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A global network for energy-efficient shipping

MTCC ASIA
Maritime Technology Cooperation Centre

GHG Technical References For Ship Operators

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Technical Manual

Contents

- **Chapter 1 Operational options**

1. Reducing speed[1]

At its core, slow steaming is when there is a deliberate reduction in the cruising speed of a sea vessel. This intentional slowing down of a vessel is primarily done to reduce fuel consumption and pollution from emissions.

Different types of slow steaming

First, there is a method of slow steaming where a ship brings its speed down to a level that would not necessitate the ship's owners to modify the engine in any way. This would essentially be the cut-out point for the auxiliary blowers of the engine.

The second type of slow steaming involves the ship owners and charterers agreeing that vessel is able to slow steam with a great reduction in speed (towards the lower limit of 12 knots). When this is agreed upon, there will be an extra, yet optional, provision that will handle the very slow steaming.

The first type is the most common way slow steaming is conducted. There are obvious reasons for this, such as the bypassing of a need for retrofitting of a ship's engine. The second type of slow steaming is rarely applied and when it is, there are only a few cases where it becomes implemented.

Benefits of slow steaming

As alluded to, there are primarily financial, environmental, and performance-related benefits. In order for shipping companies to stay afloat when fuel prices rise and when recessions occur, slow steaming becomes more of a necessity than an option. However, the decision for slow steaming is also made by companies to become environmentally responsible.

The environmental benefits are connected to the use of less fuel. For example, when a vessel reduces its speed by 10%, the engine power gets reduced be nearly 30%. Less power needed means less fuel is needed. When there is less fuel used, there are less emissions produced and released into the environment. The end result of this is less pollution and contribution to the global issue of climate change. With increasing pressure on all industries to reduce their carbon emissions, implementing the use of slow steaming is essentially becoming a requirement.

The financial benefits involve using less fuel. The cost of fuel is something that can be reduced when less fuel is needed. Thankfully, it provides an effective way for shipping companies to save more money, since they will be using less power. There are also performance benefits as a vessel will become more reliable and efficient when it regularly implements slow steaming.

Concerns and challenges

While there are definitive benefits to slow steaming, there are also concerns and challenges with this strategy. There are additional routines and inspections which have to be performed, which are done to ensure minimal engine damage.

One issue is that slow steaming can foul up the turbochargers. This results in a reduction of the ship's efficiency. Turbochargers that operate beyond the range they have been designed for will lead to less air flow. With this reduction comes the potential for more carbon deposits. The increase in these deposits on the fuel injectors can negatively affect the ship's performance.

Another issue is the fouling of the exhaust gas economizer. The result of this is that there is less capacity and more danger of a hazardous soot fire breaking out.

A third issue possible with slow steaming is less scavenge air pressure. This is why scavenge inspections have to be a normal and frequent occurrence. If inspections are not regularly carried out, there is potential for improper combustion. Another scavenge issue that also poses a challenge is an elevated risk in scavenge fires. This threat necessitates additional scavenge draining, as well as the area under the pistons.

2. Trim optimization[2]

Most ships are designed to carry a certain amount of cargo at a designated speed, consuming a certain amount of fuel under a specified trim condition. Loaded or ballast, trim has a significant influence on the resistance of the ship through water. Therefore, optimizing the trim can deliver significant savings.

For any given draft and speed, there is a trim condition that gives minimum resistance. Therefore, the optimum vessel trim is a function of draft and speed. A ship's optimum trim may be established as part of routine operations or through tank testing or the use of computational methods. Computational Fluid Dynamics (CFD) methods are used extensively to estimate optimal trim settings for energy efficiency. However, these may require information from ship model tests and full-scale measurements.

Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and software systems to solve and analyze problems that involve fluid flows, including liquids and gases. In shipping, it is widely used to estimate ship resistances and improve ship design via a reduced number of trial and error experiments such as ship's model tank testing. CFD methods involve a significant level of numerical calculations, thus high computer powers that are readily available. On-going research and development has yielded much more accurate estimation of a ship's resistance and powering using this technique; including its use for establishing a ship's optimal trim.

Operationally, design, or safety factors may preclude the full use of trim optimization. The possibility of trimming a ship should be seen concerning stability, maneuverability, and other safety and operational aspects. It is the master or chief officer of the vessel that will ultimately ensure all situations are considered.

Benefits

Trim optimization has significant economic benefits in terms of fuel savings. These economic benefits will vary from one ship's size and type to others. It should be emphasized that even small trim changes can have a large impact on vessel performance. A 2% to 4% reduction potential in fuel consumption is generally referred to in most literature. However, depending on ship type and operation draft, this number may be higher or lower. Therefore, all possible measures should be tried to ensure that this potential is for energy-saving realized. Sailing just 5-10 centimeters off optimal trim might cause ships to operate at higher fuel consumption levels than normal.

There is a bulk of shreds of evidence on significant fuel saving potentials due to trim. Ship resistance is altered due to a vessel's trim through viscous resistance, which is a function of the wetted hull surface area. When trim changes, wetted surface area and thereby hull resistance will be affected. By definition, if resistance increases, fuel consumption, and emissions also increase.

Trim needs to be optimized before and during a ship's voyage through a proper loading of the ship or use of ballast water to achieve a floating position that consumes the least propulsion power. Ships normally record their trim before the voyage by directly reading the draft marks. So, considering that the weight distributions on the ship allow trim adjustment, finding the appropriate and optimal floating position before voyage becomes possible (this is referred to as "static trim" when the ship is not sailing). However, knowing the exact trim and draught during a ship's voyage is important. The trim under operational condition is normally referred to as "dynamic trim" and is different from "static trim" due to the impact of ship motion. Its measurement requires real-time readings through sensors and relevant onboard data systems.

A vessel with high trim and draught fluctuations (more changes of dynamic trim) during its voyage might benefit more from trim adjustments than those with small fluctuations.

Barriers to trim optimization

The good application of trim optimization can be affected by the following constraints:

Ship loading: The weight distribution on board must be determined to allow trim optimization. Therefore, adequate communication between ship and port is paramount. As stated above, the loading computers may be effectively used for safe loading as well as for setting the optimal trim.

Operational risk challenges: This includes the oversight of bending moments and shear forces when practicing trim optimization. In this respect, it should be noted that not all vessels have real-time stability assessors or calculators onboard. Additionally, danger to cargo in particular for those ships with deck cargos, is also another constraint.

Real-time bunker and water transfers onboard: The officers on the watch might have incomplete knowledge of the bunker and water (grey/freshwater) transfers onboard. Therefore, they may not be aware of the effects of such activities on the trim. Again this highlights the importance of shipboard communications between deck department and engine department.

Watch changeover: Sometimes the information regarding ballast operations is not passed on during the watch changeover between the crew.

Removing of the above barriers requires a good understanding of the subject and training of shipboard crew and their dedication to best practice and a continuous improvement approach to the problem for long-term sustainable culture of best practices.

● Chapter 2 Low- carbon fuels (Alternative fuels)[3]

1. Wind

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.

