Study on the use of ethyl and methyl alcohol as alternative fuels in shipping

Final Report Version 20151204.5

Authors:

Joanne Ellis (SSPA Sweden AB)

Kim Tanneberger (LR EMEA)

Report prepared for the European Maritime Safety Agency (EMSA)

SSPA Project Number: 20157412

Summary

Introduction

Methyl and ethyl alcohol fuels, also referred to as methanol and ethanol, are good potential alternatives for reducing both the emissions and carbon footprint of ship operations. As they are sulphur-free, use of methanol and ethanol fuels would ensure compliance with the European Commission Sulphur Directive. The European Maritime Safety Agency (EMSA) commissioned this study to gain more information about the benefits and challenges associated with these fuels and to evaluate their potential for the shipping industry.

Previous and current projects

Methanol has been investigated as a marine fuel in a few past research projects, two of which involved pilot test installations on ships. The Swedish EffShip project identified methanol as a promising marine fuel after studying alternatives and carrying out laboratory testing on a diesel concept engine. This led to further testing and development within the SPIRETH project, which led to the world's first methanol conversion of main engines on a passenger ferry, the *Stena Germanica*, in 2015. Waterfront Shipping has commissioned seven new chemical tankers with dual fuel methanol engines to be delivered in 2016. New research projects underway or recently started include a German Project, Methaship, to develop designs of methanol passenger vessels, and the EU Horizon 2020 project LeanShips, which includes a work package to test a marine methanol engine in a laboratory. These new projects demonstrate the growing interest and potential of methanol as a marine fuel. No projects have been identified for ethanol on ships, but it has been used in diesel engines in road transport for many years.

Properties, safety and regulations

Methanol and ethanol are both colourless, flammable liquids. Methanol is the simplest of alcohols and is widely used in the chemical industry. It can be produced from many different feedstocks, both fossil and renewable, with the majority produced from natural gas. Renewable methanol is produced from pulp mill residue in Sweden, waste in Canada, and from CO_2 emissions at a small commercial plant in Iceland. Ethanol is also an alcohol and is mainly produced from biomass, with the majority on the world market produced from corn and sugar cane. Both methanol and ethanol have about half of the energy density of conventional fossil fuels, which means that more fuel storage space will be required on board a vessel as compared to conventional fuels. They can also be corrosive to some materials, so materials selection for tank coatings, piping, seals and other components must consider compatibility. Methanol is classed as toxic so requires additional considerations during use to limit inhalation exposure and skin contact. Ethanol is not classified as toxic to humans.

The flashpoints of methanol and ethanol are both below the minimum flashpoint for marine fuels specified in the International Maritime Organizations (IMO) Safety of Life at Sea Convention (SOLAS). This means that a risk assessment or evaluation must be carried out for each case demonstrating fire safety equivalent to conventional fuels for marine use. Guidelines are currently in draft for the use of methanol and ethanol fuels on ships, for future incorporation in the newly adopted International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code). This will facilitate the use of these fuels on board ships. The previously described *Stena Germanica* and Waterfront Shipping chemical tanker projects both carried out risk assessments and were approved for installation, demonstrating that safety considerations are not a barrier to the use of methanol fuel systems on ships.

Availability

Methanol is widely available as it is used extensively in the chemical industry. There are large bulk storage terminals in both Rotterdam and Antwerp, and it is transported both with short sea shipping and by inland waterways to customers. Ethanol is the most widely used biofuel in land based transportation and can be found at most large chemical storage hubs in Europe.

Environmental impacts

Methanol and ethanol both have many advantages regarding environment impacts as compared to conventional fuels – they are clean-burning, contain no sulphur, and can be produced from renewable feedstocks. Emissions of both methanol and ethanol from combustion in diesel engines are low compared to conventional fuel oils with no after-treatment. Particulate emissions are very low, and nitrogen oxide emissions are also lower than with conventional fuels, although the amounts depend on the combustion concept and temperature. If a pilot fuel ignition concept is used with methanol and ethanol there will be a very small amount of sulphur oxide emissions which will depend on the amount and sulphur content of the pilot fuel.

The environmental impact of production and use of methanol "well to wake", using greenhouse gas equivalents as an indicator of global warming potential, varies according to the feedstock. Methanol produced using natural gas as a feedstock has "well to tank" emissions similar to other fossil fuels such as LNG and MDO. Bio-methanol produced from second generation biomass such as waste wood has a much lower global warming potential than fossil fuels and is lower than ethanol by most production methods. "Well to wake" emissions from ethanol are lower than fossil fuels but the amount varies with production methods and feedstock. For example the ethanol produced in Brazil and in Sweden has much lower "well to tank" greenhouse gas emissions than that produced from corn in the US.

The behaviour of methanol and ethanol fuels when spilled to the aquatic environment is also important from an environmental performance perspective as ship accidents such as collisions, groundings and foundering may result in fuel and cargo spills. Both methanol and ethanol dissolve readily in water, are biodegradable, and do not bioaccumulate. They are not rated as toxic to aquatic organisms.

Cost and economic analysis

Prior to the recent oil price crash, methanol prices were below the price of low sulphur marine gas oil (MGO) on an energy basis for two years from 2011 to 2013, making it an attractive sulphur compliance option. With the low oil prices in 2014 and early 2015, methanol was comparatively more expensive but in late 2015 the price of methanol has started to move closer to the levels of MGO again. Cheap natural gas, a primary feedstock for producing methanol, contributes to lower production costs and thus methanol may be economically attractive again compared to conventional fuel alternatives. Ethanol prices have been higher than MGO traditionally, similar to other types of biofuels. Fuels from non-fossil feedstock, including bio-methanol, tend to have a higher price than fossil fuels.

Investment costs for both methanol and ethanol retrofit and new build solutions are estimated to be in the same range as costs for installing exhaust gas after treatment (scrubber and SCR) for use with heavy fuel oil, and below the costs of investments for LNG solutions. Operating costs are primarily fuel costs. The payback time analysis carried out for this study indicate that methanol is competitive with other fuels and emissions compliance strategies, but this depends on the fuel price differentials. Based on historic price differentials, methanol will have shorter payback times than both LNG and ethanol solutions for meeting sulphur emission control area requirements. With the current low oil prices at the end of 2015, the conventional fuel oil alternatives have shorter payback times.

Acknowledgments

This report was complied with contributions gratefully received from:

- LR EMEA contributors Paul Davies, Fabio Fantozzi, Jonathan Morley, Gary Pogson, Francesco Sandrelli, Karel Vinke, and Timothy Wilson. Kimberly Ross is acknowledged for Graphic Design of Figures: 1, 4, 5, 7, 8, 11.
- SSPA contributors Björn Forsman, Maria Bännstrand, and Roger Karlsson participated in the hazard identification sessions and Björn Forsman and Joakim Lundman provided review comments on the report.

Acknowledgment and thanks is given to all of those who participated in the safety assessment workshop and generously shared their knowledge and experience.

Carlos Pereira and Ricardo Batista from the European Maritime Safety Agency are thanked for their guidance and valuable comments throughout the study and report production.

Table of contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

ADR	International Carriage of Dangerous Goods by Road
BLG	Bulk Liquids and Gases Sub-Committee (International Maritime Organization)
BS	Bunker Station
CAS	Chemical Abstract Service
CCC	Sub-Committee on Carriage of Cargoes and Containers (CCC) - formerly DSC
CCTV	Closed Circuit Television
CO	Carbon Monoxide
DE	Design and Equipment sub-committee (IMO) - In 2014 this was moved to the Ship Design and Construction (SDC) sub-committee
DME	Di-Methyl Ether
DMX	A grade of marine distillate fuel with flashpoint 43°C, primarily used in emergency generators, defined under ISO 8217, International Fuel Oil Standards
DNEL	Derived No Effect Level
DWT	Deadweight tonnage
ECA	Emission control area
ECHA	European Chemicals Agency
EIA	Energy Information Administration
EN	European Standard
ESD	Emergency Shutdown
EtOH	Ethanol
FOBAS	Fuel Oil Bunker Analysis & Advisory Service
FP	Flash point
FPR	Fuel Preparation Room
FSHS	Fuel Storage Hold Space
FSS Code	International Code for Fire Safety Systems
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
HAZID	Hazard Identification Study
HFO	Heavy Fuel Oil
HFRR	High Frequency Reciprocating Rig (used for lubricity testing)
IBC Code	International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk
IC	Investment Cost

ICSC	International Chemical Safety Cards
IEC	International Electrotechnical Commission
IG	Inert Gas
IGF Code	Draft international code of safety for ships using gases or other low flash point fuels which is under development by the International Maritime Organization
IGC Code	International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
ILO	International Labour Office
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IOELV	Indicative Occupational Exposure Limit Value
IR	Infra-red
ISO	International Organization for Standardization
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LR	Lloyds Register
MARPOL	International Convention for the Prevention of Pollution from Ships
MC	Maintenance Cost
MDO	Marine Diesel Oil
MeOH	Methanol
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
mmBtu	One million British Thermal Units
MSC	Maritime Safety Committee - IMO
NIST	National Institute of Standards
NOx	Nitrogen Oxides
OECD	Organisation for Economic Cooperation and Development
OEL	Occupational Exposure Limit
on-deck	i.e. open-deck
OPEC	Organization of Petroleum Exporting Countries
PM	Particulate Matter
PNEC	Predicted No Effect Concentration
RFO	Residual Fuel Oil
SC	Safeguard for a Cargo Ship

SCOEL	Scientific Committee on Occupational Exposure Limits
SFOC	Specific Fuel Oil Consumption
SIDS	Screening Information Data Set
SOFC	Solid Oxide Fuel Cell
SOLAS	International Convention for the Safety of Life at Sea
SOx	Sulphur Oxides
SP	Safeguard for a Passenger Ship
TCC	Tag Closed Cup (a method of measuring flash point)
THC	Total Hydrocarbons
TMIV	Tank Master Isolation Valve
UN	United Nations
WHO	World Health Organization
WSD	Wear Scar Diameter

1 Introduction

This study on the use of ethyl and methyl alcohols as alternative fuels for shipping was commissioned by the European Maritime Safety Agency (EMSA), as part of this European agency's role in supporting EU member States and the European Commission with regards to solutions for sustainable shipping, namely in the development of knowledge and information regarding alternative fuels. In this context, and as the main motivation for this study, it can be highlighted that methanol (methyl alcohol) in particular has been receiving increased interest as an alternative marine fuel, which not only results in reduced air emissions, but also increases the available options to ship owners for complying with increasingly stringent environmental regulations. The adoption of an alternative fuel solution often has the advantage of not having the need to install exhaust gas cleaning systems (EGCS), as is the case with methyl/ethyl alcohols.

Methanol can be produced from many feedstocks, including second generation biomass, wastes, and even CO_2. Ethanol (ethyl alcohol) is a biofuel that has similar properties to methanol when used as a fuel and similar emission reduction potential. Evaluating these as alternative fuels for use in shipping requires an adequate understanding of different aspects related to their production, distribution and use. Market, regulatory and safety aspects are, amongst others, the main areas that are covered in the present study, which aims to cover not only the availability of methyl/ethyl alcohols but also the regulatory framework and the risk and safety aspects related to the use, and bunkering, of these particular low flashpoint fuels.

The present study includes both a compilation of information on different aspects of methyl/ethyl alcohols and an analysis of two distinct areas which are investigated using a case study exercise approach: 1) economic aspects of using these alternative fuels for newbuild ships and retrofits, and 2) risk and safety. The compilation and review of information highlighting methyl/ethyl alcohols characteristics, regulations, standards and existing research projects provides an insight into the current situation regarding these fuels. The second part of the study, the case study investigation of the economic and risk and safety aspects, has the objective of contributing to expert and decision-making discussion at different levels.

The economic analysis is considered to be relevant to ship owners who are today considering different compliance strategies for their newbuild/retrofit projects and to ship designers who endeavour to include in their concept designs some earlier indicative life-cycle cost figures. The risk and safety investigation, consisting primarily of a safety assessment of generic passenger and cargo ship designs, is intended to motivate discussion on the different safety and risk management aspects specific to methyl/ethyl alcohol fuelled ships.

The information contained in the present study, along with both the economic and safety assessments, is expected to be useful in informing not only ship owners, ship designers and other maritime industry stakeholders, but also the wider maritime community about the potential of these fuels in the context of sustainable shipping.

2 State of play on the use of ethyl and methyl alcohol in the shipping sector

The use of alternative fuels in the shipping industry has been receiving increasing attention as a method of complying with low sulphur requirements for fuels and reduced emissions of sulphur oxides. Although liquefied natural gas (LNG) has been the subject of many previous studies, more recently methyl alcohol (methanol) has been identified as a promising fuel alternative with no sulphur.

This chapter provides information on the current and potential future use of ethyl and methyl alcohol as a fuel in the shipping sector through presentation and discussion of the following areas:

- Past, current, and future projects, with emphasis on those carried out in the EU
- Chemical and physical properties of ethanol and methanol
- Availability, suitability and environmental sustainability of the fuels, with comparison to conventional fuels and LNG
- Cost and economic data, with comparison to other compliant fuels and fuels with exhaust gas treatment systems.

Results of the work carried out for each of the above areas are provided in the following sub-chapters of the report.

2.1 Inventory of past, current and future projects involving the marine use of ethyl and methyl alcohol fuels

Past, current, and future projects involving the use of methyl alcohol as fuel were identified through project partner networks, review of conference and workshop proceedings, and literature searches. Table 1 provides a compilation of the projects identified along with information on project type, time frame, fuels tested, ship types investigated, and project coordinator. More detailed information about each identified project, including project results, where available, project partners, and project sponsors, is provided in a short text description in sub-sections following the table. No projects using ethyl alcohol as marine fuel were identified in the course of this study. There is some reference to ethanol blended with gasoline for small pleasure boat gasoline engines, but nothing was found in relation to use in large marine diesel engines. The lack of ethanol projects could be due to the consistently high price of ethanol as compared to methanol, making it unattractive as a primary candidate for a ship fuel (see Section 2.4).

