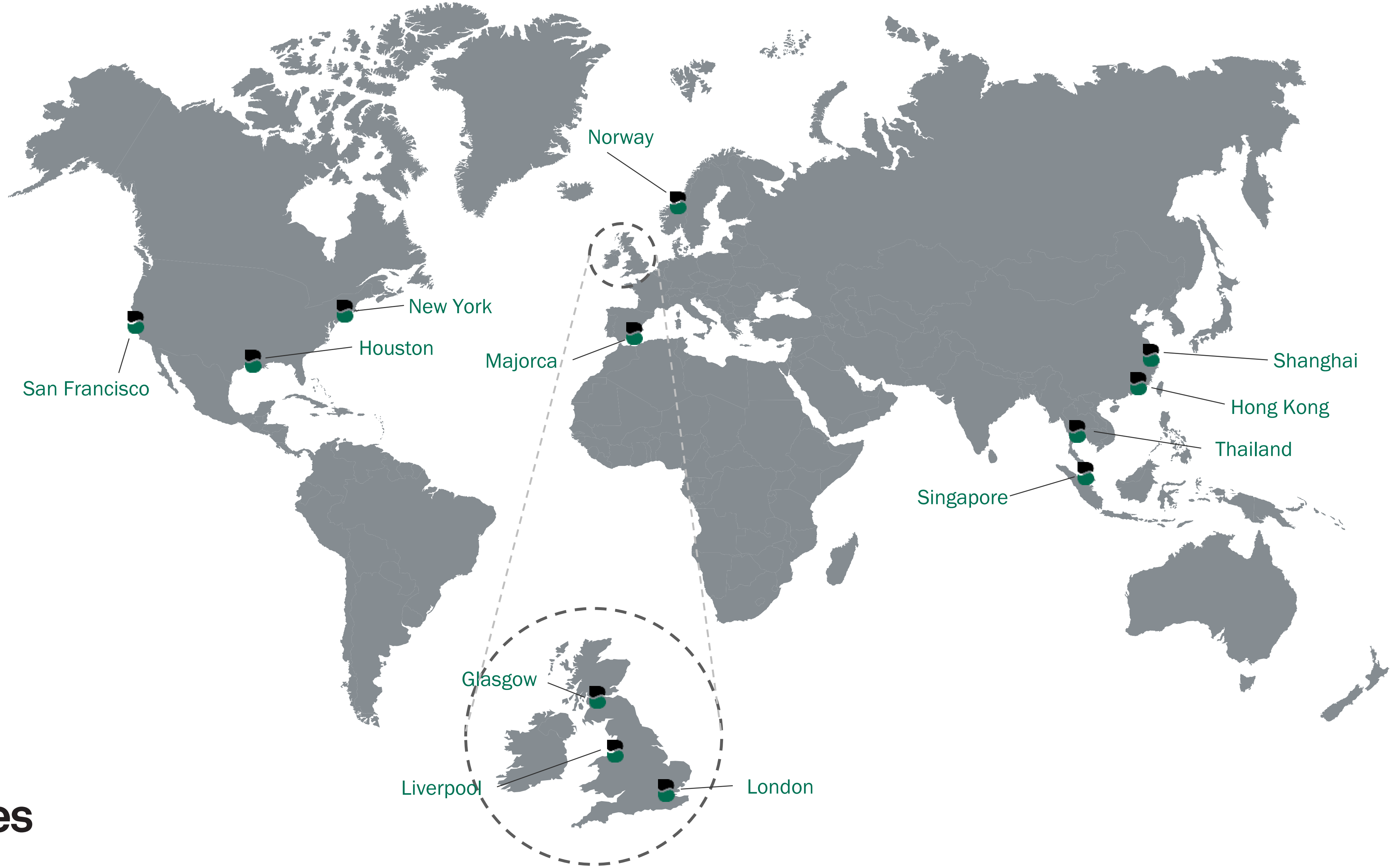
Introduction to Brookes Bell

Who is Brookes Bell

- Multi-disciplinary technical and scientific consultancy, serving the marine and energy markets since 1903.
- Global reach including operations in Europe, Asia and the Americas.
- Casualty investigation, forensic analysis, technical dispute resolution, expert witness work and forensic laboratory analysis.