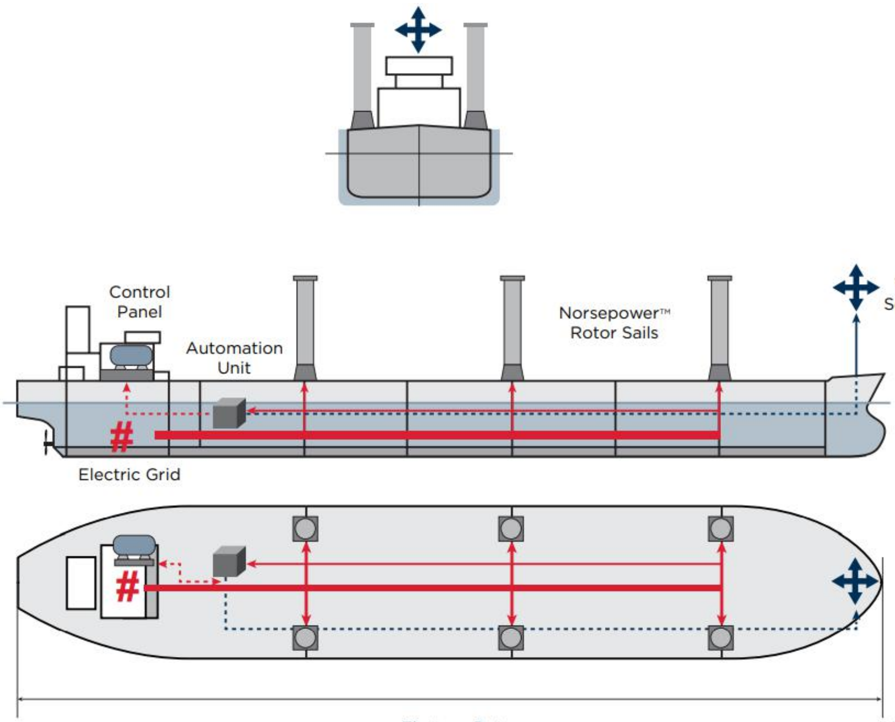
Flettner rotor: Flettner Rotors were demonstrated as early as 1926 with an Atlantic crossing but have seen limited use since. In 2010, a 9,700 dwt cargo ship was equipped with four Flettner Rotors to evaluate their role in increasing fuel efficiency.

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

Vessel Shin Aitoku Maru with rigid sails

Image courtesy of Bluebird

pending.



Flettner Rotor

© Norsepow

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 2 MW 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.

2. Battery

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).

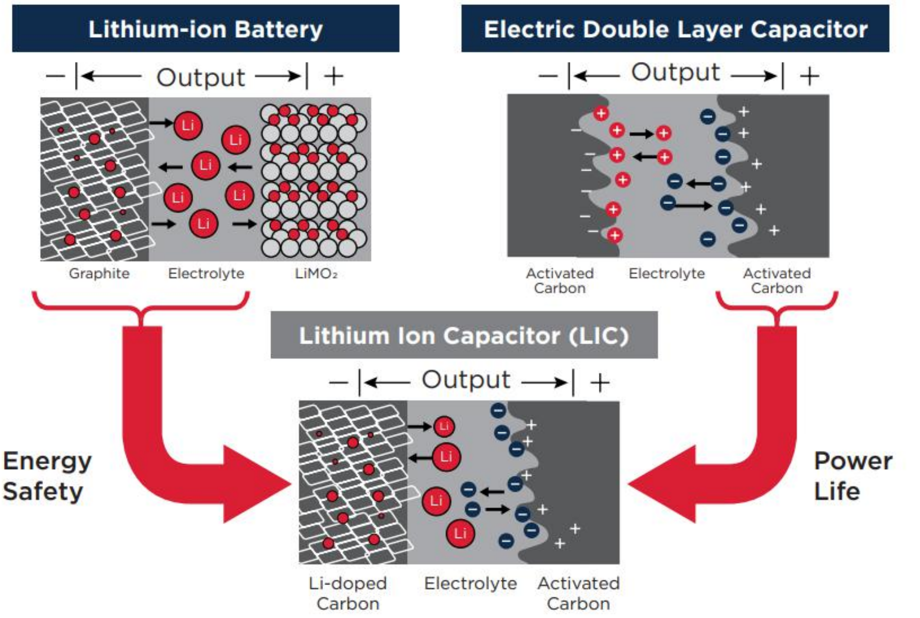
Currently, only batteries are widely used in marine applications and, even then, they are only used as a primary power source on small vessels undertaking very short voyages. While the technology is continually improving, its cost, weight, space requirements, recharge times and endurance ranges may prevent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

Super capacitors 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.

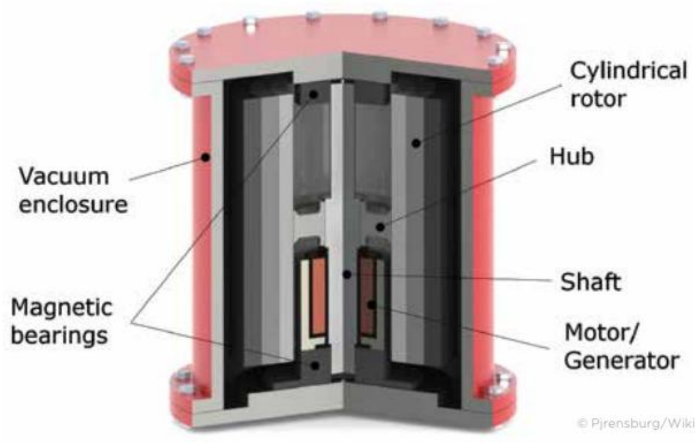
They can be more efficient than batteries because of their significantly higher power density, faster charging and discharging processes, and more numerous cycles, making them suitable for fast delivery of the high or ‘pulse’ power required by bow thrusters, starting generators or motors and offshore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

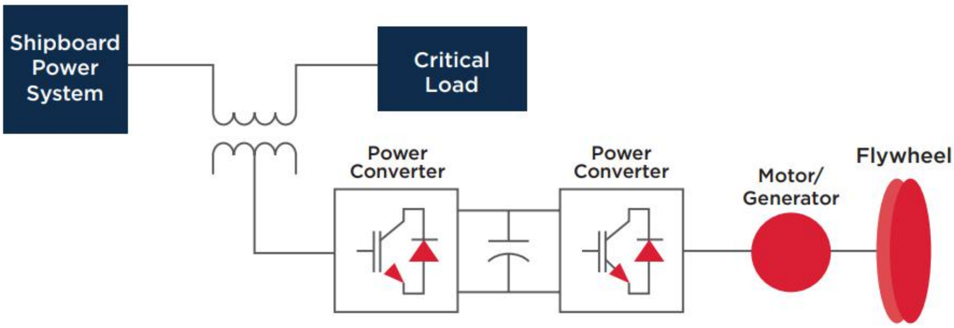
Generally, advanced energy storage technologies — predominantly lithium-ion batteries — are gradually replacing conventional batteries (lead-acid, nickel-cadmium and alkaline, etc.). The former have no flammable gas emissions during normal operation, overwhelmingly higher energy density (reducing weight),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



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

GHG performance

Carbon dioxide (CO2), 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 CO2 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.