Projects investigating the use of methanol as a marine fuel are relatively recent, with the first project identified by this study starting in 2006. Recently there have been a number of projects initiated to further investigate the potential of methanol for ship fuel, as shown on the timeline in Figure 1.

Table 1: List of projects involving the use of methanol as marine fuel

Project Name	Dates	Project Type, Coordinator	Fuels Tested	Ship Types
METHAPU Validation of Renewable Methanol Based Auxiliary Power System for Commercial Vessels	2006-2009	Prototype EU FP6 Project, coordinated by Wärtsilä Finland	Methanol in Solid Oxide Fuel Cell	Car Carrier (PCTC)
Effship Efficient Shipping with Low Emissions	2009-2013	Primarily paper study with some laboratory testing, coordinated by SSPA Sweden AB and ScandiNAOS	Methanol in laboratory trials, other fuels discussed in desk studies	General to most ship types, with case examples of a short-sea ro-ro vessel and a Panamax tanker
SPIRETH Alcohol (spirits) and ethers as marine fuel	2011-2014	Laboratory testing, on-board testing (DME converted from methanol) with an auxiliary diesel engine, coordinated by SSPA Sweden AB and ScandiNAOS	Methanol in a converted main engine (in a lab) DME (converted from methanol on-board) in an auxiliary engine	Passenger Ferry (RoPax)
Methanol: The marine fuel of the future (Also referred to as "Pilot Methanol" by Zero Vison Tool)	2013-2015	Conversion of main engines and testing on-board, project coordinated by Stena AB	Methanol	RoPax ferry *Stena Germanica*
MethaShip	2014-2018	Design study coordinated by Meyer Werft	Methanol and DME	Cruise Vessel, RoPax
Waterfront Shipping Tanker newbuilding projects	2013-2016	Commercial Ship Construction	Methanol (Dual-Fuel Engines)	Chemical tankers
LeanShips Low Energy and Near to Zero Emissions Ships	2015-2019	Horizon 2020 project with 8 demonstrators (1 methanol) coordinated by DAMEN	Methanol, LNG, and conventional fuels with emissions abatement	2 cases: Small waterplane area twin hull and trailing suction hopper dredger.
proFLASH	2015 (Phase 1: preFLASH)	Study of the effects of methanol and LNG properties on fire detection and extinguishing systems, coordinated by SP Technical Research Institute of Sweden	Methanol and LNG	All
SUMMETH Sustainable Marine Methanol	2015	MARTEC II project coordinated by SSPA, focused on smaller marine engines	Methanol (laboratory engine tests)	Road ferry

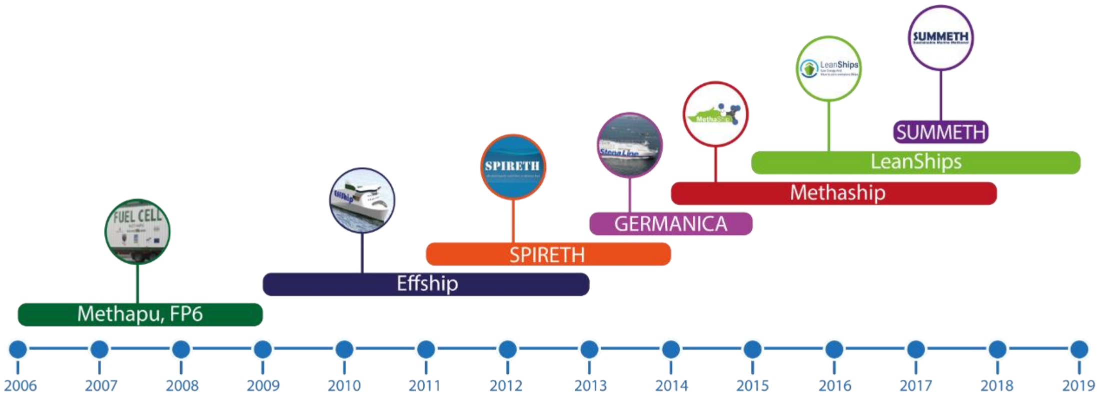


Figure 1: Timeline showing some of the main projects investigating the use of methanol as a marine fuel.

More details about the technical work, outcomes (where projects have been completed), partners, sponsors, and references for each of the projects shown in Table 2.1 are provided in the following sub-sections.

2.1.1 METHAPU

The METHAPU project (Full name: "Validation of Renewable Methanol Based Auxiliary Power System for Commercial Vessels") was the earliest project identified where methanol was tested as a fuel on board a ship. An overall goal was to evaluate the use of solid oxide fuel cell (SOFC) technology and methanol as a means of providing electrical power for essential services on board an internationally trading cargo vessel covered by the SOLAS convention and 'in class' [1]. Methanol was bunkered from a road tanker truck to a tank installed on the weather deck of a car carrier for the demonstration project. Fort [1] states that the project was successful in demonstrating that the methanol fuel cell system installed on board the vessel "would present no greater risk to the ship, its occupants or the environment than that associated with conventional marine machinery and marine fuels".

METHAPU was co-funded by the European Commission (EC) under the 6th Framework Research Programme (FP6), with contributions from project partners which included Wärtsilä Finland (coordinator), Wallenius Marine AB, Det Norske Veritas AS, Lloyd's Register, and University of Genoa.

2.1.2 EffShip - Efficient Shipping with Low Emissions

The EffShip project was based on the vision of a sustainable and successful maritime transport industry which is energy-efficient and has minimal environmental impacts [2]. The project investigated a range of solutions for achieving this vision: alternative fuels, abatement technologies, energy recovery, and complementary propulsion including wind.

For short term solutions, the use of alternative fuels including natural gas, LNG, methanol, and dimethyl ether (DME) were investigated and compared within the project. The fuels investigation concluded that methanol is the best alternative fuel when considering quick availability within existing infrastructure, price, and relatively simple engine and ship technology adaptations for marine use [2]. The EffShip project also included some initial engine tests on a Wärtsilä Vaasa 4L32LNGD, using the methanol diesel concept with pilot fuel ignition [3]. Test results showed engine efficiency similar to diesel fuel, very low particulate matter, and low Tier II NOx values [3].

The EffShip project was a national Swedish project co-financed by Vinnova (The Swedish Innovation Agency) and the project partners, which included SSPA Sweden AB (co-coordinator), ScandiNAOS (co-coordinator), Chalmers University of Technology, Göteborg Energi, S-Man, Stora Enso, Stena Rederi AB, DEC Marine, Wärtsilä, and Swedish Orient Line.

2.1.3 SPIRETH ("Alcohol (spirits) and ethers as marine fuel")

The SPIRETH project developed as a spin-off from the EffShip project described above. Methanol had been identified as a promising alternative fuel by the EffShip project group and the need for further testing and demonstration was identified. Two testing and development streams were carried out - for methanol and dimethyl ether (DME) derived from methanol. The methanol test stream involved conversion of a full scale marine diesel engine to run efficiently on methanol with pilot fuel ignition, and performance testing in a laboratory. For DME, a methanol to DME conversion process plant was developed for shipboard operation. This plant, developed by Haldor Topsøe, was installed on board the *Stena Scanrail* RoPax ferry and the DME fuel mix produced from the plant was tested using an adapted diesel auxiliary engine. Methanol was bunkered onto the ship for the testing and stored in a methanol tank on the weather deck [4].

Figure 2: The *Stena Scanrail* with methanol tank installation forward of the port side funnel (Photo by Joanne Ellis, courtesy SPIRETH Project)

There were some difficulties with fuel ignition in the auxiliary engines using the DME fuel mix, but once combustion was established it was quite similar to diesel. Use of ignition improver and preheating improved starting but further testing and engine development was recommended [4].

The methanol engine conversion part of the project resulted in development of a retrofit solution for conversion of a ship's main diesel engine, a Wärtsilä-Sulzer 8 cylinder Z40S, to methanol operation. This solution used the same methanol diesel concept with pilot ignition as tested in the EffShip project preliminary tests. For SPIRETH, engine modification included design and installation of a new injector and modification of the cylinder head, among other on-engine modifications. A high pressure pump was used to supply fuel to the engine. The converted engine was tested in a laboratory with good results regarding efficiency and emissions. Reduced NOx and particulate matter with methanol operation as compared to the reference tests with low sulphur diesel fuel were reported [5]. The same or better efficiency was reported. Further work on the same engine was continued in the *Stena Germanica* project, with an additional test program in the laboratory.

The SPIRETH project was co-funded by the Swedish Energy Agency, the Baltic Sea Action Plan Facility Fund (Nordic Investment Bank), the Nordic Council of Ministers' Energy & Transport Programme, the Danish Maritime Fund, and the project partners. Partners included SSPA Sweden AB (co-coordinator), ScandiNAOS (co-coordinator), Stena Rederi AB, Wärtsilä Finland, Haldor Topsoe, Lloyds Regiser EMEA, and Methanex.

2.1.4 Methanol: The marine fuel of the future

"Methanol: The marine fuel of the future" is a pilot action to test the performance of methanol on the passenger ferry *Stena Germanica*, which traffics the route between Gothenburg, Sweden, and Kiel, Germany. Bunkering systems including a bunkering vessel are also being investigated as part of the project. The project was granted 50% support under the 2012 Trans-European transport network (TEN-T) multi-annual program. Project partners are Stena AB (coordinator), Wärtsilä Finland OY, Stena Oil AB, Seehafen KIEL GmbH & Co. KG, and Göteborgs Hamn AB.

Figure 3: The *Stena Germanica* (Courtesy Stena AB)

The *Stena Germanica's* fuel system and one main engine were converted to methanol/MGO dual fuel operation and the vessel re-entered service on March 26, 2015 [6]. Conversion of the remaining three main engines is planned to take place during late 2015 to 2016 while the vessel is in service. The engine retrofit concept was developed during the SPIRETH project described previously, using a Wärtsilä-Sulzer engine. Further work regarding optimisation and testing of the system is ongoing. On board emissions testing is planned when engine conversion and optimisation work is complete, with some results possibly available at the end of the first quarter of 2016. Emissions' testing was carried out as part of the laboratory testing of the engine prior to retrofit on the vessel.

2.1.5 MethaShip

The MethaShip project is being carried out to assess the feasibility of building new methanol-powered vessels. Designs for a cruise ship and a RO-PAX ferry will be developed during the three-year project which began in 2014. Project coordinator Meyer Werft will develop the cruise ship design and partner Flensburger will develop the Ro-Pax ferry concept [7]. The other main partner, LR Marine, will carry out the approval in principle for both concepts. The MethaShip project will also study bunkering options for methanol and assess port authorities' possibilities and opinions regarding methanol supply [7]. Associated partners include Helm AG, Caterpillar, and MAN.

2.1.6 Waterfront Shipping Chemical Tankers

Waterfront Shipping has commissioned seven new 50000 DWT tanker vessels using MAN ME-LGI flex engines running on methanol, fuel oil, marine diesel oil, or gas oil, with delivery of the ships scheduled for 2016 [8]. Mitsui OSK Lines Ltd. will own three of the vessels, and Marinvest/Skagerrak Invest and Westfal-Larsen will each own two [9]. The ships are being built by Hyundai Mipo Dockyard and Minaminippon Shipbuilding Co., Ltd. [8]. Laboratory demonstration of the two stroke engine with methanol was reported in 2015 [10]. The engine uses a pilot injection of MGO or HFO to initiate combustion, and a fuel booster injection valve is used to raise fuel injection pressure to 600 bar. Methanol is delivered to the engine in liquid condition at a supply pressure of 8 bar [9].

2.1.7 LeanShips

LeanShips, "Low Energy and Near To Zero Emissions Ships", is funded under the new European Research and Innovation Framework Program HORIZON 2020, with a total cost of approximately 23 million EUR. The main aim of the project is "to demonstrate the effectiveness and reliability of energy saving and emission reduction technologies at real scale" [11]. The project began in May 2015 and there are eight demonstrators planned to be included in the project as follows:

- A CNG (Compressed Natural Gas) powered RSD (Reverse Stern Drive) Tug
- An LNG tug
- Marine Diesel Oil (MDO) or Methanol Dual Fuel for Offshore Service Vessel
- Efficient LNG carrier
- Retrofit of short sea cargo ship (SECA) with LNG
- Inland cargo ship with large oscillating propulsor
- Large propeller for general cargo vessel
- Energy efficient PAX /cruise ships. [11]

The demonstrator involving methanol is being led by the University of Gent and will include laboratory demonstration and testing of a dual fuel engine. This work is being conducted in work package 5, which is titled "Demonstrating the potential of methanol as an alternative fuel" [12]. Work will include:

- Conversion of a high speed marine diesel engine to methanol dual fuel operation and mapping the engine's power, efficiency, and emissions with methanol operation
- Life cycle assessment of the use of methanol as a fuel in shipping using two cases – a small waterplane area twin hull vessel and a trailing suction hopper dredger
- Pilots for dissemination and market uptake [12].

The LeanShips project is coordinated by Damen Shipyards Group with joint management by Netherlands Maritime Technology Foundation (NMT), the Center of Maritime Technologies (CMT) and Cetena, the Italian ship research centre. There are 46 participants in the project. Participants in the methanol demonstrator work package are University of Gent, DAMEN, Abeking & Rasmussen, Dredging International, Kant, Volvo Penta, and Methanex.

2.1.8 proFLASH

The first phase of proFLASH, referred to as "preFLASH", was initiated in May 2015 and is a theoretical investigation of how LNG and methanol properties can affect fire detection and extinguishing systems on ships. The work also includes a literature study of applicable regulations and class rules. Aims of preFLASH are to identify hazards introduced by the new fuels, limitations of traditional fire protection systems, potential systems solutions to manage the introduced hazards, and to propose methods for verifying detection and extinguishing systems for methanol and LNG. The second phase of the proFLASH project aims to further evaluate the effectiveness of fire-extinguishing systems for methanol and LNG through full-scale testing [13]. ProFLASH is anticipating start-up in 2016, pending approval of project funding.