Brookes Bell

A global presence



Brookes Bell

A rich heritage

1903 · 1985 · 1998 · 2005 · 2010 · 2011 · 2012 · 2013 · 2015 · 2016 · 2017 · 2018 · 2019 · 2021 · 2023 · 2024

1903
Brookes Bell founded by retired Naval Officer, Frederick H Smith, in Liverpool

1985
London office opened

1998
Brookes Bell merge with Jarrett Kirman & Partners

2005
Partnership attained LLP status

2010
Brookes Bell established presence in Shanghai

2011
Acquired Bunker Claims International

Acquired Glasgow based Safety at Sea

Formed company in Hong Kong

2012
Brookes Bell R&D division commenced operations

2012
Brookes Bell established presence in Singapore

2013
Brookes Bell Metallurgical Services opened in Birkenhead

2015
Winners of the Mersey Maritime **Global Reach Award** recognising expansion into Asia
All units certified to ISO 9001:2008 Quality Standard

2016
Winners of Mersey Maritime **SME of the Year Award**

2017
Upgrading all units to ISO 9001:2015 Quality Standard

2018
Brookes Bell acquired by Thomas Miller Holdings

2019
Winner of the Mersey Maritime **Business of the Year Award**

2019
Brookes Bell acquired Associated Petroleum Consultants

2021
The Lab opened in Bidston.

Acquired 3D Marine USA Inc.

2023
Acquired Neale Consulting Engineers

Brookes Bell

Who we work with

UKP&I

HILL DICKINSON

NorthStandard

WIKBORG | REIN

The Swedish Club

BAE SYSTEMS

BRITANNIA P&I
TRUSTED SINCE 1855

HFW

WATSON FARLEY & WILLIAMS

THE AMERICAN CLUB 1917

babcock™

JAPAN P&I CLUB
日本船主責任相互保険組合

Campbell Johnston Clark

NAVIUM

birketts

STEPHENSON HARWOOD

SKULD

WEST.

Steamship Mutual

SB SB EASTHAM

The London P&I Club

gard

PENNINGTONS MANCHES COOPER

NORWEGIAN HULL CLUB

ReedSmith

SHIPOWNERS

PRESTON TURNBULL

Schjødt

CLYDE&CO

Kennedys

TATHAM&Co

Brookes Bell

Areas of expertise

Master Mariners	Salvage & Wreck
Marine Engineering	Naval Architecture
Science & Cargo	Metallurgy
Fire Investigation	Paint & Coatings
Fuel & Bunkers	Liquid Cargoes
Personal Injury	Tribology
Superyachts	The Lab

Current marine fuels

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Current marine fuels

- Fossil fuels – HSFO, VLSFO, ULSFO, LSMDO, LDMGO.
- Biofuels – B5 up to B100.
- LNG / LPG.
- Methanol.
- Ammonia.
- Hydrogen.

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Current issues associated with marine fuels

- SOLAS – Safety of Life at Sea.
- MARPOL (**Mar**ine **Pol**lution) – sulphur, micro carbon residue.
- Mechanical damage – catfines, sediment, chemical contamination.
- Financial – density.

