SETTING THE COURSE TO
LOW CARBON SHIPPING

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2030 OUTLOOK | 2050 VISION

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EXECUTIVE SUMMARY

This publication is an outlook illuminating potential pathways to low-carbon shipping. Its purpose is to inform by concisely organizing current knowledge on the technologies and issues that could help to reduce greenhouse gas (GHG) emissions from shipping. It is meant to serve as a comprehensive reference document and should not be seen as making recommendations or as an advisory.

A better understanding of existing technologies and strategies can help the maritime industry reach the International Maritime Organization's (IMO) GHG targets for 2030. The even more ambitious emissions goals set for 2050, however, lie beyond the reach of current technology. To achieve those goals new technology (including fuels) will need to be developed, with the main thrust of research and innovation occurring before 2030, giving any new products and ideas time to develop and mature.

The third IMO Greenhouse Gas Study, which is dated 2014 but relies on data from no later than 2012, notes that from 2007-2012 international shipping contributed on average 2.6 percent of global carbon dioxide (CO_2) emissions. Although that shows shipping's inherent efficiency as transporter of almost 90 percent of worldwide trade, the third study expects growth in global trade to expand the demand for seaborne transport and raise its CO_2 output comparatively faster than other industries, if shipping continues business as usual.

A fourth IMO GHG Study is being commissioned in part to update the underlying statistics in the current assessments and partly to replace dated economic models that lead the third study to forecast a potentially very large range of GHG output from shipping in 2050. Its objective is to reduce some of the uncertainties of the previous forecast, and to establish annual global inventories for GHGs and pollutants from 2012 to 2018. For those reasons the fourth study will be a critical foundation for future decisions.

In the short term, the main strategies to help shipping meet the IMO's emissions goals for 2030 include: establishing speed limits; coordinating 'just-in-time' arrivals of ships at ports; design refinements such as hull optimization and propeller optimization; and enhancements to design efficiency, such as those mandated by the IMO's Energy Efficiency Design Index (EEDI).

In 2015, "slow steaming" was estimated to have reduced shipping's overall CO_2 output, as well as helping to reduce its carbon intensity by 30 percent, against 2008 levels. Just-in-time shipping and other digitally aided initiatives could further reduce fuel consumption and emissions by optimizing vessel speeds, routes and reducing carbon-inducing waiting times without requiring additional capacity.

Great emphasis also is being placed on alternative fuels, the most available of which is liquefied natural gas (LNG). As yet, there are no "zero-carbon" and few "carbon-neutral" fuel solutions, when assessed from the "well-to-wake" perspective (when GHG output is traced from source to combustion). All alternative fuels known at this time have limitations, even if some show promise.

All alternative fuels and energy sources have shortcomings in terms of practical application for international shipping, from onboard storage and energy density to supporting infrastructure and supply systems.

At present, there is no obvious fuel choice for the global fleet of the future. For the immediate future, the fuel solution for a vast part of international shipping remains a choice between a variety of distillate fuel oils or LNG.

LNG provides a clear illustration of the challenges inherent in adopting an alternative fuel globally. It has taken 10 years for LNG bunkering infrastructure to develop and supply less than 1 percent of the global fleet. Other alternative fuels will face similar developmental, regulatory and supply chain challenges.

It is not just the vessels that will require a technological transformation. A few new fuels may be adaptable to traditional bunkering processes, but many will require specialized infrastructure, handling, training and a dedicated value chain of production, storage and distribution.

There is great hope in hydrogen, for example, and many demonstrations are underway to advance its use for shipping propulsion. However, current power generation technologies using hydrogen as fuel provide very limited power output. Producing it as a fuel remains very energy intensive and expensive. In addition, storing hydrogen creates significant problems that need to be overcome.

Methanol is another alternative fuel that sounds good, but has drawbacks. For example, it is highly toxic and heavier than air, so leaks accumulate rather than dissipate; and its corrosive nature is a threat to some of the materials used in combustion engines and their fuel-supply lines. Similarly, batteries and other energy storage systems have potential to serve international shipping's ambition to lower emissions at least in some sectors. But issues involving space requirements, weight and charge capacity need to be solved before they can be adopted widely for other than very short services.

It is entirely possible the global solution to shipping's emissions challenge will be found by combining several strategies and future technologies (including new fuels). There may not be a silver bullet for an industry with such diverse operational requirements. Absent a global solution, compromises will need to be made. But the industry cannot make those decisions until the full costs and benefits of each technology are understood.

ABS worked with the Herbert Engineering Corporation to specify design requirements for two aspirational state-of-the-art containerships — one a feeder ship (2,000 TEU), the other a Neo-Panamax (14,000 TEU) — with conventional technology, operational profiles and propulsion units that burn low-sulfur heavy fuel oil (HFO). The fully assessed concept designs were then modified to create versions of each that could run on hydrogen fuel cells and liquid biofuels, using the industry's current knowledge of the technologies involved. The assessments provide a window into what may be possible, but also what some of the limitations would be. The designs could not be built today, but they may be possible for 2030, and the project offers insights into the fuels, design criteria (such as onboard arrangements), cargo capacity and propulsive power potential.

These concept designs highlight the gap between the state-of-the-art technology of today and the demands of the 2050 GHG targets. The fuels used in the designs were selected to represent different strategies that could be available by 2030, not to forecast which fuels were likely to be adopted. For example, biofuel is a drop-in fuel that can be adapted to use existing technology and infrastructure. While its use would require only a modest evolution in ship design, its availability on a global basis and the feedstock used to produce it are unknowns.

Another option is the hydrogen fuel cell, which represents a new fuel source and a new technology for generating power. The evolution of this technology would require significant acceleration to become feasible by 2030, in particular to develop greater power and endurance. But it represents a potential zero-carbon future when produced using renewable energy.

Markets are a powerful incentive for innovation, and regulation is needed to establish common goals. When it comes to reducing the GHG emissions for shipping, not only will supporting regulation potentially have an impact on ship designs, fuel selections and vessel operations, it may also affect the choice of cargoes that will be transported, as well as the trade routes and ship sizes.

In that light, the industry needs regulation that provides a compliance framework that is technically proven, safe and commercially sustainable, one that does not penalize early adopters of new technologies. Without this, the regulatory risks will loom over shipowners as they plan for the next 30 years.

Finally, lowering the carbon footprint of an industry that moves almost 90 percent of global trade is a significant undertaking. Change on that scale will not come quickly; great efforts will be required to ensure that shipping's positive contributions to global trade and the economy remain visible for all to see. Even with early and effective regulation, the path to a low-carbon future will involve new technologies and operating procedures. In that light, safety will need to be an even stronger focus for the industry, as those changes could introduce risks that may not be adequately managed or eliminated by today's standards.

INTRODUCTION

The regulatory landscape of the modern maritime world is largely a product of reaction to accidents and pollution incidents and therefore focused on improving safety (SOLAS) and reducing the negative impact on the environment (MARPOL). The drivers for technology innovation have been the desire to improve fuel efficiency (engine development) as well as compliance with regulatory requirements (ballast water treatment technology).

On the regulatory front, each of the changes were preceded by a long period of concern, questioning and debate within the industry, and followed by extensive work at the International Maritime Organization (IMO) to turn the safety and environmental goals into technical regulations.

In every instance, from the Oil Pollution Act of 1990 (OPA 90) forward, the entire process of regulatory conception, formulation and, especially, implementation would have been aided by the presence of a comprehensive, living document that summarized the challenges and offered solutions as they arose.

Because such a document did not exist, industry often experienced long periods of uncertainty as it sought to understand the goals of any new mandate, helped to create the technical rules that achieved their intent and then adapted them to their final legislative forms.

The regulatory changes set for 2020 — and those expected for 2030 and 2050 — will be more disruptive than any past environmental regulations, and their challenge to industry at least as great, to achieve cleaner and low-carbon emissions. Chief among these will be new rules that support the lower-carbon emissions goals of the IMO's preliminary greenhouse gas (GHG) strategy.

Reduction of carbon dioxide (CO_2) and other GHGs is a separate challenge from the simultaneous goal, now being aggressively pursued worldwide, of reducing the emission of pollutants such as nitrogen oxide (NOx) and sulfur oxide (SOx) that are threats to human and environmental health. It is an aspirational goal with a decades-long vision, the specifics of which are likely to evolve alongside the changes they inspire in ship design, technology and practices.

The overall challenge these movements present must be addressed in parallel, holistically, with mindfulness and intelligence, if the maritime sector is to emerge a more efficient, profitable and sustainable industry than it is today. Recognizing that, ABS has developed this outlook document to reference available carbon reduction strategies prior to 2030 and the technology gaps for meeting the 2050 targets, and to inform the shipping industry as it journeys into the unknown waters of the 2030/2050 emissions challenge. It is designed to help bring into focus the numerous issues surrounding the decarbonization movement as it evolves from today's ambitions to tomorrow's reality.

Although the nearest of these issues involve choices between new fuels, energy sources and emissions-mitigation systems, this outlook is not to be seen as a forecaster, making recommendations, or a shopper's guide for choosing equipment or technologies. It is a tool aimed at helping shipowners to understand the complexity of the task ahead and to move forward effectively as they assess their options for a transition to low-carbon operations and further to the no-carbon future of shipping.

SECTION 1 | EXTENT OF THE CHALLENGE

THE 2030 | 2050 CHALLENGE

The transition to a low-carbon and clean-emissions future is challenging the industry to find solutions that are commercially viable, technically feasible and safe. In April 2018, the International Maritime Organization (IMO) agreed to a preliminary goal aimed at reducing carbon dioxide (CO_2) emissions from shipping by a minimum of 40 percent per cargo tonne-mile by 2030 (and to pursue a 70 percent reduction by 2050), and a 50 percent reduction in overall GHG emissions by 2050, compared to 2008 levels.

In October 2018, 34 CEOs from across the world and the maritime value chain signed a call to action in support of decarbonization.

> “The signatory CEOs believe that a shift to a low-carbon economy by 2050 has the potential to create new opportunities for business through both technological and business model innovation. The shipping industry must rise to the biggest technology challenge in 100 years, and regulations should provide long-term certainty for financiers, builders, owners and charterers to make the required investments in low-carbon technologies. CEOs accept the need for transparency to help drive change.” — *Global Maritime Forum*

IMO GHG STRATEGY AND TARGETS

According to the third IMO GHG study (2014), from 2007-2012 international shipping on average accounted for 2.6 percent of annual global CO_2 emissions. This comparatively small proportion illustrates its efficiency in transporting almost 90 percent of worldwide trade.

However, the projected growth in global trade and seaborne transport will see the CO_2 output from shipping grow faster than other industries, if we continue business as usual.

Since shipping is already an efficient mode of transport and significant reductions in fuel consumption have been achieved recently from improvements in design and operations, it will be difficult to find further meaningful GHG-related gains solely by using current technology.

The reduction targets for 2030 are challenging but, as they are a measure of carbon intensity, they allow for trade growth. However, any measures taken to meet those goals must also consider 2050 targets if they are to account for the growth in trade and transportation demand while reducing GHG emissions. This will require new technologies.


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Spring 2018 (MEPC 72)	Adoption of the Initial Strategy including, inter alia, a list of candidate short, mid and long-term further measures with possible timelines, to be revised as appropriate as additional information becomes available
January 2019	Start of Phase 1: Data collection (ships to collect data)
Spring 2019 (MEPC 74)	Initiation of Fourth IMO GHG Study using data from 2012-2018
Summer 2020	Data from 2019 to be reported to IMO
Autumn 2020 (MEPC 76)	Start of Phase 2: data analysis (no later than autumn 2020) Publication of Fourth IMO GHG Study for consideration by MEPC 76
Spring 2021 (MEPC 77)	Secretariat report summarizing the 2019 data pursuant to regulation 22A.10 Initiation of work on adjustments on Initial IMO Strategy, based on Data Collection System (DCS) data
Summer 2021	Data for 2020 to be reported to IMO
Spring 2022 (MEPC 78)	Phase 3: Decision step Secretariat report summarizing the 2020 data pursuant to regulation 22A.10
Summer 2022	Data for 2021 to be reported to IMO
Spring 2023 (MEPC 80)	Secretariat report summarizing the 2021 data pursuant to regulation 22A.10 Adoption of Revised IMO Strategy, including short, mid and long-term further measure(s), as required, with implementation schedules.

2050 GHG CHALLENGE IN ROUGH NUMBERS

The third IMO GHG study estimated that in 2008 international shipping emitted 921 million tonnes of CO_2 and estimated that by 2050 that volume could grow by as much as 250 percent to 2,300m tonnes.

To reduce its CO_2 output to 460m tonnes (and achieve the target minimum 50 percent reduction) the fleet would need to emit 1,840m tonnes less than in 2008, while growing to meet the demands of expanded trade.

Mainly as a result of slow steaming in weak market conditions, estimated CO_2 emissions in 2012 dropped to 796 million tonnes, a 14 percent reduction relative to 2008.

The calculated carbon intensity targets using the third IMO GHG Study and the United Nations Conference on Trade and Development (UNCTAD) data (not specified in the IMO Initial Strategy):

- 2008 benchmark: 22 grams of CO_2 per tonne-mile, over 41.9 trillion tonne-miles [1]
- 2030 target: 13.2 grams CO_2 per tonne-mile
- 2050 target: 6.6 grams CO_2 per tonne-mile

The estimates for 2015 are 810m tonnes of CO_2 and 53.3 trillion tonne-miles, or a carbon density of 15.2 grams CO_2 per tonne-mile, a 30 percent reduction relative to 2008.

If we assume that the 2030 target can be met with available technology, slower speeds, improvements in efficiency and limited use of low-carbon fuels, the gap between 2030 emissions and 2050 targets will still remain large.

More perspective on the magnitude of the challenge can be gained by using simple math and conservative estimates. Assuming CO_2 emissions do not increase from 2015 to 2030 as global trade and the international fleet grows, that would imply a 350m-tonne reduction in CO_2 emissions a year by 2050. And this would need to be achieved while trade volumes grow 90 percent from 2030 to 2050, based on the historical average rate of 3.2 percent per year; even using a conservative rate of 1.5 percent p.a., trade volumes would still grow 35 percent over the same period.

[1] Seaborne transport data from the United Nations Conference on Trade and Development 'Review of Maritime Transport'

POTENTIAL SOLUTIONS

There are a number of energy initiatives and technologies that could potentially contribute to the decarbonization of shipping.

Improvements to the energy efficiency of ship designs will be required by the next phase of the IMO's Energy Efficiency Design Index (EEDI), but their contribution to GHG reduction targets will be minimal without introduction of low carbon fuels. Further advances in ship technology could make another contribution, but new low- and zero-carbon energy sources will be needed to reach the 2050 targets.

Although many new energy sources and propulsion technologies are being tested, more development is required for most of them if they are to become viable for international shipping.

In the recent commercial environment where low charter and freight rates were the norm, slow-steaming initiatives reduced the overall CO_2 output from shipping. Even if there are regulatory complications, slow steaming and speed optimization should be considered as compliance options, as they are already widely used by the industry to respond to market conditions.

Using digital technology to simplify shipping practices could reduce fuel consumption and emissions by optimizing vessel speeds and routes, reducing waiting times and streamlining contractual transactions.

Information-driven, just-in-time shipping, for example, could introduce slower speeds without regulations having to make them mandatory. With improved vessel utilization, less additional capacity would be required. Likewise, digital technology and improved connectivity will encourage next level of performance optimization, preventative maintenance and matching ships to cargo.

Market-based measures are the most controversial topic related to the decarbonization of shipping. The objective of setting a price for carbon is to provide an incentive for investment in low-carbon technology and the capital for related research and development.

Understanding the impact and efficacy of technology options and their degrees of maturity will be critical for making investment decisions. And the readiness of some technologies will differ between shipping sectors; for example, some battery technologies may be available for vessels with short operating ranges, but not for the longer routes.

Closing the emission between 2030 and 2050 will require a combination of measures. Among those, alternative fuels have the most potential. But making them available for large-scale consumption will require the biggest investment.

For the owner, setting the course to low-carbon shipping will require some skillful navigation.

SECTION 1 | EXTENT OF THE CHALLENGE

ECONOMIC AND TRADE GROWTH FORECASTS

As shipping sets its course towards a low-carbon future, its practitioners will do so knowing that competition for energy resources and arable land will grow. The number of people who presently share this planet (7.6 billion) is forecast to reach 8.6 billion in 2030 and 9.8 billion by 2050, according to the latest data from the United Nations Department of Economic and Social affairs. It estimates that 83 million people will be added to the planet annually; so with each generation, the global head count will grow by about the current population of India.

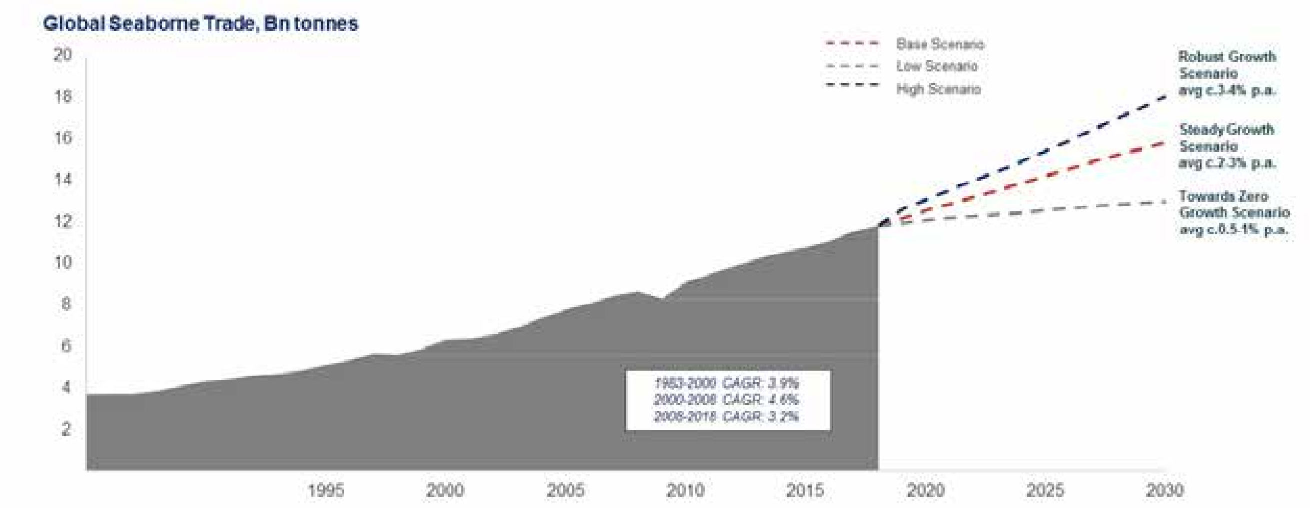
By 2050, in fact, the U.N. expects India to surpass China as the world's most populous nation, and Nigeria to surpass the U.S. as the third most populous.

Most of the population growth will be concentrated in the developing world, and it will spark a boom in industrialization as those nations satisfy demand for food, housing, transportation and new infrastructure. This, and continued demand from the well-capitalized developed economies, will stimulate an increase in the flow of trade across nearly all types of goods and, ultimately, greater demand for maritime transport.

In its Shipping Sector to 2030 report, Clarksons Research says, if global economic growth remains steady at 2.4 percent per year, the present volume of seaborne trade will expand by four billion tons a year by 2030, by which time the world fleet will require 13,000 more vessels to serve it.

The consequent increase in greenhouse gas (GHG) emissions from ships, according to the third IMO GHG Study (2014), could range from 20 percent – in its 'business-as-usual' scenario – to 85 percent, if global GDP expands at an exceptionally high rate.

Beyond 2030, fleet projections become increasingly speculative, because the geopolitical, developmental and commercial influences that keep the world fleet working are likely to be vastly different than today. That said, the IMO's third study used a range of scenarios that combined global energy consumption, GDP growth and demand for maritime transport to determine that carbon emissions from shipping could increase anywhere from 50-250 percent by 2050.



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The IMO’s work remains the best and most comprehensive GHG study available. But the broad range of its emissions forecast was queried by the Baltic and International Maritime Council (BIMCO), the world’s largest international shipping association, which has a long history of offering guidance to industry. Early this year (2019), BIMCO called for the fourth IMO GHG study to use more realistic economic models, arguing that trade patterns, energy use and the times in general will have changed significantly in the 5-6 years since the IMO’s third study was conducted.

In particular, BIMCO said any new GHG study should specifically avoid two GDP scenarios from the International Panel on Climate Change’s (IPCC) Shared Socio-economic Pathways that were used in the IMO’s third study, because they forecast considerably higher (up to two percentage points) mid-term economic growth than current trends and projections, including one by the Organization for Economic Cooperation and Development (OECD).

In collaboration with CE Delft, the consultancy that helped to model and calculate the third IMO study, BIMCO revised the GHG calculation to include the most recent GDP projections from the OECD. If conditions remain consistent, BIMCO now believes that by 2050 shipping can reduce its absolute emissions by 20 percent (over 2008 values) and still remain broadly on course to support the IPCC’s global temperature goals for the planet.

