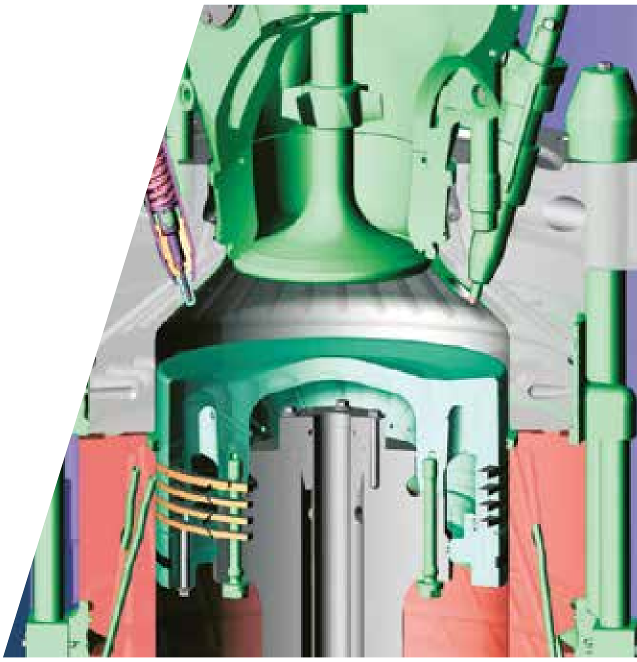
Fuel Switching Advisory 2015



Our Mission

The mission of ABS is to serve the public interest as well as the needs of our members and clients by promoting the security of life and property and preserving the natural environment.

Health, Safety, Quality & Environmental Policy

We will respond to the needs of our members and clients and the public by delivering quality service in support of our Mission that provides for the safety of life and property and the preservation of the marine environment.

We are committed to continually improving the effectiveness of our health, safety, quality and environmental (HSQE) performance and management system with the goal of preventing injury, ill health and pollution.

We will comply with all applicable legal requirements as well as any additional requirements ABS subscribes to which relate to HSQE aspects, objectives and targets.

FOUNDED 1862 ABS

Table of Contents

Introduction 1

Background 3

Section 1 IMO Regulations & Status 5
Regulation for Sulfur Limits 6
SECAs & ECAs 6
Bunker Delivery Notes & Sampling 8

Section 2 Other Regional, National & Local Regulations 10
EU In-port Regulations 10
EU Commission Recommendation 10
EU Commission Decision for LNG Carriers 11
California Air Resources Board (CARB) Regulations 11
California At-Berth Ocean-Going Vessels Regulation 14
US EPA Regulations 15

Section 3 Marine Fuels 16
Fuel Standards 16
Sulfur & Viscosity Ranges 17
Ultra-low Sulfur Diesel Oil 17
New ECA Low Sulfur Fuel Oils 18
Viscosity 19

Section 4 Effects of Low Sulfur Fuels on Operation 21
Potential Effects of Fuel Switching on Diesel Engines 21
Potential Effects of Fuel Switching on Boilers 25

Section 5 Operating with Dual Fuels: HFO & Distillate 27
ABS Suggestions for Fuel Switching 28
ABS Fuel Switching Requirements 29
Guidance for Fuel Switching Procedures 31
Considerations for Diesel Engines 33
Considerations for Boilers 39
LNG Vessels with Propulsion Boilers 42
Ship Design for ECA Compliance 42

Appendix I Use of Low- Sulfur Marine Fuel for Main & Auxiliary Diesel Engines 48

Appendix II Use of Marine Low Sulfur Fuel for Boilers 54

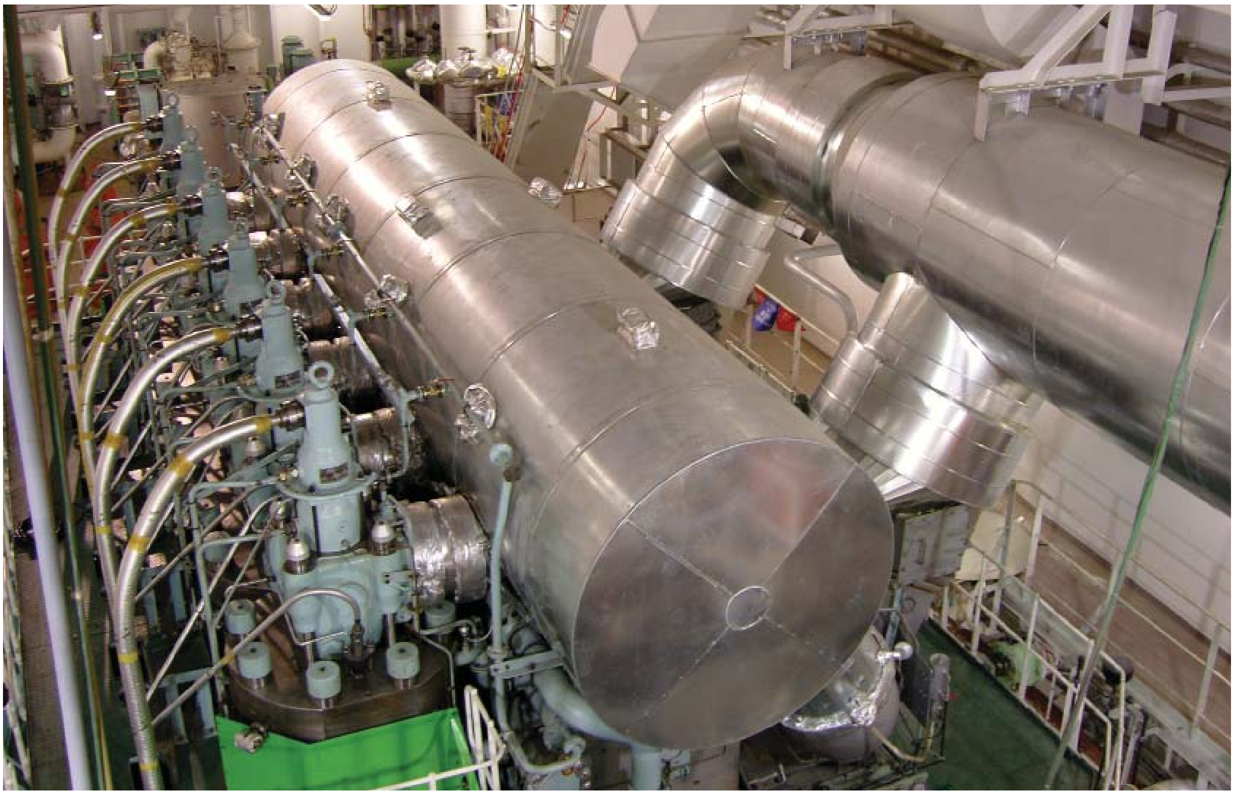
Appendix III Fuel Oil Management Plan 58

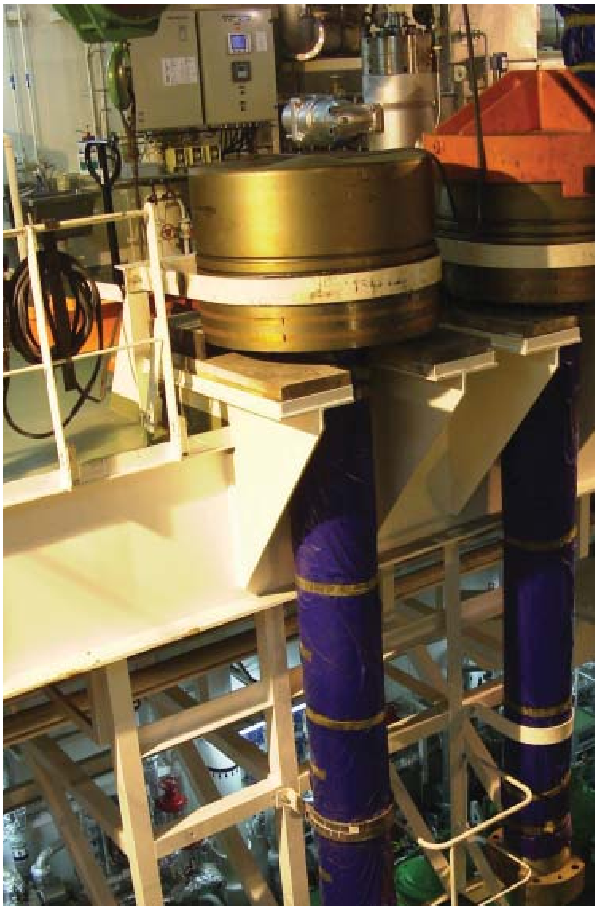
Introduction

Ship-sourced emissions are receiving increased scrutiny from the International Maritime Organization (IMO), government environmental agencies, public health advocates and non-governmental environmental groups. The goal of these groups is to reduce the harmful effects of ship emissions on air quality. Initial regulations have been oriented towards reducing harmful emissions in coastal and port areas with a focus on the release of sulfur oxide (SOx), nitrogen oxide (NOx) and particulate matter (PM).

To comply with the various regulations, vessels are forced to either use scrubbers to reduce harmful exhaust gas emissions or change the type of fuel they use while operating in restricted waters. Exhaust gases from diesel engines contain combustion process gases (water vapor and carbon dioxide (CO_2)) and lesser amounts of various impurities: NOx, SOx, carbon monoxide (CO), polyaromatic hydro carbon (PAH) and PM. The operation of combustion boilers onboard vessels also contributes to harmful air emissions. The specific regulations influencing fuel switching primarily address the amount of sulfur in the fuel.

SOx emissions are generated by the sulfur compounds in the fuel during the combustion process and available evidence has shown that human health hazards are associated with exposure to exhaust gas emissions. When present over land, SOx results in acid rain and smog, which can cause breathing problems (asthma) and premature death. The exhaust gas also contains PAH in the PM, which can be carcinogenic. Other emission components include aldehydes, benzene, 1.3-butadiene PAHs and nitro-PAHs. Global SOx emissions from international shipping represent about 12% of global SOx from anthropogenic sources as reported in the latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5). Relative contribution attributed to shipping when compared to all mobile sources in port areas is much higher and expected to increase.





Regulations intended to limit the extent and types of pollutants have been introduced on both global and regional scales. If operation within sulfur restricted areas is planned and the vessel is not designed to operate on low sulfur fuels, modifications to the vessel's installed equipment and systems may be needed and owners should evaluate the potential risks associated with such operation.

ABS first published a Fuel Switching Advisory Notice in March 2010. This 2014 Advisory provides a significant update and provides guidance to shipowners, operators and builders to identify potential risks associated with fuel switching and best practices associated with safe operations. The suggestions are provided for information purposes only and are not intended to replace any applicable local, national or international safety, operational or material requirements. It is recognized that safe operation of the vessel is the owner's responsibility.

ABS Rules cover the general requirements for piping, automation and electrical arrangements that apply to systems and equipment used for low sulfur fuels. In addition, ABS has also provided Notes on the Use of Low Sulfur Marine Fuel for Main & Auxiliary Diesel Engines and Boilers. These documents are included here as Appendix I & II.

Several alerts have been issued regarding fuel switching. These include the:

- United States Coast Guard (USCG) Marine Safety Alert 03-09, dated 16 June 2009
- American Petroleum Institute (API) Technical Considerations of Fuel Switching Practices, dated August 2010
- USCG Marine Safety Alert 11-01, dated 11 July 2011 on Fuel Switching Safety, regarding the switching of fuel oil from residual fuel to distillate fuels
- USCG Marine Safety Information Bulletin 14-01, dated 09 September 2014 on preventing losses of propulsion and improving fuel switching safety
- USCG Marine Safety Alert 2-15 dated 3 March 2015 stresses the importance of establishing effective fuel oil changeover procedures

In August 2013, the California Air Resources Board (CARB) reported fines for three international shipping companies with a combined total of $445,250 for failure to switch from heavy fuel oil (HFO) to low-sulfur marine distillate fuel upon entering regulated California waters, as required by state law. This is one example of the cost of failure to comply with the fuel requirements. On 15 January 2015, the US EPA issued a memorandum outlining the "Penalty Policy for Violations by Ships of the Sulfur in Fuel Standard and Related Provisions".

Background

The primary international regulatory mechanism for controlling ship emissions is Annex VI of MARPOL (Regulations for the Prevention of Air Pollution from Ships). Annex VI allows for the establishment of Emission Control Areas (ECAs) and effective 1 January 2015 the sulfur content of fuel burned in ECA is 0.1%. SOx and PM emission controls apply to all fuel oil, as defined in Regulation 2.9 of Annex VI, used in combustion equipment and devices onboard unless an approved exhaust gas cleaning system, i.e. scrubber system, is fitted. Alternatively, vessels may choose to utilize innovative new ECA 0.1% sulfur content premium marine fuel which has properties similar to heavy fuel oil (HFO). Another option for vessels is to be designed or retrofitted to operate on liquefied natural gas (LNG) or other natural gases. In some ports, there is also a goal to stop all emissions from ships at the dock by requiring the use of shore power.

The focus of this Advisory is the switching from traditional residual fuel oil to lower viscosity, distillate fuels. Most of the existing marine engines and other fuel burning equipment in operation were specifically designed to burn HFO or marine diesel oil (MDO). Design modifications and operational adjustments may be necessary for engines and equipment to use alternative fuels. Appendix I and II contain additional information.

It is important to recognize that many systems supporting engine operation are directly supplied by the engine manufacturer. As such, involving the engine manufacturer (or another entity recognized by the engine manufacturer) to be responsible for the overall arrangement, including any needed design adjustments, may be a prudent course of action.

The fuel and lubricants utilized by marine diesel engines are highly finished petroleum-based products combined with chemical additives. Many of the fuel and oil properties, such as specific energy content, ignition quality and specific gravity are related to the hydrocarbon composition. Complete and incomplete combustion of fuel in the diesel engine results in the formation of a complex mixture of gaseous and particulate exhaust. During combustion, sulfur compounds in the fuel are predominantly oxidized to sulfur dioxide (SO_2) and some sulfur trioxide (SO_3).

PM is a complex mixture of extremely small particles and liquid droplets that consist of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The PM 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 PM in the exhaust stream can be significantly reduced by burning cleaner, low sulfur distillate fuels, e.g. marine gas oil (MGO), as opposed to residual fuels. To achieve a reduction of SOx and PM in local atmospheres, the use of low sulfur fuel has become mandatory in a number of coastal and port areas. NOx compounds are not affected significantly by the type of fuel burned but can be reduced by controlling the combustion process.

Because fuel is a major component of vessel operating costs, most ship machinery plants have been designed to operate primarily using lower cost HFO, with provision for occasional operation using MDO, particularly when maneuvering. Some smaller diesel engine ships and most high speed ships, such as fast ferries, use MDO as their primary fuel.

However, use of heavy fuels and some types of MDO are becoming progressively restricted under emission regulatory regimes. Ships will have to operate using new ECA low sulfur fuels, clean distillate fuel, or gas fuel (i.e. LNG, Ethane etc.) when trading in areas where strict emission limits are in effect. Another option that may be available in some locations is the use of an effective emissions scrubbing system to meet the low sulfur fuel requirements. Table 1 shows some examples of the difference in cost between residual and distillate fuels and how rapidly the prices of both have increased in recent years.

Table 1: Fuel Cost Examples

Location	**Fuel Cost (USD) per Type of Fuel**			
	2005 October			
	IFO 380	**IFO 180**	**MDO**	**MGO**
Fujairah	298	313	552	555
Houston	291	313	689	N/A
Rotterdam	265	285	523	580
Singapore	323	335	538	543
Location	**2015 April**			
Fujairah	369	388	N/A	737
Houston	343	477	N/A	644
Rotterdam	337	364	N/A	570
Singapore	350	372	564	574

The main reason for switching fuels is the difference in price/cost between HFO and MDO/MGO, as shown by the Bunkerworld data above. MDO/MGO is about 45 percent more costly per unit weight. Since most machinery plants were not designed to operate using MGO, many potential difficulties can arise during the fuel switching process and during sustained operation.