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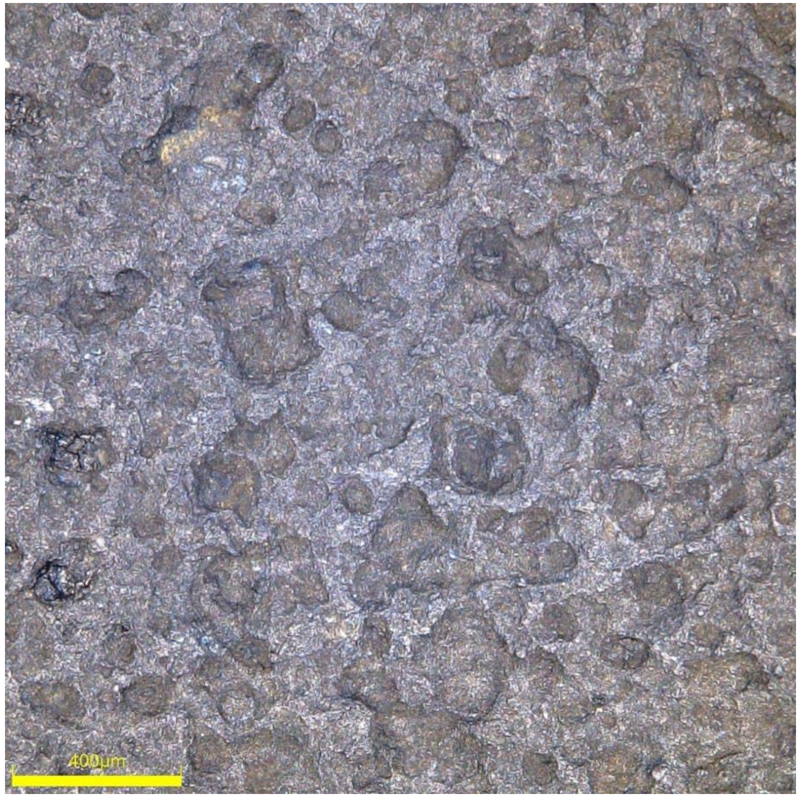
Current issues associated with marine fuels

Plunger 1 at 0° position, detail 1 of 5, 140x



Plunger 1 at 0° position, detail 2 of 5, 140x

Biofuels

Biofuel

Biofuels are a renewable fuel source, which can be considered carbon-neutral because the organic matter used to produce biofuels roughly absorbs as much carbon dioxide during their lifetime as it releases when burned. However, their potential to reduce the amount of arable land earmarked for normal food production is a concern.

Technology

- First Generation: rely on food crops as feedstock, including corn, soy, sugarcane, starch, vegetable oil, animal fats and bio-waste which are processed to produce oil. The most common biofuels include biodiesel and biogas.
- Second Generation: Biofuels are produced from lignocellulose biomass; plant dry matter composed of cellulose, hemicellulose and lignin.
- Third Generation: Biofuels are produced from algae, which are capable of higher yields with lower resources than other feedstock.
- Fourth Generation: Unlike biomass derivatives, production of these biofuels – such as electro and photobiological solar fuels – does not compete for the arable lands required to produce food.

Application

- Directly used as a fuel in IC engines with minimum modification.

Biofuel

Challenges

- Storage: Biofuels have a limited shelf life and tend to oxidise and degrade over time. The degradation of biodiesel can produce highly corrosive hydrogen sulphide, which corrodes metals, including steel storage tanks.
- Biofuel blends are susceptible to microbial growth.
- As a fuel, lubricity, conductivity, and corrosion are areas of concern.
- Biofuels with high acidity can cause increased wear.
- Production cost.
- Feedstock competes for increasingly limited agricultural resources.

GHG Performance

- Burning biofuels, which have similar properties to fossil fuels, potentially provides a net reduction in CO2 output because producing biofuels is a comparatively less carbon-intensive process. Biomass such as wood, however, typically produces more greenhouse emissions for the same amount of energy as equivalent fossil fuels.

Alternative fuels

Liquefied Natural Gas (LNG)

Liquefied natural gas (LNG) is mainly methane, the hydrocarbon with the smallest carbon content, giving it the biggest potential among the fossil fuels to reduce shipping's carbon footprint.

Technology

- Natural gas is a mixture of hydrocarbon and petroleum deposits.
- Contains methane, ethane, propane, and butane.
- When refrigerated to about -162°C, it forms a liquid, reducing its volume to 1/600th of its gaseous state.
- LNG density is about half that of heavy fuel oil (HFO), but its calorific value is roughly 20% higher.
- While using LNG as fuel should require about 1.8 times more tank-storage volume than HFO.

Application

- LNG-fuel steam boilers to feed turbines for propulsion.
- Dual fuel diesel engines (DFDE) for propulsion and power generation.

