MARINE FUEL OIL ADVISORY

MARCH 2023

ABS

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INTRODUCTION

Ship-sourced emissions have received increased scrutiny from the International Maritime Organization (IMO), government environmental agencies, public health advocates and non-governmental environmental groups. The goal of these entities is to reduce ship emissions to improve air quality. Initial regulations have been geared toward reducing SOx and NOx emissions in areas where shipping crosses paths with people, such as coastal and port areas. The IMO's 2020 Global Sulfur Cap expanded marine emissions requirements further to further reduce SOx emissions in waters outside of coastal zones.

To comply with the various regulations, vessels must adopt different approaches to control emissions. SOx restrictions are based on the level of sulfur content in the fuel used, which can be controlled using low sulfur fuel oil, biofuels or alternate technologies such as an exhaust gas cleaning system. An additional benefit of reducing SOx emissions is a decrease in the levels of particulate matter (PM), a pollutant directly regulated by the U.S. Environmental Protection Agency (EPA). To control NOx emissions from new ships, based on their construction date and Emission Control Area (ECA) application date, ships subject to MARPOL are required to comply with the Tier II NOx limits outside ECAs and the Tier III NOx limits within ECAs. Where these NOx emission limits cannot be met by the base engine itself, NOx reduction technologies such as exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) may be applied.

Due to the IMO 2020 fuel sulfur limits, increased use of dual-fuel engines, alternative fuels, biofuels and the wider variation of marine fuel specifications, it is vital that industry understands the available fuel options and the impacts on their fleets. This Advisory provides in-depth technical guidance covering a range of topics, from engine considerations to fuel properties to operational risks. Using this Advisory to understand the implications of different marine fuels, owners and operators can make informed decisions on the operation and future of their fleets.

TERMINOLOGY

Different acronyms are used by ISO, IMO and industry to define the categories of fuels used in the marine industry. Some of these acronyms are similar but their meaning may differ. IMO resolution MEPC.320(74), 2019 entitled Guidelines for Consistent Implementation of the 0.50% Sulfur Limit under MARPOL Annex VI, provides definitions of different marine fuels primarily based on the sulfur content. These new names are different than current generic acronyms e.g., HFO (Heavy Fuel Oil), MDO (Marine Diesel Oil), MGO (Marine Gas Oil) etc. The following definitions of marine fuel oils are used in this advisory:

1. Distillate marine fuels (DM) are as specified in ISO 8217:2017 (e.g., DMX, DMA, DMZ, DMB)
   Note: ISO 8217:2017 introduced distillate biofuels grade terminology for the DMA, DMZ and DMB grades with up to 7% FAME (Fatty Acid Methyl Ester) as DFA, DFZ and DFB.
2. Residual marine fuels (RM) are as specified in ISO 8217:2017 (e.g., RMA, RMB, RMD, RME, RMG, RMK)
3. Ultra-low sulfur fuel oil (ULSFO) (e.g., maximum 0.10% S ULSFO-DM, maximum 0.10% S ULSFO-RM)
4. Very low sulfur fuel oil (VLSFO) (e.g., maximum 0.50% S VLSFO-DM, maximum 0.50% S VLSFO-RM)
5. High sulfur heavy fuel oil (HSHFO) exceeding 0.50% S.

Comparison of fuel oil terminology uses by different organization:

IMO (MEPC.320 (74))	IACS (UI-SC123)	ISO (8217:2017)	Industry
DM		DMX, DMA, DMZ, DMB DFA, DFZ, DFB	Distillate Fuel
RM		RMA, RMB, RMD, RME, RMG, RMK	Residual Fuel
ULSFO-DM (≤0.10% S)	LSDMF (≤0.1%S)	DMX, DMA, DMZ, DMB (Sulfur content varies)	MGO (≤0.10% S)/ ECA Fuel
ULSFO-RM (≤0.10% S)	LSRMF (≤0.1% S)	RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	ECA Fuel
VLSFO-DM (≤0.50% S)	DMF (>0.1 % S)	DMX, DMA, DMZ, DMB DFA, DFZ, DFB (Sulfur content varies)	MGO (≤0.50% S)/ Global Fuel
VLSFO-RM (≤0.50% S)	RMF (>0.1% S)	RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	Global Fuel
HSHFO (>0.50% S)		RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	HFO (sulfur content varies)

Notes:
DM - Distillate Marine Fuels
RM - Residual Marine Fuels
ULSFO - Ultra-low Sulfur Fuel Oil
VLSFO - Very Low Sulfur Fuel Oil
HSHFO - High Sulfur Heavy Fuel Oil
MGO – Marine Gas Oil
LSDMF - Low Sulphur Distillate Marine Fuel
LSRMF - Low Sulphur Residual Marine Fuel
DMF - Distillate Marine Fuel
RMF - Residual Marine Fuel
HFO - Heavy Fuel Oil
ECA – Emission Control Area

BACKGROUND

The primary international regulatory mechanism for controlling air pollution from ships is IMO MARPOL Annex VI, Regulations for the Prevention of Air Pollution from Ships. The regulation limits the use of fuels with a sulfur content of up to 0.10% within the Emission Control Areas (ECAs) from January 1, 2015 and a sulfur content of up to 0.50% to be used globally from January 1, 2020. As defined in Regulation 2.9 of Annex VI, SOx emission controls apply to all fuel oil used in combustion equipment and devices onboard unless an approved exhaust gas cleaning system, such as a scrubber system, is installed. Alternatively, owners/operators may choose to utilize low sulfur content Marine Gas Oil (MGO) or 0.10% Heavy Fuel Oil (HFO) specifically developed for use in ECAs.

Most of the existing marine engines and other fuel burning equipment in operation are specifically designed to use HFO, MDO or MGO. Design modifications and operational adjustments may be necessary for engines and equipment to use alternative fuels.

Fuels utilized by marine diesel engines are petroleum-based products typically blended to meet the standard specifications. Many of the fuel and oil properties, such as specific energy content, ignition quality and specific gravity, are related to their hydrocarbon composition. Combustion of fuel in the diesel engine results in the formation of a complex mixture of gaseous and particulate exhaust emissions. During combustion, sulfur compounds in the fuel are predominantly oxidized to sulfur dioxide (SO2) and some sulfur trioxide (SO3) commonly known as SOx.

Particulate Matter (PM) is a complex mixture of particles and liquid droplets, generally from unburned fuel, oil and incombustibles, and which consists of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The Particulate Matter that exists in the emission stream has been shown to affect the heart and lungs and cause serious health effects in exposed persons.

The amount of SOx and Particulate Matter in the exhaust stream can be significantly reduced by burning cleaner, ultra-low sulfur marine fuel oils, e.g. ULSFO-DM or ULSFO-RM, and very low sulfur marine fuels e.g. VLSFO-DM or VLSFO-RM. To achieve a reduction of SOx and Particulate Matter in the environment, the use of 0.5% S fuel is mandatory globally from 2020 unless alternative technology such as an Exhaust Gas Cleaning System is being used.

ABS first published a Fuel Switching Advisory Notice in March 2010, which was revised in 2014 with significant updates and new guidance to shipowners, operators and builders to identify the potential risks of fuel switching and best practices. This Marine Fuel Oil Advisory has been developed considering the requirements on the use of fuels meeting new emissions standards or required limits. The major components of the previous Fuel Switching Advisory were incorporated into this new document. This document provides guidance to ship owners, operators and builders on different aspects of marine fuel oils, specifically addressing fuel specifications, quality, and key considerations prior to or during use.

SECTION 1 – INTERNATIONAL REQUIREMENTS

MARPOL Annex VI was adopted by the Protocol of 1997 to MARPOL and entered into force on 19 May 2005. It represents worldwide consensus that harmful air emissions from ships should be decreased as the ability to do so develops. Consequently, the IMO Marine Environment Protection Committee (MEPC) 58th Session in October 2008, adopted a Revised MARPOL Annex VI – Resolution MEPC.176(58), applicable from July 1, 2010. The revisions adopted include progressive reductions of SOx emissions from ships, progressive reductions of NOx emissions from marine engines and revised criteria for ECAs. As a result of the IMO's Marine Environment Protection Committee meeting held in October 2016 (MEPC 70), a marine fuel sulfur cap of 0.50% effective January 1, 2020 was confirmed. Under this global sulfur limit, ships must transition to marine fuels with a sulfur content of no more than 0.50% unless using approved equivalent methods under regulation 4.1 of MARPOL Annex VI, such as an exhaust gas cleaning system (EGCS).

Furthermore, the MEPC 73rd session in October 2018, approved amendments to regulation 14 of MARPOL Annex VI and the form of the Supplement to the IAPP Certificate concerning the prohibition of the carriage of non-compliant fuel oil for combustion purposes with a sulfur content exceeding 0.50%. Exemptions for ships equipped with an equivalent arrangement were also approved.

The Resolution provides controls specific to operation inside ECAs established to limit the emission of SOx and Particulate Matter (PM) and those applicable outside such areas and are primarily achieved by limiting the maximum sulfur content of the fuel oils used onboard. These fuel oil sulfur limits (expressed by weight in terms of % m/m) are subject to a series of step changes over the years, as shown in Table 1 and Table 2.

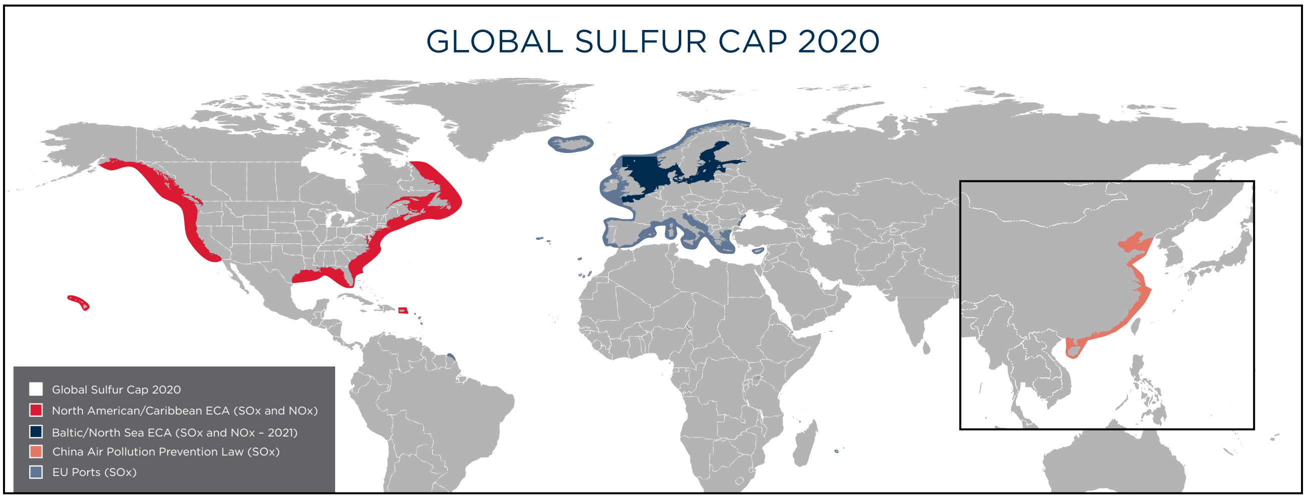


Table 1: MARPOL Annex VI, Regulation 14 – Global SOx Compliance Dates

Compliance Date	Sulfur Limit in Fuel (% m/m)
January 1, 2000	4.5%
July 1, 2012	3.5%
January 1, 2020	0.50%

Table 2: MARPOL Annex VI, Regulation 14 – Emission Control Area Compliance Dates

Compliance Date	Sulfur Limit in Fuel (% m/m)
January 1, 2000	1.5%
July 1, 2012	1.0%
January 1, 2015	0.10%

SECAS AND ECAS

Regulations 13 (NOx) and 14 (SOx) of Annex VI contain provisions for countries to apply to the IMO for designation of emission control areas (ECAs) to further reduce harmful emissions from ships operating in their coastal waters. The first two ECAs approved by the IMO, originally only for SOx and known as SECAs, were the Baltic Sea and the North Sea (including the English Channel), as shown in Figure 1. The IMO then approved two more ECAs: the North American and US Caribbean Sea, as shown in Figure 2 and Figure 3 respectively. These later ECAs include NOx Tier III emission restrictions in addition to the SOx emissions restrictions. The NOx Tier III emissions restrictions were enforced from January 1, 2016 in these two ECAs. It should be noted that MARPOL Annex VI does not specifically limit PM but PM is reduced by regulating the sulfate portion of PM formation through the fuel sulfur content requirements of Regulation 14 to Annex VI.

During MEPC 71, the IMO adopted Resolution MEPC.286(71), amendments to MARPOL Annex VI, introducing two new NOx Emission Control Areas (ECAs)– the Baltic Sea and the North Sea – by adding the NOx limits to the original SECA SOx limits, and which for NOx purposes is applicable for ships whose keel is laid on or after January 1, 2021, or existing ships which replace an engine with "non-identical" engines, or install an additional engine on or after that date.

The IMO Annex VI Emission Control Areas are identified in Table 3.

Figure 1: Baltic and North Sea/English Channel ECA

Figure 2: The North American ECA 200 nautical miles offshore US and Canada, including Hawaii, St. Lawrence Waterway and the Great Lakes

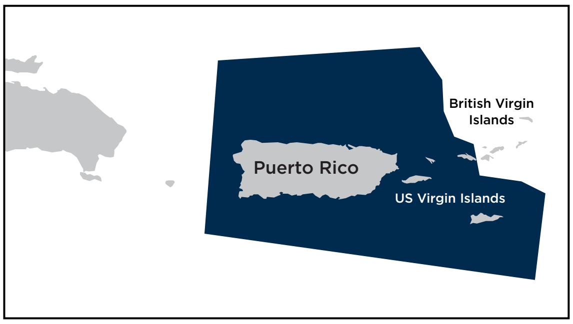


Figure 3: The United States Caribbean Sea ECA

Table 3: Effective Dates of SOx and NOX emissions in different Emission Control Areas

Emission Control Area	SOx Effective Dates	NOx Effective Dates
Baltic Sea	May 19, 2006	January 1, 2021
North Sea	May 22, 2007	January 1, 2021
North American	August 1, 2012	January 1, 2016
US Caribbean Sea	January 1, 2014	January 1, 2016

Beginning January 1, 2015, ships that operate in an ECA are required to use low sulfur fuel with a sulfur content no greater than 0.10%. To meet these requirements, vessels must use ultra-low sulfur oil (e.g., ULSFO-DM or ULSFO-RM) fuel. Alternatively, ships can use higher sulfur HFO if they use an approved exhaust gas cleaning system (EGCS), also known as a scrubber.

To satisfy the lower 0.10% sulfur content in ECAs, some vessels switch to lower sulfur fuels as they approach the area. In such cases, the ship shall carry on board a written procedure showing how the fuel oil changeover is to be accomplished, ensuring sufficient time will be allotted for the fuel system to be flushed of all noncompliant fuel prior to entering the ECA. The date, time and place of the fuel changeover and the volume of low sulfur fuel in each tank shall be logged when entering and leaving the ECA. The crew must be trained to carry out the fuel management and fuel switching procedure. An example Fuel Oil Management Plan template is included as Appendix 1.

Similarly, when ships are entering or exiting a NOx ECA, the engine NOx Tier and on/off status of marine diesel engines installed onboard shall be recorded in a logbook, including when the on/off status changes within the ECA.

BUNKER DELIVERY NOTES AND SAMPLING

Regulation 18 of MARPOL Annex VI provides that in the event compliant fuel oil cannot be obtained, a party to MARPOL Annex VI shall take reasonable steps to promote the availability of fuels which comply with the Annex. In the event a compliant fuel oil cannot be obtained, Regulation 18 of MARPOL Annex VI currently provides that a Party to MARPOL Annex VI can request evidence outlining the attempts made to obtain the compliant fuel, including attempts made to locate alternative sources. When a ship visits a port where the operator cannot purchase compliant fuel oil due to non-availability, the operator is to notify the ship's Administration and the next destination port authority; the Administration shall notify IMO of the non-availability of compliant fuel oil. This notification is commonly referred to as a Fuel Oil Non-Availability Report (FONAR). The standard format of FONAR is provided in Appendix 1 of MEPC.320(74).