Elsewhere, the World Maritime University (WMU) recently published a report in collaboration with the International Transport Workers Federation on the effects of technology and autonomous ships on the future demand for seafarers, entitled Transport 2040: Automation, Technology, Employment – The Future of Work (2019).

It was not as carbon-centric as the IMO’s GHG studies, but the WMU report was significant in that it decoupled the link between GDP growth and transport demand after 2030, based on the idea that the historical correlation that existed between them would be significantly altered by a reduced demand for coal and oil.

The report offered projections for GHG emissions that were well below even the BIMCO/CE Delft recalculation. In response, BIMCO proposed that the IMO consider decoupling GDP growth and transport demand for their fourth GHG study.

All this forecasting data leaves today's shipowners in the unenviable position of having few concrete answers – and an ever-growing list of questions – regarding which technologies and practices to employ as they start their journeys to decarbonization.

The differing forecasts are based on assumptions about the expansion of world trade and the growth of the international fleet; and not just the total number of ships, but the sectors, subsectors and routes on which they are deployed, the trading patterns they follow, and the speeds at which they travel.

Any calculation of future GHG emissions is necessarily derived from those breakdowns and, even if the calculations are mathematically sound, the result inevitably reflects the assumptions made by the analysts regarding how a basket of variables is likely to evolve.

More than anything, what the forecasts clearly illustrate is the size of the challenge inherent in the IMO's 2030 and 2050 GHG targets based on current carbon output, as well as the projected expansions in energy consumption and demand for maritime transport.

For the shipowner, what the population forecasts illustrate is the pending competition for energy (renewable, or otherwise), food (so, arable land where renewable energy feedstock like biomass could be grown) and the raw resources used to make renewable and carbon-based fuels.

Add it all up, and shipowners may not like today's number. But the pragmatists and visionaries alike know the path to a low-carbon future is not reversible, and the reward for getting there is a more sustainable industry.

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SECTION 2 | IMO INITIAL GHG STRATEGY

EMISSION REGULATIONS

The International Maritime Organization's (IMO) emissions targets are taking steps towards reducing the industry's greenhouse gas (GHG) emissions by at least 50 percent by 2050, compared to 2008. The agreement to reduce GHGs was forged in April 2018 and demonstrated its members' commitment to support the U.N.'s Paris Agreement on combating climate change.

The IMO's focus on regulating air emissions regulations started in 1997 with additions to the International Convention for the Prevention of Pollution from Ships (MARPOL). MARPOL focused on pollutants: nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds, polychlorinated biphenyls and heavy metals, and chlorofluorocarbons. MARPOL Annex VI, which entered into force in May 2005, limits airborne emissions from ships; these limits were further tightened in October 2008, revisions that became active in July 2010.

To measure carbon dioxide (CO_2) emissions, the IMO commissioned three greenhouse gas studies:

1. In 2000, the first study estimated that, in 1996, international shipping had contributed about 1.8 percent of man-made CO_2 emissions
2. In 2009, the second study estimated that, in 2007, emissions from international shipping totaled 880 million tonnes, or about 2.7 percent of man-made CO_2 output
3. In 2014, the third study estimated that, in 2012, international shipping emissions had dipped to 796 million tonnes, or about 2.2 percent of man-made CO_2 emissions; it also raised the estimates for the second study to 885 million tonnes, or 2.8 percent

In 2011, MARPOL Annex VI was amended to add new requirements for the energy efficiency of ships. The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) became mandatory measures from the start of 2013. These initiatives focus on the efficiency of the design relative to cargo transport capacity, coupled with a plan to improve operational efficiency. It was the first step in preparing the industry to adopt carbon-reduction targets.

The EEDI index required new ships to improve their energy efficiency by 10 percent starting in 2015, by 20 percent starting in 2020 and by 30 percent starting in 2025. Regulatory measures discussed at the IMO during Marine Environment Protection Committee (MEPC) 74th session further strengthened those requirements and accelerated the implementation timeline for specific ship types and deadweight tonnage segments.

At the 74th session of the IMO's MEPC its members decided to accelerate the Phase III requirements of the EEDI, for some ship types, with adoption scheduled for MEPC 75. The move will bring forward the start dates (to 2022 from 2025) and increase the energy-efficiency targets for specific types and sizes of new ships (see table).

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Ship type	Starting year	Reduction rate for Phase 3
Gas Carriers	2022 (15,000 dwt and above)	30% (retain)
	2025 (10,000-15,000 dwt)	30% (retain)
	2025 (2,000-10,000 dwt)	0-30% (retain)
Containerships	2022 (200,000 dwt and above)	50%
	2022 (120,000-200,000 dwt)	45%
	2022 (80,000-120,000 dwt)	40%
	2022 (40,000-80,000 dwt)	35%
	2022 (15,000-40,000 dwt)	30% (retain)
	2022 (10,000-15,000 dwt)	15-30%
General Cargo Ships	2022 (15,000 dwt and above)	30% (retain)
	2022 (3,000-15,000 dwt)	0-30% (retain)
Refrigerated Cargo Ships	2025 (5,000 dwt and above)	30% (retain)
	2025 (3,000-5,000 dwt)	0%-30% (retain)
Combination Carriers	2025 (20,000 dwt and above)	30% (retain)
	2025 (4,000-20,000 dwt)	
LNG Carriers	2022 (10,000 dwt and above)	30% (retain)
Cruise Passenger Ships having Non-conventional Propulsion	2022 (85,000 gt and above)	30% (retain)
	2022 (25,000-85,000 gt)	0-30% (retain)

MEPC 74 approved amendments to MARPOL Annex VI to accelerate EEDI Phase 3 in 2022 (from 2025) and to increase the reduction rates for specific ship types/sizes

Regarding the potential conflict between EEDI compliance and the Interim Guideline's requirements for minimum propulsion power on ships, there was broad support to develop and apply the Shaft Power Limitation ([SPL] MEPC 74/5/5). The SPL was seen as an option that could resolve demand to improve energy efficiency, while addressing concerns about minimum power, especially for large bulk carriers and oil tankers.

There were significant technical barriers still to be addressed, including which engine power should be used for NOx certifications of marine diesel engines and whether criteria for the optimum propeller design should reflect use in adverse weather or normal operating conditions. The Committee invited member governments and international organizations to submit proposals on the limitations to shaft power at a future session and encouraged them to hastily complete the revision of the Interim Guidelines on minimum power.

In July 2015, Europe introduced the European Union Monitoring, Reporting and Verification (EU MRV) legislation requiring shipowners and operators to monitor, report and verify CO_2 emissions each year for vessels larger than 5,000 gt calling at any port in the EU, including Norway and Iceland. Data collection has taken place on a per-voyage basis from the start of 2018.

The IMO also adopted mandatory data collection requirements to monitor the industry's consumption of fuel oils; records of other data, including proxies for transport work, was required for the same classes of ships, which account for about 85 percent of CO_2 emissions from international shipping. The data will provide a foundation for more measures.

In April 2018, the IMO's MEPC adopted a strategy to reduce the GHG from ships and the carbon intensity of international shipping. Initial targets are to reduce the average CO_2 emissions per 'transport work' by at least 40 percent by 2030; it also committed 'as soon as possible' to pursue a 50 percent reduction by 2050. More specifically, the strategy envisages for the first time a reduction in GHG emissions from international shipping that is consistent with the Paris Agreement's temperature goals.

The MEPC also approved a roadmap (2017-2023) for developing a "comprehensive IMO strategy on reduction of GHG emissions from ships." The final strategy is due in 2023, supported by data collection from ships starting in 2019 and a fourth IMO GHG study. The timeline and roadmap for the strategy include short-term, mid-term and long-term measures to be concluded from 2018-2023, 2023-2030 and beyond 2030, respectively.

NATIONAL PROPOSALS

In April 2018, the International Maritime Organization (IMO) adopted its Initial Strategy to reduce the greenhouse gas (GHG) emissions from ships, defining its commitment to support the temperature goals set by the U.N.'s Paris Agreement in 2015. The IMO membership vowed to reduce carbon dioxide (CO_2) emissions per transport work at least 40 percent by 2030 and to reduce annual GHG emissions at least 50 percent by 2050, compared with 2008.

“In aiming for early action, the timeline for short-term measures should prioritize potential early measures that the organization could develop...with a view to achieve further reduction of GHG emissions from international shipping before 2023,” the IMO said in announcing the targets.

The national proposals for short-term measures sent in response reflect the determination of the many delegations to find a workable solution. They largely focus on three areas: enforced speed limits; just-in-time shipping; and methods to assess operational efficiency.

Greece proposed the adoption of speed restrictions, a concept backed by a letter to the IMO from more than 100 industry leaders. France proposed worldwide speed limits and the idea of fleet-wide annual emissions caps to be imposed on shipping companies by 2023. It was unclear how speed limits could be enforced.

The French proposal includes an idea for enforcement that perhaps illustrates the challenge of reaching agreement. It cited recent instances of operators not taking the opportunity to reduce speed because they feared losing a competitive advantage, or running afoul of contractual obligations. The solution, it said, was “to develop an internationally binding regulation which would frame and limit possible contractual obligations”, setting the stage for mandatory speed limits.

The IMO has recognized that ships and ports are intrinsically linked when it comes to reducing the maritime industry's GHG output; ships are estimated to use about 15 percent of their fuel at ports or in harbors.

In line with the French submission, a proposal from a ports-based collaboration notes similar contractual challenges, but suggests an alternative solution. It recommends focusing on the emission-reduction potential of improving inter-party communications and data analyses to support the concept of just-in-time shipping.

It cited a recent analysis by the Port of Rotterdam which found that if all incoming containerships calling at the port in 2018 had known their time of arrival at the Pilot Boarding Place 12 hours in advance, the shipping emissions for the last 12 hours of those voyages could have been reduced by 4 percent (or 134,000 tonnes of CO_2) for the year.

Approximately 70 percent of bulkers and tankers are contractually obliged to maintain a minimum speed and to proceed to port with utmost dispatch, according to the proposal. For these vessels, it said, charter-party clauses need to be included that allow the master to reduce speed without a breach of contract.

A collective proposal from Argentina, Canada, the Cook Islands, Iran, New Zealand, Panama, Singapore and others, seeks to enhance cooperation between ports and international shipping to develop GHG solutions.

It calls for cooperation on voyage optimization and encourages the use of the emissions toolkits that were developed by the Global Maritime Energy Efficiency Partnerships, a project driven by the IMO's Marine Environment Division, to assess port emissions and develop strategies to reduce them.

Separately, Denmark, Germany and Spain called for a more flexible goal-based approach to reducing emissions that would let shipowners decide how to reach the targets, while offering incentives for operational improvements such as hull cleaning.

Recognizing that a significant proportion of the fleet in 2030 still will be comprised of ships built before the IMO's Energy Efficiency Design Index (EEDI) entered into force, the proposal cited the need for "a short-term measure to target the existing fleet." That measure, it said, should involve a mandatory reduction in speed.

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Chile and Peru, however, pointed out that reducing vessel speeds could negatively impact the states that export perishable commodities and are far from their markets. Mandatory slow steaming, they said, could reduce product quality and create market distortions that have negative economic repercussions.

China and Japan offered proposals regarding the knotty problem of operational efficiency.

China said it believes improving the energy-efficiency framework to reduce carbon intensity will be challenging, “given the inherent distinction between a ship’s operational energy efficiency and its design efficiency.”

It offered three prerequisites for pursuing a practical solution: exploring alternative ways to measure the energy efficiency of ship operations without using commercially sensitive data; developing methods for evaluating the carbon intensity of the shipping industry as a whole, or specific segments; and to consider establishing a benchmark to stimulate improvements in the energy efficiency from operations.

Seeking a “technical, goal-based and fair approach for all ships,” Japan proposed a measure on energy efficiency for existing ships based on IMO instruments. It calls for development of a simplified index for calculating energy efficiency performance, which it terms the Energy Efficiency Existing Ship Index (EEXI).

The delegation would like to see a specific calculation method developed for the EEXI, the metrics of which would be compatible with that of EEDI, so that “the attained EEDI can be used as an alternative to EEXI.” If adopted, these improvements in design efficiency would fall under the mandate of International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI.

The proposal allows each ship to choose its own way to improve its energy efficiency, such as by imposing shaft/engine power limitations, changing fuels or using energy-saving devices. A goal-based approach to achieving energy efficiency “should be the fundamental basis for regulatory measures,” it said.

The proposals highlight some fundamental differences in how to approach building greater energy efficiency into the global fleet, while showing a collective determination to improve emissions performance.

SECTION 2 | IMO INITIAL GHG STRATEGY

THE FOURTH IMO GHG STUDY

The Initial International Maritime Organization (IMO) Strategy on Reduction of greenhouse gas (GHG) Emissions from Ships identifies 'levels of ambition' for the international shipping sector with respect to the decline of carbon intensity and the reduction of annual GHG emissions. It outlines follow-up actions leading to the adoption of the Revised IMO Strategy in the spring of 2023. The follow up actions will lead to adjustments in the Initial Strategy, largely informed by data collected from ships between 2012 and 2018, and the completion of the fourth IMO GHG Study.

The terms of reference for the study were concluded at Marine Environment Protection Committee 74th Session (MEPC 74), which convened May 13-17, 2019. The objective of the fourth study is to reduce some of the uncertainties associated with emission estimates, and to establish annual inventories for the global GHG emissions and associated pollutants caused by international shipping (and from shipping as a whole) from 2012 to 2018.

The third IMO GHG study (2014) differentiated international and domestic shipping based on the type and size of the ship. Since the same ship can be engaged in international and domestic trade, the fourth study will categorize international shipping as between ports of different countries, while domestic shipping will be defined as between ports of the same country. This will address concerns about double counting.

The GHGs considered under the process established by the U.N.'s Framework Convention on Climate Change include: carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. Other substances that may contribute to climate change include: nitrogen oxides, non-methane volatile organic compounds, carbon monoxide, particulate matter, sulfur oxides and black carbon.

The fourth study also should provide estimates on carbon intensity, in other words CO_2 emissions per transport work, using the estimated inventories it establishes. Since the third study did not provide an estimate of carbon intensity for 2008, the baseline year, the fourth study is expected to provide that.

The fourth study is also expected to develop 'business-as-usual' scenarios, and provide projections on transport demand and shipping emissions out to 2050. Its final report will be submitted to MEPC 76 in the fall of 2020.

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SHORT-SEA VS DEEP-SEA SHIPPING

In an era when maritime trade is increasingly global and governed by international regulation, it would be easy to assume that all ships are created equal when the industry sets course to decarbonize its fuels. They are not, however. And as shipowners try to find the most strategic path to lowering the carbon footprint of their fleets, it is important to make the distinction between those ships that ply coastal or limited regional routes and those involved in the intercontinental trades.

While both short- and deep-sea vessels can be involved in international trade and move similar types of goods, the two markets are distinctly different in areas such as the suitability and pace of technological adoption, available resources, and the complexity and oversight of regulatory regimes.

For example, the short sea trades often see vessels spend the majority of their time plying environmental control areas such as the Baltic Sea, or rivers and lakes that are located close to urban areas where emissions are more strictly monitored and regulated.

The owners of deep-sea fleets tend to be more vulnerable to supply chain risks (such as trade sanctions) and more able to benefit from economies of scale when international trade and relations are strong.

There have been recent suggestions that a rise in regional trade would shorten supply chains and reduce shipping ‘s overall output of greenhouse gases (GHG). However, the larger vessels used for intercontinental trade offer their own operational (and therefore carbon) efficiencies for cargo transport, particularly on a tonne-mile basis, so striking a balance with global emissions regulation will be critical.

Below are some differences between the sectors that may influence how regulation is developed and applied, as well as how – and how quickly – shipowners can chart their courses towards low-carbon fuels and the adoption of more sustainable forms of energy.

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SHORT-SEA

The short-sea routes lend themselves to cargo specialization and because the performance of the trades also relies on fewer economies, they tend to be less volatile than international routes.

For example, about 60 percent of Europe's seaborne trade by volume is generated from short-sea shipping around areas such as the Mediterranean, across the North and Irish Seas, between Baltic nations and among the continental countries served by rivers. There are similar national and regional trade clusters in Asia, Africa, North and South America.

Because their businesses tend to be reliant on fewer jurisdictions, short-sea traders are typically more affected by local and regional regulations. Ownership tends to be scattered across a network of smaller players, who can struggle to find the resources to adopt capital-intensive technology (or programs) unless they are supported by government initiatives.

The Connecting Europe Facility and Horizon 2020 are examples of government incentives while other governments, through various programs, support application of new technologies in the local marine industry.

The short routes of the coastal trades are ideal for trialing new energy technologies and alternative fuels such as batteries and liquefied natural gas (LNG), which may require regulatory support, frequent recharging or specialized infrastructure. It is important to keep in mind that short-sea shipping competes with land-based transportation. If the regulatory climate makes it uncompetitive, work could shift to land-based transportation.

As such, the short-sea trades are often the proving ground for new fuels and technologies.

DEEP-SEA

Owners of deep-sea fleets tend to be proponents of global regulation. Any trend towards stronger regional regulations for carbon emissions, for example, would increase the complexity of gaining and maintaining compliance because they usually operate in multiple jurisdictions.

The deep-sea trades are served by many of the world's largest vessels. While most are made to benefit from economies of scale, they tend be designed for a singular cargo, the supply of which is vulnerable to fluctuations of that market.

With comparatively higher supply-chain risks and consequences than in the coastal trades, deep-sea shipowners tend to be more cautious about change, both technological and regulatory. Rather than be early adopters, they are likely to adopt new energy sources or alternative fuel technologies slowly, after they are proven in the maritime market.

The owners of larger fleets may also experience pressure from their charterers for their ships to have better than average performance on GHG emissions.

There are some similarities between the two trades: both trade internationally and some vessel types, such as handysize bulkers and large feeder containerships, have the flexibility to serve both sectors.

However, for the most part, they have very different operational profiles that require careful consideration before adopting new fuels or energy sources. Global emissions solutions will need to be flexible enough to serve both markets, while ensuring that the International Maritime Organization's (IMO) goals for 2030 and beyond are met.

OPERATIONAL OPTIONS: SPEED, UTILIZATION AND JUST-IN-TIME

Whether or not the International Maritime Organization's (IMO) 2030 emissions goals are met will depend in large part on whether the shipping industry can squeeze more operating efficiency out of existing assets and technology. There has been no shortage of ideas as to how that might be achieved. Representative nations at the IMO recently submitted proposals that suggested ways to reduce the greenhouse gas (GHG) emissions from shipping through a number of approaches, including:

- Improving the energy efficiency of existing ships by building on the framework from the IMO's Energy Efficiency Design Index (EEDI)
- Further develop the EEDI framework for new ships
- Improve the energy efficiency of existing ships by building on the framework from IMO's Ship Energy Efficiency Management Plan
- Identify operational energy-efficiency indicators
- Develop speed-optimization and speed-reduction mechanisms
- Develop regulatory measures to reduce methane slip
- Develop regulatory measures to reduce emissions of volatile organic compounds
- Encourage the development of national action plans
- Encourage port developments and activities to reduce GHG emissions
- Initiate and support research and development activities
- Encourage incentive schemes for first movers
- Develop life-cycle GHG and/or carbon-intensity guidelines for all types of fuels

To assess the potential of the main operational options available to shipping, Maritime Strategies International (MSI) prepared a recent report for ABS. The options, and their potential impact on the industry's carbon footprint, are assessed under the sub-titles below.

As a base case, MSI assumed the following compound annual growth rates for each of the major vessel types during the period 2019-2030:

- 0.9 percent for dry bulk
- 0.9 percent for oil tankers
- 3.9 percent for containerships

REDUCING SPEED

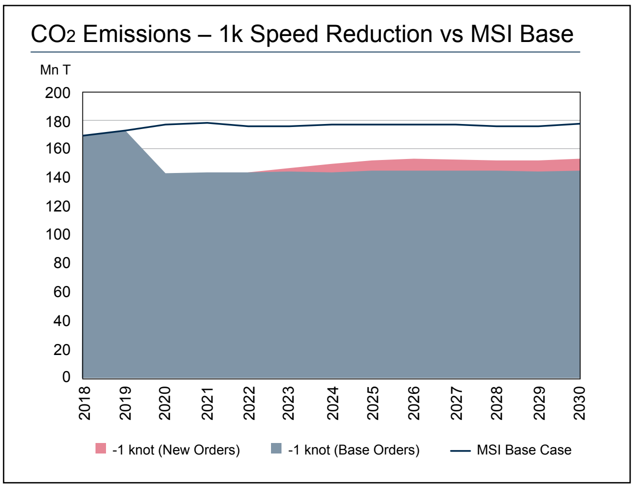
Speed reduction is an operational measure that can have a significant impact on reducing GHG emissions in a relatively short amount of time. France, supported by a large number of shipping companies, proposed the creation of a regulatory mandate to reduce vessel speeds, based on recent experiences in a commercial environment where low charter and freight rates were the norm.