Liquefied Natural Gas (LNG)	
Chemical composition	CH_4
Boiling point, °C at 1 Bar	-162°C
Net Calorific Value, MJ/kg	48
Auto Ignition Temperature, ˚C	650
Flammable Range, % vol in air	5 – 15%
Energy Density, MJ/lt	21.6
Volume Comparison to HFO	1.85
Carbon Content	0.75
Carbon Reduction Potential (Compared to HFO)	26%
CO_2 Emission, CO_2 kg/kWh	0.201
Low Flashpoint Fuel	Yes
Toxic Fuel	

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Liquefied Natural Gas (LNG)

Challenges

- Regulatory: IGF Code for LNG has been in force since 2017.
- Bunkering: The global infrastructure for LNG bunkering is limited.
- Methane Slip: Over a 100-year timescale, methane has 28 times greater GWP than carbon dioxide and is 84 times more potent on a 20-year timescale.
- Fuel Supply Systems: gas fuel systems use more advanced technology than conventional fuel oil, and they require more crew training.

GHG Performance

- LNG has a potential CO2 reduction of 21% compared to HFO/Diesel in practice (Methane Slip). However, it will not be sufficient on its own to meet the IMO's GHG targets for 2030.
- LNG contains no sulphur.
- Compared to diesel, LNG significantly reduces particulate matter (90-99%).
- Depending on the engine technology, NOx output may be reduced by 25%.

Safety

- LNG is a low-flash point fuel, thus vapour flammability.
- It is not considered to be corrosive or toxic. Can cause asphyxiation.
- LNG is cryogenic. It can cause brittleness and fracturing if in contact with the ship's structure and cryogenic burns to crew.

Methanol

Methanol is produced from hydrogen and CO2 in a methanol synthesis process, commonly produced on a commercial scale from natural gas. It could also be produced from renewable sources such as biomass.

Technology

- Available worldwide and has been used in a variety of applications, such as in the chemical industry, for many decades.
- Methanol has the highest hydrogen-to-carbon ratio of any liquid fuel, a relationship that potentially lowers the CO2 emissions compared to conventional fuels.
- Methanol's energy density and specific energy value are significantly lower than that of conventional fuel oils; it requires about 2.54 times more storage volume for the same energy content.

Application

- MAN Energy Solutions has developed the 'ME-LGI' IC engine for high-pressure injection of low flashpoint liquid fuels such as methanol.
- Wärtsilä has developed a retrofit conversion option, which is a variant of its HP-DF engine technology.

Methanol	
Chemical Composition	CH3OH
Boiling Point, ˚C at 1 Bar	65
Net Calorific Value, MJ/kg	19.9
Auto Ignition Temperature, ˚C	440
Flammable Range, % vol in air	6-36%
Energy Density, MJ/lt	15.7
Volume Comparison to HFO	2.54
Carbon Content	0.375
Carbon Reduction Potential (Compared to HFO)	11%
CO2 Emission, CO2 kg/kWh	0.248
Low Flashpoint Fuel	Yes
Toxic Fuel	No

Methanol

Challenges

- Shipping has limited experience with operating marine engines designed to use methanol.
- Methanol's energy density and specific energy value are significantly lower than that of conventional fuel oils; it requires about 2.54 times more storage volume for the same energy content.
- Methanol is corrosive, rendering vulnerable some of the materials currently used in combustion engines; a redesign of some engine parts or the use of corrosion inhibitors (as additives to fuel) and speciality coatings may be required.

GHG Performance

- Industry studies indicate that life-cycle Nitrogen Oxide (NOx) and Sulphur Oxide (SOx) emissions for methanol are about 45% and 8% of conventional fuels per unit of energy.
- When natural gas is used as feedstock, the GHG emissions from well-to-tank are higher, which implies that well-to-propeller emissions are slightly higher than conventional fuels.

Safety

- Hazards associated with low flashpoint methanol gas.
- Hazards involving handling low-temperature, pressurised and flammable gas; it is also corrosive and toxic and can cause asphyxiation.

Ammonia

Ammonia is the second most widely used chemical, supporting the production of fertilisers, pharmaceuticals, purified water and many other chemical applications.

Technology

- Ammonia also needs about 2.5 times more tank volume than HFO to generate the same energy.
- At higher pressures (10 Bar), ammonia becomes a liquid, making it easier to transport and store. In large quantities, it can be transported in LPG carriers and has a boiling point of -33°C.