Vessels unable to obtain compliant low sulfur fuel oil prior to entering the North American ECA are required to file a report with the US Environmental Protection Agency (EPA) and authorities at the relevant destination port using the EPA's Fuel Oil Non-Availability Report (FONAR).

A vessel unable to obtain compliant low sulfur fuel oil prior to entering the Baltic and North Sea SECAs must provide evidence that it attempted to purchase compliant fuel oil in accordance with its voyage plan and that, despite best efforts, no such fuel oil was available. If a ship provides the above information, the competent authority shall consider all relevant circumstances, and the evidence presented, to determine the appropriate action to take, including not taking control measures.

Regulation 14 requires suppliers of any fuel intended for use in an ECA to document the sulfur content in accordance with Regulation 18. Lower sulfur content fuel shall be segregated from higher sulfur content fuel.

Paragraph 3 of the revised Regulation 18 gives specific requirements for the quality and contents of fuel oils. Per paragraphs 5 and 6, each ship shall receive and retain on board for three years bunker delivery notes from the fuel supplier containing the details of the fuel supplied. The form of the bunker delivery note shall follow the sample provided in Appendix V of the Revised MARPOL Annex VI which was revised and adopted in the 71st session of the IMO's Marine Environment Protection Committee. The Resolution MEPC. 286(71) amendments to the MARPOL Annex VI bunker delivery note (BDN) contains the supplier's declaration confirming the product does not exceed specific sulfur limits. Delivery notes should also be accompanied by product Material Safety Data Sheets (MSDS).

Per paragraphs 8.1 and 8.2 of Regulation 18, each bunker delivery note shall be accompanied by a representative sample of the fuel oil delivered. This sample is to be collected from the ship's bunker manifold, not the supply barge. The sample shall be sealed and signed by the supplier's representative and the Master or officer in charge of the bunker operation on completion of bunkering. It shall be retained under the ship's control for a period of not less than 12 months. It is necessary that oversight by the ship is applied both to the bunker delivery note and the representative fuel oil sample. When the bunker delivery notes or the representative sample are not in compliance with the relevant requirements or if the BDN shows compliant fuel, but the master has independent test results of the fuel oil sample taken by the ship during the bunkering which indicates non-compliance, the master or officer in charge of the bunker operation may have documented the discrepancy through a notification to the ship's Flag Administration with copies to the bunkering port authorities, authority of the port of destination and the bunker supplier, and a further copy retained onboard with any relevant commercial documentation.

If the stated sulfur content of the sample requires analysis, it shall be performed in accordance with the verification procedure set forth in Appendix VI of the Revised MARPOL Annex VI. The analysis shall verify the sulfur content of the supplied fuel oil. Samples shall remain sealed until opened at the laboratory, which shall confirm chain of custody. A detailed sample handling and verification procedure shall be followed by the laboratory.

The amended Regulation 14 of the Annex VI in accordance with MEPC.1/circ.882 dated July 16, 2019, has additional requirements on "In-use and on board fuel oil sampling and testing" where if the competent authority of a Party requires the in-use or onboard fuel oil sample to be analyzed, it shall be done in accordance with the verification procedure set forth in appendix VI of MARPOL Annex VI to determine whether the fuel oil being used or carried for use on board meets the requirements in paragraph 1 or 4 of Regulation 14.

The on board fuel oil sampling and verification is to be conducted in accordance with the guidelines provided by resolution MEPC. 324(75) of the International Maritime Organization.

The in-use fuel oil sample shall be drawn considering the guidelines of the MEPC.1/Circ.864/Rev.1 and the content of the document provided below.

The sample shall be sealed by the representative of the competent authority with a unique means of identification installed in the presence of the ship's representative. The ship shall be given the option of retaining a duplicate sample.

The requirements of the "In-use fuel oil sampling point" are:

1. Ships shall be fitted or designated for the purpose of taking representative samples of the fuel oil being used on board.
2. For a ship constructed before entry into force of these requirements, the sampling point(s) shall be fitted or designated no later than the first renewal survey that occurs 12 months or more after the entry into force of this regulation.
3. The above requirements are not applicable to a fuel oil service system for a low-flashpoint fuel for combustion purposes for propulsion or operation on board the ship.
4. The competent authority of a Party shall, as appropriate, utilize the sampling point(s) which is/are fitted or designated for the purpose of taking representative sample(s) of the fuel oil being used on board to verify the fuel oil's compliance with Regulation 14. Taking fuel oil samples by the competent authority of the Party shall be performed as expeditiously as possible without causing undue delay to the ship.

The guidelines provided by MEPC.1/Circ.864/Rev.1 dated 21 May 2019 for on board sampling for the verification of the sulfur content of the fuel oil used on board ships on following:

Sampling location:

1. The in-use representative sample or samples should be obtained from a designated sampling point or points.
2. The number and location of designated fuel oil sampling points should be confirmed by the Administration following consideration of possible fuel oil cross-contamination and service tank arrangements.
3. Fuel oil sampling points to be used should fulfill all the following conditions:
    a. be easily and safely accessible;
    b. take into account different fuel oil grades being used for the fuel oil combustion machinery item;
    c. be downstream of the in-use fuel oil service tank;
    d. be as close to the fuel oil combustion machinery as safely feasible taking into account the type of fuel oil, flow-rate, temperature, and pressure behind the selected sampling point;
    e. be clearly marked for easy identification and described in either the piping diagram or other relevant documents;
    f. each sampling point should be located in a position shielded from any heated surface or electrical equipment and the shielding device or construction should be sturdy enough to endure leaks, splashes or spray under design pressure of the fuel oil supply line so as to preclude impingement of fuel oil onto such surface or equipment; and
    g. the sampling arrangement should be provided with suitable drainage to the drain tank or other safe location.

Sample handling:

1. The fuel oil sample should be taken when a steady flow is established in the fuel oil circulating system.
2. The sampling connection should be thoroughly flushed through with the fuel oil in use prior to drawing the sample.
3. The sample or samples should be collected in a sampling container or containers and should be representative of the fuel oil being used.
4. The sample bottles should be sealed by the inspector with a unique means of identification applied in the presence of the ship's representative.
5. The ship should be given the option of retaining a sample.
6. The label should include the following information:
    a. sampling point location where the sample was drawn;
    b. date and port of sampling;
    c. name and IMO number of the ship;
    d. details of seal identification; and
    e. signatures and names of the inspector and the ship's representative.

SECTION 2 – REGIONAL, NATIONAL AND LOCAL REQUIREMENTS

In addition to the international regulations issued by the IMO, there are other fuel and air emissions regulations issued by regions, countries and the State of California that may also be applicable, depending on the area of operation.

The European Union (EU) and California Air Resources Board (CARB) have adopted regulations requiring the use of low sulfur marine fuels in designated areas. These regulations require owners to assess their operations within the affected regions and evaluate engine's and associated machinery/equipment's ability to operate with low sulfur fuel.

EU IN-PORT REGULATIONS

EU Commission Regulation Article 4b of the EU Council Directive 1999/32/EC, dated April 26, 1999, denotes a reduction in the sulfur content of certain liquid fuels and is amended by EU Directive 93/12/EEC. The regulation was further amended several times and then Codified for clarity as EU Directive 2016/802/EU of May 11, 2016. As amended in 2005 by EU Directive 2005/33/EC (effective January 1, 2010) , it introduced a 0.10% sulfur limit (m/m) for marine fuel at berth.

These directives apply to all types of marine fuel used by ships at berth for more than two hours in EU ports unless an approved emission abatement technology is employed, or shore power is used. It should be noted that both main and auxiliary boilers fall under the requirements of the EU Directive. Vessels using boilers burning HFO or MDO to power steam-driven cargo pumps are impacted by the EU Directive and are required to burn low sulfur content fuel while in port.

EU COMMISSION DECISION ON LNG CARRIERS

Recognizing that many liquefied natural gas (LNG) carriers use a mixture of boil off gas (BOG) and HFO, the Commission took action to allow the use of such mixtures, provided the resulting emissions of sulfur dioxide are demonstrated to be equal to or lower than that required by the EU Directive. The Commission Decision 2010/769/ EU, dated December 13, 2010, established a technological abatement method for LNG carriers to utilize a mixture of boil-offgas and marine fuel while at berth as an alternative to use of low sulfur marine fuels meeting the requirements of Article 4b of the Council Directive 1999/32/EC, as amended by Directive 2016/802/EU. The calculation criteria for this alternative technological abatement method are set out in the Annex of the Commission Decision 2010/769/EU. Further, in a letter to the European Community Shipowners' Associations (ECSA) dated June 6, 2014, the Commission clarified that provided *"the HFO pilot fuel used in the mixture has sulfur content in mass equal or lower than 0.50%, the requirements of Article 4c of the Directive are complied with and the abatement method in question shall be allowed in SECAs as an alternative compliance option with Directive 2012/33/EU."*

UNITED STATES REGULATIONS

The U.S. Environmental Protection Agency (EPA) and U.S. Coast Guard are authorized to administer MARPOL Annex VI by the Act to Prevent Pollution from Ships. U.S. EPA regulations implementing Annex VI are codified at 40 CFR Part 1043. Table 2 of Part 1043.60 specifically covers the fuel oil sulfur limits in accordance with the requirements of the regulation 14 of MARPOL Annex VI.

The NOx emission limits in Regulation 13 of MARPOL Annex VI are applicable to U.S. flagged ships trading in international waters and foreign flag ships while operating in the U.S. ECA areas. US flagged vessels are also subject to engine requirements under the Clean Air Act. The U.S. EPA categorizes marine engines under Clean Air Act regulations in 40 CFR 1042 based on cylinder displacement.

Engines intended to be installed onboard U.S. flagged vessels are to comply with the emission requirements laid down in 40 CFR Part 1042 and 40 CFR Part 1043 and in addition to NOx, limit hydrocarbons (HC), PM and carbon monoxide (CO).

For further information see the ABS Advisory on NOX Tier III Compliance.

CALIFORNIA AIR RESOURCES BOARD (CARB) REGULATIONS

The California "Fuel Sulfur and Other Operation Requirements for Ocean-Going Vessels within California Waters and 24 Nautical Miles of the California Baseline" (also known as the Ocean Going Vessel (OGV) Fuel Regulation), in force since July 2009, was designed to provide significant air quality benefits by requiring the use of cleaner, low sulfur marine distillate fuel in ship main engines, auxiliary engines and auxiliary boilers. The OGV Fuel Regulation does not apply to propulsion boilers.

Amendments were made to align California's OGV Fuel requirements with the North American ECA, including the implementation of the 1.0% sulfur limit effective August 1, 2012. The original regulation required the use of 0.10% sulfur distillate fuel, beginning January 1, 2012, but was amended on June 23, 2011, extending the effective date for Phase II by two years, to January 1, 2014 (See Table 4 where DMA and DMB are marine distillate fuel designations).

Table 4: CARB Fuel Requirements for Ocean-Going Vessels (OGV)

Fuel Requirement	Effective Date	ARB's California OGV Fuel Requirement Sulfur Content Limit
Phase I	January 1, 2000	Marine Gas Oil (DMA) at or below 1.50% sulfur; or Marine Diesel Oil (DMB) at or below 0.50% sulfur
	August 1, 2012	Marine Gas Oil (DMA) at or below 1.0% sulfur; or Marine Diesel Oil (DMB) at or below 0.50% sulfur
Phase II	January 1, 2014	Marine Gas Oil (DMA) at or below 0.10% sulfur; or Marine Diesel Oil (DMB) at or below 0.10% sulfur

Operators must comply with both the California OGV Fuel Regulations and the North American ECA requirements. All engines and boilers, except main propulsion boilers, are affected by the above regulations and it is mandatory to operate engines and auxiliary boilers on low sulfur marine fuel with a sulfur content indicated in the respective regulations noted above.

Originally, all California waters within 24 nautical miles of the California baseline were affected by the OGV Fuel Regulation. Then, in June 2011, the regulatory boundary in Southern California was amended to also include the region 24 nautical miles from each of the Channel Islands. The boundary was also changed to align more closely with the California baseline denoted by the 2007 National Oceanic and Atmospheric Administration (NOAA) charts. The current restricted area is illustrated in Figure 4. Even though the California regulations allow use of MDO under both Phase I and Phase II, MDO is currently not available with sufficiently low sulfur content, and thus, ships will effectively be using MGO to satisfy the low sulfur distillate fuel requirement during Phase II.

The CARB OGV Fuel regulations do not include provisions for the use of equivalent arrangements (i.e., EGCS/Scrubber) or the use of low sulfur residual fuels which includes 0.10% Heavy Fuel Oil known as ECA compliant fuel oil. In this regard, the CARB Marine Notice 2014-1, dated August 2014 authorized a temporary "Research Exemption" which was revised and ended on December 31, 2017 as per CARB Marine Notice 2017-1, dated August 2017.

CARB allows vessel to operate in California waters using only 0.10% sulfur distillate fuel oil (e.g. ULSFO-DM). Using 0.10% Residual Fuel (e.g. ULSFO-RM) or scrubbers is prohibited and is not a compliance option under the California Oceangoing Vessel Fuel Regulations. The regulation requires the use of distillate grade marine fuels (marine gas oil (DMA/DMX) or marine diesel oil (DMB)) with a maximum sulfur level of 0.1% while operating main engines, diesel-electric engines, auxiliary engines, and auxiliary boilers.

According to the Marine Notice 2020-2 dated October 2020, CARB utilizes Test Method ISO 10370 (determination of carbon residue - micro method) which can identify non-compliant vessels that are operating on contaminated fuels e.g., fuel meeting the sulfur limit but not meeting the distillate grade requirements as referenced in the regulation.

CARB encourages vessel owners and operators to have effective operating procedures and crew training so that vessels will carry the correct distillate grade fuel, eliminate all areas of potential contamination with residual grade fuels, and perform complete flushing of all residual grade fuel oils from engines and fuel oil supply systems once fuel changeover has been completed prior entering into the regulated California waters.

To help ships avoid loss of propulsion from fuel switching and the accompanying potential for oil spills due to collision or grounding, the State of California Office of Spill Prevention and Response published a practical guideline for vessels intending to enter the Emission Control Area for the first time. According to the document, "Preventing Loss of Propulsion after Fuel Switch to Low Sulfur Distillate Fuel Oil," the vessel's crew should conduct a "trial" fuel switch by practicing a full switch to low sulfur distillate fuel within 45 days prior to entering regulated California waters for the first time. The vessel's crew should also operate main and auxiliary engines no less than four (4) hours on low sulfur fuel oil. This will help crew members identify any specific change over operational issues or problems.

The guidelines also strongly advised the following be conducted 45 days prior to entry into regulated California waters:

- Operate main engine from the engine control room.
- Operate main engine from engine side (local).

Crew should become familiar with "Failure to Start" procedures while maneuvering and establish corrective protocols for "Failure to Start" incidents.

While underway, after fuel switching is completed, the Master should ensure one of the Senior Engine Room Officers is in the engine control room while the vessel sails through pilotage waters and is:

- Able to operate the main engine from the engine control room.
- Able to operate the main engine from engine side (Local).

Provisions for a safety exemption is included in California Code of Regulations, title 13, section 2299.2, subsection (c)(5), and title 17, section 93118.2, subsection (c)(5). The safety exemption provides the Master of the vessel with an exemption from the regulation in situations where compliance would endanger the safety of the vessel, its crew, its cargo or its passengers due to severe weather conditions, equipment failure, fuel contamination, or other extraordinary reasons beyond the Master's reasonable control.