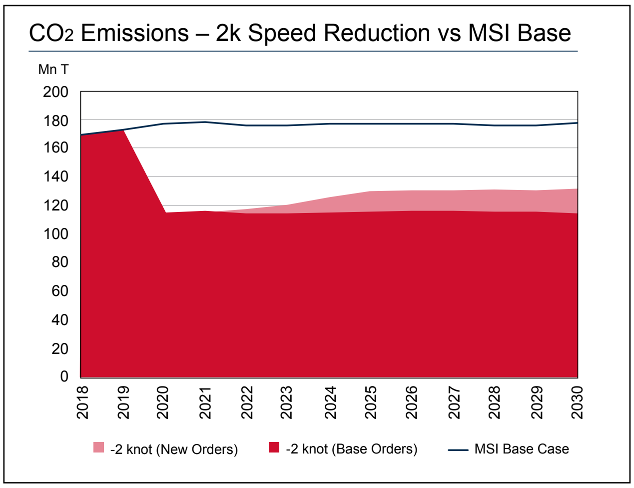
It is estimated that 'slow steaming', as it is known, reduced shipping's overall carbon dioxide (CO_2) output in 2015 by dropping the carbon intensity of maritime transport by 30 percent compared with 2008 levels.

Using their proprietary econometric models, MSI modeled the impact of reducing average vessel speeds by one and two knots on the cargo carrying capacity required for each sector.

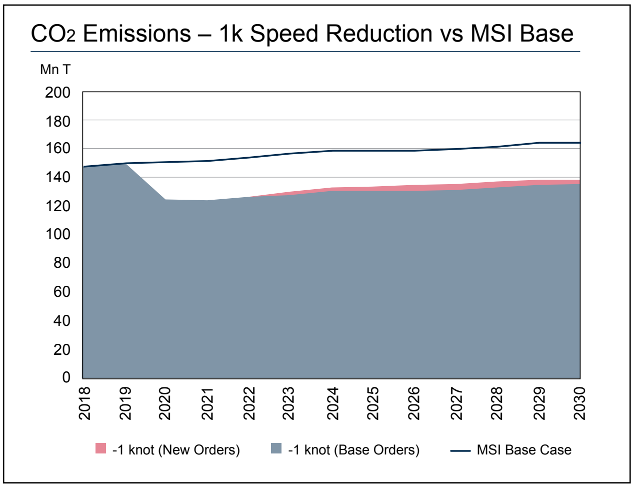
An increase in required cargo carrying capacity results in a spike in vessels utilization and earnings if the supply side remains unchanged, and subsequently an incremental newbuilding requirement to bring utilization back in line with MSI's base case.

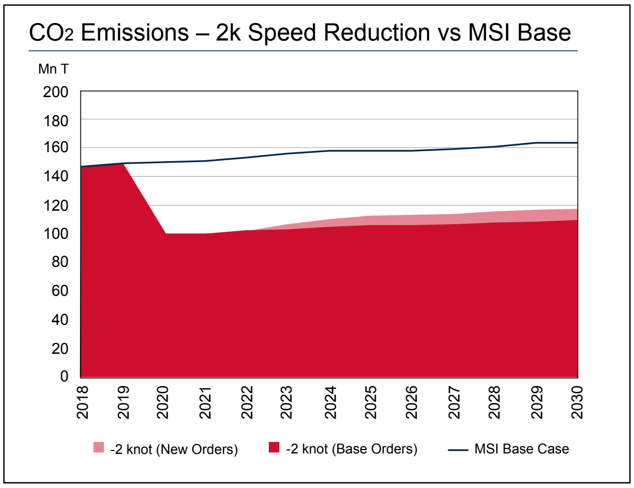
BULK CARRIER


CO_2 Emissions – 1k Speed Reduction vs MSI Base

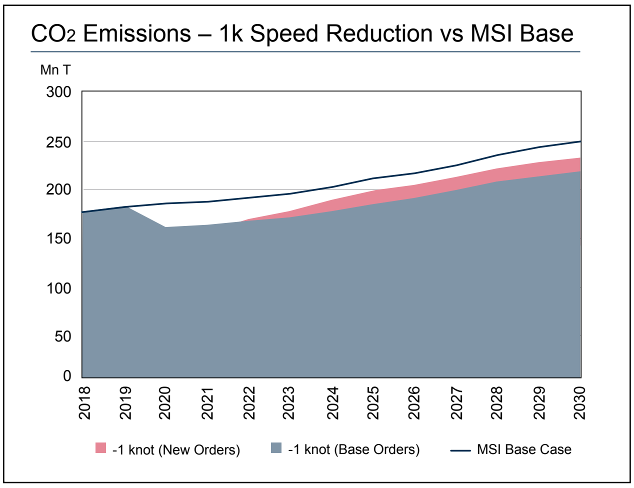

CO_2 Emissions – 2k Speed Reduction vs MSI Base

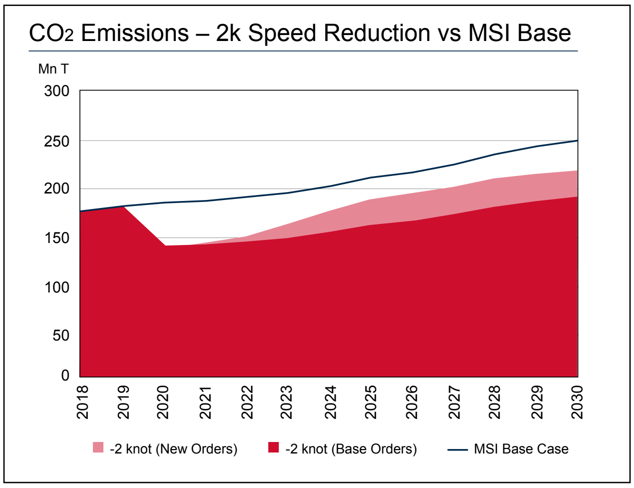
TANKER


CO_2 Emissions – 1k Speed Reduction vs MSI Base


CO_2 Emissions – 2k Speed Reduction vs MSI Base

CONTAINERSHIP





MSI believes that, for the three major vessel types, reducing vessel speeds by one knot increases average annual requirements for dwt capacity by:

- 6 percent for dry bulk
- 3.8 percent for oil tankers
- 8 percent for containerships

Reducing vessel speeds by two knots increases demand for capacity by:

- 13.4 percent for dry bulk
- 8.2 percent for oil tankers
- 17.4 percent for containerships

The above figures account for the incremental orders required to compensate for the impact of reduced speed on the capacity that is required.

The reduced speeds have a significant short-term impact before the incremental orders are added to the fleet and, even accounting for the increases in tonnage by 2025, overall CO_2 emissions are reduced (see chart below).

Ship type	CO_2 Emissions Reduction	
	1-knot Speed Reduction	2-knot Speed Reduction
Dry Bulk	13%	25%
Oil Tankers	15%	28%
Containerships	6%	11%

JUST-IN-TIME SHIPPING

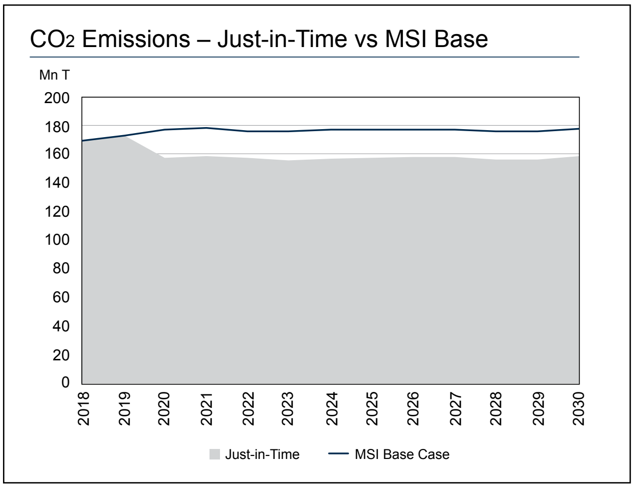
For a number of years, the use of data from automated identification systems has made it possible for the industry to operationally benefit from knowing details such as the estimated time of arrival, the arrival port, draught and navigational speeds, etc.

Those data points are being used today to track vessels and to support limited adjustments to voyage planning. However, deeper analyses of the data on vessel positions and berth availability are revealing the type of information that soon could make ‘just-in-time’ shipping a reality.

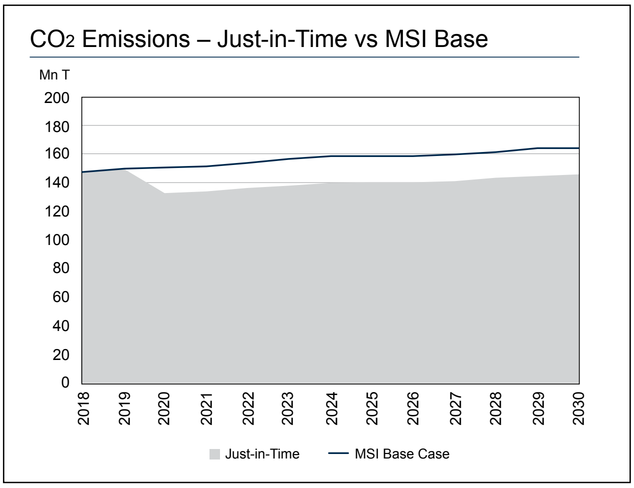
More efficient communications between vessels and ports on the availability of berths and ancillary service providers such as tug operators would optimize marine traffic, with all the commercial and environmental benefits.

MSI modeled the effect of potential efficiency improvements created by just-in-time shipping by presuming an average 5 percent reduction in speed, assuming no impact on cargo-carrying capacity and no adjustment to the size of the fleet. Based on that basic analysis, the CO_2 emissions savings are around 10-11 percent annually.

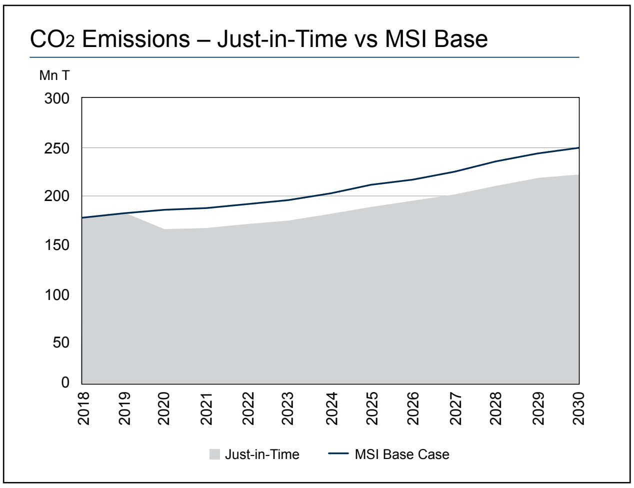
BULK CARRIER



TANKER



CONTAINERSHIP

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VESSEL UTILIZATION

Enhancing fleet utilization by improving planning and reducing the time spent in the ballast condition also holds promise.

The use of advanced analytics to investigate cargo movements and create related strategies to reduce time spent in ballast – or with sub-optimal cargo loads while in transit – could improve vessel utilization and lower the industry's total fleet requirement.

MSI investigated the three main shipping sectors, improving the ballast ratio by 10 percent.

If better fleet utilization leads to the decommissioning of less fuel fuel-efficient ships, and reduced ship ordering, the reduction in CO_2 emissions are modeled at 3.3 percent, 3.6 percent and 3.7 percent for bulkers, tankers and containerships, respectively.

Applied individually or in concert, these operational initiatives are some of the potential pathways to achieving 2030 emissions reduction targets.


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SECTION 3 | OPERATIONAL, DESIGN AND FUEL SOLUTIONS

SHIP TECHNOLOGY OPTIONS

Shipping's search for greater fuel efficiency – and reduced greenhouse gas (GHG) emissions per tonne-mile – has kept design houses and ship model basins busy for some time. Further optimization of existing technology has a role to play in the decarbonization of commercial shipping. Below are approaches that have been implemented by designers to produce more fuel efficient ships, even if sometimes the efficiency gains can be difficult to assess, especially when used in combination.

OPTIMIZING HULL FORMS

The process of optimizing a ship's principal particulars requires sophisticated analytical tools to investigate multiple technical disciplines such as hydrodynamics, ship structures, environmental and safety performances.

Economic studies also are applied to evaluate the merits of each principal particular in the process of optimizing the design.

Optimizing the energy efficiency of the vessel can involve several projects, including: optimizing the hull form given the principal particulars (lines development); optimizing the propeller(s) to improve the flow from the hull and the power transmitted from the engine; design and arrangement of the rudder in relation to the propeller and flow lines; and the investigation of energy-saving devices.

A comprehensive series of model tests and assessments using computational fluid dynamics are needed to optimize a hull form. These can include looking for ways to enhance the propeller and rudder, and maximize energy-saving devices.

Propulsion-improving devices, which are also known as energy-saving devices, can be applied to improve propulsion efficiency. They are commonly categorized into the following types:

- **Wake Equalizers:** Improve the flow conditions around the hull leading toward the propeller assembly
- **Pre-swirl Devices:** Improve the angle of attack of the flow on the propeller blades and reduce the momentum of the rotation flow after the propeller
- **Post-swirl Devices:** Suppress characteristics detrimental to efficient flow, convert the rotational components of the flow from the propeller's wake into axial thrust, or condition the flow to improve the rudder efficiency
- **High Efficiency Propellers (Ducted Propellers, Contra-rotating Propellers, etc.):** Optimized along with the hull form to improve the efficiency of propulsion under defined operational conditions

REDUCING HULL FRICTION

The surface roughness of a ship's hull can be affected by physical and biological causes that reduce hydrodynamic efficiency. Mechanical damage and coating failures have to be addressed and fouling has to be controlled through a program designed to manage the hull's roughness.

More effective coatings can help to maintain favorable conditions on a hull's surface for an extended period of time and preserve low levels of hydrodynamic friction.

'Air lubrication' is an innovative energy efficiency technology that can be included in the calculation of a vessel's Energy Efficiency Design Index (EEDI), an International Maritime Organization (IMO) regulation that assesses a ship design's energy-efficiency level per cargo transport.

REGULATIONS IMPACT ON ALTERNATIVE FUELS

To meet the medium and long-term emissions goals set by the International Maritime Organization (IMO), low- and zero-carbon fuels will need to emerge as viable options for worldwide shipping, in tandem with technological advances. Once their viability is proven, the timeliness of the availability of these fuels at scale and the infrastructure that transports and delivers them will be critical for each to achieve widespread adoption and help the industry to meet its reduction targets.

Traditionally, regulation also has influenced the rates of fuel adoption. Below is some historical context, and the current state of play. The International Convention for the Safety of Life at Sea (SOLAS) has historically prohibited the use of low flashpoint (less than 60°C) fuel oils for use on commercial ships, except for use in emergency generators, where the limit is 43°C and subject to a number of other requirements detailed in its regulations.

When the IMO adopted the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code), SOLAS was amended to make the IGF Code mandatory, and those amendments were also adopted by the IMO.

Prior to that, the only guidance from the IMO for using natural gas as a fuel came in the form of an ‘interim guideline’ adopted in June 2009. Its adoption of the IGF Code introduced the framework and requirements under SOLAS for burning fuels with a flashpoint less than 60°C.

Under the ‘one ship, one code’ policy, the IMO clarified that, with the exception of ships burning cargo as fuel under the IGC Code (The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk), the IGF Code governed all new ships over 500 gt (and conversions) built after 2016 that use low flashpoint fuels.

The IGF Code includes detailed prescriptive requirements for natural gas and risk assessments, but the latter need only be applied to specific sections, such as those covering the sizing of drip trays and general fuel containment.

Other low flashpoint fuels can be used as marine fuels, if they meet the intent of the IGF Code’s goals and functional requirements, and provide an equivalent level of safety.

In the longer term, the IGF Code is expected to expand to cover other low flashpoint fuels as industry applications and experience grows. Before that, the IMO will issue more interim guidelines, including those governing ships using methyl or ethyl alcohol as fuel,’ which were approved in principle in September 2018.

For gas carriers, the use of natural gas as a fuel is permitted under the IGC Code. In 2014, a new section for ‘alternative fuels and technologies’ was introduced permitting the burning of cargoes other than natural gas, provided they are not identified as toxic.

Similarly, the 2016 IGC Code allows alternative fuels to be burned if the same level of safety as that required for natural gas is ensured. Projects considering this approach need to discuss a roadmap to approval with the Code’s administrators, as well any approach to risk assessment.

By adopting the IGF and 2016 IGC codes, the IMO has established the regulatory safety requirements and framework for the use of natural gas and other low flashpoint fuels ships of all types.

SECTION 3 | OPERATIONAL, DESIGN AND FUEL SOLUTIONS

INFRASTRUCTURE

As shipowners evaluate the different fuel types to find a viable path to lower carbon shipping, it becomes apparent that the availability of supply and the state of supporting infrastructure are very important variables in that process. According to the International Energy Agency (IEA), demand for marine fuels in 2018 was about 4.3 million barrels per day, mostly heavy fuel oil (HFO) and marine gasoil (MGO). Replacing or retrofitting any part of that global network of assets to serve new fuels will be a very capital and resource-intensive process.

Any fuel being considered to replace the supply of fossil fuels needs to be able to offer a similar quantity and level of availability in major ports such as Houston, Rotterdam, Singapore and Fujairah, just for starters.

Moreover, any new low and zero-carbon fuels adopted by different countries specifically for their local fleets may need to develop or adapt a substantial amount of new infrastructure, depending on the chosen technology.

Marine fuel infrastructure serves more than global supply requirements at local ports, it comprises the complete value chain of assets that support manufacturing, processing, distribution and storage and delivery to the end user.

Liquefied natural gas (LNG) provides a clear illustration of what it will take to adopt alternative fuels globally. It has taken 10 years for LNG bunkering infrastructure to develop and supply less than 1 percent of the global fleet. Other alternative fuels will face similar challenges and headwinds coming from regulatory, supply chain and commercial developments.

Unlike the current storage and distribution networks, the requirements of future infrastructure may need to be flexible enough to serve the different technologies (fuels) used by each vessel; as operators transition to the low carbon era, their vessels may need to use multiple types of fuels for propulsion and power generation.

Some of the new fuels may be adaptable to traditional bunkering processes, but many may require special handling procedures, onshore and offshore employee training and a dedicated value chain of production, storage and distribution. It is not just the vessels that will require a transformation of their technology.

Also, with regional requirements and operational limitations, some fleets may need to adopt a fuel technology that is only widely offered in a dedicated area (such as environmental control areas, or jurisdictions with more stringent fuel regulations).

To minimize restricted routes and port operations, global options will need to exist for large-scale operations. Among the alternative fuels, the supply of LNG is served by one of the most established networks of marine infrastructure (providing approximately eight million tons of fuel per year), but is still very limited compared to HFO and MGO bunkering.

Many of the alternative fuel options such as ammonia and methanol have extensive established chemical or process industry infrastructure, which can be leveraged and extended for distribution to marine terminals and ports. Any other alternative fuel being considered will need its suppliers and distributors to have the ability to scale up to support the marine transport networks that opt to use it.

For shipowners, the criteria for selecting a fuel pathway are destined to be about more than the search for lower emissions.

RENEWABLE VS NONRENEWABLE FUELS

The two primary areas of discussion on renewable fuels are sourcing and the fuel production process. As we discuss below, the term alternative fuels implies fuels not currently in full production for marine applications, including liquefied natural gas (LNG), liquefied petroleum gas (LPG), methanol, ammonia, hydrogen, biofuels and synthetic fuels.

SOURCING OF FUELS

Renewable energy and fuels are from natural sources that are replaceable over a relatively short period.

- Renewable energies include solar, wind, hydro and geothermal
- Renewable fuels are biomass fuels, which are grown (crops, trees, etc.) and much of the material used is waste, so renewable
- Hydrogen is renewable, when sourced from water via electrolysis with electricity produced by renewable energy or renewable fuels.

Nonrenewable energies come from resources that are replaceable, but by natural processes that can take centuries to develop; examples include coal, gas and oil. The most common example in the marine industry is heavy fuel oil (HFO). Nuclear is nonrenewable energy; the availability of uranium used for nuclear reactions is finite.

FUEL PRODUCTION PROCESS

Many fuels have to be processed for use in marine applications, either refined or reformed into more usable formats. When evaluating ‘well-to-wake’ emissions, assessing the production processes is critical because those activities vary widely in energy intensity.

WELL-TO-WAKE VS TANK-TO-WAKE

‘Tank to wake’ only considers the emissions from burning or using an energy source, not the process of sourcing the fuel or getting it to the ship.

To measure net carbon impact, ‘well-to-wake’ emissions should be considered for alternative fuels because the process examines the life cycle of a fuel, including production, transportation and use. For example, when used as a fuel, hydrogen is incredibly clean; when run in a fuel cell, its output is electricity, water and heat. But it is primarily produced from natural gas (nonrenewable), via an activity that is very energy intensive and produces significant emissions from the power sources. Alternatively it can be produced by electrolysis with energy produced by nonrenewable fuel.

USING RENEWABLE POWER IN THE PRODUCTION PROCESS

To maximize the emissions savings from alternative types of fuel, the production process will require power from renewable resources.

Because some regions with significant wind energy generation have limited demand during off-peak hours, studies are looking at ways to use the potential surplus to generate alternative fuels and store energy.

