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Preparing for IMO 2020:
Marine Emission Solutions

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Introduction

Over 80% of global trade is carried by sea.[1] With more than 125,000 commercial and naval vessels operating around the world, ship-engine emissions are projected to rise by 250% by 2050 unless controls are imposed.[2] Pollution from ship engines is so significant that in 2016 the International Maritime Organization (IMO) issued "IMO 2020 Rule" to cut fuel sulphur content 86% by the year 2020. A component of acid rain, sulphur oxide (SOx) emissions contribute to ocean acidification that harms marine habitats and ecosystems. To comply with IMO 2020, commercial vessel operators and owners have two routes to take:

- Enhance engines and fuels: Commercial vessel operators can purchase higher cost low sulphur fuel oil (LSFO) or marine gasoil (MGO)—or for a high initial capital cost, they can retrofit their engine systems with scrubbers to remove SOx from emissions in conventional fuels.
- Use alternative propulsion systems: Operators can convert to alternative propulsion systems, such as liquefied natural gas (LNG) or modern electric systems that adopt hybrid technologies which integrate energy storage.

To gain an understanding of the best course to follow, ship operators and owners are advised to consider how regulations will affect the cost and availability of LSFO, the value of using improved engines and fuels, and the value of employing hybrid/electric drive technologies as an alternative to a 100% fossil-fueled ship.

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[1] "IMO (International Maritime Organization)." Business.un.org. Accessed October 31, 2018. https://business.un.org/en/entities/13.

[2] Jr., John H. Cushman, et al. "World Agrees to Cut Shipping Emissions 50 Percent by 2050." InsideClimate News. April 16, 2018. Accessed October 31, 2018. https://insideclimatenews.org/news/13042018/ocean-shipping-imo-agreement-reduce-climate-change-emissions-fuel-oil-zero-carbon-clean-energy-technology.

With more than 125,000 commercial and naval vessels operating around the world, ship-engine emissions are projected to rise by 250% by 2050 unless controls are imposed.[2]

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Section I
How regulations affect sulphur fuel costs and availability

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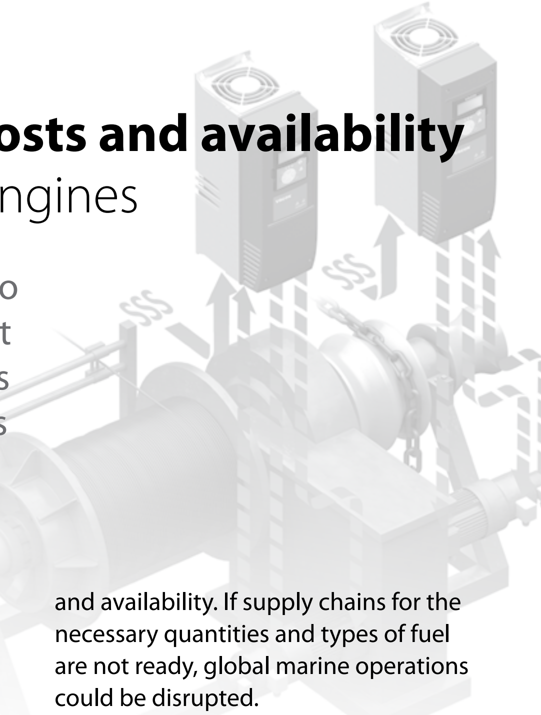
How regulations affect sulphur fuel costs and availability

Impact of global emission standards for engines



The IMO 2020 Rule requires ships to use MGO fuel with no more than 0.5% sulphur content compared to the current limit of 3.5%. In ships operating in Emission Control Areas (ECAs), which in North America extend 200 nautical miles from U.S. coasts, the sulphur content limit remains at the 2015 standard of 0.1%.

Sulphur and sulphur compounds naturally occur in petroleum, and special processing or low-sulphur feedstock is required to produce fuel with low sulphur content. Due to tight supplies and strong demand as the year 2020 draws near, there is no guarantee that LSFO supplies will be sufficient. To be confident to achieve the reduction from 3.5% to 0.5%, operators will need to do significant planning to ensure fuel is available for their vessel or fleet to avoid penalties.