3. 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 (CO2)-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 characteristic

Chemical composition	NH_3
Boiling point,°C 1bar	-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.

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 630ºC, 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.

4. 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.

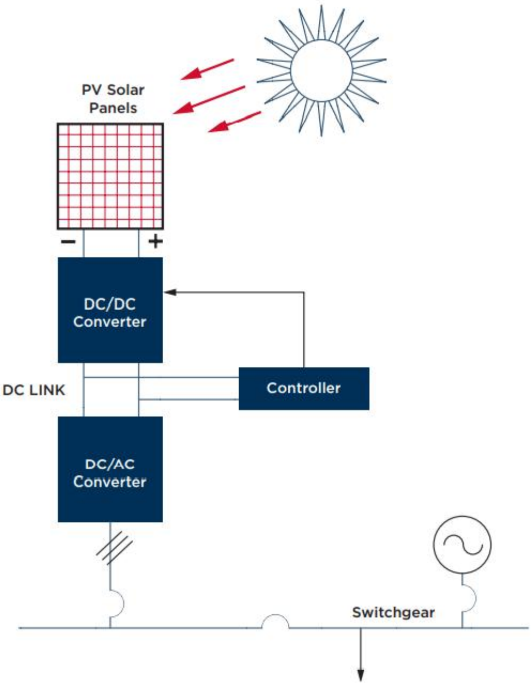
PV cells are often referred to in terms of the amount of energy they convert in full sunlight conditions, this is known as kilowatt peak.

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 (537m2) 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

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/m2), 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 CO2 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 CO2 reduction set by the IMO Energy Efficiency Design Index (EEDI) (10 percent per ton-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.

5. 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 characteristic

Chemical composition	H_2
Boiling point,°C 1bar	-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.

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.

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.

6. 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 (CO2) 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 characteristic

Chemical composition	CH_4
Boiling point,°C 1bar	-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.

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 CO2 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 595ºC. When released from LNG, methane vapors will at first be heavier than air and then rapidly become lighter than air as it warms beyond -100ºC. 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.

7. LPG

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.

Fuel characteristic

Chemical composition	COMBINATION*
Boiling point,°C 1bar	-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

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.

Application

Shipping companies are working with partners (engine manufacturers, systems designers and class) to use LPG engines on new buildings, 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 m3). 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 (CO2) 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. CO2 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 372ºC. 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.

8. 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 (CO2) footprint of its use as fuel.

Due to its potential to reduce the CO2 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 characteristic

Chemical composition	CH_3OH
Boiling point,°C 1bar	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 CO2 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 440ºC, 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

9. 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 (CO2) 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.

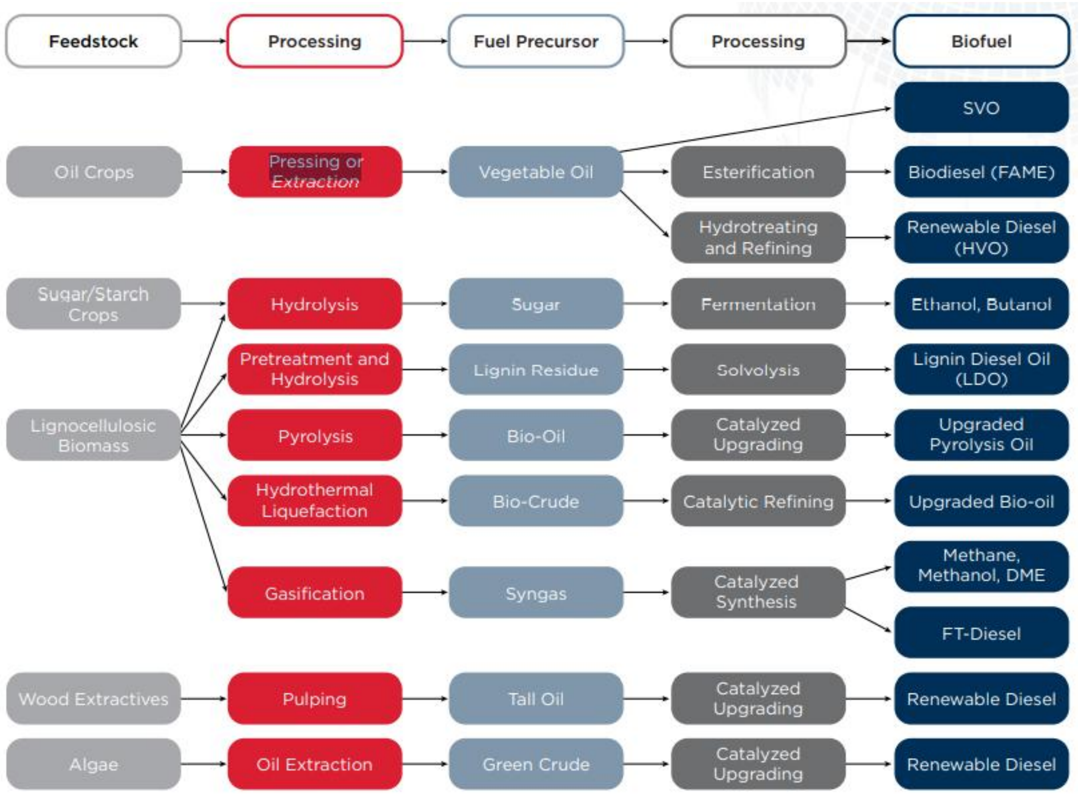
Third generation: Biofuels are produced from algae, which is capable of higher yields with lower resources than other feedstock. Biodiesel, butanol, gasoline, methane, ethanol, vegetable oil and jet fuel all can be produced from algae. Most of the related activities remain at the research stage.

Fourth Generation: Unlike biomass derivatives, production of these biofuels — such as electro and photobiological 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.



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 CO2 output because producing biofuels is a comparatively less carbon-intensive process. Biomass such as wood, however, typically produces more greenhouse emissions for the same amount of energy as equivalent fossil fuels.

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.

10. 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 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.

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 CO2). 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 CO2 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.

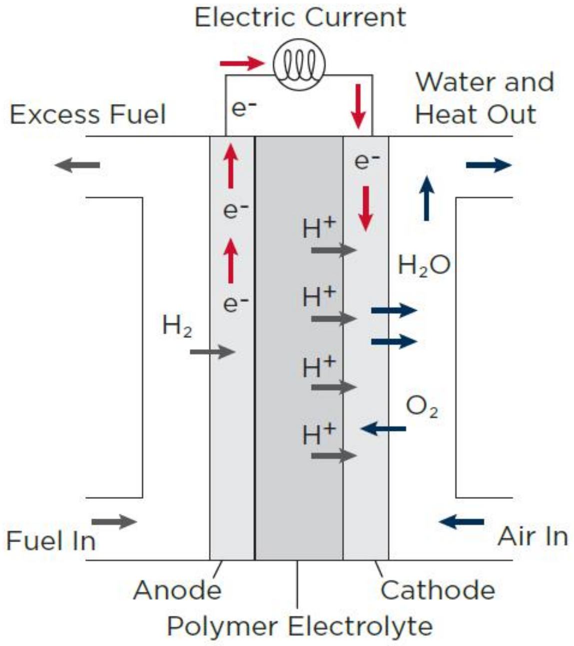
At present, there have been no reports of renewable synthetic fuels being used in marine applications. A key benefit of their use is that modifications required to the existing vessel equipment and systems would be minimal.