One of the options is to generate hydrogen from the electrolysis of water. Not only is hydrogen sourced from a plentiful resource, water, once it is used in a fuel cell, water is a byproduct of the process, creating a renewable energy cycle.

Ammonia can benefit from a similar process. Normally, ammonia is generated from mixing nitrogen with hydrogen that has been generated from methane reformation. If hydrogen is generated from a renewable process, ammonia does not require fossil fuels for production.

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LNG

Liquefied natural gas (LNG) is mainly methane, the hydrocarbon with the smallest carbon content, giving it the biggest potential among the fossil fuels to reduce shipping's carbon footprint. Although the marine application of LNG as a fuel is growing, it is currently used by a very small part of the global shipping fleet: At the end 2018, 782 LNG and non-gas carriers were either using it or currently being built to use it as a fuel, according to International Gas Union (IGU) numbers.

LNG is the cleanest-burning fossil fuel currently available at scale; its use as a marine fuel is supported by advanced engine technologies that have been proven in practice. As a fuel, it reduces nitrogen oxide (NOx) emissions, eliminates most sulfur oxides (SOx) and particulate matter, and contributes to carbon dioxide (CO_2) reduction (a maximum potential of 21 percent as compared with heavy fuel oil [HFO]). It will not meet the International Maritime Organization's (IMO) greenhouse gas (GHG) targets for 2030 or 2050 alone. But, combined with other technologies, it has the potential to play an important role.

FUEL CHARACTERISTICS

Chemical Composition	CH_4
Boiling Point, °C 1 bar	-162°C
LHV, MJ/kg	48
Auto Ignition Temp, °C	650
Flammable Range, % vol in air	5-15%
Energy Density, MJ/lt	21.6
Volume Comparison HFO (Energy Density)	1.85
Carbon Content	0.75
Carbon Content Reduction (Compared to HFO)	12%
CO_2, kg CO_2/kWh	0.2061
CO_2, kg CO_2/kWh Reduction (Compared to HFO)	26%
Low Flashpoint Fuel	Yes

TECHNOLOGY

Natural gas is a mixture of hydrocarbon gases often found with or near petroleum deposits. It predominantly contains methane (70-99 percent by mass, depending on its origin), lesser amounts of ethane, propane, butane and traces of nitrogen. When refrigerated to about -162°C, it forms a liquid, reducing its volume to 1/600th of its gaseous state, making it safer and easier to store and transport.

LNG density is about half that of heavy fuel oil (HFO), but its calorific value is roughly 20 percent higher. While using LNG as fuel should require about 1.8 times more tank-storage volume than HFO for the same range of transport, due to the shapes, insulation and segregation required of cryogenic tanks, the fuel containment and supply systems often require three to four times more space on board.

Global reserves of natural gas were estimated in 2017 by the U.S. International Energy Agency (IEA) at 7,124 trillion cubic feet, or enough for at least 60 years at the current rates of global consumption, and significantly more than the stores of liquid petroleum gas (LPG).

APPLICATION

While the early generation of LNG carriers used LNG-fueled steam boilers to feed their turbines for propulsion, the newer generations use dual fuel diesel engines (DFDE) for propulsion and power generation. As of December 2018, more than 525 LNG carriers were in service or on order and most were designed to operate using LNG boil-off gases as fuel. Of the operational ships, roughly 30 percent have DFDE power plants, with a small proportion driven by slow speed dual fuel (SSDF) diesel engines. Of the ships on order, the majority will be DFDE (40 percent) or SSDF (50 percent driven. Excluding LNG carriers, at the end of January 2019 there were 163 LNG fueled vessels in the global fleet, with the biggest subsectors – ferry and offshore support ships – predominantly captive to specific regions.

In the past decade, LNG-fuel applications have transitioned to a wider range of ship types, including tugboats, very large container carriers, tankers and cruise ships; the latter is an area of high interest for newbuilding orders.

CHALLENGES

Even though the use of LNG as a marine fuel is increasing, there are obstacles to the pace of adoption. Bunkering infrastructure is presently limited, newbuilding and conversion costs are comparatively high and it has limited potential to meet the industry's ambitious emissions reduction targets by itself.

Regulatory: While IGF Code for LNG has been in force since 2017, there are aspects mainly related to its supply that have not been addressed on a global level. Not all ports have established local regulations to govern the procedures of LNG bunkering. However, several bodies and industry societies such as the International Association of Classification Societies (IACS), Society for Gas as a Marine Fuel (SGMF), and the International Organization for Standardization (ISO) are working to adopt universal regulations and have issued guides to accommodate its bunkering.

Bunkering: The global infrastructure for LNG bunkering is limited. Ports and shipowners in northern Europe have led the way; in the U.S., several Gulf ports are building capability at a pace driven, at least initially, by the number of U.S.-owned LNG fueled vessels coming out of the yards; the port of Singapore is leading the way in Asia.

Methane Slip: While the combustion process in Diesel Cycle engines minimizes how much methane escapes, the premixed Otto Cycle versions allow leaks to occur through the exhaust, which may grow during low load and idle conditions. Otto Cycle engine technology is improving, however, and the amount of methane slip will continue to fall.

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Fuel Supply Systems: The complexity of the fuel supply varies according to the technology. The number and types of fuel containment systems and the pressure of the supply contribute to the complexity of specific systems. Overall, gas fuel systems use advanced technology that is considered more sophisticated than conventional fuel oil, and they require more crew training.

Capital Expenditure: The initial investment cost of using LNG fuel propulsion is 1.25 to 1.4 times higher than conventionally fueled vessels. However, if the cost of LNG fuel remains lower than for conventional fuels, the operating costs will too.

Operational Expenditure: Due to the similar thermal efficiency of gas-fueled engines to liquid diesel ones and the higher heating value of natural gas, the energy consumption of the gas-fueled engines is roughly equal to those that are HFO or marine gasoil (MGO) fueled. Maintenance requirements are less demanding because gas combustion is cleaner. So far, the time between overhauls is roughly equal.

GHG PERFORMANCE

With LNG's potential CO_2 reduction (against HFO/diesel) capped at 21 percent based on recent testing, it will not be sufficient on its own to meet the IMO's GHG targets for 2030. For example, with the comparative overall GHG benefit after considering life-cycle emissions and methane slip from operations, reductions may actually slip to 5-10 percent Nevertheless, it still has positive role to play in reducing the overall carbon footprint of the fleet and in promoting the use of cleaner fuels. LNG contains no sulfur, so any SOx emissions come from liquid pilot fuels and lubricating oils.

Compared to diesel, LNG in combustion significantly reduces particulate matter (90-99 percent). Depending on the engine technology, NOx output may be reduced by 25 percent for engines operating in the Diesel cycle, and significantly more for those operating in the Otto cycle.

SAFETY

The International Convention for the Safety of Life at Sea (SOLAS) has long prohibited the use of fuels with flashpoints lower than 60°C. Since the introduction of the IGF Code and the new IGC Code in 2016, the IMO has created regulatory and safety frameworks for the industry-wide use of LNG and other low flashpoint fuels.

Familiarity with the properties and characteristics of methane is critical to understanding the safety hazards associated with the use of LNG as a marine fuel. It is not considered to be corrosive nor toxic.

The hazards are associated with its storage, transportation and combustion, and they include cryogenic temperatures, vapor flammability and asphyxiation. Due to heat leakage through the insulation into the LNG cryogenic tanks, some of their contents continuously evaporate and generate boil-off gas, which increases tank pressure, potentially raising the risk of LNG and methane vapor releases. Those vapors are flammable and have the potential to asphyxiate workers.

If a vapor spill comes in contact with a ship's structure, it causes brittleness and fracturing. Personnel with accidental contact with LNG or unprotected containment systems may receive cryogenic burns.
In a liquid state, LNG is not considered flammable and cannot ignite. However, LNG vapors become flammable when the percentage of methane in air reaches 5-15 percent and it can ignite when introduced to an ignition source.

The autoignition temperature of methane is relatively high, at 595°C. When released from LNG, methane vapors will at first be heavier than air and then rapidly become lighter than air as it warms beyond -100°C. It is therefore critical that safeguards are in place to prevent a flammable mixture from occurring, and to ensure that any sources of ignition are nowhere near.

LIQUEFIED PETROLEUM GAS

Liquefied petroleum gas (LPG) is a mixture of hydrocarbons consisting mainly of propane and butane in liquid form. It is a by-product from oil and gas production or the oil refining process and can be derived from the production of biodiesel. The use of LPG as fuel is a relatively new concept in the commercial shipping industry and it is expected to be limited to LPG carriers. The world's first order was recently placed for dual-fuel engines designed to use LPG on a series of very large gas carriers.

TECHNOLOGY

There is an extensive knowledge and experience with the widespread use of LPG for land applications. A dedicated network of LPG terminals and carriers could be reconfigured to supply bunkers. The bunker infrastructure needs to be developed, but the product is easier to handle and store than liquefied natural gas (LNG), which simplifies bunkering supply systems.

LPG's calorific value is 12-15 percent higher than that of heavy fuel oil (HFO); its typical heating value is also higher. However, LPG's energy density per unit is lower than that of fuel oils'; therefore, as with the use of LNG and other low flashpoint fuels, a greater volume is required (typically, 1.5 times) to produce the same energy content when replacing marine fuel oils.

In large quantities, LPG is stored or transported in pressure vessels at around 18 bar or semi-pressurized/ refrigerated tanks at 5-8 bar and -10 to -20°C.

FUEL CHARACTERISTICS

Chemical Composition	COMBINATION*
Boiling Point, °C 1 bar	-26.2
LHV, MJ/kg	46.06
Auto Ignition Temp, °C	428
Flammable Range, % vol in air	1.6-10%
Energy Density, MJ/lt	24.88
Volume Comparison HFO (Energy Density)	1.6208333
Carbon Content	0.82148
Carbon Content Reduction (Compared to HFO)	3.3%
CO_2, kg CO_2/kWh	0.2353
CO_2, kg CO_2/kWh Reduction (Compared to HFO)	15.6%
Low Flashpoint Fuel	Yes

*60% Propane, 40% Butane

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APPLICATION

Shipping companies are working with partners (engine manufacturers, systems designers and class) to use LPG engines on newbuildings, or to retrofit vessels with the technology. Currently, there is only one marine dual fuel engine, MAN ME-LGI, designed specifically for LPG as an alternative, but more manufacturers are expected to offer alternates. MAN also offers a generic engine variant capable of burning multiple fuels as gas, such as ethane or methane, in addition to LPG. This may be particularly useful if gas carriers anticipate carrying a number of products.

Typically, an LPG tank needs three times more volume than a tank for HFO. LPG fuels tanks are mainly non-refrigerated or semi-refrigerated C-Type tanks (up to 5,000 m^3). They do not have the cryogenic complexity associated with LNG storage and are not required to withstand cryogenic temperatures.

Providing LPG bunkering infrastructure, including shipboard equipment, would be less costly than the operating systems and equipment required for LNG.

CHALLENGES

LPG is used extensively by many industries, including automotive, chemical production, textiles, farming and metals, so there would be well-established competition for the product if shipping significantly widens its use as a fuel.

The requirements of increasingly stringent emissions regulations may limit significant adoption of LPG because, although it offers more environmental benefits than HFO or diesel, its carbon dioxide (CO_2) and nitrogen oxide (NOx) emissions are higher than for LNG.

GHG PERFORMANCE

Compared to HFO LPG reduces NOx emissions by 15-20 percent due to its lower combustion temperatures. Using LPG as a fuel reduces sulfur oxide (SOx) emissions by 90-97 percent, due to its very low sulfur content. CO_2 output is reduced by 13-18 percent.

SAFETY

Understanding properties and characteristics of low flashpoint petroleum gas, which mainly consists of propane and butane, is key to understanding the safety hazards associated with the use of LPG as a marine fuel. It is neither corrosive nor toxic.

The hazards associated with petroleum gas storage, transportation and combustion include those associated with low temperature service, pressurized storage tanks, flammable gases and asphyxiation.

Due to heat leakage through the insulation into the LPG tanks, it continuously evaporates and generates boil-off gas, which increases pressure if not maintained. Personnel with accidental contact with LPG can receive cold burns to the skin.

LPG vaporizes rapidly and the vapor is flammable when the percentage of petroleum gas in air is between 1.5-11 percent and it can ignite when introduced to an ignition source. Smaller volumes of its vapors can create a hazardous atmosphere compared with LNG.

The autoignition temperature of petroleum gas depends on the ratio of products (e.g. propane and butane) in its mix and can be as low as 372°C. This comparatively lower autoignition temperature requires electrical equipment with T1 surface temperature ratings (LNG requires T1).

LPG is heavier than air, so any leaks tend to accumulate in the lower sections of a space. Special attention needs to be given to the ventilation and the placement of detection equipment of double barrier concepts (such as tanks) and machinery spaces.

METHANOL

Methanol is available worldwide and has been used in a variety of applications, such as in the chemical industry, for many decades. It is most commonly produced on a commercial scale from natural gas, but it can also be produced from renewable sources such as biomass, which could considerably reduce the carbon dioxide (CO_2) footprint of its use as fuel.

Due to its potential to reduce the CO_2 output from marine fuels, applications of methanol are drawing a wider interest from owners of both passenger and cargo ships.

It is a colorless and tasteless liquid at ambient temperature and pressure and is easier to store and handle compared with gas or cryogenic fuels. There are also fewer challenges involved in adopting methanol as marine fuel compared to gases such as liquefied natural gas (LNG).

There are, however, a number of limitations (discussed below) that could restrict its adoption.

FUEL CHARACTERISTICS

Chemical Composition	CH_3OH
Boiling Point, °C 1 bar	65
LHV, MJ/kg	19.9
Auto Ignition Temp, °C	440
Flammable Range, % vol in air	6.0-36%
Energy Density, MJ/lt	15.7
Volume Comparison HFO (Energy Density)	2.54
Carbon Content	0.375
Carbon Content Reduction (Compared to HFO)	56%
CO_2, kg CO_2/kWh	0.2486
CO_2, kg CO_2/kWh Reduction (Compared to HFO)	11%
Low Flashpoint Fuel	Yes

TECHNOLOGY

Methanol has the highest hydrogen-to-carbon ratio of any liquid fuel, a relationship that potentially lowers the CO_2 emissions from combustion, when compared to conventional fuel oils.

From an environmental perspective, methanol is readily dissolved in water, a state that would lessen the impact if it is spilled.

Methanol's energy density and specific energy value is significantly lower than that of conventional fuel oils; it requires about 2.54 times more storage volume for the same energy content.

PRODUCTION

There are various feedstocks used to produce methanol, natural gas currently being one of the most common. The process, which is energy intensive, combines reforming and converting in three steps: synthesized gas (syngas) preparation, methanol synthesis and methanol purification/distillation.

Biomass also can be used as feedstock. The process is similar to that for using natural gas as feedstock: synthesis gas (syngas) is formed when the feedstock is subjected to a specific temperature and pressure.

Production of methanol from biomass is seen as greenhouse gas (GHG)-neutral process (the amount of carbon released is roughly equal to the carbon absorbed by the plant matter during its lifetime), but emissions may be produced when generating energy for the process.

Using coal as feedstock for methanol production is possible, but it would have a negative impact on GHG emissions.

METHANOL AS A MARINE FUEL

Methanol's application as a marine fuel is technically possible, but bunkering facilities, onboard containment and fuel supply systems, and marine engines would all need to be developed for use at scale.

However, because the chemical and other industries have been shipping methanol around the world for decades (Clarkson Platou estimates that 26.7 million tons was shipped in 2017), much of the infrastructure exists today to transport and supply methanol at ports.

In liquid form, only minor modifications would be needed to convert the systems and infrastructure used for conventional marine fuels.

Onboard containment of methanol is less challenging than LNG, so bunker vessels are also a viable option for waterborne distribution and fueling.

PROPULSION OPTIONS

MAN Energy Solutions has developed the 'ME-LGI' engine for high-pressure injection of low flashpoint liquid fuels such as methanol. It uses a relatively low-pressure supply with high-pressure pumping within the injector. Less than 10 methanol burning ME-LGI engines are presently in operation.

Wärtsilä has developed a retrofit conversion option, which is a variant of its HP-DF engine technology.

APPLICATION

The first significant marine vessel retrofitted to run on methanol as a fuel was the RoPax ferry, *Stena Germanica*, operating between Gothenburg and Kiel, where there are bunkering and support facilities. The ferry uses a retrofit engine for burning methanol and requires a pilot fuel (5 percent diesel and 95 percent methanol).

Canada's Waterfront Shipping is currently operating ships designed to carry cargo, seven methanol carriers, with four more on order; they will all feature two-stroke dual-fuel engines that can run on methanol, fuel oil, marine diesel oil or gas oil.

The Swedish Maritime Administration operates a high speed pilot boat that also uses methanol as a fuel.

CHALLENGES

Shipping has limited experience with operating marine engines designed to use methanol, so there would be a considerable learning curve to ensure the required level of industry crewing and onshore competence to use the fuel safely, and at scale.

LOW ENERGY DENSITY

Methanol's heating value and energy density is much lower than that of LNG and conventional liquid fuels, so more space is needed for its tanks. As this can result in less cargo space, it may have influenced methanol's limited adoption as an alternative fuel.

The volume required for methanol is close to 1.5 times the volume of LNG with the equivalent heat value.

CORROSION

Methanol is corrosive, rendering vulnerable some of the materials currently used in combustion engines; a redesign of some engine parts, or the use corrosion inhibitors (as additives to fuel) and specialty coatings may be required.

REGULATION

The current IGF Code does not cover methanol as a fuel. However, any low flashpoint fuel may be considered under its alternative design provisions (2.3 of the IGF Code) and risk assessments (4.2). At the International Maritime Organization (IMO) level, proposals have been made to amend the IGF Code and include the requirements for using methanol as marine fuel.

GHG PERFORMANCE

Industry studies indicate that life-cycle nitrogen oxide (NOx) and sulfur oxide (SOx) emissions for methanol are about 45 percent and 8 percent of conventional fuels per unit energy, according to the IMO; its GHG emission performance will depend on the feedstock and source of energy used for production.

When natural gas is used as feedstock, the GHG emissions from well-to-tank are higher, which implies that well-to-propeller emissions are slightly higher than conventional fuels.

SAFETY

Understanding the properties and characteristics of low flashpoint methanol gas, is critical to understanding the safety hazards associated with the use of methanol as a marine fuel.

The hazards associated with storing, transporting and combusting methanol include low-temperature service, pressurized storage tanks and flammable gas; it is also corrosive and toxic, and can cause asphyxiation.

As an acutely toxic substance, extensive exposure can result in death. Because it is corrosive, skin or eye contact can cause irritation, and contact with the cold-service methanol can cause burns to the skin.

Methanol is a flammable liquid and does not vaporize rapidly like a liquefied gas. The vapor is flammable when the percentage in air is between 6-26 percent and introduced to an ignition source.

The autoignition temperature of methanol gas is 440°C, a temperature that requires electrical equipment to be assigned a T2 surface temperature rating.

Methanol vapor is heavier than air, indicating that any leaks would have the tendency to accumulate in the bilges or low sections of a space. Therefore, special attention needs to be given to the placement of ventilation and detection arrangements in double barrier concepts and machinery spaces.

AMMONIA

Ammonia is a compound of nitrogen and hydrogen that is commonly found in nature as a colorless gas at atmospheric pressure and normal temperatures. Although it has fueled internal combustion engines on land for 75 years, ammonia is in the early stages of development for marine propulsion; no vessels are currently using it, but ammonia-fueled engines are under development, and it is also being explored for use in fuel cells.

While its combustion offers considerable reductions in greenhouse gas (GHG) and other pollutants compared with conventional fuels, its negative overall GHG contributions during the production life cycle make its use just marginally better.

It is potentially a carbon dioxide (CO_2)-free bunker alternative, but that will require using renewable energy during production, adding cost. Additionally, for engine combustion, ammonia usually needs a promoter fuel, which may increase the overall carbon footprint of its use.

FUEL CHARACTERISTICS

Chemical Composition	NH_3
Boiling Point, °C 1 bar	-33
LHV, MJ/kg	22.5
Auto Ignition Temp, °C	630
Flammable Range, % vol in air	15-33.6%
Energy Density, MJ/lt	15.7
Volume Comparison HFO (Energy Density)	2.55
Carbon Content	0
Carbon Content Reduction (Compared to HFO)	100%
CO_2, kg CO_2/kWh	0
CO_2, kg CO_2/kWh Reduction (Compared to HFO)	100%
Low Flashpoint Fuel	No

TECHNOLOGY

Ammonia is the second most widely used chemical, supporting the production of fertilizers, pharmaceuticals, purified water and many other chemical applications. It can be produced using fossil fuels such as natural gas as feedstock, or with renewables.

One form of carbon free ammonia is produced through renewable electricity, which provides hydrogen. The ammonia is then formed through the Haber-Bosch process, which combines hydrogen with atmospheric nitrogen.

At higher pressures ammonia becomes a liquid, making it easier to transport and store. In large quantities, it can be transported in LPG carriers and has a boiling point of -33°C.