Application

- Ammonia can be used in internal combustion engines that use spark- or compression-ignition systems, where it is cracked with a catalyst. Hydrogen will ignite and burn with the ammonia, which produces water, nitrogen and nitrogen oxide (NOx).
- Used as a fuel for Direct Ammonia Fuel Cells to generate electrical power.
- Used as a 'Hydrogen Carrier'.

Ammonia	
Chemical Composition	NH_3
Boiling Point, ˚C at 1 Bar	-33
Net Calorific Value, MJ/kg	22.5
Auto Ignition Temperature, ˚C	630
Flammable Range, % vol in air	15-33%
Energy Density, MJ/lt	15.7
Volume Comparison to HFO	2.55
Carbon Content	0
Carbon Reduction Potential (Compared to HFO)	100%
CO_2 Emission, CO_2 kg/kWh	0
Low Flashpoint Fuel	No
Toxic Fuel	Yes

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Ammonia

Challenges

- Not economically feasible for the shipping industry (high CAPEX and OPEX).
- Selective catalytic reduction systems (SCR) or equivalent measures would be needed to manage the NOx output from internal combustion engines operating in the diesel cycle.
- Ammonia can cause cracking in the containment and fuel supply systems made of carbon manganese steel or nickel steel, so specialised sealants may be required.

GHG Performance

- Ammonia is carbon-free and, when synthesised from renewable power sources, it is also a carbon-free process.
- If sufficient quantities can be produced using carbon-neutral technology, ammonia has significant potential to be a pathway towards reaching the International Maritime Organization's (IMO) GHG reduction targets for 2050.

Safety

- Hazards associated with handling low-temperature, pressurised, flammable gas.
- Corrosive and toxic.

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Hydrogen

Hydrogen is the most abundant element on earth, it is almost always found as part of another compound and needs to be separated before it can be used as fuel similar to ammonia, the vast majority of hydrogen production is currently sourced from natural gas and coal.

Technology

- The biggest consumers of hydrogen are the chemical industries and refineries as a reactant for chemical processes.
- About 95% of hydrogen is produced from fossil fuels, such as natural gas and oil known as steam-methane reforming.
- Hydrogen also can be produced using electricity through the electrolysis of water.

Application

- Hydrogen is used as a fuel in internal combustion engines. However, compared to its use in fuel cells, it has much lower efficiency. The most common type of hydrogen fuel cell is the Proton Exchange Membrane.

Hydrogen	
Chemical Composition	H2
Boiling Point, ˚C at 1 Bar	-253
Net Calorific Value, MJ/kg	120.2
Auto Ignition Temperature, ˚C	535
Flammable Range, % vol in air	4-74%
Energy Density, MJ/lt	9.2
Volume Comparison to HFO	4.33
Carbon Content	0
Carbon Reduction Potential (Compared to HFO)	100%
CO2 Emission, CO2 kg/kWh	0
Low Flashpoint Fuel	Yes
Toxic Fuel	No

Hydrogen

Challenges

- Storage & Containment- Hydrogen can be stored as a compressed gas or a cryogenic liquid at -253˚C.
- The hydrogen atom is the smallest element in the periodic table, causing it to exhibit high permeation through the materials used for the containment structure.
- Due to its low volumetric density, it would require 4 times the storage space compared to conventional fuels.
- Hydrogen production and processing techniques are energy intensive, potentially creating more net GHG emissions than burning fossil fuels.
- Hydrogen has explosive properties and other safety issues hence public concern may have to be managed.

GHG Performance

- It is the cleanest marine fuel currently available in terms of its combusted output of nitrogen oxide (NOx), Sulfur Oxide (SOx) and particulate matter.

