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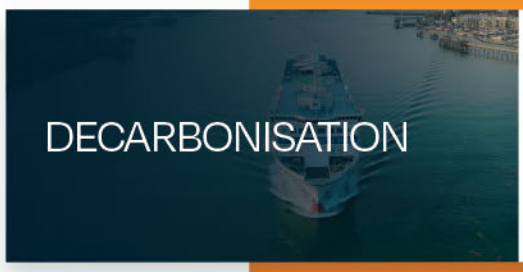
CONTENTS

February 2024

FEATURES



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MORE THAN ONE POSITIVE TO CHARTING A QUIETER COURSE

By **Daniel Johnson**

As part of its weekly 15-15 webinar series, shipping association BIMCO recently featured a highly informative presentation on underwater noise associated with merchant ships by Krista Trounce, research manager of the Vancouver Fraser Port Authority-led Enhancing Cetacean Habitat and Observation (ECHO) programme. Launched 10 years ago, ECHO's aim is to better understand and reduce the cumulative effects of shipping on marine mammals throughout the southern coast of British Columbia in Canada.

The presentation touched on what different vessel types sound like (according to ECHO's dataset, container ships are the loudest closely followed by vehicle carriers and then bulkers, tankers and cruise ships), the main factors influencing vessel-generated noise, approaches to noise management and the benefits of quieter ship operations in the area, which are not only a boon for whales and dolphins but also for shipowners' pockets: a Port of Vancouver EcoAction initiative offers discounted harbour dues for environmentally responsible shipping and last year introduced a striking 75% reduction for vessels using alternative marine fuels, connecting to shore power and obtaining a classification society underwater noise notation.

It has long been known that underwater radiated noise (URN) from commercial shipping is hugely detrimental to sea life, especially marine mammals – the issue was first raised at the International Maritime Organization (IMO) in 2004. The topic has been a relatively low-key one for the industry in the years since, however 2023 saw a significant development with IMO updating its technical guidelines relating to the reduction of underwater noise for the first time in nine years at the 80th meeting of the Marine Environment Protection Committee (MEPC 80).

The revised guidelines (MEPC.1/Circ.906), which were overshadowed somewhat by MEPC 80's headline improved greenhouse gas (GHG) emissions strategy, lay the groundwork for potential future regulation and recommend that shipowners and designers consider noise management planning at the earliest stages of the design of ships and modify existing vessels to mitigate underwater noise.

Work on URN continued at last month's Sub-Committee on Ship Design and Construction (SDC 10) meeting (see page 6) where an action plan to increase awareness, uptake and implementation of the revised guidelines was agreed. It outlines several tasks to be carried out by relevant organs and bodies, including the establishment of a three-year experience-building phase (EBP) during which member states and international organisations are invited to share lessons learned and best practices that have emerged in the implementation of the revised guidelines. The plan will go to the next Marine Environment Protection Committee (MEPC 81) in March.

SOURCE: DICK MARTIN/UNSPLASH

Although IMO's revised guidelines are non-mandatory, there is some optimism that industry adoption will accelerate once shipowners grasp the significant synergy between the application of energy efficiency measures and reduction of underwater noise.

Research released by the University of Southampton late last year, commissioned by the International Chamber of Shipping (ICS), provides a direct link between vessel efficiency and URN. The results of the study suggest that reducing vessel speed by 20% can lead to a 6dB decrease in URN in fixed-pitch propeller vessels, while wind-assisted propulsion systems have the potential to reduce URN by up to 10dB. Air lubrication systems can achieve even greater underwater noise reductions, surpassing 10dB.

Furthermore, as the maritime industry undergoes a transition towards vessel electrification, employing fuel cell, battery or hybrid technologies, the incorporation of azimuth propulsion and podded propulsors, along with their related machinery, can significantly reduce URN emissions from vessels, according to the study.

"We welcome this report. It recognises that most energy efficiency measures will also reduce URN, and therefore presents a win-win situation for shipowners," noted ICS's technical director, Chris Waddington. ICS is in consultation with its member associations to ensure the new study is shared and that the potential co-benefits are understood.

With noise levels from merchant shipping predicted to increase by up to 103% by 2030 compared with 2015, it is to be hoped that the financial incentives of meeting GHG strategy targets added to initiatives such as EcoAction will help shipowners prioritise ship designs and operations that collectively increase energy efficiency, lower emissions and reduce URN.

Accompanying this month's issue you will also have found our *Offshore Wind Vessels 2024* supplement. It's intended as an overview of the current state of this fast-growing sector, with insight and interviews with some of those involved in the design and classification of the ships and their equipment. Thanks to our friends at the Japanese External Trade Organization (JETRO) for their sponsorship. ■

NEWS

IMO

IMO HEAD HIGHLIGHTS GROWING RED SEA CRISIS AND URGES RELEASE OF CAR CARRIER AND CREW

Arsenio Dominguez, secretary general of the International Maritime Organization (IMO), has used his address to member states at the 10th session of the Sub-Committee on Ship Design and Construction (SDC 10) to express grave concern over the escalating attacks on international shipping in the Red Sea area.

Opening the first official meeting of the IMO calendar at the organisation's London headquarters, Dominguez reiterated his strong condemnation of the recent assaults and called for the immediate release of the *Galaxy Leader* and its crew.

ARSENIO DOMINGUEZ ADDRESSES THE SHIP DESIGN AND CONSTRUCTION SUB-COMMITTEE AT IMO HEADQUARTERS. SOURCE: IMO

The car carrier and its crew have been held captive by Houthi groups since November 2023, and efforts to secure their release are ongoing.

Dominguez underscored three key messages regarding the Red Sea situation: emphasising seafarers as innocent victims and asserting their safety as paramount, urging the upholding of the principle of freedom of navigation for the safe trade of essential goods, and calling for the de-escalation of the situation.

Commending the role of the Sub-Committee in ensuring maritime safety, Dominguez welcomed its contributions. The latest meeting, chaired by Erik Tvedt of Denmark, ran from 22-26 January and covered various issues related to the safe design and construction of ships. The discussions included the reduction of underwater noise from commercial shipping, addressing its impact on marine wildlife and the marine environment.

The Sub-Committee reports its findings to the IMO's Maritime Safety Committee, the highest technical body of the organisation, as part of broader efforts to enhance maritime safety and address challenges faced by the global shipping industry.

AUTONOMOUS SHIPS

AI SPECIALISTS MARINE AI AND MARAUTEC LATEST COMPANIES TO JOIN ONE SEA ALLIANCE

One Sea, the global association dedicated to advancing autonomous maritime transport, has welcomed Marine AI and Marautec as its newest members. These new additions follow a period of substantial growth in 2023 for One Sea, solidifying its standing in the industry.

Marine AI, based in Plymouth, UK, employs cognitive artificial intelligence to enhance maritime capabilities. Specialising in both manned and unmanned marine vehicle design, the company's GuardianAI software stack deploys AI to power COLREGs-compliant software for vessel decision support.

China-headquartered Marautec specialises in AI-enabled visual detection and data fusion technology for the maritime industry. The company is a leading provider of situational awareness technology for navigational safety and maritime autonomous surface ships in China and a founding member of the Shipping AI Data Centre, an open sharing platform for solving industrial issues.

One Sea secretary general Sinikka Hartonen says: "We are delighted to welcome Marine AI and Marautec to the One Sea Association. As technology continues to advance and the use of artificial intelligence increases, particularly in solutions designed for automated and autonomous operations, a mutual understanding of how such technologies can be safely implemented at sea is essential.

"We very much look forward to collaborating with both companies towards our common goals."

LNG

METHANE SLIP IN LNG SHIPS GREATER THAN EXPECTED, STUDY FINDS

Significantly more methane escapes when ships run on liquefied natural gas (LNG) than previously assumed, according to a new study.

The report from the International Council on Clean Transportation (ICCT) characterises methane emissions from ships fuelled by LNG operating in Europe and Australia and is based on data collected by drones, helicopters and onboard sensors during the two-year Fugitive and Unburned Methane Emissions from the Ships (FUMES) project.

FUMES is a collaboration between the ICCT, Explicit ApS and the Netherlands Organisation for Applied Scientific Research (TNO). According to the ICCT, the FUMES report contains the most comprehensive dataset of real-world methane emissions from LNG-fuelled ships to date, including 'methane slip' from engines and fugitive methane emissions from LNG cargo unloading operations.

Methane slip is the proportion of LNG fuel, which consists mainly of methane, that escapes unburned from the engine. Real-world methane slip measured in the plumes of 18 ships using the most common type of LNG marine engine, the low-pressure dual-fuel (LPDF) four-stroke, averaged 6.4%, whereas EU regulations currently assume 3.1% methane slip and the International Maritime Organization (IMO) assumes 3.5%.

The report recommends that EU and IMO policymakers consider increasing the default methane slip value for LPDF four-stroke engines to at least 6%. The ICCT also suggests that ships that use LNG as fuel should be required to eliminate their emissions while they are in port by plugging into shore power or through other abatement measures.

It also argues for methane emissions from LNG storage and refuelling points to be monitored, reported and verified; and because lower engine loads tend to have higher methane and NOx emissions, the IMO should stipulate that emissions should also be tested at 10% engine load during engine certification tests.

EXPLICIT APS USES A DRONE TO MEASURE METHANE EMISSIONS IN THE EXHAUST PLUME. SOURCE: EXPLICIT APS

Dr Bryan Comer, lead author of the report and director of the ICCT marine programme, says: "This study demonstrates the importance of collecting and analysing real-world data. Regulators need to use the best available data to develop effective climate policies.

"If methane slip assumptions remain too low, shipowners will be able to use LNG in high-methane-slip engines longer, effectively getting an unfair advantage over lower-emitting fuels and engines. This is contrary to the goals of rapidly decarbonising the shipping sector to align with the Paris Agreement and counterproductive to reducing global methane emissions this decade, as called for in the Global Methane Pledge."

LNG bunker industry body SEA-LNG has called into question the study's relevance as an input into regulatory development, specifically the determination of emissions factors used in IMO and EU regulations, claiming that it "suffers from a range of significant methodological limitations".

CONTAINER SHIPS

BMA TECHNOLOGY, A2B-ONLINE AND SEDEF SHIPYARD PARTNER FOR GREEN NEWBUILDS

THE VESSELS ARE EXPECTED TO ACHIEVE OVERALL EMISSION REDUCTIONS OF UP TO 95%. SOURCE: A2B-ONLINE

BMA Technology of Turkey has teamed up with Netherlands-headquartered A2B-online and Turkey's Sedef Shipyard for the construction of two methanol-electric container ships, each with a capacity of 650TEU.

Each vessel will be driven by 3.2MW of propulsion power and are designed to incorporate the latest technologies aimed at drastically reducing CO_2 emissions.

Marine electrical systems specialist BMA Technology will supply a comprehensive suite of electrical solutions including electric drives, motors, Li-ion batteries, low-voltage switchboards and alarm monitoring and control systems.

Designed with a focus on sustainability, the container ships are equipped with 1.5MWh battery capacity, enabling them to operate emission-free during harbour and inland water operations. The vessels are expected to achieve overall CO_2 emission reductions of up to 95%.

Hakki Yigit Bayrak, business development director at BMA Technology, says: "Our collaboration with A2B-online and Sedef Shipyard is a testament to our commitment to sustainable maritime solutions. We are proud to be part of this vision, which showcases our dedication to reducing environmental impact through cutting-edge electrical technologies.

"The number of projects in which we have implemented these and similar solutions have now reached seven ships."

A2B-online is a provider of flexible trailer, container and shipping services from the European continent to the UK. The new vessels are expected to be in service by the end of 2024, operating between Moerdijk in the Netherlands and Immingham in the UK.

OFFSHORE

NKT PLACES ORDER FOR NEW CABLE-LAYING VESSEL

NKT, the Danish offshore cabling specialist, has signed a contract with Norway's Vard for the construction of a new cable-laying vessel.

The order, valued at between €200 and €250 million, is driven by a strong market outlook and record order backlog, says NKT.

The vessel will be designed by the Norwegian company Salt Ship Design and constructed in parallel with NKT expanding its site in Karlskrona, Sweden, with a new high-voltage factory. Both assets are expected to be operational from 2027.

The hull for the cable-layer will be built at Vard Tulcea in Romania and outfitted and delivered from one of Vard's yards in Norway in Q4 2026.

"We thank NTK for the opportunity to build this state-of-the-art cable-laying vessel," says Roy Arne Stavik, senior vice president of sales and marketing at Vard. "At Vard we are committed to help customers reduce risk through our unique global value chain and long track record in delivering complex and customised vessels, such as this cable-lay vessel for power cable. We have established us as the leading actor in the cable-layer market and will deliver as planned."

Once delivered, the new vessel will work alongside NKT's existing cable-laying vessel, the 140m *NKT Victoria*, to connect offshore wind farms to land as part of a project led by transmission grid operator TenneT.

CABLE-LAYING VESSEL *NKT VICTORIA*. SOURCE: ALAN JAMIESON/CC-BY-2.0

NEWS ANALYSIS

MIDDLE EAST WOES GROW AND AMMONIA LOOKS SET FOR TAKE OFF

By **Malcolm Latarche**, Correspondent

If there were ever hopes for a quick end to the impact on shipping of the Gaza conflict they look to have rapidly dissipated as events continue to escalate. Drone and missile attacks on ships in the Red Sea now number well over 20 and whilst the number of successful strikes has been mercifully few, that on the Trafigura Aframax product tanker *Marlin Luanda* in late January did cause a fire in the cargo. No crew were injured, and the fire was extinguished after 20 hours with the vessel being diverted to a safe port to effect repairs.

A US and UK naval presence in the area has made responses and has brought down some of the attack drones and missiles but more and more operators are either cancelling calls to ports in the area or opting to avoid the area completely. Earlier in January it was reported that transits through the Suez Canal had decreased by an estimated 42% over the last two months. UNCTAD reports that container ship transits through Suez have plummeted by 67%. Tanker transits and gas carriers are also experiencing significant declines.

Virtually all of the major container operators are now using the route around the Cape of Good Hope and adding to their fuel bills as they do. That in turn is pushing up freight costs with rates more than doubling to around $5,000 on routes from the Far East to Northern Europe. Container xChange CEO Christian Roeloffs said: "The rerouting via the Cape of Good Hope adds complexity to the situation. We expect freight rates to remain elevated, and supply chain managers will need to navigate ongoing schedule disruptions."

The increased freight rates will come as something of a bonus for operators most of whom had struggled to stem losses throughout 2023 but will do little to help merchants as it will cut into their profits. Adding to their woes, most lines to Europe are now adding surcharges to cover their EU ETS liabilities which will be increasing because of the longer voyages. Also likely to suffer are ship recyclers as the added ton/mileage caused by avoiding Suez means that excess fleet capacity is being absorbed.

Suez is not the only canal with problems, water levels in Panama have seen transits there decrease by around 36% compared with a year earlier.

On the alternative fuels front, developments in ammonia have predominated in January after methanol proved the rising star in 2023. According to DNV, last year saw 138 newbuilding projects with methanol as the fuel as opposed to LNG with just 130. Most of the new orders for methanol were for container ships (106), with bulkers (13) and car carriers (10) highlighting that methanol has now become a mainstream fuel.

THE FIRE ABOARD TRAFIGURA AFRAMAX'S PRODUCT TANKER *MARLIN LUANDA*. SOURCE: X/@INDIANNAVY

Engine makers have been promising a future for ammonia for some time with this year and next expected to be pivotal in its adoption. In January MAN ES subsidiary MAN Cryo's design for an ammonia fuel-supply system jointly developed with Chinese company, Yada Green Energy Solutions, was granted approval in principle (AiP) from DNV and Bureau Veritas.

Japanese companies clearly see a promising future for ammonia-fuelled ships. Ocean Network Express (ONE) was also given AiP by DNV for an ammonia dual-fuel container ship design. Developed by ONE, Nikon Shipyard Co. and DNV, the 3,500TEU vessel design is the result of a joint development programme launched in late 2022. ONE's research into ammonia as a marine fuel has included participation in a GCMD-led ammonia bunkering pilot safety study in Singapore.

In a separate project a consortium comprising NYK, JEC, IHI Power Systems and Nihon Shipyard have signed a series of contracts to build the world's first ammonia-fuelled medium gas carrier (AFMGC). The target is a completed ship by November 2026.

The ship as currently designed is a 40,000m^3 ammonia carrier powered by an ammonia burning dual-fuel two-stroke engine produced by JEC. And with ammonia-fuelled auxiliaries from IHI. NYK is also involved in a project announced late last year along with Corporación Nacional del Cobre de Chile (CODELCO), Oshima Shipbuilding and Sumitomo Corporation to study, design and construct the world's first ammonia dual-fuel Handymax bulk carrier. ■

NEWS EQUIPMENT

PROPULSION

ABB AND NCLH EXPAND LONG-TERM PARTNERSHIP

ABB has signed a partnership agreement with Norwegian Cruise Line Holdings (NCLH) to enhance safety and efficiency and reduce emissions across the Norwegian Cruise Line fleet equipped with Azipod propulsion systems.