The typical heating value for ammonia is similar to methanol. As with most alternative fuels, it has a lower energy density than fuel oils, so producing the same energy content would require about 2.55 times as much volume.

APPLICATION

As a fuel, ammonia can be used in internal combustion engines that use spark- or compression-ignition systems, where it is cracked with a catalyst. Hydrogen will ignite and burn with the ammonia, which produces water, nitrogen and nitrogen oxide (NOx).

At present, only one engine manufacturer is proposing ammonia as a fuel. Its slow flame velocity and the challenges inherent in its combustion usually require a large percentage of pilot oil fuel to achieve ignition. Ammonia's octane rating is higher than heavy fuel oil (HFO), which could encourage its use in high-compression engines. It has a lower energy density than gasoline.

FUEL CELLS

Interest is growing for the use of ammonia as a feeder to hydrogen-fed fuel cells; once cracked, the hydrogen from ammonia can be abundant for cells that generate electric power. Certain fuel cell types can internally reform the fuel to run on ammonia directly, eliminating the need to separate the hydrogen and nitrogen elements before input.

STORAGE

Ammonia maintains a liquid state at high or low temperatures. Industrial scale storage uses low temperatures, which require energy to maintain. However, this option has a lower capital cost than pressurization, which takes more steel for storage. Ammonia also needs about 2.5 times more tank volume than HFO to generate the same energy.

TRANSPORTATION

Ammonia can be transported on land and sea – via pipeline, shipping, trucking and rail. Ships transport comparatively higher amounts in either liquid or gas states. Road and rail transport use pressurized storage vessels for safety and simplicity, but their weights, and therefore capacity, are limited.

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CHALLENGES

At present, ammonia as a fuel is not economically feasible for the shipping industry, which would need production on a large scale for use to expand beyond dedicated ammonia carriers. It is difficult and costly to produce industrial-scale volumes of ammonia; the infrastructure exists for the fertilization industry, but not marine.

As with other alternative fuel technologies, the production and processing techniques for its use as fuel are not refined and are costlier than for HFO; major onboard equipment modifications would be required before shipowners could use it for vessel propulsion.

When used for internal combustion engines, ammonia produces water, nitrogen, unburned ammonia and NOx. Its combustion may be carbon free, but managing its byproducts will be a key environmental challenge.

Selective catalytic reduction systems (SCR) or equivalent measures would be needed to manage the NOx output from internal combustion engines operating in the diesel cycle. But because ammonia is the basic reactant in a SCR, the abatement would be more efficient than for a diesel installation.

Ammonia can cause cracking in the containment and fuel supply systems made of carbon manganese steel or nickel steel, so specialized sealants may be required.

In a liquid state, ammonia is not considered flammable and cannot ignite. But it vaporizes rapidly and the vapor is flammable when the percentage in air is between 15-33.6 percent.

The autoignition temperature of ammonia gas is 630°C, a temperature that requires electrical equipment to be assigned a T1 surface temperature rating.

Due to heat leakage through the insulation into the tanks, ammonia continuously evaporates and generates boil-off gas, which increases pressure if not maintained.

GHG PERFORMANCE

Ammonia is carbon free and, when synthesized from renewable power sources, it is also a carbon-free process. Like hydrogen, it can be produced from fossil fuels using ‘green’ methods such as carbon capture and storage or renewable energy, both of which may influence its cost competitiveness.

If sufficient quantities can be produced using carbon-neutral technology, ammonia has significant potential to be a pathway towards reaching the International Maritime Organization’s (IMO) GHG reduction targets for 2050.

SAFETY

Understanding the properties and characteristics of ammonia gas – which include low-temperature service, pressurized storage tanks, flammable gases, and working with corrosive and toxic materials – is key to addressing the safety hazards of using ammonia as a marine fuel.

It is toxic and corrosive and contact can result in irritation, blindness and death. Inhalation quickly burns the nose, throat and areas in the upper chest.

Accidental contact with cold-service ammonia can cause skins burns.

HYDROGEN

Although abundant as an element, hydrogen is almost always found as part of another compound and needs to be separated before it can be used as a marine fuel. Once separated, it can be used along with oxygen from the air in a fuel cell, for example, to create electricity through an electrochemical process.

About 95 percent of hydrogen is produced from fossil fuels, such as natural gas and oil.

It is the cleanest marine fuel currently available in terms of its combusted output of nitrogen oxide (NOx), sulfur oxide (SOx) and particulate matter. In parallel, when produced from renewable energy it has almost zero greenhouse gas (GHG) emissions.

Many demonstrations are underway to advance its use for shipping propulsion and evaluate its role as a sustainable transport option for international trade by sea. However, the current applications provide very limited power output, and hydrogen production is very energy intensive, expensive and not available at scale.

FUEL CHARACTERISTICS

Chemical Composition	H_2
Boiling Point, °C 1 bar	-253
LHV, MJ/kg	120.2
Auto Ignition Temp, °C	535
Flammable Range, % vol in air	4-74%
Energy Density, MJ/lt	9.2
Volume Comparison HFO (Energy Density)	4.33
Carbon Content	0
Carbon Content Reduction (Compared to HFO)	100%
CO_2, kg CO_2/kWh	0
CO_2, kg CO_2/kWh Reduction (Compared to HFO)	100%
Low Flashpoint Fuel	Yes

TECHNOLOGY

The biggest consumers of hydrogen are the chemical industries and refineries, which utilize more than 90 percent of global production. In these industries it is not used as fuel but as a reactant for their related processes.

While hydrogen can be generated through multiple processes, it is predominantly (about 95 percent) made by the thermal processing of natural gas. There are several major barriers to its wider adoption of this process – cost being one – but as uses for its clean generation are explored, electrolysis and renewables are the key pathways.

The most common form of hydrogen production is natural gas reforming, occasionally know as steam-methane reforming, as it uses high temperature steam. When exposed to steam and heat, the carbon atoms of methane are separated, later reformed separately to produce hydrogen and carbon dioxide through an operation that requires natural gas. Hydrogen fuels produced from these sources will not meet the International Maritime Organization's (IMO) 2050 GHG goals for emissions reductions. However, it is also possible to reform renewable liquids such as methanol.

The process of charcoal gasification (which can also use biomass) predominantly requires carbon and water. When burned in a reactor at a very high temperature (1200-1500°C), the charcoal releases gas that separates and reforms to produce hydrogen and carbon monoxide.

Hydrogen also can be produced using electricity, through the electrolysis of water. An electric current is used to split water into oxygen and hydrogen. This method is comparatively less emissions-effective when it is powered by fossil fuels. But when electrolysis is powered by renewable energy it is the best solution, offering a near zero carbon footprint (other than the carbon produced to manufacture renewable energy technology, such as photovoltaic cells, etc.).

Other electrolysis-related processes being explored, include: ‘high temperature water splitting,’ which uses heat generated by solar concentrators or nuclear reactors to create chemical reactions that split water to produce hydrogen; ‘photobiological water splitting’, which uses microbes, such as green algae that consume water in the presence of sunlight, producing hydrogen as a byproduct; and ‘photoelectrochemical water splitting’, which uses photoelectrochemical systems to produce hydrogen from water, using special semiconductors and energy from sunlight.

APPLICATION

In its current limited application as a marine fuel, hydrogen is either used to generate power by combustion in piston engines or gas turbines, or it is used directly as a fuel for fuel cells.

INTERNAL COMBUSTION ENGINES

Hydrogen is used as a fuel in internal combustion engines. However, compared to its use in fuel cells, it has much lower efficiency. It is normally combined with carbon-based pilot fuels, increasing the net emissions. It is a clean burning alternative, and the related technologies will continue to be researched as a replacement for fossil fuels.

FUEL CELLS

The most common type of hydrogen fuel cells is the Proton Exchange Membrane. However, there are many other types, details of which can be found in the ABS *Advisory on Hybrid Electric Power Systems*.

CHALLENGES

STORAGE

Hydrogen is stored as a compressed gas or a liquid, and advancements in related storage technology are a key to its greater adoption as a marine fuel. In gas form, storage requires high-pressure tanks, and its low volumetric density makes those units large (about four times the size of conventional fuels), heavy and difficult to accommodate. In liquid form, the tanks can be smaller, but they need to withstand cryogenic temperatures of -253°C. Leakage in enclosed spaces can quickly cause asphyxiation, so storage systems need their design and application to consider the appropriate materials, ventilation and leak detection.

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The heating value of hydrogen is the highest of all potential fuels but its energy density per volume, even when liquefied, is significantly lower than that of distillates. To create the same energy content as diesel, for example, requires about 4.1 times the volume of hydrogen. Currently, the compressed or liquefied storage of pure hydrogen may appear practical only for small ships, but engine manufacturers are currently exploring technologies that could support its use in ocean-going vessels.

TRANSPORTATION

The transportation of hydrogen poses similar challenges to its storage. Its smaller molecules make it more prone to leaking and, along with its flammability, can make transportation difficult. While assessments of many options are ongoing, the development of effective transportation and logistics to support its delivery are key to its adoption as a marine fuel.

REGULATIONS AND STANDARDS

While the use of hydrogen as a marine fuel is covered in the IGF Code, at this nascent stage of its application as a marine fuel, the IMO currently is not developing hydrogen-focused requirements. As a fuel, it will be treated as an alternative design under the IGF Code and require an equivalent review.

LEAKAGE/HAZARD

As hydrogen is comprised of the smallest molecules, containing them is a technical challenge. It exhibits high permeation through the walls of its container, which means any systems need to anticipate leakage and their designs need to emphasize ventilation and space configuration. Leakage forms heavy condensation, which create fire hazards and, in liquid form, it makes steel structures brittle.

RENEWABLES VS STANDARD PRODUCTION

The standard energy intensive production of hydrogen from hydrocarbons reduces the net GHG reductions from its use; a transition to renewable sources would gain the full benefit of hydrogen.

ECONOMIC FEASIBILITY

Hydrogen production and processing techniques are energy intensive, potentially creating more net GHG emissions than burning fossil fuels. A transition to renewables and the development of additional technologies would make hydrogen more feasible.

PUBLIC AWARENESS

Because hydrogen has explosive properties and other safety issues, public concern may have to be managed.

GHG PERFORMANCE

The combustion of hydrogen is carbon-free and, when synthesized from renewable power, it is almost a carbon-free process, with water and electricity the main products of its use in fuel cells. However, when produced by standard methane reformation, net carbon production can be worse than traditional fuels.

SAFETY

Key safety challenges include assuring its safe containment, identifying the risks to personnel and the hazards associated with the ships' physical layouts, operations and maintenance. Containing and transporting hydrogen has considerable safety implications for onshore and offshore personnel. Asphyxiation and explosion are among the high profile risks.

For the user, significant work will need to be done to assess the hazards associated with physical layout, operations, maintenance, transfer and carriage of the fuel at scale. Onboard ventilation, alarm systems and fire-protection strategies – and other measures to limit the likelihood and consequence of leakage – will need to be designed-in to hydrogen-dedicated assets after extensive risk assessments.

BIOFUELS

Biomass is a renewable fuel source, the use of which for marine fuels can be considered a carbon-neutral way of generating energy because the organic matter used to produce biofuels roughly absorb as much carbon dioxide (CO_2) during their lifetime as they release when burned. Biofuels are produced from organic matter that is largely unsuitable for food or feed, however, their potential to reduce the amount of arable land earmarked for normal food production is a concern.

Some types of biofuels support greenhouse gas (GHG) reduction but, ultimately, they may not be 'cleaner' fuels in terms of nitrogen oxide (NOx), sulfur oxide (SOx) and particulate matters. A recent report by the International Transport Forum (ITF) found that standard methods of producing biodiesel, for example, can reduce GHG by 70-80 percent, compared to conventional fuels due to the amount of carbon absorbed in growing the feedstock. But they produce slightly more NOx emissions due to the higher oxygen content.

There are questions about whether biofuels can fully meet future demand, with conservative estimates used by the ITF implying that these types of fuels may be able to power only a limited portion of the global fleet.

TECHNOLOGY

First Generation: Biofuels rely on food crops as feedstock – including corn, soy, sugarcane, starch, vegetable oil, animal fats and bio-waste – which are processed to produce oil. The most common biofuels include biodiesel, biogas, bio-alcohols, syngas and vegetable oil.

However, demand for viable food and arable land is expected to intensify in line with forecasts for global population growth (60 percent from 2000-2050, to about 9.8 billion, according to the U.N.). Proposals to reduce the production capacity of first generation biofuels – Europe, for example, has regulations set to enter force in 2020 that will limit to 7 percent the proportion that can be made from food stock – will influence industry uptake.

Second Generation: Biofuels are produced from lignocellulose biomass – plant dry matter composed of cellulose, hemicellulose and lignin – such as switchgrass, trees, bushes and corn stalks. They are known as 'advanced biofuels' due to improvements in processing technology, which include thermochemical and biochemical fuel-producing treatments.

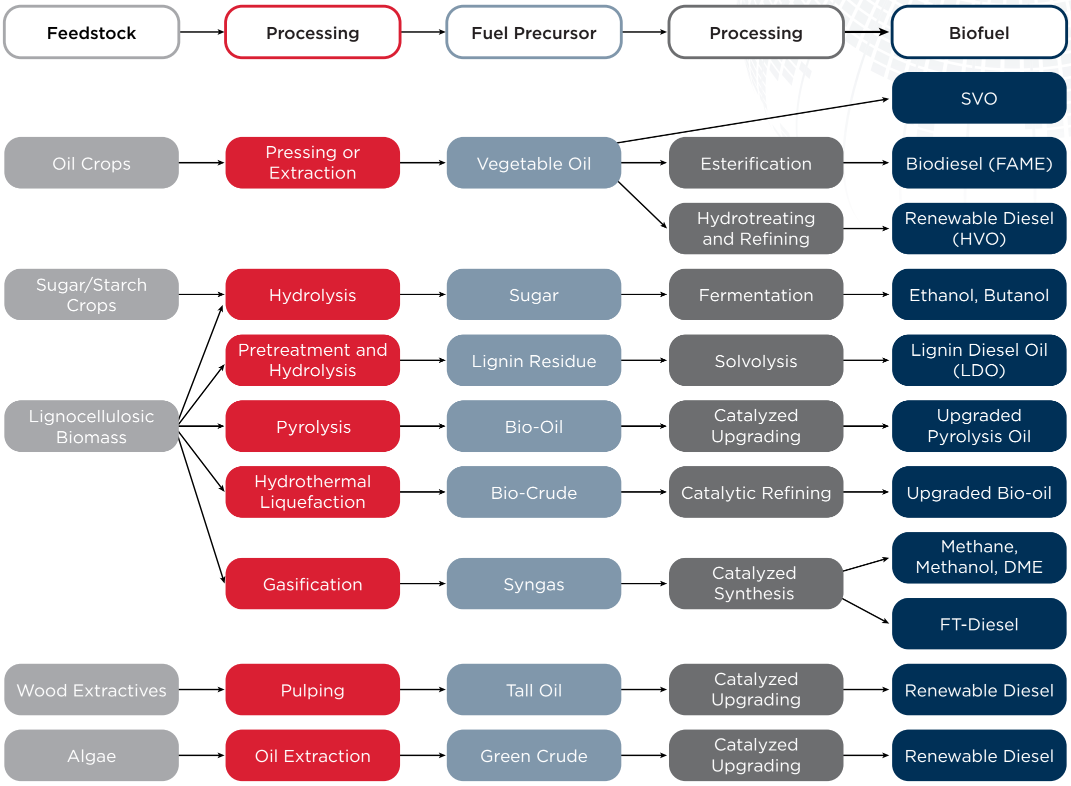
Third Generation: Biofuels are produced from algae, which is capable of higher yields with lower resources than other feedstock. Biodiesel, butanol, gasoline, methane, ethanol, vegetable oil and jet fuel all can be produced from algae. Most of the related activities remain at the research stage.

Fourth Generation: Unlike biomass derivatives, production of these biofuels – such as electro and photo-biological solar fuels – do not compete for the arable lands required to produce food.

APPLICATION

Biofuels are already used for transportation, power generation and heat. Extensive research has explored the potential of bio-refineries and various feedstocks; onboard testing has examined blending bio and fossil fuels, a mixture known as 'drop-in' fuels, which limit potentially expensive modifications to processing equipment and engines.

In the latest specification, ISO8217 (2017) recommended limiting the proportion of fatty acid methyl esters (known as FAME) in distillate fuel oil blends to 7 percent, creating the first industry standard for fuel oil with a provision for biofuel. With some ports offering incentives for low carbon fuels, a few companies are currently exploring the viability of shifting vessels to biodiesel.



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CHALLENGES

There is minimal experience and data attesting to the safety and reliability of biofuels. Other obstacles are listed below. Over time, some of these challenges may fade as the technology advances to reduce production costs.

STORAGE

Biofuels tend to oxidize and degrade (over a few months) during storage. They degrade faster in water, a fact that has positive effects for oil spills, but negative ones for long-term storage. The degradation of biodiesel can produce highly corrosive hydrogen sulfide, which corrodes metals, including steel storage tanks.

Biofuel blends are susceptible to microbial growth, partly because of the biodegradable nature of B100 biodiesel (100 percent biodiesel). Proper draining of the tanks is advised (at least twice a day) to minimize water and sludge build up, and to reduce the risk of creating conditions that favor microbial activity

B100 (100 percent biodiesel) has the tendency to form wax at a greater rate than conventional diesel oil fuels, so storage temperatures need to be watched closely; a good practice is to keep the temperature 10°C above pour point and to locate fuel tanks away from the colder regions of the ship.

FUEL PROPERTIES

For biodiesel, fuel lubricity, conductivity and corrosion are areas of concern. Due to oxidation, it tends to lose lubricity over long periods of time, which may cause wear on essential components. Because electrical conductivity can cause static charges, it is likely to need anti-static additives. Corrosion can weaken steel holding tanks and pipelines over time, compromising storage and transportation.

Biofuels with high acidity can cause increased wear on engine components, so the engine manufacturer should be consulted when the operator is considering using FAME in a conventional engine.

Special attention should be given to Common Rail injection systems due to the frequent heating and cooling cycles of the recirculated fuel which favor water build-up. In general, engine manufacturers should be contacted before using biofuels.

Properties and Indicative Prices

Properties	HFO	MDO	LNG	FAME	HVO	Ethanol	Methanol
Heating Value (MI/kg)	39	43	48	38	43	27	20
Sulfur (% m/m)	<3.5	2	0	0	0	0	0
Price (USD/Mt)	290	482	270	1040	542	503	464

COST

The relatively complex process of producing biofuels can increase the cost. Currently, their production cannot compete with fossil fuels; even first generation biofuels such as palm, soybean and rapeseed are relatively expensive and of limited availability.

PRODUCTION

Producing biofuels of any generation can require different chemical reaction and refining processes, as well as varying feedstocks. Common reaction processes are often applied, rather than those designed specifically for the industrial creation of biofuels. With many feedstocks and production processes, testing and standardization is required.

AVAILABILITY OF FEEDSTOCK

Feedstock competes for increasingly limited agricultural resources, and biofuels would need to be produced at an industrial scale to meet the needs of global shipping. As it is not mass produced, the supply of biomass could be unreliable, geographically limited and cyclical, depending on environmental conditions.

As demand for food security grows, questions about the appropriate uses for feedstock and agricultural resources could escalate. Other related issues include: genetic engineering, water availability and pollution, fertilizer effects and biodiversity.

GHG PERFORMANCE

Burning biofuels, which have similar properties to fossil fuels, potentially provides a net reduction in CO_2 output because producing biofuels is a comparatively less carbon-intensive process. Biomass such as wood, however, typically produces more greenhouse emissions for the same amount of energy as equivalent fossil fuels.

The sulfur content of biofuels is very low, complying with 2020 requirements and potentially removing any demand for exhaust gas cleaning systems.

Therefore, using certain biofuels as an alternative to fossil fuels can slow the effects of GHGs, but it is very unlikely to eliminate or reverse any damage

SECTION 3 | OPERATIONAL, DESIGN AND FUEL SOLUTIONS

CARBON CAPTURE AND SYNTHETIC FUELS

As the maritime industry charts a course towards lower carbon shipping, some influential energy mix forecasts project the continuation of a prominent role for carbon-based fuels in the medium term. If accurate, this suggests that marine applications for carbon capture and storage (CCS) technology and synthetic fuels will need to be developed more rapidly to meet the International Maritime Organization's (IMO) greenhouse gas (GHG) goals for 2030 and 2050.

CARBON CAPTURE

Carbon capture involves the collection, transportation and storage of carbon dioxide emissions. The technology itself is considered an alternate low carbon solution. It captures carbon dioxide (CO_2) from the combustion of carbon-based fuels (used in power generation, at industrial plants, etc.) and manages the emissions from those sources by separating the CO_2 from other substances created by combustion.

The capture can occur before or after combustion. Pre-combustion processes generate hydrogen and CO_2 from carbon-based fuels (solids, liquids and gas) through a process that is similar to the reforming process used to generate hydrogen for use in fuel cells (see Page 47).

The post-combustion process separates the CO_2 from the other combustion products by using solvents or catalysts, filtering and other separation methods that absorb CO_2.