Possible shortages could lead to significant price swings, making budgeting and investment scenarios complex. Industry analyst Wood Mackenzie forecasts a 25% increase in price for lower sulphur content fuel based on a SOx scrubber adoption rate of about 2%, but some scenarios could cause LSFO prices to spike by as much as 60%.[3]

The possible price ranges are illustrated in Figure 1. The price premium per metric ton of fuel has averaged $225 between 2012 and 2017. As of October 1, 2018, the Houston bunker price was $465 for intermediate fuel oil (IFO380 = 3.5% sulphur) and $745 for marine gasoil (MGO = 0.5% sulphur), a price gap of $280.[4]

In another scenario, an analysis by Stillwater Associates indicates that Rotterdam low sulphur fuel oil (LSFO) to high sulphur fuel oil (HSFO) spreads will increase from $2 in mid-2018 to $19 per barrel at the end of 2019, representing a percentage spread increase from 3% to 35% over 18 months, in anticipation of a sharp spike in demand for compliant fuel.[5]

Foreseeing more complexity, analysts cited by Wood Mackenzie posit that the very low adoption rate of scrubbers used to remove SOx could lead fuel suppliers to jettison HSFO supply overall, disincentivizing further adoption of scrubbers.

Overall, these scenarios indicate the uncertainty surrounding LSFO prices and availability. If supply chains for the necessary quantities and types of fuel are not ready, global marine operations could be disrupted.

Port standards setting the direction

From a global perspective, Nordic standards and markets are the most progressive in moving to low sulphur MGO, as evidenced by rapid adoption of zero-emission technologies in several waterways. These developments serve as an example for how the rest of the world may respond.

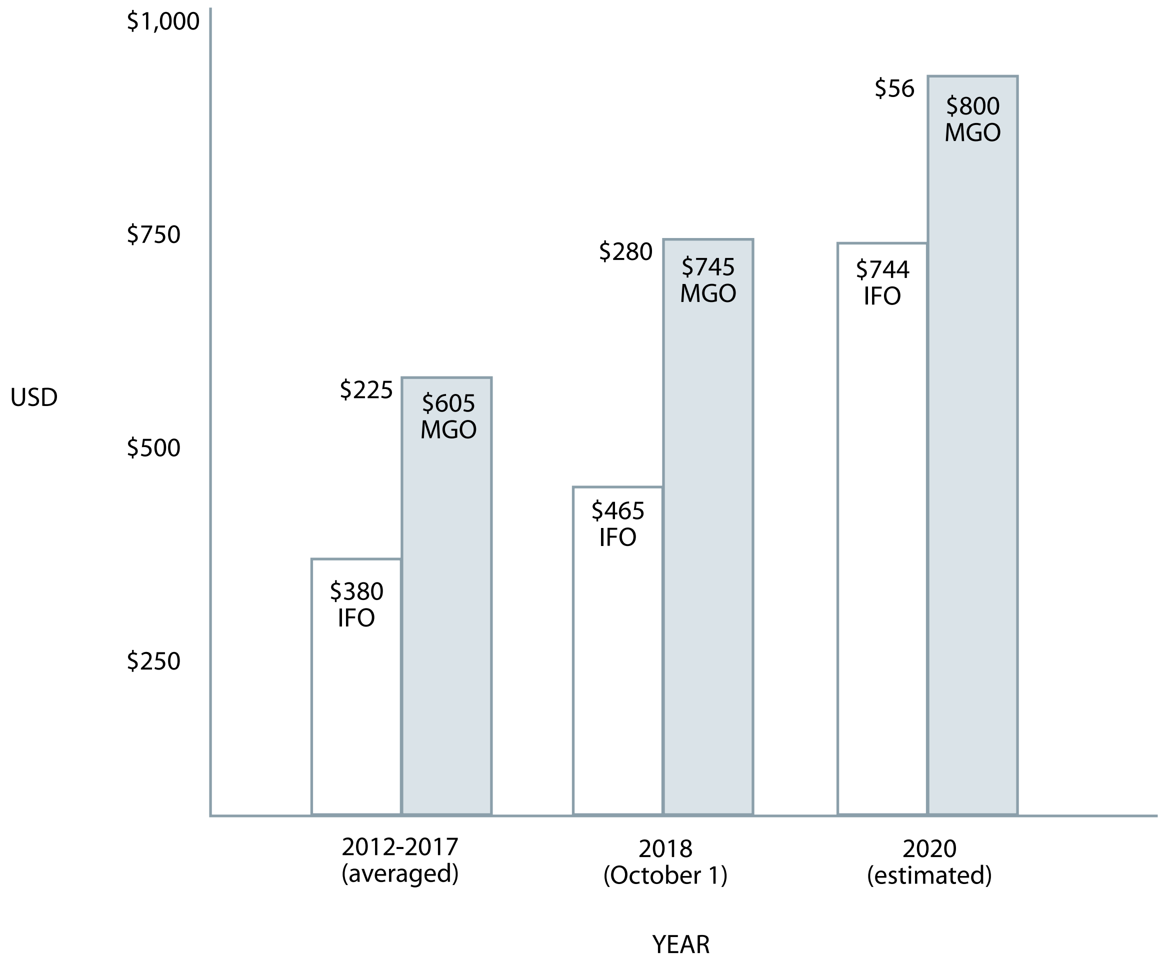
Leading the way in North America, the Port of Long Beach (PLB) is targeting zero emissions by 2035. Starting now, substantial changes are already underway that will affect equipment purchases to meet emission standards. Other ports on the West Coast also have bold strategies, following the lead of PLB.