Together the two project phases will address issues including how to detect fires from clean-burning fuels such as methanol and LNG with no smoke and low-visibility flames, and determine the effective ways of extinguishing fire from a fuel such as methanol with bound oxygen [14].

The SP Fire Research department of the SP Technical Research Institute of Sweden is coordinating proFLASH. Participants in phase 1 included the Swedish Transport Agency, Lloyd's Register Marine, Stena, Marinvest, ScandiNAOS, Tyco, Ultrafog and Consilium.

2.1.9 SUMMETH

SUMMETH, "Sustainable marine methanol", is a project supported by the MARTEC II network. The objective of the project is to investigate methanol combustion concepts for smaller marine engines (about 250 to 1200 kW), develop a design for a case study ship using these engines, and to assess the requirements and potential for using renewable methanol for the marine market. The project will include laboratory testing of methanol engine concepts and the conceptual design of a road ferry. The project began in 2015 and will continue to the end of 2017. SSPA Sweden AB is the project coordinator and partners include ScandiNAOS, Marine Benchmark, Lund University, Scania, the Swedish Transport Association Road Ferries, and VTT Technical Research Institute of Finland. The project is co-funded by the Swedish Maritime Administration, the Methanol Institute, and Region Västra Götaland.

2.1.10 Other recent studies planned and completed

The Methanol Institute commissioned a report on the use of methanol as marine fuel which was completed in late 2015 [77].The International Maritime Organization issued an invitation to tender for a desk study on the use of methanol as an alternative fuel for ships, with a report to be completed by the end of 2015.

2.1.11 Engine Development Projects

In addition to work in publically-funded projects specifically directed at shipping, there has also been work carried out by engine manufacturers on the use of alcohol fuels in engines. Table 2 lists some examples of engines developed for methanol or ethanol that have been used in "real-world" applications.

Table 2: Diesel cycle engine operation involving methanol and ethanol fuels. Blue shaded rows describe marine engine projects, while green rows show land-based applications of heavy duty diesel engines.

Engine Manufacturer	Fuels	Engine speed and type	Engine model	Comment
Wärtsilä	Dual fuel **methanol** and MGO	Medium speed four-stroke **marine** main engine, pilot ignition	**Retrofit** kit for Wärtsilä-Sulzer 8 cylinder Z40S	Installed on the ropax ferry *Stena Germanica* in 2015
MAN Diesel & Turbo	Dual fuel – Conventional fuel together with low flashpoint liquids **methanol, ethanol**, LPG, gasoline, or DME possible	Slow speed two-stroke **marine** main engine, pilot ignition	ME-LGI series introduced 2013 **New production engine**	Methanol dual fuel engines installed on chemical tankers to be delivered in 2016
Scania	**Ethanol** 95% with additives	High speed 9-litre diesel engine for use in trucks and buses	Scania ED9 **Production engine**	Scania ethanol engines have been used on public transit buses for many years (first operation in 1985)
Caterpillar	**Methanol** 100%	High speed 4-stroke engine, 261 kW, adapted with "glow plug" ignition, used in long-haul trucks	Adapted Caterpillar 3406 DITA Engine (**retrofit** for test study)	More than 5000 hours operation in a test project in long-haul trucks in 1987-1988

Wärtsilä's ongoing work on development and testing of a retrofit solution for conversion of the Wärtsilä-Sulzer 8 cylinder Z40S was started during the SPIRETH project in 2011 and continued as part of the *Stena Germanica* conversion project. MAN developed their ME-LGI flex fuel engines in 2013 [9], with the first of these engines to be used with methanol to be installed on chemical tankers delivered in 2016.

Evaluation of methanol combustion is being carried out by Caterpillar and MAN 4 Stroke Division within the METHASHIP project [15]. Caterpillar carried out long-duration testing of an adapted high speed diesel automotive engine during 1987-1988 [16]. These tests involved operation of heavy duty trucks for about 5000 hours on long-haul service in Canada. Engine adaptations included installation of a "glow plug" for ignition-assist. "Neat" (100%) methanol was used as fuel in the tests and NOx and particle emissions were found to be reduced relative to diesel operation [16]. Engine performance was stated to be equal to the conventional diesel fuel comparator.

Research on using methanol fuel in a 4-stroke high speed marine engine was conducted in Japan in the early 1990s [17]. The lower emissions from methanol and the economic advantages in terms of reduced maintenance and fuel treatment as compared to using heavy fuel oil were cited as advantages for methanol. The research project tested a 4-stroke marine diesel engine in the laboratory and concluded that adapting the fuel injection system and using dual-fuel system could result in performance comparable to that of single fuel oil. Emissions of smoke were reduced and NOx emissions from methanol operation was about half that compared to operation on gas oil.

For ethanol operation, only land-based examples were found. Scania has developed diesel-principle engines operating on ethanol, which have been used for many years for bus and truck operation, with further development to focus on optimizing efficiency and minimising emissions [18].

Two university research programs have also been identified where research is focused on methanol as a fuel, as follows:

- Lund University (Sweden) –"MOT-2030 Highly Efficient Methanol Engines for Fossil Free Transport 2030)". This research program, involving PhD students, is stated to have the goal of investigating methanol behaviour in partially premixed combustion (PPC) engines. The main project sponsor is the Swedish Energy Agency, with support from Volvo, Scania, Wärtsilä, Stena and Volvo Cars.
- Ghent University (Belgium) – Methanol has been a focus for research at University of Ghent's Department of Flow, Heat, and Combustion Mechanics since 2009 [12]. Both experimental and modelling work on methanol engines has been carried out. This research group will be carrying out work specifically on a high speed marine diesel engine as part of the 4-year Horizon 2020 research project LeanShips, which began in 2015.

2.2 Description of chemical and physical properties and other material dependent parameters of ethyl and methyl alcohol fuels

The following main groups of properties, characteristics, and representative safety hazards of methyl alcohol and ethyl alcohol were investigated and are summarized in the following discussion:

- Selected chemical and physical properties
- Corrosion and effects on materials

- Toxicity and effects on human health
- Behaviour when spilled to the aquatic environment

Comparisons to conventional marine fuels and LNG properties and toxicity are included.

A brief general description of each of the fuels is provided as an introduction before proceeding to the more detailed table of properties.

Note that the comparison of these substances is not simple. Conventional fuel oils, which are complex liquid mixtures, will be compared with pure/ quasi pure liquids or at least simple mixtures (if considering some water content) and with a gaseous mixture (LNG).

Conventional marine fuels include residual fuel oil and distillate fuels, such as 0.1% sulphur marine gas oil:

- Residual Fuel Oil (RFO): RFO, also referred to as heavy fuel oil (HFO), is described as a complex mixture of heavy aliphatic and aromatic compounds, bitumens and asphaltenes [19]. The characteristics of RFO may vary considerably depending on the crude oil from which it was produced as well as the composition of any light fuels or products blended with the residual oil to achieve a specified viscosity and flash point. There are a range of grades of residual heavy fuel oil. Specific characteristics and composition are specified in international standard ISO 8217:2012 [20]. Residual fuel oil grades in this standard are RMA, RMB, RMD, RME, RMG and RMK (see Appendix I for the ISO marine fuel standard specifications for these grades).
- Distillate Marine Fuel oil: Commonly referred to as marine gas oil (MGO), this is for the most part now supplied with maximum 0.1% sulphur content. However this needs to be specified on order, as MGO can be supplied with higher sulphur contents in some locations. It is a complex mixture of aliphatic and aromatic hydrocarbons that is produced by the distillation of crude oil. It consists primarily of hydrocarbons with carbon numbers in the range of C9 to C20, with exact composition varying depending on the crude oil from which it was distilled and the distillation process. MGO is defined in the ISO marine fuel standard 8217:2012 for distillate grades specified as DMX, DMA, DMZ and DMB with characteristics described in Appendix II.

Flash point requirement for all grades distillate and residual is a minimum of 60°C, in line with the IMO's Safety of Life at Sea convention (SOLAS). The one exception is the DMX grade distillate fuel used in emergency generators, for which the flash point minimum limit is 43°C.

Methyl and ethyl alcohol (methanol and ethanol)

- Methyl alcohol: Also referred to as methanol, wood alcohol, wood naphtha or wood spirits, methyl alcohol has the chemical formula CH_3OH (often abbreviated MeOH). It is the simplest of the alcohols, and is a colourless, flammable liquid at ambient temperatures. It is widely used in the chemical industry and industrial grade methanol is commonly provided 99.85% pure on a weight basis according to the International Methanol Consumers and Producers Association (IMPCA) methanol standard [21]. Methanol can be produced from many different feedstocks such as fossil natural gas, coal, farmed wood, wood waste, and even carbon dioxide. The chemical composition remains the same regardless of the source.
- Ethyl alcohol: Also referred to as ethanol or drinking alcohol, ethyl alcohol has the chemical formula C_2H_5OH (often abbreviated EtOH). It is a colourless, flammable liquid with major uses including as a solvent, fuel additive, or fuel. Ethanol as a blending

component for gasoline in the EU must contain 98.7% ethanol and higher saturated alcohols according to the European Standard EN 15376 specification. ‘Neat’ E100 hydrous ethanol used in Brazil has a maximum water content of approximately 5% [22]. Ethanol is mainly produced by fermentation and distillation of biomass containing sugar or starch, such as corn, sugar cane, or wheat.

Methanol and ethanol contain hydrogen and carbon as do HFO, MGO, and LNG, but their molecules also contain oxygen in a hydroxyl group (OH). The oxygen content makes the behaviour of alcohols as fuel different from conventional fuels with regards to ignition, combustion, energy density by mass, and emission of particulates and NOx. It also creates differences with fire suppression methods based on oxygen displacement.

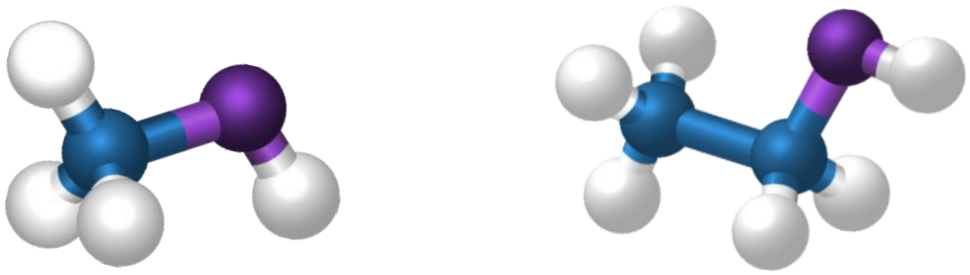


Figure 4: Methanol molecule on the left and ethanol on the right. The oxygen atom is shown in purple.

Liquefied Natural Gas (LNG): LNG is natural gas that has been cooled to a temperature of about -162°C, where it becomes liquid form. The main component of LNG is methane, which has the chemical formula CH_4. LNG also contains smaller percentages of heavier hydrocarbons such as ethane, propane, butane and pentane, as well as nitrogen. The exact composition of LNG varies by source and by liquefaction process. In addition the boil-off process in tanks may change the composition. These slight differences in composition may result in variations in heating value. Typically, at least 95% of natural gas is methane [23].

2.2.1 Selected chemical and physical properties and parameters of ethanol and methanol

Selected chemical and physical properties of ethanol, methanol, HFO, MGO, and LNG are presented in Table 3. These properties include boiling temperature, density, viscosity, lower heating value (indicative of energy density), lubricity, vapour density, flashpoint, auto ignition temperature, and ignition energy.

Table 3: Selected chemical and physical properties of methanol, ethanol, HFO, MGO, and LNG (see Appendix III for the table annotated with references)

Properties	HFO	MGO	LNG	Methanol	Ethanol
Physical State	liquid	liquid	cryogenic liquid	liquid	liquid
Boiling Temperature at 1 bar [°C]	-	175-650	-161	65	78
Density at 15°C [kg/m³] (LNG shown at -160°C)	989	Max. 900	(-160°C,1 bar) 448	796	792
Dynamic Viscosity at 40°C [cSt]	-	3.5	-	(at 25°C) 0.6	1.1
Lower Heating Value [MJ/kg]	40	43	(-162°C and 1 bar) 50	20	28
Lubricity WSD [µm]	-	280-400	-	1100	1057
Vapour Density air=1	-	>5	0.55	1.1	1.6
Flash Point (TCC) [°C]	>60	>60	-175	12	17
Auto Ignition Temperature [°C]	-	250 - 500	540	464	363
Flammability Limits [by % Vol of Mixture]	**-**	0.3 -10	5 - 15	6 – 36	3.3-19

A discussion of the relevance of the properties and parameters listed in Table 3 is as follows:

Boiling Temperature at 1 bar [°C]

This is the temperature at which the vapour pressure of the material equals ambient pressure. Pure substances boil at specified pressure at a defined temperature. This temperature stays constant under continued addition of heat until all material is vaporised. Mixtures usually have a boiling range.

Note that vapour pressure is not listed in the table as it is usually provided in the form of a vapour pressure versus temperature curve or table, rather than a single value.

Methanol and ethanol both have boiling temperatures that are lower than MGO, but higher than ambient temperatures that should be experienced on board a ship or in the receiving environment. Thus they remain in liquid form at ambient temperature and pressure. LNG, however, would boil and become gas if released.

Density at 15°C [kg/m³]

Density is important in that it is used to determine the mass of fuel delivered. Fuel treatment systems on board are dependent on the density difference between fuel oil and water [24]. In the case of methanol and ethanol, onboard treatment of fuels is not necessary.

Density is an important parameter to estimate the volume required for storage of fuel. Equally, it is relevant to how much fuel can be brought to the cylinder for combustion. Density measurement and limits are specified in ISO 8217 [20] for marine fuels. Both methanol and ethanol are of lower density than MGO, HFO, and water.