CROSS-INDUSTRY APPLICATIONS

In power and industrial plants, the option selected for transportation and storage is based on the amount of available space. CO_2 has been safely transported and used by many industries for decades and can be moved by ship, truck or pipeline.

Currently, for permanent storage, a safe and suitable underground location is required. The process of injecting CO_2 is well established in the offshore industry, where it is used for enhanced oil recovery. To maximize absorption, storage locations are selected on the basis of depth, pressure and temperatures.

In general, regulations and policies for CCS are mostly in development, with Europe being a notable early adopter. The European Union's CCS Directive on Geological Storage of Carbon Dioxide came into force in 2009, providing regulatory requirements for storage.

The U.K. Department of Energy and Climate Change also has projects in motion to support the relatively new technologies and, in the U.S., the Environmental Protection Agency (EPA) is working on developing regulations to track national CCS activity and ensure safe practice.

MARINE CARBON CAPTURE TECHNOLOGIES

It is possible to deploy carbon capture technologies onboard vessels; the same post-combustion options exist for absorbing or filtering the CO_2 from the exhaust gas. It can be captured onboard, stored and transferred to shore to produce more fuel.

The challenge in the marine environment is the handling and storage of any CO_2 that is captured. This process would require significant space for CO_2 in gaseous form and significant power when it is being cooled and liquefied for storage.

Another challenge for any ship would be in transporting the CO_2 to its final location. This would require the ship to have a system to discharge the CO_2 at port facilities, from where it could be transported for final storage.

SYNTHETIC FUELS

Synthetic fuels' is a term that applies to any manufactured fuel that is comparable in composition and energy to natural fuels.

The primary process for developing renewable synthetic fuels is to combine hydrogen (produced by water electrolysis) and a carbon source (from biomass, or captured CO_2). The product, synthesis gas (syngas), can be converted into different forms of fuel.

The primary purpose of this fuel type is to provide a carbon-neutral fuel source. The carbon captured to create the fuel offsets any CO_2 emissions from the combustion process.

Synthetic fuels are only carbon neutral when they are generated by using power from renewable sources. The manufacturing process is very expensive and labor-intensive, but the technology continues to develop, which will help to reduce the cost and promote opportunities for future fuels.

At present, there have been no reports of renewable synthetic fuels being used in marine applications. A key benefit of their use is that modifications required to the existing vessel equipment and systems would be minimal.

SECTION 3 | OPERATIONAL, DESIGN AND FUEL SOLUTIONS

FUEL CELLS

Fuel cells use a chemical process to convert fuel into electricity and, unlike batteries, they do not need to be recharged, producing electricity as long as there is a fuel source. They consist of a negative electrode (anode) and a positive electrode (cathode), an electrolyte, a fuel and oxygen (air) system, electrical terminals and ancillary devices.

Although hydrogen is the most commonly used fuel in fuel cells, methanol and ammonia are viable alternatives. A fuel such as hydrogen is fed to the anode side and air is fed to the cathode side. At the node, a catalyst separates the hydrogen molecules into protons and electrons. A proton exchange membrane directs protons to the cathode.

The electrons go through an external electric circuit to power a load, while the protons travel through the electrolyte to the cathode, where they unite with oxygen (air) and electrons to produce heat and water.

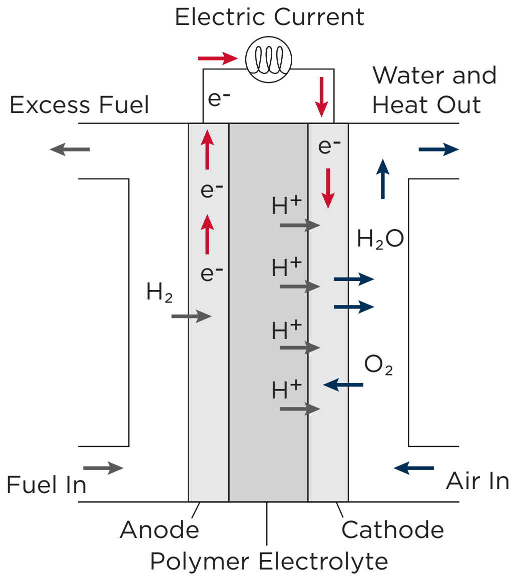


Image Courtesy of Woodbank

Typical PEM Fuel Cell

While there are a number of government-funded initiatives to develop vessels powered by fuel cells, adoption of the technology is expected to be limited for the following reasons:

- The capital costs are comparatively high; government funding and incentive programs are currently required to make the technology viable
- Bunkering infrastructure needs to be developed; access to hydrogen is limited, while methanol is more widespread
- Hydrogen and methanol require significant storage capacity on board a ship
- Fuel input needs to be renewable to maximize emissions savings

Given these limitations, fuel cells initially may find use as a supplementary, rather than a primary, source of energy for shipping.

TECHNOLOGY

The main difference among fuel cell types is the electrolyte, and they are generally classified accordingly.

Proton Exchange Membrane (PEM) Fuel Cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum-alloy catalyst. They need only hydrogen, (airborne) oxygen and water to operate and are typically fueled with pure hydrogen supplied from storage tanks or reformers (a device that extracts pure hydrogen from hydrocarbon or alcohol fuels).

PEM fuel cells operate at relatively low temperatures, typically less than 120°C (248°F) and usually use a noble-metal catalyst (platinum) to separate the hydrogen's electrons and protons.

Alkaline Fuel Cells (AFC) use a solution of potassium hydroxide in water as the electrolyte and a variety of nonprecious metals as catalysts at the anode and cathode. They operate at temperatures between 100°C and 250°C. The fuel supplied to an AFC must be pure hydrogen, as CO_2 can reduce fuel-cell performance.

Phosphoric Acid Fuel Cells use liquid phosphoric acid as an electrolyte that is contained in a Teflon-bonded silicon-carbide matrix, and porous carbon electrodes containing a platinum catalyst. They operate at temperatures between 150°C and 220°C and are comparatively more tolerant of the impurities from fossil fuels that have been reformed into hydrogen.

Molten Carbonate Fuel Cells are high temperature fuel cells that use an electrolyte composed of a molten carbonate-salt mixture suspended in a porous, chemically inert, ceramic lithium-aluminum oxide matrix.

They operate at 600°C to 700°C and do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. Because they operate at high temperatures, methane and other light hydrocarbons in the fuels are converted to hydrogen within the fuel cell by a process called 'internal reforming'.

Solid Oxide Fuel Cells use a hard, non-porous ceramic compound as the electrolyte. They operate at 650°C to 1000°C, precluding the need for a precious-metal catalyst such as platinum. They reform fuels internally, which allows the use of a variety of fuels such as natural gas, biogas and gases made from coal.

APPLICATION AND CHALLENGES FOR MARINE USE

Hydrogen fuel cells have been successfully deployed on naval submarines equipped with liquid hydrogen and/or oxygen fuel cell systems; some applications also have been completed for ferries and small vessels.

From an electrical perspective, the use of a fuel cell is sufficiently advanced to be readily deployed in the marine environment; power electronic converters are readily available to connect the fuel cell to AC or DC electrical networks, and can be programmed to provide voltage, frequency regulation and load sharing. Their power output ranges from kilowatts to multiple megawatts, and they can be integrated to provide more power.

There are no maritime regulations providing prescriptive requirements for fuel cell installations. Reviews for marine and offshore installations are primarily risk-based studies in combination with IMO regulations, IACS requirements and industrial standards relevant to the specific design and configuration of the system. The IGF Code is being revised to address requirements for fuel cell systems.

CHALLENGES

INCREASED COST

Fuel cell systems can be two to three times more expensive than internal combustion engines. At present, they are mostly hand assembled and require expensive catalysts such as platinum. However, mass production is becoming more common, as is the use of less expensive catalysts, and it is expected that prices will decrease as more units are sold.

INCREASED WEIGHT

The combined weight of the fuel cells, support systems and fuel storage is presently greater than that of a comparable combustion engine system. However, fuel cell systems are generally lighter than comparable battery systems.

INCREASED COMPLEXITY

Fuel cells require complex support and control systems. The support systems can include vaporizers, reformers, fuel purifiers, pumps, heat exchangers and power conversion equipment.

Unfamiliarity with non-traditional fuels, concerns about safety, volatility and hazardous areas increase the complexity, as does the fact that fuel cells have a relatively slow dynamic response that may require the integration of energy storage to serve large dynamic load changes.

BUNKERING AVAILABILITY

Bunkering stations for gaseous and liquid hydrogen or other hydrogen sources (LNG, methanol, ammonia, etc.) are limited, so these fuels often need to be transported to the site. The production and distribution networks for fuels to power fuel cells will need to develop before they are widely accepted by the marine industry

GHG REDUCTIONS

Fuel cells provide zero emission power at the point of use, but they can have multiple feeder fuels.

Depending on the type of fuel cell, reformation – the process of extracting pure hydrogen from hydrocarbon or alcohol fuels – is required prior to introduction of the fuel cell or internally.

With hydrogen as a fuel source, they are carbon-free (when synthesized from renewable power), with water and electricity the only byproducts. With most other feeder fuels, the carbon footprint of using fuel cells for marine power will grow.

SAFETY

Fuel management, identifying the risks to personnel and managing the hazardous areas associated with the ships' physical layouts, operations and maintenance are all key safety challenges with fuel cell systems. Toxic exposure, asphyxiation and explosion are among the higher profile risks to crews.

Hydrogen, methane and other gaseous fuels that are lighter than air (propane is heavier) need special ventilation arrangements to prevent the creation of hazardous areas. For many types of fuel cells, the non-hydrogen supply is externally reformed to hydrogen and other byproducts prior to introduction into the fuel cell, so the hydrogen portion of the fuel system (from the reformer to the cell) needs special consideration.

Another challenge is in recognizing the safety requirements for the intake and exhaust, including airflow and allowable backpressure.

BATTERIES

Energy storage systems (ESS) help ships to store excess energy for later use, supplementing or replacing the onboard generators currently powered by fossil fuels. The main types include electrochemical (such as lithium-ion batteries, presently the most popular advanced storage technology in the marine industry), electrical (supercapacitors) and mechanical (flywheels).

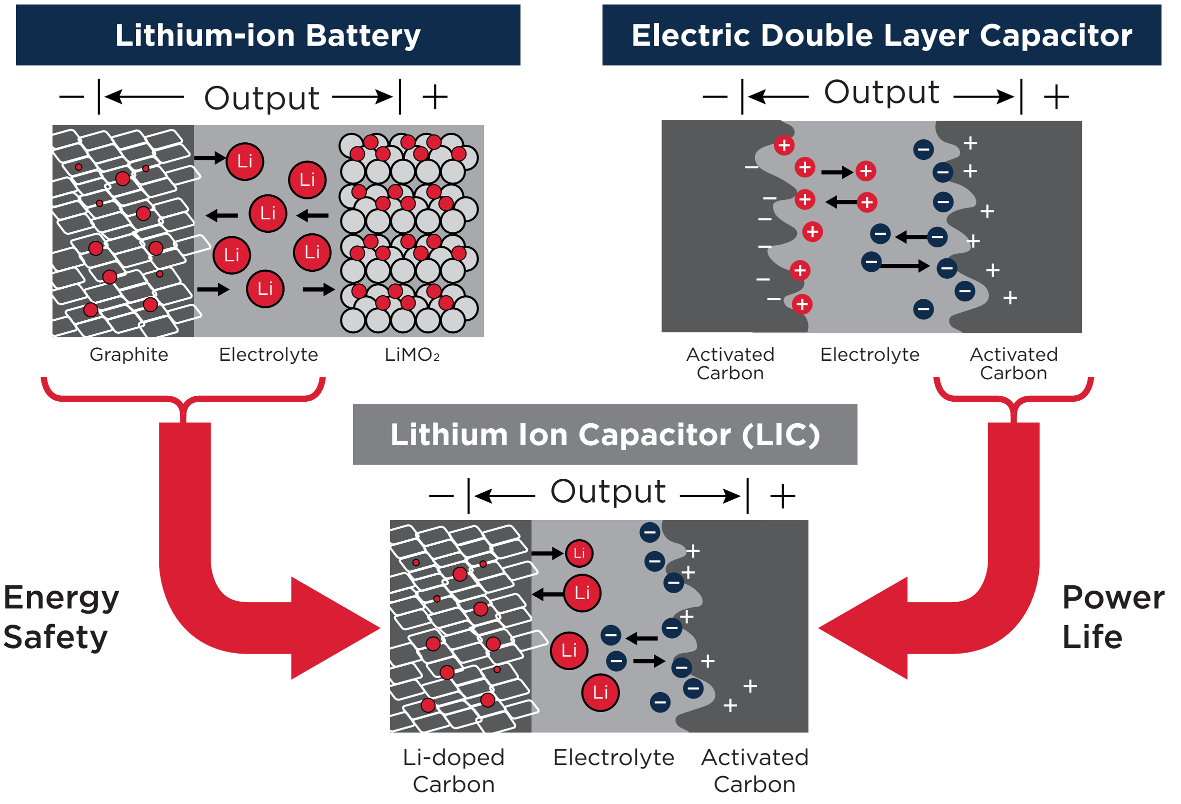
Currently, only batteries are widely used in marine applications and, even then, they are only used as a primary power source on small vessels undertaking very short voyages. While the technology is continually improving, its cost, weight, space requirements, recharge times and endurance ranges may prevent its use in the medium term on all but runs of less than a day.

TECHNOLOGY

Using any form of ESS adds capital costs for energy storage units (cells, modules and packs), cooling units, transformers, power converters, custom cables, control and monitoring devices.

Generally, the technologies differ in how they store energy, the speed of the charging or discharging processes, the storage capacity per charging period, the number of charging or discharging cycles before deterioration, and how long the energy can be retained.

Lithium-ion batteries are a rapidly evolving technology that can collaborate with other intermittent green energies (wind and solar) and conventional fuels to provide a flexible and robust power generation plant with a smaller carbon footprint.



Lithium-Ion Capacitor Construction

Image courtesy of JSR Micro, Inc.

The main element of a lithium-ion battery system is the lithium-ion cell, where an electrochemical reaction absorbs and releases energy. These batteries offer zero hydrogen gas emissions compared to other battery types, as well as higher energy density (less weight and space requirements), reduced maintenance and lower internal resistance (higher efficiency) than other energy storage options.

They can be charged and discharged many times over their lifespans (about 10 years), depending on operational profiles and environmental conditions.

Supercapacitors store energy in an electric field, the volume of which is directly related to the materials used for the electrode, their construction and arrangement. Their commercial application is relatively new and made possible by the development of the electrode materials.

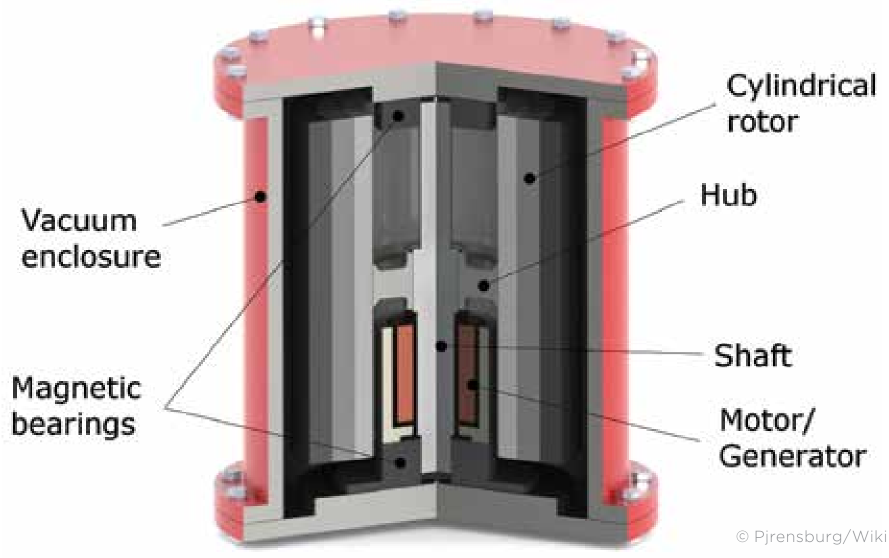
They can be more efficient than batteries because of their significantly higher power density, faster charging and discharging processes, and more numerous cycles, making them suitable for fast delivery of the high or 'pulse' power required by bow thrusters, starting generators or motors and offshore heavy lifting.

A flywheel is a rotating assembly that consists of an energy storage unit (the flywheel) and a mechanical or magneto-electric energy converter. Energy is stored in the rotating assembly in a kinetic form. No commercial marine vessel currently has a flywheel ESS installed. But the technology may have a potential application in heave-compensation systems on drilling units.

Generally, advanced energy storage technologies – predominantly lithium-ion batteries – are gradually replacing conventional batteries (lead-acid, nickel-cadmium and alkaline, etc.). The former have no flammable gas emissions during normal operation, overwhelmingly higher energy density (reducing weight), much higher specific energy (reducing carbon footprint) and considerably longer shelf lives.

APPLICATION

At their current energy density, ESS have yet to replace internal combustion engines on long-range vessels. However, they are the sole source of power for local ferry runs and research ships that regularly navigate in emission control areas.



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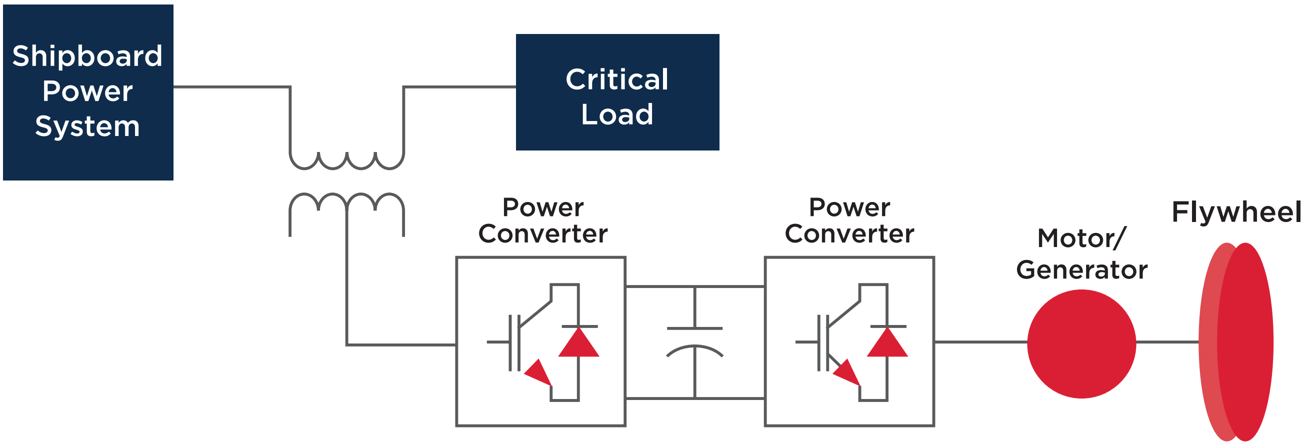
Cross-Section of a Typical Flywheel Enclosure



Basic Circuit of a FESS

In hybrid applications, they play a supplemental role to diesel engine-driven dynamic positioning systems and increasing power response – reducing noise and simplifying maintenance. The hybrid applications that perform auxiliary functions for conventional engines – i.e., for running deck equipment while at port, or to support sudden fluctuations in power requirements – have proportional greenhouse gas (GHG) benefits.

ESS are zero-emission, energy-saving technologies that can reduce the marine industry's reliance on internal combustion engines as environmental regulations strengthen. They offer flexibility in that they can be recharged from onshore or from surplus power produced by a ship's generators at sea.

CHALLENGES

The sizing of the ESS is critical for each ship and is dependent on its operational profile, anticipated power demand, schedule, range, the system's maintenance costs, weight and volume, and the emission-reduction target.

COST AND SCALE

The balance between energy-saving performance and investment needs to be carefully assessed; for vessels solely powered by battery systems, the installation cost is heavily influenced by the number of batteries required.

Any ships designed for conventional power, transmission systems and fuel tanks may have inadequate space for the batteries, auxiliaries and machinery of an electric propulsion system. Their hull structure may need to be redesigned and stability recalculated to reflect the new location and weight of the battery systems.

In small ships, such as ferries, the application of ESS lithium-ion batteries has proven more popular because the length of the voyages are limited and they operate in standard port infrastructure.

Larger vessels may have more space to accommodate batteries but, due to their longer voyages, the size of the battery storage can impose limitations on their ability to carry full cargo volumes, compared to conventionally powered vessels.

For hybrid applications where ESS provide supplemental propulsion power, battery costs can be cut correspondingly and, in line with its operating profile, plans to size the main electrical plant should be similarly modified.

OPERATIONAL ISSUES

When the batteries are being charged, the ship's AC power distribution system may not be efficient for the energy transfers between the ESS and the electric grid.

New technology for distributing direct current may need to be introduced to the electric propulsion system to integrate the ESS with any renewable energy and to help the prime mover operate efficiently. This may require a complete redesign of some equipment, and way the system is protected.

When power and battery recharging are supplied at port, the shoreside infrastructure may need to be upgraded to suit the new arrangement onboard.