CALIFORNIA AT-BERTH OCEAN-GOING VESSELS REGULATION

California Code of Regulation (CCR), Section 93118.3 addresses Airborne Toxic Control Measures for Auxiliary Diesel Engines Operated on Ocean-Going Vessels (OGV) Berthed at a California Port. This CCR is applicable to U.S or foreign flagged container vessels, passenger vessels and refrigerated cargo vessels when they visit California ports, including the Port of Los Angeles, Long Beach, Oakland, San Diego, Hueneme, and San Francisco.

The purpose is to reduce oxides of nitrogen (NOx) and diesel particulate matter (PM) emissions from the operation of auxiliary engines while these vessels are berthed at a California port. The CCR mandates that any OGV (in addition to above three types), if equipped to use high voltage shore power, the vessel is required to perform 'Cold Ironing' while visiting any California port. This reduces emissions by limiting the time during which auxiliary diesel engines are operated on the regulated vessels while such vessels are-berthed in a California port. Vessels visiting terminals are permitted to use one or more control techniques including electric power from the utility grid, electrical power from sources that are not part of an utility's electrical grid (distributed generation), or alternative control technologies that achieve equivalent emission reductions.

Figure 4: California's Ocean Going Vessel Regulatory Zone

The California At-Berth OGV Regulation ultimately requires a fleet operator to reduce at-berth emissions from its vessels' auxiliary engines. Fleet means a number of vessels owned/operated by an entity that visits a specific California port as per following criteria:

- A fleet composed solely of container or refrigerated cargo vessels that visits the same California port 25 times or more in a calendar year; and
- A fleet composed solely of passenger vessels that visits the same California port 5 times or more in a calendar year.

A reduced onboard power generation option was implemented from January 1, 2014 and the requirement changes to next levels on January 1, 2017 and January 1, 2020 respectively where ship operators are to use high voltage shore power to perform 'Cold Ironing'. This reduced power generation includes percent of a fleet's visit to a port and the percentage reduction of on board power generation from the fleet's baseline power generation. Beginning January 1, 2017, this value became 70 percent and beginning January 1, 2020, it increases to 80 percent.

Table 5: California At-Berth OGV Regulation Compliance Schedule

Requirements	Percentage of fleet's visits to port required to meet operational time limits	Percentage reduction of AE power generation from fleet's baseline
2014	50%	50%
2017	70%	70%
2020	80%	80%

CARB has developed new sections 93130-93130.22 of title 17 of the CCR on airborne toxic control measure from auxiliary diesel engines operated onboard Ocean Going Vessels at Berth. This new section supersedes the current section 93118.3 of title 17 of the CCR on January 1, 2023.

The new sections 93130-93130.22 have noticeable changes compared to the existing section 93118.3, where key requirements include:

- Every vessel visiting a terminal/berth of a California port is to use either shore power or a CARB Approved Emission Control Strategy (CAECS) during each visit.
- The effective compliance date of each type of vessel is as per below table:

Compliance Start Date	Vessel Type
January 1, 2023	Container, refrigerated cargo and passenger
January 1, 2025	Roll-on roll-off
January 1, 2025	Tanker (Visits only ports of Los Angeles or Long Beach)
January 1, 2027	All remaining tanker

- Both vessel and terminal operators must report vessel visit information within 30 days of each vessel's departure.
- Expended scope of regulated vessel types as mentioned in above table.
- Extended the application of the regulation to all ports in California receiving an ocean-going vessel.
- Shared responsibilities among all crucial parties, including vessel owners, vessel operators, terminal operators, port authorities and CAECS operators.

Shore power is the preferred method for compliance if the ocean-going vessel is provided with commissioned shore power equipment. Other CARB Approved Emission Control Strategy (CAECS) are acceptable when vessel is not equipped with shore power equipment. Both NOx and PM emissions are limited. The NOx limitation applies not only to auxiliary engine, but also to auxiliary boilers on tankers. The limitation for auxiliary engines is more stringent than IMO Tier III limit.

THE PEOPLE'S REPUBLIC OF CHINA REGULATIONS

The Chinese government announced in late 2015 their three-year plan to reduce SOx emissions starting on January 1, 2016, with the issuance of their Implementation Plan for Marine Air Pollutant Emission Control Areas for Pearl River Delta, Yangtze River Delta, and Bohai Rim Area. The three emission control areas were known as China Domestic ECA 2015.

Figure 5: China ECA

An upgraded Plan was released on November 30, 2018 by the Ministry of Transport of The People's Republic of China named as Implementation Plan for Marine Air Pollutant Emission Control Areas. The three specific ECAs have been removed from the title, which reflects the change to the scope of China Domestic ECA 2015. According to the officially published document, the emission control areas are categorized as Coastal Emission Control Area and Inland Water Emission Control Area.

The scope of Coastal Emission Control Area has been extended to cover all China coastal territorial waters (12 nautical miles from the coastal line), excluding the territorial waters from the coastline of Hong Kong, Macao and Taiwan. Hainan Island territorial coastal waters are within China ECA and are specifically defined. The Inland Water Emission Control Area includes the navigable waters of Yangtze River and Xi-Jiang River. The ECA extension is illustrated in Figure 5.

The latest China ECA plan requires ships to comply with the SOx emission and particulate matter control requirements:

- Beginning January 1, 2019, ships entering the new China ECAs must use fuel with ≤0.50% sulfur content.
- Starting January 1, 2020, ships entering the Inland Water ECA must use fuel with ≤0.10% sulfur content.
- Starting January 1, 2022, ships entering the regulated waters of Hainan Island must use fuel with ≤0.10% Sulfur content.

Operation of a scrubber as an equivalent alternative may be subject to restrictions, as discharge of washwater from open loop systems is not permitted in the China Inland Water ECA, Bohai Rim Waters, and port areas within the Coastal ECA. The possibility of a 0.10% Sulphur cap in all China ECAs from 2025 is expected to be enacted at a later date.

HONG KONG SPECIAL ADMINISTRATIVE REGION OF THE PRC REGULATIONS

As of July 1, 2015, the Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation, requires oceangoing vessels to use compliant fuels while berthing in Hong Kong. Compliant fuels, defined by the regulation, are marine fuels with a sulfur content of ≤0.50%, liquefied natural gas and any other fuels approved by the air pollution control authority.

The Regulation requires vessels to:

- Switch to compliant fuel within one hour of arriving at their berth and burn compliant fuel until one hour prior to departure
- Record dates and times of vessel's arrival, departure and of commencement and completion of fuel change-over operations as soon as practicable after each occurrence
- Maintain records onboard the vessel for at least three years, readily available for inspection at all reasonable times

Approved technologies such as EGCS may be used subject to their capability of achieving a reduction of sulfur dioxide, which could be considered at least as effective as the use of low-sulfur marine fuel. Ocean going vessels installed with such approved technologies may be exempt from switching to one of the compliant fuels. Written applications for exemptions based on the use of approved technologies must be made to the authorities at least 14 days before the date on which the vessel intends to make its first exempted call at Hong Kong.

Additional information may be obtained from "Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation" Chapter 311AA, gazette Number E.R. 2 of 2015.

SECTION 3 – MARINE FUELS

There are internationally recognized standards that define key characteristics of fuel oils and their components denoting suitability for use on board ships. However, there are important considerations that may not be covered in these standards.

FUEL STANDARDS

The most widely used fuel standard in the marine industry is ISO 8217 with the latest edition issued in 2017. Other existing guidelines or standards are the guidelines published by the International Council on Combustion Engines (CIMAC) WG7 fuels group, the ISO 8216-1:2017 Standard and the American Society for Testing and Materials (ASTM) D-975 Standard Specification for Diesel Fuel. Frequently, vessels are designed to use fuel from a specific designation of one of the standards, usually from ISO 8217.

The ISO 8217 standard specifies the requirements for fuels for use in marine diesel engines, boilers, and stationary diesel engines prior to conventional onboard treatment. It specifies seven categories of distillate fuels and six categories of residual fuels. The ISO standard defines fuel as hydrocarbons from petroleum crude oil, oil sands and shale, hydrocarbons from synthetic or renewable sources that are similar in composition to petroleum distillate fuels and including blends of the aforementioned products with a fatty acid methyl ester (FAME) component, where permitted by the standard. ISO 8217 provides the detailed specifications of distillate (DM) grades, distillate FAME (DF) grades and residual (RM) grade marine fuel oils.

The current ISO 8217:2017 (Sixth edition) standard introduced additional grades of FAME distillates (DFA, DFZ and DFB grades) allowing for bio-fuel blends containing FAME of up to 7.0% by volume. The 2017 edition also introduced requirements on cold flow properties for winter grade DMA and DMZ distillates (cloud point and cold filter plugging point), and a change of the scope to allow for inclusion of hydrocarbons from synthetic or renewable sources. Also, there were substantial amendments to the general requirements where sulfur limits are reduced for several distillate grades and a number of informative annexes (i.e., sulfur content, flash point, catalyst fines and precision and interpretation of test results) were deleted; however, the key information is available within the body of the document and in referenced industry publications.

At the time of publication, the standard recognized that a number of fuels were being offered to the marine industry (to meet the IMO fuel sulfur limit changes) which did not conform exactly to the normal distillate or residual fuel categorization. Future updates of the standard intend to cover these fuels as industry experience develops. However, the ISO 8217 technical committee (ISO TC28/SC4/WG6) provided an interim solution by publishing a publicly available specification (ISO/PAS 23263) on September 2019. The document was developed in cooperation with ship owners, operators, classification societies, fuel testing services, engine designers, marine fuel suppliers, traders, fuel additive suppliers and the petroleum industry. The document addresses quality considerations that apply to marine fuels in view of the implementation of maximum 0.50% S and the range of marine fuels that will be placed on the market in response to the new statutory requirements. The document provided general and specific considerations on different fuel properties but in general the 0.50% S Sulfur fuel oilswill be required to meet the existing ISO 8217 standards.

At present no other universally accepted standard has been developed to define the properties of the 0.50% Heavy Fuel Oils. Furthermore, it is anticipated that inaddition to the oil majors, regional suppliers will emerge to supply the market needs, potentially creating fuel oil which may vary between suppliers. They may be based

on Vacuum Gas Oil (VGO), or blends incorporating various heavy and light refinery product streams, including residual fuel oils and middle distillates.

The distillate fuels are categorized as DMX, DMA, DFA, DMZ, DFZ, DMB and DFB while residual fuels are characterized as RMA, RMB, RMD, RME, RMG and RMK.

The ISO 8217 standard covers the fuel characteristics limits of viscosity, density, cetane index/CCAI, sulfur, flash point, hydrogen sulfide, acid number, total sediment, carbon residue, cloud point, pour point, cold filter plugging point, appearance, water, ash, lubricity, vanadium, sodium, aluminum plus silicon (cat fine), calcium and zinc. Most of these characteristics are applicable for both type of oils, except for a few which are applicable to either distillate or residual fuels as denoted in Table 1 and 2 of ISO 8217.

FUEL TYPES

The IMO limits on fuel sulfur content influence the types of fuels that can be selected for use on ships, and thus it is helpful to understand the maximum/minimum values and typical ranges of sulfur content and viscosity for the standard fuels used on ships. The list of fuels provided in Table 6 are based on IMO Resolution MEPC.320(74) along with other relevant data.

Table 6: Typical Parameters of Marine Fuel

Fuel Types	ISO Category	Viscosity (cSt) (at 50°C for Residual and 40°C for Distillate Fuels)		**Sulfur Mass (%)**
		Minimum	Maximum	Maximum
Distillate Marine Fuels (DM)	DMX	1.4	5.5	1.0
	DMA, DFA	2.0	6.0	1.0
	DMZ, DFZ	3.0	6.0	1.0
	DMB, DFB	2.0	11.0	1.5
Residual Marine Fuels (RM)	RMA, RMB, RMD, RME, RMG, RMK	“-“	10 - 700	Statutory Requirements
Ultra-low Sulfur Fuel Oil (ULSFO-DM)	DMA, DMX	1.4[2]	6.0[2]	≤0.10
Ultra-low Sulfur Fuel Oil (ULSFO-RM)	Mixed fuel with RM category	8	60[3]	≤0.10
Very low Sulfur Fuel Oil (VLSFO-DM)	DMA, DMX	1.4[2]	6.0[2]	≤0.50
Very low Sulfur Fuel Oil (VLSFO-RM)	Mixed fuel with RM category	“-“	80[3]	≤0.10
High Sulfur Heavy Fuel Oil (HSHFO)	RMA, RMB, RMD, RME, RMG, RMK	“-“	10 - 700	>0.50

Notes:

1. Notwithstanding the limits given, the purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations.
2. Viscosity varies in each category.
3. Viscosity varies among different fuels produced by various companies.

DISTILLATE TYPE ULTRA-LOW SULFUR FUEL OIL (ULSFO-DM) AND DISTILLATE TYPE VERY LOW SULFUR FUEL OIL(VLSFO-DM)

Distillate fuels are components of crude oil that evaporate in fractional distillation and are then condensed into liquid fractions. These fuels are commonly known as Marine Gas Oil (MGO) which consists exclusively of 'clear and bright' distillates and falls within the ISO DMX, DMA/DFA, DMZ/DFZ, DMB/DFB categories. MGO usually consistsof a blend of various distillates and is similar to diesel fuel but has higher density. Marine Diesel Oil (MDO) is generally composed of various blends of distillates and a small portion of Heavy Fuel Oil.

Distillate fuels can be produced with varying degrees of sulfur content. The ISO DMA category has a maximum sulfur limit of 1.0%, and the DMB category a maximum limit of 1.50%, although 0.10% sulfur content MGO in these grades is available for marine use, and as required for statutory compliance in ECAs. MDO is typically available for marine use at a maximum of 1.50% sulfur.

RESIDUAL TYPE ULTRA-LOW SULFUR FUEL OIL (ULSFO-RM)

Various marine fuel suppliers developed new low sulfur fuel oils which were specially designed to help marine operators comply with the 0.10% ECA sulfur limits that entered into force in 2015. These new fuel oils contain low sulfur but have a higher viscosity than the distillate fuels. These are known as 0.10% Heavy Fuel Oil, or ECA fuel oils. Similar types of fuel oil containing 0.50% sulfur, e.g., residual type very low sulfur fuel (VLSFO-RM) have also entered the market for complying with the IMO global limit applicable from January 1, 2020. Examples of ULSFO-RM fuels are listed in Table 7.

Table 7: Ultra-low Sulfur Fuel Oil – Residual (ULSFO-RM)

	Shell ULSFO	ExxonMobil HDME 50	ExxonMobil AFME 200	LUKOIL	CEP SA	BP	Phillips 66
Density (kg/m³)	790-910	900-915	917	886	868	845.4	855.2
Viscosity (cSt)	10-60	30-45	67	16	8.8	8.8	8.6
Micro Carbon (MCR) (mass %)	2	<0.30	<10	0.1	0.1	0.1	0.04
Sulfur (mass %)	<0.1	<0.10	<0.10	0.07	0.05	0.03	0.06
Pour Point (° C)	18	6-12	6-15	18	-12	21	-12
Flash Point (° C)	>60	<70	<70	165	72	>70	79
Water (vol. %)	0.05	0.05	<0.5	0.05	0.004	0.01	0
Acid Number (mg KOH/g)	<0.5	<0.1	<0.1	0.5	0.27	0.04	NA
Vanadium (mg/kg)	2	<1	1	1	NA	<1	<0.10
Al+Si (mg/kg)	12-20	<5	<10	2	NA	<1	2
Lubricity (microns)	NA	<320	NA	270	410	326	NA
CCAI	800	795-810	799	793	NA	765	NA

These fuels can simplify the fuel changeover procedures necessary to enter areas with emissions control requirements and eliminate the need to install a cooler or chiller that may be needed when switching to distillates. It is recommended that the ship operator confirms suitability of any new fuel with the engine manufacturer prior to use if not fully in compliance with the ISO standard. Some of these new fuels have a high pour point and may form wax crystals in low ambient temperatures. Since these fuels are highly paraffinic, compatibility with existing bunkers also needs to be considered.