These difficulties stem from the effects of the low sulfur and low viscosity characteristics of MGO on machinery plants originally designed for HFO. Similar effects may be seen in plants designed for MDO operation but to a less significant degree than those designed for HFO.

This ABS Fuel Switching Advisory has been prepared to provide guidance to ship owners, operators and builders about how switching operations between HFO and MGO impact the operation, safety and design of ships.

Section 1 | IMO Regulations & Status

Since the harmful effects of SOx emissions from ships have been known for many years, measures have been taken under Annex VI of MARPOL (Regulations for the Prevention of Air Pollution from Ships) to regulate the sulfur content in fuel. This has resulted in a gradual lowering of sulfur in residual fuels from 6% by mass, in the 1970s, to a maximum of 3.5% in the current MARPOL Annex VI regulations, as determined by the International Organization for Standardization (ISO) standard for marine fuels. Currently, the worldwide average sulfur content of residuals fuel oils supplied for use on board ship is about 2.4%.

In response to the desire of some countries to further reduce SOx emissions from ships in their coastal waters, Annex VI permits the establishment of sulfur emission control areas (SECAs). IMO has also introduced ECAs which control more emission components than only those associated with sulfur compounds.

Some coastal areas, countries and regions, such as the state of California and the European Union (EU), as described in later sections of this Advisory, are placing even stricter controls on ship emissions in coastal areas and in ports. They are implementing new regulations outside the IMO with a continual mission to improve the air quality around these areas by controlling ship sourced emissions. In some ports, there is also a goal to stop all emissions from ships at the dock by requiring the use of shore power while the ship is alongside. This practice is commonly referred to as cold ironing or alternate marine power.

Since shipping is, by nature, truly international, it continues to be recognized that the IMO is the most effective forum for addressing air pollution from ships on a worldwide platform. As part of this process, countries are submitting requests for identification of their coastal waters as ECAs to the IMO.

Regulation for Sulfur Limits

Annex VI of MARPOL took effect on 19 May 2005. It represents worldwide acceptance that harmful emissions from ships should be decreased in a progressive manner as the capability to do so develops. As a consequence, the IMO Marine Environment Protection Committee (MEPC) 58th Session in October 2008, adopted a Revised MARPOL Annex VI – Resolution MEPC.176(58), applicable from 1 July 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.

The Resolution provides controls specific to operation inside ECAs established to limit the emission of SOx and particulate matter (SECAs) 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 in terms of % m/m – that is by weight) are subject to a series of step changes over the years, as shown in Table 2 and Table 3, below.

Table 2: MARPOL Annex VI, Regulation 14 – Global SOx Compliance Dates

Compliance Date	Sulfur Limit in Fuel (% m/m)
1 January 2000	4.5%
1 July 2012	3.5%
1 January 2020*	0.5%

Note: *Compliance date is to be reviewed in 2018 with a possible alternative date of 2025.

Table 3: MARPOL Annex VI, Regulation 14 –Emission Control Area Compliance Dates

Compliance Date	Sulfur Limit in Fuel (% m/m)
1 January 2000	1.5%
1 July 2012	1.0%
1 January 2015	0.1%

Note: There are currently two SOx Emission Control Areas (Baltic Sea & North Sea) and two designated Emission Control Areas (North American & US Caribbean Sea).

SECAs & ECAs

Regulation 14 of Annex VI contains provisions for nations to apply to the IMO for designation of special areas to further reduce harmful emissions from ships operating in their coastal waters. The first two ECAs approved by the IMO, 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 ECAs include PM and NOx emissions restrictions in addition to SOx emission restrictions. It should be noted that IMO does not specifically limit PM but regulates the sulfate portion of PM formation through the fuel sulfur content requirements of Regulation 14 to Annex VI. The IMO Annex VI Special Areas are identified in Table 4.

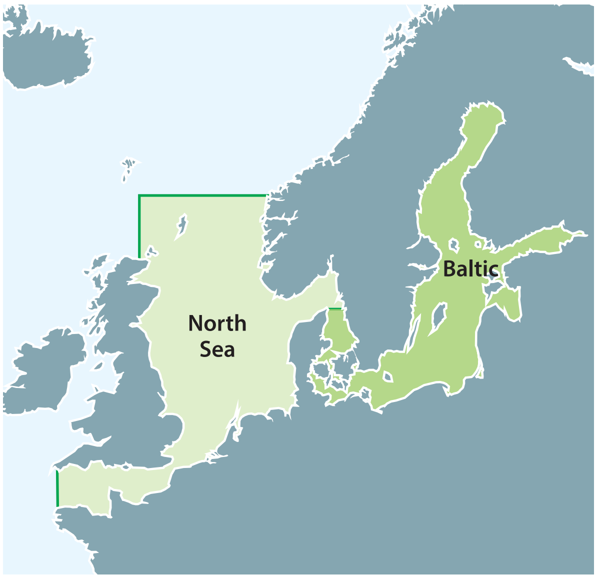


Figure 1: The Baltic Sea and the North Sea and English Channel

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

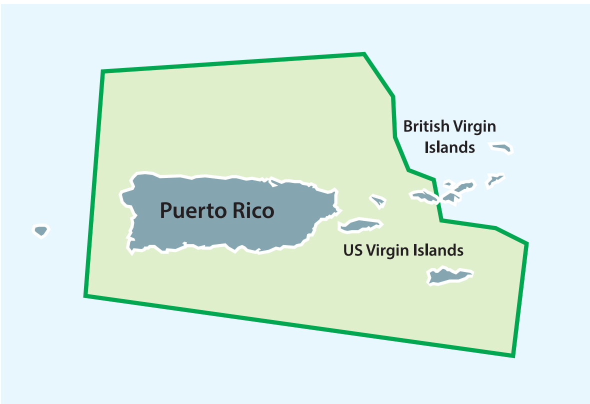


Figure 3: The United States Caribbean Sea ECA

Table 4: Annex VI Prevention of Air Pollution by Ships (Emission Control Areas)

Annex VI Special Area	Adopted	Entry into Force Date	Effective Date
Baltic Sea (SOx)	26 September 1997	19 May 2005	19 May 2006
North Sea (SOx)	22 July 2005 (Resolution MEPC.132(53))	22 November 2006	22 May 2007
North American (SOx, NOx and PM)	26 March 2010 (Resolution MEPC.190(60))	1 August 2011	1 August 2012
US Caribbean Sea (SOx NOx and PM)	15 July 2011 (Resolution MEPC.202(62))	1 January 2013	1 January 2014

Beginning 1 January 2015, ships that operate in an ECA have been required to use low sulfur fuel, with sulfur content no greater than 0.1 percent. To meet the ECA requirements, vessels will need to use distillate fuel (e.g. MGO) or newly developed new ECA 0.1% ECA compliant heavy fuel. Alternatively, ships can use higher sulfur HFO if operating with an approved exhaust gas cleaning system (EGCS).

Ships 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 an 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 safely carry out the fuel management and fuel switching procedure. An example Fuel Oil Management Plan template is included as Appendix III of this Advisory.

Bunker Delivery Notes & Sampling

Regulation 18, as revised by MEPC.176(58), with an effective date of 1 July 2010, contains the latest requirements for fuel oil availability and quality. It states that parties to MARPOL Annex VI shall take reasonable steps to promote the availability of fuels which comply with the Annex. It also lays out the steps that can be taken by regulatory agencies and actions that can be taken by a ship if such fuel is found to not be available.

Vessels that are unable to find 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 find compliant low sulfur fuel oil prior to entering the Baltic and North Sea SECAs needs to 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 made available for purchase. If a ship provides the above information, the competent authority shall take into account all relevant circumstances, and the evidence presented, to determine the appropriate action to take, including not taking control measures (see MEPC.1/Circ.637).

Regulation 14 requires suppliers of any fuel to be used 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 a bunker delivery note 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. Delivery notes should also be accompanied by product Material Safety Data Sheets (MSDS).

Per paragraphs 8.1 and 8.2 of the revised 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 note or the representative sample does not contain information demonstrating compliance with the relevant requirements, documentation must be prepared for the ship's Flag State Administration and copies submitted to the bunkering port authorities and the bunker supplier, and a further copy retained onboard with any relevant commercial documentation (Resolution MEPC.181(59)).

If the stated sulfur content of the sample is required to be analyzed, it shall be done 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 check and confirm the seal number against the sample label on the test record. A detailed sampling and verification procedure shall be followed by the laboratory.

Section 2 | Other Regional, National & Local Regulations

In addition to regulations issued by the IMO, other regions, countries and the State of California have implemented fuel content and emission regulations.

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 the engine and other associated machinery/equipment capabilities to operate with low sulfur fuel. It should be noted that both main and auxiliary boilers fall under the requirements of the EU Directive.

EU In-port Regulations

EU Commission Regulation Article 4b of the EU Council Directive 1999/32/EC dated 26 April 1999 relates to a reduction in the sulfur content of certain liquid fuels and amends EU Directive 93/12/EEC. As amended, it introduces a 0.1 percent sulfur limit (m/m) for marine fuel at berth. The regulation was further amended with EU Directive 2005/33/EC dated 6 July 2005, effective date 1 January 2010, and then with EU Directive 2012/33/EU of 21 November 2012.

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 available (i.e., cold ironing). Vessels with 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 Recommendation

As a result of information from shipowner associations reporting an inability to meet the EU in-port regulations due to the unavailability of parts required to modify engines, insufficient trained personnel to effect the modifications, and the safety considerations associated with fuel switching for non-modified engines, the EU Commission issued a recommendation to EU Member States (2009/1020/EU) on the safe implementation of the use of low sulfur fuel by ships at berth in Community ports. The EU recommendation, dated 21 December 2009, urged that, when enforcing the requirement, Member States should consider the existence of detailed evidence of the steps taken by ships to achieve safe compliance with the Directive. The Member States may consider the existence of an "approved retrofit plan" when assessing penalties for noncomplying ships.

EU Commission Decision for 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 such mixtures, provided the resulting emissions of sulfur dioxide is demonstrated to be equal to or lower than required by the EU Directive. The Commission Decision 2010/769/EU, dated 13 December 2010, established a technological abatement method for LNG carriers to run on a mixture of boil-off gas and marine fuel while at berth in Community ports as an alternative to using low sulfur marine fuels meeting the requirements of Article 4b of the Council Directive 1999/32/EC, as amended by Directive 2012/33/EC. 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 6 June 2014, the Commission clarified that provided "the HFO pilot fuel used in the mixture has sulphur 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."

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" (or, the Ocean Going Vessel (OGV) Fuel Regulation), which has been enforced since July 2009, was designed to provide significant air quality benefits by requiring ships to use 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 addition of the 1.0% sulfur limit effective 1 August 2012. The original regulation required the use of 0.1 percent sulfur distillate fuel, beginning 1 January 2012, but was amended on 23 June 2011, extending the effective date for Phase II by two years, to 1 January 2014 (See Table 5 where DMA and DMB are marine distillate fuel designations).

Table 5: CARB Fuel Requirements for Ocean-Going Vessels (OGV)

Fuel Requirement	Effective Date	ARB's California OGV Fuel Requirement Percent Sulfur Content Limit
Phase I	1 January 2000	Marine gas oil (DMA) at or below 1.5% sulfur; or Marine diesel oil (DMB) at or below 0.5% sulfur
	August 1, 2012	Marine gas oil (DMA) at or below 1.0% sulfur; or Marine diesel oil (DMB) at or below 0.5% sulfur
Phase II	January 1, 2014	Marine gas oil (DMA) at or below 0.1% sulfur; or Marine diesel oil (DMB) at or below 0.1% sulfur

Operators should be aware they must comply with both the California OGV Fuel Regulation 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 the sulfur content as indicated in the respective regulations noted above.

Originally, all California waters within 24 nautical miles of the California baseline (coastal boundary) 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 identified in updated (2007 rather than 2005) National Oceanic and Atmospheric Administration (NOAA) charts. The current restricted area is illustrated in Figure 4.

Figure 4: California's Ocean Going Vessel Regulatory Zone

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, so ships will effectively be using MGO or, possibly, 0.1% new ECA fuels to satisfy the low sulfur distillate fuel requirement during Phase II. The CARB OGV Fuel Regulation does not currently recognize the use of non-distillate low sulfur fuels or alternative emission control technologies (i.e., EGCS) for compliance with the sulfur reduction limits.

To help ships avoid loss of propulsion from fuel switching and the accompanying potential of spilling oil from allision, 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 of entering ECA waters and 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 advise the following to be conducted every 45 day period prior to entry into ECA ports:

Ship engineers should:

1. Operate the main engine from the engine control room.
2. Operate the 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:

1. Able to operate the ship main engine from the engine control room.
2. Able to operate the ship main engine from engine side (Local).

Provision 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.

The CARB OGV Fuel regulations do not include provisions for the use of equivalent arrangements (i.e. EGCS) or the use of low sulfur residual fuels. However, the California OGV Fuel Regulation includes a sunset provision which states that the requirements of the California OGV Fuel Regulation will cease to apply if the North American ECA requirements and enforcement are determined to achieve emissions reductions equivalent to the California OGV Fuel Regulation within regulated California Waters. The CARB announced in August 2014 that vessels complying with the ECA Regulations may be considered to be in compliance with the OGV Fuel regulation by applying for a Temporary Experimental or Research Exemption – California Air Resource Board Marine Notice 2014-1.

During the sunset review period, ship operators can request a "Temporary Experimental or 'Research Exemption'" which would allow a vessel in compliance with the North American ECA to operate in CA California regulated waters. Therefore, vessels would be permitted to achieve compliance through use of low sulfur residual fuels, or equivalent alternative emissions control technologies. The sunset review period lasts until the evaluation of emissions reductions achieved by the ECA Regulation in North America compared to the emissions reductions achieved by the California OGV Fuel Regulation is completed. ARB staff anticipates that this evaluation will be final by April 2015. For details, ship operators may refer to the CARB Marine Notice 2014-1, issued August 2014.

California At-Berth Ocean-Going Vessels Regulation

The 2007 "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port" (or, California At-Berth OGV Regulation) applies to containership, passengership, and refrigerated-cargo ship fleets that visit California Ports and meet or exceed a minimum visit threshold: 25 annual visits to a port for containership and refrigerated-cargo ship fleets, and five annual visits to a port for passengership fleets. A "fleet" means all owned or chartered ships of one vessel type that visit a California Port and are under the direct control of the same company. California Ports are defined in the regulation as the Ports of San Diego, Long Beach, Los Angeles, Oakland, Hueneme, and San Francisco. The Ports of Los Angeles and Long Beach are considered one port in the regulation.

The California At-Berth OGV Regulation is designed to reduce the public's exposure to air pollutants from ships docked at California Ports, supporting several health-related goals of the Air Resources Board, including reducing diesel engine PM, reducing emissions from goods-movement activities, achieving and maintaining ambient air quality standards, and reducing greenhouse gas (GHG) emissions.

The California At-Berth OGV Regulation ultimately requires a fleet operator to reduce at-berth emissions from its vessels' auxiliary engines at each California Port by 80 percent by 2020 (see Table 6). The regulation provides vessel fleets two options to reduce emissions:

- Shut down auxiliary engines for most of a vessel's stay in port and connect the vessel to some other source of power, most likely grid-based shore power; or
- Use alternative control technique(s) that achieve equivalent emission reductions.