TECHNICAL CHALLENGES

Technical Challenges for Lithium-ion Batteries	Technical Challenges for Supercapacitors	Technical Challenges for Flywheels
• Complicated Monitoring and Protection Circuits • Aging • Temperature Sensitivity • Thermal Runaway	• Low Energy Density (Can only supply high power for short time period which is not suitable for long duration loads) • High self-discharge rate	• Design issues related to a dynamic shipboard environment (vibration and unpredictable movement) • High self-discharge rate

Technical Issues of Energy Storage Systems

GHG PERFORMANCE

Carbon dioxide (CO_2), nitrogen oxide (NOx) and sulfur oxide (SOx) are reduced when using full electric (battery) and hybrid (battery and diesel) configurations. The energy efficiency of electric propulsion systems – including gearbox and shaft losses – can exceed 90 percent, compared to about 40 percent for conventional propulsion with diesel engines.

Reports suggest that explorer-class vessels, designed for cruising in the Arctic and Antarctic areas, have the potential to reduce fuel consumption by up to 20 percent, including a 30-minute voyage operating with full battery propulsion; the consequential decrease in CO_2 emissions has been estimated at 6,400 metric tons per year.

SAFETY

Lithium-ion batteries will not generate the hydrogen gases that lead-acid batteries do during normal operation, but their internal structure and the cell's electrode materials can short circuit when overcharged or discharged for long periods, or when they are damaged.

The thermal runaway from lithium-ion batteries is a severe fire hazard. Any spilled electrolyte may compromise the ship's structural strength, and the vapors are toxic. While safer electrode materials are continuously being discovered, specifically designed thermal management, firefighting and ventilation systems are required.

Although ESS standards for marine applications continue to mature, ABS has published several Guides to address these technologies.

SOLAR

Developments in solar-module technologies are encouraging the integration of solar energy into many applications that were previously considered uneconomical. The maritime industry has been mainly focused on deploying this technology on smaller vessels, but the use of photovoltaic (PV) solar technology in larger ships is slowly gaining consideration and is seen as one of the viable pathways to reducing the greenhouse gas (GHG) contribution from shipping.

The unit price of PV modules has fallen consistently over the past decade (80 percent, according to the International Renewable Energy Agency [IRENA]), while the efficiency of PV cells has increased significantly (up to 39 percent) over the same period.

TECHNOLOGY

Photovoltaic cells typically consist of one or two layers of a semi-conducting material, usually silicon. When light is projected onto the cell, an electric field is created across the layers that produces DC voltage at the solar panel's terminals; the greater the intensity of the light, the more voltage that becomes available.

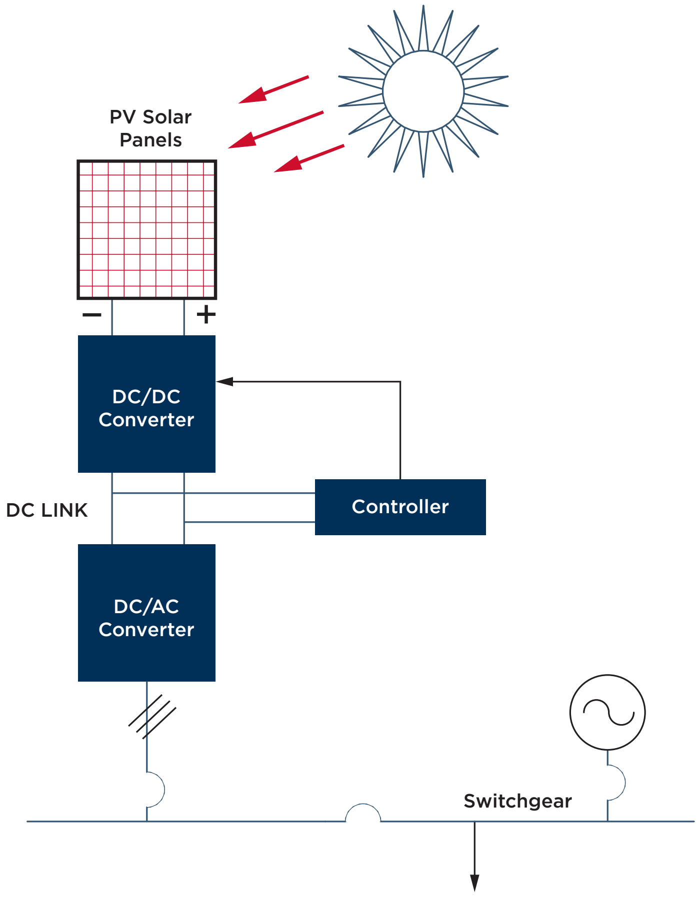
PV cells are often referred to in terms of the amount of energy they convert in full sunlight conditions, this is known as kilowatt peak.

The solar cell is the fundamental building block of solar PV technology. Cells are wired together to form a module, or panel, and the panels are joined together to form a PV solar panel system.

A power electronic converter is often placed between the solar panel and the load to stabilize the voltage delivered from the PV modules. In some cases, the converter will perform a DC/DC conversion; in others, it acts as an inverter, a specialized converter that converts DC power into alternating current, or AC power.

Typical marine installations will need a hybrid genset, PV modules and energy storage (typically, a battery) working together in an integrated system to improve the performance of the vessel's electric power system.

PV Solar Power Generation Operation



APPLICATION

Large-scale solar panel installations on vessels so far have been limited to yachts and sailing boats to cover small 'hotel' loads, lighting and instrumentation equipment. The standard power production from PV a system is 100-200 watts per square meter, but technologies are becoming available to improve this rate.

For large commercial vessels there have been a few installations, which were technically similar. Due to the power loads required by commercial vessels, solar systems will need larger areas for deployment. Due the physical constraints of the conversion apparatus, solar power on larger ships has been limited to assisting power plants (gensets), feed loads during harbor operations and short voyages.

Some examples of recent solar adoption include:

Auriga Leader: A hybrid car carrier with solar power generating 0.05 percent of the propulsion power and 1 percent of its electrical usage (see picture below)

Emerald Ace: A hybrid car carrier with solar panels and 2.2MWh of lithium-ion batteries, enabling generator-free port stays

Planet Solar: A solar-powered 31 m yacht equipped with 93kW of solar panels (537m^2) and 8.5 tons of lithium batteries. It circumnavigated the globe in 2012

Blue Star Delos: A ferry with a solar panel array used to investigate viability

CHALLENGES

The application of PV Solar technology on commercial ships has physical challenges and some related to the marine environment, including:

The regions of operation are likely to be limited to areas where the radiation from solar energy is optimal. However, PV tracking technology is extensively used for land applications and could be adopted to enhance the performance of solar energy systems on vessels.

Image courtesy of NYK Line

© Kingtony/Shutterstock

Adverse environmental conditions such as humidity, shading, corrosion problems (including salt deposits on the panels) and wind are issues faced by PV system technology.

The limited deck space for PV arrangements on most ships keeps the potential aggregate power output low (average ~150W/m^2), even with the technology's latest advances. At present, this confines its suitability to smaller vessels.

PV systems offer a comparatively low power contribution. Due to the low power output of present solar energy technology, the installation of PV cells would require the integration of storage systems to improve availability, potentially compounding space restraints and adding weight.

GHG PERFORMANCE

With power contributions from solar energy, the consumption of conventional fuel will drop, broadly in line with the amount of electric power generated by the PV system. With present solar technology, the bulk of the savings in CO_2 emissions mainly can be expected to come from lower fuel consumption during port stays, although a smaller proportion may be derived in transit.

Whether that will be enough to meet even the voluntary first-term targets for CO_2 reduction set by the IMO Energy Efficiency Design Index (EEDI) (10 percent per tonne-mile) will depend on factors such as the ships' deadweights, installed PV power capacities, operating modes, etc.

Consideration also will need to be given to the weight added by the new solar systems, including structural changes.

SAFETY

The potential effects of the added weight from the PV solar modules and support structure on vessel stability must be accounted for in the design stages especially for smaller vessels. Changes also may be necessary to ensure the continued efficiency in the operation of propulsion systems.

SECTION 3 | OPERATIONAL, DESIGN AND FUEL SOLUTIONS

WIND POWER

The wind's kinetic energy can be used to power energy conversion devices to provide propulsion, electricity or perform mechanical tasks. Wind-assisted propulsion differs from conventional applications in one fundamental way: the wind is used to supplement a ships propulsion and, accordingly, to reduce fuel consumption at a set speed. It is not yet used as the sole source of power for commercial ships.

The size of wind-assisted ship designs are restricted by the need for a large clear deck, minimal rigging, vessel stability and limitations on crew sizes, all of which can confine the potential thrust provided by the wind-harnessing equipment.

TECHNOLOGY

A **Flettner Rotor** is a large cylinder mounted vertically on the deck and mechanically (or electrically) spun. When wind meets the spinning rotor, airflow accelerates on one side of it and decelerates on the other. Fluctuations in the speed of the airflow produces different pressures, which create a lift force perpendicular to the direction of the wind flow. A controllable interior mechanism varies the direction of the force to direct the thrust of propulsion.

The **Kite Sail** concept involves a very large kite being deployed from the bow of the ship to create traction and help pull it. Alternatively, the kite also can extend and retract to generate electrical power.

Manufacturers of the technology say retrofitting the kite sail is a relatively low cost because the process causes minimal interference with the ship's structure. Some automated-deployment systems have proven problematic, but the computer controls can determine the ideal angle and position of the kite.

The **Towing Kite Sail** concept is like the kite sail except that it consists of two layers of fabric shaped as an airfoil to provide the traction (also generated by lift) that helps to pull the ship.

RIGID SAIL

A few Japanese merchant ships were fitted in the 1980s with rigid sails to reduce fuel consumption. This system was retrofitted to a small freighter to evaluate the fuel impact. The results of the study indicated a potential savings of between 15-25 percent of fuel consumption.

APPLICATION

The four technologies described above are available for production and have been offered for installation on vessels.

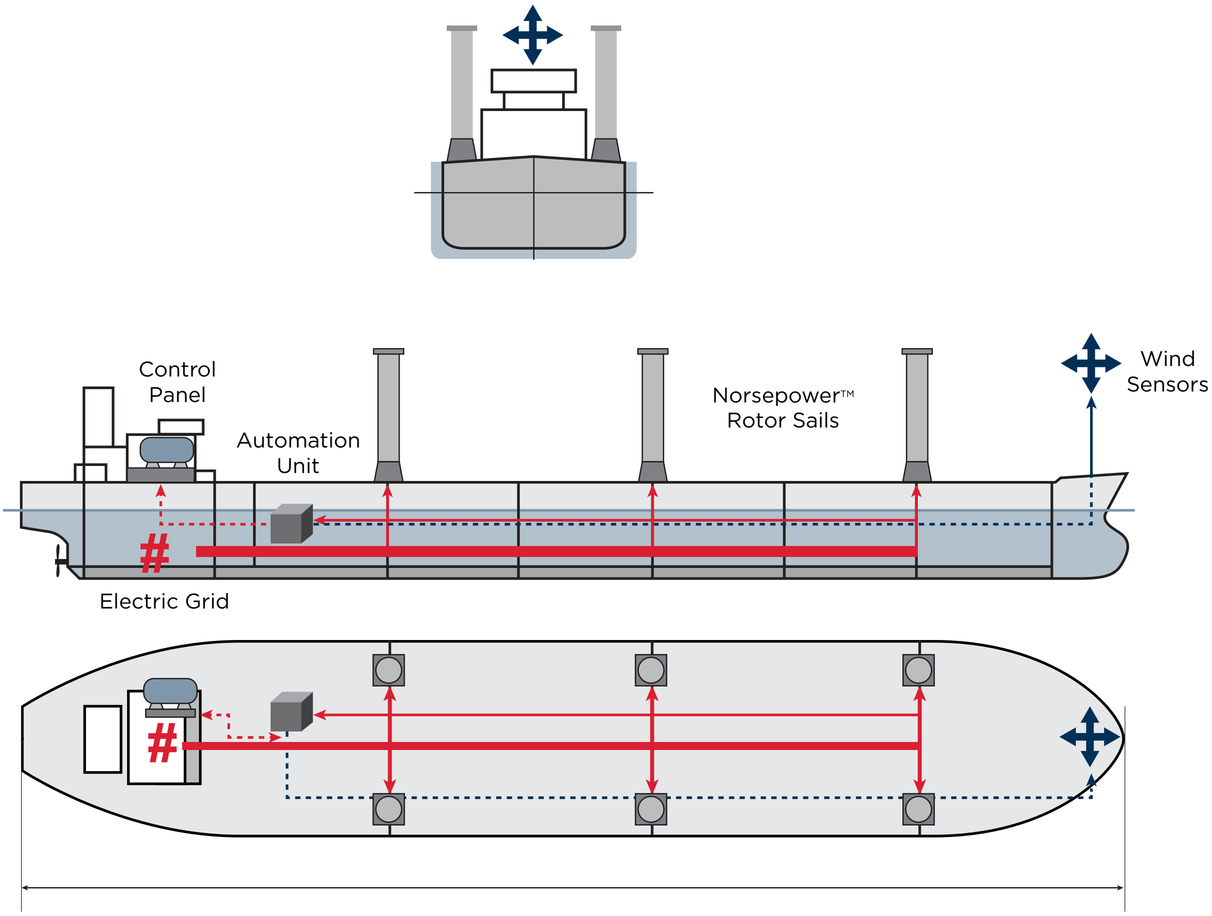
FLETTNER ROTOR

Flettner Rotors were demonstrated as early as 1926 with an Atlantic crossing but have seen limited use since. In 2010, a 9,700 dwt cargo ship was equipped with four Flettner Rotors to evaluate their role in increasing fuel efficiency.

In mid 2018, two Norsepower rotors were installed on a 109,647 dwt long-range product tanker owned by a European shipowner. Results from that project are pending.

Vessel Shin Aitoku Maru with rigid sails

Image courtesy of Bluebird



Flettner Rotor

© Norsepower

Because the only element of the technology requiring control is the rotation speed, the technology requires relatively little operator input.

Manufacturers say rotors are specifically suited to tankers, ro/ros, general cargo and bulk carriers and can be retrofitted to existing ships. The number and size of rotor sails required depends on the dimensions, speed and operating profile of each vessel.

KITE SAIL: SKYSAILS

This system has found recent use on several ships, with the most notable being *MS Beluga Skysails*, a merchant ship specifically designed with a kite sail system. On its maiden voyage during the first quarter of 2008, *Beluga Skysails* transited from Germany to Venezuela, the United States and back to northern Europe. In October 2008, it was chartered by the U.S. Military Sealift Command (MSC) to deliver cargo to the U.K.

The maker says they generate more propulsion power per square meter of sail area than conventional sail propulsion for two reasons: its autopilot's ability to navigate “dynamically” in figure eights in front of the ship increases the kite's airspeed in a multiple of the real wind speed; and operating the kite at altitudes from 100-500 meters gives it access to stronger and more stable winds than are available near the water's surface.

CHALLENGES

All these technologies have similar challenges due to the nature of wind-assisted propulsion, namely:

- Performance is dependent on external factors such as, geographic location, season, availability, wind strength and direction
- Issues with wind direction and vessel performance, upwind and downwind
- The electrical power load demands from the extra crew they require
- Maintenance and life expectancy of investment
- Availability of components for repair, and their potential for upgrades

GHG PERFORMANCE

The gains from the **Flettner Rotor** system come from the thrust force generated by the rotor sail, which allows the vessel to slow the main engine and reduce the fuel oil consumption, leading to a decrease in carbon dioxide (CO_2) emissions.

Trials aboard Bore's *M/V Estraden*, a 9,700 dwt ro/ro carrier, indicated a fuel savings of 2.6 percent using a single small rotor sail on the vessel's route in the North Sea between the Netherlands and the U.K. Based on those trials, the owner and sail-maker believed that a full system on *M/V Estraden* with two rotors could reliably deliver 5 percent gains in fuel savings.

TRACTION AND POWER KITES.

The thrust generated by the traction kite system allow the vessel to throttle back the main engine and reduce fuel oil consumption, leading to a decrease in CO_2 emissions.

According to the makers, the system is the same for all types of ships (400 m^2 kite area, about 2MW main engine equivalent in good wind conditions), giving savings of up to 10 tons of carbon a day in good wind conditions, and an average of 2-3 tons a day in suboptimal conditions.

SAFETY

In general, the three sailing technologies described here have been available for many years. Sky and rigid sails are subject to height restrictions when approaching harbors or in the presence of other vessels.

In anticipation of storms in the voyage areas, these systems must be secured so as to avoid or reduce the likelihood of damage to the systems, vessel or other nearby vessels, infrastructure, or injury to the crew.

During loading and unloading operations, they pose potential safety hazards due to the size of sails and the crew's familiarity with operations. Additionally, the change in vessel loading from the wind system need to be taken into consideration for stability based on vessel size and the type of wind installation.

SECTION 4 | CONCEPTUAL DESIGNS FOR 2030

FUTURE SHIP DESIGNS

If the shipping industry assumes that the International Maritime Organization's (IMO) carbon reduction targets for 2030 can be met using existing technology and available fuels, meeting the IMO's goals for 2050 still will require new fuels and technologies. Compliance will require new ways of thinking about research and innovation.

The current decision to halve total carbon emissions (against 2008 levels) by 2050 is destined to drive substantial demand for low and zero carbon fuels. Which fuel, and which technology, will win commercial favor is uncertain.

With that in mind, ABS worked with the Herbert Engineering Corporation (HEC) to specify design requirements for two state-of-the-art containerships with conventional technology, operational profiles and propulsion units that burn low-sulfur heavy fuel oil (LSHFO): one feeder ship (2,000 TEU capacity) and one Neo-Panamax (14,000 TEU).

Those fully assessed concept designs were then modified to create versions capable of running on hydrogen fuel cells and liquid biofuels. The end results seen below provide a window into what may be possible, using today's knowledge and technology, and extended to anticipate future development.

These designs would not be built today for commercial and technical reasons, but they could be built in 2030. Their schematics offer some insights into the limitations of today's technology, future fuels (by today's metrics) and what these designs may mean for criteria such as onboard arrangements, cargo capacity and propulsive power potential.

While the designs underwent a significant level of due diligence – including vendor consultations, etc. – they are aspirational and should in no way be seen as an endorsement of any fuel types, processes or methodologies.

THE BASELINE SHIPS

THE 2,000 TEU CONTAINERSHIP

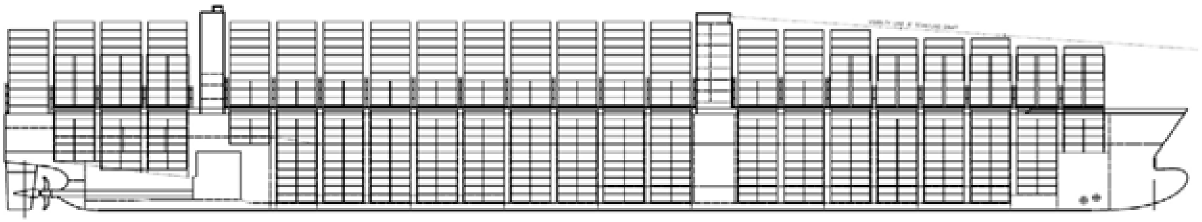
As you can see from the schematic below, the baseline ship has a conventional arrangement with a single directly connected internal combustion engine and conventional auxiliaries. It normally runs on LSHFO, without a scrubber, and marine diesel oil (MDO) in any environmental control areas (ECA).

The speed for the design draft and 85 percent maximum continuous rating (MCR) power, assuming 15 percent sea margin, is 18 knots. It employs state-of-the-art hull and propeller optimization.

THE 14,000 TEU CONTAINERSHIP

This overall design represents the current generation of Neo-Panamax 14,000 TEU carriers. It has a single directly connected engine with conventional auxiliaries and normally runs on LSHFO, without a scrubber, and MDO in any ECAs.

The speed for the design draft and 85 percent MCR power, assuming 15 percent sea margin, is 22.5 knots. It also employs current state of the art hull and propeller optimization.



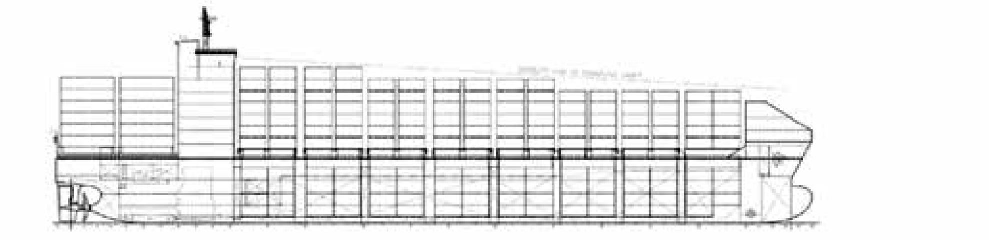
THE 2030 LIQUID BIOFUEL SHIPS

THE 2,000 TEU, BIO-FUELED CONTAINERSHIP

This ship has a conventional arrangement with single direct connected internal combustion engine (ICE) with conventional auxiliaries.