RESIDUAL TYPE VERY LOW SULFUR FUEL OIL (VLSFO-RM)

The sulfur content of crude oil varies significantly in different parts of the world, ranging from 0.1% to 4.1%. The translation of sulfur content in crude to residual bunker fuel in general ranges from a factor of 2 to 3 which means a light sweet crude having a minimum sulfur content of 0.4% would translate to a residual bunker fuel sulfur content of minimum 0.8% to 1.3%. Thus to meet the IMO regulations, the refiners have to either treat the fuel or blend it with ultra-low sulfur fuel oil. Other options to obtain a 0.50% sulfur content fuel include blending with hydro-treated residuals, heavy fractions from hydro-crackers and using lighter hydro-treated fractions.

Therefore, a wide mix of fuels can be used to meet the fuel standard specifications and the IMO fuel sulfur content requirements. The IMO 2020 0.50% global limits heralded a significant shift in the range of fuels and fuel blends offered to the marine industry, with RM grades capped at 0.50% sulfur, and thus greater effort was required from the operators to avoid issues in service. The adoption of the new fuels caused some isolated issues, but generally transitioned smoothly. The next sections examine in more detail the general and 2020 fuel considerations.

BIOFUELS

Biofuel is derived from biomass which includes cooking oils, fatty-acid-methyl-esters (FAME) or fatty-acid-ethyl-esters (FAEE), straight vegetable oils (SVO), hydrotreated vegetable oils (HVO), glycerol, and other biomass to liquid (BTL) type products. Some biofuels that are functionally equivalent to petroleum fuels and therefore compatible with existing equipment without system modifications are known as 'drop-in' biofuels.

As part of the increased interest in the use of alternative fuels that reduce air pollutants and greenhouse gases (GHGs), MARPOL Annex VI has dealt with the use of biofuels through fuel oil quality standards while the ISO standard 8217 "Petroleum products – Fuels (class F) – Specifications of marine fuels" was modified in 2017 to widen tolerances for the use of biofuels in existing and new fuel oil grades. In particular, biofuels are considered in the marine industry for their renewable qualities and reduced emissions from engines, primarily, reduced SOx, as evidenced by an International Council on Clean Transportation 2020 Working Paper. ISO 8217 states that FAME blend stock for DF grades is to meet the quality and testing specifications of either EN 14214 or ASTM D6751.

Liquid biofuels, or biofuel blends, intended to replace conventional residual or distillate fuel oils are to meet the SOLAS requirement for a flashpoint of no less than 60° C. The IMO International Safety Management Code (ISM Code) provides an international standard for the safe management and operation of ships and to prevent pollution. With respect to biofuels, the fuel supplier's fuel specifications, Bunker Delivery Note (BDN), MSDS sheets, equipment manufacturer's recommendations, and industry stakeholder guidelines provide the basis for operators to undertake their ISM Code obligations. While there are some risks to equipment and operation with certain biofuels, the "drop-in" nature and similarity to conventional residual or distillate fuels makes application relatively simple:

- Operation on distillate biofuels containing up to seven percent FAME: The grades detailed by ISO 8217:2017 are permitted and would not require NOx recertification or any onboard NOx emissions measurements to be undertaken for engines already certified to Regulation 13.
- For blends between seven and 30 percent (inclusive) biofuel: An assessment of NOx impacts is not required under the provisions of MEPC.1/Circ.795/Rev.6.
- For blends of more than 30 percent of biofuel: If biofuel can be burnt without changes to the NOx critical components or settings, an assessment of NOx impacts is also not required.

Dialogue with the flag Administration will be required for application under Regulations 3.2 or 4 and further guidance on this process can be provided by the local ABS office.

Most marine 2-stroke slow speed engines and larger 4-stroke medium speed engines, which are designed for a broad range of distillate and residual marine fuels, can already accommodate a wide variation in fuel quality and have the span of NOx performance criteria associated with the engines' adjustable features defined in the NOx Technical File. These engines are likely able to burn biofuels without any changes to the NOx critical components or settings. In these cases, confirmation from the NOx Technical File compiler or engine designer is to be obtained.

For biofuel blends of 30 percent by volume or more where the engines' NOx critical components, settings or operating values in the approved Technical File need to change to use that fuel, NOx emissions verification will be required to maintain the ship's IAPP certificate. The emissions can be measured by an onboard simplified measurement method in accordance with 6.3 of the NOx Technical Code 2008, the direct measurement and monitoring method in accordance with 6.4 of the NOx Technical Code 2008, or by reference to relevant test-bed testing. For the purposes of demonstrating compliance and as applicable to possible deviations when undertaking measurements on board, an allowance of 10 percent of the applicable limit may be accepted.

SECTION 4 – 2020 FUEL CONSIDERATIONS AND IMPACT ON OPERATIONS

COMPLIANCE OPTIONS

The regulations outlined in Sections 1 and 2 offer multiple pathways for compliance with the global 2020 requirements. These choices allow the vessel operator to address the requirement though either fuel selection or sulfur mitigation technologies. The options are:

a) Very Low Sulfur Fuel Oil (VLSFO-DM) (≤0.50% S Fuel Oil)

b) Very Low Sulfur Fuel Oil (VLSFO-RM) (≤0.50% S Fuel Oil) (may be blended, specification not known)

c) Ultra-low Sulfur Fuel Oil (ULSFO-DM) (≤0.10% S Fuel Oil)

d) Ultra-low Sulfur Fuel Oil (ULSFO-RM) (LSRMF) (≤0.10% S Fuel Oil)

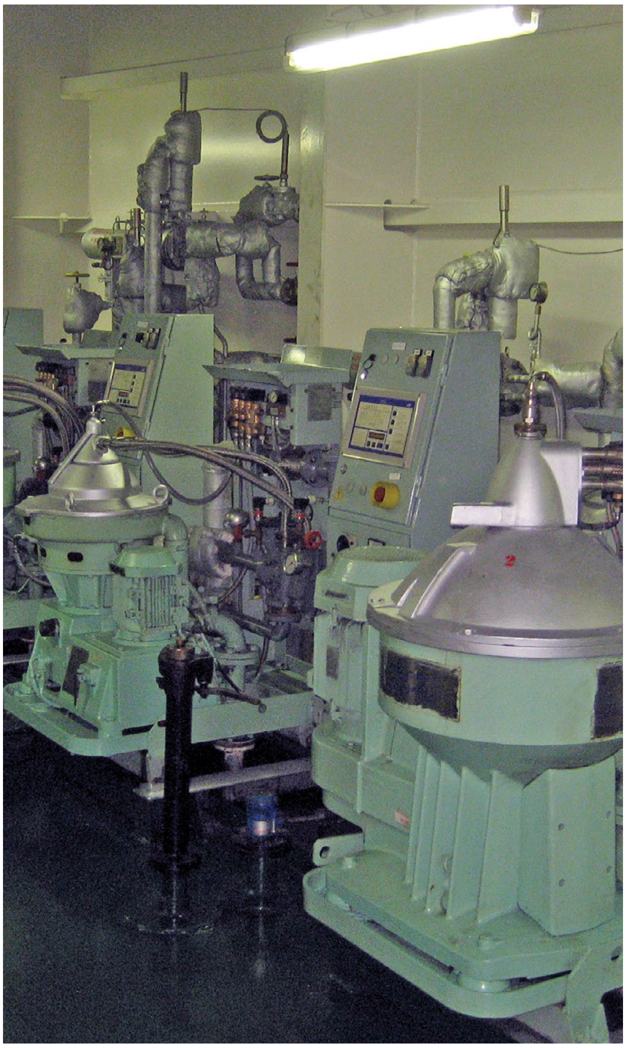
e) Exhaust Gas Cleaning System (EGCS) with High Sulfur Heavy Fuel Oil (HSHFO)

f) LNG

g) Alternative fuels e.g., LPG, ethane, methanol, CNG, biofuel, solar power and fuel cells

Options with 0.10% sulfur are most applicable for the vessels which will be operated near ECAs and with frequent transitions into and out of ECA areas, to avoid frequent fuel switchover.

Additional alternate fuels such as those listed in options f) and g) have limitations. LNG fuel can help ship owners and operators meet the sulfur limits but has high capital cost and requires supporting bunkering infrastructure. Based on the above, it is anticipated that much of the world fleet operating outside ECAs will operate on 0.50% sulfur fuel oil. With existing fuel available, some vessels will operate on High Sulfur Heavy Fuel Oil (HSHFO) and remove the SOx by using an EGCS.



KEY CONSIDERATIONS OF VERY LOW SULFUR FUEL OIL (VLSFO-RM)

Compatibility: While each individual fuel oil type should be delivered as a stable product, compatibility of one fuel oil with another cannot be readily predicted without testing. Generally, fuels of the same viscosity grade with similar densities are likely to be compatible; however, it is advised to avoid mixing fuel from different sources, or to mix VLSFO-RM with VLSFO-DM. Also, instability can be introduced during the blending process and as a result of commingling incompatible bunkers on board vessels. Vessel owners should prepare for increased bunker segregation in line with standard procedures to minimize the associated risks and work closely with their bunker suppliers to purchase compatible fuels.

The experience from the establishment of ECAs indicates that proper ship machinery operations should be sufficiently capable of addressing the concerns regarding combustion of the 0.50% VLSFO-RM fuels.

These fuels are expected to be more aligned with currently available ULSFO-RM, having a lower viscosity than the existing HSHFO. There may however be increased stability and compatibility risks if not handled correctly. Clear knowledge of the ordered product will assist the crew in carrying out the necessary adjustments to the fuel system set up for safe storage, handling, effective treatment and use of the fuels on board.

Precautions should be taken by ship crews to minimize incompatibility by avoiding mixing bunker fuels from different sources, choosing a fuel with similar viscosity and density, and avoiding the mixing of ULSFO-RM or VLSFO-RM with distillate fuel oil. When bunkering a compliant fuel, the operator must ensure it is going into a clean tank. If the two fuels are incompatible, then the mixing may cause asphaltenic material suspension from the previous fuel, which will precipitate out as sludge with a tendency to heavily load the fuel oil filters, therefore reducing the rate of fuel flow.

Overall, the new 0.50% sulfur limit creates higher risks of fuelincompatibility as more blended fuels are introduced.

Stability: Fuel oils are produced based on widely varying crude oils and refinery processes. There is a potential for a fuel to change conditions in storage in certain circumstances. Bulk fuel stored for long periods can become unstable because the asphaltenes can precipitate out of solution, causing the formation of sludge. The 'break up' is dependent on the nature of the liquid hydrocarbons in which the asphaltenes are suspended. Once a fuel has chemically broken down there is no way to satisfactorily reverse the process. Precipitated asphaltenes cannot be redissolved.

Cat Fines: These are created as a result of catalytic cracking during the crude oil refining process, during which tiny fragments of the catalyst material become entrained in the refined and residue products. These cat fines are

typically a combination of aluminum and silicon and are very hard, abrasive particles, capable of causing severe wear to engines. The size of cat fines varies generally from sub-micron up to about 30 microns. The typical acceptable cat fines limit ranges from 7 to 15mg/kg depending on engine manufacturers' recommendation. Cat fines exist in fuel oil even after being purified and conditioned which is a cause of gradual engine wear. However, if excessive amounts of cat fines are introduced into the engine, they can cause significant damage to sensitive engine components such as fuel pumps and fuel injection valves as well as cylinder liners and piston rings. Ultimately, cat fines can cause significant damage or even total failure of the engine.

The extent of these entrained cat fines is regulated through the fuel oil standards which identify the maximum amount (PPM or mg/kg of silicon and aluminum) allowed in the fuel oil. For example, in the sixth edition of ISO 8217:2017, the maximum amount of combined silicon and aluminum in Residual Marine Fuel (RM) is not to exceed 60 mg/kg for RMG and RMK grades, with the lowest limit set for RMA grade at 25 mg/kg. Furthermore, HSHFO typically has a combined silicon and aluminum concentration of around 30 mg/kg. ISO 8217:2010 reduced the limit values of cat fines to a level that ensures a minimal risk of abrasive wear assuming adequate fuel pre-treatment by maintaining the centrifugal purifier inlet temperature at a constant value, usually 95° C to 98° C, and assuming the fuel-cleaning system (tanks, centrifugal and filters) operate under optimum conditions. Moreover, appropriate fuel temperature should be maintained in the settling tank to aid settling and water content removal. Settling tanks are to be drained at regular intervals throughout the period of operation when using high cat fine content fuel. Cat fines are to be reduced as much as possible by the fuel centrifuge and, as a guideline, the level should not exceed 15 mg/kg after the centrifuge.

Consequently, even though the expected 0.50% S VLSFO-RM or 0.10%S ULSFO-RM will fall within ISO 8217 specifications, efficient fuel pre-treatment onboard is required and important to limit engine damage from cat fines.

Combustion Characteristics: The ignition characteristic of a residual fuel is indicated by the Calculated Carbon Aromaticity Index (CCAI) specified in ISO 8217. The CCAI is an indication of ignition performance in order to avoid fuels with an uncharacteristic density-viscosity relationship. The ignition and combustion characteristics of a residual marine (RM) fuel in a diesel engine is dependent on the particular type, design, operating and engine condition, load profile and the chemical properties of the fuel oil. In engine applications where the ignition quality is particularly critical, a basis for suppliers and purchasers of RM fuels to agree on tighter ignition quality characteristics. While RM fuels blending at or close to the maximum density, the CCAI limit can restrict the combination of density and viscosity.

The CCAI is determined from the density and viscosity of a RM fuel and while it does not provide information related to the combustion characteristics of RM fuel, it does provide an indication of the ignition delay. CCAI has been included to avoid residual fuel oils with uncharacteristic density viscosity relationships, which can lead to an extended ignition delay. New fuels should have their CCAI verified in line with the existing ISO 8217 specifications, and operators should note, and take action as appropriate, for the lower CCAI values (indicating reduced ignition delay) that may be applicable.

Density: Density is related to the fuel quality because fuels derived from extensive refinery processing are left with a higher carbon content, are more aromatic and thus heavier. Therefore, fuels with a high density are also high in carbon residue and asphaltenes. It is expected that the 0.50%S VLSFO-RM or 0.10%S ULSFO-RM density will be as per the existing ISO 8217 specification.

Flash Point: The flash point limit is set as a safeguard against fire. SOLAS and ISO 8217 requires a fuel flash point not less than 60° C and minimum flash point of any fuel carried in the tanks of a ship should maintain this limit. There is no permissible negative tolerance. This applies to any fuel onboard the vessel with an exception for lifeboats which can be distillate DMX grade with a flash point minimum of 43° C. Note that the current 0.10%S ULSFO-RM (also known as ECA fuel) offered by different oil companies maintains the flash point limit as required by SOLAS and as per ISO 8217 specifications. It is expected that the flash point of new fuels will be not less than 60° C as per current SOLAS limit as mentioned in ISO 8217.

Pour Point: The pour point indicates the minimum temperature at which the fuel should be stored and pumped. Temperatures below the pour point result in wax formation. Some of the blended 0.10%S ULSFO-RM fuels have a relatively higher pour point and need to be heated to avoid wax formation.

Viscosity: Viscosity is a measure of the fluidity of the product at a certain temperature. The viscosity of a fuel decreases with increasing temperature. Viscosity outside manufacturers' specifications may cause poor combustion, formation of deposits, pumping difficulties and energy loss. The viscosity of the fuel must be within the required viscosity at engine inlet, typically 2-20 mm2/s (or cSt.) and which can be reached and controlled by the ship's preheating system.

For heavy fuels with high viscosity, the required operating viscosity is achieved by heating the fuel to lower the viscosity. For distillate marine fuels (DM), the fuel at ambient temperature normally has a viscosity within the specified limits. Low sulfur fuels tend to have viscosities near or at the lower limits of allowed viscosity. Considering the required viscosity and at the engine inlet, or injection pumps, the main concern is that the fuel viscosity may fall below the lower allowable limit. Since ULSFO-DM and VLSFO-DM fuels have viscosities close to the permitted minimums, the temperature of the fuel needs to be controlled. Viscosity is not considered as a major concern for the 0.50%S VLSFO-RM or 0.10%S ULSFO-RM which is expected to be a heated fuel oil with relatively higher viscosity.