11. 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.



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.

● Chapter 3 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.

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.

- **Chapter 4 Ship-Port interface**

1. Facilitate immobilization in ports

Brief description of the measure

Implementation of this measure would allow for maintenance and repairs of the main engine (ME) to occur simultaneously with cargo operations. This would contribute to a reduction in GHG emissions as it would optimize the time spent in port, and eliminate the need for the ship to transit to another location for work to be undertaken.

Further details

In many ports, maintenance and repairs of the main engine are performed at a lay-by berth, outside of the normal ship schedule. Subsequently, ships may need to speed-up to recover the lost time and meet their voyage onward schedule, negatively impacting on emissions (both in port, due to the longer port stay, and at sea, due to higher transit speeds).

Allowing ships to undertake ME maintenance and repairs simultaneously with cargo operations would reduce the time spent in port. As most ships only have one main engine, once repairs have started, the ship cannot depart from her berth under own power. This condition is called “immobilization” and is not currently permitted by many port authorities.

Main engines of ships on average have 6 to 10 cylinders. While new container ships could have 2 MEs with 7 or 8 cylinders each, older container ships may only have 1 ME with 10 to 14 cylinders. Each cylinder has many different components (e.g. fuel pump, fuel injector, exhaust valve, piston ring or cylinder liner) which may require planned maintenance or unplanned repairs. Proper functioning of these components is critical to maintaining the engine in a condition that combustion is optimal (i.e. causes the least possible emissions under any given engine load condition).

The duration of maintenance jobs may range from 3 hours (e.g. exchange of a fuel injector) to 12 hours (e.g. replacing a piston) and up to 24 hours (e.g. replacing a cylinder liner). The frequency of maintenance jobs also varies per type and make of engine and component, e.g piston rings need replacement approximately every 16,000 running hours, an exhaust valve overhauled after 16,000 running hours and a fuel injector after 8,000 running hours. Depending on engine load and quality of fuel and lubrication oil, there is a tendency for condition-based maintenance in lieu of running hours-based maintenance. All maintenance is required to be in compliance with class requirements.

Example ports (not exhaustive) which have implemented this measure

Ports of Bremerhaven, Gothenburg, Hamburg and Rotterdam allow maintenance to main engines and grant immobilization under normal weather conditions.

Other benefits

- Reduced risk of breakdown due to maintaining optimal engine condition.
- Improved operational reliability as the ship has better planned maintenance opportunities.
- Improved safety for crew on board due to less time pressure to do the job.
- Improved navigational safety, as shifting the ship to a lay-by berth is always an additional manoeuvre with the corresponding nautical risk.
- Availability of technical expertise in port, to support ship’s staff, if required.

Main barriers

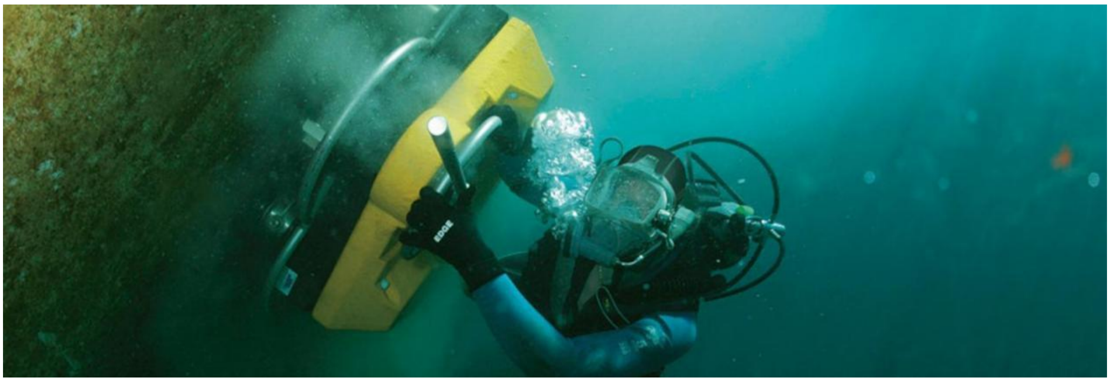
- Lack of understanding of risks associated with immobilization which results in port authorities not granting permission. In some cases, immobilization may be granted by the port authority but refused by the terminal operator.

- Lack of understanding by terminal or harbour master that maintenance and repairs on the main engine do not have any impact on the capability of the ship to be safely moored, as the mooring winches are not powered by the main engine but by the auxiliary engines.
- Potential increase of need for tugs, if the ship has to leave the berth in the event of an emergency.
- Concerns that ME repairs will take longer than envisaged, causing the ship to remain alongside for longer than planned.
- Availability of qualified crew for the intended work on the ME in conjunction with rest hour planning.

2. Facilitate hull and propeller cleaning in ports

Brief description of the measure

Implementation of this measure would allow hull and propeller cleaning to take place in port, ideally simultaneously with cargo operations. This would contribute to a reduction in GHG emissions as it would optimize the time spent in port and eliminate the need for the ship to transit to another location for hull and propeller cleaning to be performed, as well as the reduced GHG emissions as a result of the hull and propeller cleaning itself.



Further details

Many ports do not currently allow hull and propeller cleaning during the port stay. As a consequence, it can be challenging for ship operators to maintain a clean hull and propeller, which would reduce resistance of the hull and propeller through the water while steaming. Hull and propeller fouling results in increased fuel consumption and hence higher GHG emissions. Therefore, it is important for ships to regularly clean their hull and propeller. Allowing ships to clean their underwater hull and propeller, ideally simultaneously with cargo operations alongside, will optimize the time it spends in port and avoid that the ship may have to speed up in order to make up for lost time.

Hull and propeller cleaning does not need to be undertaken at every single port call and also largely depends on the trading pattern and region where the ship trades. Cleaning the hull too early may damage the anti-fouling coating system, which could in turn increase fouling.

Some ports do not allow in-water cleaning at all due to sediment/scrapings of the hull and propeller cleaning process entering the port waters, and in this respect the industry has developed the first industry standard on in-water cleaning with capture.[2]

Example ports (not exhaustive) which have implemented this measure

Ports of Algeciras, Antwerp, Ghent, Gothenburg, Rotterdam, Zeebrugge

Other benefits

- Reduced hull and propeller fouling.
- Reduced risk of invasive species polluting local waters (provided the fouling is collected).