Safety

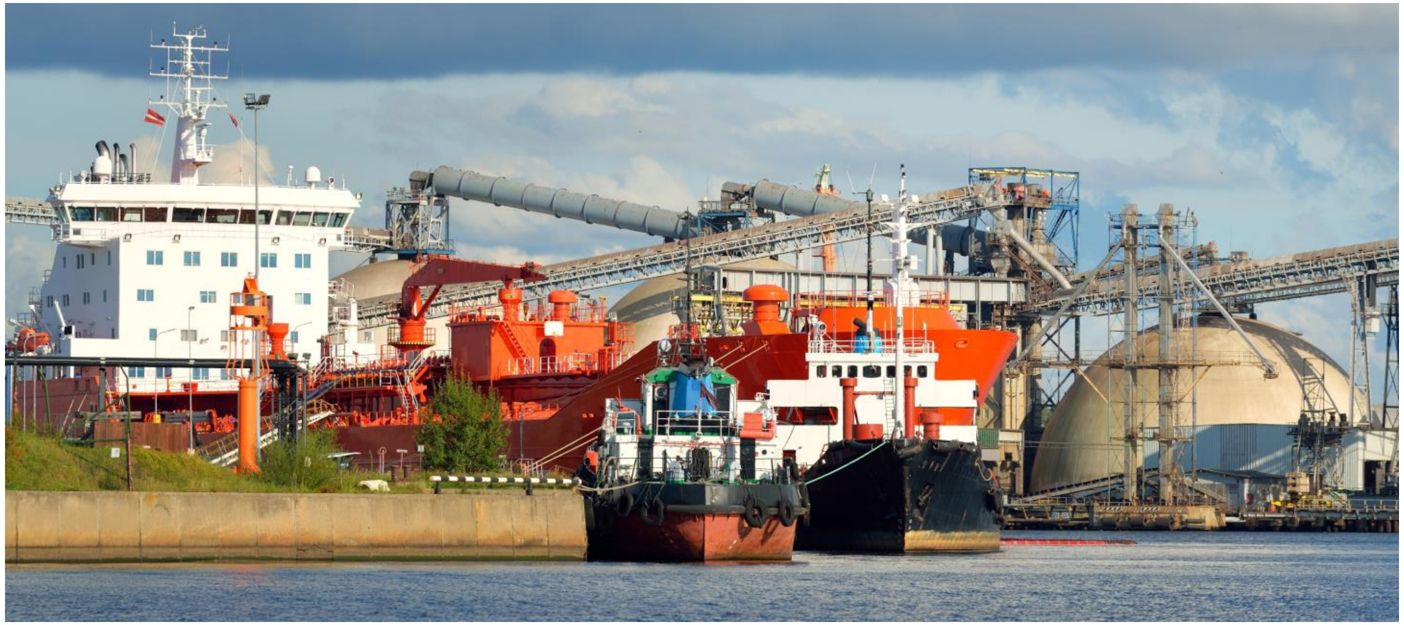
- Hazards associated with handling low-temperature, pressurised, flammable gas.
- Large flammable range and explosive.