Tank Cleaning: This is a very important and key issue to avoid debris and cat fines problems and reduce compatibility and stability issues while transitioning to 0.50%S VLSFO-RM or 0.10%S ULSFO-RM from High Sulfur Heavy Fuel Oil (HSHFO). There is a high risk of undetected residue from non-compliant fuels remaining in tanks when switching from a HSHFO to a VLSFO-RM/ULSFO-RM. If there is a fraction of the HSHFO left in the tank, it will contaminate the new product, which may then become non-compliant. Therefore, the tank and piping system should be fully flushed to clear out all last remnants of HSHFO before filling it with a lower sulfur fuel. This cleaning process takes time and cannot be carried out while the ship is in operation.

Appropriate tank cleaning is a must to avoid noncompliance and keep equipment running efficiently.

Sampling: When bunkering, a sample can be tested to ensure the fuel mix is compatible. This can be performed through sediment or spot testing. The sediment test is generally carried out in the fuel testing laboratory while the simple spot test is conducted onboard.

Table 8: Summary of the items to consider based on the different fuel types

Fuel Issue	High Sulfur Heavy Fuel Oil (HSHFO)	Distillate Ultra/ Very Low Sulfur Fuel Oil (ULSFO-DM/ VLSFO-DM)	Residual Ultra-low Sulfur Fuel Oil (ULSFO-RM)	Residual Very-low Sulfur Fuel Oil (VLSFO-RM)
Incompatibility	None	None; Fuel must however be segregated from HSHFO & follow appropriate fuel changeover procedures	None	Attention needed as specifications may differ based on the geographical locations. Recommended to minimize commingling of fuel
Instability	None	None	Possible	To ensure the total sediment ages as specified in ISO 8217:2017, Table 2
Cat FInes	Limits defined in ISO 8217:2017	Limits defined in ISO 8217:2017	Possible; if does not fall within ISO 8217:2017	Possible; risk if content of Aluminum plus Silicon exceeds the maximum limit of ISO 8217:2017, Table 2
Combustion Characteristics	Exists as per ISO 8217	Addressed under Cetane index within ISO 8217:2017	Calculated Carbon Aromaticity Index (CCAI) should meet the limits set down in ISO 8217:2017, Table 2	Calculated Carbon Aromaticity Index (CCAI) should meet the limits set down in ISO 8217:2017, Table 2
Flash Point	Exists as per SOLAS and ISO 8217	Exists as per SOLAS and ISO 8217:2017	Required to be within the limits of SOLAS and ISO 8217:2017 specifications	Concern: risks if flash point goes below 60° C and not verified after blending by supplier. Required to be within the limits of SOLAS and ISO 8217:2017 specifications
Pour Point	Exists as per ISO 8217	Exists as per ISO 8217:2017	Required to be within the limits of ISO 8217:2017 specifications	Possible; risks if pour point is too high and not verified after blending by supplier. Required to be within the limits of ISO 8217:2017 specifications

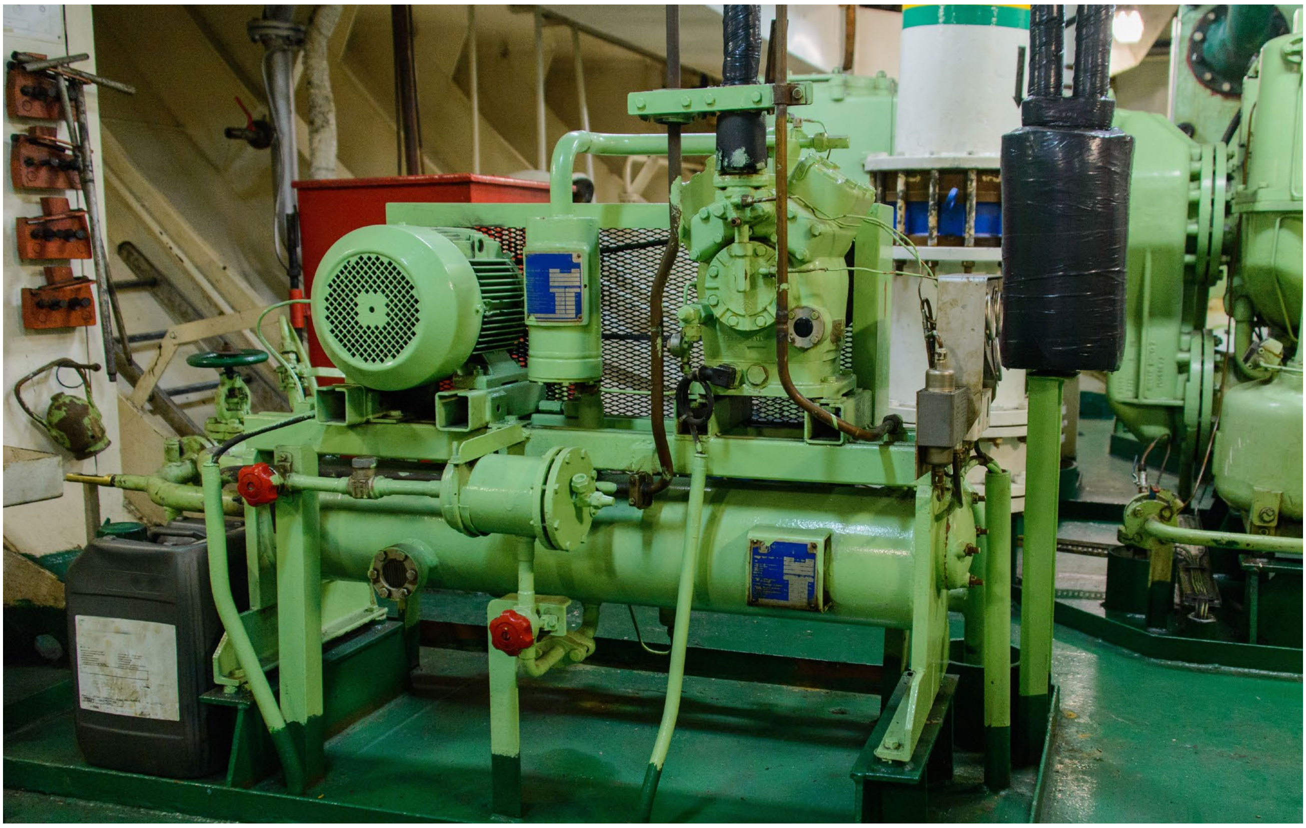
OPERATIONAL CHALLENGES OF 2020 SULFUR CAP

The change from high sulfur fuels to VLSFO-DM or VLSFO-RM to meet the global sulfur limits is significant. The following are operational challenges and items to consider associated with achieving compliance:

- Segregation of fuel oil tanks with integral piping systems is necessary. Attention is needed to avoid cross contamination, with an increased awareness of the fuel being used and the associated implications.
- New fuels may be based on local refinery configurations; the quality of which may vary considerably on a regional basis until specific guidelines/standards are provided by ISO. To avoid incompatibility, fuels from different suppliers should be kept separate and not mixed without testing.
- Blended fuel oil may be more paraffinic and may pose an increased risk of incompatibility with conventional residual fuels. Viscosity of the new fuels is expected to be lower than conventional residual fuel grades such as RMG or RMK, but higher than DMA or MGO.
- Density of new fuels is expected to be lower than conventional residual fuels and as a result centrifuges will require readjustment or recalibration.
- New fuels may require heating for delivery purposes and may need to be kept in heated tanks. If the Pour point is high and fuels are not heated, there is a potential for wax formation.
- The new fuels may need to be processed in a similar way as a Heavy Fuel Oil, purified prior to use in main and auxiliary engines. Purifiers should be correctly set up for the viscosity of the new fuel with care taken when comingling new fuel with Heavy Fuel Oil to avoid any issues that may occur due to the cleaning effect on any residues in the settling and service tanks.

- When the fuel starts to feed through the fuel service system, additional back-flushing of the fuel auto-filter can be expected because of the cleaning effect. Careful monitoring of all fuel filters is recommended.
- A vessel with only one settling tank should consider stopping the purifier and draining any remaining oil to the overflow tank before refilling with new VLSFO-RM or ULSFO-RM. Ships with two settling tanks and two service tanks will have greater flexibility and the option of cleaning tanks or draining, opening, and inspecting before filling.
- The fuel should be heated to the appropriate temperature to achieve the correct viscosity at the engine inlet according to engine manufacturer guidelines.
- The fuel temperature at the main engine and auxiliary engines can be lower than at the purifiers.

  A temperature of 75°C will enable sufficient lubricity. It is not recommended to allow excessive heating at the main engine as lubricity may be reduced. The temperature in the system should not be allowed to drop below 70°C or as recommended by the OEM and fuel supplier.
- When VLSFO-RM or ULSFO-RM is to be used in an auxiliary boiler burner, the low fuel temperature trip may need to be adjusted to suit the lower temperature requirement for the new fuel. The temperature setting for the fuel heater should be reduced as per the OEM and fuel supplier recommendation.
- Two stroke engines should use cylinder lube oil of low BN (15 to 40 in general) when operating on these low sulfur fuels. Even for four stroke engines for long term operation, the system oil BN should be lower. Operators should follow their OEM recommended guidelines for the appropriate lubricants to be used with their engines.
- The VLSFO-RM/VLSFO-DM or ULSFO-RM/ULSFO-DM are required to meet the current Table 1 or Table 2 limits of ISO 8217:2017.
- While writing the fuel clause in the Charter Party and with Insurance agencies, full information on the fuel should be provided to avoid any dispute.
- The specific technical and operational challenges of the fuel must be clearly addressed and advice obtained from the OEM(s) to ensure problem free operation.
- Most ships should have addressed the earlier outlined concerns through increasing the awareness of the crews through training and practice.
- In addition, a risk assessment should be conducted which will identify additional measures such as increased frequency of maintenance checks, reduced service life estimates and other such steps.
- In line with good practice, the impact should be assessed for each vessel. In particular, the engine manuals should be consulted regarding any restrictions associated with engine operating parameters.



OWNER AND OPERATOR PREPARATIONS FOR 2020

- Work with fuel suppliers to ensure fuel type and specification so the vessel will be suitable to use compliant fuel in time.
- Prepare to enter 'term contracts' rather than 'spot contracts' to purchase compliant fuel oil.
- Develop onboard implementation plans for fuel segregation, mixing and compatibility testing as there will be increased levels of compatibility issues between fuels.
- Create a transition plan, both shore side and onboard so that the transition goes smoothly.
- Plan for tank cleaning and contract tank cleaning services.
- Prepare budget considering increased capital and operating expenses.

IMPACT ON SHIP DESIGN

Meeting the requirements for sustained operation on low sulfur, low viscosity fuels will have two major impacts on the design of ships, in addition to impacts on the engines and boilers themselves. One is regarding the required storage capacity of low sulfur fuel and the other is the implications for fuel piping systems and equipment to segregate and handle different types of fuels with different viscosities, densities, and handling temperatures. New ships can be designed specifically to incorporate the required features. Table 9 shows some example fuel tankage arrangements for various ship types. However, based on geographical trading patterns, or requirements for emission control area operation, many ships may require modifications to provide the required capacity for all fuel types. Refer also to IACS Ui SC123 regarding service tank arrangements.

Table 9: Fuel Tankage Arrangement

Ship Type/Size	HFO		LSHFO		MDO/MGO	
	Description	m^3	Description	m^3	Description	m^3
2,500 TEU Containership	2 x Storage 1 x Settling 2 x Service	2,000			1 x Storage 1 x Service	1,300
3,700 TEU Containership	2 x Storage 1 x Settling 1 x Service	2,200			2 x Storage 1 x Settling 1 x Service	1,100
3,000 TEU Containership w/RoRo	2 x Storage 2 x Settling 2 x Service	2,400			3 x Storage 1 x Settling 1 x Service	2,300
4,500 TEU Containership	6 x Storage 1 x Settling 1 x Service	4,000	1 x Storage 1 x Settling 1 x Service	700	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO: 150 MGO: 100
9,200 TEU Containership	3 x Storage 1 x Settling 1 x Service	5,000	1 x Storage 1 x Settling 1 x Service	2,000	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO: 300 MGO: 200
13,000 TEU Containership	5 x Storage 1 x Settling 1 x Service	8,500	1 x Storage 1 x Settling 1 x Service	2,000	MDO 1 x Storage 1 x Settling 1 x Service MGO 1 x Storage 1 x Service	MDO: 400 MGO: 300
20,000 TEU Containership	6 x Storage 1 x Settling 1 x Service	12,300	2 x Storage 1 x Settling 1 x Service	2,000	1 x Storage 1 x Settling 1 x Service	600
50,000 DWT Panamax Tanker	3 x Storage 1 x Settling 1 x Service	1,200	1 x Storage 1 x Settling 1 x Service	300	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO:150 MGO:150
115,000 DWT Aframax Tanker	3 x Storage 1 x Settling 1 x Service	2,000	1 x Storage 1 x Settling 1 x Service	1,000	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO: 150 MGO: 200

Ship Type/Size	HFO		LSHFO		MDO/MGO	
	Description	m^3	Description	m^3	Description	m^3
320,000 DWT VLCC Tanker	3 x Storage 1 x Settling 1 x Service	5,000	1 x Storage 1 x Settling 1 x Service	2,000	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO: 300 MGO: 500
35,000 DWT Bulk Carrier	4 x Storage 1 x Settling 1 x Service	1,300	1 x Storage 1 x Settling 1 x Service	250	MDO 1 x Storage 1 x Settling 1 x Service MGO 1 x Storage 1 x Service	MDO: 100 MGO: 100
181,000 DWT Bulk Carrier	3 x Storage 1 x Settling 1 x Service	3,500	1 x Storage 1 x Settling 1 x Service	1,200	MDO 1 x Storage 1 x Service MGO 1 x Storage 1 x Service	MDO: 300 MGO: 400

LESSONS LEARNED FROM USING VLSFO/ULSFO SINCE 2020

Since January 2020 ships have been required to use fuels with a maximum sulfur content of 0.50% with new VLSFO and ULSFO 2020 fuels introduced to address the requirement. Since the introduction of the new fuels, a small portion of the world fleet (<1%) has experienced adverse effects from the new fuels.

The problems seen have included scuffing between piston ring and cylinder liner, deposits on piston ring groove/land, deposits on piston crown/top land, high piston ring wear, high rate of liner wear, cold corrosion, red deposits on piston crown and excessive sludge production. These issues can reduce engine performance, increase fuel consumption, and increase frequency of engine overhaul.

The typical ring/liner issues and possible reasons for these 2020 fuel problems are detailed further below.

Scuffing: This may occur for various reasons, but with respect to the 2020 fuels, the primary ways are either from cat fines which mix with fuel oil, escape the purifier, are sprayed by the injector, and then deposited into the cast iron cylinder wall which then causes hard particle abrasion during movement between the liner and piston rings. Scuffing may also occur by metal-to-metal contact due to insufficient cylinder lubrication. When higher BN cylinder oils are used with VLSFO/ULSFO, the risk of top land deposits increases. These deposits may polish the cylinder liner surface, and which may initiate cylinder liner scuffing.

Deposits: When operating engines using VLSFO/ULSFO fuels with higher BN cylinder oil, the residual alkalinity can cause damage to the piston/liner interface because of excessive deposit build-up, which can break down the lubricant film, and cause unusual wear of components (piston, piston rings, liner). For example, excessive wear on the top piston ring groove can lead to top piston ring fracture, in turn causing cylinder liner damage. Switching to a low-BN cylinder oil, matching the VLFSO/ULFSO sulfur content, and adjustment of cylinder oil feed rate is required. Some engine types (and dependent on rating, specification or fuels used) can be more prone to deposit formation if the cylinder oil and feed rate used are not suitable or managed correctly. The ship operating profile, ambient conditions, and conditions of the engine components prior to switching to the new fuels, can also make a significant difference to deposit formation, scuffing and other ringpack issues.