The agreement solidifies the strong partnership between the companies, paving the way to forward-looking collaboration in decarbonisation and digitilisation, according to the companies.

The collaboration encompasses a comprehensive 10-year fleet service agreement for Azipod propulsion, covering preventive maintenance to ensure safety and maximise vessel availability. Additionally, ABB will modernise the propulsion control system for 11 vessels and install shore connection technology on four ships, enabling emissions-free operations while in port.

"With ABB's support, we will accelerate the decarbonisation and digitalisation of our fleet, taking our operations another step forward towards a sustainable future," says Patrik Dahlgren, executive vice president, Vessel Operations, NCLH.

Juha Koskela, division president, ABB Marine & Ports, says: "We are pleased to continue our collaboration and see our solutions and services playing an integral role in the modernisation of their growing cruise fleet."

THE AGREEMENT WILL FOCUS ON INCREASING SAFETY AND REDUCING EMISSIONS OF THE NCL FLEET. SOURCE: ABB

According to ABB, the Azipod propulsion system has revolutionised marine transport since its creation three decades ago, offering unmatched gains in performance, efficiency, sustainability and reliability. Its gearless, steerable design allows for 360-degree rotation, enhancing vessel manoeuvrability and efficiency while reducing fuel consumption by up to 20%, compared to conventional shaftline systems, the firm says.

Based in the United States, NCLH operates vessels under three wholly owned subsidiaries: Norwegian Cruise Line, Oceania Cruises and Regent Seven Seas Cruises, all of which incorporate and utilise ABB technologies.

MARINE SOFTWARE

ITALIAN MARINE TECHNICAL INSTITUTIONS ENHANCE TRAINING WITH AUTOSHIP SOFTWARE

Vancouver, Canada-based marine software developer Autoship Systems Corporation (ASC) and its Italian reseller, Stefano Thermes of Navalia, in collaboration with 5K Systems of Italy, have delivered over 70 educational licenses for ASC's Autoload Onboard and Load Planning Software and Stowage Planning Systems (SPS).

The systems will be integrated into the training curriculum at 10 prominent marine technical institutions across Italy.

ASC's Autoload software utilises data from various sources such as tanks, drafts, wind and sensors, along with user input, to assess the vessel's condition. Often combined with ASC-developed load planning modules tailored to specific vessel types, the software facilitates load planning onshore and offshore.

The ASC educational package includes five models: merchant vessels (ro-ro, multipurpose and container), bulk carriers, tankers and LNG carriers.

ASC's SPS provides extensive stowage solutions for cargo management activities. It can be customised to different levels of management complexity ranging from organising rig decks or supply vessels to complex ro-ro ship cargo placement.

Located in Genova, 5K Systems is a simulation expert in the defence and civil sectors. From design to installation and support, the company maintains simulators for several navies around the world and also manages simulators for marine educational facilities.

Stefano Thermes of Navalia has been an ASC Reseller in Italy and Egypt for more than 30 years. Navalia offers marine consulting services in addition to selling and servicing ASC software.

FUEL CELLS

APPROVAL IN PRINCIPLE GRANTED FOR FIRST JAPANESE MARITIME HYDROGEN FUEL CELL SYSTEM

ClassNK has granted approval in principle (AiP) for a maritime hydrogen fuel cell system developed by YANMAR Power Technology Co, Ltd (YANMAR PT). The landmark certification marks the first AiP for a maritime hydrogen fuel cell system developed by a Japanese manufacturer.

As the shipping industry seeks sustainable solutions to reduce greenhouse gas (GHG) emissions, hydrogen fuel cells have emerged as a promising alternative. Recognising the unique characteristics of hydrogen and ongoing safety discussions at the International Maritime Organization (IMO), ClassNK has issued *Guidelines for Fuel Cell Power Systems on Board Ships (2nd Edition)* to promote the safe design and utilisation of fuel cell power systems on ships.

YANMAR PT's maritime hydrogen fuel cell system, rated at 300kW, incorporates key auxiliary components, including integrated gas valve units within the system enclosure. The design prioritises easy installation on ships and allows for parallel connection of multiple units, offering flexibility to adjust the number of hydrogen fuel cell modules based on varying ship power output requirements.

ClassNK says it conducted a thorough review of the system in accordance with its guidelines, assessing the results of required tests and risk assessments. Following confirmation of compliance with prescribed requirements, the classification society issued the AiP.

According to YANMAR PT, its maritime hydrogen fuel cell system is suitable for passenger ships and cargo ships operating in coastal areas with access to a hydrogen infrastructure. The fuel cell system should serve as a step towards sustainable and environmentally friendly maritime power solutions.

AIP HANDOVER CEREMONY: TOSHIYUKI SHIGEMI, SENIOR EXECUTIVE VICE PRESIDENT, CLASSNK, (LEFT) AND MASARU HIROSE, GENERAL MANAGER OF LARGE POWER PRODUCTS BUSINESS, YANMAR PT

SOURCE: SHUTTERSTOCK

MARINE ELECTRIFICATION

ADJUSTING COURSE FOR AN ELECTRIFIED FUTURE

By **Anatol Przytulski**, global business development manager, ABB

In July 2023, the International Maritime Organization (IMO) announced its 2023 GHG Strategy to outline the organisation's vision for the future in relation to greenhouse gas (GHG) emissions in international shipping, and to provide a framework for member states to reduce emissions – particularly CO_2 – to meet sustainability targets.

The IMO's strategy stresses the urgency to reduce carbon intensity by an average of at least 40% by 2030 and identifies the key role that the uptake of zero- or near-zero-emission technologies, fuels and/or energy sources will play in reducing carbon and GHG emissions. The IMO's vision is that zero-/near-zero-emission technologies will represent at least 5% (but striving for 10%) of the energy used in international shipping by 2030.

Energy-efficient ship design requirements are cited in the IMO strategy as an important measure for reducing the carbon intensity of international shipping.

ABB has been collaborating with customers in the marine industry for many years. We understand that electrification is one of the positive measures that vessel and shipbuilders can utilise to meet increasingly stringent climate targets through making the switch from traditional fossil fuel technologies to hybrid and fully electric systems for both on board and in port applications.

Onboard electric technologies

A key area of growth we are experiencing – particularly for ferries – is in low voltage (LV) direct current (DC) power distribution networks. DC power networks make the integration of renewables, battery storage and green hydrogen fuel cells more straightforward than alternating current (AC) distribution networks. They can also be used to maximise the efficiency of electric motors, propulsion and onboard operations using variable speed drives.

Operators could realistically reduce fuel use by 20% on vessels with variable speed motors and onboard energy storage, as the DC enables them to match the generator speed more closely to the ship's demands and shed peak loads.

To ensure power networks are safe, additional equipment is needed as short circuit currents in new DC systems are not only higher, but they can also build up 10-20 times faster. Managing this for large systems would normally require a complex mix of protection devices like circuit breakers, switches, contactors or power electronics like DC/DC converters.

In response, ABB introduced a new all-in-one circuit breaker, the SACE Infinitus, which provides marine customers with a simpler way to protect and control their DC systems. This marine and IEC-certified solid-state circuit breaker relies on a low-loss semiconductor technology which enables it to detect and respond to short circuit faults more than 100 times faster than traditional electromechanical circuit breakers. This speed enables the SACE Infinitus to halt emerging short circuit currents almost instantly – and provide the high levels of service continuity and safety required for mission-critical electric propulsion systems.

Digitalisation

Like most other industries, digitalisation is key to improved efficiencies and sustainability. In the marine industry, digitalisation is being explored as a way of improving energy efficiency, performance and safety.

As a tool for data-driven operations, the ABB Ability OCTOPUS Marine Advisory System provides operators with comprehensive energy, fuel and efficiency monitoring and benchmarking, and it has become the industry's most trusted motion monitoring and forecasting system. As international legislation starts to demand fuel monitoring and reporting, digital solutions like ABB Ability will become more important.

Digitalisation can also be used to improve propulsion efficiency. For example, we are already seeing ice-going LNG carriers using remote diagnostics systems (RDS) on board to continually record, consolidate, upload, and analyse ice-breaking propulsion performance.

Digital tools can also be used to improve safety. For instance, Cooperative Vessel Operations use machines to record and analyse the detailed behaviour of all surrounding vessels for collision avoidance, therefore creating a safer and more productive journey for the vessel and its crew.

Ship-to-shore connections

Port emissions remain a concern, as vessels traditionally run diesel generators while docked to keep vital functions ticking over.

Existing medium voltage (MV) systems, even in relatively large urban areas, are not designed with adequate capacity to accommodate the stepwise loads of vessels pulling up and plugging in. For example, a cruise ship, or container vessel, looking to connect to shore power, turn off generators, and radically reduce its fuel consumption and emissions will consume huge quantities of electricity from the grid for hours at a time.

In contrast, electric car and passenger ferries may only dock for a matter of minutes, but they require fast charging solutions with the potential to cause severe peaks in power demand.

To help manage this a number of ports – who are also now required to reduce their emissions – are investing in battery energy storage systems (BESS) which can be integrated with local renewable energy generation sources. By installing batteries on shore, ports can charge them throughout the day and night, without causing demanding grid peaks. A vessel with high power demand can then plug in to both the grid and the batteries, with the latter 'shaving' demand on the former. The result is a level grid load.

Against the global backdrop of rising energy prices and increased pressure to decarbonise, the shipping industry is facing a major overhaul as the traditional ways of operating its vessels become obsolete in a zero-carbon future. But through electrification and digitalisation, operators have the tools they need to sail ahead for a more sustainable future. ■

AUTONOMOUS SHIPS

NAVIGATING THE FUTURE OF SHIPPING: ORCA AI'S AUTONOMOUS ODYSSEY

By **Tom Barlow-Brown**

The usage of artificial intelligence in the shipping industry has been steadily growing in recent years. The technology has a myriad of uses, from monitoring carbon emissions and ship systems to navigation and threat detection. The progress in the field of AI in shipping is often pioneered by technology startups with dedicated teams of researchers pushing the boundaries of the area.

One such company is Orca AI, which since its foundation in 2018 has been working to produce a variety of AI-driven products for the maritime industry. In an exclusive interview with *The Naval Architect* from the company's office in Tel Aviv, founder and chief technology officer Dor Raviv explains how the company began and discusses the firm's new cutting-edge products.

Raviv says the company's origin story can be traced back to the Israeli Navy where he and his co-founder, Yarden Gross, served as navigation instructors 15 years ago. Raviv, a former commander for 160 sailors, specialised in teaching navigation and operations. His journey includes leading the development of the first autonomous surface ships in the Israeli Navy, marking the foundation for his venture into the scope of maritime automation.

At present the Orca AI team comprises 60 employees and its products are deployed on around 270 commercial ships across the globe and 500 more in booking.

Central linchpins

The company's current focus revolves around two central linchpins, each designed to address distinct aspects of autonomy in shipping. One of these is an onboard digital automated watchkeeper, while the other is a reliance on a data-driven fleet management dashboard for the office. Raviv's vision is clear – to establish a foundation for autonomy in shipping that is adaptable to the diverse needs of each client.

ORCA AI CO-FOUNDER DOR RAVIV

"We are talking about defining what are the use cases for autonomy," he says. "Probably not all use cases are relevant in shipping, but then we need to build products for autonomy, and every client will probably choose his own degree of autonomy."

Orca AI has not only developed a real-time channel between ships and the cloud but has also introduced ongoing video streaming and notifications for critical events. Raviv emphasises the company's commitment to a data-driven approach, drawing parallels with Tesla's methodology. The focus lies on crowdsourcing real-world data for continuous learning and improvement.

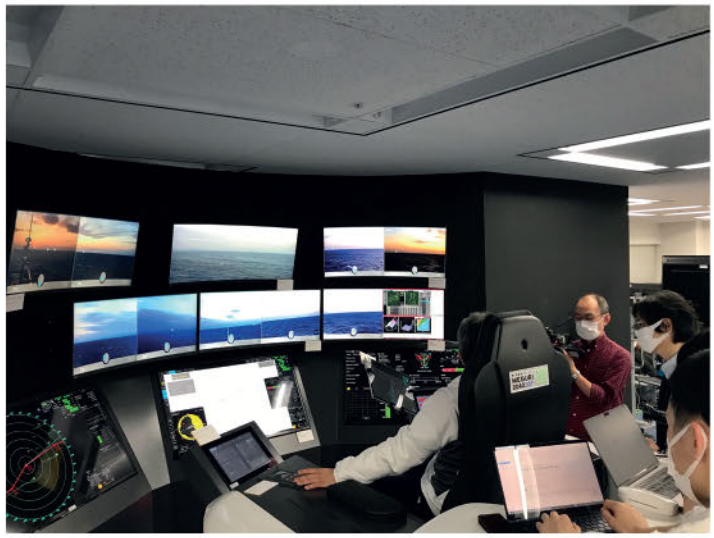
"These kinds of shipping companies actually lack transparency on what's going on with the fleet that is moving goods around the world. So, we monitor and improve events, such as the number of near misses events, sharp turns, and sudden drops in speed under various COLREG situations that influence the safety and efficiency of navigation," explains Raviv.

Raviv says the company's data driven approach is the core of its innovation aims and roadmap going forward. "We are trying to model the world without heuristics, relying on collected data – bottom up, instead of looking from the top down. By deploying a bigger fleet of ships and data collectors, and then analysing and learning patterns and trends, we are training machine learning to navigate using this data. This is our approach," he says.

The company has achieved significant milestones, securing approval from the American Bureau of Shipping for AI computer vision in collision detection and avoidance. Strategic collaborations with industry leaders like NYK in Japan showcase Orca AI's commitment to collaboration with other companies to help keep pushing the boundaries of innovation. The ongoing collaboration aims to develop automated watchkeeping capabilities, potentially reducing the manning of ship bridges under specific conditions.

Historic milestones

Orca AI achieved a historic milestone in February 2022 by conducting the world's first fully autonomous voyage. Working in collaboration with MTI, the tech arm of NYK Group, the company provided advanced 360-degree field of view coverage through computer vision, sensor fusion, and perception technologies to enable safe navigation of the vessel through highly congested waters,



WORLD'S FIRST AUTONOMOUS VOYAGE CONDUCTED IN PARTNERSHIP WITH THE NYK GROUP

despite having no prior knowledge of incoming traffic or visibility conditions. The successful outcome of this collaboration serves as proof that computer vision is an essential component for safe automated ship navigation. In summer 2023 Orca AI and NYK announced their partnership in the second development stage of the project.

Strategic collaborations such as this not only demonstrate the technical prowess of Orca AI but also highlight the importance of the collaborative ecosystem that is a prominent feature of the tech side of the maritime industry.

The company adopts an educational approach, encouraging crews to actively engage in safe navigation practices. The FleetView platform, developed by Orca AI, not only prioritises safety but also optimises operational efficiency by avoiding unnecessary manoeuvres. Raviv highlights the importance of incentivising users through data-driven profiles that distinguish between safe and unsafe crews, ultimately promoting safer navigation practices.

In an industry where human-machine collaboration is crucial, Orca AI's approach places emphasis not just on technology but on the human element - fostering a culture of safety and continuous improvement. "Our goal is to encourage our users to work better with existing navigation equipment. This is why one of our platform's KPIs is around the correct use of existing navigation equipment, while highlighting points for improvements. We track proper use and share it in real time with our users, to create a standard in safety of navigation," says Raviv.

Orca AI is also actively working on optimising fuel consumption, with plans to fully commercialise the product by the end of Q2 2024. Raviv envisions a future where autonomous ship technology becomes widespread but underscores the necessity for strong economic incentives. He emphasises the need for shipowners, shipping companies, and fleet managers to perceive tangible value in adopting such technology.

Raviv states that he is realistic about the prospects for how Orca AI fits into the economic landscape. Whilst AI in shipping is playing an increasingly crucial role, he stresses the need for it to be an attractive option for commercial consumers.

"I see autonomous ships technology coming in, but they have to come with very strong economic incentives for the clients," he says. "The shipowners, shipping companies and fleet managers have to see tangible economical value to adopt this kind of technology."

Unforeseen challenges

While Orca AI steers the ship towards autonomy, the maritime industry faces new challenges. Recent Houthi rebel drone attacks in the Red Sea and Suez Canal have exposed security vulnerabilities, impacting global trade. These attacks have led to delays and rerouting by major shipping companies, as well as a decline in ship arrivals in affected regions.

AI-based target detection can counter the rising threat of drone attacks on ships. The introduction of Orca AI's SeaPod platform as a pioneering AI tool for early detection and response to drone threats demonstrates the pivotal role AI can play in safeguarding maritime operations. Orca AI had trained the AI-assisted vision in its SeaPod platform to avoid detection of small flying objects as these were considered a false alarm. However, it has been possible for the company to retrain the system to detect airborne targets and notify the crew via an audio alarm.

ORCA AI'S SEAPOD NAVIGATION ASSISTANT

According to Raviv there is no other sensor that can detect these threats onboard. "The reliable technology excels in the early detection of small targets, notably even airborne targets, providing timely alerts to crews for actions such as taking cover or recording for evidence," he says. The SeaPod platform is an example of the possibilities that AI unlocks in ensuring not only the efficiency of ships but also the security of maritime routes against emerging threats.