[3] George, Libby. "Shipping Fuel Costs to Spike 25 Percent in 2020 on Sulfuric Cap:..." Reuters. April 11, 2018. Accessed October 31, 2018. https://www.reuters.com/article/us-shipping-fuel-costs/shipping-fuel-costs-to-spike-25-percent-in-2020-on-sulfuric-cap-woodmac-idUSKBN1HI1AT.
Also see: "How Will Upcoming IMO Sulphur Regulations Affect Shippers and Refiners?" How Will Upcoming IMO Sulphur Regulations Affect Shippers and Refiners? | Wood Mackenzie. Accessed October 31, 2018. https://www.woodmac.com/news/editorial/imo-aims-to-halve-global-shipping-emissions--but-what-will-it-cost/.

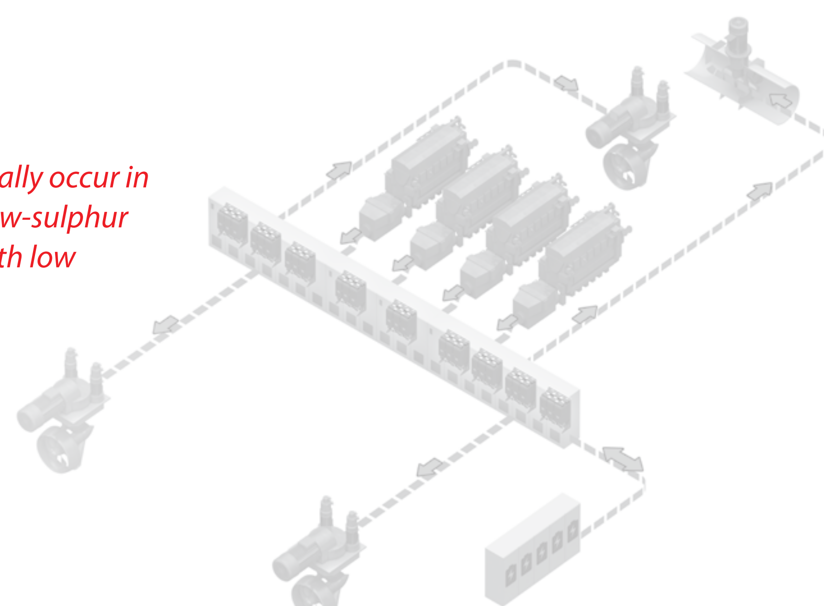
[4] Stillwater Associates. "Expected Pricing and Economic Impacts of the IMO 2020 Rule." Ship & Bunker. Accessed October 31, 2018. https://shipandbunker.com/news/world/215771-expected-pricing-and-economic-impacts-of-the-imo-2020-rule.

[5] Ibid.

Figure 1: *Price differences between IFO380 (3.5% sulphur) and MGO (0.5% sulphur) fuels*



Sulphur and sulphur compounds naturally occur in petroleum, and special processing or low-sulphur feedstock is required to produce fuel with low sulphur content.



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Section II
The value of fuel & engine improvements

Fuel utilization

When considering compliance with IMO 2020, most operators naturally think about adapting their vessels and engines to use whatever fuels may be available. Taking this track, ship owners have three options:

1. Use technology options that can utilize low-cost high sulphur fuel (HFO) with SOx scrubbers or exhaust gas cleaning systems (see discussion below)
2. Use available LSFO and MGO at higher variable cost, but which avoids capex investment for scrubbers or exhaust gas solutions
3. Use liquefied natural gas (LNG), a fuel that is virtually sulphur free. LNG prices are generally equivalent to or lower than HFO, but distribution facilities are not widespread due to limited demand today and high infrastructure development costs. As such, the extent of future LNG availability is questionable. Some ports are willing to invest, but LNG will not be available everywhere. Furthermore, the switch to LNG requires conversion to a different fuel management system that employs large refrigeration units to keep the gas in liquid state.

Technology options that allow the use of HFO

As an alternative to being exposed to the variable costs of LSFO, owners and operators can meet 2020 emission standards by investing in various technology options that can utilize HFO. For example, advanced marine engine designs are available that conform to the U.S. Environmental Protection Agency's (EPA) Tier 4 engine standards. Tier 4 engines incorporate several advanced technologies--including selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) (Figure 2). These two technologies significantly reduce nitrogen oxide (NOx) emissions for compliance in NOx Emission Control Areas such as the North Sea.