Dynamic Viscosity at 40°C [cSt]

Viscosity measures a fluid's resistance to flow. The viscosity is temperature dependent. It is important to ensure vaporisation at injection point. Too high viscosity may lead to high temperatures and too low viscosity may result in increased fuel consumption and poor combustion characteristics [24].

The low viscosity of methanol and ethanol introduces challenges for their use in diesel engines. Adaptations to the injection system are a way of addressing this.

Lower Heating Value [MJ/kg]

LHV gives a measure of the energy density by mass of the fuel. This parameter impacts on storage space in conjunction with density but can also provide an indication of the amount of heat released in a fire in conjunction with heat of evaporation.

Methanol has an LHV of 20 MJ/kg which is about half that of HFO and MGO. Thus approximately twice as much fuel by weight must be bunkered to obtain the same energy on board. Ethanol has an LHV of 28 MJ/kg, which is more than methanol but still below that of HFO and MGO. With respect to fire, the LHV of methanol and ethanol implies that less heat will be released per mass of fuel as compared to MGO and HFO.

Lubricity WSD [µm]

The parameter lubricity is a measure of the reduction in friction by a material. This parameter may have an effect on life of machinery components. The usual test is HFRR (high frequency reciprocating rig) and results are reported in micrometre wear scar diameter (WSD). The greater the wear, the poorer ability to lubricate by the material tested. The results are highly dependent on the measurement circumstances, surface size, temperature and pressure. The test method is described in international standard ISO 12156-1:2006 [25].

The poor lubricity of methanol is also a challenge which must be solved through adaptation of the injection system for diesel engines [3].

Vapour Density air=1

This parameter is interesting in order to gauge whether a vapour is likely to sink and accumulate in low areas or rise and accumulate in high areas. Methanol vapour density is very close to that of air, so it is near to neutral in buoyancy [26]. The vapour density of anhydrous ethanol is 1.6, which is heavier than air. As LNG is at ambient conditions gaseous, but stored at less than -160°C the vapour density discussion is more complex. Should a spillage occur the cold vapours may initially be heavier than air until they have warmed up sufficiently.

Liquid density of LNG at -160°C and 1 bar is 448 kg/m3 (average Norwegian LNG, [27]). At 1 bar abs and -162°C pure methane is in subcooled condition. Gas density of pure methane at 0°C and 1 bar (normal conditions) is 0.71 kg/m3 (superheated condition).

Flash Point (TCC) [°C]

Flash point is the lowest temperature at which a liquid gives off enough vapour at the surface to form an ignitable mixture in air [28]. ISO 8217 [29] states as an explanatory note: "The flash point value is not a physical constant but is dependent on the test method, the apparatus and the procedure used. In this International Standard, the test method described in ISO 2719 should be used for both distillate and residual fuels. Flash point is one of the valid indicators of the fire hazard posed by the fuel." For residual fuels, flashpoint alone is not considered to be a reliable indicator of flammability conditions existing within storage tank headspaces, and there is the potential for a flammable atmosphere to exist even below the measured flashpoint, due to the potential production of light hydrocarbons from the stored hydrocarbons [29].

The flashpoint of methanol at 12°C and ethanol at 17°C are below the range of normal ambient conditions in a ship. Thus protective measures must be taken to prevent exposure to air or ignition sources. The flashpoint of LNG at -175°C is much lower.

Auto Ignition Temperature [°C]

The auto ignition temperature is defined as “the temperature at which a material self-ignites without any obvious sources of ignition, such as a spark or flame.” [28]. According to [30] it is a function of the concentration of the vapour, the material in contact and the size of the containment.

Methanol’s auto ignition temperature of 464°C and ethanol’s of 363°C are significantly above those of MGO at 257°C, but slightly below that of LNG at 532°C.

Flammability Limits [by % Vol of Mixture]

Flammability limits give the range between the lowest and highest concentrations of vapour in air that will burn or explode [28].

Methanol’s flammability limits are wider than those of ethanol, LNG, and MGO.

Min. ignition energy at 25°C [mJ]

This is the lowest amount of energy required for ignition. This parameter is highly variable and dependent on temperature, amount of fuel and the type of fuel [30]. Methanol, ethanol, and LNG all have a minimum ignition energy below 1 mJ at 25°C, whereas for MGO it is 20 mJ.

Heat of evaporation [kJ/kg]

The heat of evaporation is the quantity of energy which is needed to vaporize a quantity of liquid at constant temperature. This parameter together with the LHV can give an indication of the heat a fire can develop. HFO and MGO are complex mixtures with evaporation rates that change over time. Rates are higher initially and decline as lighter fractions evaporate, thus there is no fixed heat of evaporation that can be applied to these substances.

2.2.2 Fuel volume and on-board space requirement

Methanol and ethanol have a lower energy density than conventional fuels and thus require more storage volume on an energy basis. Methanol and ethanol are liquid at normal on-board conditions but LNG has to be stored at -162°C to remain in a liquid state. This requires additional tank space requirements due the insulation necessary to maintain the low temperatures. Figure 5 shows the relative storage volume requirements for selected fuels based only on energy density.

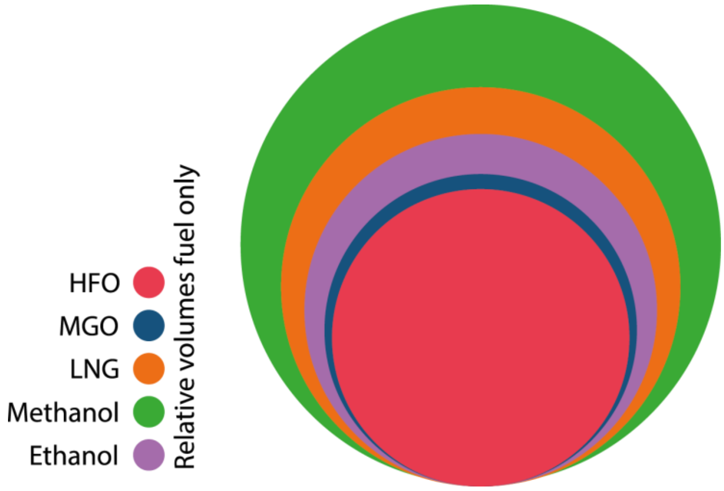


Figure 5: Relative volumes of fuels based on energy density only

Each of the fuels has additional requirements in the form of equipment and tank protection requirements. For HFO use in an ECA trading area, scrubbers and SCR equipment necessary to reduce the SO_x and NO_x emissions require additional space. Water and chemical storage is also required. For methanol and ethanol additional space in the form of protective cofferdams is required. LNG requires additional space for tank insulation to maintain the low temperature.

Actual additional space requirements will vary from vessel to vessel and depend on whether the design is a newbuild or retrofit. Rather than increasing tank size there is also the option to bunker fuel more often, depending on the trading route of the vessel. Thus fuel storage volume may not be a barrier for certain vessels such as ferries operating on a regular route within an emissions control area. As an example of additional space requirements, a comparison of fuels for a ro-ro vessel by [31] assumed a reduced cargo capacity of only 4% for both LNG and methanol as compared to MGO.

2.2.3 Effects on Materials and Property

Both methanol and ethanol are conductive polar solvents, and galvanic and dissimilar metal corrosion in methanol service may be high if incompatible materials are placed in electrical contact with one another [3]. Like methanol, ethanol is a polar solvent and may have an adverse effect on some materials. It can act as a cleaning agent and will initially mobilize sludge in storage tanks.

Methanol safe handling guidelines state that when selecting appropriate materials to be used with methanol, considerations such as type of equipment (e.g. pump, engine, pipeline, storage tank), process conditions (normal, abnormal, or emergency), anticipated inspection and maintenance program, service conditions, flow, temperature, etc. should be taken into account [32]. Similar considerations should also be made for ethanol. Information on compatibility of some selected materials with methanol and ethanol is presented in Table 4.

Table 4: Compatibility of selected materials with methanol and ethanol

Material	Methanol	Ethanol
Lead	mildly corrosive	sensitivity to degradation [33]
Aluminium alloys	Pure anhydrous methanol is mildly corrosive - periodic inspection and non-destructive testing recommended. Methanol-water solutions can be corrosive depending on application and environmental circumstances.	sensitivity to degradation [33]
Mild steel	Typically used as a construction material in cases where moisture can be excluded from the system. In presence of moisture and inorganic salts potential for corrosion within weld-heat-affected zones. Weld integrity can become an issue.	acceptable resistance to corrosion [33]
316 L stainless steel or a titanium or molybdenum stabilized grade	Recommended instead of mild steel in cases where moisture and inorganic salts may exist	acceptable resistance to corrosion [33]
low carbon 300 series stainless steel	Best practice	acceptable resistance to corrosion [33]
nitrile (Buna-N)	Suitable. Service in flowing methanol not recommended, not recommended for gaskets.	Recommended for hoses and gaskets but not for seals [34]
rubber	Natural rubber considered good, butyl rubber is poor. Many others ok.	Natural rubber degrades when in contact [33], urethane rubber is not recommended [34]
nylons	suitable	nylon 66 not recommended [34]
neoprene	Suitable	Recommended for hoses and gaskets but not for seals [34]
ethylene propylene (EPDM)	Suitable	Polypropylene and polyethylene recommended, polyurethane not recommended [34]
methyl-methacrylate plastics	No statement	degrade when in contact [33]
Teflon	good dimensional stability and is resistant to attack and degradation	Recommended [34]

Sources: For methanol, Methanol Institute [32]; for ethanol, as shown in table.

The information presented in the Table 4 is for general guidance only and it is advised that all compatibilities of products and materials be checked before use within methanol and ethanol systems. It is advised that the manufacturer of the specific material be consulted and/or tests carried out to establish compatibility.

For LNG, cryogenic resistance should also be considered in addition to materials chemical compatibility. Damage to the ship or infrastructure through contact with LNG may result, potentially through embrittlement and/or fracture of metals and materials that are not designed for such cold temperatures.

2.2.4 Lubrication

Methanol and ethanol both have a low ability to lubricate, as discussed previously in Section 2.1.1 and indicated by the high HFRR test result. The effectiveness of the chosen lubrication oil is therefore even more important than with traditional fuel oils with higher lubricity.

The lubrication oil should always be selected in discussion with the engine manufacturer and the lubrication oil supplier. As methanol and ethanol are polar agents it may be possible that some oils may not be fully miscible. In that case damage and leaks may occur. For long term trials done on Caterpillar engines for long haul truck transport, however, it was noted that the same crankcase lube oil was used for methanol as was used in operation for heavy duty diesel oil fuel [16]. The lube oil viscosity and consumption was found to be acceptable.

2.2.5 Toxicity and the Effects on Human Health

Toxicity and effects on human health are important considerations for protecting workers and limiting exposure. A short summary of toxic and human health effects for the fuels investigated in this study are as follows:

Methanol: Acute toxic effects of methanol can result from ingestion, inhalation of high concentrations of methanol vapour, and absorption through the skin of methanol liquids [35]. Humans (and non-human primates) are noted to be uniquely sensitive to methanol poisoning, with toxic effects that are “characterized by formic acidaemia, metabolic acidosis, ocular toxicity, nervous system depression, blindness, coma and death.” [35]. Methanol is stated to have a low acute toxicity to non-primate animals. For humans, almost all available information on methanol toxicity is related to acute rather than chronic exposure toxicity [35]. Further, the “vast majority of poisonings involving methanol have occurred from drinking adulterated beverages and from methanol-containing products”. [35]

Although toxic at higher levels to humans, methanol “occurs naturally in humans, animals and plants”. [35] Natural sources of methanol include fresh fruits and vegetables, fruit juices (average 140 mg/L, range 12 to 640 mg/L), and fermented beverages (up to 1.5 g/L) [35]. Other commonly encountered substances which contain methanol are exhausts from both gasoline and diesel engines and tobacco smoke [35].

Regarding lethality of methanol, the minimum lethal dose of methanol in the absence of medical treatment is between 0.3 and 1 g/kg [35]. A widely used occupational exposure limit for methanol is given as 260 mg/m3 (200 ppm) [35].

Ethanol: Ethanol has a low order of acute toxicity to humans by all routes of exposure, according to information presented in the OECD Screening Information Data Set for Ethanol [36]. It is noted to be readily absorbed by the oral and inhalation routes and subsequently metabolized and excreted in humans. Dermal uptake of ethanol is stated to be very low, and it is not accumulated in the body.

HFO: Because HFO consists of a range of substances, the specific composition will influence effects on human health. The American Petroleum Institute [37] stated that substances in the

HFO category "demonstrate low oral and dermal toxicity, minimal eye irritation, minimal to moderate skin irritation with single exposures and are not skin sensitizers. The other mammalian health effects of HFOs appear to be dependent on their content of polycyclic aromatic compounds (PAC)." They also report that dermal carcinogencity studies showed that materials with a high content of PACs are dermal carcinogens that act mainly by initiating tumour development.

LNG: Human health hazards identified for LNG are the cryogenic nature which can result in serious burns on contact, and its action as an asphyxiant when it replaces air in enclosed spaces. Methane, the major chemical component in LNG, is noted to be a simple asphyxiant with no systemic toxicity by Prasad et al. [38], who propose that no occupational exposure limit be assigned.

Exposure Levels:

Derived No Effect Level (DNEL) and Predicted No Effect Concentration (PNEC) for methanol and ethanol were obtained from the European Chemicals Agency Database and are presented in Table 5 for the selected fuels. For MGO, the inhalation and dermal DNELs for Fuel Oil No.2 are presented. Not all values were available in the database for all fuels considered in this study.

Table 5: Derived No Effect Level (DNEL) and Predicted No Effect Concentrations (PNEC) for selected fuels as obtained from the European Chemicals Agency Database

Toxicity Measure	HFO	MGO (Fuel oil No. 2)	LNG	Methanol	Ethanol
DNEL (Acute tox., inhalation) [mg/m3]	not calculated	0.12	not calculated	260	950
DNEL (Acute tox., dermal) [mg/kg bodyweight per day]	not calculated	0	not calculated	40	343
PNEC Secondary poisoning oral [mg/kg food]		not calculated	not calculated	not calculated	720
PNEC Marine water [mg/L]	not calculated	not calculated	not calculated	2.08	0.79

Data source: European Chemical Agency Database [39].