From the company's humble beginnings to its current role as a leader in maritime technology, Orca AI's story is one of innovation, collaboration, and a commitment to safety. The company is an example of how the application of maritime autonomous technology in a specific targeted way demonstrates the broader impact of responsible and data-driven innovation on the seas of the future. ■

BELGIUM FIRM AIMS FOR AUTONOMOUS, ZERO-EMISSION SHIPPING IN THE NORTH SEA AND ENGLISH CHANNEL BY 2026

By **Daniel Johnson**

The promise of autonomous, zero-emission vessels is tantalising. They offer ship operators and owners a potential key to safer voyages, reduced costs, enhanced efficiency and minimal environmental impact. While fully autonomous transoceanic commercial cargo ships are not quite on the horizon yet, there are a number of initiatives underway to develop the technology necessary for autonomous freight transport on inland waterway and short-sea routes, including one that aims to have uncrewed container ships navigating the world's busiest shipping lane by 2026.

Zulu MASS, from Belgian maritime innovator Zulu Associates, is one of the most daring autonomous ship designs to date and is set to be the first of its kind to have the capability of operating autonomously as a zero-emissions vessel in the English Channel and North Sea. The 200TEU short-sea container ship concept, which has received approval in principle (AiP) from Lloyd's Register, will be fully electrical and powered by modular energy containers provided by established energy storage companies using batteries and/or hydrogen-based power systems. In addition to zero-emission electrical propulsion, the ship will be equipped with auxiliary wind propulsion, and the feasibility of wave propulsion is being investigated.

The vessel's newly launched concept design has been produced by Dutch naval architects Conoship International. With a length of 105m, breadth of 17m and a draught of 5m, Zulu MASS is designed to carry 45ft pallet wide containers and is planned to be initially operational with Zulu Associates subsidiary Anglo Belgian Shipping Company on green corridors between the European continent and the United Kingdom.

"We're delighted to be working with Conoship International who share our passion for innovation," says Zulu Associates chief executive Antoon Van Coillie. "Working with Conoship we are challenging ourselves to build the most advanced and innovative vessel we can. As a result, apart from being fully electric and autonomous, we're adding wind blades and examining wave foil propulsion. This is an exciting time for short-sea shipbuilding. Traditional concepts are being challenged to drive change and enable new zero-emission shipping possibilities."

ANTOON VAN COILLIE

He adds: "Autonomy is still in its infancy but we want to show what is possible and support the process of regulation keeping pace with innovation. As a result, the Zulu MASS is designed to be unmanned as a part of a Maritime Autonomy System, which will allow it to compete with fossil-fuelled or hybrid vessels."

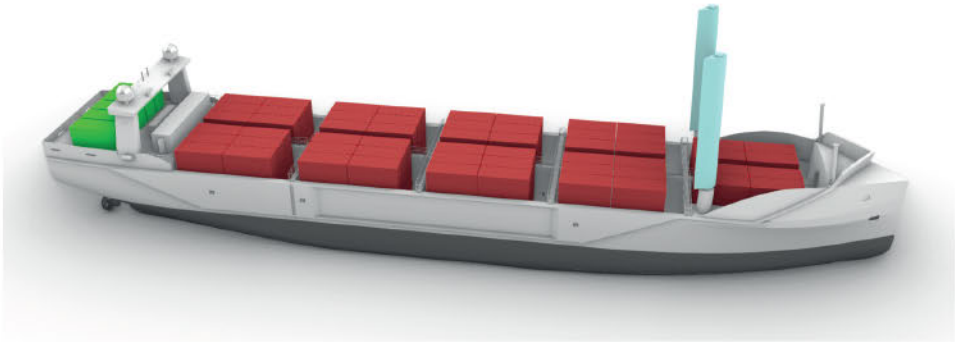
Van Coillie, an ex-banker with 20 years' experience in financial services, founded Blue Line Logistics in 2011 inventing and developing the pallet shuttle barge (aka Zulu) concept for moving palletised goods on inland waterways. Since then he has initiated programmes to develop autonomous vessels for inland and short-sea freight, establishing Zulu Associates in 2019.

Demonstrating autonomous vessel operation

Last summer a Blue Line Logistics-owned pallet shuttle barge, *Zulu 4*, successfully completed remote-operated and autonomous transport demonstrations for the AUTOSHIP project, which is part of the EU research programme Horizon 2020 and is aimed at increasing EU shipbuilding and ship technology capabilities through the advancement of next generation autonomous ships and demonstrating practical applications of the technologies. During the demonstrations the barge safely navigated a 16.5km circuit on a busy Belgian inland shipping route and also demonstrated berthing and unberthing capability. To achieve this, the vessel was upgraded with Kongsberg Maritime onboard control technology, while an onshore remote operation centre provided support.

"*Zulu 4* has now been decommissioned as a platform for autonomous operation and continues to operate manned in its normal cargo capacity," Van Coillie tells *TNA*, adding that Zulu Associates' focus is firmly on future-proofing short-sea and inland shipping with a fleet of newbuild autonomous, zero-emission vessels and barges – the company is also developing an autonomous, electrically-powered inland waterways 90TEU X-Barge, designed by Naval Dynamics of Norway for container and dry bulk shipping, which is currently in the final stages of construction design.

Van Collie notes that existing vessels are very difficult to convert into 'zero-emission' ships. Zulu Associates' concept is disruptive, he says, in the sense that the company is talking about completely new ships, conceived to consume



ZULU ASSOCIATES PLANS TO HAVE ZULU MASS IN THE WATER AS A WORLD FIRST IN 2025

as little energy as possible and to run on electricity.

He continues: "By making vessels to operate without crew on board during transit – i.e. all systems, not just navigation, need to be able to operate with no crew on the vessel – one changes the economic equation of the operation of the vessel, hence creating a margin that helps to pay for the more expensive non-fossil fuel propulsion."

This margin, he notes, is created not only through significant reduction in crew costs and onboard facilities, but also through more efficient routing and increased safety and reduced insurance costs, as the potential for human error will be significantly reduced.

Van Coillie anticipates that plans for both Zulu MASS and X-Barge will be forwarded to shipyards this year and that the first vessels will be delivered by the end of the first quarter of 2025. "We then have a year to prove our proof of concept," he says.

"Initially, the vessels will not be fully autonomous," he explains. "There will still be crew on board, which will control and support the systems running on artificial intelligence. First, we need to prove that the concept works efficiently and safely. After a year, we sail without a crew."

Once sailing autonomously, the Zulu MASS vessels will be monitored and, if necessary, steered by personnel in a control room ashore. One person will eventually be able to monitor five to 10 vessels simultaneously, according to Van Coillie.

Taking advantage of emerging regulations

He notes that the main challenge facing Zulu MASS is regulatory but says that the Belgian government's championing of marine innovation has been invaluable. The country established a legal framework for unmanned vessel pilot projects in the North Sea in July 2021. "That has given us the confidence to embrace and invest in Zulu MASS where some in the industry were being much more cautious," he says.

"The agreement between Belgium, the UK and Denmark is also very important," he adds, referring to a memorandum of understanding (MoU), 'On Cooperation Regarding the Operation of Maritime Autonomous Surface Ships (MASS)', signed by the three countries in September 2023. The MoU seeks improve collaboration in facilitating the increased use of digital technologies and autonomous systems on ships and the signatory nations have agreed to share knowledge regarding ongoing activities in these areas, with efforts to be made to involve other North Sea countries in the group and widen its activities.

In particular, the MoU looks to facilitate at-sea operation of maritime autonomous surface ships technologies in the North Sea, to ensure that they can be operated safely under the different national frameworks and requirements of each of the signatory countries. "This should harmonise the procedure to obtain approval for autonomous vessels operating between the countries, resulting in a single request replacing the need of having to apply for two or more permits," Van Coillie says.

"We aim to seize the initiative of this opportunity and get Zulu MASS in the water as a world first and industry trailblazer in 2025," he adds.

A recent addition to the Zulu Associates team has been Ann-Sofie Pauwelyn as chief regulatory officer. She joins director James Fanshawe, who retired from the Royal Navy in 2005 and now chairs the UK's Maritime Autonomous Systems Regulatory Working Group, and chief technology officer Jan Tellkamp, a naval architect with over 20 years of experience in the marine industry including work on the use of fuel cells and low-emission fuels.

Pauwelyn's previous experience includes working on the creation of new regulations, safety guidelines and test approval procedures for unmanned and autonomous shipping at the Flemish Inland Waterway Authority. "Ann-Sofie joined Zulu Associates to further work on policy and regulations for autonomous ships," explains Van Coillie. "She brings a wealth of know-how and contacts... combined with the know-how and experience of Jan and James, we are now well equipped in that area."

Next steps

With the concept design for Zulu MASS unveiled, aside from building the first vessels the next step for Zulu Associates will be signing on clients to time charter the ships. "In parallel it is also establishing the partners that will provide the infrastructure for zero-emission energy provision, be it batteries or hydrogen," says Van Coillie.

He also points out that while all of the technologies required to have Zulu MASS sailing uncrewed exist in different forms, there is a need for integration. "This will need more development in the coming year or two, mainly in the area of AI-driven decision making," he concludes. ■

LIGHTLY MANNED AUTOMATED COMBAT CAPABILITY SECURING THE WORLD'S OCEANS

By **Dr Shelley P. Gallup**, research associate professor, US Naval Postgraduate School

Considering the number of possible maritime choke points around the world, as currently seen in the Indo-Pacific, Baltic and Red Seas, there are more needs than the United States Navy (USN) with its current, expensive Guided Missile Destroyers (DDGs) can meet. America's Allies and partners are similarly constrained. What is needed is a persistent operational tactical capability close to an adversary, dissuading further aggression while not draining the budget and not putting sailors' lives at risk. The LMACC (Lightly Manned Automated Combat Capability) is proposed to fulfil this naval requirement. A coast guard variant is also envisioned, with SAR and coastal security capabilities.

Cheap and nasty: just what types of ship does the navy need? [1]

The US Navy is in a period of innovation, a "third offset" (artificial intelligence and autonomous capabilities) that has yet to be fully realised. There is a tendency to think of autonomy and AI as having arrived for implementation, or will be available as needed, for classes of autonomous vessels in planning or being built. Autonomy operational research by the Naval Postgraduate School (NPS) and this author began with a DARPA project focusing on operational development of the MUSV (Medium Unmanned Surface Vessel) *Sea Hunter* and potential uses.

Working with many of the warfare areas in the US Navy's mission responsibilities, it became apparent that the current capabilities (including adherence to international rules of the road) would still need combined human cognitive capacity and autonomy in what we now term as human-machine partnership (Gallup, 2023). Of course, there is continuing debate on missions and the boundaries of AI and fully autonomous systems at sea.

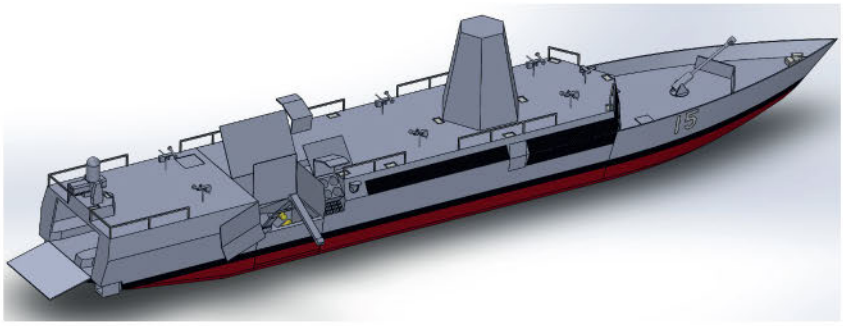
Here is the dilemma, explained through an example of the race to the moon. When President Kennedy initiated the project to place a US astronaut on the moon "by the end of this decade" (meaning by 1970), the efforts by NASA did not go directly to the moon landing. Rather there was an evolution through a sub-orbital manned flight (the Mercury program), then to longer orbital missions and spacewalks (Gemini program) to a mission to rendezvous two of the Gemini spacecraft, then an orbital mission around the moon (Apollo), and finally a landing in 1969. Each of these steps illuminated the engineering, procedures, capabilities, and massive innovations that streamed from this immense national effort.

A similar progression is needed in the case of autonomy at sea. It is evolutionary, will need to be supported by further innovation, and become reliable as part of the capabilities of navies and coast guard missions amongst nations.

Key to pursuing this evolutionary path is development of many components. First is the aida (Awareness, Interest, Desire, Action) of "automated" *vice* "autonomous." These two are often conflated. What has been learned in the *Sea Hunter* MUSV program is the use of a very high level of automation. Other innovations have come a long way of course, but true "intelligent ship" autonomy is far from attained.

A second very important dynamic at play is the need for a fourth tier, (the tiers being carriers, large amphibious

RECENTLY DECOMMISSIONED CYCLONE CLASS PCS, WITH USS *HURRICANE* IN THE FOREGROUND



CONCEPT IMAGE FOR THE LIGHTLY MANNED AUTOMATED COMBAT CAPABILITY WARSHIP

ships as well, guided missile destroyers as the second tier, submarines as the third, then small warships as the fourth) in the USN's force structure.

Lightly Manned Automated Combatant Capability

The NPS Monterey, California, is now researching the design and operations of a Lightly Manned Automated Combatant Capability system to become this fourth tier. The LMACC is a destroyer escort-sized ship, incorporating the best of automation and decision aids, well-armed, and capable of long-range, persistent operations.

The LMACC design capitalises on engineering automation built into the *Sea Hunter* such as internal engineering and plant operations and adherence to international rules of the road in a semi-autonomous mode. Additional research is ongoing to create a truly "smart ship" with such advances as human-machine integration.

The baseline LMACC design is 220ft (67m) in length at the waterline and 1,100tons. To break free of a logistics vessel, it has a range of 7,500nm at loitering speeds (12knots), and 1,500nm at 28knots. Design specifications have been developed by the US Naval Academy naval architects, in partnership with the NPS.

Any new warship design must include and be sensitive to personnel limitations we are facing. LMACC is intended to be operated fully armed and capable with a crew of about 30 personnel. Something learned from the Littoral Combat Ship (LCS) is the difficulty of creating "plug and play" variants. Rather than opting for plug and play modules, all LMACCs are armed with surface to ground, surface to surface, and anti-missile/air capability. To create true distributed maritime operations, some LMACCs will have a lengthened hull to add a secondary warfare capability (e.g. anti-air warfare, anti-submarine warfare, mine warfare and anti-surface ship warfare) to the baseline surface warfare design. To date there have been journal articles, technical reports, theses, articles in CIMSEC (Center for International Maritime Security), a master briefing, technical injections into a NPS Campaign Analysis course, and Warfare Innovation Continuum exercises.

The concept of operations is well determined. LMACC can operate individually, as a tactical pair, or in a flotilla of four to six LMACCs and five to six MUSVs. The intention here is to place the unmanned surface vessels (USVs) and the LMACCs in positions that meet a tactical need. This might be supporting the US Marine Corps in their developed Expeditionary Advance Base Operations (EABO) for force protection and light logistics support, or to the US Marine Corps' intention to be forward with a Marine Littoral Regiment (MLR), facing seaward to protect sea lanes of communications.

Considering the number of possible choke points around the world (e.g. as seen now in the Indo-Pacific, Baltic and Red Seas), there are more needs than our current, expensive DDGs can meet.

Reducing personnel affects ship design and costs

Here we get to the discussion about cost. An article on total cost analysis and simulation was published by the USN *Naval Engineer's Journal* (Gallup and Munn, 2021) to do a very deep analysis of per copy costs. Not surprisingly, people are the costliest part of a ship and limiting the personnel costs (and all that goes with their support) reduces the building cost to approximately US$100 million (2021 dollars). People increase the total cost overall, with their pay, incentives, training, and such. But they also increase the immediate building costs of a warship in their needs for everything from water storage, food storage, sleeping quarters, etc. Reducing personnel affects ship design. Conversely, a new DDG might cost multi-billions in US dollars. In addition, LMACCs can be built by yacht yards, further extending an industrial base. Instead of building for a 20-year operational life cycle, we contend that as innovations continue to develop, it is far cheaper to build new ships to incorporate these advances, than it is to try and refit older ships. This only works if the cost is kept low.

A word on the history of small ships in the US and partner nations navies. The Destroyer Escorts (DE), e.g. the USS *Johnston* and the destroyer USS *Samuel B Roberts*, were instrumental in beating the Japanese battleship fleet in WW2. The Canadian and British Flower class corvettes – originally called "Patrol Vessel, Whaler Type", a modified pre-war whale catcher design, and dubbed by Sir Winston Churchill "cheap and nasty" (1) – secured the convoy lifeline to Britain during WW2, thereby preventing defeat (Gault, 2007). The USN's final class was the Cyclone class coastal patrol ships developed originally for special operations forces, but they were not well-suited, and began a series of ownership to the US Coast Guard, back to the USN and finally found a very important mission in the Persian Gulf. So here we are, in great need of a tactical capability, close to an adversary, persistent and with operational capability that doesn't drain the budget.