To achieve marine-engine emission reductions, engine manufacturers are employing several different approaches, such as:

- **Using modular exhaust after-treatment system (EAT)** to meet Tier 4 for workboats, allowing flexible component placement for ship designers. An SCR system coated with vanadium is used for greater sulphur resistance, allowing the use of high sulphur diesel fuel.
- **Using Tier 4 SCR technology** for lower fuel and urea consumption compared to Tier 3 engine types, while achieving high engine efficiency and emissions performance. Moreover, weight is 50% lower, full power acceleration is faster and engine performance is not derated if the SCR system fails
- **Using engines ready for LNG** in addition to electric and hybrid propulsion systems that incorporate analytics, automation and emissions control systems. (Using LNG and "hybrid" or low-sulphur-content fuels can also be done with Tier 3 engines to meet Emission Control Area requirements.)
- **Using a combination** of all available technologies while promoting EGR as a way to use smaller SCR.

Validating engine performance

Emissions sensors are critical components used in engine exhaust systems to track and prove emissions compliance. One example of an in situ emission sensor technology is the marine emission sensor MES 1001 offered by Danfoss IXA. The MES 1001 ensures that fuel switching and systems are working by combining continuous emission monitoring and data collection for authorities. The sensors can also deliver data to control SCR urea dosage, improving resource utilization and system performance (Figure 3, Page 13).

***Figure 2:** Understanding emission-reducing technologies needed to make even efficient engines operate more cleanly*

Type of Technology	Configuration	Function
SCR: Selective Catalytic Reduction	An "after-treatment" system placed off the engine to process engine exhaust.	Injects urea into the exhaust stream where a catalyst converts NOx into harmless diatomic nitrogen, carbon dioxide and water vapor. Urea and water are known as diesel exhaust fluid (DEF), which costs less than diesel fuel and improves efficiency, so the added cost of the process is balanced by the savings.
EGR: Exhaust gas recirculation	Diverts some of the exhaust gas into the engine's fresh intake air	Raises the engine temperature to burn off more particulate matter.
DPF: Diesel particulate filter	Located in the exhaust system to catch particulate matter (PM) in exhaust gas using precious metal catalysts	Burns off PM automatically or through a regeneration cycle. Eventually DPFs need to be replaced when they accumulate ash. (EGR systems typically need DPF as well.)
DOC: Diesel oxidation catalysts	Also located in the exhaust system and may be located before an SCR mixing tube	Changes diesel particulates to CO2 and H2O.

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Section III
The value of hybrid/ electric alternatives

Understanding hybridization

For vessel owners interested in reducing fossil fuel consumption, hybridization and electrification technologies complement or offer an effective alternative with many benefits.

A basic definition of hybridization is any system with two or more sources of energy acting together to accomplish a task. In the automotive world, a common example of hybridization technology is the hybrid car where a conventional internal combustion engine is combined with an electric propulsion system to create a 'hybrid' powertrain. The benefits of hybridization, in this instance, are fuel savings, performance improvements and reduced emissions. Similar solutions and benefits are available and becoming more widely implemented in marine applications.

Many long-haul vessels are still operating with direct diesel propulsion and no electric propulsion system. These vessels can improve efficiency and optimize main engine load power and emissions by adding a shaft generator/motor between the propeller and the main engine. This solution, called Power Take Out (implementing this system also enables Power Take In, which can be employed, for example, in "take me home mode") is an electrical add-on that makes vessels more efficient and ready for hybridization. In hybrid vessels, a shaft generator/motor with inverter technology allows the optimum control of propulsion machinery at various speeds to save energy.

For short-haul vessels where electricity is available via a shore supply, ships can use drive technology and energy storage to source clean energy from local grids. The ship's main generators can be switched off completely to prevent unnecessary NOx and carbon emissions and noise pollution while the vessel is docked.

Benefits of hybrid and electric-propulsion drives

Given that compliance with IMO 2020 can be achieved solely with engine design and technology enhancements, why should vessel owners consider a hybrid or an electric propulsion solution? A hybrid propulsion system uses diesel-engine generators to charge batteries that can be delivered by drives to electric motors. Compared to a 100% fossil fuel power plant subject to pricing variations, or a 100% battery-powered electric drive that requires extensive dock time to charge batteries from a shore power connection, a hybrid system has several advantages:

1. Reduced engine size and complexity: Because diesel engines are used to drive generators instead of propellers, the size of engines and SCR components can all be reduced. This reduces complexity and maintenance costs as well as engine noise and emissions. It also improves the ship design, because the diesel generators can be placed freely as the engine no longer has to be physically connected to the propulsion system. The drive technology creates a smooth drive train with less current spikes, and if peak loads are present, the energy will be handled from the energy storage.
2. Improved engine efficiency: The engines can operate at their most efficient point. The gensets charge the batteries when the vessels are at a standstill or running at low speed. When the vessel accelerates, the peak power is drawn from the batteries. In other words, the electric motors are used to do what they do best—provide high torque—and the batteries are used to shave peak power and offload the horsepower demands to improve engine efficiency and downsizing.
3. Retrofit to augment or replace engines: When a higher tier engine is retrofitted into a ship (e.g. a Tier 4 engine retrofitted into a tug), horsepower may suffer. In this case, batteries can be used to provide supplemental horsepower to the original rating to secure the vessel's earning power and profitability. In other retrofit situations, it may be possible to replace one engine with a battery and electric drive. This option is feasible when vessels are replacing their backup generator and auxiliary engine.
4. Meet port operation requirements: Using batteries and electric-motor drives enable emission-free idling in port or at an offshore rig. This option meets demanding port standards, already a primary consideration for European ports.

Concerns about hybrid and electric-propulsion drives

As with the application of any advanced technology, there are several potential drawbacks or risks to be considered.

First costs of hybrid/electric solutions are higher than traditional systems due to the addition of energy storage systems. However, battery costs are coming down as electric vehicles gain market adoption, helping to improve ROI. In many cases, the benefits of hybridization result in a payback of less than four years.

Fire safety is a consideration anywhere a lithium-ion battery is deployed. One early marine li-ion battery pilot project experienced a battery fire in 2012, which highlighted the potential risks. However, a subsequent risk assessment concluded that a properly designed and installed battery energy storage system would enable the vessel to achieve performance, emissions and fuel reduction objectives safely.

To address fire-safety concerns, solution providers can employ water mist, CO_2, foam, or dry chemical powder systems,—such as those offered by Danfoss Semco marine fire protection systems--that can be customized to fit particular needs.

Case histories demonstrating the benefits of hybrid/electric vessel systems

Evidence of the benefits of hybrid/electric systems is seen in marine applications around the world employing a range of advanced technologies available now.

Ferries:

In Amsterdam, IJveer Ferry 61 uses two 250kW electric motors for propulsion, each fed by two 133kW diesel engines and a 26 li-ion polymer battery pack producing 136 kWh. AC power is converted to DC using VACON® NXP AFE drives. The 50 Hz electrical ship grid is generated by a VACON® NXP Liquid Cooled drive with MicroGrid functionality. VACON® NXP Liquid Cooled Drives are also used to power the electric azimuth thrusters. This hybrid solution delivers 30% energy cost savings and 40% CO2 and particle emissions reduction.

In Taiwan, a ferry's diesel engines were replaced with two Danfoss EM-PMI electric motors with permanent magnet technology—a smaller and more manageable solution than a diesel engine. A propulsion motor was delivered that employs Danfoss EC-C1200 converters. One converter was used as the active front end (AFE) to charge the battery directly from the city's utility grid. This custom electrification solution applied by Danfoss EDITRON (formerly Visedo) delivered 33-50% fuel savings.

Tugboats:

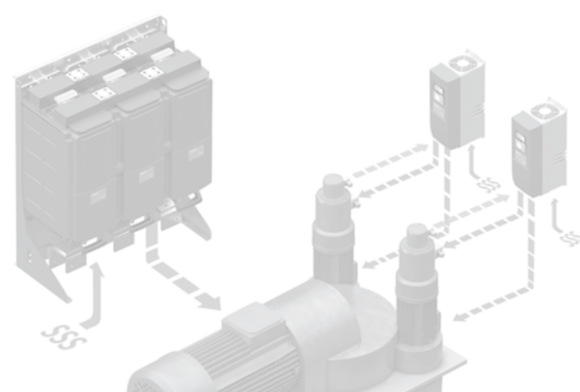
For a tug operating out of IJmuiden, Netherlands, a powertrain consisting of electric, diesel or direct diesel-electric drive was chosen because its low power profile was well-suited to the tugboat's operating requirements. The permanent magnet electric motor/generators are fully integrated with the azimuth thrusters, each of which is controlled by a Danfoss VACON® NXP drive. The hybrid powertrain delivers 20% operational cost savings on fuel and maintenance, plus 10% direct savings on diesel fuel.[9]

In Seattle, Washington, a shipyard retrofitted a tug with a hybrid diesel-electric powertrain to help reduce pollution at California's Port of Long Beach. Danfoss VACON® NXP technologies enable two 900 kW electric motors/generators to either assist the main diesel engines or act as a generator to recharge the 126 gel-cell lead acid batteries. At idle, no fossil-fueled motors are running. Stopped and tied at the dock, shore power provides for the tug's "hotel" needs and recharges the batteries. This solution produces 73% less PM, 51% less NOx and 27% less CO_2 than an earlier hybrid solution using a competitor's drive technology.[10]