Table 6: California At-Berth OGV Regulation Compliance Schedule

Date	Reduced Power Generation Option	Equivalent Emissions Reduction Option
1 January 2010	Shore power equipped ships must use shore power if available at berth	10% Emission Reduction
1 January 2012	Shore power equipped ships must use shore power if available at berth	25% Emission Reduction
1 January 2014	50% shore power visits and power reduction	50% Emission Reduction
1 January 2017	70% shore power visits and power reduction	70% Emission Reduction
1 January 2020	80% shore power visits and power reduction	80% Emission Reduction

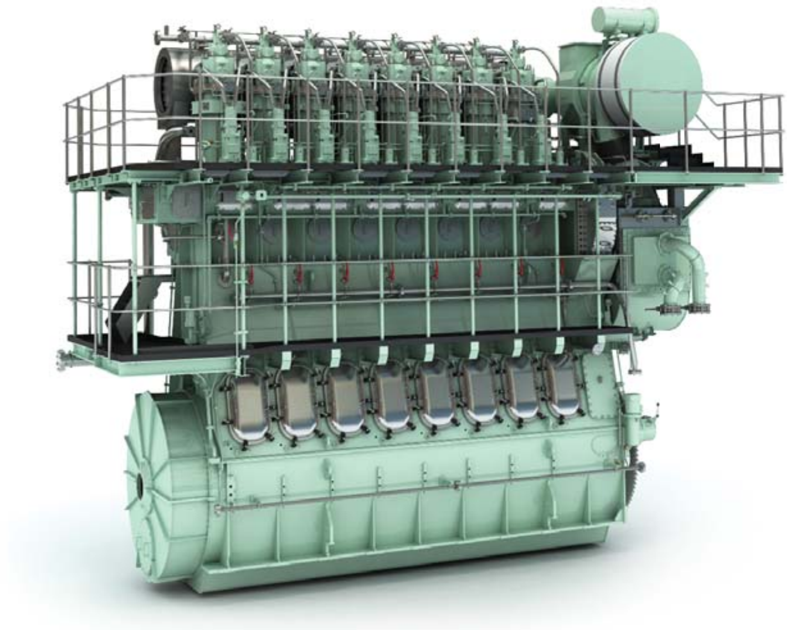
US EPA Regulations

Air emission regulations in the US for marine applications are available at 40 CFR Parts 94 and 1042. These regulations include MARPOL Annex VI regulations and have begun to come into effect over several years, phased-in based on the size and use of the engine (e.g. commercial or recreational). Three categories of engines are identified based on per-cylinder displacement. Tier 1 and Tier 2 Category 1 engines are those with displacements of less than five liters per cylinder, Category 2 engines have displacements between five and less than 30 liters per cylinder and Category 3 engines have displacements of 30 liters per cylinder or more. For Tiers 3 and 4, Category 1 represents engines up to 7 liters per cylinder displacement and Category 2 includes engines from 7 to 30 liters per cylinder. Category 3 engines have displacements of 30 liters per cylinder or more.

Under the EPA regulations, Category 1 and 2 engines have emissions limits to be phased in in four tiers. All new Category 1 and 2 engines must now be at least Tier 2 compliant on US flag vessels. The EPA Tier 2 limits are similar to Tier II limits of Annex VI for NOx, but also include limits on hydrocarbons (HC), PM and carbon monoxide (CO). These regulations based on engine size apply to all engines built after the effective date that are also installed on US flag ships, regardless of the vessel's location.

Control of the sulfur content of fuels in the US is implemented through the EPA Non-Road Diesel Equipment Regulatory Program, which is aimed at regulating the supply of low sulfur fuel for use in locomotives, ships and non-road equipment. Although EPA has not declared a specific implementation date, the eventual goal is to reduce the sulfur level to meet an ultra-low sulfur diesel (ULSD) limit of 15 ppm (0.0015 percent).

Engines complying with the EPA Tier 4 emission standards use advanced emission control strategies requiring the use of ultra-low sulfur fuel and EPA anticipates that adoption of these new engines will drive the market for ULSD and the fuel sulfur reduction goal will be achieved. In the meantime however, EPA has provided fuel makers the ability to continue producing 500ppm fuel until such time that older engines designed to operate on low sulfur fuels are no longer in service. The EPA diesel fuel program regulates production and sale of marine fuel oil for Category 3 engines to 1,000ppm.



Section 3 | Marine Fuels

There are internationally recognized standards that define key characteristics of fuel oils and what they can contain so that they will be suitable for use on board ships. It should be recognized there are important considerations that may not be covered in these standards.

Fuel Standards

The most widely used fuel standard is ISO 8217 with the latest edition issued in 2012. The 2005 and 2010 versions are still widely used.

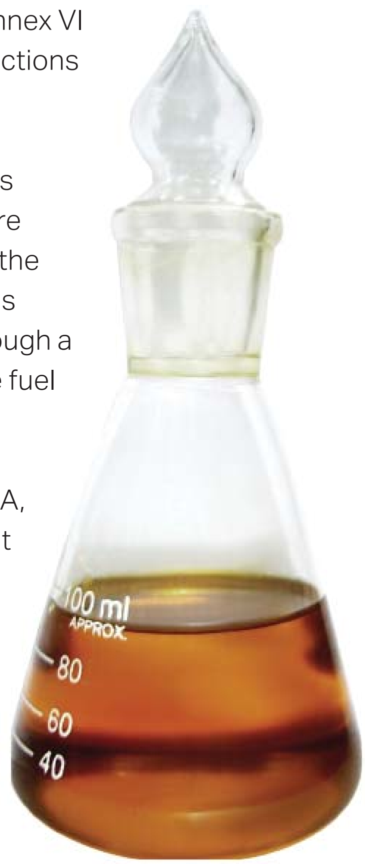
ISO 8216-1:2010 establishes the detailed classification of marine fuels and ISO 8217 specifies the parameters for petroleum fuels used in marine diesel engines and boilers prior to their treatment (i.e., purification) and use. Other existing standards are the Europe-based International Council on Combustion Engines (CIMAC), the British Standard BS6843-1:1996 and the American Society for Testing and Materials (ASTM) D-975. Frequently, vessels are designed to burn fuel from a specific designation of one of the standards, usually from ISO 8217.

The most commonly used HFO types are IFO 180 and IFO 380, where the number indicates the maximum viscosity in centistokes (cSt) at 50°C. Per ISO 8217, the highest viscosity fuel is HFO 700. Although many ships have fuel systems designed to operate up to this viscosity, it is rarely used.

In each viscosity class of the ISO fuel standards, subcategories, such as RME 180, RMF 180 and RMH 380, RMK 380, etc. exist. Fuels with a lower last number have lower viscosity and generally fewer impurities (and would generally cost more). Sulfur content in IFO 180 and 380 fuels is currently restricted to 3.5 percent per Annex VI of MARPOL and this limit will progressively decrease per the reductions required by Annex VI.

Currently available fuels have lower sulfur content than in previous years. Heavy fuels with a sulfur content of less than 1.0 percent are referred to as low sulfur heavy fuel oil (LSHFO). For some LSHFO, the low sulfur content occurs naturally because the source crude oil is sweet crude (low sulfur). For others, the fuel might have gone through a desulfurization process to achieve the required sulfur level, or the fuel is blended with lower sulfur fuels to meet the required sulfur limit.

The marine distillate fuel designations per ISO 8217 are DMX, DMA, DMB and DMC. DMX fuel is a gas oil type fuel with a low flash point (minimum 43°C). It is used only in special applications on ships since, for safety reasons, all other marine fuels have a minimum flashpoint of 60°C. DMC is not widely used because it is similar to DMB but has a higher density and more impurities, creating little demand for it. Typically, MDO means fuel that meets the DMB standard; MGO is fuel that meets the DMA standard. ISO 8217 residual fuels are identified as RMA, RMB, RMD, RME, RMG, and RMK.



Distillate fuels available in North America meet the requirements of ASTM D-975. These fuels are consumed by automotive and land-based engines and fuels sold into that market are prepared to meet one of the ASTM standard designations. The same fuels are sold to the marine market as meeting the closest ISO standard. The most commonly used fuel made to an ASTM standard used on ships is No. 2 diesel oil, which is similar to ISO 8217 Grade DMA. There are currently three standards for sulfur content in No. 2 diesel – S15, S500 and S5000 – where the number indicates the sulfur content in parts per million.

Sulfur & Viscosity Ranges

The new restrictions on sulfur content determine the types of fuels that can be used 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. Typical data is given in Table 7.
As mentioned previously, ISO 8217:2005 was revised in 2010 and subsequently in 2012 to change fuel grades, specification limits and include additional test parameters. In the update, the minimum viscosity of DMA and DMB was harmonized at 2.00 cSt at 40°C, and DMC was reclassified as a residual fuel.

Table 7: Typical Parameters of Marine Fuel

Fuel Type	Viscosity (cSt) (at 50°C for IFO and 40°C for Distillate Fuels)			Sulfur Content (%)	
	Minimum	Maximum	Typical Range		
IFO180	–	180	–	4.5%	1% - 3.5%
IFO380	–	380	–	4.5%	1% - 3.5%
DMB	–	11	2.6-6	2%	0.03% - 1.3%
DMA	1.5	6	2-4	1.5%	0.01% - 1%
ULSD	1.9	4.1	–	0.00015%	–

Ultra-low Sulfur Diesel Oil

Worldwide regulations are beginning to require the use of ultra-low sulfur diesel (ULSD) fuel. In the US, this requirement has been applied to automotive use and it will be applied to non-road engines and eventually to locomotive and marine engines. As mentioned above, marine engines complying with the EPA Tier 4 emission standards use advanced emission control strategies requiring the use of ultra-low sulfur fuel. EPA anticipates that the adoption of these new engines will drive reductions of sulfur in fuel available on the market.

ULSD has varying definitions around the world. Typical sulfur content is: 15 parts per million (ppm) (0.0015 percent) for US/Canada, 10 ppm for Europe, Australia and New Zealand; and 50 ppm in other countries.

Several issues arise with the use of ULSD. During the desulfurization process, the lubricity of the fuel reduces. This will affect pumps and components in the fuel system. To prevent excessively low lubricity in diesel fuel, minimum lubricity standards for fuels were adopted by ASTM in 2005. The refining process also reduces the aromatic content and density of the fuel, resulting in a minor decrease in its energy content on a volumetric basis on the order of 1.0 percent.

Since automotive engines use ULSD fuel exclusively, the engines and fuel system components are designed based on the characteristics of ULSD. The situation is different for marine engines because they are typically designed to operate on higher viscosity fuels with higher lubricity. This means operating a marine engine occasionally on ULSD fuel has the potential for adverse impact. Designing fuel systems and engines to operate on both common marine fuels and ULSD without causing reductions in power and efficiency is a challenge for engine designers and marine engineers.

New ECA Low Sulfur Fuel Oils

Various marine fuel suppliers have developed new ECA low sulfur fuel oils which are specially designed to help marine operators comply with 0.10% sulfur limits. These new fuel oils contain low sulfur like MGO but have a higher flash point and higher viscosity like HFO. There are currently at least 6 suppliers who are offering this fuel in limited availability worldwide (Table 8).

Table 8: Available New ECA Low Sulfur Fuel Oils

	Shell ULSFO	Exxon Mobile HDME 50	LUKOIL	CEP SA	BP	Phillips 66
Density	790-910	908.8	886	86.8	845.4	855.2
Viscosity	10-60	53.9	16	8.8	8.8	8.6
Micro Carbon (MCR)	NA	0.28	0.1	0.1	0.1	0.04
Sulfur	<0.1	0.08	0.07	0.05	0.03	0.06
Pour Point	18	6	18	-12	21	-12
Flash Point	>60	175	165	72	>70	79
Water	0.05	0.05	0.05	0.004	0.01	0
Acid Number	<0.5	0.1	0.5	0.27	0.04	NA
Vanadium	2	3	1	NA	<1	<0.10
Al+Si	20-Dec	2	2	NA	<1	2
Lubricity	NA	264	270	410	326	NA
CCAI	794	794	793	NA	765	NA
ECN	60	60	NA	NA	80.4	58.5

These fuels simplify fuel changeover procedures necessary to enter areas with emissions control requirements and eliminate the need to install a cooler or chiller. However, new ECA low sulfur fuels have not yet been categorized according to ISO 8217, therefore before use on board, the ship operator should consult the engine manufacturer to ensure use of these fuels will not affect the engine warranty. A vessel owner may request certification or confirmation from

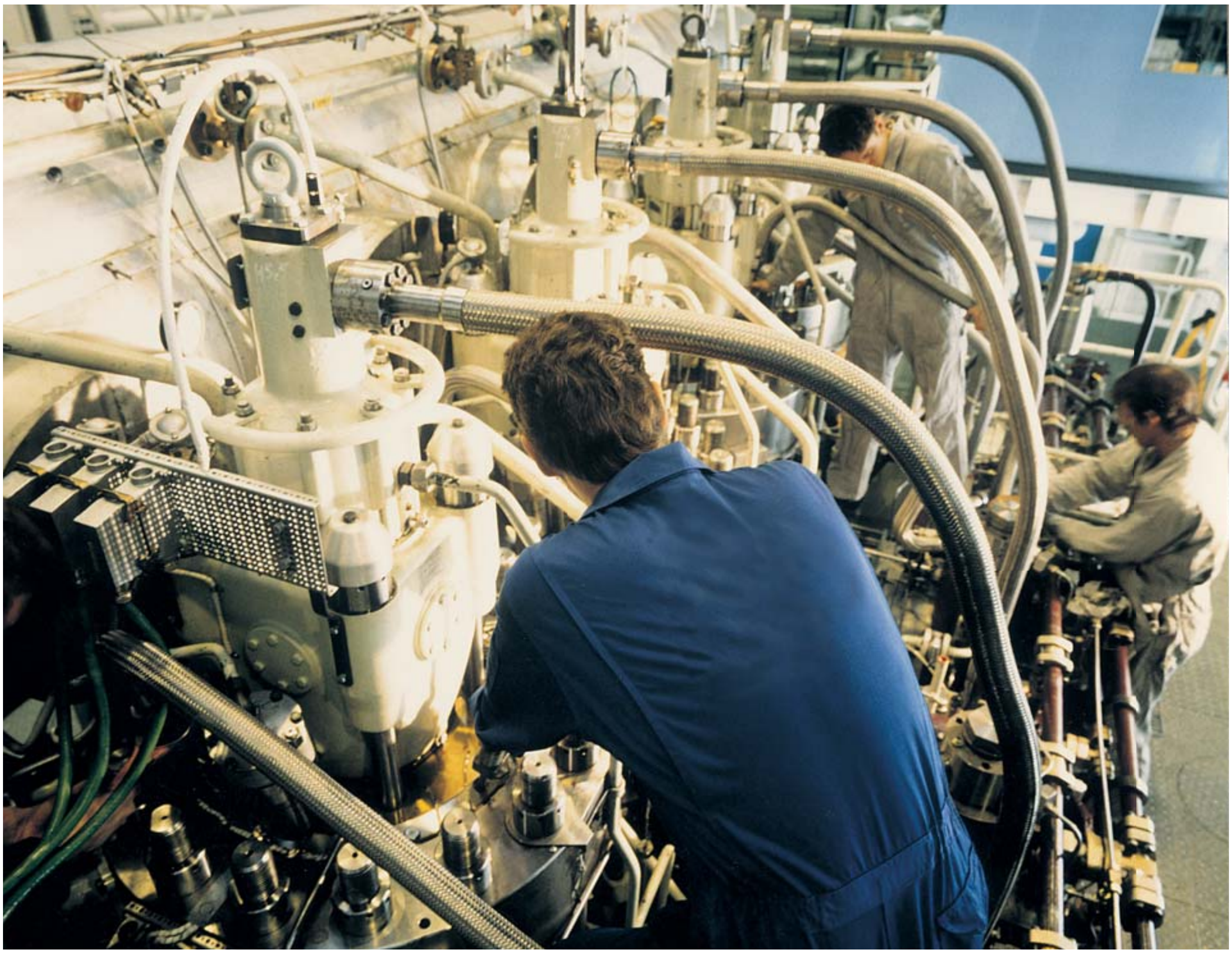
the engine manufacturer or fuel supplier that these fuels can be used. Some of these new fuels have a high pour point and, in low ambient temperatures, wax crystals might form. Noting these fuels are highly paraffinic, compatibility with existing bunkers needs to be considered.