Main barriers

- Environmental concerns regarding discharge of removed biomass.
- Lack of port reception facilities for collected biomass.
- Availability of crew/personnel to supervise operation.
- Risk owing to other simultaneous operations (such as bunkering, or cargo operations which may require the use of cooling/ballast water pumps. Use of these may create pressure differentials in the water which poses a safety risk for divers under the ship).ROVs are not able to undertake the cleaning process (especially in cases of propeller and heavier biofouling). Due to these barriers, local authorities often do not issue operating permits to hull and propeller cleaning companies.

Suggested next steps/potential solutions

- Use of hull and propeller cleaning remotely operated vehicles (ROVs), which may reduce the risk associated with divers under the ship during cargo operations. Furthermore, use of ROVs with collecting abilities to eliminate discharge of scrapings into local waters.
- Ports to undertake risk assessments to better understand and mitigate potential risks associated with hull and propeller cleaning simultaneously with cargo operations.
- Establishment of harmonized procedures for issuance of operator licences to minimize the impact on the aquatic environment and to create a level playing field.
- Transparent communication from the port authority and terminal operator on whether hull and propeller cleaning during cargo operations is permitted and under what circumstances so ship agents can plan accordingly.
- Promote industry standard to enable the provision of environmentally-sound hull and propeller cleaning services.
- Incorporate guidelines as laid down in the Guidance for the Selection of Diving Contractors to Undertake Underwater Ship Husbandry issued by the IMCA (publication IMCA M 210).

3. Facilitate simultaneous operations (simops) in ports

Brief description of the measure

Implementation of this measure would allow operations to occur simultaneously (e.g. cargo, bunkering, provisioning, tank cleaning etc.). This would contribute to a reduction in GHG emissions as it would optimize the time spent in port, as operations can be concluded in parallel rather than in sequence.

Further details

Depending on the size of the ship and the capabilities of the port, bunker operations would normally require a minimum of 6 hours, while taking provisions, spares or consumables on board could require about 1 to 4 hours. These operations fall under the responsibility of different onboard departments (i.e. bunker operations are normally under the responsibility of the chief engineer, while cargo operations are under the responsibility of the chief officer). Therefore, these can occur simultaneously, taking into consideration that crew rest hour requirements are not compromised.

Example ports (not exhaustive) which have implemented this measure

Bunkering of HFO during cargo operations is allowed in most ports. In the tanker segment this is sometimes prohibited by the terminal. Bunkering of LNG is more often than not allowed during cargo operations; however, it is becoming available in a wider range of ports, such as Ports of Barcelona, Gothenburg and Rotterdam.

Other benefits

- Improved navigational safety, as shifting the ship to a lay-by berth (for completion of bunkering operations, loading provisions, spares and consumables) may require an additional manoeuvre with the corresponding nautical risk.
- Manoeuvring the ship to a lay-by berth is an additional burden on the ship complement who are all required for shifting.
- Less demand on nautical service providers in the port.

Main barriers

- Perceived safety risk with respect to bunkering operations and potential fire/explosion hazards
- (in particular in dangerous goods terminals).
- Willingness of terminal and/or port authority to permit simultaneous operations to be carried
- out.
- In some cases, lack of available crew to support simultaneous operations with a potential effect on crew rest hours (although under certain circumstances, shore assistance can be ordered).
- Non-transparent information sharing to facilitate planning of services, hampering a proper rest hour planning for the ship and service providers.

Suggested next steps/potential solutions

- Undertake a comprehensive risk assessment with all parties (shipping, terminals and ports etc.) to analyse the potential risks of simultaneous operations and to identify possible mitigation measures. The risk assessment could also identify exactly which operations can take place simultaneously and under what conditions.
- Sharing of best practices from ports which allow simultaneous operations (e.g. in the case of chemical tankers some ports allow pre-washing of tanks to be carried out at berth simultaneously with loading/discharging of other tanks). Sharing this experience would be helpful for other ports to understand and mitigate associated risks.
- Facilitate clear information sharing between all stakeholders involved, so as to ensure proper planning of services to the ship.

4. Optimize port stay by pre-clearance

Brief description of the measure

This measure optimizes the port call and aims to eliminate unnecessary waiting time by facilitating all required clearances in advance, thereby contributing to a reduction in GHG emissions through the optimized port stay.

Ships may experience operational delays on arrival, during port operations or at departure due to clearance processes in ports. The delays may need to be recovered in transit, often resulting in higher transit speeds, and thereby increased fuel consumption and emissions. Port stay optimization can be supported by introducing pre-clearance of e.g. customs, immigration, port health or port authority formalities, avoiding waiting time to arrive, during operations alongside or to depart, in line with standard 2.1.2 of the FAL Convention: "*Public authorities shall develop procedures for the lodgment of pre-arrival and pre-departure information in order to facilitate the processing of such information for the expedited subsequent release/clearance of cargo and persons.*"

Further details

Notifications and declarations must be provided by the ship to the authorities concerned for cargo and persons' clearances. Typical clearances are granted by customs, immigration, port health and port authorities. Furthermore, there are additional clearances required on the cargo side (e.g. cargo sampling/checks to ensure quality) although this may be dependent on ship segment.

Frequently, ships face delays on arrival or departure because clearances from the relevant authorities have not been obtained. In some cases, ships may anchor, wait for port clearance, and retrieve anchor before proceeding to the port, which takes considerable time. E.g. not having received port health clearance (free pratique) can lead to delays in entering the port, and not having received customs clearance can delay the start of cargo operations, and lead to idle waiting time alongside. These delays, many of which are experienced on arrival, lead to an increased number of port hours versus planned port time, the timing of which can typically range from half an hour up to 5 hours.

Normally, the ship agent sends the reporting and data format requirements to the ship. The Master compiles and completes this data, which can be resource intensive (as the authorities in most countries require their own format), and returns it to the ship agent, who then processes this data into an electronic application (e.g. maritime single window, port community system). Since April 2019, in accordance with the revised requirements in the FAL Convention, public authorities have to establish systems for the electronic exchange of information, and hard copies are only allowed in case of force majeure where means of electronic transmission are unavailable.

In most ports it is unknown if and when authorities are boarding the ship. Often authorities board the ship at different times. Immigration officers may come on board at any time, forcing all crew to wake up for a “face check”, custom officers may board several hours later. Both can significantly impact crew rest hours, causing even a violation of rest hours (and hence the Maritime Labour Convention, MLC).

The current situation is expected to improve over time; however, it requires acceleration. A group of global industry associations in consultative status with IMO representing the maritime transportation and port sectors, consisting of IAPH, BIMCO, ICHCA, ICS, IHMA, IMPA, IPCSA, ISSA, FONASBA and the PROTECT Group, issued a joint statement on 2 June 2020 calling for intergovernmental collaboration to drive the acceleration of digitalization of maritime trade and logistics. In addition, owing to the COVID-19 pandemic, many port authorities do not board the ship anymore, demonstrating that physical presence is not necessarily required to clear the ship.

Example ports (not exhaustive) which have implemented this measure

Port of Singapore has implemented pre-clearance.

Other benefits

- Improved safety by better crew rest hour planning; often the Master and/or the crew are woken up by authorities to provide documents or to present themselves. Pre-arrival clearance would potentially eliminate this disturbance to crew rest hours.