Included in the current project to build and test a prototype of the LMACC are new command and control concepts, independent of satellite communications. New HF communications provides connectivity in a satellite denied environment. In flotilla operations with the MUSVs, a 5G cloud network is being tested to create a "sensor grid" for sensing, identification and targeting. Many energy innovations, human factors, and the idea of "virtual partners" make this a game changer in forward operations. It would be the first to fire, creating a pathway for DDGs and other larger ships to get close enough to the fight to be effective. Finally, these ships would provide affordable peacetime presence, allowing larger ships to focus on readiness and reducing the impact of any pre-emptive strike on the USN.

Coast guard variant

The LMACC concept also includes use by allied partners in the region of conflict, thus filling out naval presence in response to adversarial grey-zone competition. A coast guard variant is also envisioned, that has teeth, but also sustainment and regulatory, SAR and coastal security capabilities, again with a small crew, and a high level of automation and decision-making tools.

The LMACC public-facing website can be found at https://nps.edu/web/lmacc. The Narrative CONOPS portion requires US government certificates, but a master briefing and vessel details can be viewed here. If interested in further discussion of any points made in this article, please contact Dr Shelley Gallup via email: spgallup@nps.edu, or by telephone on +1 831 392 6964. ■

The author plans to expand on this subject, in conjunction with Dalhousie University, at the RINA's Autonomous Ships 2024 conference, to be held in Copenhagen, Denmark, from 20-21 November 2024. Please visit https://rina.org.uk/events/events-programme/autonomous-ships-2024 for further details.

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ROUTE PLANNING

OPTIMAL ROUTE PLANNING AS PART OF DX PROMOTION TO REALISE THE CIRCULAR CARBON ECONOMY

By **Yoshiko Sato**, Japan Weather Association, and **Satoshi Iwamoto**, Mitsubishi Chemical Logistics Corporation

FIGURE 1. *HISHI MARU*, THE SUBJECT SHIP FOR THE DEMONSTRATION PROJECT

Currently, the world grapples with pressing challenges, including climate change and issues linked to population growth. Meanwhile, Japan's logistics industry is facing challenges, such as those associated with addressing the 2024 problem and realising a sustainable society. To address these social issues, Mitsubishi Chemical Logistics, together with organisations including the Japan Weather Association, sought to address the challenges in ocean shipping digital transformation (DX) in 2023 as part of the promotion of the circular carbon economy. Demonstration tests were performed, and a 2.3% reduction in greenhouse gases (GHGs) was demonstrated in one voyage. This paper presents an example illustrating this promising reduction.

Background

Mitsubishi Chemical Logistics Co. is a Japanese chemical product logistics company that provides integrated domestic and international logistics services, handling 4.4 million tonnes of ocean freight annually, mainly petrochemical products. In alignment with its commitment to a circular economy and carbon neutrality, the Mitsubishi Chemical Group has intensified its initiatives. As part of these efforts, we constructed and implemented an optimal route planning support system, leveraging digital technology to actualise eco-friendly marine transportation.

The demonstration project was approved in 2022 and was implemented as part of the Ministry of Land, Infrastructure, Transport, and Tourism and the Ministry of Economy, Trade, and Industry's Project Subsidy to Promote Further Transport Efficiency Utilising AI, IoT, etc. (Demonstration Project for Innovative Operational Efficiency for Coastal Ships). The study protocol received approval and was subsequently implemented. This project strives to realise energy-saving operations by equipping existing ships in service with an optimal route planning support system, high-efficiency propellers, and energy-saving hull additions. Initiating the process, we collaborated with the Japan Weather Association and other companies to undertake the construction and installation of an optimal route planning support system. Subsequently, demonstration operations were conducted on several voyages in 2023.

Overview of the demonstration project

The subject ship for the demonstration project was Mitsubishi Chemical Logistics Co.'s *Hishi Maru*, a 1,300dwt coastal chemical tanker (Figure 1). This ship, commissioned in 2015, was already in active service at the commencement of the demonstration project. Initially built with specifications enhancing transport quality and safety, it was the most advanced vessel of its time, boasting features such as energy-saving friend fin (a device that attaches fins to the stern in front of a ship's propeller to reduce the rotational flow generated at the rear and improve propulsion efficiency) installed to improve propulsion efficiency.

The demonstration project sought to achieve a 7.47% reduction in GHG emissions through a combination of hardware and software measures with the following characteristics:

TABLE 1. OUTLINE OF WEATHER AND OCEANOGRAPHIC FORECAST

	Global	Japan Coastal
Items	Ocean wind, significant wave, wind sea, swell, ocean current	Ocean wind, significant wave, ocean current ***Improved accuracy through data assimilation.**
	Pressure, typhoon and hurricane information	
Update frequency	4 times a day	**8 times a day**
Forecast period	Up to **30 days**	Up to 4 days
Providing method	• Email / Web API / HTTP • Any area, resolution and forecast time can be selected	

- Hardware measures: Improvement of propulsion through the installation of new technology (retrofitting) by improving the propulsion equipment of existing ships.
- Software measures: Introduction (retrofitting) and operation of an optimal route planning support system for existing ships.
- Digitisation of monitoring data from existing ships in service and establishment of a real-time collection environment.
- Evaluation of actual routes using DX technology and construction of a verification environment.

Notably, aside from the propeller countermeasures implemented in this project, numerous hardware options exist for ship enhancements. These include refining the ship's design and incorporating various energy-saving measures. Currently, software measures are centred around optimal route planning. Importantly, no other alternatives are evident. Recent advancements facilitate the support for optimal route planning not only through providing voyage plans but also by evaluating actual voyage outcomes. However, precise and timely operational monitoring is essential. In this demonstration project, digitisation technology has been employed to seamlessly gather real-time monitoring data from actively operational ships – a task previously deemed challenging.

Outline of optimal route planning

Optimal route planning is a technology that i) accurately predicts the weather and sea conditions encountered during a voyage, ii) considers the ship's propulsion performance, and iii) selects an optimal route based on certain evaluation indicators. In the present context, the evaluation index is the GHG emissions (fuel consumption), and the system selects the optimal route with the lowest GHG emissions (fuel consumption).

The Japan Weather Association offers a proven optimal route planning support service tailored for coastal ships. The precision and accuracy of weather forecasts utilised for optimal route calculations hold particular significance in coastal regions, given the constrained range of route options. Independently developed and operated by the Japan Weather Association, high-precision, high-resolution forecasts, specifically designed for coastal areas, are employed (see Table 1). Moreover, prior findings demonstrate an average 3%–5% reduction in GHG emissions through the implementation of optimal route planning (Figure 2).

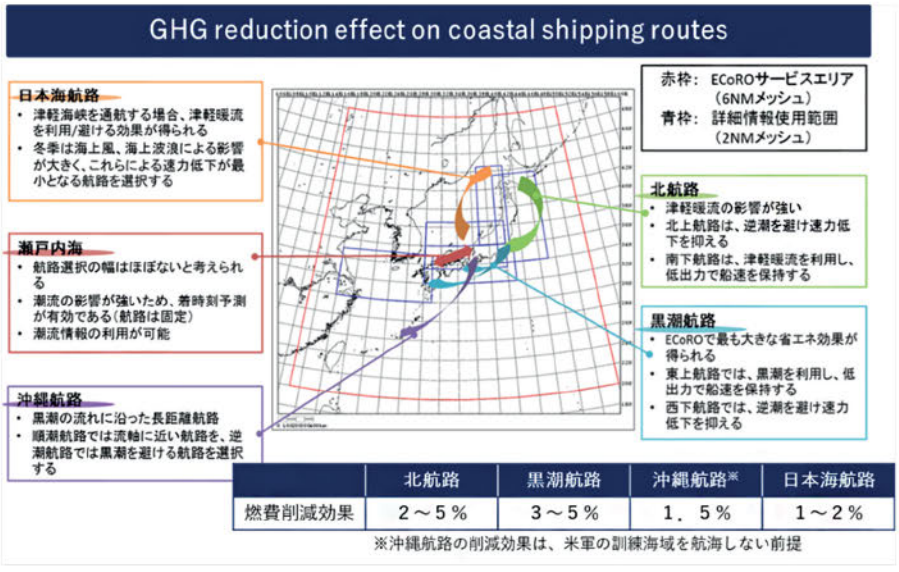


FIGURE 2. GHG REDUCTION EFFECT ON COASTAL SHIPPING ROUTES

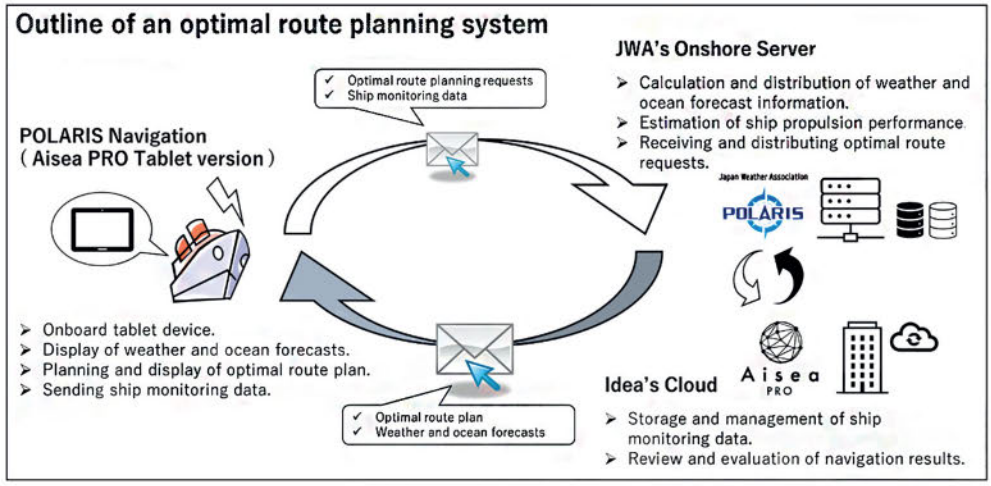


FIGURE 3. OUTLINE OF THE OPTIMAL ROUTE PLANNING SYSTEM

GHG reduction achieved through optimal route planning in demonstration trials

In this demonstration project, we combined Japan Weather Association's POLARIS Navigation and Aidea Inc.'s maritime platform Aisea PRO to create a new optimal route planning system (Figures 3 and 4) that considerably improves upon the previous system. The subjects of this project, coastal chemical tankers, are characterised by their relatively small size and limited crew. Despite their size, these vessels are notably busy because of a relatively high frequency of port calls. In light of this, our design considerations for the new system were centred around two key aspects:

1. Reducing the difficulty of implementation by making it easier to install on board ships: Conventional optimal route planning support systems for coastal ships necessitate dedicated terminals, presenting challenges in terms of implementation preparation and the allocation of space on bridge areas. To solve this problem, this project made it possible to use Aisea PRO on a tablet terminal, creating a system that can be easily introduced and used on relatively small coastal ships weighing 499tons or less.
2. Reducing the burden on the crew through easy operation using presets: we adopted a presetting method that eliminates the need for specialised operations, facilitating the recall of routes and calculation conditions. Consequently, even crews unfamiliar with equipment operation can navigate it effortlessly, thereby reducing workload and avoiding pressure during working hours.

This system was scheduled for installation on a designated ship in 2023 and has subsequently been employed on multiple voyages. To illustrate, we highlight a specific case: the route from Ube in western Japan to Chiba in eastern Japan. In this voyage (Figure 5), the optimal route was slightly offshore compared with the regular route. The fuel consumption of the usual route is estimated to be 100.0 (dimensionless value), whereas that of the optimal route is 97.7, resulting in a GHG reduction of 2.3% for the optimal route.

The primary factor contributing to the achieved 2.3% reduction on this voyage is attributed to the leveraging of ocean currents. This is elucidated through the ocean current map illustrated in Figure 6 and the time series of ship data depicted in Figure 7. First, the area boxed in red in Figure 6 indicates that the optimal route is 'forward ocean current navigation', that is, a voyage that follows the flow of ocean currents. By utilising ocean currents, it is possible to navigate with a reduced engine power for a certain period.

Next, as regards the time-series graph in Figure 7, the orange solid line indicates the typical route, the blue broken line indicates the optimal route, and the areas corresponding to those surrounded by the red box in

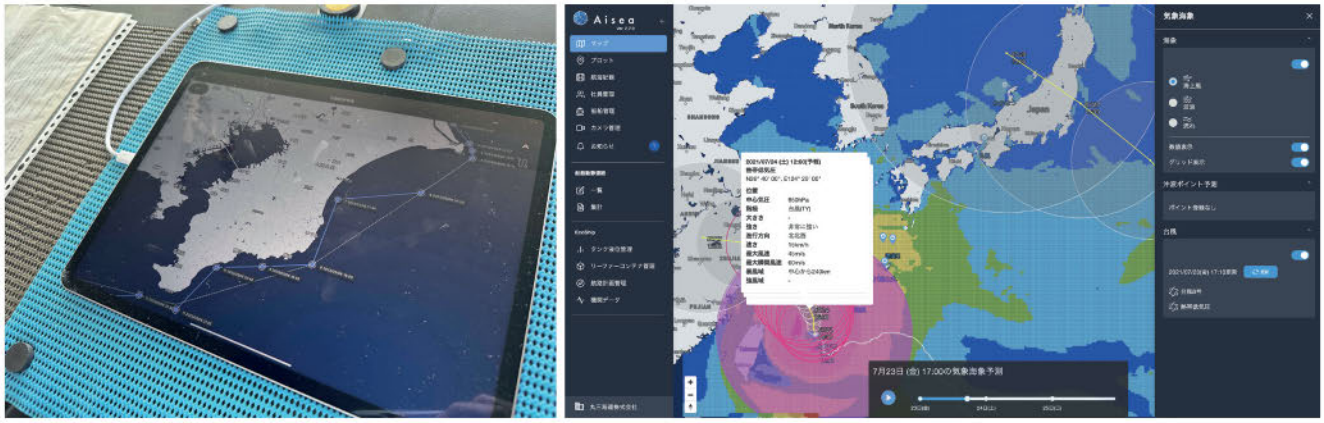


FIGURE 4. ILLUSTRATION OF THE USER INTERFACE OF THE OPTIMAL ROUTE PLANNING SYSTEM

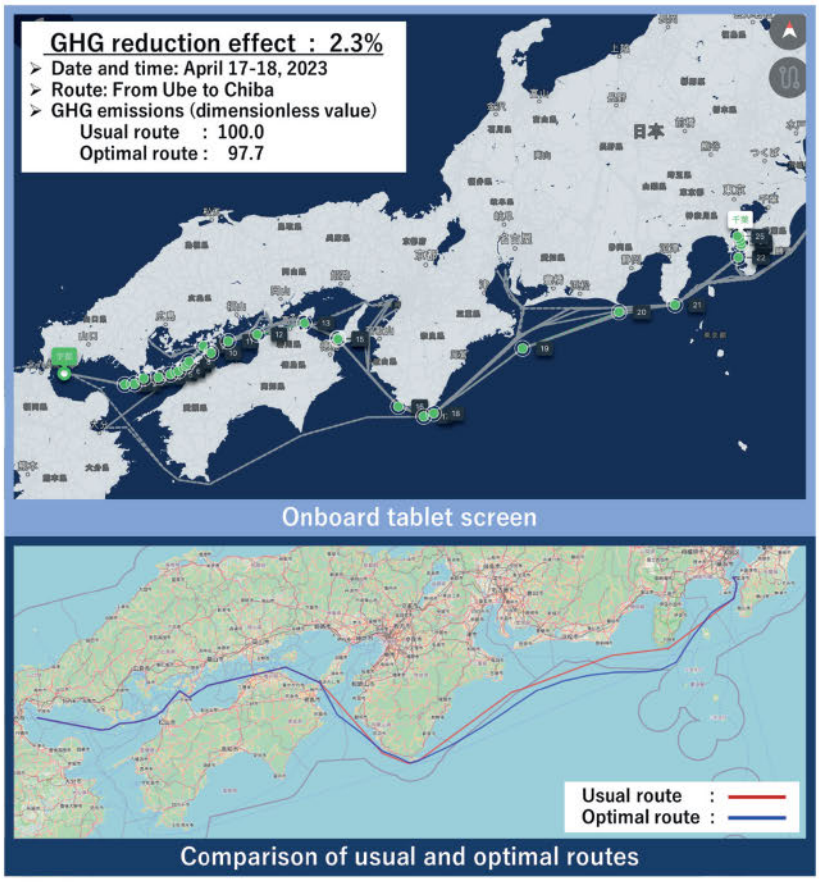


FIGURE 5. EXAMPLE OF A GHG REDUCTION VOYAGE IN DEMONSTRATION TRIALS

Figure 6 are circled in red. The ocean current graph shows that the optimal route encounters stronger forward ocean currents than the usual route. The resistance attributed to ocean currents indicates a negative value for the typical route, signifying that ocean currents do not pose resistance. Instead, the force exerted by the ocean currents is harnessed. Accordingly, the revolutions per minute (RPM), indicative of the engine power, can be reduced on the optimal route, resulting in a voyage with a low speed through water (STW) but a maintained speed over the ground (SOG) and fuel savings.