An overall 6 percent improvement in hull efficiency is assumed compared to the baseline ship, based on an optimum hull design, a larger slower turning, optimized propeller design based on a de-rated main engine, with modest aerodynamic fairing.

Conventional fuel storage and handling of liquefied biofuels is similar to current design practice. The design speed of 16 knots at the design draft is about two knots slower than the current generation of feeder ships and the ship has a corresponding overall propulsion power of less than 60 percent of the baseline design.



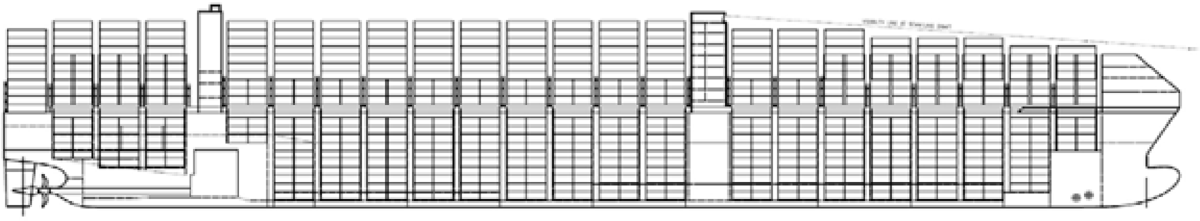
THE 14,000 TEU, BIO-FUELED CONTAINERSHIP

This overall design is essentially unchanged from the current generation of Neo-Panamax 14,000 TEU carriers. It uses a single directly connected ICE with conventional auxiliaries.

An overall 5-6 percent improvement in hull efficiency is assumed compared to the baseline ship based on an optimum hull design, and a larger slower turning optimized propeller design based on a derated main engine, with modest aerodynamic fairing.

Conventional fuel storage and handling of liquefied biofuels is similar to current design practice. The design speed of 21.5 knots at the design draft is a full knot slower than the current generation of ultra large container vessels (ULCV), and the ship has an overall propulsion power less than 80 percent of the baseline design.

In general, the liquid biofuel ships are a modest efficiency improvement from today's containerships, with the carbon reduction technology provided by the biofuel component. They are well within the technological capability that will be available in 2030. If the infrastructure for low or zero carbon biofuels can be scaled up to meet future demand, this path to a low-carbon future for marine transportation will require a modest evolution in ship design.



THE 2030 HYDROGEN FUEL CELL SHIPS

THE 2,000 TEU, HYDROGEN FUEL CELL CONTAINERSHIP

This design incorporates advanced future features and technologies, several of which are well beyond the current start-of-the-art. The ship is fully electric with all power provided by hydrogen fuel cells.

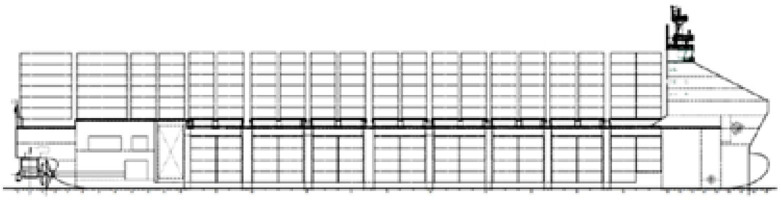
The fuel cells are sized to meet the maximum power capacity of 3.5MW for auxiliaries, and 6.3MW for propulsion, so a total of 9.8MW. The power is provided by four fuel cells at a maximum of about 2.5MW per cell and the propulsion power is provided to contra-rotating propellers, one conventional shaft propeller is driven by a 3.8MW electric motor; the second by a 2.5MW steerable pod.

There is a minimum installed battery capacity of about 6.3MWh, which is used for power conditioning and dynamic energy stability.

The design below shows hydrogen stored in a single membrane tank carrying about 1,200 m^3 of cryogenic liquid hydrogen, which is adequate for a range of 2,000 nautical miles. Alternate fuel tanks could be Type B or multiple Type C cylindrical tanks.

The accommodations are moved forward to maximize container stowage and to provide aerodynamic fairing for the deck containers. A further 8 percent improvement in hull efficiency is assumed compared to the bio-fueled ship, and 14 percent compared to baseline ship based on optimum hull design, a large slower turning optimized contra-rotating propeller design, and fully aerodynamic fairing.

The design speed of 16 knots at the design draft is about two knots slower than the current generation of feeder ships and the ship has a corresponding overall propulsion power of about 53 percent of the baseline design.



THE 14,000 TEU, HYDROGEN FUEL CELL CONTAINERSHIP

This design also incorporates advanced future features and technologies, several of which are even farther beyond the current start-of-the-art, considering the size. It is fully electric with all power provided by hydrogen fuel cells, which are sized to meet a maximum power capacity of 15MW for auxiliaries and 43MW for propulsion, or a total of 58MW. The power is provided by 20 fuel cells at just under 3MW per cell.

The propulsion is provided to contra-rotating propellers, one a conventional shaft propeller driven by a 26MW electric motor, and the second by a 17MW steerable pod.

There is a minimum battery capacity of about 36MWh, which is used for power conditioning and dynamic energy stability.

The design below indicates that the multiple membrane tanks carrying about 31,000 m^3 of cryogenic liquid hydrogen are adequate for a 12,000 nautical mile range. Alternate fuel tanks could be Type B.

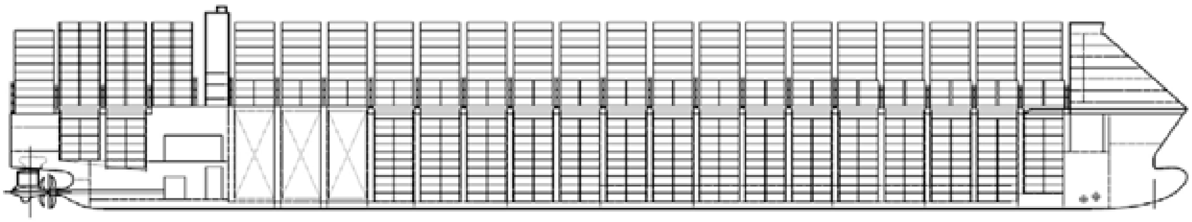
The accommodations are moved forward to maximize container stowage and to provide aerodynamic fairing for the deck containers.

Both the design range of 12,000 nautical miles and the service speed are less than the current generation of deep-sea ships and have a corresponding overall power reduction, and fuel capacity reductions.

Keeping reasonable fuel storage requirements is key to the design, considering the low energy density of hydrogen and the inability to use the wing and double bottom spaces to carry fuel.

A further 7 percent improvement in hull efficiency is assumed compared to the bio-fueled ship, and 15 percent compared to baseline ship based on optimum hull design, a large slower-turning optimized contra-rotating propeller design, with full aerodynamic fairing.

The design speed of 21.5 knots at the design draft is about a full knot slower than the current generation of deep-sea ships and the ship has a corresponding overall propulsion power of about 75 percent of the baseline design.



These concept designs highlight the gap between the state-of-the-art technology of today and the demands of the 2050 greenhouse gas (GHG) targets. The fuels used in the designs were selected to represent different strategies that could be available by 2030, not to forecast which fuels were likely to be adopted.

For example, biofuel is a drop-in fuel that can be adapted to use existing technology and infrastructure. While its use would require only a modest evolution in ship design, its availability on a global basis and the feedstock used to produce it are unknowns.

Hydrogen fuel cells represent a new fuel source and a new technology for generating power. The evolution of this design would require significant acceleration to become feasible by 2030, in particular to develop greater power and endurance. But it represents a potential zero-carbon future.

SECTION 5 | 2050 VISION

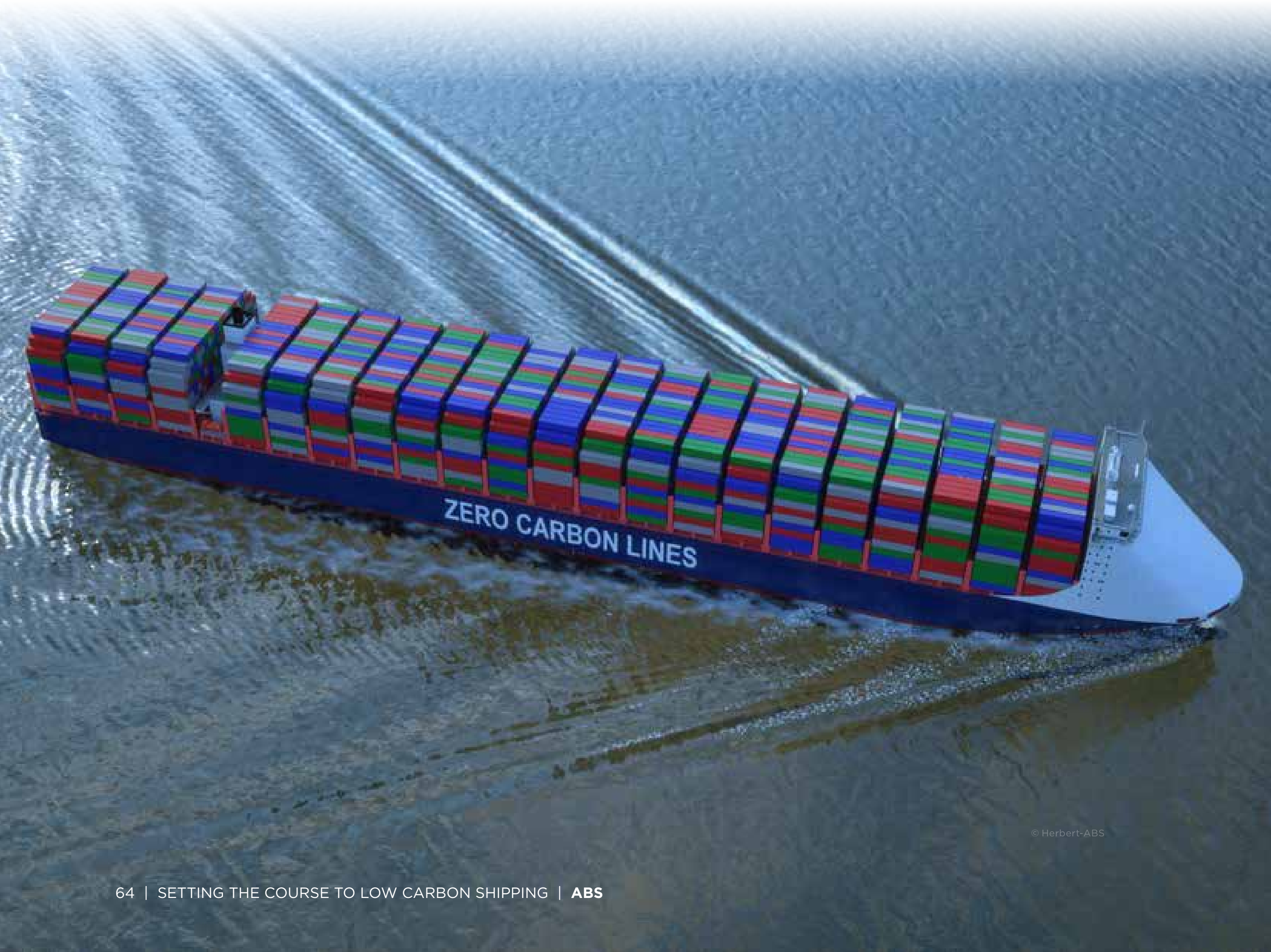
IMPACT ON VESSELS

The long-term targets (2030-2050) for reducing the carbon emissions from shipping are challenges that we do not have solutions for at present. But this much we know: we will not be able to use today's technology alone to meet tomorrow's efficiency, air pollution and carbon emission requirements. The International Maritime Organization's (IMO) 2030 reduction target for greenhouse gases (GHG) is relative to transport work, giving it some relief from the influence of any growth in trade.

However, the 2050 target is based on a reduction of total greenhouse gas (GHG) emissions and, even if we assume a slower trade growth than in the past, it will not be possible to meet that target with existing technology. This will require new ways of thinking about innovation and collaboration.

The year 2050 may seem far away, but the process of developing, adopting and implementing new technologies must start before 2030 to allow adequate time for technical and logistical troubleshooting.

As this outlook demonstrates, the biggest contribution to decarbonization could come from fuels that are either carbon-neutral, produced from biomass, or close to zero-carbon, such as those generated with renewable energy.



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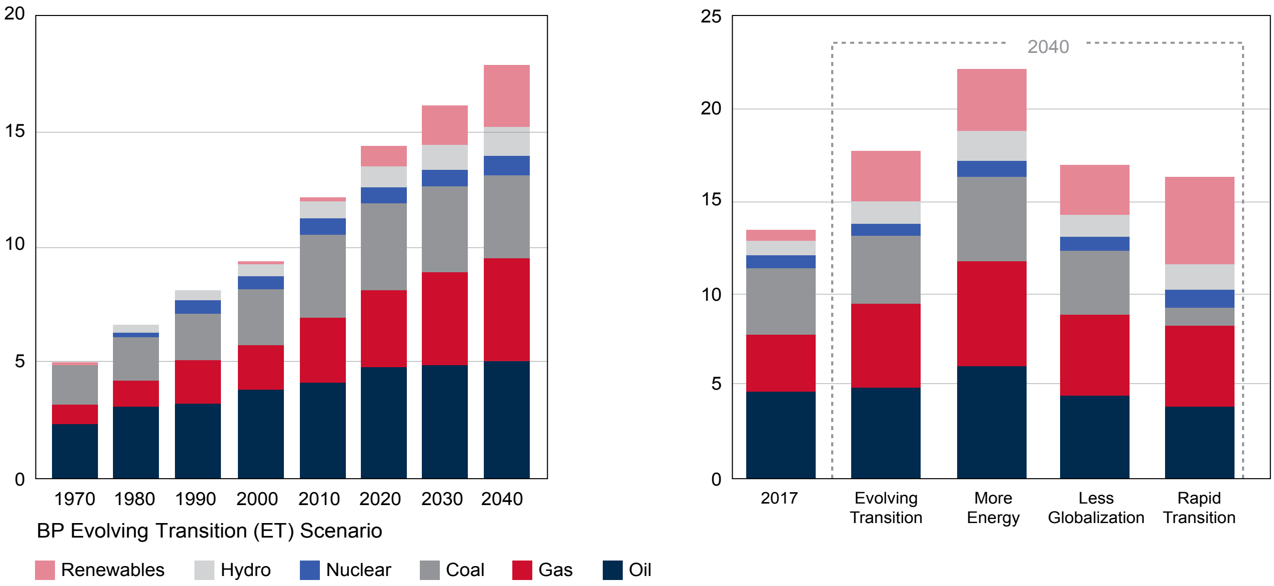
If all fuels are compared by the criteria below, fossil fuels are readily available, with better energy density and are safer and easier to handle and store.

- Availability of existing or easily adapted bunkering infrastructure,
- Availability of global production to meet a large-scale demand,
- Energy density of the fuel and its onboard storage requirements,
- carbon dioxide (CO_2) and sulfur oxide (SOx) emissions, and
- Safety risks in handling, storage and consumption

Primary Energy Consumption by Fuel
Billion toe



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Liquefied natural gas (LNG) and liquefied petroleum gas (LPG) measure well overall, but they do not offer major contributions to reducing CO_2 output. All alternative fuels have shortcomings in terms of available infrastructure and supply; all except biofuels, fall short on energy density. They all have some potential, but there is no obvious fuel choice for the global fleet of the future.

On the other hand, developing multiple fuel options, each with independent infrastructure, is unlikely to be the most cost-effective solution for the industry.

FUTURE ENERGY SOURCES

As the industry looks for future fuels, it is important to consider the available energy sources. The graphs show the BP 2019 Energy Outlook projections for the energy-source mix for fuels in an ‘Evolving Transition Scenario’ up to 2040, and compare different scenarios from ‘Evolving Transition’ to ‘Rapid Transition’.

They show a transition to a lower carbon fuel mix with the renewable energy having the fastest growth rate. However, the contribution of fossil fuels remains high, with gas showing steady growth. The scenarios have differentiated contributions, particularly from renewables and coal, but hydrocarbons remain significant in each. And they appear to support strategies that allow the continued use of fossil fuels, including the use of carbon capture and sequestration and the potential for synthetic fuels.

INVESTMENT RISKS

The investment required to reduce and ultimately remove carbon will be large and it will come during a time when global economic conditions are cast in their usual uncertainty; questions are already emerging about the long-term sustainability of some business models.

As an industry, shipping is used to finding a balance between commercial risk and opportunity. But regulatory risk, although not new, has become a greater factor. Early engagement and compliance with new regulations is something that should be encouraged, not punished by regulatory uncertainty.

The industry needs regulation that provides a level-playing field and a compliance process that is technically proven, safe and commercially sustainable. Without these key criteria, there is a huge regulatory risk looming between 2030 and 2050.

Every stakeholder – whether a shipowner, charterer or investor – must consider the life-cycle risk to asset values when making investment decisions for a low-carbon and ultimately zero-carbon future. Those risks include the impact of new regulation, meeting the sustainability requirements of charterers and consumers, and cost competitiveness.

Mitigating these risks require strategies that reward, not penalize, the early adopters of new technology and give some certainty to followers. Technology options will need to be incorporated at the newbuilding stage – in addition to any retrofits – to clear the way for investment in their development.

The regulations to reduce GHG emissions will not only have an impact on ship designs, fuel selections and vessel operations, but will also affect what cargoes will be transported and which trade routes and ship sizes will be selected. They may also challenge the existing compliance framework.

A number of critical questions need to be answered before the journey to 2050 can take a clear direction. The transition to a low-carbon future is likely to add cost to seaborne transportation; we have yet to discover on what scale, but it will be the cost of our industry's sustainability in the long term.

To reach an equitable outcome, it is critical that shipping's positive contributions to the global economy and global trade are fully understood. While we will pay our share accordingly, we also need our unique role in global trade to be recognized by consumers who are increasingly aware about the environmental footprint of the products they buy.

OUTLOOK CONCLUSIONS

- According to the third International Maritime Organization's (IMO) Greenhouse Gas (GHG) Study, from 2007-2012 international shipping on average accounted for 2.6 percent of annual global carbon dioxide (CO_2) emissions, illustrating how efficient it is at transporting almost 90 percent of worldwide trade. However, the anticipated growth in global trade and seaborne transport will see the CO_2 output from shipping grow faster than other industries, if it continues business as usual.

- In the recent commercial environment where low charter and freight rates were the norm, slow steaming reduced the overall CO_2 output from shipping. The carbon intensity reduction in 2015 relative to 2008 has been estimated at 30 percent. Even if there are regulatory complications, slow steaming and speed optimization should be considered as options to comply with the IMO's CO_2 reduction targets by 2030.

- Using digital technology to simplify shipping practices could reduce fuel consumption and emissions by optimizing vessel speeds and routes, reducing waiting times and streamlining contractual transactions.

- Information-driven, just-in-time shipping, for example, could optimize energy use and introduce slower speeds. With improved vessel utilization, less additional capacity would be required than if a mandatory speed limit was imposed.

- Even if we assume that the 2030 target can be met with available technology — slower speeds, improvements in operational efficiency and a limited use of low-carbon fuels — the gap between 2030 emissions and 2050 targets will still remain large.

- The long-term targets (beyond 2030) for reducing the carbon emissions from shipping are challenges that we do not have solutions for at present: we will not be able to use today's technology alone to meet tomorrow's efficiency, air pollution and carbon emission requirements.

- Zero-carbon ship designs, needed by 2030, require technologies that are well beyond the current state of the art.

- Improvements to the energy efficiency of ship designs will be required by the next phase of the IMO's Energy Efficiency Design Index (EEDI), but their contribution to GHG reduction targets will be small without alternative, low carbon fuels.

- The biggest contribution to decarbonization could come from fuels that are either carbon-neutral, produced from biomass, or close to zero-carbon, such as those generated with renewable energy.

- There is no obvious fuel choice for the global fleet of the future. All alternative fuels have shortcomings in terms of available infrastructure and supply; all except biofuel fall short on energy density.

- Every stakeholder — whether shipowner, charterer or investor — must consider the life-cycle risk to asset values when making investment decisions for a low-carbon and ultimately zero-carbon future. Those risks include the viability of regulation, meeting the sustainability requirements of charterers and consumers, and cost competitiveness.

- The industry needs regulation that provides a level playing field and a compliance framework that is technically proven, safe and commercially sustainable. Without these key criteria, there is a huge regulatory risk looming between 2030 and 2050.

- Operational profiles (short-sea vs deep-sea, for example) will play a key role in selection of appropriate technologies. Regional preferences for solutions may result based on the availability of infrastructure.

- The regulations to reduce GHG emissions not only will impact ship designs, fuel selections and vessel operations, they will affect what cargoes will be transported and which trade routes and ship sizes will be selected. They may also challenge the existing compliance framework.

- The transition to a low-carbon future is likely to add cost to seaborne transportation; we have yet to discover on what scale, but it will be the price of our industry's sustainability in the long term.

- To reach an equitable outcome, it is critical that shipping's positive contributions to the global economy and global trade are fully understood.

- Safety will become a stronger focus as adoption of new technologies and operational changes introduce risks that may not be mitigated or eliminated through today's standards.

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