Main barriers

- Compliance with different administrative requirements (e.g. immigration, health, security) of the port State.
- Capacity of ship operator to provide required information in the correct format in a timely manner.
- Capability of the port and the relevant authorities to handle and process digital standardized declarations and notifications.

- Willingness of port and relevant authorities to grant and accept clearances in a digital format. Digital clearances are not always accepted in the next port of call: some ports require seal and signature.
- Lack of harmonization between standards.

Suggested next steps/potential solutions

- Implementation of electronic data exchange systems.
- The Expert Group on Data Harmonization (EGDH) set up by IMO's FAL Committee should continue working on harmonizing data models, data elements and definitions for declarations and notifications. To succeed this should be implemented by the port community as well as all ship systems in order to facilitate a seamless exchange of information across borders and IT platforms.
- IMO FAL EGDH should facilitate the inclusion of new data elements into the FAL Compendium, such as time definitions related to boarding times and clearances by local authorities.
- Authorities should be clear and transparent about their clearance process, in order for the maritime community to know what to expect in advance and to be able to plan and act upon that process.

5. Improve planning of ships calling at multiple berths in one port

Brief description of the measure

This measure aims to improve the planning of ships calling at multiple berths in one port, as is often the case with container feeder ships, chemical and parcel tankers. This measure aims to ensure:

- Just in Time shifting of ships between berths; and
- Optimization of cargo operations.

Addressing the planning would result in lower GHG emissions as the ship's time under engine in port, the terminal operations as well as all services ordered (e.g. nautical service providers) are aligned which result in improved port turnaround times and present an opportunity for bunker savings in subsequent voyage to the next port of call, thereby contributing to a reduction of GHG emissions.

Further details

Today, ship agents need to collect information from all sources, usually by phone, which is very labour intensive and inefficient. There is a huge dependency on the manual follow-up of any unforeseen changes in port operations delivered to the ship, terminal completion times, completion of bunker provisions, booking of pilots and tugs etc. The process of updating all parties involved is fragmented and extremely manual in terms of manpower. While shipping is a 24/7 operation, not all crucial stakeholders might be available around the clock.

This is further exacerbated when ships call at multiple berths in one port (which is common for container feeder ships, chemical and parcel tankers) as there is no overview of the berth planning for multiple berths. Individual terminals are responsible for their own berth planning, and the port authority is responsible for the port planning. Today, most ports and terminals do not have a neutral unit that acts as a coordinating entity, which has full overview of activity within the port. As a result, the planning of a ship calling at multiple berths in one port is fragmented, and often results in unnecessary ship movements, additional shifting to lay-by berth or waiting times at the terminals, which in turn causes unnecessary GHG emissions.

Improving this coordination would result in an improved turnaround time in port, enabling speed optimization opportunities on the outbound voyage, thereby reducing GHG emissions. This measure would encourage increased exchange of high-quality and up-to-date information in order to improve planning and optimize the port stay.

The ease of implementation will depend on the existing digital infrastructure e.g. a PCS. If such a PCS is present, it may still require a change of procedures to develop the capability to exchange the event data required for implementation of the measure.

Example ports (not exhaustive) which have implemented this measure

Port of Hamburg (with the Hamburg Vessel Coordination Centre (HVCC) acting as a neutral overseeing entity).

Other benefits

- Improved safety when shifting ships within a port.
- Effective use of port infra- and suprastructure as well as service providers.

- Increased crew awareness of exact shifting times and cargo operations and therefore, improved crew rest hour planning.
- Improved planning of services and resources across the port.
- Exchange of data and information in a standardized way.

Main barriers

- The absence of a digital interoperable way of exchanging data.
- Reluctance to share relevant information (e.g. berth planning) amongst stakeholders.
- Lack of overview of activities within the port.
- Lack of neutral coordination between port stakeholders (connecting potential competitors).

Suggested next steps/potential solutions

- Incentivize and reward a collaborative approach for all stakeholders to share data.
- Establish means for electronic data exchange (e.g. through electronic PCS).
- Promote data exchange and use of international standards for electronic data exchange (IMO Compendium).

In the longer term, explore establishment of neutral coordination centres between shipping companies and terminals that could take over key-roles for affected ships such as berth planning (instead of each individual terminal) and stow planning (instead of each individual carrier). This could act as a central round-the-clock point of contact for terminals, shipping companies, ship crews and nautical service providers (such as pilots, tugs and linesmen).

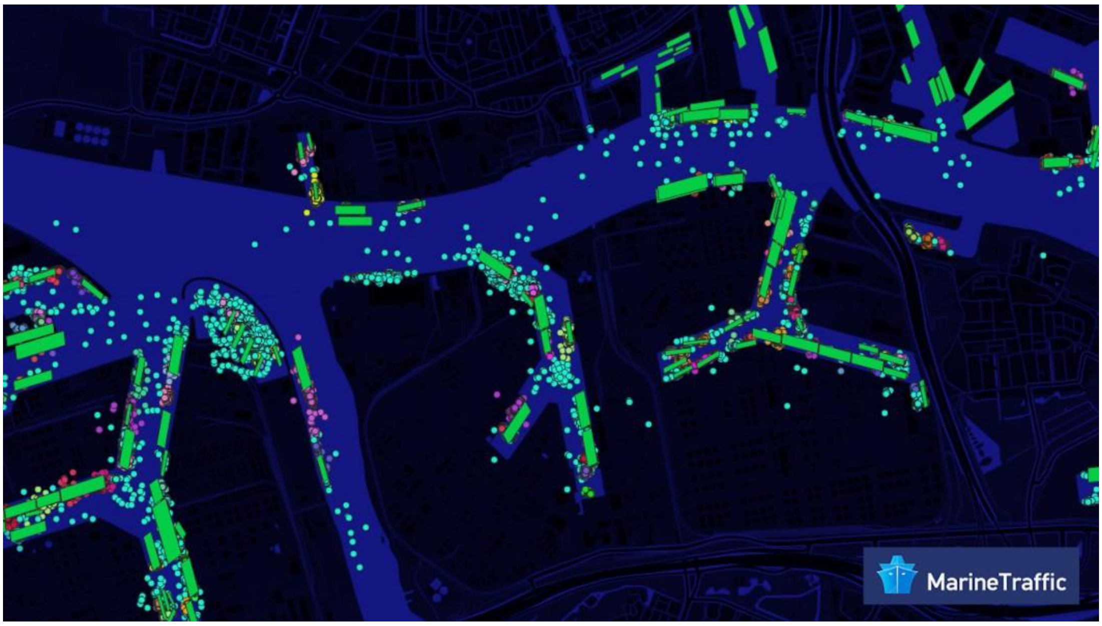
6. Improve ship/berth compatibility through improved Port Master Data

Brief description of the measure

This measure involves improving Port Master Data to ensure that the right ship size is utilized, by:

- reliable identification of the terminal and berth,
- reliable maximum length and beam per berth.

Having the right ship size utilized results in lower GHG emissions per carried ton of cargo.