Traversing the Seto Inland Sea, Japan's largest inland sea, this route encounters a congested area known for its limited route options. Notably, approximately half of the entire route lacks viable choices. Despite this route, the result of 2.3% for the entire route can be considered a sufficient impact.

Conclusion

The GHG emission reduction target for the Maritime Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism and the coastal shipping industry is 17% below the 2013 levels by 2030. Japan has more than 5,000 coastal cargo ships in Japan. State-of-the-art energy-saving technologies are commonly integrated into newly constructed ships owing to ease of implementation. However, given the extended operational lifespan of ships,

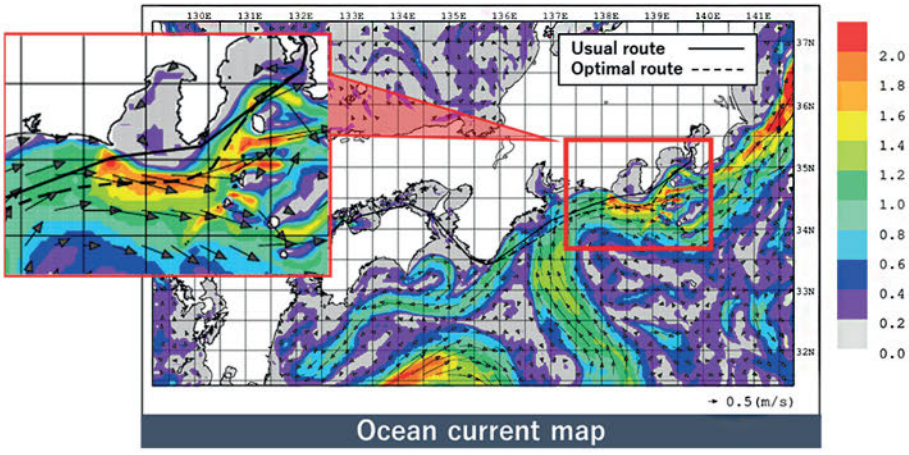


FIGURE 6. OCEAN CURRENT MAP ON THE DEMONSTRATION VOYAGE

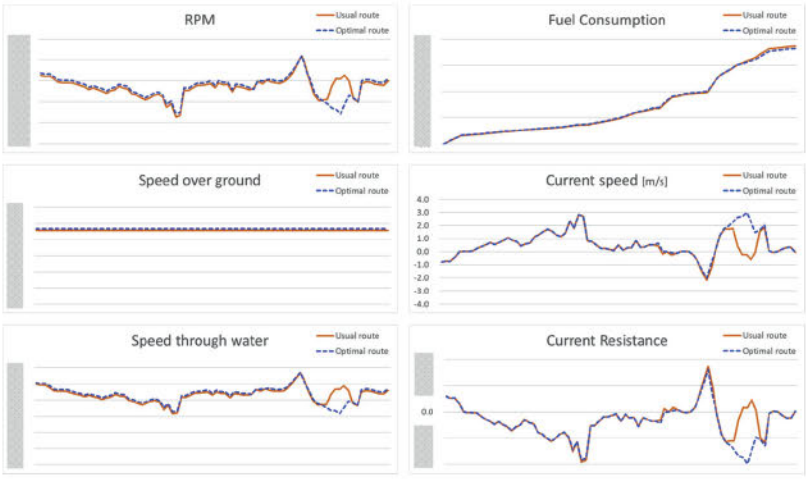


FIGURE 7. SHIP DATA FOR THE DEMONSTRATION VOYAGE

typically lasting 15–20 years or more, incorporating new technologies into existing vessels becomes essential for meeting reduction targets. In anticipation of this situation, Mitsubishi Chemical Logistics Co. proposed a plan to save energy and reduce GHG emissions by using technology that can be installed on ships already in service; this plan was adopted by the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure, Transport, and Tourism, and demonstration experiments were conducted. Focusing on GHG reduction measures achievable through software readily installable on existing ships, we designed and implemented an optimal route planning support system, subsequently conducting a demonstration. Consequently, although still at an early stage, a GHG reduction of 2.3% was demonstrated.

To meet industry-wide reduction targets, it is imperative to not only construct new ships but also, as demonstrated in this study, innovate and implement technology on existing vessels. Encouraging such support in the future holds the potential to further advance energy conservation within the transportation sector. ■

ICON OF THE SEAS ARRIVES IN MIAMI AHEAD OF ITS OFFICIAL DEBUT ON 27 JANUARY 2024. SOURCE: ROYAL CARIBBEAN INTERNATIONAL

CRUISE SHIPS

ECONOMIES OF SCALE POWERFUL DRIVER TO BUILD EVER BIGGER CRUISE SHIPS

By **Kari Reinikainen**, Correspondent

Forty years ago, the shipping media carried stories about a 250,000gt cruise ship that the chairman of what was then Norwegian Caribbean Line (NCL), Knut Kloster, was planning to build: it was more than three times the size of the largest cruise ship then in service. With the introduction of Royal Caribbean International's (RCI) 248,663gt *Icon of the Seas*, the scale that Kloster thought of four decades ago has now been reached.

Economies of scale have been a powerful driver in the trend towards ever bigger cruise vessels and they may continue to encourage owners to look for future vessels that are even bigger than the three Icon class ships on order at Meyer Turku in Finland. "Cruise vessels will, in my opinion, get bigger," summarises Finn Wollesen, managing director of consultant naval architects Knud E. Hansen in Denmark.

While the contemporary market is traditionally the one that employs the biggest ships, such as *Icon of the Seas*, the trend towards larger tonnage has not been limited to this segment.

In the premium market, the first newbuildings of Celebrity Cruises that entered service in the early 1990s had a gross tonnage of about 47,500. The company, which is now part of the Royal Caribbean Group, is currently building its Edge class of ships, the largest of which have a gross tonnage of 140,600.

Even at the very top of the price range, the trend goes towards larger tonnage. The first cruise yachts, *Seadream I* and *Seadream II*, were built in the mid-1980s and have a gross tonnage of about 4,200. By contrast, *Ilma*, the next cruise yacht of Ritz Carlton, is due to have a figure in the region of 46,750gt.

Kristian Knaapi, sales manager at Finnish consultant naval architects Deltamarin says that transition to CO_2-free fuels might increase the main dimensions of a future newbuildings. "However, the needed space for new fuels is actually not [taken] away from passenger areas. The tanks and the other needed equipment will be located in areas where there are no passengers, mainly under the main deck into machinery spaces," he says.

"Most probably the investment cost for the vessel will be slightly bigger. This is mainly caused by bigger outer dimensions or new added technology needed for alternative fuels," he points out.

From yachts to floating cities

Richard Fain, now chairman of the Royal Caribbean Group, once recalled in a presentation how the first purpose-built cruise ships that entered service in the early 1970s were externally modelled after yachts to set these ships of about 20,000gt apart from the appearance of ocean liners, some of which were still in service.

KRISTIAN KNAAPI OF DELTAMARIN

By the end of the following decade, ships of some 75,000gt were entering service and these were essentially floating hotels. A decade later, the largest contemporary market vessels were of about 137,000gt and could be thought of as floating resorts. By 2010, the first cruise vessels in excess of 200,000gt were in service and these are essentially floating cities.

There are a few important points here. The first one is the gradual evolution of the size of these ships: a jump from some 70,000gt to 250,000gt that Kloster contemplated four decades ago. A step-by-step growth was possible because the gradual growth of the leading operators, both organic and through mergers and acquisitions, enabled them to finance that growth.

This again was possibly thanks to the steady increase in demand that the industry has enjoyed over the decades. Kloster's vision – partly based on the success of the 70,202gt *SS Norway*, a former ocean liner built as *SS France* in 1962 that NCL had introduced in 1980 – presumably had two key elements of the industry in the background: economies of scale and supply-led growth.

Cruise industry executives frequently mention the power of new vessels to drive the business forward. In all its segments – contemporary, premium and luxury – the gradual increase in the size of ships has also led to a far wider range of services on offer.

The first-generation cruise liners had a main dining room and a buffet; today some ships have almost two dozen dining venues. Spas that originally comprised a few treatment rooms have evolved to relaxation and wellness areas covering hundreds of square metres.

Land-based and operational challenges

While the two principal drivers that encourage owners to look at ever larger ships – economies of scale and supply-led growth – remain intact, some factors that have the potential to discourage them are also on the horizon and these are based on land.

DAMEN'S DRYDOCK IN BREST CAN ACCEPT VESSELS DRAWING UP TO 13M OF WATER. SOURCE: ERWAN GUEGUENIAT/DAMEN SHIPREPAIR

One of them is the need to drydock these ships, while investment in ports to handle very big ships is often slow to take place. In some locations, a strong anti-cruise sentiment is emerging as part of the locals' concerns over the effects of overtourism to their communities.

The size of drydocks is a factor that can potentially limit the growth of cruise ships in the future. One of the important aspects is draught. Many of the largest drydocks, particularly in Europe, were constructed in the third quarter of last century with the building of large tankers in mind.

This business was eventually lost to shipyards in Asia and the facilities in Europe can be used for repair and refit work. A tanker in ballast has a very shallow draught, but the largest cruise ships draw up to 10m of water. There is little than can be done to reduce the draught to allow a cruise ship to enter drydock, explains Rogier van der Laan, cruise sales manager at Damen Shiprepair & Conversion in the Netherlands.

The Damen group itself has two very large drydocks, one in Rotterdam and the other in Brest and the French facility can accept vessels drawing up to 13m of water, which is more than any cruise vessel does, he points out.

The size of largest cruise ships has increased very quickly and the land-based infrastructure needed to handle these ships often has not kept pace with this development, says John Garner, managing director of JG Maritime Solutions Ltd in the UK.

Handling the turnaround of a ship the size of *Icon of the Seas*, with a capacity of 7,600 passengers when all berths are in use, is a major logistical operation that requires not just the right facilities, but also an organisation that runs efficiently: cruise ships usually arrive early in the morning and sail late afternoon on the same day after new passengers have embarked at the turnaround port.

In many ports, jetties are not long enough to handle the largest cruise ships. This can be addressed by either lengthening the jetty or building a dolphin, with mooring facilities and a walkway to the pier for shore personnel.

However, as the superstructure of a modern cruise ship has cabins that mostly have balconies, it is very high and has a large area to catch winds. This poses operational challenges as strong winds have in some cases pulled bollards off their mountings and large cruise ships have also had minor collisions when manoeuvring in port in windy conditions, Garner points out.

Back to the future?

While economies of scale, including fuel economy, will continue to advocate even larger vessels, this may lead to a change in the dynamics of the cruise industry itself. Not all ports can or even want to accommodate very large ships, which cater for the contemporary market segment. This can lead to a diversification of destinations from the side of ports as some welcome the largest ships, while others may focus on smaller ships of more upscale lines instead.

Icon of the Seas exceeded the size of the previous biggest cruise ship in the world, RCI's *Wonder of the Seas*, by about 12,000gt. Both in absolute gross ton and in percentage terms, the growth is slowing. In the 1980s, the size of largest cruise ship newbuildings roughly doubled – converted liners still held the pole position as largest cruise liners in the world for most of the decade – while *Voyager of the Seas* of 1999 and of about 137,000gt was roughly one-third larger than the previously largest cruise ship then in service.

A sharp increase in the tonnage of the Icon class might require a concept change, both in terms of the design of the vessel and how it would be operated. Port infrastructure is probably the most critical point. Cruise lines themselves are already building their own terminals in key turnaround ports to ensure smooth operations in them. But ports of call could be another matter. Perhaps huge tenders that resemble landing craft of amphibious assault ships of major navies could solve the problem there. After all, this was part of the vision of Kloster four decades ago. ■

CHINA REACHES MILESTONE WITH MAIDEN VOYAGE OF FIRST DOMESTICALLY BUILT LARGE CRUISE SHIP

By **Tom Barlow-Brown**

The Chinese cruise industry reached a historic milestone at the start of the year with the country's first domestically built large cruise ship embarking on its maiden commercial voyage.

The *Adora Magic City* set sail from Shanghai in January and its launch represents a significant step for China's shipbuilding sector, positioning the nation as the one that is simultaneously constructing aircraft carriers, large liquefied natural gas (LNG) carriers, and large cruise ships. It also concludes eight years of research and development, followed by five years of design and construction, which began in 2018.

CHINA'S HOMEGROWN CRUISE SHIP *ADORA MAGIC CITY*. SOURCE: CSSC

Adora Magic City was delivered in November 2023, when the builders Shanghai Waigaoqiao Shipbuilding Co., Ltd. (SWS), a subsidiary of China State Shipbuilding Corporation (CSSC), along with China Communications and Transportation Design Institute (CCTD) and Adora Cruises, signed the official handover documents.

Designed to accommodate up to 5,246 passengers across 2,125 guest rooms, the new cruise ship boasts a total carrying capacity of 135,500dwt. It is equipped with a 16-floor, 40,000m^2 living and entertainment public area, making it a mobile "modern city on the sea".

The vessel has a length of 323.6m, a moulded breadth of 37.2m, design draught of 8.26m, and a maximum height of 72.2m. It incorporates 107 systems with 55,000 pieces of equipment, and 25 million components, and houses 4,750km of cables, 365km of pipes, and 120km of air ducts. It can reach a top speed of 22.6knots.

Notably, *Adora Magic City* will also be the world's first 5G-enabled cruise ship, featuring a substantial shopping area due to the absence of a casino, complying with local regulations. Adora Cruises envisions delivering a unique combination of traditional elegance, modern flair, and a captivating sea experience.

The Finnish maritime technology company Wärtsilä was involved in the delivery of a suite of solutions to the ship. These included advanced automation and control systems, lighting, navigation, engine and bridge control, bow thruster system, dynamic trim system, and various cable and steel parts. Wärtsilä also installed its own bow thruster system, as well as its dynamic trim system and supplied further steel parts for the vessel.

The vessel's initial seven-day voyage began when it left Shanghai Wusongkou International Cruise Port with 3,000 people on board, far short of its maximum capacity. It made stops at Jeju Island in South Korea as well as Nagasaki and Fukuoka in Japan.

The vessel's owner, Adora Cruises, is a relatively recent entrant into the cruise industry. The company, formerly CSSC Carnival Cruise Shipping Ltd, was originally founded as a joint venture between Carnival Corporation and CSSC. However, following a delayed launch due to the Covid-19 pandemic it changed its name to Adora Cruises. According to *Cruise Industry News*, the company, which is managed by Ranfeng Chen, is poised to become China's leading cruise line in 2024. Adora Cruises also officially debuted the refurbished 85,619gt *Mediterranea* in September 2023.

The cruise line plans year-round deployment from multiple homeports, offering routes to Japan, South Korea, and Southeast Asia. Recent government approval for outbound group tours to Japan and South Korea has also boosted bookings.

The collaborative efforts of CSSC, SWS, CCTD, and Adora Cruises in the development and delivery of *Adora Magic City* indicates the combined effect of collaboration between major companies within China's shipbuilding ecosystem. It also highlights the nation's continuing emergence as a global leader in ship construction, technology, and innovation.

The delivery of the vessel is significant as it demonstrates the progress the Chinese maritime industry has made in recent years. It also cements CSSC as the fourth shipbuilding group globally to successfully design and construct large cruise ships. The company, first established in 1999, is one of China's largest and most prominent state-owned shipbuilding conglomerates. The corporation plays a pivotal role in China's shipbuilding landscape.

The completion of *Adora Magic City* not only signifies a monumental achievement for CSSC and its subsidiaries but also positions China as a formidable force in the global cruise ship market. The *Adora Magic City* sets sail as a symbol of China's technological prowess, innovation, and ambition in the maritime industry. ■

SHIPBUILDING TECHNOLOGY

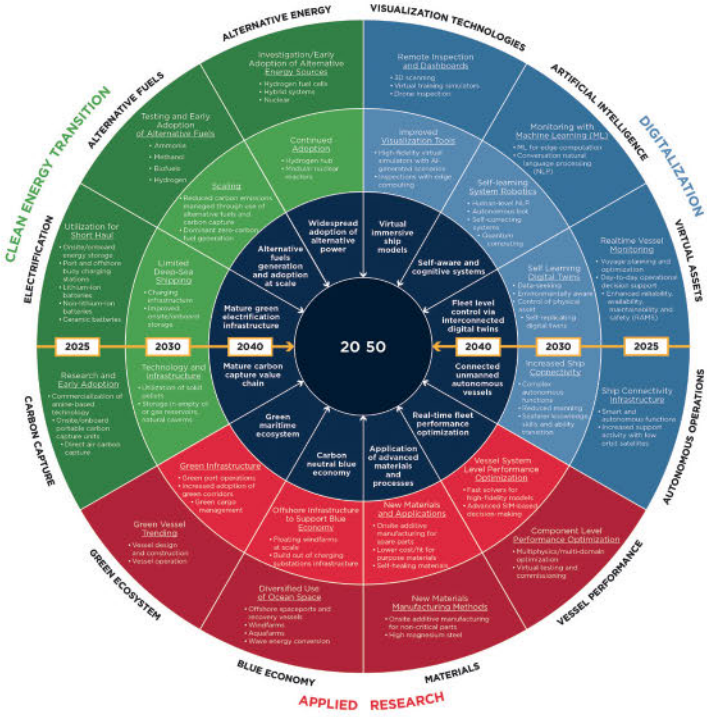
ABS AND HANWHA'S LATEST COLLABORATION SHOWCASES INNOVATIVE SHIP DESIGN TECHNOLOGY

By **Tom Barlow-Brown**

In the ever-changing currents of shipbuilding technology a newly announced collaboration between the American Bureau of Shipping (ABS) and South Korean shipbuilding company Hanwha could be a transformative force in naval architecture.