Cruise ships:

A major river cruise line based its first river cruisers on an electrical energy and drive system using the VACON® NXP Liquid Cooled Drive that enables an efficient DC bus. Each ship is fitted with four asynchronous generators controlled by VACON® NXP drives that power the electric propulsion system and the onboard grid. Asynchronous generators are significantly more cost-effective than conventional gensets (standardized sets comprising a diesel engine and generator). The solution allows variable speed operation that optimizes fuel efficiency to yield 20% fuel savings. The drive also minimizes noise levels for the passengers. Given these and other benefits, the cruise line has made this electrical propulsion system standard on 50 vessels since 2009.[11]

A basic definition of hybridization is any system with two or more sources of energy acting together to accomplish a task.



[7] "Second Hybrid IJveer Ferry Powers Its Way across the Amsterdam 'IJ'." EST-Floattech. June 26, 2017. Accessed October 31, 2018. https://www.est-floattech.com/hybrid-ijveer-60-and-61/.
See also: "Hybrid ferries connect the city of Amsterdam nonstop." Danfoss. Accessed October 31, 2018. http://did.danfoss.com/en/equip-differently/hybrid-ferries/.

[8] "Danfoss Powers Asia's First E-ferry in Taiwan." Danfoss. Accessed October 31, 2018. https://www.danfoss.com/en/service-and-support/case-studies/dps/danfoss-powers-asia-s-first-e-ferry-in-taiwan/.

[9] "Hybrid powertrain improves tugboat economy and maneuverability." Danfoss. Accessed October 31, 2018. http://files.danfoss.com/download/Drives/DKDDPC940A102_Telstar.pdf

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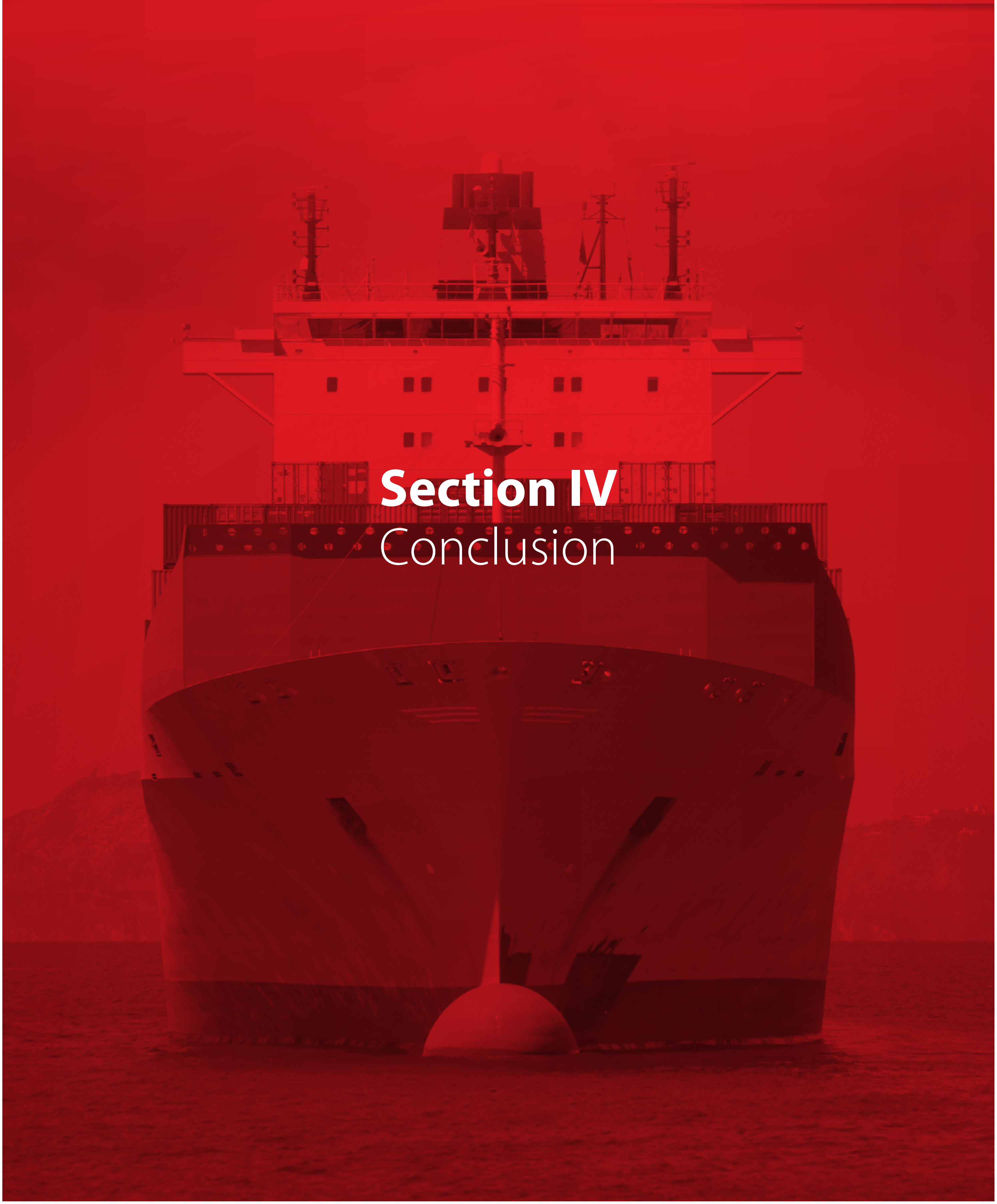
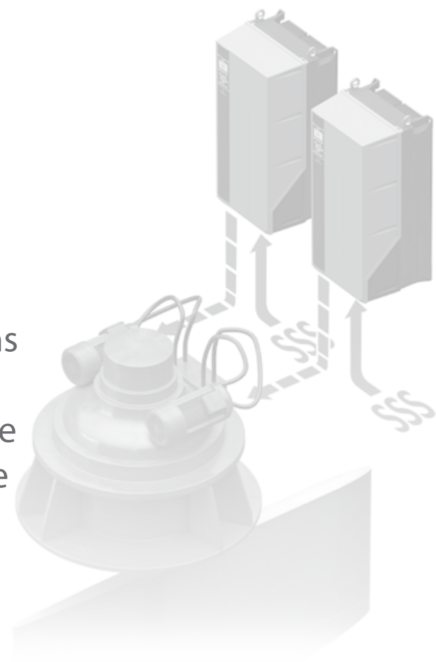