Comparison of alternative fuels

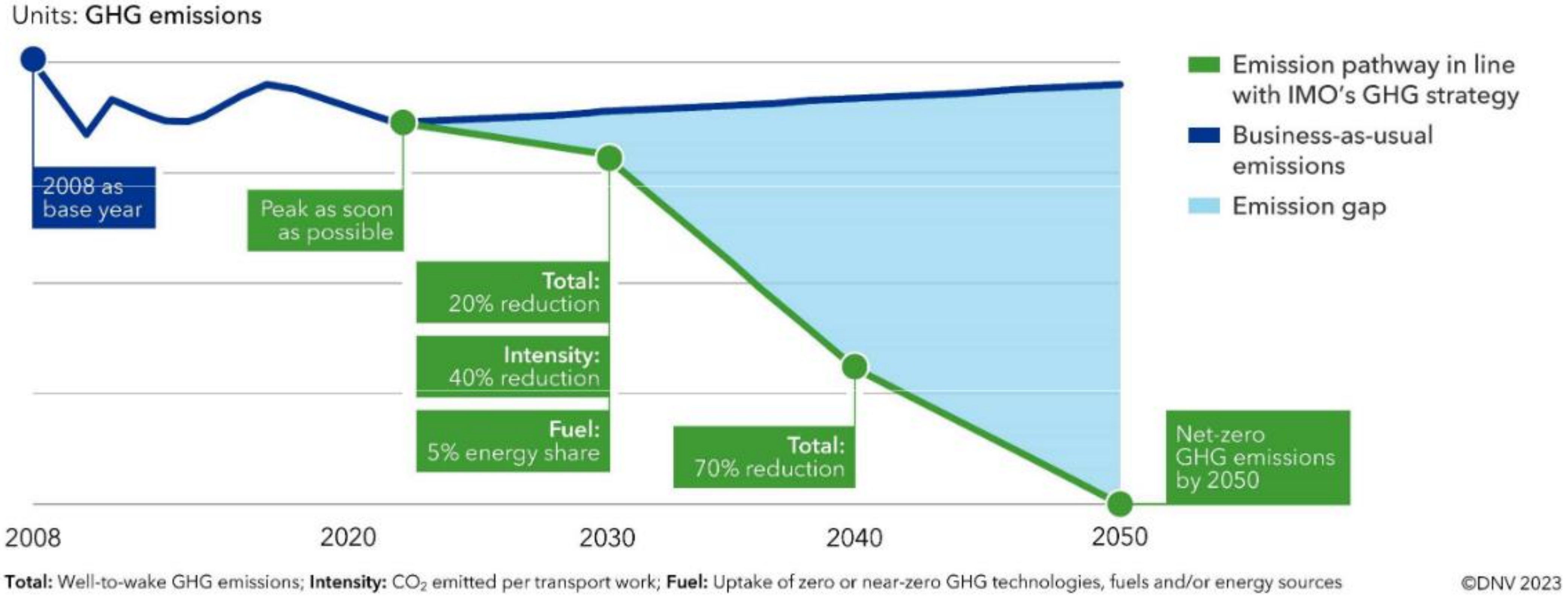
	LNG	Methanol (CH_3OH)	Ammonia (NH_3)	Hydrogen (H_2)
Flash Point, ˚C at 1 Bar	-162˚C	65˚C	-33˚C	-253 ˚C
Auto Ignition Temperature, ˚C	650	440	630	535
Flammable Range, % vol in air	5-15%	6-36%	15-33%	4-74%
Energy Density, MJ/lt	21.6	15.7	15.7	9.2
Volume Comparison to HFO	1.85	2.54	2.55	4.33
Low Flashpoint Fuel	Yes	Yes	No	Yes
Toxic Fuel	No	Yes	Yes	No

Why alternative fuels are being considered for shipping?

- Global shipping accounts for around 3% of the world's greenhouse gas (GHG) emissions.
- The maritime industry is responsible for nearly 90% of global commerce, hence there is an increasing pressure on the sector to reduce its carbon footprint swiftly.
- GHG emissions study predicts around 1,500 million tons in 2050 under business-as-usual conditions, corresponding to a 130% increase in global CO2 emissions compared to 2008.



IMO strategy for the reduction in GHG emissions



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FuelEU

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FuelEU

- FuelEU Maritime: Overview & Objectives.

What is it:

Part of the EU's "Fit for 55" package targeting significant GHG reductions from shipping.

A technology-neutral regulation promoting renewable and low-carbon fuel use.

Objectives:

Reduce GHG intensity (well-to-wake) by up to 80% by 2050.

Support climate neutrality with progressive milestones, starting with modest reductions (~2%) in 2025.

Encourage industry innovation while providing flexibility in technology choice.