High Wear Rate: It is recommended that maximum total iron content is analyzed for each cylinder to evaluate the individual cylinder wear condition. Periodical analysis of drain oil samples provides the condition of the cylinder and accordingly the oil feed rate can be adjusted so that the total iron (Fe) content does not exceed the recommended parameters provided by the engine manufacturer. The maximum iron content level varies with the engine design and bore size but typically for an engine of an ocean-going vessel the total maximum iron content for safe operation is within the range of 100 – 200 ppm.

Cold Corrosion: The general trends to increase the efficiency of internal combustion engines have led to increases in BMEP (Brake Mean Effective Pressure), ultra-long stroke designs and increases in cylinder firing pressures. Careful management of cylinder liner temperature is required to avoid cylinder liner issues, and particularly to manage cold or hot corrosion problems with the different fuels and varying fuel sulfur contents. Reduced cylinder wall temperatures can cause increased water and acid condensation on the cylinder walls. This can lead to cold corrosion, with the formation of sulfuric acid, which can corrode the liner surface and create excessive wear of the liner material.

Ship operators should use the appropriate cylinder lubricating oil to protect the engine cylinder components i.e., protect against excessive cylinder liner and piston ring wear to prolong service intervals. The oil should have the ability to improve cleanliness to prevent ring sticking and minimize deposit formation on the pistons, rings and throughout the combustion chamber exhaust areas. However, running engines smoothly using VLSFO is not just about choosing the right cylinder oil or cylinder oil feed rate, it is also important to maintain the correct procedures and practices during operation. Operators should follow the original engine manufacturers' (OEM) guidelines/recommendations on the use of VLSFO/ULSFO for the correct engine operation. To reduce the risk of these piston/liner issues, the following should also be considered:

Cat Fines: For details on cat fines refer also to Section 4. The cat fines limits for residual fuel oil are outlined in ISO 8217:2017, however these limits can often be much higher than the acceptable cat fines limit recommended by engine designers or manufacturers. It is essential to remove cat fines using the correct cleaning process to reach the recommended level after the centrifuge, and prior to the fuel entering the engine fuel system and cylinder liner – see Figure 6. The usual procedure is to drain the settling tank at regular intervals throughout the period of operation and purify the fuel by centrifuge with optimum settings. If cat fines have already entered the engine, proper operation of the fuel cleaning equipment must be verified and adjusted as required.

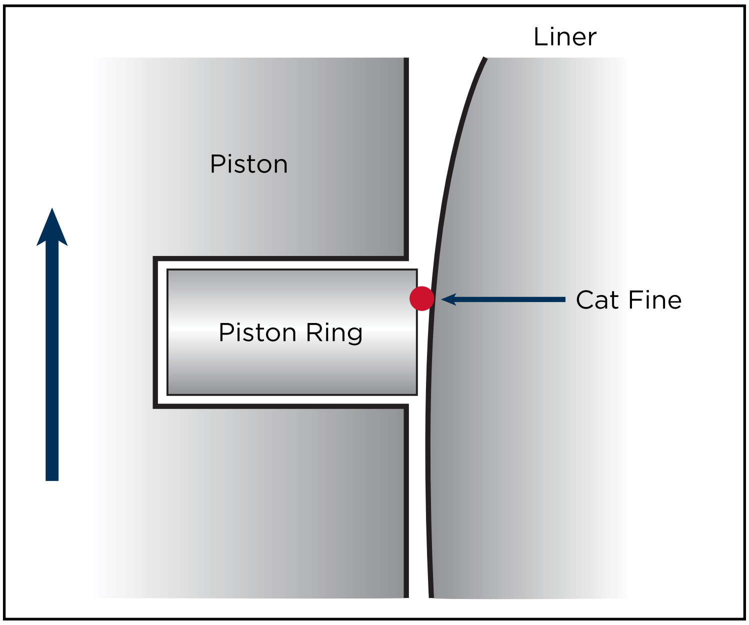


Figure 6: Cat Fines

Cylinder Oil Grade: The correct grade cylinder oil is to be selected to facilitate appropriate cylinder lubrication when using VLSFO, and ULSFO of either distillate (DM) or residual (RM) grades. The main purposes of the cylinder oil are to lubricate the piston and liner, reduce friction, introduce wear protection, minimize risk of seizures, neutralize acids, and maintain clean piston, piston rings, ringlands, and liner which is essential to ensure free movement of the rings, by managing and preventing excessive deposit build-up. it is important to pay close attention to the properties of the lube oils and their impact on the equipment. The cylinder oils recommended/ approved by the engine manufacturer are to be used. Cylinder oil performance and cleaning ability are the key factors to maintaining good cylinder condition. A cylinder oil with higher detergency properties is to be considered to help prevent deposit build-up.

Cylinder oil with suitable alkalinity (based number - BN) will neutralize the sulfuric acids that are produced during the combustion process to prevent corrosion on pistons, piston rings and cylinder liners. The oil develops a film between the cylinder liner and the piston rings to reduce friction. Also, the cylinder oil can keep the piston, the piston rings, and the cylinder liners free from deposits. A cylinder lubricant oil with an appropriate base number (BN) is to match the sulfur content of the fuel oil to ensure sufficient protection of combustion chamber components against corrosion. The sulfur content of the fuels may vary depending on ECA operation, globally outside ECAs, whether alternative fuels (methane, methanol, ethane, LPG, etc.) with negligible sulfur are applied, or whether there are other engine design features, such as Exhaust Gas Recirculation (EGR), that may affect cylinder operating conditions. Also, high sulfur (above 0.50% to 3.5%S) fuels may be used by ships installed with SOx scrubbers. The ship operators are to select the correct cylinder lubrication oil with appropriate BN considering the sulfur content of fuel oil, engine operating conditions, cylinder lubricating feed rate and engine manufacturer's recommendation. Ship operators may also consider application of automated cylinder oil switching or mixing systems that can facilitate the use of the correct cylinder oil when entering or exiting ECAs or switching between different fuels.

Cylinder Oil Feed Rate: The cylinder oil feed rate is to be kept to the minimum possible (to reduce consumption rates) while being sufficiently high to maintain the acceptable cleanliness, acceptable wear and avoiding hard contact such as micro-seizures on the piston rings and cylinder liners. The typical feed rate range for cylinder oil is between 0.6 g/kWh and 1.2 g/kWh for two stroke marine engines. The specific cylinder lubricating feed rate is set at 100% MCR in the engine control system, but for part load operation, a correction factor is typically applied; the effective feed rate at part load is usually higher than the set feed rate.

The feed rate is to be optimized based on the engine manufacturers' recommendations. For example, initially the feed rate of a selected cylinder oil is set to 1.0 g/kWh, then the engine is monitored in operation for deposit formation and gradually the feed rate is reduced based on drain oil sample analysis and visual inspection. It is important to decrease the feed rate in small steps, for example in steps of 0.05 g/kWh, until the minimum feed rate is reached. When optimizing to minimum feed rate, attention is to be paid to confirm signs of hard contact or micro-seizures on the rings, ring land deposits, or other abnormalities before determining the minimum feed rate. The feed rate must be kept sufficiently high to avoid micro-seizures. If the condition starts to deteriorate above the minimum feed rate, then it is recommended to change the cylinder oil type and/or BN level to a different oil with increased detergency properties.

Piston Ring Design and Coatings: The major engine manufacturers have developed special ceramic coated piston rings which can have lower wear rates for both cylinder liners and piston rings. The ceramic coated piston rings are patented by different companies and known as Cermet coated, Chromium ceramic coated etc., as appropriately used by the specific engine designers/ manufacturers.

The running surface coating of ceramic piston rings can attain maximum corrosion protection and lowest possible wear over the component lifetime. If, significant corrosive attack takes place, the wear rate of the cylinder liner and piston rings will increase during this period but can go back to a regular wear rate level after suitable lubrication conditions have been re-established. This is because the Ceramic coated piston ring coating does not disintegrate, even under severe corrosive conditions.

RECOMMENDATIONS

Operators should follow the engine designer/manufacturer recommendations and guidance applicable to their particular engine design and fuels on which they operate. In addition, the items below are generally considered good practice:

i. Ensure tanks are arranged and cleaned for the range of fuels intended to be used, that those fuels are specified in accordance with the ISO 8217 standard, and that all compatibility, stability, etc. checks are procedures are followed and as outlined in Sections 3 and 4 of this Advisory.
ii. Take all necessary precautions and actions to remove cat fines from the fuels to the OEM recommended level.

iii. Use cylinder lubrication oil which is recommended/approved by the OEM for the specific engine type/ model and fuels being used.

iv. Evaluate drain oil samples of every cylinder as recommended by the OEM. In general practice, samples should be taken at regular intervals of 14 days or monthly, or more frequently if suspected wear issues are detected.

v. Test the total content of iron (Fe) and residual BN in the cylinder oil drain samples. Laboratory testing according to ASTM D5185-09 is the most appropriate measuring method. But the BN is to be tested in accordance with ISO 3771:2011(E) procedure. Onboard analysis kits should be used to compare the results with the laboratory analysis.

vi. Cylinder oil BN levels in drain oil samples may vary depending on the engine and oil type. Generally, the remaining BN should not be lower than 25% of the new cylinder oil.

vii. Optimize the correct cylinder oil lubrication feed rate, following the procedure developed and provided by the OEM.

viii. Regularly check the piston ring and the cylinder liner conditions through scavenge port inspections.

ix. Follow the OEM guidance on piston and piston ring specifications, consider replacing the installed pistons and/or piston rings with the OEM recommended ceramic coated piston rings at an appropriate maintenance point.

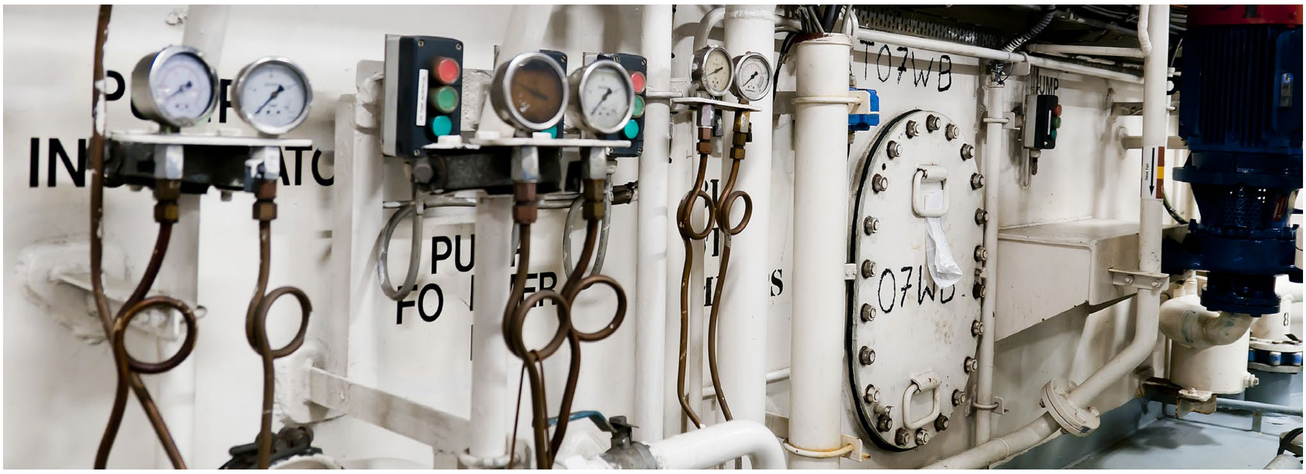
x. Optimize cylinder liners with the engine temperature profiles, and in accordance with OEM guidance, to prevent cold corrosion.

SECTION 5 – FUEL SWITCHING

Fuel oil switching from VLSFO-RM/ULSFO-RM/ HSHFO to ultra-low sulfur distillate fuel oil i.e., ULSFO-DM can be challenging, and appropriate procedures are to be used to avoid fuel supply problems or loss of power/ propulsion. Also, any fuel changeover is to be completed prior to entering regulated waters (e.g., ECAs or California water) to avoid non-compliance. Fuel changeover from VLSFO-RM to ULSFO-RM can be simpler because both are heated fuel oils, but changeover from residual to distillate or vice-versa is to be carried out very carefully and in accordance with the OEM recommendations. Note, CARB prohibits the use of EGCS (SOx scrubber) in California waters, so vessels using HSHFO with EGCS are required to change to ULSFO-DM.

It is important to check the suitability of each component in the fuel system and the combustion system of each engine and boiler for the range of fuels expected to be used by the vessel. It is also important to prepare fuel changeover and operating procedures for the vessel based on the modified fuel system design. Without these efforts there is a real potential to damage auxiliary machinery, engines, boilers, and their components. Other possible risks include a deficiency of required power, leading to a possible loss of propulsion or the inability to generate power at critical times during vessel maneuvering, placing the ship and the environment at risk.

For new design vessels, consideration should be given to incorporating electronic fuel control and direct fuel injection combustion systems, which allow engines to burn a wide variety of fuels more efficiently, resulting in better power generation, cleaner emissions, and increased fuel economy.



FUEL SWITCHING CONSIDERATIONS

This section of the Advisory discusses some of the key items that should be addressed in a fuel switching procedure. The most common issues that arise in switching over to operation on VLSFO-DM/ULSFO-DM are noted below. It is recommended that all vessels operating in areas where low sulfur fuel is required carry out the measures below.

- Prepare an evaluation and risk analysis including consultation with manufacturers guidance and information to outline the issues and risks of using low sulfur distillate fuel. This analysis should cover the entire fuel system and its components, engines, boilers, and control systems. In addition to the engine or boiler maker's advice, issues related to other components in the system may also need to be addressed by individuals specializing in specific systems or sub-systems. Check for any service or maintenance requirements that are recommended when using VLSFO-DM/ULSFO-DM. A copy of the risk analysis report should be maintained on board for reference.
- Prepare a detailed fuel switching procedure (or manual) in consultation with the engine/machinery makers guidance and information and place it on board. Include any required inspections or maintenance schedules. Properly train the crews in the fuel switching procedures. As this is a safety issue, a copy of this procedure should be retained on board, and its availability may be verified during ISM audits. Note that for fuel changeovers associated with entry/exit to ECAs, the fuel changeover procedure is required to be carried for compliance with regulation 14 of Annex VI, and details relating to the fuel changeovers recorded in the entry/exit logbook, as may be inspected by the flag Administration or Port State Control.
- Consult with fuel suppliers to select VLSFO-DM/ULSFO-DM (with viscosity at or above the minimum required for the machinery on board). Independent fuel oil testing is recommended.
- System seals, gaskets, flanges, and other fittings should be carefully examined and maintained to prevent any fuel seepage and leakage. Fine spray particles from such leakage may pose a severe fire safety risk.
- Maintain fuel oil purifiers, filters, and strainers in accordance with the OEM recommendations.
- Check and maintain control systems, including hardware, wiring, alarms, set points and instrumentation such as transmitters, and indicators.
- Conduct crew training (initial and periodic).
- Monitor engine cylinder lubrication carefully to identify any increases in lube oil consumption which may be caused by liner lacquering. Periodic testing of in-use lubricating oils can give early indications of unusual wear.
- Concerns with boiler operation and burner steam atomizing with VLSFO-DM/ULSFO-DM (including distortion of the tubes) should be assessed with the manufacturer. For burners having parallel tubes for steam and fuel oil, due to the lower temperature of VLSFO-DM/ULSFO-DM, tubes conveying VLSFO-DM/ ULSFO-DM can distort due to temperature gradients.
- Ensure the burner management and flame supervision systems safely include VLSFO-DM/ULSFO-DM operation.
- Complete fuel switching prior to entering an ECA, port or restricted water to satisfy regulations and reduce risks.

  ABS is prepared to issue Statement of Fact (SOF) certificates as a service to owners wanting documentary proof they operate in compliance with the air emissions fuel storage, handling, and changeover regulations. After inspection by an ABS surveyor, ABS will verify that the vessel has dedicated low sulfur fuel (e.g. VLSFO-DM/ ULSFO-DM) storage tanks, fuel piping systems suitable for low sulfur distillate use that maintain segregation from other fuels and has operational procedures on hand (See Appendix 1).