Occupational Exposure Limits:

Recommended or mandatory occupational exposure limits (OELs) have been developed in many countries for airborne exposure to chemicals [40]. In the UK the EH40/2005 Workplace exposure limits regulate the amount of hazardous substances an employee can be exposed to in a working day. On a European-wide basis, Indicative Occupational Exposure Limit Values (IOELVs) are set in Commission Directives [41], [42] and member states must establish national OELs which take them into account. In most countries the OELs are legally binding. Table 6 shows the indicative occupational exposure limit value for methanol and the national OELs for the UK and Sweden for methanol and ethanol.

Table 6: EC Indicative Occupational Exposure Limit Values and national Occupational Exposure Limit Values from UK and Sweden for methanol and ethanol

Exposure Limits	Methanol	Ethanol
Indicative Occupational Exposure Limit Value from European Commission Directive		
8 hour time weighted average reference period	200 ppm 260 mg/m^3	not listed
UK Workplace Exposure Limit [43]		
Long-term exposure limit (8 hour time weighted average reference period)	200 ppm 266 mg/m^3	1000 ppm 1920 mg/m^3
Short term exposure limit (15 minute reference period)	250 ppm 333 mg/m^3	not listed
Swedish Occupational Exposure Limit Value [44]		
Level Limit Value (LVL) – value for exposure for one working day (8 hours)	200 ppm 250 mg/m^3	500 ppm 1000 mg/m^3
Short Term Value (STV) – time weighted average for a 15 minute reference period	250 ppm 350 mg/m^3	1000 ppm 1900 mg/m^3

Exposure limits were not provided for methane gas and petroleum fuels in the EC directives or the UK workplace exposure limits. The Swedish Work Environment Authority provided maximum acceptable total concentration of hydrocarbons in air for selected petroleum fuels. They stated that limit values were not defined for petroleum fuels because these fuels are mixtures of a large number of substances where concentrations are often not known in detail, and which can vary from one batch of fuel to another. The maximum acceptable total concentration of hydrocarbons in air, given as a time-weighted average for a working day, were as follows for diesel and heating oil:

- Diesel MK1 350 mg/m^3 max. acceptable total hydrocarbons in air
- Heating oil 250 mg/m^3 max. acceptable total hydrocarbons in air.

Maximum values were not given for marine fuels but the concentrations for diesel and heating oil give an indication for comparison with the methanol and ethanol values.

2.3 Availability, production, and distribution of ethyl and methyl alcohol fuels

In terms of availability, both production capacity and the ability to transport and distribute the fuel to ships are important when considering feasibility of their use. Production, availability, and distribution of methanol and ethanol are described in the following sub-sections.

2.3.1 Methanol production, availability, and distribution

Methanol is widely used in the chemical industry, and fuel applications are starting to grow, particularly in China, where it is increasingly used as a blender or alternative to gasoline. A recent report on alternative fuels transport systems in the EU [45] states that according to a new IHS global market study worldwide methanol demand has increased 23% during the two-year period from 2010 to 2012, driven by Chinese demand growth, and that annual demand for methanol is expected to increase by more than 9% per annum from 61 million metric tons (MMT) in 2012, to 146 MMT in 2022. To meet this increasing demand as well as to take advantage of cheap shale gas, production in the US alone is expected to increase from four million to over seventeen million tons annually between 2015 and 2020 ([45] based on data from the Methanol Institute). Total global production capacity in 2013 was just over 100 million tonnes. Figure 6 shows the major global methanol production locations. The data was provided by the Methaship project and shows mainly the larger production locations (>1000 kT/annum (production capacity in 2013)) and some selected smaller locations.

The vast majority of methanol is produced from gas and coal. Steam reformation of fossil natural gas is the lowest cost production method. Production of methanol is done close to the feedstock when natural gas is used. Production plants have even been moved to take advantage of a cheaper and more reliable source of gas – as was done when Methanex relocated a plant from Chile to Geismar, Lousiana. The transport of the finished product, methanol, is cheaper and more efficient than liquefying and transporting the feedstock gas to the production plant.

In China, coal is often used as feedstock, but this methanol is not exported. Methanol can be produced from any other carbon feedstock such as biomass (second generation biomass such as farmed wood and wood industry waste is most often considered), or from any organic waste. Chemrec in Sweden has produced renewable methanol from a process for gasification of black liquor (a by-product of pulp and paper mills) [46]. Bio-methanol produced from wood biomass has the potential of being a carbon negative fuel [47]. The Enerkem plant (capacity: 0.4 million m^3) located in Edmonton, Alberta, Canada, utilises waste to produce methanol. Until 2012 there was a facility in the Netherlands producing methanol from glycerine.

Carbon Recycling International in Iceland is producing methanol certified as a renewable fuel of non-biological origin, using energy and CO_2 emissions from a geothermal plant. The capacity of this plant is 50 million litres. The methanol produced from non-fossil feedstocks can be used directly or blended with methanol from fossil fuel origins to reduce the overall “well to wake” global warming potential of the fuel. Due to the wide availability of feedstock, particularly the increasing natural gas finds including unconventional sources in shale gas, there should be sufficient supply of methanol to meet demands. Figure 7 shows production of methanol in and near Europe. The only large scale production of methanol from natural gas within Europe is located in Norway. Some of the methanol from the Iceland plant is imported to Europe for blending for automotive fuels.

Figure 6: Global Methanol Production and Transport (Feedstock indicated by colour, export of methanol indicated by arrows). Source: MethaShip Project

Figure 7: Methanol production in and around Europe from natural gas (orange circles) and refinery residue (purple circles). Source: Methaship Project

Methanol is used widely in the chemical industry and there is established storage and distribution infrastructure for this in Europe. For example there are large storage terminals for bulk chemicals (including methanol) in Rotterdam and Antwerp. Methanol is reported to be one of the most handled chemicals in Baltic Sea ports [48], implying an established storage and distribution network in the Baltic Sea region. Land transport of methanol can be done in class 3 flammable liquid road transport trucks or by rail tanker. For the SPIRETH project, methanol was bunkered to the ship in Gothenburg with a road tanker truck. Bunkering of methanol could also be done with a small chemical tanker. Figure 8 shows a possible production and supply chain for methanol produced from natural gas and delivered to a ship's fuel tanks. Production and supply chains for LNG and marine petroleum fuels are also shown for comparison. The production and transport steps for methanol up to the local storage point are common to those used for methanol produced and transported to Europe for chemical industry use, and infrastructure already exists. Local storage tanks may need to be provided in some ports for ship fuel, if there are not already existing tanks. Methanol is a class 3 flammable liquid according to the UN classification system and tank requirements are similar to those of other class 3 flammable liquids such as ethanol, gasoline and petroleum distillates.

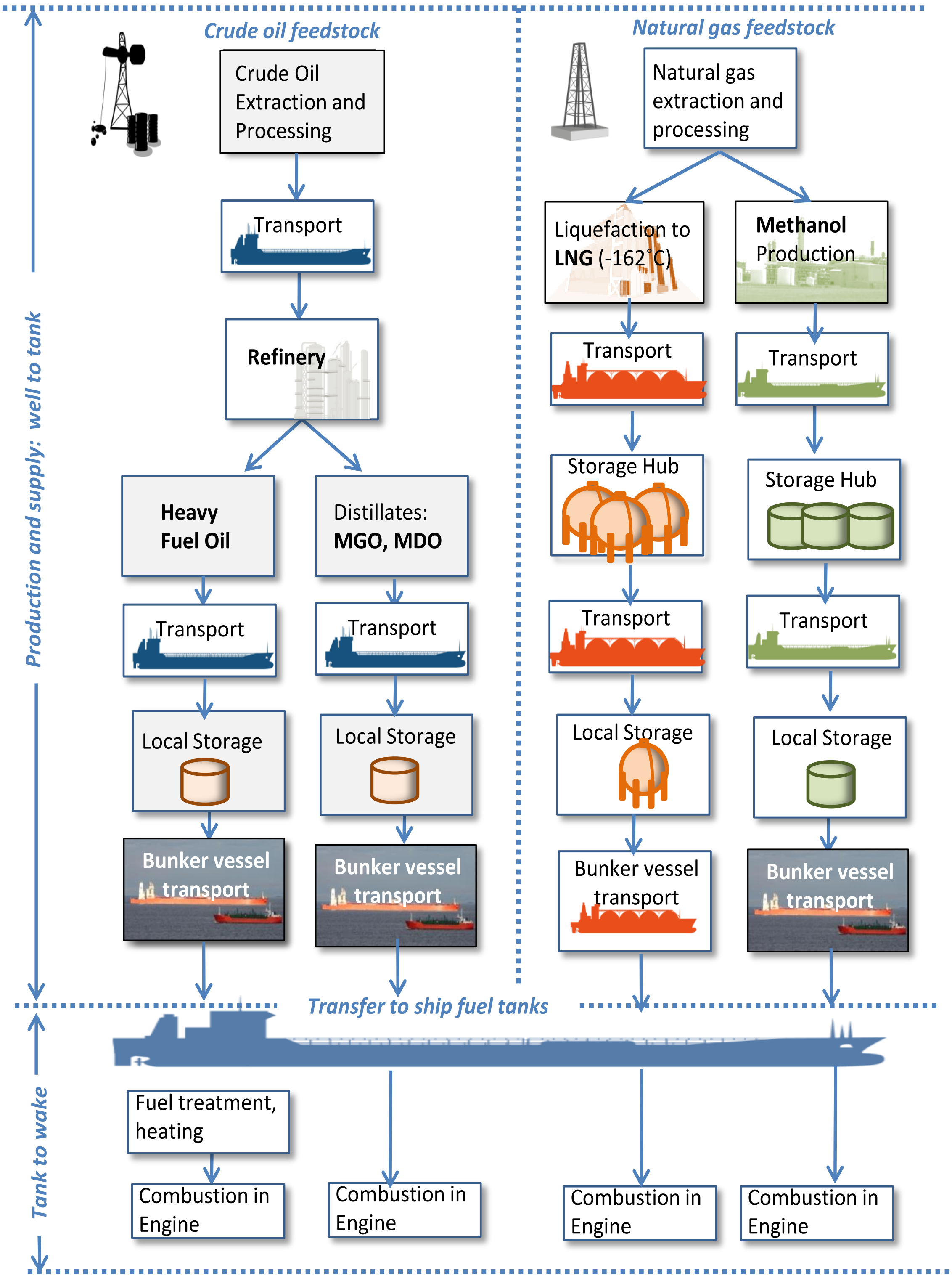


Figure 8: Production and supply chain for methanol, LNG and conventional marine fuels from fossil feedstock

2.3.2 Ethanol production, availability, and distribution

About 87% of the ethanol produced worldwide is reported to be used as fuel ethanol and the balance is used for applications such as industrial and beverages [49]. Ethanol is the most widely used bio-fuel in the world.

Ethanol is most commonly produced from crops containing sugar or starch, with corn commonly used in the United States and sugar cane in Brazil. The US and Brazil are the world's largest producers of bio-ethanol. In Europe bio-ethanol production uses wheat and sugar beets as a feedstock. The most common production method includes fermentation and distillation of the biomass to create ethanol. Production of ethanol from non-crop feedstocks such as grasses and wood is currently very small but much research is underway in this area [50]. Ethanol production from waste gas from steel mill exhaust is also being investigated, but there are claims that this process is very energy intensive [51].

Worldwide production of ethanol was 84.5 billion litres in 2011. Europe's ethanol production accounts for about 5% of worldwide production in 2011. Ethanol production is primarily from crops, and its use as a transportation fuel will likely be limited within the EU resulting from European Parliament legislation limiting the use of crop-based biofuels to 7%. A 2015 report on alternative fuels transport systems in the EU [45] states that "the potential of biofuels will be limited by the availability of land, water, energy, and sustainability considerations."

Regarding transport and distribution of ethanol, it is very similar to methanol in that it is a Class 3 flammable liquid and solvent. Bulk storage is available at large chemical storage hubs such as Antwerp and Rotterdam. The Teeside terminal in the UK stores and handles bio-ethanol produced at one of Europe's largest bio-ethanol plants, which is located in the north-east of England.

2.4 Environmental considerations regarding methanol and ethanol as marine fuels

Environmental effects from both production and use of fuels are an important consideration when evaluating the feasibility of alternative fuels. Emissions and environmental effects during use should be considered both from the perspective of existing regulations such as for sulphur and NO_x emissions and also for parameters such as particulates which are known to have health and environmental effects and thus may be governed by future regulations. The global warming potential of fuel production and use is also of great importance. There are many processes involved in converting a primary energy source to fuel and transporting and distributing the fuel to the end user. Figure 9 gives an overview of steps involved "from well to wake" for fuel production and use.