Viscosity

Manufacturers of diesel engines normally set a range of fuel viscosities over which the engine can be operated. The minimum and maximum viscosities apply to the fuel at the fuel injection pumps in running condition. For heavy fuels with high viscosity, the required operating viscosity is achieved by heating the fuel to lower the viscosity. For distillate fuels, 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 increased fuel temperature at the injection pumps, the main concern is if the fuel viscosity is below the lower allowable limit.

Typical minimum viscosity levels for various engine types are listed below. Engine makers should be consulted for limits applicable to any specific engine as the minimum viscosity limits vary between engine makers and engine types from the same maker.

- Slow Speed Diesel Engines (cross head type with rated speed of less than 400 rpm): 2 cSt is typical minimum fuel viscosity.
- Medium Speed Diesel Engines (trunk piston type with rated speed of 400 rpm to less than 1400 rpm): 1.8 to 3.0 cSt is minimum viscosity depending on make and type.
- High Speed Diesel Engines (trunk piston type with rated speed of 1400 rpm and above): 1.4 to 1.5 cSt is minimum viscosity depending if the engine is designed for DMX fuel (1.4 cSt min) as well as DMA fuel (1.5 cSt min).



It is important to note these minimum viscosities are the fuel temperature values at the fuel injection pumps, not the nominal viscosity at standard conditions such as 40°C. Since low sulfur fuels have viscosities close to the permitted minimums, the temperature of the fuel needs to be controlled. For example, if DMA fuel with viscosity at the lower end of the permitted range is used in a slow speed diesel engine, the fuel temperature at the engine needs to be kept at 40°C or below at all times.

There are many circumstances when the fuel can easily be above this temperature, such as during and just after changeover from HFO usage, during warm weather and from the heating that occurs during recirculation of fuel through a hot engine and back to the mixing tank. In the past this has not been an issue for several reasons. Ships normally used heavy fuel from "pier to pier" and only occasionally changed to MDO for short periods of time. Furthermore, normally available MDO had a viscosity at 40°C (standard condition) that was sufficiently above 2 cSt over the typical range of temperatures found at the injection pumps and the viscosity remained above 2 cSt even when the temperature exceeded 40°C.

When ships operate in ECAs under the very low sulfur requirements, there can potentially be days of operation using DMA fuel. DMA grade fuel commonly known as MGO is available with a viscosity close to the minimum value of 2 cSt at 40°C and thus any fuel temperature rise above 40°C will result in fuel with too low a viscosity at the engine, with potentially harmful effects. However, low sulfur MGO is also offered on the market as DMZ grade, with a viscosity of 3 cSt at 40°C , the average viscosity is about 3.20 cSt according to a fuel testing source.

Section 4 | Effects of Low Sulfur Fuels on Operation

Low and extra low sulfur content in fuels has many potential negative effects on diesel engines and boilers from an operational standpoint. Records show that 30 to 40 ships per year, on average, have lost propulsion off California as a result of improper fuel switching procedures.

Potential Effects of Fuel Switching on Diesel Engines

Thermal Shock – Ships switching from burning heavy fuel oil to low sulfur distillate fuel (0.1% S) prior entering a region with emission restrictions are required to deal with a huge temperature gradient in fuels added to the engine because heavy fuel oil must be heated before delivery to the engines and distillate is unheated. The main problem is thermal shock, which is exacerbated by very short changeover times. Switching fuels has to be done very carefully as a result of this temperature difference.

For example, when switching from HFO to MGO (0.1% S), the temperature of the fuel entering the engine is reduced from a minimum of 95°C to 40°C. In practice, the engine load may be reduced to 25% - 40% of normal operating conditions and safe fuel switching should occur gradually over a 40 – 60 minute time period. As the fuel system is changed from HFO to low sulfur distillate, the cooler fuel must be introduced gradually so that the system temperature is lowered only about 20°C per minute to prevent thermal shock. Blended fuels with very different flash points result in irregular heat release upon combustion and fuel of an improper temperature leads to low ignition quality, causing degraded liner and piston ring condition.

The fuel switching is to be carried out by trained, competent crew members while the vessel is in a safe location, i.e., away from traffic zones and channels. Adequate notice must be provided to bridge personnel and the vessel should be under maneuvering alert conditions, so that, should a blackout or power fluctuation occur, the ship's location, momentum, control and maneuverability will not adversely affect the safety of the ship.

Effects of Low Viscosity –Many potential negative effects are possible if the fuel viscosity level drops below its recommended level due to increased temperature during engine operation. Generally, most low sulfur distillate fuel (MGO) has viscosity between 1.5 to 3 cSt at 40°C, which is the minimum range for engine operating requirements. Low fuel viscosity influences on the engine include negative impacts on engine condition and increases in required maintenance, wear of fuel injection and supply pumps, required engine adjustments. It is achievable, but very difficult for engine designers to account for all of these factors at the same time, which complicates engine operation.

1. **Reduced effectiveness as a lubricant** – Fuel temperature fluctuations during fuel changeovers reduce fuel viscosity and lubricity and may cause sticking / scuffing of fuel injection components. The lower viscosity will reduce the film thickness between the fuel injection pump plunger, casing and in the fuel valves which can lead to excessive wear and possible sticking, causing failure of the fuel pump. Special fuel injection pumps may be available that are more suitable for lower sulfur distillates, such as tungsten carbide coated pumps. Another alternative is to install a fuel pump lubrication system. Any new types of fuel injection equipment installed to address lubrication issues shall be certified by the engine maker to maintain engine compliance with emission standards and may require re-certification of engines.

2. **Loss of capacity** – Fuel supply and circulation pumps will have decreased delivery capability due to low viscosity fuel leaking around the pump rotors. This will prevent the ship from achieving full power.
3. **Low density** – Low sulfur, low viscosity fuels typically have lower density when compared to heavy fuel oils. Lower fuel density results in less energy per volume of fuel and thus will require more fuel to be supplied to the engine to maintain equivalent power. The difference in output per unit volume of fuel delivered to the engine can be 6 to 15 percent between HFO and low sulfur distillate for a four-stroke engine. When also considering the increased leakage in fuel injector pumps caused by the use of low sulfur fuels, this problem is further exacerbated.
4. **Leakage of fuel** – Fuel leaking through the fuel injector pump barrel and plunger, suction and spill valve push rods may result in a higher load indication position of the fuel rack and may require adjustment of the governor for sustained operation on low viscosity fuel. This situation is aggravated on engines having high running hours, with worn injector pumps. Engine governors and automation need to be able to adjust to the required changes in fuel rack position and governor settings.

Purification of Fuel - An existing HFO purification system may not be suitable for low viscosity, low density fuels. MGO purification is not always required, but is sometimes recommended. To do so may require the installation of a separate MGO purifier and a separate piping system to maintain fuel segregation.

Lube Oil Base Number (BN) Does Not Match the Acidity of the Fuel – Engine lubricants are matched for the type of fuel that will be used in the engine. A change of fuel may also include a change in the pH of the fuel to one not compatible with the lubricant used in the engine. This especially applies to slow speed engines. Because of the higher levels of acid formed on the cylinder liner when using traditional HFO with sulfur content of 2.0 percent or higher, ships with slow speed engines normally operate with cylinder oils with a BN of about 70.

Prolonged service with mismatched fuel and cylinder oil can cause accelerated piston ring and liner wear due to hard deposition of calcium. The reason for this is that alkaline compounds such as calcium salts are used to neutralize the sulfuric acid formed on the liner when using high sulfur fuels. If excessive alkaline compounds are present due to use of a mismatched fuel with lower than anticipated acidity, hard deposits of the alkaline compound will occur on the liner. The hard deposits can lead to bore polishing, liner lacquering and sudden severe wear of the liner.

For short-term operation on low sulfur fuel (several days to one week), continued operation with 70

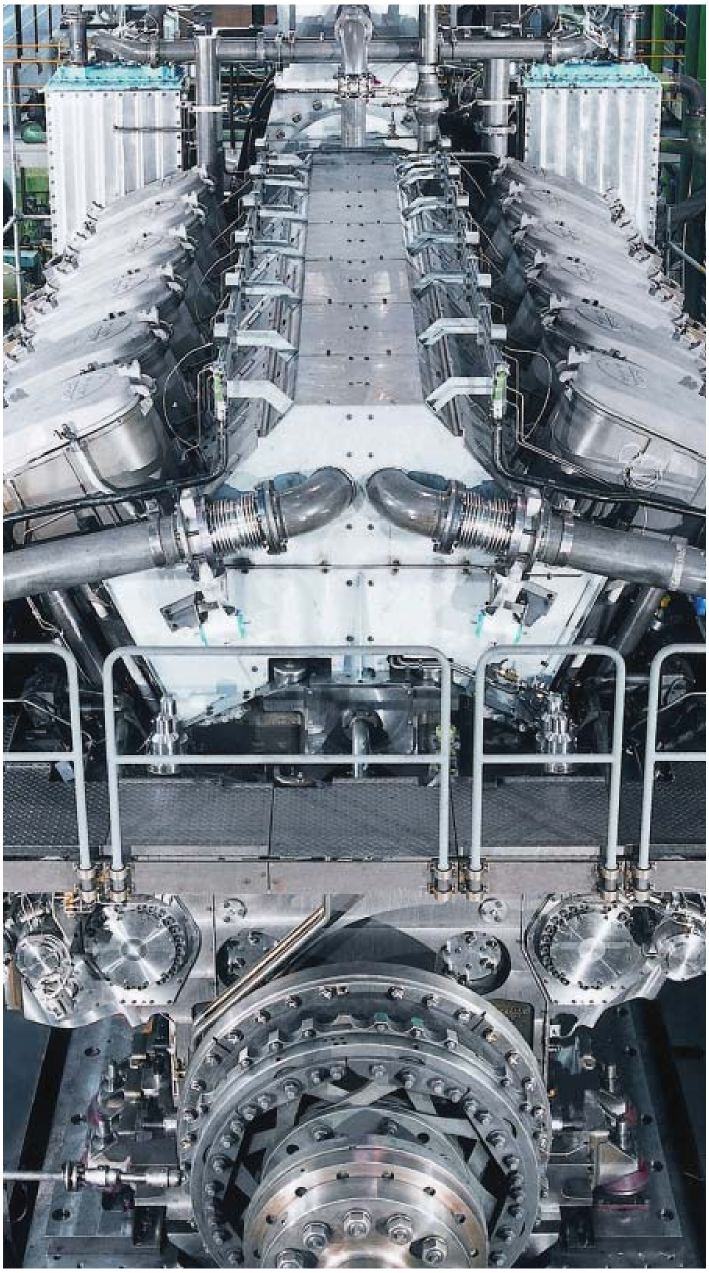
BN cylinder oil is generally accepted by engine manufacturers, provided cylinder oil lubrication rates are kept at minimum levels. For longer term operation with low sulfur fuel, a change to a lower oil (BN 40 or BN 50) is recommended. Long-term operation on low sulfur level fuels requires careful matching of cylinder oil, including alkaline compounds and detergent levels, to the operating conditions of the engine. Engine manufacturers should be consulted if this type of operation is planned.

If an engine is changed to low BN cylinder oil and then operated with high sulfur fuel, the risk exists of excessive acid formation and rapid cylinder liner wear. For trunk piston engines it is also important to carefully select the correct lube oil if operation with both HFO and low sulfur distillate is desired. In the case of truly extended operation on dual fuels, a drain/refill system or a set of engines for each oil type may be necessary.

The more complex refining of low sulfur fuel, including the desulfurization process, can lead to fuels with poor ignition and combustion characteristics. This affects medium and high-speed diesel engines in particular, which are more sensitive to this quality. Studies are underway to better understand this phenomenon.

Lack of Lubricity – The sulfur in fuel, in chemical combination with other components of fuel oil has a lubricating effect. Reduced sulfur content can lead to further lack of lubricity, which can further promote sticking and seizing of fuel injector pumps caused by low viscosity, as discussed above. The ISO 12156-1 standard offers a test method for fuel lubricity that vessel operators can request fuel suppliers to carry out. If the test results are outside commonly used limits, i.e. 460 to 520 microns, fuel suppliers can be requested to add a lubricity additive. Consideration must be given, however, to the effects of the additive on engine emissions.

Incompatibility of Fuels – Mixing two types of fuels can lead to a risk of incompatibility between the two fuels, particularly when mixing heavy fuel and low sulfur distillate fuels. If incompatibility occurs, it may result in clogging of fuel filters and separators and sticking of fuel injection pumps, all of which can lead to loss of power or even shut down the propulsion plant, putting the ship at risk. Compatibility problems can be caused by differences in the mixed fuels' stability reserves. HFO fuels typically have high aromatic levels and contain asphaltenes. If the stability level of the HFO is low, there can be difficulties when mixing with more paraffinic, low sulfur fuels. As a consequence, the asphaltenes can precipitate out of the blend as heavy sludge, causing clogs. The most obvious way to avoid incompatibility between fuels is to check the compatibility before bunkering by using available test kits.



Catalyst (Cat) Fines – Catalyst (Cat) fines are very hard, abrasive particles of concentrated silicon and aluminum generated while refining crude oil by catalytic cracking at high temperature. This process takes place in special cracking towers at a temperature of around 500°C. After the conversion, there may be a large quantity of cat fines in both the residues of the cracking towers and the distilled crude oil products. If the cat fines are not reduced to an acceptable limit, the scouring action of these fines can cause extremely rapid wear or damage with potentially severe consequences or total failure of certain engine moving parts or components, such as fuel injector pumps, injectors, piston rings and liners.

The size of cat fines varies from sub-micron up to approximately thirty (30) microns or occasionally larger. The usable limits are typically identified in the range of 7 to 15mg/kg depending on the engine manufacturers' recommendation. Very small fines can pass through wear sites without causing significant damage, but the larger sizes should not enter areas of potential wear. Testing can reveal the relative distribution of cat fines and provide data for a risk analysis. Since heavier fuels go through less refining, they will have fewer cat fines. Low sulfur fuels often contain higher levels of cat fines.

Bunker quality reports in recent years indicate an increase in cat fines, especially in lower sulfur HFO and distillates as a result of blending low sulfur components derived from catalytic crackers with HFO to yield compliant fuels.

Potential Effects of Fuel Switching on Boilers

Boilers are the most at-risk component on board ships when switching from HFO to low sulfur diesel oil. The fuel supply systems, burners and combustion controls all need to be adjusted when switching fuels on boilers designed to operate using HFO. There is a risk for furnace failure/rupture causing damage to the boiler, which, if left unresolved, may eventually lead to fire onboard the vessel.

Fuel systems designed to use HFO are to be modified prior to introducing MGO into the system. The existing fuel oil system should not be used for MGO operation without appropriate modifications due to the following:

- Risks of failures to fuel supply pumps and associated valves
- Risks of unintentional fuel evaporation
- For burners having parallel tubes for steam and fuel oil, due to the lower temperature of MGO, tubes conveying MGO can distort due to temperature gradients
- The need to change burner management and flame supervision systems to include MGO operation

Small boilers are commonly used on ships for auxiliary steam production and to heat HFO. Medium-size boilers are used to supply additional steam for cargo tank heating and cargo pump operation on tankers. Thermal oil heaters have fuel systems and burners similar to auxiliary boilers and the same concerns exist for them. Even though most boilers are designed to operate on marine diesel oil as a standby to heavy fuel, they are generally not designed to operate for sustained periods of time or at full capacity on the low viscosity, low sulfur fuels now required for emission compliance. When boilers operate on this type of fuel for sustained periods of time, several issues can arise.

Burner system fuel supply pumps need to be designed to operate with the low viscosity and low density of low sulfur fuels. For example, Alfa Laval, Aalborg, a major boiler supplier, designs its fuel pumps for a minimum viscosity of 4.5 cSt, which is higher than the normal viscosity of MGO of 2 to 4 cSt. To operate with lower viscosity fuel, supply pumps would need to be modified or a second pump that is optimized for low viscosity would need to be provided. Moreover, fuel supply control systems must be adjusted to supply an adequate volume of low density low sulfur fuel oil.