Further details

Today, many ports and terminals do not have easily accessible and high quality data available about the maximum ship sizes that can be accommodated. AIS data can increase the understanding of the maximum ship sizes for ports, terminals and berths, based on metadata of many ships calling at a particular port, terminal and berth. This data is key for 85 per cent of the shipping business: deploying the right ship that fits at the berth of both the load and discharge port.

Furthermore, many ports and terminals do not have unique identifiers for individual berths that are used on a global level. This can result in misunderstandings and miscommunications regarding which berth a ship should be going to. Without a common understanding of which terminal and berth the ship should go to, it is difficult to obtain accurate information on the maximum length and beam of the ship that the terminal can accommodate. As a result, a ship may not be optimized for that particular berth.

According to regulation 19 of Chapter V of SOLAS,[5] AIS is compulsory. Data entry in the AIS equipment is also compulsory; however, it is inputted manually and it is not specified in what format. Currently, the metadata inputted for AIS to identify the next port of call is a free text field (UNLOCODE), which makes it difficult to analyse the data. The UNLOCODE, which is used to identify the port, is typed in manually, allowing for human error and different codes to be used. The terminal and berth identifiers are currently not inputted into AIS. Inclusion of the identifiers for the terminal and berth in the AIS metadata would allow for the proper and efficient identification of the terminal and berth.

Collating all this AIS data from ships could support efficient identification of the next port of call, including identification of the terminal and berth, taking into account ship length and beam. Analysis of this data could contribute to improving the global availability of Port Master Data.

Example ships which have implemented this measure

Currently, no ships are completing the AIS data in a uniform fashion.

Other benefits

- Facilitate berth to berth passage planning as per IMO resolution A.893(21).
- Enable clarification of locations in sales contract and charter party to facilitate safe berth clauses.
- Increased safety – as risk of collisions is decreased (when destination of ship is known to other ships).
- Automatic validation of the IMO GISIS database.
- Automatic reporting about the last 10 port visits for the security declaration.
- Automatic validation if the ship called at a terminal with a higher security risk (ISPS level 2 or 3).
- Automatic validation of Electronic Navigational Chart (ENC) data.
- Automatic alerts if too many ships will end up in the same VTS section.
- Automatic reporting to VTS sector re. destination, especially for inland ships.
- Automatic collection of port passage information to a particular berth (e.g. route, number of tugs, etc.).
- Automatic validation of sailing time from Pilot Boarding Place to berth.

Main barriers

- Ambiguous identification of port, terminal and berth.
- Maximum number of characters in the AIS free text field.
- Concern over the disclosure of commercially sensitive data about the terminal of destination.
- Concern over security risk from AIS metadata when transiting high risk areas.
- The terminal identifier exists but is not easily accessible (IMO Port facility number in the GISIS database).
- The berth identified does not exist on a global level(in the supply chain industry, unique identifiers do exist for locations, i.e. the Global Location Number (GLN)).

Suggested next steps/potential solutions

- Promote accessibility of Port Master Data to all relevant stakeholders (e.g. charterers, traders etc.).

- To mitigate concerns over disclosure of commercially sensitive data regarding the destination, terminal, the ship to only disclose the terminal data close to arrival at the berth.
- Link and expand Port Master Data to existing terminal databases to close the gap between port and terminal data (e.g. OCIMF Marine Terminal Information System).
- Develop best practice and guidance to complete AIS data in a uniform fashion.
- Long term solution is an AIS menu to select the port, terminal and berth of destination via the Electronic Chart Display Information System (ECDIS).

7. Enable ship deadweight optimization through improved Port Master Data

Brief description of the measure

This measure involves improving Port Master Data (depths, water density, tidal heights) to enable optimization of the draught of the ship, eliminating unnecessary allowances and additional buffers in the Under Keel Clearance (UKC).

Improved access to reliable and up to date Port Master Data allows for better optimization of the deadweight capacity and therefore contributes to a reduction in GHG emissions per cargo ton transported.

Further details

Today, ships face many challenges in the availability of reliable and up to date Port Master Data, such as the depths of the deep-water route, fairway, harbour basin and the berth pocket. Owing to the lack of this information, many ships sail with underutilized capacity, as Masters often maintain an additional buffer in the UKC when assessing the allowable draught of the ship on arrival and departure. In applying this measure, and optimizing the deadweight at the loading port, the depth of the discharge port and the approaches in both ports also need to be taken into consideration.

Port authorities face challenges in collecting and publishing port infrastructure data (e.g. name and location of berth, depths). This could be for several reasons (see barriers below), including that the port authority may not be the data owner of all port data (e.g. terminals may be the data owner of depths at the berth). Furthermore, the information gathered is not necessarily shared with the national hydrographic office. Sometimes the data is published directly by the port (e.g. on websites) in a format that conflicts with official ENC, either by different values and/or by different (local) reference levels (Chart Datums, CD). In such cases, the data cannot be readily used.

As a result of this lack of sharing and inconsistency in data formats, some national hydrographic offices are unable to publish this information in their official Nautical Publications (NPs) as they cannot guarantee the correctness of the data. Without access to reliable data, those requiring the information will often resort to collecting the data themselves, through various means such as questionnaires to mariners, ship agents etc. in order to make the most informed decisions, but will take into consideration additional UKC allowances because the data is not verified.

In addition, most NPs do not display the accurate height of tide – usually, only predictions for astronomical tide are displayed. However, since ports are affected by environmental conditions such as wind direction, river flow or barometric pressure, deviations to the astronomical predictions occur. Some ports do publish the local height of tide, but not in a standardized manner and not always with the same timeframe or accuracy.

Most NPs do not display the accurate water density; normally they only display an average water density for the entire port area. Most ports however have different water densities, ranging from e.g. 1025 kg/m3 close to the harbour entrance (sea water) to 1000 kg/m3 further inland (fresh water). Water density may also change with the tide.

To cater for these uncertainties, Masters often apply allowances for the maximum draught in their UKC calculations, especially at the berth, where the ship will also be positioned during low tide.

It should be noted that, in accordance with regulation 9 of Chapter V of SOLAS, "*Contracting Governments undertake to arrange for the collection and compilation of hydrographic data and the publication, dissemination and keeping up to date of all nautical information necessary for safe navigation*."

Example ports (not exhaustive) which have implemented this measure

Ports of Brisbane, Cairns

The Port of Rotterdam shares its local ENC with the HO and is working to change the format allowing automatic processing of the data. Also, the local Chart Datum (Normaal Amsterdams Peil, NAP) is changed to an international Chart Datum (Lowest Astronomical Tide, LAT).

Other benefits

- Improved safety of navigation – this is predominantly the main reason why accurate and up-to- date Port Master Data is crucial. Most incidents happen in the approaches, anchorages or harbour basins of ports,[6] as this is by far the busiest time for the Mariner and ship. Therefore, improving the quality and the availability of port information is an important risk mitigation strategy as it will help the Mariner to execute safe navigation from Pilot Boarding Place to berth and vice versa.

- Ensuring that accurate data is provided strengthens the legal position of the port in the event of an incident.