Announced in January 2023, the deal signed by the two organisations is the latest in a series of joint projects under the umbrella of ABS' Smart Yard initiative. The two companies hope the new collaboration will set new benchmarks for progress and steer the industry towards a digitally empowered future.

ABS, a global authority in classification services, prides itself on a rich history of active involvement in joint development projects. Insights from Patrick Ryan, senior vice president and chief technology officer at ABS reveal that the organisation consistently undertakes an impressive average of around 75 such projects annually across diverse domains. However, the collaboration with Hanwha goes beyond a one-off project; it represents a strategic alliance that surpasses conventional joint development initiatives.



ABS'S INNOVATION OUTLOOK

Ryan highlights the significance of the Smart Yard agreement. "It allows ABS and Hanwha to collaborate in various ideation processes, creating a robust framework for different ideas and innovations to move forward in using technology to fulfil our mission," he states. This emphasises the strategic depth of the collaboration, underscoring the shared commitment to pushing the boundaries of maritime technology.

In February 2023 ABS launched the *Guide for Smart Technologies for Shipyards*, a detailed series of conditions to guide the industry in the application of smart technologies at shipyards. The guide, a first of its kind, offers insight into how shipyards can incorporate new digital technologies in their operational processes. This joint development project, with a primary focus on shipbuilding and Smart Yard technology, seeks to redefine existing norms and envisions a future where the maritime sector is fully digitalised by the year 2050.

The Smart Yard project focuses on utilising digital technologies to augment safety and efficiency during ship construction and surveying. According to ABS, these new technologies utilise digital and data-driven innovation in three key areas. The first is the concept of hyperconnectivity which will allow real-time data access and information sharing between shipyards, clients and classification societies. Secondly, advanced automation will help aid production by allowing more tasks to be performed using automation in order to replace human responsibilities. Lastly, data-driven intelligence generated through analysis by engineering algorithms or human level computer intelligence will assist the overall design process.

Hanwha is the latest company to collaborate on the Smart Yard project, following the successful collaboration between ABS and companies such as Seatrium. The collaboration between ABS and Hanwha encompasses a broad spectrum, touching upon simulations, digital twins, wearable devices, and cyber controls.

The South Korean company is a notable player in the shipbuilding industry and brings a wealth of experience and innovation to the table. Formerly known as DSME (Daewoo Shipbuilding & Marine Engineering), the company has a storied history that extends over decades. ABS and Hanwha have cultivated a longstanding relationship, with numerous joint projects spanning years. This history of collaboration forms the bedrock of their

current joint endeavours, contributing to the seamless synergy evident in their Smart Yard collaboration.

ABS emphasises that the significance of this partnership goes beyond technological innovation. The critical role of collaborative projects such as that between Hanwha and itself helps to advance the digitalisation of the maritime industry and plays a pivotal role in achieving safety and environmental goals.

The collaboration with Hanwha therefore extends beyond technology and safety and plays a part in the broader context of the industry's digitalisation. Hanwha brings a unique perspective and expertise to the collaboration, according to Ryan.

"Hanwha is an important client for us. They're very forward-looking, certainly in autonomy, smart technology, cyber, and related technological paths connected to the smart yard agreement," he acknowledges, a sentiment which highlights the qualities of the partnership and the depth of understanding between the two companies.

From the focused emphasis on Smart Yard technology in the strategic application of artificial intelligence, virtual assets, and autonomous functions, the project also encompasses a broad spectrum of activities.

The ultimate goal, as articulated by Ryan, is to be able to support a fully digitalised shipbuilding industry.

It is just one of a series of initiatives designed to enable development of transformational technologies in the marine and offshore industries. The company has developed a conceptual guide for this purpose, known as the "Technology Trends" wheel. This serves as a dynamic tool, providing strategic guidance to ABS and its collaborators, aligning their projects with the overarching vision of digitalisation across the maritime sector.

Using the wheel as a guide, Ryan hopes that companies will be able to understand how technologies can be combined to push the boundaries of technological innovation in the maritime industry. "I could build a virtual model of a carbon capture system that uses AI to make decisions on when the system should be performing in different carbon capture technologies," he says, as an example of how the technologies can intersect.

ABS hopes that the Hanwha collaboration will be a blueprint for the future of maritime innovation. The strategic alliance between the two companies underscores the resilience and determination of both to embrace the opportunities presented by cutting-edge technologies. ■

CONFERENCES

RINA CONFERENCE PROVIDES INTENSE DEBATE ON CII RATING SYSTEM AND MARITIME DECARBONISATION

By **Tom Barlow-Brown**

The Royal Institution of Naval Architects' (RINA) technical conference on Managing CII and Associated Challenges, held at the International Maritime Organization's (IMO) headquarters in London on 16-17 January, painted a revealing picture of the maritime industry at a pivotal moment as it delved into the adoption of the IMO Carbon Intensity Indicator (CII) rating system.

The event served as a timely and significant research platform, offering a space for in-depth discussions and debates that are anticipated to influence key decisions leading at forthcoming meetings of IMO's Marine Environment Protection Committee (MEPC).

CII is designed to work as a comprehensive metric for assessing and benchmarking the carbon intensity of vessels, promoting transparency and accountability in the pursuit of a more sustainable future. However, its adoption has been seen as contentious and many argue that a 'one size fits all' approach will hinder, rather than aid attempts by the industry to become more environmentally friendly.

RINA first

Managing CII and Associated Challenges, the first conference of its kind organised by RINA, was attended by nearly 100 people. It aimed to provide a unique opportunity for industry leaders, experts, and professionals to share insights, research findings, and practical strategies related to managing the new CII and overcome challenges the industry faces. The diverse range of sessions, including presentations on Owner Experience, Ship Type Specific topics, Operational Strategies, Technical Strategies, and New Metrics for CII, offered a holistic view of the issues at hand.

Chris Waddington, technical director of the International Chamber of Shipping (ICS), expressed his satisfaction with the conference. According to Waddington, the event achieved an important balance, encompassing diverse elements such as presentations, Q&A sessions, discussions, and networking time. He praised the well-structured nature of the event, highlighting its success in providing valuable technical information while offering opportunities for participants to expand on the topics through interactive sessions at the end of the conference.

"For ICS it's quite a complicated issue because we represent the whole industry," stated Waddington. "But for us we're looking for a holistic solution. So CII has got to be something very simple, which is fair to everyone, or it's got to reflect the complexity of the industry."

The knowledge generated and shared during the conference is expected to play a crucial role in shaping discussions and decisions at MEPC. Under its remit as an NGO at IMO, RINA has already made a record number of submissions ahead of the deadline for MEPC 81, which takes place 18-22 March. However,

RINA CHIEF EXECUTIVE CHRIS BOYD WELCOMES DELEGATES TO THE MANAGING CII AND ASSOCIATED CHALLENGES CONFERENCE. SOURCE: RINA

it's likely the insights gained from the conference discussions will inform policy considerations, industry standards, and potential revisions or enhancements to the CII rating system to be further discussed at MEPC 82 in the autumn. This collective effort is essential in ensuring that the maritime industry continues to evolve toward a more sustainable and environmentally responsible future.

H2 of 2024 set to be key

"A key time is probably going to be the second half of this year because the data is being submitted by the shipowners through ICS," noted Chris Waddington. "So the CII ratings will be confirmed as a part of a progressive process around the middle of year. I think that's going to reveal the true extent of the things that need to be improved in the system."

CII is a key component of the IMO's efforts to assess and improve the energy efficiency of ships, which applies to all cargo, ro-pax and cruise ships with a gross tonnage above 5,000. The aim of the new system is to provide a measure of how efficiently a ship transports goods or passengers, expressed in grams of CO_2 emitted per unit of cargo-carrying capacity and nautical mile. This indicator aims to incentivise and promote the reduction of greenhouse gas (GHG) emissions from the maritime sector.

At present the CII comprises of several components. Central to this is a system wherein ships are assigned an annual rating from A to E, based on their carbon intensity. These are expected to become increasingly stringent as the industry works towards the IMO's decarbonisation targets, particularly looking forward to 2030. If a ship receives a D rating for three consecutive years or an E rating in a single year, a corrective action plan needs to be developed. This plan is integrated into the Ship Energy Efficiency Management Plan (SEEMP) and requires approval.

CII is intended to serve as a mechanism to drive continuous improvement in the energy efficiency of ships, encouraging the maritime industry to adopt measures that contribute to the overall goal of reducing carbon emissions and achieving a more sustainable shipping sector.

The conference marked a significant moment for RINA as it plans to organise further events on crucial industry topics and position itself as a key contributor to the ongoing global dialogue on decarbonisation the maritime sector. The research platform provided by the conference is anticipated to have a lasting impact on the industry, influencing decisions and shaping the path towards a more sustainable maritime future. ■

DECARBONISATION

MARITIME DECARBONISATION: A STOCKTAKE

By **Dr Jonathan Williams**, CEO, MSE International

MSE INTERNATIONAL IS A PARTNER IN THE SEA CHANGE PROJECT AT PORTSMOUTH INTERNATIONAL PORT. SOURCE: PORTSMOUTH INTERNATIONAL PORT

Archives at the port of Portsmouth contain some fascinating photographs showing the port as it transitioned from the age of sail to the age of steam. New coal 'bunkers' dominated the scene. Arguably, the ongoing maritime transition from fossil fuels to carbon-neutral energy sources is equally far-reaching. Now seems a good time to take stock of progress.

Vessel propulsion

A substantial amount of innovation has already taken place in developing zero-carbon and low-carbon propulsion for ships as well as for smaller craft. Studies have shown that current battery technology offers a feasible propulsion solution for vessels with a limited range requirement including ferries, leisure craft and some workboats. Where range requirements don't allow all-electric propulsion, ferry and workboat operators are looking at hybrid drives whose engines can run on various biofuels (such as HVO or bio-MGO) or so-called e-fuels (such as methanol or ammonia produced using renewable electricity). These drives allow for more efficient engine operation at cruising speed, but with additional peak power available for manoeuvring or getting onto plane. Such drives are probably essential to achieve decarbonisation in line with short-term 2035 targets. Indeed, MSE is just initiating its HyCap project with partner Marine & Industrial Transmissions, to build and test a prototype hybrid drive with peak power provided by a supercapacitor, using a high-power interface being developed by the University of Birmingham.

Deep-sea ship operators (where all-electric propulsion is not presently viable) still face uncertainty in the type of fuel they will be using in future, but it seems clear that biofuels and e-fuels will play a crucial role in the long run. Given the likely high price of these fuels, there is a clear role for energy efficiency measures. The IMO 4th Greenhouse Gas study has confirmed this role and it is encouraging that several wind-assist technology demonstration projects are now underway.

However, carbon-neutral fuel will still be needed in very large quantities. DNV's Energy Transition Outlook has usefully explored a range of possible scenarios for the maritime fuel mix in 2050. Relative price is a major factor. The 'winning' fuels will likely emerge as substantial investment is made in specific new refining and distribution capacity, driving down the price of certain carbon-neutral fuels. The role of hydrogen fuel for vessel propulsion is likely to be small, limited to niche applications where gravimetric energy density is of paramount importance or in locations where hydrogen is produced for other sectors (cement, steel, glass, etc).

Shore power provision

Whatever energy vector it uses for propulsion (and for meeting hotel load), a vessel is entirely dependent on the system that conveys this energy vector to it. Shore power systems that supply electrical energy to ships and boats are already well-developed, even though high-power systems for larger vessels are still rare in the UK. The Sea Change project at Portsmouth International Port is building and demonstrating a novel multi-vessel system, and MSE as a project partner is working to maximise the take-up of this technology by other ports. Meanwhile, high-power DC chargers for

smaller vessels are already being deployed at scale, benefiting from some common components with electric vehicle (EV) recharging systems.

There are, however, two critical barriers that have not been adequately addressed: electricity supply infrastructure and electricity pricing. Shore power systems for large ships can typically draw up to 10MW per vessel and this power is drawn from the local distribution network. As further shore power systems are deployed, alongside EV recharging infrastructure and electric heat pumps, the load on these networks, and on the transmission grid itself, will become extremely challenging to meet. Network operators will increasingly seek to impose demand-side response measures on their customers to balance supply and demand. It remains unclear how this could be accommodated by ports needing to service vessels' energy requirements to a schedule. The alternative would be additional transmission and network capacity to provide sufficient headroom to accommodate load peaks, but this would be very costly.

It is widely acknowledged that current high electricity prices make shore power uneconomic for vessel operators compared with their continued use of auxiliary generators. As more ports offer access to shore power, vessel operators will be free to choose where they target their carbon emissions reduction needed to meet their CII (Carbon Intensity Index) obligations. Appropriate energy pricing policies are therefore needed to ensure that UK shore power facilities are fully utilised and deliver their expected carbon reductions and air quality improvements.

The role of battery storage

An ability to store electrical energy cheaply, efficiently and densely would transform the pace of maritime decarbonisation. Although battery technology currently falls considerably short of this ideal, it is important to factor in the dynamics of battery innovation in the future. Analysis by the Rocky Mountain Institute has tracked these dynamics over time with some remarkable results. The cost of battery storage (in $/kWh) has reduced by roughly a factor of 10 each decade, almost entirely due to economies of scale in manufacturing. As costs reduce, more markets find the technology attractive, demand increases and further economies of scale are available. Furthermore, as market size increases so does the R&D spend, achieving almost a doubling of energy density each decade.

Compared with automotive, the maritime sector is at an early stage in battery adoption. However, as marinised battery systems similarly benefit from these dynamics over the coming decades, the share of market where electric propulsion is attractive will continue to grow.

In addition to onboard batteries, there is also a crucial role for battery storage in ports. As with non-maritime grid-scale energy storage, there is growing interest in the use of flow battery technology in these stationary applications, where energy density is relatively less important. Durability is the major advantage of flow batteries, vital in applications having a demanding duty cycle (e.g. where several charge-discharge cycles are taking place daily). There are many different flow battery chemistries under development at present, and most of these have not yet started to scale, so costs are presently quite high. However, this will change quickly, mainly driven by the large expansion foreseen in grid-scale storage up to a projected global market of 1TWh/year by 2050. Port energy storage systems will be able to piggy-back on these economies of scale, with battery costs likely falling to a few 10's of $/kWh.

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In anticipation of these trends, MSE trialled a battery system in Portsmouth International Port in its PESO project, with partners Swanbarton developing the battery controls and interfaces. This battery is now being re-used in the Sea Change shore power system, with the goal of assessing how a larger battery could be deployed to manage peak loads and to optimise port-wide energy use under an AI-based control system.

How digitalisation will help

The use of AI to manage battery use is just one way in which maritime digitalisation can reinforce the route to decarbonisation. Rapidly growing interest in digital twins is an indicator of how system monitoring and advanced data analytics are enabling a multitude of information services to assist vessel and port operations. Although one of the main drivers for deployment of marine digital twins is the forecasting of system integrity and minimising the risk of unplanned maintenance, they can also help to optimise vessels' energy efficiency. Drag losses from hull biofouling can be a major source of excessive fuel use, and digital twins can help to schedule hull cleaning in order to maximise cost-effectiveness.

As digital twin systems create a capacity and a business case for data acquisition, the extent of instrumentation on vessels and on port machinery is proliferating. Electric and hybrid drives incorporate much more extensive sensors (generally multiple temperatures, currents, voltages as well as torque and speed) than conventional drive trains. This creates potential for advanced data analytics to monitor system state-of-health. MSE has been exploring this potential under the DriveWise project alongside partners RED

Scientific. This has uncovered strong interest in such applications of maritime AI, but also some barriers to data sharing that we need to overcome.

Using this kind of AI application to forecast the vessel's energy requirements at the destination port will become important to optimise port energy management. This aspect of port/vessel interaction has been considered in detail under MSE's SPINE project, with support from MarRI-UK. This project includes partners Ricardo and Swanbarton developing a port energy system optimisation model alongside partners Marico and Hydrosurv working on vessel instrumentation and secure data communications. These capabilities are also enabling increasing levels of vessel autonomy which is set to expand alongside decarbonisation. Indeed, the two are inter-related as reduced crewing costs support the economics of slow-steaming which is recognised as a major contributor to meeting the industry's net-zero ambitions.