To be suitable for operation with low viscosity fuels, burners need to be adjusted or changed out. A lower viscosity fuel will cause an increase in fuel demand for equivalent steam production. As the fuel input through the burners increases, excessive smoke may be created if the combustion air is not also balanced. For rotary cup burners, the higher heat radiation from increased fuel input can cause coking of the burners unless special heat shields are in place.

For steam atomizing burners, the high temperature of the steam will lower the viscosity of the low sulfur fuel and may cause over-firing. For continuous operation with lighter fuels, either compressed air atomizing medium or special type steam atomizing lances which do not heat the fuel in the same way as the traditional lance should be used.

Boiler control systems should be adjusted to provide adequate pre and post operation purge sequences to clear the furnace of flammable vapors from evaporated light fuels. Also, the easier evaporation of light fuels can cause accidental ignition in the case of a missing flame or ignition source. Burner automation and controls will need to be adjusted to suit low viscosity, low sulfur fuels.

Fuel preheaters and fuel heat tracing need to be bypassed or shut off to stop heating of low sulfur fuels to prevent further reduction in viscosity. Care should be taken to avoid pumping MGO through heated fuel pipes and consideration given to installing separate MGO pipes. Fuel supply pumps that continuously circulate fuel during boiler standby conditions – a necessary requirement when using HFO – should have the control system changed to stop the fuel pumps when the boilers are not in operation. Continuous recirculation can heat the fuel and cause the viscosity to decrease to an unacceptable level. Use of fuel coolers should be considered to keep fuel cool enough to achieve required viscosity levels.

Usually only one flame scanner is installed on a burner for main flame supervision, but two scanners may be needed because of the different spectral emission ranges of HFO and distillate fuels. An additional, separate flame scanner is recommended to detect the operation of the ignition burner.

Because of the integrated and specialized nature of boiler burners and controls, it is recommended that each boiler fuel and burner system be checked for feasibility of operation on low sulfur, low viscosity fuel oil and any required modifications be implemented prior to its use. Only skilled and experienced persons, preferably authorized by the manufacturer, should conduct such a review. Proper fuel switching procedures should be prepared and the crew trained in their implementation with the importance of safety highlighted. Any changes or modifications to the fuel and burner systems will require class review.

In addition to information received from manufacturers, please consult the ABS Notes on Use of Low Sulfur Marine Fuel for Boilers (Appendix II). It contains ABS' requirements regarding operating boilers on MGO.

Section 5 | Operating with Dual Fuels: HFO & Distillate

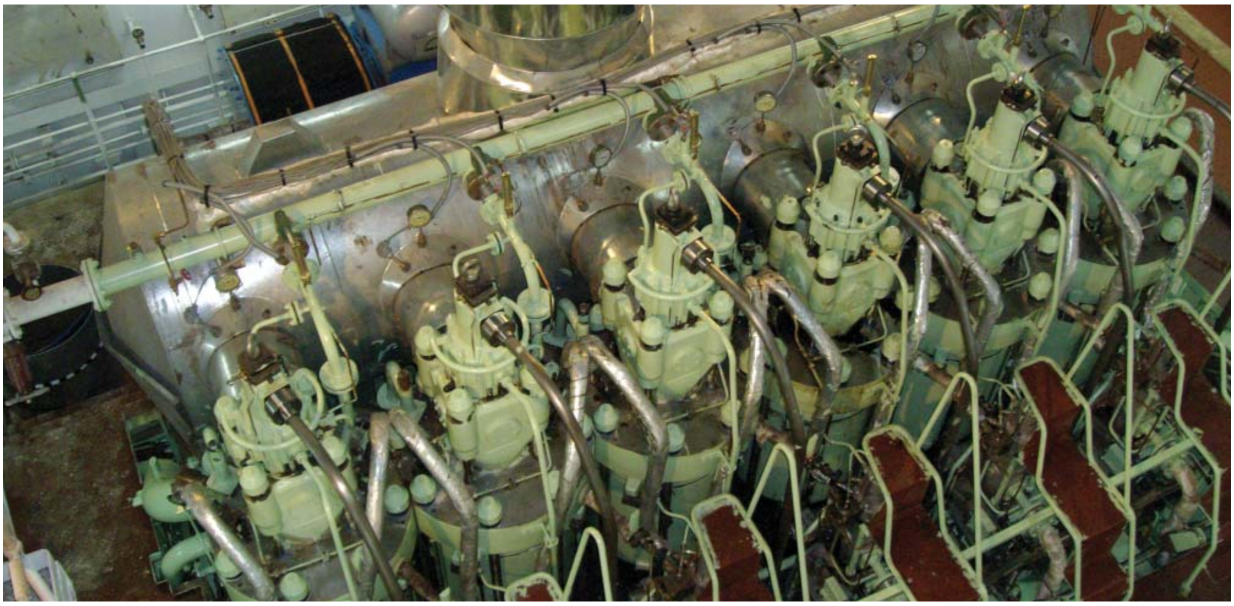
Since the era of costly fuels began in the 1970s, ships have generally been designed to operate primarily on low cost heavy fuel, with MDO sometimes used for smaller auxiliary engines and to prepare a vessel for long-term shutdown. The uni-fuel concept, where all primary machinery operates on the same HFO, was widely adopted as fuel prices increased. However, the low sulfur emission regulations now in effect require sustained operation on distillate. As discussed in the previous section, machinery plants designed for heavy fuel operation cannot be assumed suitable for sustained operation on MGO without appropriate modification.

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 real danger of damage to 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 newly 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.

Consideration should be given to compliance with MARPOL Annex VI when modifying anything that affects the combustion process of a marine engine. The engine maker should confirm that the modification was included by the configurations used during engine emission testing. Otherwise additional testing may be required.

This section of the Advisory discusses some of the key items that should be considered and addressed in a fuel switching procedure. The most commonly occurring issues that arise in switching over to operation on MGO are highlighted below, including the recommendations and requirements from ABS.



ABS Suggestions for Fuel Switching

As guidance to shipowners and operators, ABS has issued two Fuel Switching Compliance Notes, one for engines and one for boilers (see Appendix I and II respectively). The Notes suggest that all vessels operating in areas where low sulfur fuel is required should carry out the measures below. For further guidance on this matter please contact the applicable ABS Divisional Technical office, Assistant Chief Surveyor office or ABS Operational and Environmental Performance.

1. Prepare an evaluation and risk analysis including consultation with manufacturers that outlines the issues and risks involved with operating the ship on low sulfur fuel. This analysis should cover the entire fuel system and its components, engines, boilers and control systems. It is recommended that, in addition to engine or boiler maker advice, issues related to other components in the system should also be addressed by individuals specializing in specific systems or sub-systems. Check for any service or maintenance requirements that are recommended when using MGO. A copy of the risk analysis report should be maintained on board for reference by any interested party.
2. Prepare a detailed fuel switching procedure (or manual) in consultation with engine/machinery makers and place it on board. Include any required inspections or maintenance schedules. Properly train crew in the 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.
3. Consult with fuel suppliers to select and receive proper MGO on board (with viscosity at or above the minimum required for the machinery on board). Independent fuel oil testing is recommended.
4. System seals, gaskets, flanges and other fittings should be carefully maintained to correct any fuel seepage and leakage. Fine spray particles from such leakage may pose a severe fire safety risk.
5. The fuel oil purifiers, filters and strainers are to be maintained appropriately.
6. Control systems including alarms, transmitters, indicators, etc., are to be checked and maintained for correct operation.
7. Crew training (initial and periodic) is to be conducted.
8. Cylinder lubrication is to be monitored 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, providing an opportunity to address any issues before damage is caused.

9. Concerns with steam atomizing with MGO (including distortion of the tubes) should be assessed with the manufacturer and corrected. For burners having parallel tubes for steam and fuel oil, due to the lower temperature of MGO, tubes conveying MGO can distort due to temperature gradients.
10. Ensure the burner management and flame supervision systems safely include MGO operation
11. Fuel switching is to be fully completed prior to entering a port or restricted water to satisfy the regulations and reduce risks to the ship from the fuel switching process.
12. 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 regulations. After inspection by an ABS surveyor, ABS will verify that the vessel has dedicated low sulfur fuel (e.g. MGO) 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 III).

ABS 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. If there are any questions, please contact the applicable ABS Technical office or Assistant Chief Surveyor office.

Owners and operators are required to evaluate the engine and associated machinery and equipment operation on 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.

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 HFO to low sulfur, low viscosity fuel
- Is optimized for fuel switch over from low sulfur, low viscosity fuel to HFO
- Is capable of maneuvering in congested waters or a channel while switching between fuels
- Machineries are capable of operation on low sulfur fuel during long idle times
- Lube oil is standardized for HFO operation and whether the engines are allowed to operate on low sulfur fuel for a specified duration using that lube oil
- May start any engine at berth or anchorage using low sulfur fuel

A detailed fuel changeover procedure (or manual) is to be developed by the vessel owner or operator in consultation with the engine and/or machinery manufacturers and placed on board. If the engines are capable of operating on low sulfur marine fuel such as MGO, although they were originally designed to operate on HFO and/or MDO, this fuel changeover procedure (or manual) shall be maintained.

Manufacturers and associated systems providers are to be consulted to determine whether or not 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. A fuel system and component inspection and maintenance schedule is recommended:

- System seals, gaskets, flanges, purifiers, filters and strainers and other fittings are to be carefully maintained since fuel seepage and leakage may occur from the use of MGO in systems which have previously used HFO and/or MDO.
- Control systems including pressure and temperature alarms, flow indicators, filter differential pressure transmitters etc., are all to be properly calibrated and kept operational.
- Crew training (initial and periodic) is to be conducted.

Cylinder lubrication consumption is to be carefully monitored since a high consumption may be indicative of liner lacquering. HFO and low sulfur fuels should be tested by a reputable fuel oil testing laboratory to provide data that can be used to assess risks when switching fuels to the engine. The laboratory results can also provide information to help operational optimization and may result in reduced fuel use. If the design evaluation carried out for the operation on low sulfur fuel identifies any modifications to the ship and its machinery, the report shall be submitted, together with modification plans and data, to the applicable ABS Technical office.

The design evaluation is to identify potential hazard scenarios associated with aspects of the proposed modifications. Issues to be considered are the fuel switching process, fuel properties and processing, fuel compatibilities, concerns regarding engine starting on low sulfur fuels and other relevant issues. The analysis is to cover fuel switching to and from HFO and low sulfur fuel, issues that arise with maneuvering while switching over, long idle times and starting engines in port. Potential hazards include, but are not limited to, loss of propulsion, blackouts, failure to start engines, fire and explosions. Please refer to the ABS Notes on Use of Low Sulfur Marine Fuel for Engines and Boilers (Appendix I and II) for more details on what is required in the analysis.

All design modifications are to be in compliance with original manufacturer's recommendations whenever possible. A competent entity other than the manufacturer 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 fuel (i.e., MGO) tanks and systems are to be arranged to facilitate effective 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 due to operational considerations. HFO and low sulfur fuel piping systems (including pipe fittings and equipment) are to be arranged so as to carry out effective flushing of HFO from the system.

Guidance for Fuel Switching Procedures

The issues related to fuel switching are unique to each ship and its condition so there are no universal procedures that can be applied to all or even most ships. 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 in 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.

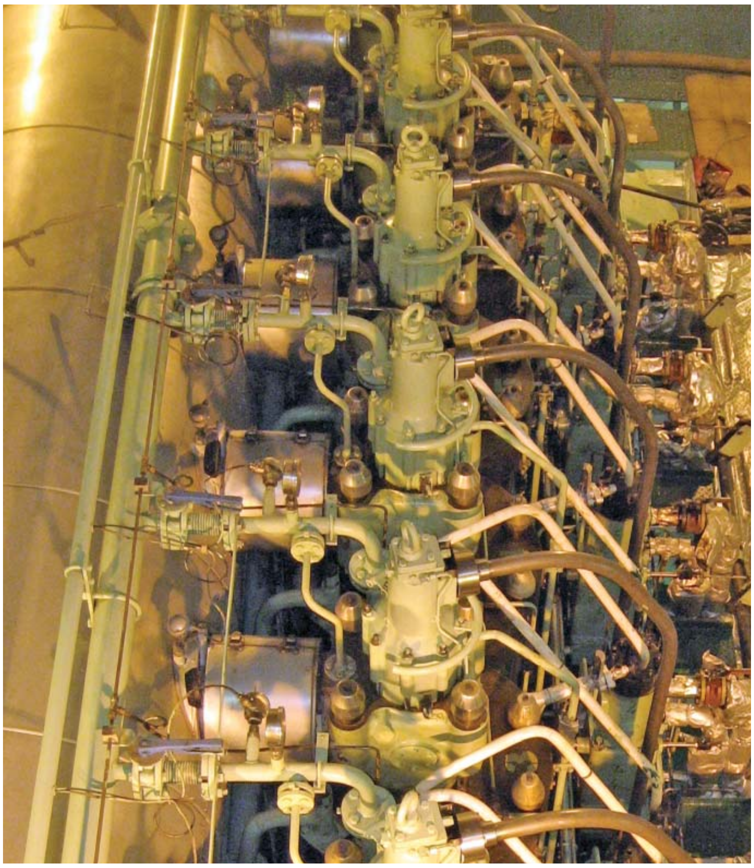
Operating crew are to be well trained in how to use the procedure and aware of any safety issues that can arise and how to respond to them. All new crew members joining a ship are to be trained prior to their participating in the fuel switching process. The proper implementation of fuel switching and 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, such as in the state of California, 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. Where operation on lower sulfur fuel is only required after vessel docking in port, such as current EU requirements (0.1% fuel "at berth"), then fuel switching can safely be carried out in port while alongside or in anchorage.

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):

1. 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.
2. 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 heavy fuel tank. This works well to accommodate low sulfur fuel MDO or MGO.

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.

3. There is a concern that thermal shock may be caused during fuel changeover from HFO to low sulfur fuel because heated HFO has been delivered to the engines and the distillate low sulfur fuel replacing the HFO 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 HFO 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.

4. 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.

Considerations for Diesel Engines

During the changeover process it may be necessary to re-set or re-adjust various equipment (such as control valves, temperature sensors, the viscosity meter/controller, etc.) 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 that uses 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 arrangement is to install the cooler in the fuel return line between the engine and the mixing tank. This will remove 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. See Figure 5 for a typical cooler installation with the cooler in the fuel supply line.