Section IV
Conclusion



To meet IMO 2020 international marine emission standards, commercial vessel operators can take one of three different options: 1) purchase higher cost low sulphur fuel oil (LSFO) or marine gas oil (MGO); 2) retrofit their engine systems with a selective catalytic reduction (SCR) scrubbers that entail a high initial capital cost; or, 3) convert to alternative propulsion systems like liquefied natural gas (LNG) or electric solutions. For each of these options, hybrid/electric drive technologies make it possible to optimize power generation and propulsion on board. To make the most advantageous decision, vessel owners and operators can compare these solutions in their specific applications, and plan ahead to avoid fuel cost and supply uncertainties looming on the horizon.

Firefighting—Reliable SEM-SAFE® Fire Fighting Systems from Danfoss Semco A/S. With more than 50 years of experience in the engineering, design, production and sales of fixed fire-fighting systems, Danfoss Semco A/S is dedicated to offering optimum solutions for ensuring fire safety for passengers and crew while reducing asset damage and keeping downtime to a minimum. The SEM-SAFE® fire-fighting systems from Danfoss are based on two key technologies: high-pressure water mist and low-pressure CO_2. The SEM-SAFE® high-pressure water mist technology is an environmentally friendly fire fighting media, perfect for applications such as accommodation, bilge and engine rooms. The SEM-SAFE® low-pressure CO_2 technology is a cost saving fire-fighting solution for large engine rooms and cargo holds.

Sensors and monitoring systems--Danfoss IXA: Dedicated to solving engine energy optimization and emission gas monitoring problems, Danfoss IXA offers advanced marine emission sensors to enable ship owners to comply with local and international emission regulations. MES products and services can continuously measure NO, NOx, SO2 and NH3 directly (in situ) in the exhaust system. The resultant sensor data enable dynamic engine control, closed feedback loops for after-treatment systems (e.g., scrubbers and SCRs) as well as documentation of fuel shifting.