FUEL SWITCHING REQUIREMENTS

ABS has specific requirements that apply to the fuel switching process and any modifications made to fuel systems and diesel engine components.

Owners and operators are required to evaluate the engine and associated machinery and equipment using low sulfur fuel. This evaluation should be a systematic assessment of related systems taking into consideration the potential risks identified in the design and operational review. Appropriate measures based on the assessment results must then be taken. The vessel owner is responsible for the vessel and its safe operation. It is recommended that the engine manufacturer or another entity recognized by the engine manufacturer be employed to carry out the design evaluation and oversee any modifications that may be required.

The evaluation is to consider, under all normal and abnormal modes of operation, the following, including (but not limited to) whether the vessel:

- Is fitted with dedicated low sulfur fuel oil storage tank(s), fuel oil piping system is arranged to support low sulfur fuel supplies for the main engine, auxiliary engines, and boiler etc.
- Is optimized for fuel switch over from residual fuel oil to distillate fuel oil, low viscosity fuel
- Is optimized for fuel switch over from distillate fuel oil, low viscosity fuel to residual fuel oil
- Machineries are capable of operation on low sulfur fuel during extended idle periods
- May start any engine at berth or anchorage using ULSFO-DM

Manufacturers and associated systems providers are to be consulted to determine whether their existing fuel systems/arrangements require modifications or additional safeguards for the intended fuels. Engine manufacturers are to be consulted regarding any service or maintenance requirements when operating on low sulfur fuel.

All design modifications are to be in compliance with original manufacturer's recommendations whenever possible. A competent 3rd party can be used for design modifications provided that the entity is recognized by the original manufacturer and/or is willing to undertake the full responsibility for the modified design. Any modifications to existing installations including piping systems, control systems, equipment and fittings will be subject to ABS review and approval for design assessment and survey. Any new pumps in the fuel system are required to be ABS certified. All modifications shall be carried out in accordance with the approved drawings and details to the satisfaction of the attending surveyor.

Low sulfur distillate fuel (i.e., VLSFO-DM/ULSFO-DM) tanks and systems are to be arranged to facilitate fuel changeover. Sufficient capacity for the intended operation must be carefully considered and planned. While not specifically mandated, installation of dedicated low sulfur fuel service tanks may be necessary. Residual and distillate fuel piping systems (including pipe fittings and equipment) are to be arranged to carry out effective flushing from the system.

FUEL SWITCHING PROCEDURES

The issues related to fuel switching are unique to each ship and its condition. However, there are certain general principles and procedures that apply to most ships and understanding these will be helpful in developing the fuel switching procedure for any specific ship. It is highly recommended that a well thought out fuel switching procedure or manual (onboard procedure and checklist) be developed by competent and experienced persons for any ship that will transit waters that require the use of low sulfur fuel, so that the fuel switching can be carried out safely with no risk to the crew, ship or environment. This is a requirement of MARPOL Annex VI, Regulation 14 (6) for ships entering and leaving an ECA.

Operating crews are to be well trained in how to use the procedure and be aware of any safety issues that can arise and how to respond to them. All new crew members joining a ship are to be trained prior to participating in the fuel switching process. The proper implementation of fuel switching and reliable operation of the propulsion machinery through the time of the switching and while operating on the low sulfur fuel is of great importance because the requirement to operate on low sulfur fuels is generally applicable to ports and coastal waters where there is the greatest risk to the ship and environment from loss or reduction in a ship's propulsion power.

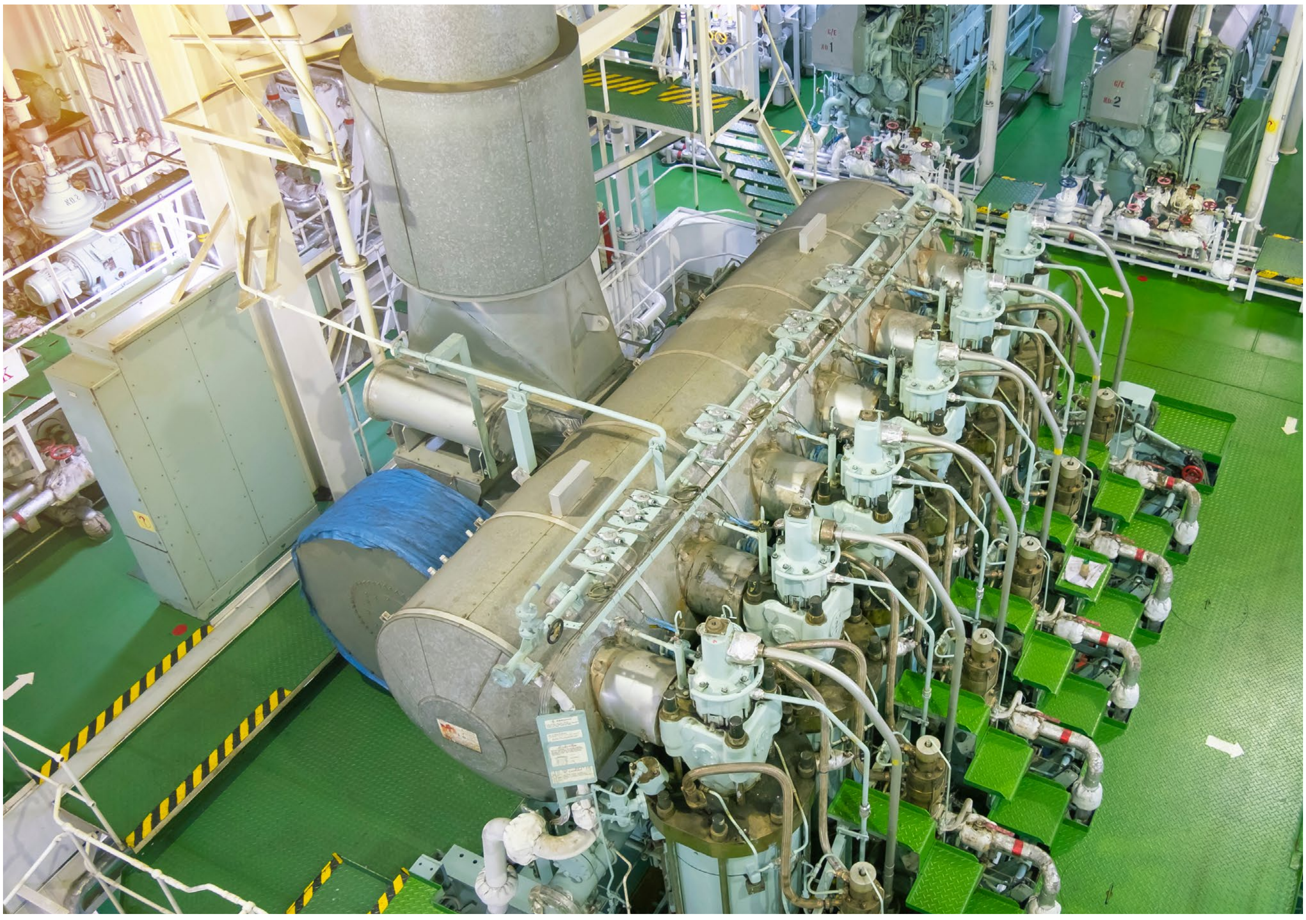
Where fuel switching is required for operation in coastal waters, it is recommended the vessel carry out the changeover operation in safe navigable waters prior to entering crowded and restricted channels and port areas, or areas where there is a higher risk of grounding or collision. The vessel operator shall follow the ship's onboard procedure and checklist to safely perform the changeover.

The following are important steps and issues that are to be considered in the preparation of a fuel switching procedure, as one or more of these events could lead to unexpected shut down of the main or auxiliary engine(s):

- A competent person is to carry out an assessment of the fuel system on board the ship and determine the requirements for safe and effective operation on low sulfur fuel.
- The arrangements of fuel storage, settling and service tanks are to be considered in the fuel switching procedure. This will determine whether fuel switching can be done by segregating the systems or by mixing fuels. Segregating fuels is the preferred method as it allows much quicker switching and there is less potential for compatibility issues. Segregation can be carried out on ships that have separate fuel lines between fuel storage, settling and service tanks.

  Most ships built after 1998, because of SOLAS requirements, have double service tanks and more than two storage tanks, so the possibility for segregation exists. In many cases the second service tank is a diesel fuel tank and not a residual fuel tank. This works well to accommodate low sulfur distillate fuel oil.

  Having separate, segregated fuel systems greatly simplifies the switching process and reduces the risks and crew effort as the switching is done by changing over the valve or valves that supply fuel to the fuel service pumps for the engine or boiler. The switching verification process is also much simpler with a segregated system because the time for the valve changeover can be easily recorded and the time to flush the fuel system with the new fuel is significantly reduced.



- There is a concern that thermal shock may be caused during fuel changeover from residual fuel to distillate fuel because heated residual (e.g. VLSFO-RM/ULSFO-RM/HSHFO) has been delivered to the engines and the distillate (e.g. VLSFO-DM/ULSFO-DM) replacing the residual fuel is unheated. Thermal shock may be caused if the changeover time is too short. Switching fuels is to be carried out very carefully, by maintaining a steady drop in temperature, reducing the engine load, and slowly by-passing the fuel oil heater prior to beginning the fuel changeover. The fuel temperature must be lowered slowly (about 2°C per minute) to prevent thermal shock to the fuel system.

  When changing engine operation from residual to distillate rapidly; an uneven temperature change could cause thermal shock, creating uncontrolled clearance adaptation which can lead to sticking or scuffing of the high pressure fuel injection components or complete fuel pump seizure.

- Prolonged engine operation with an incompatible crankcase or cylinder lubricating oil could result in accelerated piston ring/liner wear. Alkaline compounds such as calcium salts are used to neutralize the sulfuric acid formed on the liner when using high sulfur fuels. If the pH of the lubricating oil does not match the fuel used in the engine, alkaline crystals may build on the liner. This can cause a loss of sufficient oil film thickness, bore polishing, liner lacquering and sudden severe wear of the liner.

DIESEL ENGINES

During the changeover process it may be necessary to re-set or re-adjust various equipment (such as control valves, temperature sensors, and viscosity meter/controllers) employed in the monitoring and control systems, unless this is accomplished automatically. Where manually adjusted, changes should be conducted in accordance with the engine maker's recommendations.

Control of Viscosity: When operating on low viscosity low sulfur fuels, one way to keep viscosity above the minimum value for delivery at the engine fuel injection pumps is to install a fuel cooler to keep the fuel temperature below 40°C. This is especially true for operation in summer and tropical conditions since ambient temperature in the engine room and fuel tanks can be above 40°C. A fuel cooler using the central freshwater (FW) cooling system as the cooling medium may not provide adequate cooling as the cooling water normally has a set point temperature of 36°C to 38°C. In this case, adding a chiller unit to the cooler can lower the fuel temperature to about 20°C to 25°C and will be effective in maintaining the viscosity above the required minimum.

There are several locations where the cooler can be installed in the fuel service system. One location is in the fuel return line between the engine and the mixing tank. This removes the heat added to the fuel during circulation through the engine. This cooler location is effective if the fuel source (tank) is at the required temperature and it is only necessary to reduce heat from the fuel returned to the mixing tank. It also allows the fuel supplied to the engine to be gradually lowered in temperature since the cooled fuel is mixed with the warmer fuel in the mixing tank rather than introducing cooled fuel directly to the engine. An alternative fuel cooler location is in the fuel supply pipe prior to the engine. In this arrangement the temperature of the fuel to the engine is directly controlled and it is more effective at cooling the fuel below 40°C because it removes heat introduced from the engine return, the fuel source and service pumps in the fuel system.

The temperature of the fuel out of the cooler can be controlled if a means of adjusting the cooling medium flow (i.e., by a temperature sensor in the fuel outlet line) is provided. In this way the fuel can gradually be brought to the desired temperature during fuel switching. Abrupt lowering of the fuel temperature should be avoided. Fuel oil coolers for boilers are similar in concept to those for diesel engines.

Procedures for Switching with Fuel Mixing: A ship lacking a tank arrangement permitting segregation of fuel beyond the storage tanks must develop procedures for fuel mixing. One method is to reduce the level in the settling tank to about 20 percent before filling with the alternate fuel. This arrangement may require up to several days of operation and several dilutions to reduce the sulfur level in the mixed fuel to the required level before entering an ECA. This can lead to high consumption of expensive low sulfur fuel, so consideration should be made to install a segregated fuel system on any ship that regularly operates in areas where low sulfur fuel is required. It is important to ensure compatibility of any fuels prior to mixing.

Reducing Ship Power: Prior to commencement of fuel switching, it is generally recommended to reduce ship power to the specific level indicated in the vessel's fuel switching procedure. Typically, this is 25% to 40% maximum continuous rating (MCR), depending on the specifics of the propulsion plant.

Thermal Shock Avoidance while Switching Fuels: Avoiding thermal shock to the fuel system is one of the critical elements to be considered in a fuel switching procedure. Engine makers normally offer guidance on the maximum allowed rate of temperature change in fuel systems. A commonly stated rate is 2°C per minute.

For example, if a ship is using VLSFO-RM/HSHFO heated to about 150°C prior to the fuel booster pumps and switching to ULSFO-DM at 40°C, the temperature difference is about 110°C. Under these conditions and considering a 2°C per minute permitted rate of change, the fuel switching process should take a minimum of 55 minutes to complete safely. Consider using longer than the minimum time to prevent short term rapid temperature changes during the process. There are several important factors that should be taken into consideration in controlling the rate of temperature change during change over.

Manually Fuel Switching: Many ships carry out fuel switching by manually changing over a single three- way valve. This immediately changes the fuel source. If the fuel switching is done at high power levels, the fuel change is carried out in a relatively short period of time as the fuel circulates at a high rate through the mixing tank. Rapid change from residual fuel to distillate fuel can lead to overheating the distillate fuel, causing a rapid loss of viscosity and possible gassing in the fuel system. Too rapid of a change from unheated distillate to heated residual fuel oil can lead to excessive cooling of the residual fuel oil and excessive viscosity at the fuel injectors, again causing loss of power and possible shutdown.

If a single changeover valve is provided, it is recommended to carry out fuel switching with the engine at low power levels so the fuel change will occur gradually enough to remain within the temperature rate of change limits. Fuel switching is not to be carried out at higher power levels and it is recommended that an automated fuel changeover system that changes the fuel in a timed and regulated manner be installed. Such automated systems are now offered by some engine makers and by fuel system equipment suppliers.

Fuel Pump Considerations: With the introduction of low sulfur fuel oil such as VLSFO-DM/ULSFO-DM into the fuel system, the existing residual oil service pumps may lose suction because of reduced fuel oil viscosity and lubricity. Due to less lubrication, overheating of the existing residual fuel pumps (if they are not designed to handle distillate) may occur.

Therefore, it may be necessary to install different types of pumps to handle low viscosity fuel. For ships contracted for construction on or after July 1, 2013, IACS UI 255 provides guidance for fuel service pump arrangements required to maintain normal operation of propulsion machinery for compliance with SOLAS II-I/26.3.4. Also, excessive wear within the fuel injection pump can result from the lower lubricating properties of 0.10%sulfur fuels (ULSFO-DM). This could necessitate replacement of the existing injection pump with a new fuel pump. Engine fuel injection pumps may be replaced with special pumps (e.g. tungsten carbide-coated fuel injection pumps).

Consideration must be given to MARPOL Annex VI compliance when replacing or modifying any NOx critical components, or settings that can influence the combustion process, and hence NOx emissions. It may be necessary for an engine manufacturer to install some specific components for operation on certain fuel grades or for certain operational requirements. In such instances, some of these components may require justification to demonstrate their suitability as allowable alternative NOx critical components (and that may be included in the NOx Technical File), or settings of that particular engine group or family. In essence, the engine manufacturer must confirm that the modification was covered by the configurations used during emission testing of the engine. Otherwise, additional testing may be needed. ABS do not anticipate any major effects when techniques such as a coating or surface treatment are adopted to resolve fuel injection pump lubricity issues.