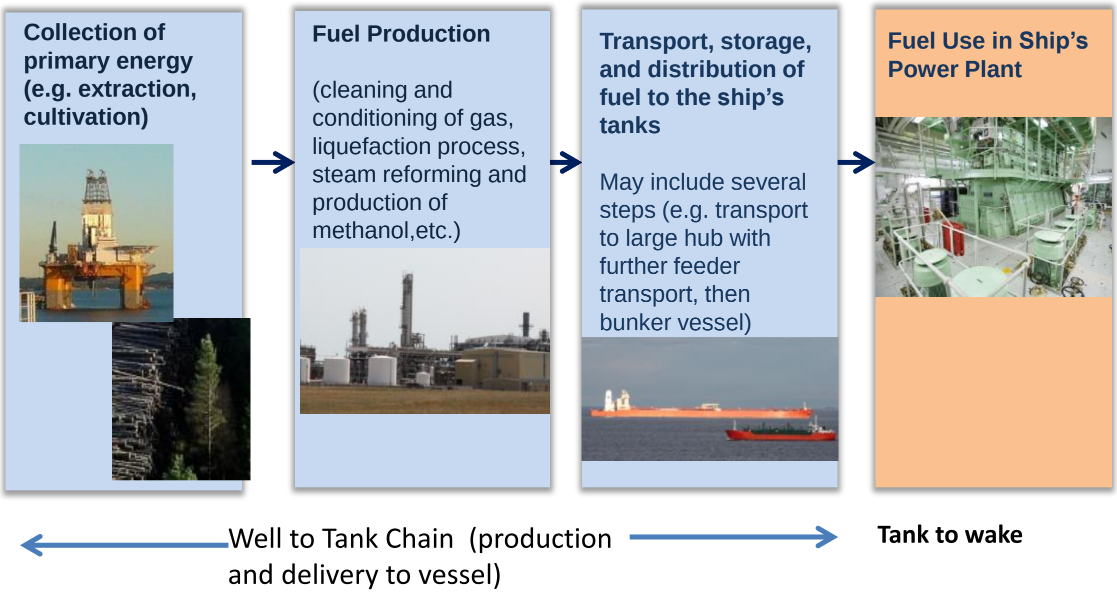


Figure 9: Overview of steps in the fuel well-to-wake life cycle

2.4.1 Well to Wake Greenhouse Gas Emissions of Selected Fuels

Emissions of greenhouse gases from fuel production and use have a direct impact on climate and thus are very important when comparing the environmental impact of different fuels. Although not regulated directly for shipping, greenhouse gas emissions have been the subject of major studies carried out for the IMO (e.g. [52]). Greenhouse gas emissions are usually presented as carbon dioxide equivalency (CO_2e), which describes the amount of CO_2 that would have the same global warming potential (GWP) as other emitted substances such as methane (CH_4) and nitrous oxide (N_2O) when measured over a specified time period. The production of fuels can contribute significantly to the total greenhouse gas emissions and should be considered together with fuel combustion to get an overall picture of the "well to wake" greenhouse gas emissions. "Well to tank" and "tank to wake" estimates of greenhouse gas emissions for selected methanol and ethanol production pathways are discussed in the following sections and compared to marine diesel oil and LNG.

Well to Tank: Greenhouse gas emissions data for a wide range of fuels is available in the JEC - Joint Research Centre-EUCAR-CONCAWE collaboration study "Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context" [53]. Although the study is for automotive fuels used in Europe, it provides a very transparent breakdown of the steps in the well-to-tank (WTT) pathways, and many of these steps are also applicable for marine fuels. The main difference for marine fuels is seen in the final part of the pathway - primarily the conditioning and distribution steps. For automotive fuels, these steps include transport of fuels from the point of import (for finished fuels) and production (for fuels refined in Europe) to individual retail stations, as well as distribution from the retail station to the vehicle tank. The final transport steps are often by road or rail. For marine fuels, however, the final distribution steps are usually by waterborne transport - for example from a main hub port or refinery by feeder vessel to a regional depot and then final distribution with a bunker ship. For the assessment of the well-to-tank greenhouse gas emissions for methanol, ethanol, and LNG as marine fuels for this study, data from the JEC WTT study were used for the steps up to distribution within Europe, and the final conditioning and distribution steps were modified or replaced to be more representative of marine fuel distribution.

Fuel pathways used to estimate the greenhouse gas emissions for well to tank for marine fuels for this study are as follows:

Marine Gas Oil (MGO): Crude oil produced and conditioned in the Middle East and transported to coastal European refineries. Transport from the refinery by coastal tanker to a local depot was assumed, and distribution by a bunker vessel.

LNG: Remote natural gas conditioned and liquefied at source in the Middle East, with long distance transport by LNG carrier to Rotterdam. Further transport was assumed by smaller LNG feeder vessel to a local depot, with unloading and final distribution by a bunker vessel.

Methanol (fossil feedstock): Remote natural gas used as feedstock, synthesis to methanol near the gas plant, long distance transport by chemical tanker to a European hub. Further transport assumed by smaller coast tanker to a local depot, with final distribution to the vessel by a bunker vessel.

Methanol (biomass feedstock): Two possible pathways for methanol biofuel produced in Europe were considered:

- Methanol from farmed wood: Short rotation forestry with poplar or willow was assumed, with a short distance transport to a synthesis/gasification plant.
- Methanol from waste wood via black liquor: Waste wood for the feedstock, transport to a pulp mill, production of methanol by gasification of pulp mill black liquor.

For both methanol biofuel cases it was assumed that the methanol would be distributed an average distance of 150 km from inland production locations to port depots.

Ethanol (sugar cane): Produced in Brazil from sugar cane using current best practices for production. Transport by road to a sea port in Brazil, long distance sea transport to a main hub in Europe, transport by feeder vessel to a local depot, and distribution by bunker vessel.

Ethanol (corn): Corn cultivation in the United States, processing of the corn, transport to production plant, production of ethanol, long distance sea transport to a main hub in Europe, transport by feeder vessel to a local depot, and distribution by bunker vessel.

Well to tank greenhouse gas emissions for each of the fuels is shown in Figure 9.

Tank to wake

Tank to wake carbon dioxide emissions result from the combustion of fuel to produce power for the vessel. Combustion emissions factors giving carbon dioxide (CO_2) emitted per MJ of fuel burned are shown in Table 7. The Intergovernmental Panel on Climate Change (IPCC) default values for waterborne navigation were used for MDO and LNG. Methanol and ethanol values were obtained from the JEC Well-to-tank study [54].

Table 7: Combustion emissions factors as grams of CO_2 per MJ of fuel

Fuel	Combustion Emission Factor (CO_2 / MJ fuel)
Marine Diesel Oil	74.1
LNG	56.1
Methanol	69.1
Ethanol	71.4

Well to Wake

The CO_2 emitted per gram of fuel combusted is shown in Figure 10 together with the well-to-tank greenhouse gas emissions in grams carbon dioxide equivalents per MJ of fuel produced. This figure gives a comparative representation of well-to-wake greenhouse gas emissions. Note that for LNG, both a zero methane slip and 25 gCO_2e/MJ methane slip are shown. Methane slip refers to the release of unburned methane at low engine loads that occurs specifically with LNG engines. There is very limited published measurement data for methane slip in actual operational conditions. Methane is a potent greenhouse gas so it is important to include any projected releases during production, supply, and use of LNG. Note that there is no methane slip from combustion of methanol.

Emissions of carbon dioxide from combustion of the biofuels on board the ship were taken to be zero. These included ethanol and methanol produced from wood waste and farmed wood. This is in line with the EU Renewable Energy Directive (2009/28/EC) rules for calculating the greenhouse gas impact of biofuels, which states that the emissions from the fuel in use shall be taken to be zero for biofuels and bioliquids. Biomass based-fuels are most often considered 'carbon neutral' in lifecycle assessments because the amount of CO_2 released during combustion is the same as that captured by the plant during growth [55].

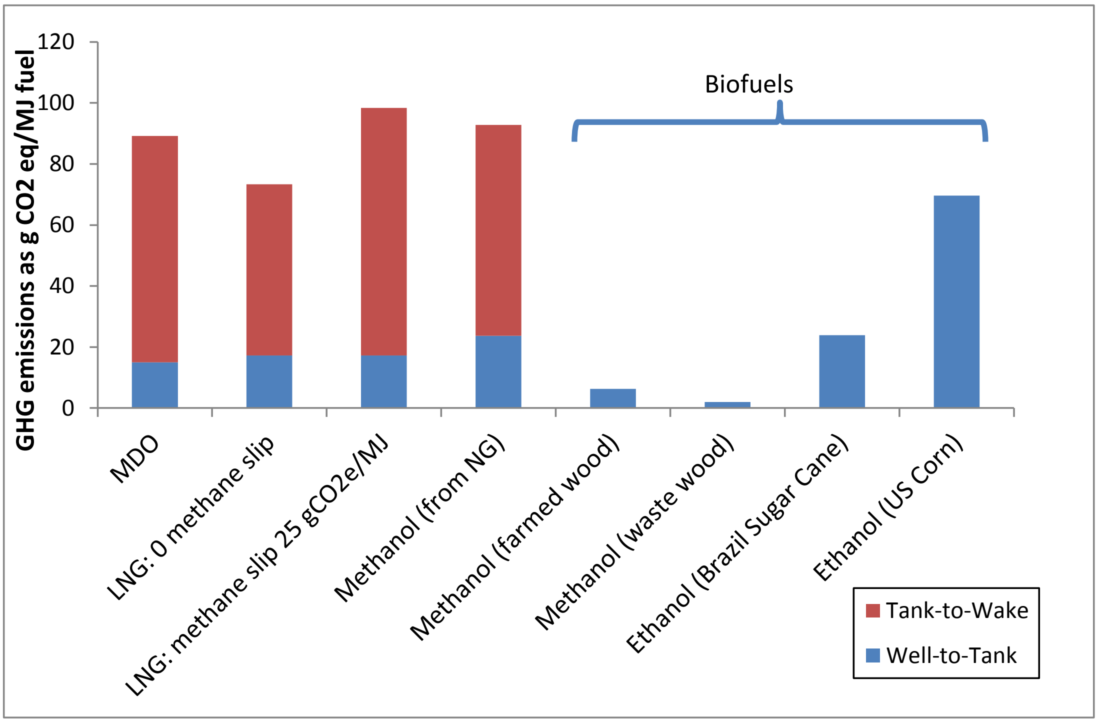


Figure 10: Well to Wake Emissions for Selected Fuels, shown as grams of CO_2 equivalent / MJ of fuel combusted

2.4.2 Operational Emissions of SOx, NOx, and Particulate Matter

Methanol and ethanol do not contain sulphur and are relatively pure substances that are expected to produce very low particulate emissions during combustion.

Methanol: Actual emissions levels from laboratory testing have been reported by Haraldson [5] for a Wärtsilä Vasa 32 engine and for a Wärtsilä Sulzer Z40SMD (the same engine type that was retrofitted for the *Stena Germanica*). For the initial tests on the Vasa 32 engine, NO_x emissions ranged from 3 to 5 g/kWh, as compared to the reference MGO test with NO_x at about 11.8 g/kWh. Less than 1 g/kWh of CO (carbon monoxide) and THC (total hydrocarbons) were reported for methanol combustion. Particulate measurements were not reported but were stated to be low. For the tests on the converted Wärtsilä Sulzer Z40SMD engine, NO_x in the range of about 4 to 5 g/kWh were reported, as compared to the reference tests with LFO where NO_x was about 11.5 g/kWh. It should be noted that although the reductions achieved were considered good, NO_x reduction was not a main consideration for this specific conversion given that the *Stena Germanica* did not need to meet Tier III NO_x levels. Thus optimization work to reduce NO_x was not a main priority and it was considered that even lower NO_x could possibly be achieved. For PM, a 95% particulates reduction was reported compared to HFO380 [56]. In addition CO_2 was calculated to be approximately 7% lower, SO_x reduction was 99%, there was no methane slip, and formaldehyde was below TA-luft levels [56]. The small amount of SO_x and particulates was attributed to the use of small amounts of pilot diesel fuel for ignition of the methanol.

Emissions measurements, including particulates, are expected to be taken from the methanol engines installed onboard the *Stena Germanica* during the first quarter of 2016. These engines will have been further optimised on-board, building from the laboratory testing carried out previously.

A Japanese study in the early 1990s measured emissions from laboratory testing of a high-speed 4-stroke diesel engine operating on methanol with pilot fuel [17]. NOx emissions were stated to be half of those for operation on gas oil under the same load conditions.

Conclusions from operational experience with heavy duty methanol engines for transit buses in the United States were that methanol demonstrated an ability to produce "reliably low NO_x emissions in combination with low PM emissions" [57].

<u>Ethanol</u>: As mentioned previously, no information on ethanol testing on marine engines has been found. Information on emissions from the Scania Alcohol Compression Ignition engine using ED95 fuel (95% ethanol by volume) can be looked at as an example of what can be achieved with a diesel concept engine using ethanol. These engines have been used for heavy duty vehicles (public transport buses) for many years. Emissions data reported in [58] shows EURO 5 PM levels of 0.02 g/kWh were met without particle filter for the 3rd generation Scania Engine.

Potential emissions for SO_x and NO_x for a chemical carrier case ship were calculated using the ship data described in the payback analysis in Section 2.5.2. This gives an indication of the relative emissions reductions that can be achieved for the alternative fuels as compared to MGO and HFO with a scrubber and SCR. Annual emissions for the case ship example are shown in Figure 11 and were estimated as follows:

$$m_{SOx}[kg] = percent_S \cdot 20 \left[\frac{kg}{tonne}\right] \cdot m_{fuel}[tonne] \quad (1)$$

$$m_{NOx}[g] = t[h] \cdot E\ [kWh] \cdot NOx \left[\frac{g}{kWh}\right] \quad (2)$$

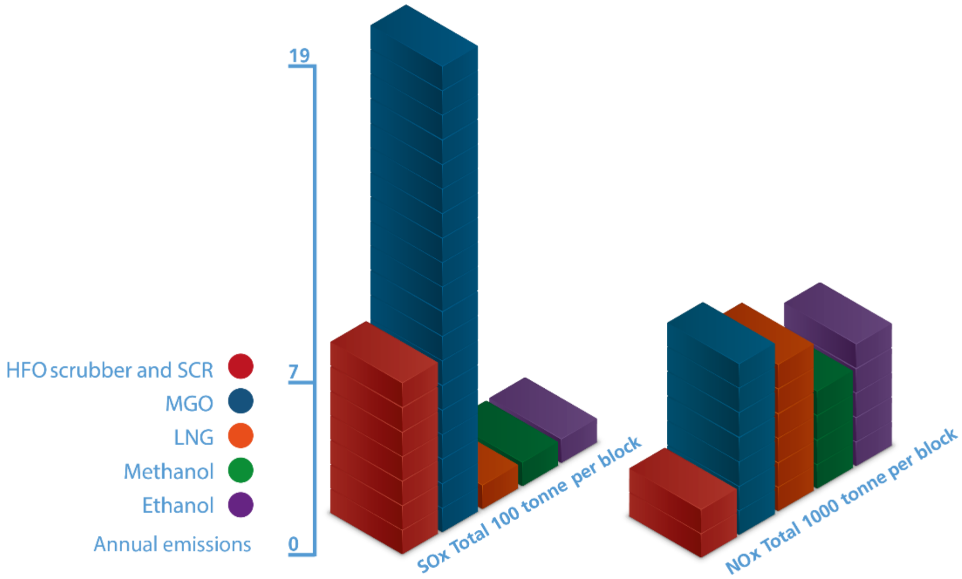


Figure 11: Potential annual emissions in tonnes of SOx and NOx from HFO (with scrubber and SCR), MGO, LNG, methanol and ethanol (front to back). The small SOx emission from LNG, methanol and ethanol are from 5% pilot fuel assumed for dual fuel engines.