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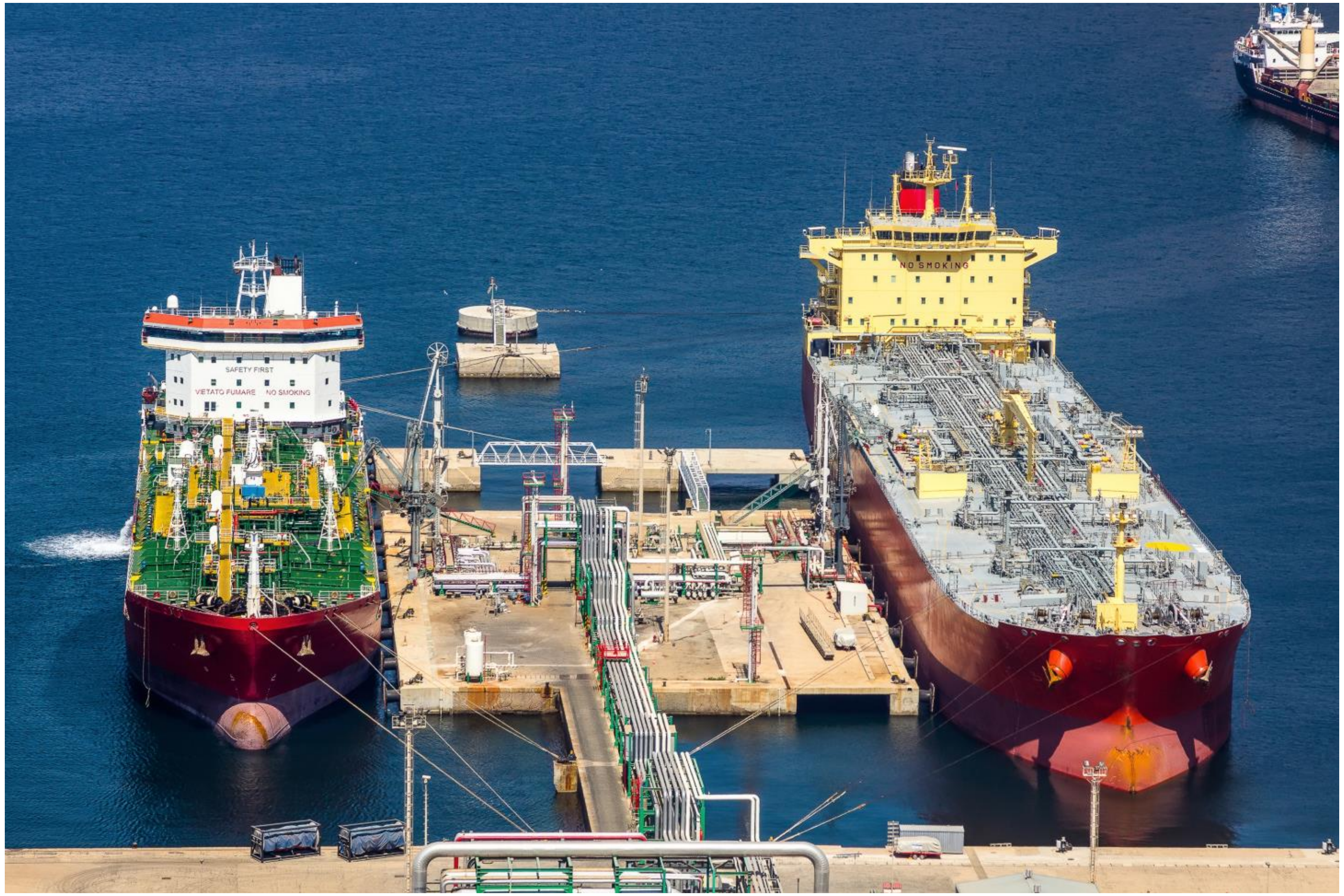
Scope and requirements

Scope:	Applies to ships above 5,000 GT—covering 90% of maritime CO_2 emissions.	Covers 100% of intra-EU/EEA voyages and 50% of voyages between EU/EEA and non-EU/EEA ports.	Targets the entire fuel lifecycle—from production to combustion.
Compliance Mechanisms:	Mandates annual monitoring, reporting, and verification of fuel consumption and emissions.	Requires specific measures (e.g., onshore power supply for specified vessels in port).	Provides flexibility through tailored compliance strategies for diverse ship types.

FuelEU Maritime Regulation

- The FuelEU Maritime regulation aims to reduce greenhouse gas (GHG) emissions from ships. The goal is to achieve a GHG intensity target of 91.16 g CO_2e/MJ by 2025. This regulation encourages the use of cleaner fuels and technologies to meet the target.

Understanding GHG intensity



- GHG intensity measures the amount of greenhouse gases emitted per unit of energy produced. Think of it like fuel efficiency in cars: lower GHG intensity means cleaner fuel. Ships need to use fuels with lower GHG intensity to meet the regulation target.

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Compliance example – BlueWave Shipping Ltd.

- BlueWave Shipping Ltd. has 25 ships:
  - 20 ships use VLSFO (Very Low Sulphur Fuel Oil).
  - 5 ships use B100 biofuel (carbon neutral).
- The VLSFO ships slightly exceed the GHG target, but the B100 ships generate credits. These credits offset the excess emissions, allowing the company to comply with the regulation.

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Thank you

Questions

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