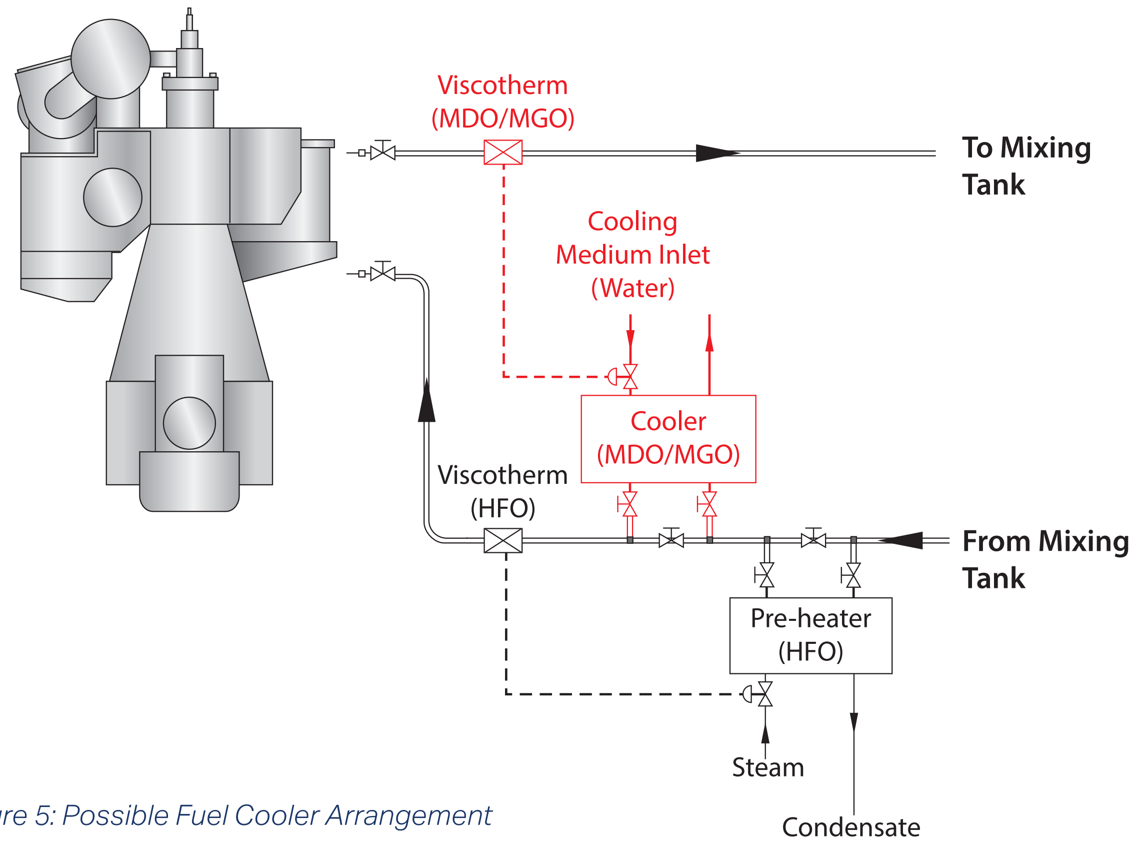


Figure 5: Possible Fuel Cooler Arrangement

Procedures for Switching with Fuel Mixing - A ship which does not have a tank arrangement that permits segregation of fuel beyond the storage tanks will have to develop procedures for fuel mixing. One way to do this is to reduce the level in the settling tank to about 20 percent before filling with the alternate fuel. With this arrangement, up to several days of operation, and several dilutions, may be necessary 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 trades 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 a power level of 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 that of 2°C per minute.

For example: if a ship is using HFO heated to about 150°C prior to the fuel booster pumps and switching to MGO 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 HFO to distillate can lead to overheating the low sulfur fuel, causing a rapid loss of viscosity and possible gassing in the fuel system. Too rapid of a change from unheated low sulfur fuel to HFO can lead to excessive cooling of the HFO 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 MGO into the fuel system, the existing HFO service pumps may lose suction because of reduced fuel oil viscosity and lubricity. Due to less lubrication, overheating of the existing HFO 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 1 July 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 0.1 percent sulfur fuels. 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 should be given to incorporating electronic fuel control and direct fuel injection combustion systems into the design for new engine systems. This allows engines to burn fuel more efficiently, resulting in better power generation, cleaner emissions and increased fuel economy.

Consideration must be given to MARPOL Annex VI compliance when modifying any part of the combustion process. 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, these components must have been covered by testing to demonstrate their suitability as allowable alternative NOx sensitive components (included in 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 does not anticipate any major effects when techniques such as a coating or surface treatment are adopted to resolve the fuel injection pump lubricity issues. However, the ignition quality of the different fuel types may demand a different fuel oil injection system, including a new setting for injection timing. This could result in major modifications requiring re-certification of the engines.

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 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 will adjust 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 HFO to low sulfur fuel, engine components and fuel in the mixing tank will retain heat. As the tank of hot fuel continues to be replaced by low sulfur, 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 a fuel coolers can be of value to avoid the 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 that are clear of hazards.

Purifier Operation – For extended operation on low sulfur 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). If operating on low sulfur fuel, a separate purifier may be used for continued purification of the HFO and low sulfur fuel tanks. In general, the purification of a fuel such as MGO 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 the residue of tanks, purification (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 the following actions vessel owners/ operators can take to prevent failure due to fuel quality concerns:

- 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, in-line 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 MGO heating arrangement

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

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 of time. If injector cooling has been secured, it should be turned on when the engine is returned to operation with heated HFO. Consult with the engine manufacturer regarding this item.

Temperature Monitoring - Temperatures of the engine and its components must be continually monitored to ensure they are maintained at normal service temperatures. Adjust or re-set engine control equipment such as control valves, temperature sensors, viscosity controller, etc., as needed, to account for the new fuel type, where this is not done automatically. As crew members gain experience with fuel switching there will be better understanding of what needs to be adjusted and monitored during the switching process and during sustained operation 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 high levels of alkaline additives, i.e., high BN oil 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.

Considerations for Boilers

If a boiler has been originally designed to burn only HFO or MDO, there are several points that should be considered when changing fuels.

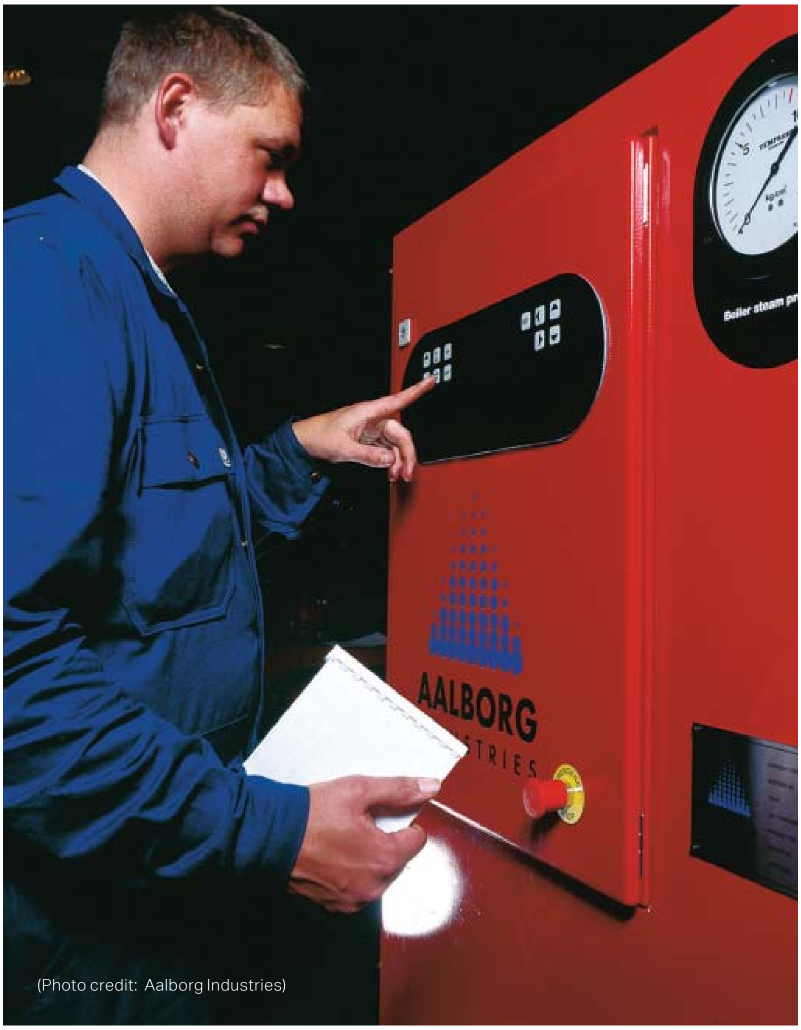
Usually, during initial flashing and when the furnace temperatures are low (particularly after repair), the boilers can use small amounts of MGO. However, they cannot sustain use of MGO during normal operations and meet steam demand without modifications.

Boiler explosions can occur due to incorrect operations. Examples include: when the boiler furnace is not properly purged before ignition, when there is a high pressure of fuel gas built up in the burner due to flame failure and when the control system is malfunctioning or disconnected. Unburned fuel may be admitted to a hot furnace following flame failure, leading to an explosion in the furnace if a source of ignition exists.

Systems providing fuel atomization may have to be reassessed because steam atomization may not be suitable for MGO 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 MGO may cause coke deposits on rotary cup types of 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 HFO and/or MDO may have to be modified or new types of burner assemblies accommodating both HFO and MGO may be necessary. The existing piping used to transport heated HFO from the service pump to the boiler may not be suitable to transport MGO, since there is a concern that MGO flowing through hot piping may vaporize, creating vapor locks causing irregular fuel flow towards the burner and resulting in flame extinction.

(Photo credit: Aalborg Industries)



(Photo credit: Aalborg Industries)

Therefore, MGO is not to be delivered through heated pipes to the burner. Consideration should be given to provide dedicated MGO delivery piping and accessories. The burning of MGO may also necessitate swift and effective flame failure detection. Boiler/equipment manufacturers should be consulted for specific recommendations. To avoid vaporization by heating MGO 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 HFO instead of MGO, a flame failure may occur when the fuel is changed over to MGO because the photo cells may not have the color spectrum necessary for MGO. Equipment and/or machinery manufacturers should be consulted for specific recommendations based on applications. Also, safety features need to 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 HFO and MGO flames like flame length.

Existing HFO service pumps may have difficulties with suction of the lighter oil because of viscosity.

Also, HFO has better lubrication properties than MGO. Accordingly, overheating of the existing HFO 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 MGO.

HFO has a higher density and a lower calorific value than MGO. The fuel supply control system is therefore to 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, filter differential pressure transmitters, etc., 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 should be kept up to date

When a low-load firing operation without a pilot fuel (i.e., burning only MGO) 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 in order 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 HFO in combination with the boil off from the cargo. Therefore, fuel oil systems in these vessels will need to be modified to use MGO. MGO 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 remain uninterrupted for propulsion boilers
- Risk of failures in fuel service pumps and associated valves will be present
- Risk of unintentional fuel oil evaporation is possible
- Steam atomizing in burners having concentric type fuel injectors can over heat MGO
- Atomizing burners with parallel tubes for steam and fuel oil can distort due to the temperature gradient between unheated MGO and steam
- The design of the burner management system (BMS) and flame supervision is based on HFO

LNG Vessels with Propulsion Boilers

There are a number of considerations that should be made when burning LNG gas. Low load firing operation without use of proposed pilot fuel is of particular concern during maneuvering conditions with large and rapid load changes. It is recommended that a safety assessment be made for each operational case to ascertain safe operation, particularly if such operations have not been assumed in the original boiler system design. The assessment should include, among other considerations, boiler management system and combustion controls suitability for low load firing operations. The flame scanner type and positioning to detect failures during low load firing operations are also to be considered during the safety assessment.

Ship Design for ECA Compliance

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 on the required storage capacity of low sulfur fuel and the other is on the fuel piping system and equipment to segregate and handle two fuels with different viscosities, densities and handling temperatures. New ships can be designed specifically to incorporate the needed features. Table 9 shows the fuel tankage arrangements recently provided for various ship types. However, many of the emission requirements apply to all ships and existing ships that require modifications as well. This section discusses how these changes impact the design and arrangement of the ship.

Table 9: Fuel Tankage Arrangement.

Ship Type/Size	HFO		LSHFO		MDO/MGO	
	Description	m^3	Description	m^3	Description	m^3
4,500 TEU Containership	6 HFO Stor + 1 Sett + 1 Svc	4,000	1 LSHFO Stor + 1 Sett + 1 Svc	700	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO: 150 MGO: 100
9,200 TEU Containership	3 HFO Stor + 1 Sett + 1 Svc	5,000	1 LSHFO Stor + 1 Sett + 1 Svc	2,000	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO: 300 MGO: 200
13,000 TEU Containership	5 HFO Stor + 1 Sett + 1 Svc	8,500	1 LSHFO Stor + 1 Sett + 1 Svc	2,000	1 MDO Stor + 1 Sett + 1 Svc 1 LSMDO/MGO Stor + 1 Svc	MDO: 400 MGO: 300
50,000 DWT Panamax Tanker	3 HFO Stor + 1 Sett + 1 Svc	1,200	1 LSHFO Stor + 1 Sett + 1 Svc	300	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO:150 MGO:150
115,000 DWT Aframax Tanker	3 HFO Stor + 1 Sett + 1 Svc	2,000	1 LSHFO Stor + 1 Sett + 1 Svc	1,000	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO:150 MGO:200
1608,000 DWT Suezmax Tanker	3 HFO Stor + 1 Sett + 1 Svc	2,500	1 LSHFO Stor + 1 Sett + 1 Svc	1,500	1 MDO Stor + 1 Sett + 1 Svc 1 MGO Stor + 1 Svc	MDO:200 MGO:250
320,000 DWT VLCC Tanker	3 HFO Stor + 1 Sett + 1 Svc	5,000	1 LSHFO Stor + 1 Sett + 1 Svc	2,000	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO:300 MGO:500
35,000 DWT Bulk Carrier	4 HFO Stor + 1 Sett + 1 Svc	1,300	1 LSHFO Stor + 1 Sett + 1 Svc	250	1 MDO Stor + 1 Sett + 1 Svc 1 MGO Stor + 1 Svc	MDO:100 MGO:100
181K Bulk Carrier	3 HFO Stor + 1 Sett + 1 Svc	3,500	1 LSHFO Stor + 1 Sett + 1 Svc	1,200	1 MDO Stor + 1 Svc 1 MGO Stor + 1 Svc	MDO:300 MGO:400

Intended voyage routes will determine the length of the voyage that will be within an ECA and some alteration in a ship's route planning may be justified to limit the length of transit in an ECA. Because of the size of the ECAs (particularly those for the US with a minimum 400 nautical miles round trip and Canada), regardless of route planning, it is expected there will be multiple days of operation with low sulfur fuel, including time to fuel switch, time at sea in the ECA, time maneuvering in port and time at the pier. The amount of low sulfur fuel required for transiting the ECA and operation in port (if not using shore power) must be estimated and compared to available capacity of distillate fuel storage tanks, service tanks and purifier capacity.

Most ships are now designed to accommodate MDO. To comply with the 0.1 percent sulfur requirement, vessels must use MGO or new ECA 0.1% sulfur content premium marine fuel. Most ship owners do not want to carry three types of fuel on the ship, so it is assumed they will choose to switch their distillate fuel tanks to MGO or new ECA 0.1% sulfur content premium marine fuel.

The ship's route will determine whether an existing ship has adequate fuel carrying capacity. For example, for the 24 nautical mile zone off the California coast, transit through the Great Lakes, Mississippi River, Sacramento River, Puget Sound, Columbia River, etc. as well as the EU requirement for low sulfur fuel usage in port, or even to reach many ports in the North Sea/English Channel ECA, many ships may have adequate existing distillate tank capacity. This should be checked for any ship planning to enter one of these areas.

A vessel transiting to ports in the Baltic Sea area from the Atlantic Ocean must operate in both the North Sea/English Channel and Baltic Sea ECA and a vessel transit through the North American ECA spends the majority of its voyage in the ECA. It is likely the required capacity of distillate fuel will exceed the available capacity for these voyages.

Consider a typical trans-Atlantic roundtrip voyage to Houston, Texas: The ship will first encounter the ECA off the US East Coast. On the most direct great circle route, the entry could be north of Cape Hatteras. From the entry point, the ship would have to transit south along the US East Coast, around the tip of Florida and across the Gulf of Mexico to Houston and back again for a similar return trip. This voyage is about 1,750 nm each way for a total of over 3,500 nm depending on where the ECA is entered and exited. During the entire time in the ECA the vessel must operate on low sulfur fuel. Coastwise voyages up and down the US East Coast and the US West Coast could similarly be 750 to 1,000 nm each way. Voyages to Baltic Sea ports are of similar distance within emission control areas.

Designers and owners of new ships are to carefully assess where the ship is intended to trade, anticipate the distances to be traveled in ECAs and expect that additional ECAs will be adopted in the future.

The first step to determine whether a ship will require modification is to calculate the required storage capacity for distillate fuels. This will be a function of:

- Which ECAs vessel will operate in a particular voyage
- The size of the ECA and length of required transit
- Expected volume of fuel required
- Possible need to re-route in order to obtain low sulfur fuels (although suppliers are likely to be concentrated in or near ECA)
- Extent to which compliant fuel is carried outside an ECA (poor bunker tank utilization/fuel switching method);
- Duration of port stay
- Shore power availability/capacity

This is further complicated given that ships are constructed for a long service life, typically 20 to 25 years, and changes to trading patterns are likely during such a long period of time. For these reasons, much larger capacity for low sulfur fuel storage than was traditionally accommodated in the past should be included in any new ship designed to trade in areas with emission restrictions. A separate fuel bunkering and transfer piping system should be provided for the low sulfur fuel.