Conclusions

The momentum of investment in maritime decarbonisation is growing rapidly as regulatory targets become more urgent. In the UK and Europe, growing innovation funding from government is helping to drive an expanding portfolio of leading-edge projects. Realistic scenarios for achieving maritime carbon neutrality are in place, and many of the technologies that will be needed to attain them are under development.

However, the scale of investment needed is huge, on landside infrastructure as well as on vessels. Although much uncertainty about future fuels remains, the direction of travel will become clearer as investment in large-scale refining and distribution assets is committed. Equally as economies of scale in battery storage accelerate, on the back on non-maritime scale-up, maritime electrification will expand rapidly.

Strong expansion of data acquisition from vessel and port machinery is already underway, mobilised by digital twin approaches. The potential role of data analytics is widely recognised to monetise these data resources and to enable efficiency gains. However, fresh thinking on collaboration and data sharing is needed to exploit this potential fully.

Finally, nimble policy development by governments is essential, to ensure that early-stage deployments of decarbonised solutions are investable. Taxpayer support programmes for first-of-a-kind technologies is needed, properly coordinated internationally with other government programmes to maximise cost-effectiveness. ■

A SUSTAINABLE POWERPLANT FOR PASSENGER VESSELS

By **Ing. Arch. Martin Jezdinsky MSc**, email: martin.jezdinsky@gmail.com

This article presents a novel system of onboard electricity generation for passenger vessels with largely variable consumption rates due to varying operational scenarios, such as superyachts or cruise vessels, preserving their particulars while implying minimal changes to the current ratio of usable and technical space.

The presented research has been done in cooperation with Damen Yachting in the Netherlands and the proposed plant concept validated using the Amels 60 as a reference vessel. The proposed solution has been part of author's dissertation work submitted at Newcastle University and is winner of the MSc category of the REECE Foundation Engineering Net Zero Prize 2023. The unique features described in this article are subject to filed patent application.

Introduction

For millennia the atmospheric CO_2 had never been above 300ppm. The value oscillated between 180-300 for the past 800,000 years (NASA, 2023). In the 1950s, this threshold was crossed and nowadays the atmospheric CO_2 curve resembles a parabolic increase, with a 2021 yearly average of 414.7ppm, showing no signs of slowing down (Lindsey, 2022). Continuing the current trend, researchers predict thawing of frozen soils as soon as 2040s, which will release methane – a 56 times more potent greenhouse gas (GHG) than CO_2 on a 20-year comparison – causing dramatic acceleration of climate change (Hughes, 2020). The United Nations Intergovernmental Panel on Climate Change (IPCC) indicates that an increase in the global average temperature by more than 1.5°C "risks unleashing far more severe climate change impacts" and hence world leaders have stressed the need to limit global warming to 1.5°C by the end of this century. To achieve that, "greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030" (United Nations).

The IMO reflected this in its 2018-adopted Initial Strategy on Reduction of GHG Emissions from Ships with the aim to phase out GHG emissions from shipping by scaling up the Energy Efficiency Design Index (MARPOL, Annex VI, Chapter 4) requirements. The expectation was for all new ships to be 40% more efficient by 2030 compared to those built in 2008 and aimed toward 70% by 2050 (Chircop & Shan, 2020). Despite the strategy ambitions (which were significantly strengthened in 2023), IMO was criticised for moving too slow and in 2021 the European Commission adopted a series of legislative proposals aiming at GHG emissions reduction by at least 55% in 2030 compared to 1990 levels which includes extension of the EU Emission Trading System to maritime transport. "The necessary technology development and deployment has to happen already by 2030 to prepare for much more rapid change thereafter" (European Commission, 2021).

There are several approaches to the challenge, e.g. making use of alternative fuels, dual fuel engines and fuel cells. With the combustion engine being a mature technology, one could argue the possibilities for major improvement of the technology in terms of CO_2 reduction are slim and, if shipbuilders are not to rely on the energy sector completely, a different approach might be necessary to achieve the goals set above.

The system proposed here is based on a methanol-powered high-temperature fuel cell, making use of high-quality waste heat by means of a steam turbine operating on the Rankine cycle, which is the primary means of cooling for the fuel cell. The fuel efficiency of the system is expected to remain constant at around 85%, which is

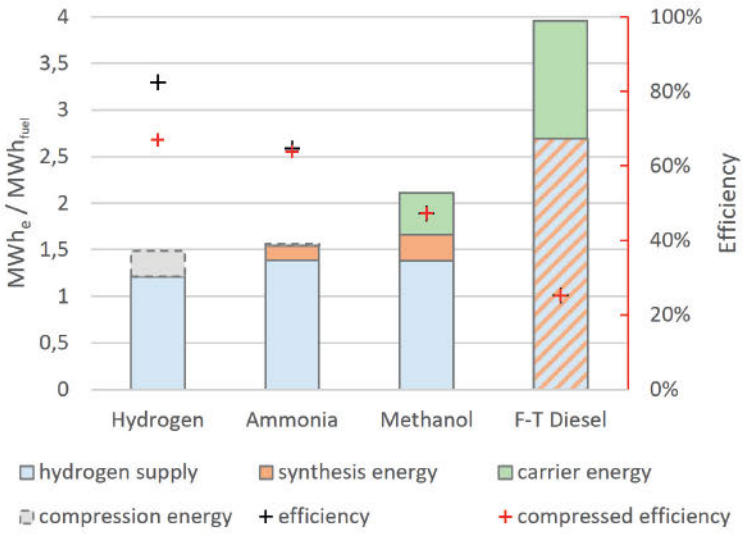

FIGURE 1. THE COST OF FUEL CIRCULARITY: IMPACT OF TRANSPORTATION NEGLECTED (HYDROGEN COMPRESSION AT 70MPA, AMMONIA LIQUIFIED AT 5MPA). ASSEMBLED BY THE AUTHOR FROM VARIOUS SOURCES

a significant increase compared to contemporary high-speed diesel engines, with peak efficiency around 40%. The superior efficiency of the powerplant compensates for the lower energy density of methanol, mitigating its impact on vessel arrangement. It also results in lower consumption, reducing the vessel GHG footprint by up to 53% and operating cost at the same time.

Fuel considerations

To achieve circularity, only synthetic fuels can be considered, which re-use the emissions for fuel synthesis, inducing no change to the environment. Multiple fuels can be synthesised in a circular way, the most discussed alternatives are hydrogen (via electrolysis of water), ammonia (hydrogen + atmospheric nitrogen) and methanol (hydrogen + atmospheric carbon dioxide). Even energy dense fuels such as diesel can be synthesised in a circular manner, using the so-called Fischer-Tropsch Synthesis.

From a carbon emissions perspective, circular fuels are all equal. However, to judge their sustainability, the overall cycle needs to be considered with energy consumption being the most vital indicator. Figure 1 shows the cost of fuel synthesis in terms of energy consumed per energy contained in the synthesised fuel with uncompressed hydrogen being the most efficient energy transformation with 83% efficiency, while synthesised diesel only preserves 25% of inserted energy.

While pure hydrogen is the most efficient energy carrier, storage of a sufficient amount for blue sea cruise vessels would be a challenge, requiring significant reduction of usable space on board. Ammonia is a close second-best option, but the toxic nature of the fuel is an issue. Even if the installation on board had a high level of safety, the discharge containing trace amounts of ammonia remains highly toxic to aquatic animals even in very low concentrations, not to speak of the need of a pressure vessel on board to store ammonia in liquid phase.

Methanol synthesis is only 47% efficient, but it doesn't require pressurising under ambient conditions due to its higher evaporation temperature of 65°C. It is also easier to separate from water discharge by simple distillation at temperatures between 65°C and 99°C and far less harmful to environment than ammonia. Energy density of methanol is only 45% that of diesel fuel (5.5MWh/t and 12.1MWh/t respectively) and it releases nearly as much carbon dioxide

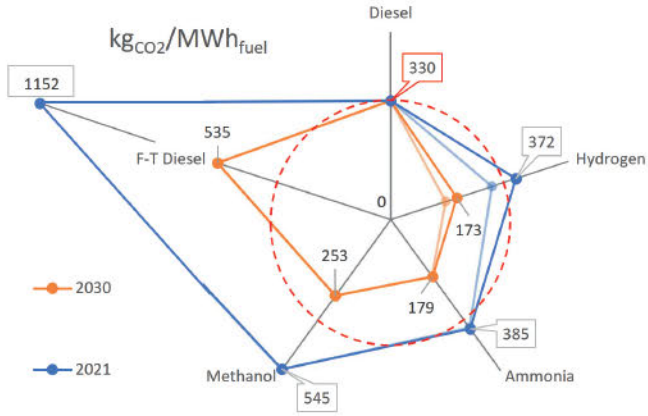

FIGURE 2. PROJECTED FUTURE DEVELOPMENT OF CO_2 IMPACT OF VARIOUS FUELS. NOTE: MWH AS STORED IN FUEL, EFFICIENCY OF USED FUEL CELL OR COMBUSTION ENGINE NEED TO BE CONSIDERED TO OBTAIN EMISSIONS OF MWH OUTPUT. ASSEMBLED BY AUTHOR FROM VARIOUS SOURCES

per MWh as diesel fuel (252kg/MWh and 261kg/MWh respectively). Both methanol and diesel can be synthesised in circular manner, but methanol preserves almost twice the amount of inserted energy compared to Fischer-Tropsch diesel (Figure 1), which makes it cheaper to produce.

The energy demand cycle is a crucial factor to consider, not just for cost, but also the environmental perspective. While the purest of fuels, hydrogen gas, has no direct CO_2 emissions, its production process has had a stable carbon footprint of 9.7gCO_2/gH2 over the past three years. This is expected to drop to 4.5gCO_2/gH2 by 2030 (Bermudez, Evangelopoulou, & Pavan, 2022). The significance of these numbers is shown in Figure 2.

The chart compares CO_2 emissions from fossil diesel fuel to those of various synthetic fuels, assuming all would be synthesised using renewable hydrogen. The data suggests that in such scenario, diesel remains the least harming substance to use nowadays, only surpassed by uncompressed hydrogen. This illustrates the importance of energy demand for fuel synthesis and its direct link to sustainability in terms of the environmental as well as commercial aspect. From this perspective, methanol is not the most sustainable of all options, but it is the best fit for purpose considering usability of the vessel, and possible pollution hazards from other alternatives.

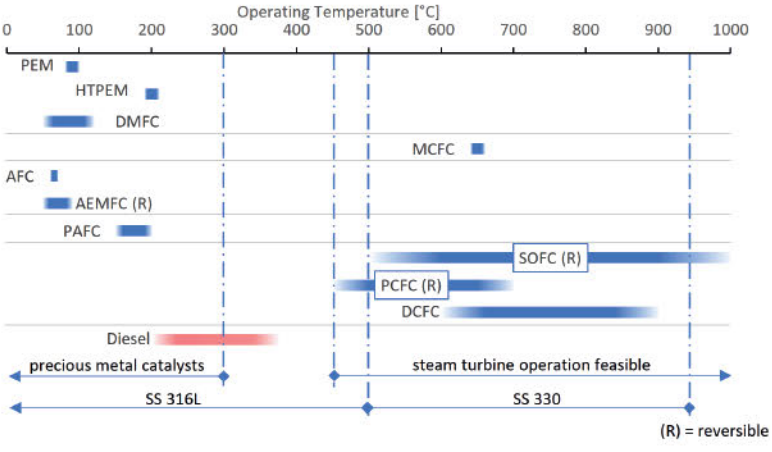

FIGURE 3. FUEL CELL FAMILY SORTED BY OPERATING TEMPERATURE: PROTON EXCHANGE MEMBRANE (PEM), HIGH-TEMPERATURE PEM (HTPEM), DIRECT METHANOL (DMFC), MOLTEN CARBONATE (DMFC), ALKALINE (AFC), ANIONIC EXCHANGE MEMBRANE (AEMFC), PHOSPHORIC ACID (PAFC), SOLID OXIDE (SOFC), AMMONIA PROTONIC CERAMIC (PCFC), DIRECT CARBON (DCFC), DIESEL ENGINE SHOWN FOR REFERENCE. ASSEMBLED BY AUTHOR FROM VARIOUS SOURCE

Fuel to electricity

Fuel cells (FC) have been a hot topic in recent years with an increasing number of products already available on the market and lively research being conducted on all aspects of the technology. Fuel cells have a number of advantages compared to combustion engines, most importantly higher theoretical efficiency – up to 76% (Haseli, 2018). From an operations point of view, it is the lack of vibrations which is highly appealing for passenger vessel applications. For the purposes of this article two main groups of FCs are identified in Figure 3, differentiated by their operating temperature. The low-temperature group operates in range of 50-250°C while high-temperature FCs have an operating temperature range of 450-1,000°C.

Despite the complexity of related research topics, the basic principle remains the same – the so-called cold combustion reacting hydrogen with oxygen, producing water while releasing energy. To supply the needed hydrogen, this needs to be separated from the carbon carrier molecule in methanol first, using a process called reforming. Multiple reforming methods are available for hydrogen separation from methanol, but in combination with fuel cell steam reforming (SR) is of the highest interest as fuel cells discharge water as waste product, while SR requires a mixture of methanol (CH^3OH) and water (H_2O), reacting to hydrogen gas and CO_2 (besides CO_2, the hydrogen rich gas may contain trace amounts of methane (CH^4), unreacted methanol and steam). The balanced chained reactions are shown in Figure 3.

The oxidation in the fuel cell releases 1mol of water per each mol of supplied hydrogen, while steam reforming only requires 1/3mol of water for the same amount of hydrogen produced. This means steam reforming may recycle part of the reacted hydrogen back into the supply stream, increasing the amount of hydrogen gas in the supply stream by 50% compared to other reforming methods. Consequently, this arrangement alone increases the fuel energy density of the stored methanol from 5.5MWh/t to 8.25MWh/t (68% that of diesel fuel).

To maximise the harvest of this energy in a form of usable electricity, heat management needs to be considered. Cold

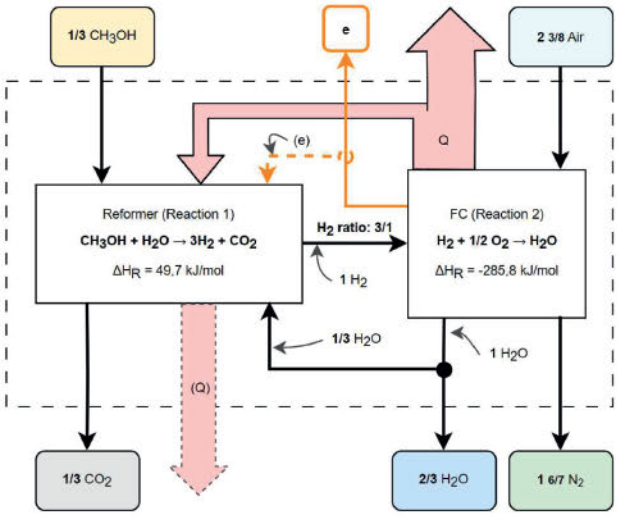

FIGURE 4. METHANOL REFORMER + FC: BALANCED 1MOL REACTION

combustion is exothermic, releasing a significant amount of heat while steam reforming is endothermic, and heat needs to be supplied to the mix for the reaction to take place. Even here the fuel cell can be used as a single source, provided the reforming reaction temperature (T1) is equal or below that of the cold combustion (T2). Nowadays, steam reforming is performed under temperatures of between 200-300°C but these require noble catalysts, increasing hardware cost (Zhou, *et al.*, 2018). Higher reaction temperatures without the need for precious catalysts have been tested with promising results at a temperature range of 400-500°C (Ding, Zhang, Ge, Li, & Shen, 2022). The impact of FC operating temperature T2 on fuel efficiency of the combined system depicted in Figure 3 is shown in Figure 4.

Electric efficiency (ηE) of the fuel cell has been set at a conservative 55%. The higher overall fuel efficiency (ηF) illustrates the effect of hydrogen returned to the supply stream in the form of water. Consequently, a fuel cell supplying heat at temperature above the three thresholds – methanol evaporation temperature, water evaporation temperature and temperature of the reforming reaction – will render the best results, while a significant amount of energy remains contained in the high-quality heat (Qout@T2). It concludes that a high-temperature fuel cell operating above 500°C is desirable for a futureproof powerplant.

The planar type of solid oxide fuel cell (SOFC) operating at about 650°C is an ideal match for purpose. Solid oxide fuel cells reach superior electric efficiency, up to 60%, and do not require precious metal catalysts. They feature superior power density and specific power spanning 4-10kW/l and 3-5kW/kg respectively, which makes them more compact and lighter than other power generating technologies including combustion engines (Nicholas, 2014). They can be easily scaled, and the technology is meanwhile in commercial stage with standardised domestic SOFC units available on the retail market (typically fuelled by natural gas). Multiple vessel installations have been done before, reaching fuel efficiencies above 60%. SOFC disadvantages relate to their high operating temperature, most notably long start-up times – up to 24 hours – and stress from temperature cycling when switching between OFF and ON mode.