If new pumps are installed in the fuel system, they are required to be certified by the attending surveyor at the manufacturer's plant as required by 4-6-1/7.3.1 of the ABS *Marine Vessel Rules*.

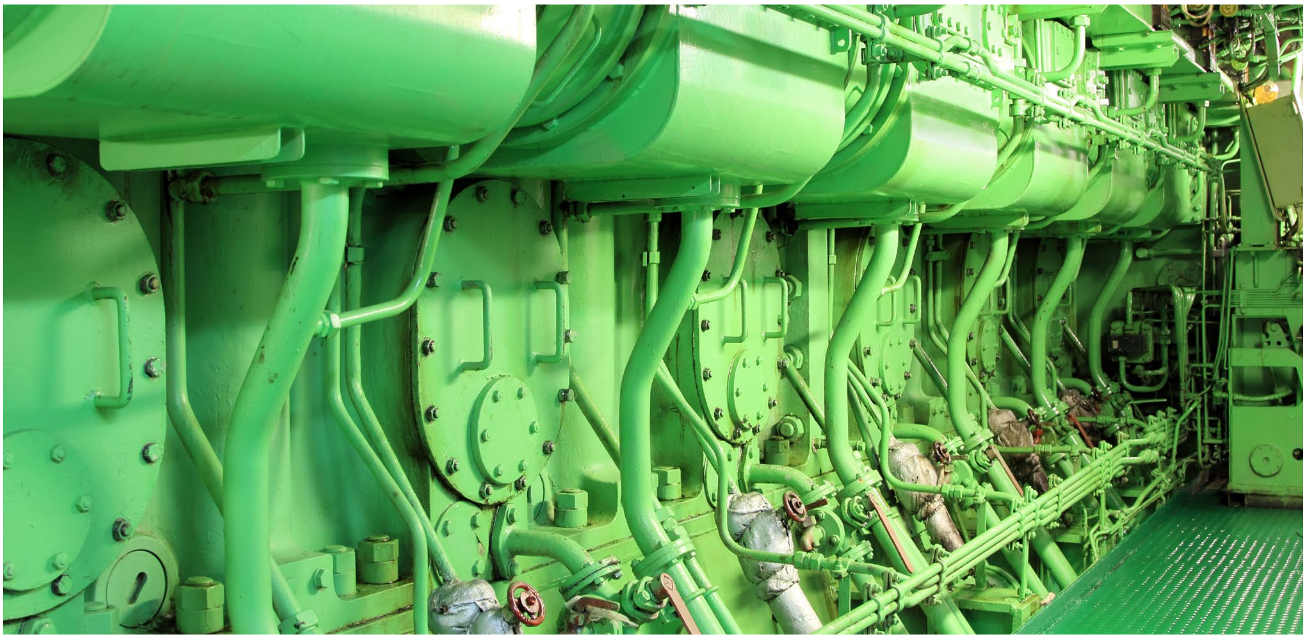
Fuel Heating: Fuel heaters and pipe heat tracing should be turned off or on in a controlled manner during the fuel switching process. Most ships have a viscosity control system that controls the heat supply to the fuel preheaters located in the fuel supply system. This system adjusts the heat supply to the preheaters as the fuel viscosity changes during the fuel switch. However, when the change to low viscosity fuel oil is completed, the heat supply must be turned off, along with any heat tracing.

Gassing: When switching from heated residual fuel to unheated distillate fuel, engine components and fuel in the mixing tank will retain heat. As the tank of hot fuel continues to be replaced by distillate, low viscosity fuel, there is real danger of the fuel heating to a point that it will flash in the booster pumps. This "gassing" of fuel will prevent fuel delivery to the engine, causing a shut-down condition. The fuel temperature should be closely monitored during the switchover process and components should be given sufficient time to cool before the fuel system is completely flushed by low sulfur fuel. Use of fuel coolers can be of value to avoid gassing of low viscosity fuel.

Fuel Compatibility: Compatibility of the mixed fuels is an issue and is discussed in Section 4. During the fuel switching process, fuel filters, strainers and the mixing tank should be carefully checked for evidence of clogging and excessive sludge formation. This is one reason why fuel switching is best done ahead of time in open waters clear of hazards.

Purifier Operation: For extended operation on distillate fuel, purifiers may be adjusted to suit the new fuel. The purifier suction and return are to be checked to make sure the pipes lead to the correct tank(s). In general, the purification of a fuel such as VLSFO-DM/ULSFO-DM may not be required. However, some engine makers may recommend purification. In that case, the purifier operational details are to be in accordance with the purifier maker's instructions and recommendations.

The usual procedure to reduce cat fines includes settling out oil in the storage tanks, regularly draining tank residue , purification (using a centrifuge) and other suitable treatment. Testing can reveal the amount and the size of the cat fines, enabling the vessel to adjust its purification process to the specific fuel need. There are also optimized onboard cleaning systems and automatic tank and separator systems on the market that help maximize cat fine removal. ABS recommends contacting the engine manufacturer for more details.



ABS recommends vessel owners/ operators take the following actions to prevent failure due to fuel quality:

- Check engine manufacturer's maximum recommended cat fines concentration
- Optimize the use of separators, purifiers, and clarifiers
- Verify that cleaning systems can remove increased concentrations of cat fines which may occur in heavy weather
- Consult engine manufacturers regarding the use of additional fine mesh filter(s)
- Use a homogenizer immediately upstream of a separator, purifier, or clarifier
- Use an electronic, inline cat fine monitoring system
- Use separate fuel service and booster pumps for low sulfur fuel oil operation
- Add a fuel oil cooler/chiller to control viscosity
- Use a separate piping arrangement with fuel change over mechanism
- Use appropriate BN lubrication oil for extended operation with low sulfur fuels
- Modify electronic control system for both engines and boiler
- Modify or change-out boiler burners
- Operations in cold areas may cause wax in distillates to solidify and may need VLSFO-DM/ULSFO-DM distillate fuel heating arrangement

Intelligent fuel oil testing also provides information on other specific parameters useful in optimizing the combustion efficiency such as calorific value, water content and ignition point and/or delay. These values should be routinely scrutinized to optimize combustion and minimize costs.

Fuel Injector Cooling: If an engine is equipped with fuel injector cooling, it may need to be turned off or on during fuel switching. When the engine is operating on unheated low sulfur fuel, fuel injector cooling may not be needed and should be turned off to prevent over cooling if the engine is to be operated for an extended period. If injector cooling has been secured, it should be turned on when the engine is returned to operation with heated fuel oil. The engine manufacturer should be consulted regarding this item.

Temperature Monitoring: Temperature of the engine and its components must be continually monitored to ensure they are maintained at normal service temperatures. Adjustment or resetting of engine control equipment such as control valves, temperature sensors, or viscosity controller may be needed, to account for the new fuel type, if not done automatically. As crew members gain experience with fuel switching there will be a better understanding of what needs to be adjusted and monitored during the switching process and during sustained operations with low sulfur fuel. During fuel switches, vigilance is needed to spot potential problems before they become serious. Fuel switching procedures should be adjusted to account for identified problems.

Powering Up: Once the propulsion and generating plant are stabilized on the new fuel and all components are at normal service temperatures, the propulsion plant should be able to be brought back to normal power and the vessel can proceed into restricted and port areas.

Considerations for Lube Oil: If sustained operation (more than five to seven days) is planned on a fuel with a sulfur content greatly different from the fuel the vessel typically uses, slow-speed diesel engine makers recommend that the cylinder oil be changed to accommodate the sulfur content of the fuel being used. Lubricating oil with a high level of alkaline additives is recommended by many manufacturers for use with high sulfur fuels. Therefore, a lower total base number (TBN) crankcase oil for medium speed engines (i.e., trunk-type) or cylinder lube oil for slow speed engines (cross-head type) should be selected if a low sulfur fuel is going to be used permanently or for a prolonged period of time; see also information in Section 4.

BOILERS

If a boiler has been originally designed to burn only residual marine fuel (e.g. HSHFO or MDO), there are several points that should be considered before changing to distillate fuels. Usually, during initial flashing and when the furnace temperatures are low (particularly after repair), the boilers can use small amounts of distillate fuel (e.g. VLSFO-DM/ULSFO-DM) . However, they cannot sustain use of VLSFO-DM/ULSFO-DM during normal operations and meet steam demand without modifications.

Boiler explosions can occur due to incorrect operations. For example, when the boiler furnace is not properly purged before ignition, high pressure fuel gas may build up in the burner due to flame failure, or when the control system is malfunctioning or disconnected. Unburned fuel may be admitted to a hot furnace following flame failure, leading to an explosion.

Systems providing fuel atomization may have to be reassessed because steam atomization may not be suitable for VLSFO DM/ULSFO-DM due to the possibility of fuel vaporization before exiting the burner tip. This could lead to flame instability, improper combustion and, possibly, flame extinguishment. Equipment manufacturers should be consulted to determine the necessary safeguards.

Use of VLSFO-DM/ULSFO-DM may cause coke deposits on rotary cup type burners. Protective heat shields are necessary to prevent coke build up. The changeover process should consider solubility of asphaltenes (i.e., fuel compatibility). Existing burners designed for residual fuel e.g., HSHFO /MDO may require modification or new types of burner assemblies accommodating both residual (e.g., VLSFO-RM/ULSFO-RM) and distillate (e.g., VLSFO-DM/ULSFO-DM) fuel oil. The existing piping used to transport heated residual fuel from the service pump to the boiler may not be suitable to transport distillate fuel, since there may be vaporization while flowing through hot piping, creating vapor lock, and causing irregular fuel flow towards the burner and resulting in flame extinction.

Therefore, distillate fuels (e.g. VLSFO-DM/ULSFO-DM) are not to be delivered through heated pipes to the burner. Consideration should be given to provide dedicated delivery piping and accessories. The burning of VLSFO-DM/ ULSFO-DM may also necessitate swift and effective flame failure detection. Boiler/equipment manufacturers should be consulted for specific recommendations. To avoid vaporization by heating VLSFO-DM/ ULSFO-DM in the piping system, heat tracing of the fuel pipes should be turned off or the heaters should be bypassed and/ or switched off.

If a boiler is designed to burn residual fuel (e.g., HSHFO) instead of distillate fuel (e.g., VLSFO-DM/ULSFO-DM), a flame failure may occur when the fuel is changed over to distillate because the flame scanner photocells may lack the color spectrum necessary for distillate. Equipment and/or machinery manufacturers should be consulted for specific recommendations based on the application. Also, safety features should be developed or considered to promptly and effectively deal with flame failures and all of the possible ramifications of a flame failure. For example, flame supervision may have to be complemented with another flame scanner due to the different properties of residual fuel and distillate fuel flames, such as flame length. Existing HSHFO service pumps may have difficulties with suction of the lighter oil because of viscosity. Also, HSHFO has better lubrication properties than low sulfur distillate fuel. Accordingly, overheating of the existing HSHFO service pumps due to lack of lubrication, may result (unless the pump was originally designed to handle low viscosity fuel). It may be necessary to install completely different service pumps and associated valves to handle low viscosity distillate fuel.

HSHFO has a higher density and a lower calorific value than distillate fuel. The fuel supply control system must therefore be adjusted to supply an adequate volume of low density low sulfur fuel oil to maintain equivalent steam generation. This will cause an increase in burner fuel throughput and will potentially cause excessive smoke due to the change in the fuel air ratio. The fuel to air ratio will be too rich for safe combustion and must be adjusted.

A detailed, boiler-specific, fuel changeover operation manual is to be readily available for the operating crew on board. In addition, it is suggested that vessel owners and operators consider the following:

- Establishment of a fuel system inspection and maintenance schedule
- System pressure and temperature alarms, flow indicators, and filter differential pressure transmitters should all be operational
- Maintenance of system seals, gaskets, flanges, fittings, brackets and supports
- Detailed system diagram(s) should be available
- Initial and periodic crew training should be conducted and their training needs assessments kept up to date

When a low-load firing operation without a pilot fuel (i.e., burning only distillate fuel) is proposed, and if such operation has not been assumed in the original boiler system design, ABS recommends a safety assessment be made for each individual operational case to ascertain safe operations.

This should include, among other considerations, the following:

- A boiler management system and combustion control that is suitable for intended low-load firing operation
- Flame scanner type and positioning suitable to detect failure at low-load firing operations

When boilers are used for propulsion, maneuvering conditions may demand large and rapid load changes. Therefore, if the boiler is in operation without a pilot fuel, under maneuvering conditions, and such operation has not been assumed in the original boiler system design, ABS recommends safety assessments be made for each individual operational case to ascertain its safety and feasibility.

Fuel oil systems in LNG ships with steam turbine propulsion are designed for HSHFO in combination with the boil off from the cargo. Therefore, fuel oil systems in these vessels will need to be modified to use distillate fuel.

Low sulfur distillate is not to be used in the fuel oil systems in these vessels without modifications for the following reasons:

- It is important that the fuel supply remains uninterrupted for propulsion boilers
- There is a risk of failure in fuel service pumps and associated valves
- There is a risk of unintentional fuel oil evaporation
- Steam atomizing in burners having concentric type fuel injectors can overheat distillate fuel
- Atomizing burners with parallel tubes for steam and fuel oil can distort due to the temperature gradient between unheated fuel and steam
- The design of the burner management system (BMS) and flame supervision is based on HSHFO

APPENDIX 1 – FUEL OIL MANAGEMENT PLAN

A Fuel Oil Management Plan template, is available at:
http://ww2.eagle.org/content/dam/eagle/rules-and-resources/forms/fomp-review1.docx

LIST OF ACRONYMS

ABS	American Bureau of Shipping
ASTM	American Society for Testing and Materials
BDN	Bunker Delivery Note
BN	Base Number
BOG	Boil Off Gas
CARB	California Air Resources Board
CCAI	Calculated Carbon Aromaticity Index
CCR	California Code of Regulation
CFR	Code of Federal Regulation
CIMAC	International Council on Combustion Engines
CNG	Compressed Natural Gas
CO	Carbon Monoxide
cSt	Centistoke (Kinematic Viscosity Unit)
DM	Distillate Marine Fuel
DMX, DMA, DMZ, DMB, DFA, DFZ, DFB	Distillate Grade ISO Fuel Oil Categories
ECA	Emission Control Area
ECSA	European Community Shipowners' Associations
EGCS	Exhaust Gas Cleaning System
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
EU	European Union
FAME	Fatty Acid Methyl Ester
FONAR	Fuel Oil Non-Availability Report
HFO	Heavy Fuel Oil
HSHFO	High Sulfur Heavy Fuel Oil
HVO	Hydrotreated Vegetable Oil
IACS	International Association of Classification Societies
IAPP	International Air Pollution Prevention
IMO	International Maritime Organization
ISM	International Safety Management
ISO	International Organization for Standardization
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSHFO	Low Sulfur Heavy Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
NOx	Nitrogen Oxide
OGV	Ocean Going Vessel
PM	Particulate Matter
PRC	People's Republic of China
RM	Residual Marine Fuel
RMA, RMB, RMD, RME, RMG, RMK	Residual Grade ISO Fuel Oil Categories
SCR	Selective Catalytic Reduction
SECA	Sulfur Emission Control Areas
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
SOLAS	Safety of Life at Sea
SOx	Sulfur Oxide
TBN	Total Base Number
VLSFO-DM	Very Low Sulfur Fuel Oil – Distillate Marine (Sulfur contains ≤0.50%)
VLSFO-RM	Very Low Sulfur Fuel Oil – Residual Marine (Sulfur contains ≤0.50%)
VGO	Vacuum Gas Oil
ULSFO-DM	Ultra-Low Sulfur Fuel Oil –Distillate Marine (Sulfur contains ≤0.10%)
VLSFO-RM	Ultra-Low Sulfur Fuel Oil – Residual Marine (Sulfur contains ≤0.10%)

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