For the emissions estimates shown in Figure 11 it was assumed that the solutions for LNG, methanol, and ethanol were dual-fuel engines with 5% of total energy supplied by MGO pilot fuel with 0.1% sulphur content. Emissions estimates for LNG were based on engine data from MAN [59] and those for methanol from Haraldson [5]. The sulphur content of the HFO option was assumed to be 3.5% with 99% SOx removal by an open loop scrubber and 75% NOx removal in the exhaust gas cleaning system [60]. Exhaust gas cleaning systems represent a cost in terms of space, fuel use, consumables, and maintenance. The LNG, methanol, and ethanol solutions used for the calculations do not have exhaust gas cleaning.

It should be noted that other SO_x and NO_x emissions abatement technologies are available but were not considered in the calculations. Examples of these technologies for sulphur oxide abatement include:

Wet Scrubber

- Open loop
- Closed loop
- Hybrid

Dry scrubber.

Other technologies for NO_x abatement include:

Primary:

- Engine operation
- Direct water injection
- Humid air motor
- Exhaust Gas Recirculation

Secondary:

- Selective Catalytic Reactor (SCR)

The selected combination of technologies (open loop scrubber and SCR) for HFO shown in Figure 11 is not without its difficulties. It is crucial that design ensures they are compatible and remaining sulphur oxides do not poison the catalyst used for NO_x reduction. Catalyst temperatures need to be maintained high enough, if necessary with additional heating, to ensure the NO_x reduction takes place effectively.

2.4.3 Environmental impacts of fuel spills to the aquatic environment

The behaviour of alternative fuels when spilled to the aquatic environment is also important to consider when assessing overall environmental performance. Ship accidents such as collisions, groundings and foundering will continue to result in fuel and cargo spills and the impacts from different fuel types should be considered. There have been large spills with extensive environmental consequences during transport of oil (e.g. *Prestige*, *Exxon Valdez*, *Erika)* as well as from fuel bunker tanks from other ship types. Methanol and ethanol are soluble in water and biodegradable, so their effects in the event of a large spill are expected to be much less as compared to conventional fuels.

The Bonn Agreement Counter Pollution Manual contains a behavior classification system that classifies gaseous, liquid, and solid chemicals according to their physical behaviour when spilled to the sea [61]. The main categories are evaporators, floaters, dissolvers, and sinkers. The actual behavior of a specific chemical or substance can be more complex and depends partly on environmental conditions (water temperature, etc.). Information on whether a fuel or cargo will evaporate, float, dilute or sink is important for first responders to a spill at sea. It is also important when considering the effects on aquatic organisms. An overview of the primary behavior of HFO, MGO, methanol, ethanol, and LNG when spilled to large receiving water bodies is provided in Table 8.

Table 8: Primary behavior of selected fuels when spilled to the aquatic environment

Fuel Type	Primary behavior when spilled to a large receiving water body
Marine gasoil (MGO) or Marine diesel oil (MDO)	Will evaporate to some degree and disperse into the water column. MGO and MDO will generally not persist on the surface [62].
HFO (Heavy fuel oil)	May float or sink, depending on viscosity and water temperature, does not readily dissipate or degrade and is highly persistent [19].
Methanol	Methyl alcohol is fully miscible with water. It will mix quickly into the water column, with some fraction evaporating depending on temperature.
Ethanol	Ethyl alcohol is also fully miscible with water, and most will quickly dissolve into the water column, with some evaporation possible.
LNG	LNG will evaporate into methane gas after a spill. Initially a pool will form, and evaporation rates will depend on the size of the pool and temperature of the receiving water. Methane gas will not have any residual effects on the receiving water.

Specific impacts will depend on environmental conditions (weather, wind, waves, temperature) as well as the characteristics and special sensitivities of the receiving water body and organisms within. Further general discussion on each of the fuels is as follows:

HFO and MGO: The fate and effect of hydrocarbon fuels when spilled to the marine environment differs depending on the type of fuel. Distillate fuels behave differently when spilled than do heavy fuel oils, as they are lighter and there will be more evaporation. Heavy fuel oils are resistant to evaporation and tend to stay on the surface, entraining water droplets to form a water in oil emulsion. Sinking has also been observed on many occasions – some heavy fuel oils are denser than water and some may have sediment particles incorporated [19]. They do not dissipate readily or degrade naturally, and are considered to be highly persistent [19]. Lighter distillate oils can mix or become entrained in the water column posing a risk for organisms there. Heavier residual fuel oils pose more of a surface and shoreline risk.

Methanol and ethanol: Both methanol and ethanol dissolve in water. Methanol is classified as a “dissolver evaporator” by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) [63]. Ethanol is classified as a “dissolver” (GESAMP). They are both readily biodegradable, however, and do not bioaccumulate. Although methanol is toxic to humans it is not rated as toxic to aquatic organisms using the GESAMP rating system [63]. The Baltic Sea Risk (BRISK) study did not consider methanol to be hazardous to the marine environment of the Baltic Sea in the event of a spill, due to its solubility and low toxicity to aquatic organisms [64].

LNG: Although the fuel is in liquid form during storage, it will quickly revert to a gas if spilled to an aquatic environment. The gas should have a very limited effect on the receiving water but could be a safety risk to the surrounding area before it disperses. Extensive field studies of LNG spills on water have been carried out at US facilities [65]. These studies have focussed on behaviour related to safety, such as the potential for rapid phase transition (RPT) explosion behaviour and pool spread, boil off rates, and vaporisation.

2.5 Cost and economic analysis

A cost and economic analysis was carried out to compare the following compliance alternatives for operation of ships within sulphur emission control areas:

- High Sulphur Marine Fuel Oil with an open loop scrubber exhaust-gas cleaning system and SCR
- Marine gas oil (MGO) compliant with 0.1% sulphur requirement
- LNG
- Methanol
- Ethanol

Investment and operation costs were estimated for three case study ships to give an indication of costs to ship operators. The following sub-sections describe the fuel price and cost assumptions, ship cost analysis, and results.

2.5.1 Fuel Prices Historical Comparison and Assumptions for Analysis

Fuel costs represent the major part of ship operating costs and thus the fuel prices selected for use in the economic analysis can have a major impact on the payback time. For this study, a review of historical fuel prices for the past six years was carried out to select representative prices and relative differences between the fuels for the economic analysis. There is an established long term market for traditional, oil-based bunker fuels, and thus good historical price data. For LNG, methanol, and ethanol, historical prices for the six year period from 2009 to 2015 were estimated from other market types and sources. Fuel price estimates for each of the main fuel types were obtained or estimated as follows:

MGO (Marine Gas Oil): Bunker Index MGO was used as a representative price of MGO. This index is described by Bunker Index as the Average Global Bunker Price (AGBP) for all marine gasoil (MGO) port prices published on the Bunker Index website. Historical prices in $US/tonne from the Bunker Index website were compiled and are shown plotted in Figure 10. Current prices of MGO with 0.1% sulphur can also be considered to be representative of those of MDO with 0.1% sulphur. For example in November 2015 there was a marginal price difference between MGO and MDO of about 10 $US/tonne. MGO is much more commonly used and widely available within Europe than MDO for 0.1% sulphur compliant fuels.

HFO/IFO (Heavy Fuel Oil/Intermediate Fuel Oil): 380-cst (centistoke) fuel and 180-cst are the two main high sulphur fuel oils (HSFO) available. 380-cst is ordered by the majority of ships using high sulphur fuel oil. Thus the Bunker Index 380-cst was used as a representative price for the less expensive heavier fuel oils containing residuals and having a higher sulphur content. The less commonly used 180-cst IFO had a price that was only about 5% higher than the 380-cst fuel oil price in November 2015, so the 380-cst price can be considered indicative for this fuel as well. The Bunker Index 380-cst price is the Average Global Bunker Price (AGBP) for all 380-centistoke (cst) port prices published on the Bunker Index website, excluding 380-cst low sulphur - maximum 1.5% & 1.0% sulphur. The high-sulphur fuels used within European waters have an average sulphur content of 2.7% sulphur content, although a maximum content of up to 3.5% is allowed according to regulations. Historical prices in US$/tonne for 380-cst fuel oil were compiled and are shown plotted as HFO in Figure 10.

LNG: LNG does not yet have a well-established market as a marine fuel, and historical bunker prices for LNG in a time series from 2009 could not be found for this study. As a proxy, historical monthly prices for natural gas in Europe were used as a base for the historical costs with additional cost added to each unit mmBTU (one million British Thermal Units) to reflect distribution, storage and bunkering costs for LNG as marine fuel. Specifically monthly prices for European Natural Gas from the World Bank Commodities Price Data ("The Pink Sheet") were used as a base for the estimate. This price is described as the average import border price with a component of spot price, including UK. US$6/mmBTU was added to the base price to account for liquefaction, distribution, storage and bunkering costs. This additional cost was adapted after [66] to obtain an estimate of the price for LNG to a ship. Checks of the resulting price estimations, as plotted on Figure 10, show quite good agreement with the following specific prices found in references:

- US$724/tonne for LNG marine fuel for 2015 [47]
- US$712 to $820/tonne for LNG bunkered to a ship in the Netherlands (converted from €650 and €750 per tonne for LNG bunkered in the ship), 2015, from [67].
- US$815/tonne in Göteborg in early 2012 (converted from €0.046/Kwh in [68].

Methanol: Methanol has only been used as a marine fuel for pilot studies but is a widely traded chemical commodity. Methanol official list prices are set in open contract negotiation between producers and purchasers. Methanex, which is the world's largest producer and supplier of methanol to international markets, posts 3-month regional contract prices for Europe, North America, and Asia. The individual producers like Methanex usually offer their customers discounts from the list price. Stenhede [3] stated that in 2010 the "average" discount on contracted prices was 15%. The historical methanol contract prices for Europe [69] are shown on Figure 10. Regarding bunkering and distribution costs, Bengtsson et al. [68]

added US$37 per tonne to the spot methanol price to cover the delivery to the customer for their estimation of costs for ships operating on methanol. For this current study, the posted contract price was considered a reasonable proxy for the price of fuel delivered to the ship, given that there is likely to be a discount as stated in Stenhede [3], which would be more than the US$37 used by Bengtsson et al. [68] to cover delivery to the vessel.

Ethanol: Ethanol has not been used, to our knowledge, as a ship fuel but there is price information from its use as a fuel and fuel blender with gasoline for land transport (automobiles and light duty vehicles). Historical wholesale truckload price for ethanol from United States Department of Agriculture is shown plotted on Figure 10.

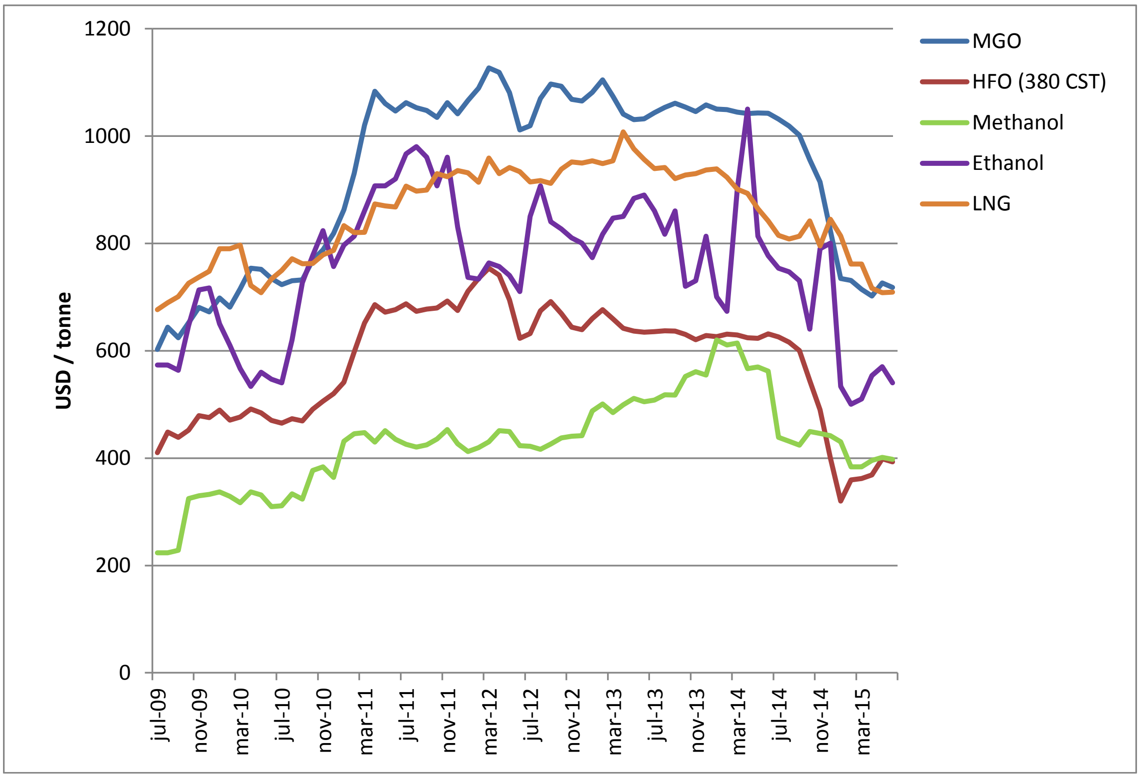


Figure 12: Historical MGO, HFO, Methanol, Ethanol and LNG (approximated) prices shown as USD/tonne

Historical prices of each of the fuels are also shown in Figure 13 on an energy rather than tonne basis. Conversions were made using the lower heating values (LHV) for each of the fuels as described in the fuel properties section 2.2 of the report.