For existing ships with inadequate distillate capacity and as supplemental capacity for new ships, HFO tanks can be changed over to distillate fuel or designed for dual use, either HFO or distillate. Particularly when planning to fill a tank with MGO that was previously filled with HFO, adequate safeguards should be in place to segregate the MGO from HFO contamination (such as separate fuel suction/fill connection to the tank for HFO or MGO). After emptying HFO from a tank to be converted to MGO, thorough cleaning of the tank and any combined piping should be carried out before bunkering MGO.

Specifically for tankers, standard designs do not have fuel oil tanks located within the cargo area but aft of the aftermost cargo/slop tank bulkhead or forward of the foremost cargo tank bulkhead. Any proposal for locating fuel tanks within the cargo tank block to increase compliant fuel capacity onboard tankers needs to be specially considered to avoid any possible contamination of bunker fuel by low flashpoint cargo or chemical cargoes.

The second area affected by operation on low sulfur fuel is the design of the fuel system. Since it is required to document that the correct fuel is used throughout the period of time a ship operates in a sulfur content regulated area, it is best to have the low sulfur fuel segregated at all times from out-of-compliance fuel. Keeping this segregation right up to the fuel pump feeding directly to the engines or boiler allows for the quickest fuel switching and easiest

determination of the time when the fuel switch was completed (outside the ECA). It also allows better demonstration that the fuel was uncontaminated and met the required sulfur level since only the sulfur level as bunkered need be considered, without any consideration of effects of mixing beyond the short period of time for switching.

The design of a segregated HFO system is quite well known and has been carried out on many ships designed to use LSHFO. Generally, the design includes a common HFO bunkering, transfer and purification system, but provides separate LSHFO storage, settling and service tanks. The LSHFO service tank has a separate supply pipe to the changeover valve in the fuel supply system to the engine or boiler.

In much the same way, segregated fuel systems are recommended for vessels using dual fuel operation with distillate as the second fuel. The following recommendations for designing fuel systems should be considered to make fuel switching easier to carry out and to provide more certainty for recording the specific time when a switch has been completed:

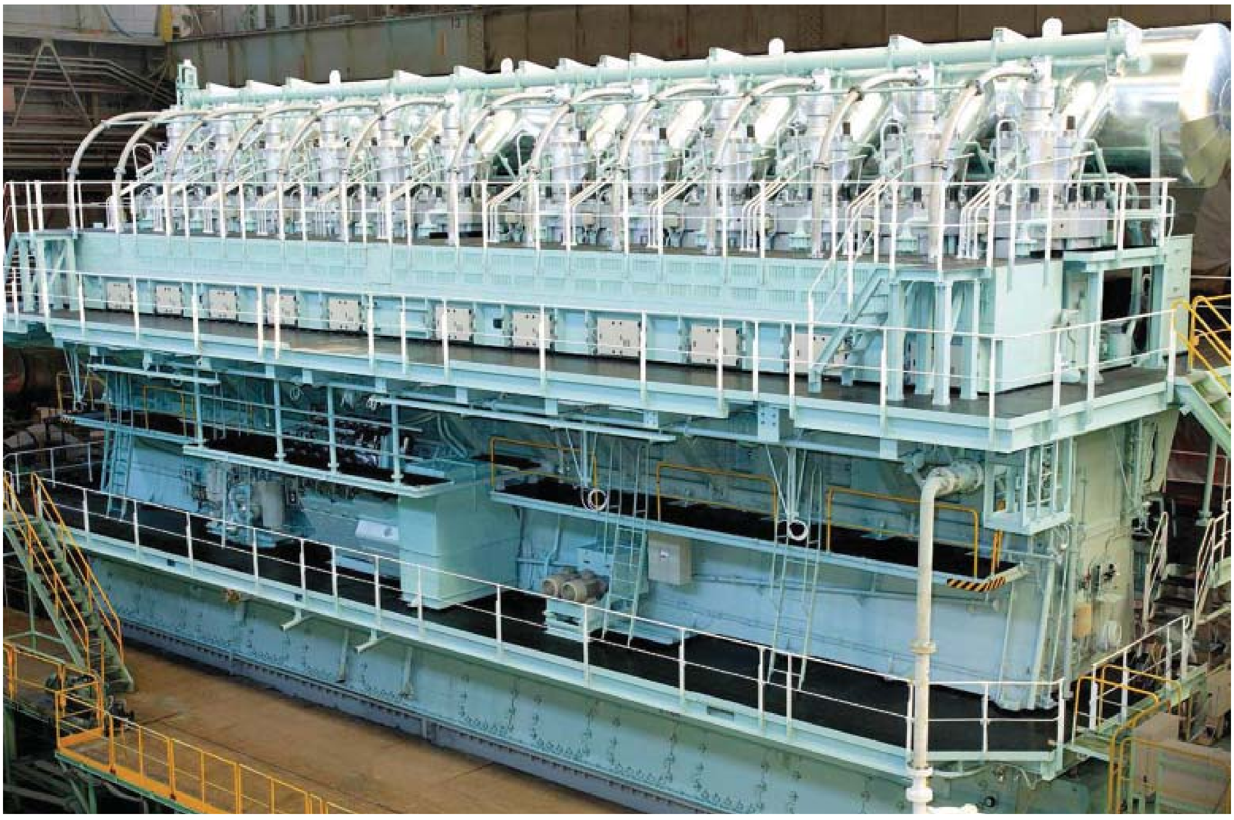
- Provide for separate fill connection and pipes for distillate fuel
- Provide for a separate settling tank and service tank for low sulfur fuel. For sustained periods of operation on distillate, consider installing two service tanks so there is the ability to change service tanks in case one becomes contaminated
- Provide for separate transfer piping system for distillate fuel (suction and discharge lines) and upgraded transfer pump capacity; high enough to maintain the settling/service tanks when the Main Engine and Auxiliaries are operating at normal sea loads. For vessels installed with instrumentation and automation to allow for unattended machinery space operation e.g. ACC/ ACCU, notation is to be reviewed by Class to ensure the safe performance of new/upgraded essential components.
- Provide a separate purification system, including a separate purifier, for distillate fuel
- Provide for a fuel cooler (preferably a chilled type down to 20 to 25°C) so the ship can operate on low viscosity distillate in warm weather conditions and better control the temperature of the fuel to the engine or boiler
- Install an automated fuel changeover valve or system that can provide timed changeover of fuel from one type to another so that temperature shock and large viscosity changes can be avoided.
- In consultation with boiler and/or engine manufacturers, provide for required equipment and controls to operate safely on low viscosity fuel.

Appendix 1 | Use of Low Sulfur Marine Fuel for Main & Auxiliary Diesel Engines

ABS is aware that as a consequence of the EU regulations, main engines, auxiliary engines and boilers will be required to operate on low sulfur fuels (unless under Regulation 1, an approved exhaust gas scrubber/treatment system is fitted or shore-power is made available, i.e., cold ironing) which will likely be marine gas oil (MGO). Please note that many of these engines and equipment (e.g. boilers) were specifically designed to operate on heavy fuel oil (HFO) or marine diesel oil (MDO). Thus, ABS considers design modifications and operational adjustments may be necessary to some of these engines and equipment.

In addition, where these engines and equipment are capable of operating on MGO, though originally designed to operate on HFO, a well-designed and efficient change-over procedure to and from MGO (i.e., low sulfur marine fuel oil) needs to be followed in order to maintain engine and equipment safety and availability. ABS does caution that ABS is not an engine or system design expert, so this information should be used in working with such experts, not in place of such expertise.

In light of the regulations and with a view to assist the owners, operators, shipyards and designers as appropriate, ABS highlights certain issues (design and operational), makes the following suggestions, and specifies the requirements that are to be satisfied for ABS classification purposes. It is important to recognize that many systems are directly supplied by the engine manufacturer. In modern engines, typically the engine control is integrated with an outside sourced control system. As such, involving the engine manufacturer or another entity recognized by the engine manufacturer to be responsible for the overall arrangement including any needed design adjustments may be a prudent course of action.



Design and Operational Issues

1. **Design Issues**

    a. New fuel pump: With the introduction of low sulfur fuel oil such as MGO into the fuel system, the existing HFO pumps may have difficulties with suction of the light gas oil (MGO) because of reduced fuel oil viscosity and lubricity. Accordingly, due to lack of lubrication, this may eventually result in overheating of the existing HFO pumps (if not designed to handle MGO). Therefore, it may be necessary to install different types of pumps to deal with MGO.

    b. Excessive wear within the fuel pump can result from the lower lubricating properties of MGO (0.1%S fuels). This could also necessitate replacement of the existing HFO pump with a new fuel pump. This includes fuel injection pumps which may necessitate replacement with a special pump (e.g. tungsten carbide coated fuel injection pump).

    c. For new designs, consideration might be appropriate to incorporate electronic fuel control and direct fuel injection combustion systems into the engine systems allowing the engines to burn fuel more efficiently, resulting in more power, cleaner emissions, and increased fuel economy.

    d. Consideration must be given to MARPOL Annex VI compliance when modifying anything that affects the combustion process. 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, these components must have been covered by testing to demonstrate their suitability as allowable alternative NOx components 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 does not anticipate any major effects when techniques such as a coating or surface treatment are adopted to resolve the fuel pump lubricity issues. However, the differences in ignition quality of the different fuel types may demand a different fuel oil injection system, including a new setting for injection timing. This could result in major modifications requiring re-certification of the engines.

    e. It is to be noted that MGO with a minimum viscosity of 1.5 cSt at 40°C (ISO 8217) requires approximately 22°C to keep the limit to 2 cSt. Maintaining the fuel oil temperature in the required range may be difficult with existing systems. The consequence of not doing so may be “sticking” of fuel system components. Thus, to maintain a minimum viscosity of 2 cSt it may be necessary to install a new cooler together with appropriate controls in the design of the modified fuel oil system.

    f. For the lowest viscosity MGOs, a cooler may not be sufficient. In such cases, it may be necessary to include in the design a “chiller” (along with appropriate controls), which removes heat through vapor-compression or an absorption refrigeration cycle.

g. In some industries, additives have been used to improve lubrication and mitigate the viscosity issue. Fuel suppliers, engine and pump suppliers should be consulted.

h. MGO tanks (including capacity) and systems should be arranged to facilitate effective change-over. Sufficient capacity for the intended operation should be carefully considered and planned. While not specifically mandated, installation of dedicated MGO service tanks may be necessary due to operational considerations.

i. HFO and MGO piping systems (including pipe fittings and equipment) should be arranged so as to carry out effective flushing of HFO from the system.

j. Low-BN cylinder oil tank(s) may also be needed. See item (p) in Operational Issues.

2. **Operational Issues**

k. There exists a concern during a fuel change-over from HFO to low sulfur fuel such as MGO because the pipes and other parts of the fuel oil pumping system are heated when using HFO. MGO flowing through the same hot piping may vaporize creating vapor locks and causing irregular fuel flow to injectors resulting in engine stoppage. Therefore, MGO is not to be used through heated pipes to engines.

l. Sticking/scuffing of high pressure fuel oil injection components: When changing engine operation from HFO to MGO, rapid or uneven temperature change could cause thermal shock creating uncontrolled clearance adaptation which can lead to sticking or scuffing of the fuel valves, fuel pump plungers, suction valves or fuel pump seizure.

m. Accelerated piston ring and liner wear: Prolonged engine operation with incompatible crankcase or cylinder lubricating oil could result in accelerated piston ring/liner wear.

n. There may be a loss of sufficient oil film thickness due to liner lacquering.

o. One or more of the above events in items (l), (m) or (n) could lead to unexpected shut down of the main or auxiliary engine(s).

p. Lubricating oil with high levels of alkaline additives, i.e., high-BN (base number) oil is recommended by many manufacturers for use with high sulfur fuels. Therefore, a lower TBN (total base number) 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 (MDO or MGO) is going to be used permanently or for a prolonged period of time.

q. In addition to selecting lower TBN lubricating oil with the use of low sulfur fuel oil, it may also be necessary to adjust the cylinder lubrication feed rate to match the total alkaline content of the cylinder oil with that in the fuel oil in accordance with a specific formula.

If low sulfur fuels are used predominantly, low-BN cylinder oil is generally recommended by manufacturers, either BN40 or BN50 oil as compared to the typical BN70 cylinder lubricating oil used with HFO. Where frequent fuel oil changes are necessary due to the vessel's trading pattern, it is recommended that a second grade of cylinder lubricating oil with a lower base number (BN) than the first be considered.

r. In general, the purification of MGO may not be required. However, some engine makers may recommend purification. In that case, the purifier operational details should be in accordance with the purifier maker's instructions and recommendations.

s. During engine operation with MGO, since the engine jacket cooling water temperature can be lower than that with the engine operating with HFO, the fresh water generator system should be checked, temperature carefully monitored and re-adjustment made if necessary.

t. During the change-over process it may be necessary to re-set or re-adjust various equipment (such as control valves, temperature sensors, viscosity meter/controller etc.) employed in the monitoring and control systems, unless this is accomplished automatically. Where manually adjusted, this should be in accordance with the engine maker's recommendations.

u. "Cat fines" are substances like silicon and aluminum compounds which are required as catalysts in the refining process known as catalytic cracking (cat cracking). This process takes place in special cracking towers at a temperature of around 500°C. After the conversion, there may be a large quantity of catalyst fines (cat fines) in both the residues of the cracking towers and the distilled crude oil products.

   These cat fines have a negative impact on the end products. They vary both in size and hardness. The fines are also extremely abrasive. Since the heavier fuels go through less refining they will have less cat fines. The low sulfur fuels often contain higher levels of cat fines.

   The usual procedure to reduce cat fines includes settling out oil in the storage tanks, regular draining of tanks, purification (centrifuge) and other suitable treatment.

   If the cat fines are not reduced to an acceptable limit, the scouring action of these fines can cause extremely rapid wear or damage to certain engine moving parts or components, particularly items such as fuel pumps, injectors, piston rings and liners with potentially severe consequences or total failure.

ABS Suggestions

Owners/operators are required to evaluate the engine and other associated machinery and equipment operation with low sulfur fuel by systematically assessing related systems taking into consideration (but not limited to) the potential risks identified in the Design and Operational Issues (items (a) through (u) as applicable), and see that appropriate measures are to 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.

1. A detailed fuel change-over procedure (or manual) should be developed by the vessel owner/operator in consultation with the engine and/or machinery manufacturers and placed on board.

   If the engines are capable of operating on low sulfur marine fuel such as MGO, although they were originally designed to operate on HFO/MDO, this fuel change-over procedure (or manual) should still be developed and placed on board.
2. Fuel oil suppliers should be consulted to select and receive proper MGO on board.
3. Manufacturers and associated systems providers should be consulted to determine whether or not their existing fuel systems/arrangements require modifications or additional safeguards for the intended fuels.
4. Engine manufacturers should be consulted regarding any service or maintenance requirements when operating on MGO (i.e., low sulfur fuel). A fuel system/component inspection and maintenance schedule should be established.
5. System seals, gaskets, flanges and other fittings should be carefully maintained since fuel seepage and leakage may occur from the use of MGO in systems which have previously used HFO/MDO.
6. System purifiers, filters and strainers should be maintained.
7. Control systems including pressure and temperature alarms, flow indicators, filter differential pressure transmitters etc., should all be operational.
8. Crew training (initial and periodic) should be conducted. Their training needs assessments should be kept up-to-date.
9. Fuel change-over should be completed well before entering the Regulated California Waters.
10. Cylinder lubrication consumption should be carefully monitored since a high consumption may be indicative of liner lacquering.