Main barriers

- Lack of accurate and up to date Port Master Data

- Ports and/or terminals may be reluctant to share depth data because of lack of knowledge of potential legal consequences.

- Ports and/or terminals may have legacy systems and local standards that would require alignment and harmonization with international standards in order to ensure compliance. For example, local port authorities may use different Chart Datum, employ different methodologies for taking soundings or use different terminology in their local standards, so additional efforts may be required to bridge any differences in order to comply with international standards.

- Ports and/or terminals may not have the resources (financial or technical/technological capacity) to implement a scheme to improve its Port Master Data.

- Lack of trust in available Port Master Data, which in turn leads to additional buffers added to the UKC.

Suggested next steps/potential solutions

- Developing incentives for ports and terminals to share data regularly.

- Increasing awareness and strengthening international compliance with the IHO S-44 standard[7] including gathering of data to ensuring compability of Chart Datum with the IHO S-44 standard (otherwise the hydrographic office is unable to use that survey in an official ENC, or paper chart).

- Promote publication of Port Master Data in a digital format in a standardized way (alignment of current data).

- Promote accessibility of up-to-date Port Master Data to all nautical staff on board and raise awareness of how that information can be used to eliminate unnecessary buffers in UKC.

- Sharing best practice with ports and terminals together with HOs on how to share data, in which format, and with which Notice of Intended Use.

- Sharing knowledge about their legal position regarding not sharing data versus being forced to share data after an incident has happened.

8. Optimize speed between ports

Brief description of the measure

This measure would allow for ships to optimize speed between ports, to arrive “Just In Time” when the berth, fairway and nautical services are all available. This “Just In Time Arrival” concept (JIT Arrival) will improve the port call process and ultimately reduce GHG emissions.

Through the application of JIT Arrival, GHG emissions and air pollutants can be reduced in a twofold manner:

- for the ship voyage through the optimization of the sailing speed and hence more optimal engine efficiency resulting in lower fuel consumption; and
- for the port area as the amount of time ships manoeuvring in the approaches or waiting at anchorage is reduced.

Further details

The process of a port call nowadays is not really optimized, because of the late availability and inaccuracy of information. This can result in a suboptimal port call process, due to unnecessary waiting time, which in turn results in excess GHG emissions from the ship. Ships, in general, “hurry” at full sea speed to the next port, only to find out that the berth is not available because of e.g. another ship is alongside, the cargo is not available for loading, or there is no tank available for discharging. This results in either having to “wait” outside the port at anchorages for many hours, days or even weeks, or manoeuvre at very low speeds in the port area while waiting for the availability of berth, fairway and nautical services. This “hurry up and wait” ship operation has many disadvantages and from an environmental, safety and economic perspective can be improved significantly.

Sending a Requested Time of Arrival (RTA) Pilot Boarding Place (PBP) (ideally, at least 12 hours before arrival) would allow the ship to optimize its speed to arrive Just In Time at the PBP when the availability of: 1. berth; 2. fairway; and 3. nautical services (pilots, tugs and linesmen) is ensured. This may still include anchor time as the optimized speed may take the ship to PBP before the RTA PBP. In a JIT Arrival scenario, the RTA PBP is frequently communicated to the ship, thereby enabling the Master to take a decision to optimize the ship’s speed.

JIT Arrival is not to be confused with slow steaming or an average/absolute speed limit. Through the application of JIT Arrival, the overall length or duration of a voyage is not impacted and remains the same. Instead, the voyage overall is optimized – the ship may spend more days sailing, but the aim is to minimize and preferably eliminate waiting time and enable sailing at a speed which gives reduced fuel consumption per mile steamed.

The ease of implementation will depend on the existing digital infrastructure e.g. a PCS. If such a PCS is present, it may still require a change of procedures to develop the capability to exchange the event data required for implementation of the measure.

Example ports (not exhaustive) which have implemented this measure

Port of Newcastle (AU) for bulk sector, ports with locks (e.g. Amsterdam, Ghent), Port of Busan (new port section), Port Everglades for cruise liners.

Other benefits

- Optimized port processes.
- Better capacity planning of nautical services (pilots, tugs and linesmen).
- Better capacity planning of terminals, berths and related resources.
- Better capacity planning of ship services (bunkers, MARPOL/waste, provisions, surveys etc.).
- Enhanced supply chain visibility due to improved predictability of cargo whereabouts.
- Optimized stock and asset management.
- Better planning of type and timing of hinterland modalities.
- Improved compliance to MLC due to improved rest hour planning.
- Reduced lube oil consumption.
- Less risk on piracy.
- Less accidents in anchorages.
- Less hull fouling.

Main barriers

- Today, there is no requirement or incentive for Ports and Terminals to facilitate the shipping sector to realize reduction of GHG emissions from ships at sea.
- Contractual barriers exclusively apply to those ships that operate under voyage charter (i.e. most bulkers and tankers), during the laden voyage. This is because voyage charter parties include a Due Dispatch clause which obliges the ship's Master contractually to proceed to the next port with utmost dispatch, regardless of whether a berth is available or not. Additional complications are e.g. when a ship carries several different cargoes, cargoes which may be traded many times between the load and discharge port, and shipping industry being rather reluctant to make amendments to charter parties.[8]
- Reluctance of key stakeholders (port, terminals and shipping) and data owners in the port call process to share information and data.
- Lack of data quality, timeliness and standardization of data being shared.
- The Master/Charterer is not always aware of the latest update of the RTA Berth to the Cargo buyer/seller, preventing further optimization of the ship's speed.

Suggested next steps/potential solutions

- Promote inclusion of a JIT Arrival standard clause in the voyage charter party to allow the ship's Master to optimize speed, without being in breach of contract (see BIMCO clause).[9]

- Incentivize and reward a collaborative approach for all stakeholders to participate (including encouraging terminals not to give berthing priority by arrival order).
- Promote data exchange and use of international standards for electronic data exchange (IMO Compendium).
- Demonstrate proof of concept and share experience from ports implementing JIT Arrivals. Port authorities could introduce JIT Arrivals by requiring the ship to be at the PBP at a specific agreed time.

For further information, please refer to the Just In Time Arrival Guide – Barriers and Potential Solutions (GloMEEP, Low Carbon GIA, 2020).

- **References**

[1] How Slow Steaming impacts Shippers and Carriers - Container xChange (container-xchange.com)

[2] Ship-board Energy Efficiency Measures - Trim optimization (shipsbusiness.com)

[3] Setting the course to low carbon shipping, ABS, 2019.

[4] https://www.bimco.org/news/priority-news/20210402-shipping-industry-takes-new-step-to-protect-marine-environments

[5] Regulation 19, Chapter V, SOLAS.

[6] http://www.emsa.europa.eu/publications/item/3734-annual-overview-of-marine-casualties-and-incidents-2019.html

[7] The S-44 Publication sets out the “Standards for Hydrographic Surveys”, developed by the International Hydrographic Office (IHO)

[8] IMO GIA Just In Time Arrival Guide.

[9] https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/just-in-time-arrival-clause-for-voyage-charter-parties-2021.