Heat management

Typical cruise vessel operation modes feature large variations in consumption, since hotel load is typically a fraction of propulsion load. The operation modes are switched frequently between cruises and port calls or anchor time which results in the need for a highly flexible powerplant able to readily handle the variable demand. In the case of superyachts, the aspect of unpredictability needs to be accounted for as well, further increasing the flexibility demand on the plant. It is a simple matter to split the modular FC stacks to match the power demand for each scenario, but the flexibility requirements are in strong contrast to the long start-up times of the separate modules. The problem can be solved by the introduction of a STAND-BY mode, with at least one FC module continuously operating and the remaining units being kept near operating temperature using the waste heat of

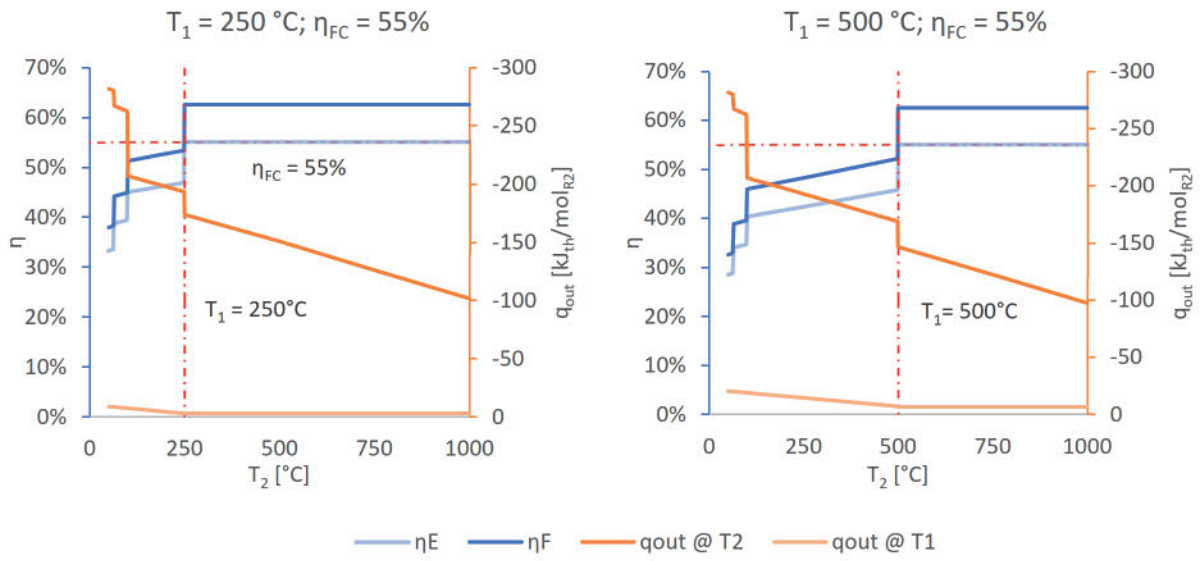

FIGURE 5. METHANOL STEAM REFORMER + FC: TEMPERATURE VS. EFFICIENCY

the former. The principle is shown in Figure 6, featuring a hotel module designed to match average continuous load and propulsion modules in STAND-BY mode. The system is assisted by a battery bank for peak load shaving and storing power during load dips.

This arrangement eliminates the OFF mode, replacing it with ON/STAND-BY operational characteristics of the plant. That solves both the long start-up times as well as any thermal cycling loads on the FCs.

FCs are typically cooled by excess air, but its low density makes it a poor heat transfer agent. Using independent liquid helps to reduce equipment size while improving the heat transfer characteristics as well as FC efficiency due to more equal heat distribution, better control over oxidant flow and lower energy demand for coolant circulation compared to air cooled systems (Fan, *et al.*, 2022).

To transfer the high temperature between modules, a suitable heat agent needs to be used. The typical engine oil boiling temperature is around 300°C, which makes it poorly suited for purpose. The agent should remain liquid over a large range of temperatures to handle the high-temperature fuel cell as well as any periods of deactivation. The ideal candidate with liquid state temperature range of -12-785°C is sodium potassium alloy (NaK), already used as a heat transfer agent within the primary cooling circuit in nuclear powerplants and submarines (Sandu & Brasoveanu, 2001). NaK comes with a number of hazards – it may cause serious or permanent injury, can be ignited under ambient temperature, readily undergoes violent chemical changes at elevated temperatures and pressures and reacts violently with water (NOAA, 2010). Despite the hazards, systems using NaK are considered mature technology with proven track record.

With heat distribution between the FCs solved, a large temperature gap remains between the final coolant (sea water) and the primary cooling circuit. To maximise the plant efficiency, four closed circuits are proposed as depicted in Figure 7.

The primary circuit distributes heat between fuel cells, transferring the heat from operating modules to the STAND-BY units.

The secondary circuit supplies heat to reformers and evaporators. Multiple reformers can be used to match particular FC module demand. Much like in the primary circuit, temperature cycling, and performance delay, is eliminated.

After the heat demand of the high-temperature system is satisfied, much of the waste heat remains in the cooling agent. This is supplied to the Rankine cycle for secondary electricity generation. The Rankine cycle consists of a boiler (heat exchanger 2), steam turbine and condenser (heat exchangers 3 and 4).

The variable heat supplied from the primary circuit calls for corresponding flexibility within the Rankine cycle to absorb all the supplied heat and generate electricity in a constant manner. The simplest way to achieve such flexibility is by using a variable torque generator. Originally developed for wind turbines to permit the handling

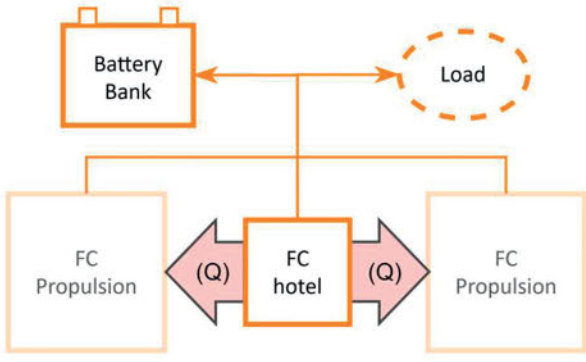

FIGURE 6. STAND-BY MODE DIAGRAM

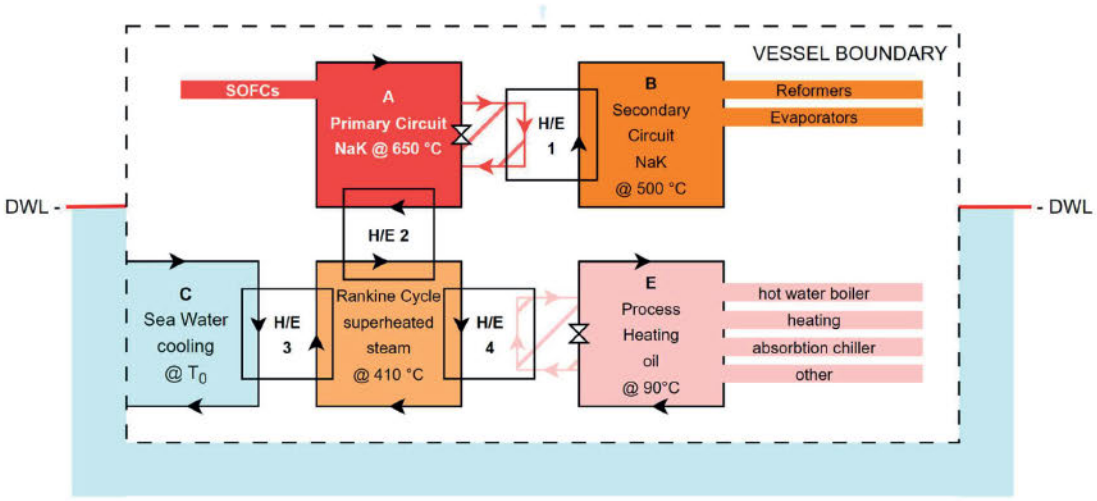

FIGURE 7. HEAT MANAGEMENT CONCEPT

of variable wind speeds, this device is well suited for purpose, requiring no further hardware. It can be set up to react to varying heat supply by reducing or increasing torque on the electric generator. This implies the amount of generated electricity will be directly proportional to the amount of supplied heat, which is directly proportional to electricity generated within the primary circuit. Consequently, the proportion of electricity generated by the steam turbine remains a constant percentage of that generated by the fuel cells in all operation modes. This arrangement eliminates the complex start-up and shutdown procedures typical for steam turbines as the turbine is activated with the commissioning of the core plant and only needs to be deactivated with full shutdown of the system.

The contribution of steam turbine to electricity generation has been calculated as 19.5%, pushing the overall fuel efficiency to 84.9% in all scenarios. It should be noted that the number will decrease slightly for scenarios where a significant part of the plant remains in STAND-BY mode, due to heat losses to environment at the inactive units.

The steam in the Rankine cycle is condensed using the process heater (heat exchanger 4) and ultimately the sea water (heat exchanger 3) as coolant. The heat retrieved from the condenser can be used for onboard heating applications, further lowering electricity demand, and increasing the vessel efficiency.

System arrangement

For the powerplant to reach its full potential, the flow of products and reactants needs to be understood. Figure 8 shows the installation schema of the plant with the SOFC in its core. The FC is supplied with air as oxidant on the cathode and hydrogen rich gas on the anode. The exhaust stream on the cathode consists of nitrogen and any excess air, while all CO_2 is discharged on the anode side.

As reactants exit the fuel cell at high temperature (T2 = 650°C), it is desirable to use this heat to pre-heat the air stream and hydrogen rich gas stream to operating temperature by means of heat exchangers. It is also desirable for the anode waste stream to be pre-cooled even further before entering the first condenser. This can be done by means of dedicated cooler, or by placing an absorbtion chiller between the FC and Condenser 1 which will use the waste heat to generate chilled water, further reducing the net energy consumption of the vessel.

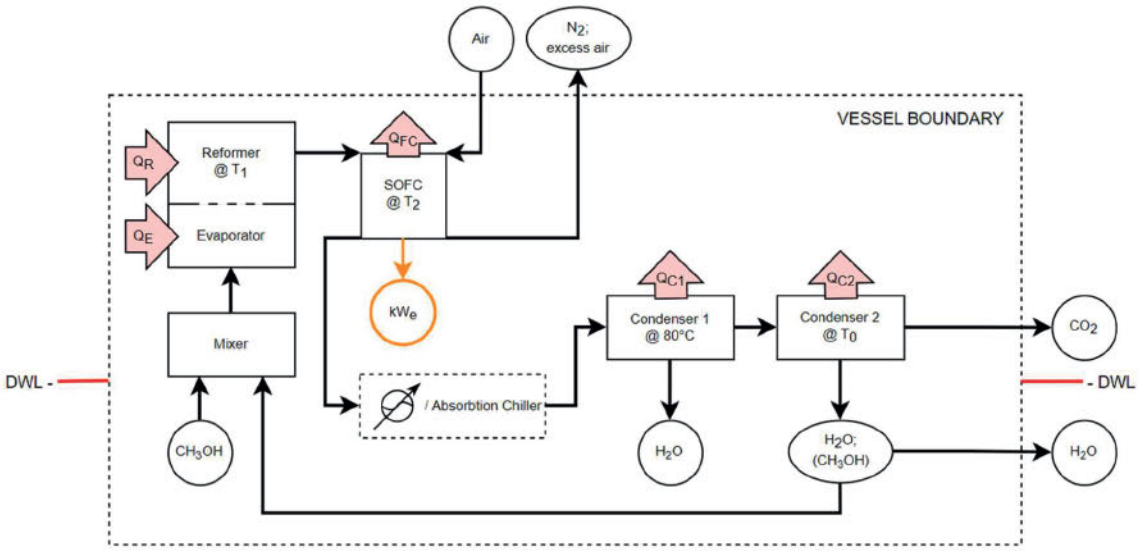

FIGURE 8. POWERPLANT OPERATION

To recycle water back into the reformer, two condensers are placed downstream of the anode. The first condenser operates in a temperature range between 65°C and 99°C (here 80°C), so that pure water is condensed. This can be used as drinking water on board after treatment. The second condenser operates at lowest achievable temperature to rapidly dehumidify the exhaust gas. The condensate will contain water with trace amounts of methanol and will be used to supply water for the methanol mixer to obtain the desirable ratio of methanol to water for steam reforming. Excess water and CO_2 can be discharged to the environment (post treatment of both exhaust streams may be desirable depending on purity of the exhaust. Possible impurities include hydrogen gas, traces of methanol, carbon monoxide and methane).

In theory, the purified CO_2 exhaust could be stored on board to prevent release to environment, however this would be space restricting and would negatively impact the usable volume of the vessel. That said, purified CO_2 is valuable resource and before releasing it to environment, part of it can be utilised on board as inerting gas (for vessels using methanol as fuel, inerting of void spaces such as tanks and cofferdams is required). As the fuel gets depleted in the tanks, overpressure needs to be maintained by supplying additional gas. Typically, nitrogen is used for this purpose as it can be separated from air easily, but storing a fraction of the CO_2 exhaust would eliminate the need for a nitrogen generator onboard, reducing the complexity of the vessel.

The powerplant is designed to always remain active to keep the ON/STAND-BY operational characteristics. While it can be deactivated for long periods of stand still, it may require up to 24hours to reactivate the plant, which makes cold ironing undesirable for short time periods, resulting in continuous release of CO_2 even during port time. A possible solution is a separate CO_2 shore connector, which would supply the exhaust stream directly to a shore-based CO_2 storage network, such as that under development by the International Energy Agency (iea, 2023). The gas can then be re-used for fuel synthesis eliminating the energy intensive air separation process.

Final considerations

Carbon neutrality can't be achieved within single industry and active participation of the energy sector is inevitable. However, the responsibility for vessel operations remains with the owner and the operational footprint and sustainability level is greatly prescribed by the vessel design. Using a high-efficiency system is highly desirable and the most sustainable approach to futureproof shipping.

While the system particulars will vary depending on vessel size and operational characteristics, the efficiency level of the proposed system remains near constant. Fuel efficiency of the vessel doubles compared to diesel engines while direct CO_2 emissions reduction achieved with the system is up to 53% (varies with vessel utilisation). The identified savings from use of low-quality waste heat may further improve the number.

MARTIN JEZDINSKY

Besides the environmental aspect, commercial constraints need to be kept in mind for any wide scale applicable system. In today's prices, SOFCs are approximately four times more expensive per kW output than high-speed marine diesel engines. Consequently, the capex of the proposed powerplant will be significantly higher than that using internal combustion engines and the steam turbine is expected to add another US$1,000/kW output. While this multiplies the powerplant budget of a vessel by significant factor, the overall cost of the vessel will not increase anywhere near that dramatically, as the powerplant is only a fraction of a vessel price. Furthermore, the reduction in consumption renders immediate return on investment. Considering methanol at €88/MWh and low sulphur diesel at €55/MWh, opex of the proposed plant is only 78% that of combustion engines. This is considered conservative as methanol traded below marine gas oil for most of 2022 (Methanol Institute, 2023). Considering the evidence described in first part of this article, the economic benefit is expected to increase in time.

About the author

Martin Jezdinsky graduated with distinction from the Newcastle University MTEC Naval Architecture programme in 2023 and from the Czech Technical University in Prague, Faculty of Architecture, in 2014 after clearing the Yacht Design programme at The Landing School in Maine, USA (2011). He has been pursuing a career in shipbuilding, first as practicing yacht designer (2011-2018) before moving towards managerial tasks as a project engineer and project manager in various passenger vessel projects. ■

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Mr Arsenio Dominguez

Secretary-General

International Maritime Organization

Mr. Arsenio Dominguez was elected Secretary-General of the Organization by the 129th session of the IMO Council in July 2023 for a four-year period beginning 1 January 2024.

The election was endorsed by the IMO's Assembly at its 33rd session in December 2023. Mr. Arsenio Dominguez (Republic of Panama) is the tenth elected Secretary-General of the International Maritime Organization.

Prior to starting his position as Secretary-General, Mr. Arsenio Dominguez Velasco was a Director of IMO's Marine Environment Division. He joined the IMO Secretariat in 2017, first as Chief of Staff to the Secretary-General, Kitack Lim, before being appointed in 2020 as Director of the Organization's Administrative Division.

His maritime career began in 1996 as a port engineer at Armadores del Caribe in Panama before moving to become a Drydock Assistant Manager at Braswell Shipyard.

In 1998 Mr. Dominguez Velasco moved to London to join the Panama Maritime Authority as Head of the Technical and Documentation Regional Office for Europe and North of Africa. He went on to represent Panama in a variety of roles at the organization, culminating in 2014 with his appointment as Panama's Ambassador and Permanent Representative to IMO until 2017.

Between 2014 and 2017, Mr. Dominguez Velasco chaired IMO's Marine Environment Protection Committee (MEPC), and in 2015 he chaired the Technical Committee of the 25th session of the IMO Assembly. Prior to this, between 2010 and 2014, he chaired the Maritime Security – Piracy and Armed Robbery Working Group under the auspices of the organization's Maritime Safety Committee.

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