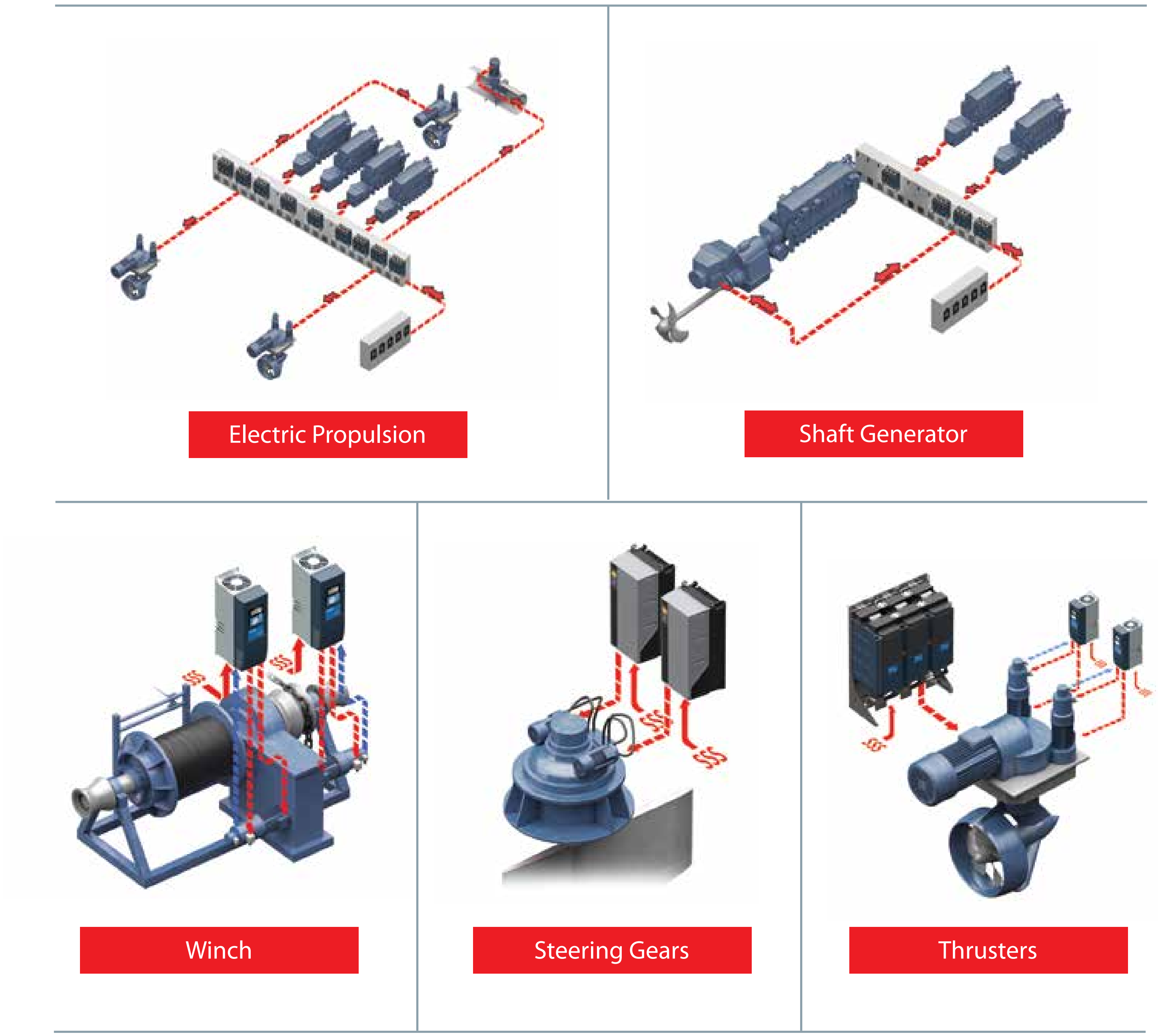
Smart hybrid and electric drivetrains—Danfoss EDITRON: Providing electric powertrains ranging from 30 to 2,000 kW, Danfoss EDITRON (formed from acquiring Visedo) offers a wide range of marine systems from single rotating machines to whole power plant and propulsion systems. In a revolutionary approach for smaller vessels, the EDITRON DC-grid hybrid propulsion solution can meet demanding weight, size, fuel consumption and emission-reduction targets that already meet IMO 2020 requirements.

Connecting electric motors, power conversions, energy sources and battery storage—hybrid solutions—Danfoss VACON® NXP Technologies: To reduce a ship engine's workload and emissions, Danfoss VACON® NXP offers a range of technologies that connect and condition electrical current to perform a variety of essential electrical functions. AC drives control the power supply to electric motors. AC converters allow power to be sourced from the local grid, rather than the ship's main engine or generators—or AC converters can be applied as a shaft-generator solution. DC/DC converters enable connections between energy storage batteries and the DC link across the shipboard grid.

[10] Flannery, Jim. "Harbor Tugs Move to Diesel/electric Power." Soundings Online. February 01, 2011. Accessed October 31, 2018. https://www.soundingsonline.com/news/harbor-tugs-move-to-dieselelectric-power.

[10] "VACON® NXP Liquid Cooled Drive Provides Quiet and Clean River Cruising." Danfoss. March 31, 2017. Accessed October 31, 2018. https://www.danfoss.com/en/service-and-support/case-studies/dds/vacon-nxp-liquid-cooled-drive-provides-quiet-and-clean-river-cruising/.

Figure 3: *Danfoss technologies that reduce marine engine emissions and improve energy efficiency*



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