ABS Requirements to be Satisfied

1. General

   a. Where modifications are identified, details of all modifications together with the aforementioned design evaluation are required to be submitted to ABS for approval.

   b. Where the owner is satisfied that modifications to the vessel's installed equipment and systems are not required, it is recommended that the design evaluation be maintained on board. As this is a safety issue, the analysis substantiating the safe operation with low sulfur fuel is to be available only for consideration during ISM audits as evidence that safe operation has been considered.

   c. The design evaluation is to consider under all normal and abnormal modes of operation, including (but not limited to) the following:
      - Switch over to low sulfur, low viscosity fuel
      - Switch over to HFO from MGO
      - Maneuvering in congested waters or harbors while switching over
      - Long idle times
      - Starting engine at berth or anchorage

2. For modified systems, ABS requires the following:

   a. Design modifications, if any, are to be carried out by the original manufacturer or a competent entity that will be responsible for the modified design.

   b. Any modification to existing installations (including piping arrangements, control systems, equipment and other fittings) will be subject to ABS review and approval for both design assessment and survey. Accordingly, the details of the modifications considering the recommendations are required to be submitted to an ABS technical office for review of general piping (such as pipe materials suitability, pressure and fittings), automation and controls systems and other safety requirements in accordance with the applicable Rules. A copy of the design evaluation in conjunction with the modifications is to be submitted to ABS for approval.

   c. If new fuel oil pumps are installed, 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 Rules.

   d. All modifications are to be carried out in accordance with approved drawings and details to the satisfaction of the attending surveyor.

Appendix 2 | Use of Marine Low Sulfur Fuel for Boilers

ll engines (main and auxiliary engines) and boilers are affected by the new low sulfur regulations. (As for boilers, please note that the EU Directive applies to main and auxiliary boilers, while the CARB Regulations apply only to the auxiliary boilers, i.e., non-propulsion boilers.) This section addresses those issues that are associated with boilers operating on low sulfur marine fuel.

In modern boilers, typically the control is integrated with an outside sourced control system. As such, starting with the boiler and control manufacturer and involving a person or outside consultant to be responsible for the overall arrangement including any needed design adjustments may be a prudent course of action. It is to be noted that where boilers and equipment are not originally designed to burn lighter types of fuels such as MGO, existing installations of boilers, burners/equipment and fuel systems may need to be modified as a consequence of the mentioned legislation. For such modified systems, certain ABS class requirements would apply. These ABS Requirements are identified separately from the ABS Suggestions to provide clarity.

ABS Suggestions

1. Owners and operators are required to evaluate the boiler and other associated machinery/ equipment operation with low sulfur fuel by systematically assessing the related potential risks involved. ABS recommends that vessel owners and operators consult with the boiler manufacturer and associated systems provider(s) or other competent designer recognized by the boiler manufacturer or designer to determine whether or not their existing fuel systems/ arrangements require modifications or additional safeguards regarding the intended use of MGO fuels. This should also include obtaining the manufacturers' opinions regarding fuel switching guidance or procedures, if applicable, particularly where the plant was not originally designed for use of MGO.
    a. Where the owner is satisfied that modifications to the vessel's installed equipment and systems are not required, it is recommended that the risk analysis be maintained on board. As this is a safety issue, the analysis substantiating the safe operation with low sulfur fuel is to be available only for consideration during ISM audits as evidence that safe operation has been considered.
2. ABS considers that LNG carriers and oil carriers, where boilers burning HFO/MDO are used to power steam-driven cargo pumps, will also be affected by the new EU Directive and CARB requirements requiring the burning of low sulfur content fuel while in port.
3. Where a boiler has been originally designed to burn only HFO/MDO, the following points should be noted:
    a. Usually during initial flashing from cold when furnace temperatures are low (particularly after repair) the boilers can use small amounts of MGO but cannot sustain use of MGO during normal operation to meet the normal steam demand without modifications.
    b. Boiler explosions can take place due to incorrect operations. For example, if the boiler furnace is not properly purged before ignition (i.e., pre-ignition purge), when there is a high pressure of fuel gas built up in the burner due to flame failure, and when the control system is malfunctioning or disconnected.

c. Unburned fuel may be admitted to a hot furnace following flame failure. This could result in an explosion in the furnace, as a source of ignition within the furnace could exist.

d. Systems providing fuel atomization may have to be re-assessed because steam atomization may not be suitable owing to vaporization of MGO fuel 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.

e. Use of MGO may cause coke deposits on rotary cup types of burners. Protective heat shields are necessary to prevent coke build up. The change-over process should consider solubility of asphaltenes (i.e., fuel compatibility).

f. Existing burners designed for HFO/MDO may have to be modified or new types of burner assemblies accommodating both HFO and MGO may be necessary.

g. The existing piping used to transport heated HFO from the pump to the boiler may not be suitable to transport MGO, since:
   - MGO needs to be delivered at ambient temperature (storage tank temperature), and
   - There exists a concern that MGO flowing through hot piping may vaporize creating vapor locks and causing irregular fuel flow towards the burner resulting in flame extinction.

   Therefore, MGO is not to be delivered through heated pipes to the burner. Consideration should be given to dedicated MGO delivery piping and accessories. The burning of MGO may also necessitate speedy and effective flame failure detection. Boiler/equipment manufacturers should be consulted for specific recommendations in this regard.

h. To avoid vaporization by heating of MGO in the piping system, heat tracing of fuel pipes should be turned off or heaters bypassed and/or switched off.

i. Flame stability should be considered. Where a boiler is designed to burn HFO instead of MGO, a flame failure may occur when the fuel is changed over to MGO. Photo cells may not have the color spectrum necessary for MGOs. Equipment and/or machinery manufacturers should be consulted for specific recommendations based on applications. Also, safety features to promptly and effectively deal with flame failures, and all of the possible ramifications of a flame failure, need to be developed/considered. For example, flame supervision may have to be complemented with another flame scanner due to different properties of HFO and MGO flames such as flame length.

j. Existing HFO pumps may have difficulties with suction of the light oil (MGO) because of viscosity (HFO is more viscous than MGO). Also, HFO has better lubrication properties than MGO. Accordingly, due to lack of lubrication, this may eventually result in overheating of the existing HFO pumps (unless it was originally designed to handle MGO). It may be necessary to install completely different and new types of pumps and associated valves to handle MGO.

k. HFO has a higher density and a lower calorific value than MGO. Therefore, if the original burner setting for HFO is not changed before using MGO to control the amount of fuel injected into the burner, increased smoke emissions may result from boiler uptake. Further, fuel/air ratio, governed by fuel pressure only, will be too rich for safe combustion.

l. A detailed fuel change-over operation manual should be readily available for the operating crew on board.

m. In addition to the above, it is suggested that vessel owners and operators consider the following:
   - A fuel system inspection and maintenance schedule should be established.
   - System pressure and temperature alarms, flow indicators, filter differential pressure transmitters, etc., should all be operational.
   - System seals, gaskets, flanges, fittings, brackets and supports need to be maintained.
   - A detailed system diagram should be available.
   - Initial and periodic crew training should be conducted. Their training needs assessments should be kept up-to-date.

n. Where a low-load firing operation without a pilot (i.e., burning only gas) is proposed, and if such operation has not been assumed in the original boiler system design, ABS would recommend that a safety assessment be made for each individual operational case in order to ascertain safe operations. This should include, amongst other considerations, the following:
   - Boiler management system and combustion control that is suitable for intended low-load firing operation.
   - Flame scanner type and positioning that are suitable to detect failure at low-load firing operations.

o. It should be noted that when boilers are used for propulsion, maneuvering conditions may demand large and rapid load changes. Therefore, if boiler operation without a pilot under maneuvering conditions is proposed and such operation has not been assumed in the original boiler system design, ABS recommends that safety assessments be made for each individual operational case in order to ascertain the feasibility of such an operation.

p. The fuel oil systems in LNG ships with steam turbine propulsion are designed for HFO in combination with the boil-off from the cargo. Therefore, fuel oil systems in these vessels will need to be modified to use MGO. The reasons MGO is not to be used in the fuel oil systems in these vessels without modifications include the following:
   - It is important that the fuel supply remain uninterrupted for propulsion boilers.
   - Risk of failures in fuel pumps and valves.
   - Unintentional fuel oil evaporation risks.
   - For burners having concentric type fuel injectors, steam atomizing can heat up MGO.
   - For burners having parallel tubes for steam and fuel oil, due to the lower temperature of MGO, tubes conveying MGO can distort due to temperature gradients.
   - The design of the burner management system (BMS) and flame supervision is based on HFO.

ABS Requirements

For modified systems, ABS requires the following:

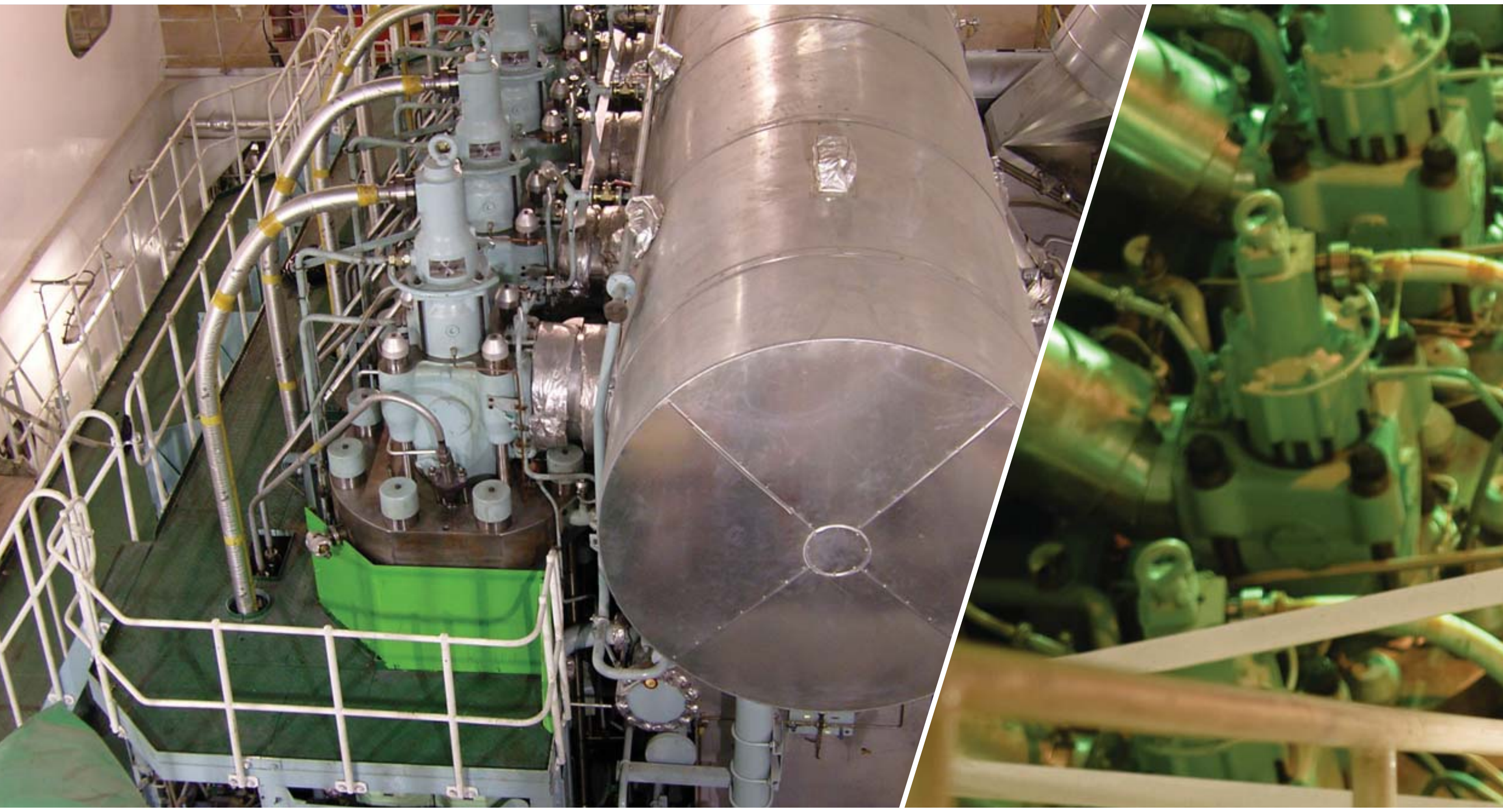
1. For boilers which have not been originally designed to continuously burn MGO, it may be necessary to carry out modifications to the existing fuel oil piping arrangements including the burner management and associated control systems. The owners and operators (or separate entities if employed) are required to evaluate the boiler operation with low sulfur fuel by systematically assessing related systems taking into consideration (but not limited to) these potential risks identified in ABS Suggestions 3 (a) through (p) as applicable, and appropriate measures are to be taken for safe operation of the boilers. Where modifications are identified, details of all modifications together with the aforementioned design evaluation are required to be submitted to ABS for approval.
2. Design modifications, if any, are to be carried out by the original manufacturer or a competent entity that is considered responsible for the modified design.
3. Any modification to existing boiler installations (including piping arrangements and control systems) will be subject to ABS review and approval for both design assessment and survey. Accordingly, the details of the modifications considering the above suggestions are required to be submitted to an ABS technical office for review of general piping (such as pipe materials suitability, pressure and fittings), automation and controls systems and other safety requirements in accordance with the applicable Rules.
4. All modifications are to be carried out in accordance with approved drawings/details to the satisfaction of the attending surveyor.

Appendix 3 | Fuel Oil Management Plan

Section 1	General Information	
	1	General
	2	Development of the Fuel Oil Management Plan
	2.1	General Contents of Plan
	2.2	General Guidance for Using the Template
Section 2	Fuel Oil Management Plan Template	
	1	Cover Page
	2	Review Record & Revision History
	3	Table of Contents
	4	Introduction
	5	Vessel Particulars
	6	SOx Emissions – Regulations/Requirements
	7	Bunker Consumption Monitoring
	7.1	General
	7.2	Fuel Oil Consumption Monitoring
	7.3	Bunker Available Onboard
	7.4	Bunker Required for Voyage
	7.5	Bunker Purchasing
	7.6	Bunker Delivery Note
	7.7	Fuel Oil Availability
	8	Actions Required Prior Bunkering
	8.1	General Requirements
	8.2	Bunkering Plan
	8.3	Chief Engineer's Bunkering Orders
	8.4	Watchkeeping/Duties
	8.5	Communication

8.6 Training - Bunker Crew
9 Actions Required During Bunkering
10 Actions Required Upon Completion of Bunkering
11 Sampling
11.1 Introduction
11.2 Definitions
11.3 Sampling Methods
11.4 Sampling & Sample Integrity
11.5 Sampling Location
11.6 Sealing of the Retained Sample
11.7 Retained Sample Storage
11.8 Handling Retention of the Commercial Purposes Bunker Sample
12 Fuel Switching Procedure
12.1 Fuel Change-over from HFO (Heavy Fuel Oil) to MGO (Marine Gas Oil)
12.2 Fuel Change-over Procedure for Other Engines, Boilers
12.3 Fuel Change-over Procedure with Different Type Fuels
12.4 IMO Record Keeping Requirements
12.5 EU Record Keeping Requirements
12.6 California Air Resources Board (CARB) Recordkeeping Requirements
13 Machinery Particulars
14 Duties/Responsibilities
14.1 Operation Manager of the Company
14.2 Marine Superintendent of the Company
14.3 Master of the Vessel
14.4 Chief Engineer of the Vessel
15 List of Drawings Require to Attach with this FO Management Plan
16 Annexes I-VI

To access the Fuel Oil Management Plan Sample Template, please use the following link:
http://ww2.eagle.org/content/dam/eagle/forms/fomp-review.docx



TX 03/10 6000 10043
TX 07/15 5000 15076

World Headquarters
16855 Northchase Drive
Houston, TX 77060 USA
Tel: 1-281-877-5800
Fax: 1-281-877-5803
Email: ABS-WorldHQ@eagle.org
www.eagle.org