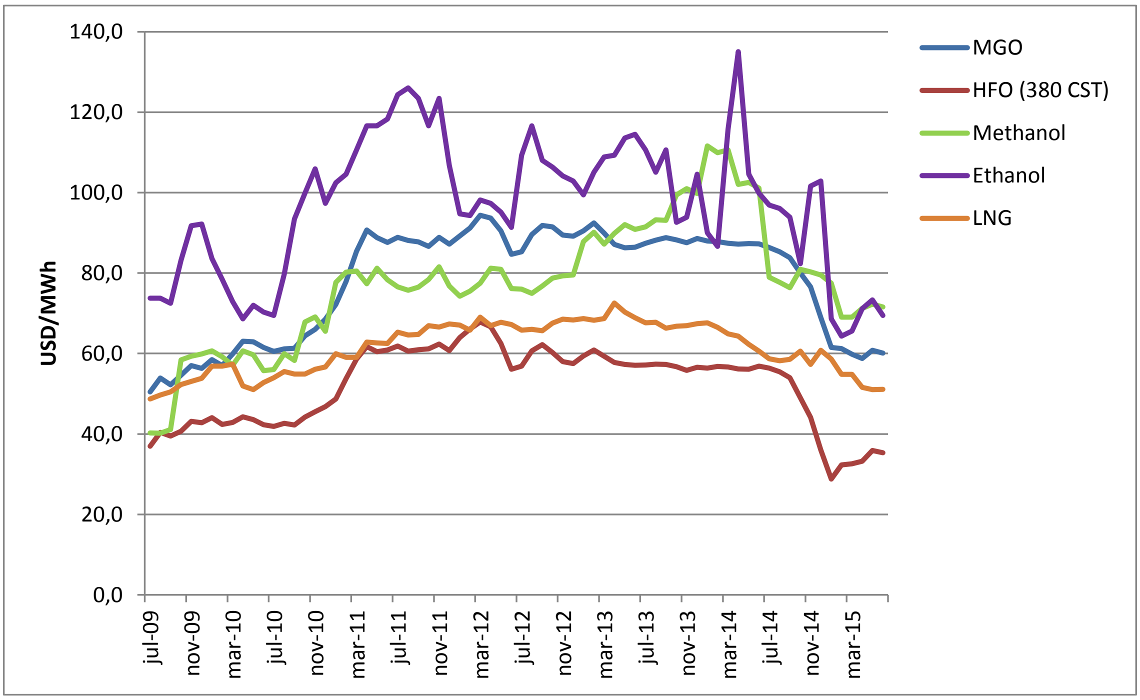


Figure 13: Historical MGO, HFO, Methanol, Ethanol and LNG (approximated) prices calculated on an energy basis (per MWh)

MGO and HFO have maintained a relatively consistent price differential during the period shown in Figure 13. Methanol also maintained a relatively consistent price spread from MGO and HFO, until early 2013, when it begins to increase in cost relative to the conventional fuels. Methanol experienced a global demand increase of 23% during the period of 2010 to 2012, as reported in [45], referring to an IHS global market study. The primary feedstock in the production of methanol, natural gas, is falling in price and new production capacities are being built in the US to take advantage of lower gas prices and increased demand. New production facilities coming on line in 2016 and 2017 may potentially see methanol revert to a lower price differential similar to 2011/2012.

LNG also has natural gas as a feedstock, which is then processed, liquefied and transported. As shown on the historical price curves LNG also approximately follows the prices of oil products. The EIA [70] states that “international LNG contracts are often linked to crude oil prices, even though their relationship may be weakening”. Also, there are many applications where LNG competes directly with petroleum products [70].

Ethanol, which also competes with liquid petroleum transport fuels, shows a more erratic price history, but is usually higher in price on an energy basis than the other fuels shown in Figure 13. The feedstock for most ethanol is crops such as corn for US ethanol and sugarcane for Brazilian ethanol. Prices for US ethanol are stated to be influenced by crop prices – for example a serious drought in 2012 in the Midwestern United States resulted in higher prices and a drop in production [71].

General Fuel Price Trends and Future Price Projections: Energy prices as indicated by the World Bank commodity price index declined significantly during 2014, and this includes prices of primary fuels. The World Bank [72] suggests that the 2014-2015 oil price crash resulted from supply-related factors, with large inventories of oil and climbing oil production, including from unconventional sources such as shale oil. In addition, OPEC’s switch in policy from maintaining price targets to protecting a market share was noted to have had an effect. The World Bank Commodity Markets Outlook (April 2015) projects that oil prices will remain flat for the rest of 2015 and natural gas prices are expected to fall following the lead of oil, "especially in Europe and Asian LNG markets". The World Bank Commodities price forecast shows crude oil prices beginning to rise gradually in 2016 and continue a slow rise to 2025. Gas prices, however, show minimal increase in Europe and Japan to 2025 (in real 2010 US dollars). The US Energy Information Administration [70] also projects an increase in oil prices, with a 30% rise in North Sea Brent Crude oil prices from 2013 to 2040 predicted for the reference scenario (higher and lower scenarios are also provided).

Fuel price scenarios for the payback time calculations: Two historical fuel prices points were selected for carrying out the payback time calculations and comparisons for the case vessels in this study. January 2012 was selected as a price case representing a period with relatively consistent price differentials among MGO, HFO, methanol, and LNG. January 2015 was selected as potentially representative of a "worst case" situation for alternative fuels because the prices of HFO and MGO were both very low as a result of the oil price crash, whereas the alternative fuels (LNG and methanol) have not reduced by the same extent. For LNG and methanol, however, it seems likely that future prices will revert to a more typical relationship with fuel oils as seen previously. This is because both are produced from natural gas, which is expected to continue to drop in price due to the many new unconventional sources now being developed.

2.5.2 Ship Investment and Operational Cost Analysis

Ship investment and operational costs were estimated for three case ships: a ferry, a chemical tanker, and a cruise ship. The main parameters and operational profile assumed for the ships are shown in Table 9. Different types of trade were assumed for the vessels with regards to percentage of time operating outside of an ECA area. Both retrofit and new build solutions were considered.

Table 9: Ship main parameters and operational profile

Ship	Ship parameter			Main Engine		Operational Profile [73]				AUX *sfoc* at MCR [g/kWh]
	L [m]	B [m]	P_{inst} [MW]	ME *sfoc* at MCR [g/kWh]	Ref	Days at sea, *t*	*ME* $P_{\%}$	*AUX* $P_{\%}$	Days AUX, *t*	
Ro-ro Ferry	250	30	4x5	176	[74]	232	65	70	360	
Chemical Tanker	190	32	1x10	167	[9]	251	80	50	450	192
Cruise Ship	230	29	23	181	[75]	227	65	70	360	

2.5.2.1 Investment Costs

Investment costs for the compliance strategy alternatives MGO, HFO with scrubber and SCR, and LNG were based on price information from engine manufacturers as presented in the Danish Maritime Authority (DMA) study [76]. As the focus of the comparison is fuel choice, only machinery and related costs were included in the estimate, which is presented as USD per installed kW engine power. Costs were updated to 2015 values using an inflation rate of 4%

(for the period 11/2011 to 11/2015) for the EU and converted from EUR to USD using an exchange rate of 1 EUR to 1.12 USD. For the methanol option, investment cost for the retrofit used a value of EUR 350/kW reported for the conversion of the 24 MW Ro-Pax ferry *Stena Germanica* retrofit project carried out in 2015 [77]. This was converted to USD for the comparison calculations. For the methanol new build, a cost of EUR 700/kW for the engine and auxiliary systems was used as reported in [68] in 2012, and this was updated to 2015 USD values using an inflation rate of 4% and currency exchange of 1 EUR to 1.12 USD. Given the limited experience with marine methanol installations, costs for this option should be considered approximate. For the ethanol alternative the investment costs were assumed to be the same as for methanol, due to similarities in the properties of the two alcohols. Scope of engine modifications and associated equipment are expected to be similar. Investment costs assumed for the analysis are provided in Table 10. The cost for new builds includes the cost for engines, generators and electrical equipment while the costs for the retrofit is for converting the existing engine and associated systems.

Table 10 Assumed investment costs per kW for the fuel compliance strategies

Fuel and compliance strategy	Retrofit	New builds (includes engine, generator, etc.)
MGO (engine upgrade, SCR/EGR)	150 000 + 63 $/kW	120 000 + 542 $/kW
HFO (scrubber & SCR)	489 $/kW	926 $/kW
LNG dual fuel 4 stroke plus tanks	664 $/kW	1275 $/kW
Methanol dual fuel 4 stroke	392 $/kW	815 $/kW
Ethanol dual fuel 4 stroke	392 $/kW	815 $/kW

Using the installed engine power per case ship as described in Table 9 above, total investment machinery costs per case were estimated and are shown in Table 11. The new build costs include new engines, generators, and associated equipment and thus are higher than the retrofit which has existing engines and require investment only for the upgrade.

Table 11 Investment costs for the case study ships for the fuel compliance strategies (in million USD)

Fuel and compliance strategy	Retrofit (retrofitting engine)			New builds (includes engines, generators, etc.)		
	Ro-ro Ferry	Chemical Tanker	Cruise ship	Ro-ro Ferry	Chemical Tanker	Cruise ship
MGO (SCR/EGR)	1.4	0.8	1.6	11.0	5.5	12.6
HFO (scrubber & SCR)	9.8	4.9	11.3	18.5	9.3	21.3
LNG dual fuel 4 stroke	13.3	6.6	15.3	25.5	12.8	29.3
Methanol dual fuel	7.8	3.9	9.0	16.3	8.2	18.7
Ethanol dual fuel	7.8	3.9	9.0	16.3	8.2	18.7

For the payback time calculation, as discussed in Section 2.5.2.4, the MGO case was assumed to be the baseline scenario against which comparisons are made. Thus the investment costs from this case were subtracted from the other options to give the additional investment cost required above this option. The additional costs above this option would include for example the differential for a more expensive dual fuel engine, extra tank requirements, and associated equipment.

2.5.2.2 Equipment operation and maintenance cost

Equipment operation and maintenance costs for each of the compliance strategies are described as follows:

HFO and Emissions Abatement:

This includes costs for operation of an open loop scrubber and SCR and is based on [78]. The energy cost for scrubber operation was included in the scrubber operational costs.

MGO:

This is the baseline scenario so no additional costs were assumed.

LNG fuel:

For the chemical tanker, ferry, and cruise ship cases an operational cost of 6 $/MWh was assumed, based on [68], which gives an estimate of 5-6 $/MWh, and on internal Lloyds Register information sources, which gave a similar indication.

Methanol and Ethanol Fuel:

Operational costs for methanol and ethanol were assumed to be 4 $/MWh, based on an estimate of 3-4.5 $/MWh as given in [68] for methanol operational costs. This is about 35% less than LNG operational costs but seemed reasonable as the replacement components are expected to be cheaper because they will not have to withstand cryogenic temperatures.

New build vs. retrofit:

It is assumed that operational costs are the same for the retrofit and the new build options.

2.5.2.3 Fuel Cost

Since **fuel prices** have demonstrated considerable variation over time, three fuel price scenarios were selected for the analysis. Two of these were based on historical price differences as described above in Section 2.5.1. These were January 2012, representing an “average” scenario with a period of relatively consistent price differentials between conventional fuel oils and alternatives (methanol and LNG), and June 2015, representing a “worst case” for alternative fuels with low prices of HFO and MGO due to the oil price crash. In addition to these a third “best case” scenario was selected where HFO and MGO prices were high and methanol and ethanol prices were relatively low. The prices used for methanol in this scenario are representative of early 2015 prices. The prices for MGO and HFO were high prices from early 2012. The specific prices used in the scenarios are shown in Table 12.

Table 12: Fuel prices by scenario used in the payback analysis (shown in US$)

Fuel	Low oil price scenario		Average Scenario		High oil price scenario	
	$/tonne	$/MWh	$/tonne	$/MWh	$/tonne	$/MWh
HFO	393	35.4	711	69.5	870	78.3
MGO	718	60.1	1066	89.3	1600	134.0
LNG	709	51.1	931	67.1	959	69.1
Methanol	398	71.6	412	74.2	400	72.0
Ethanol	570	69.5	737	94.8	680	87.4

To calculate fuel cost, first the mass and energy of heavy fuel oil required was calculated using the equations shown below. The terms used in the equations are: P_{abs} - used Power, $P_{\%}$ - percent Load, P_{inst} - installed Power, *sfoc* – specific fuel oil consumption, *t* - time, E_{fuel} – Energy for fuel indicated, m_{fuel}- mass of fuel indicated, LHV_{fuel} – energy density by mass of fuel indicated.

$$P_{abs} = P_{\%} P_{inst} \quad (3)$$

$$m_{HFO} = P_{abs} \cdot t \cdot sfoc \quad (4)$$

$$E_{HFO} = m_{HFO} \cdot LHV_{HFO} \quad (5)$$

As different fuel options were to be investigated for each case study vessel, the following equations were used to calculate the fuel consumption of the other fuel options:

$$E_{HFO} = E_{fuel} \quad (6)$$

$$m_{fuel} = LHV_{fuel} \cdot E_{fuel} \quad (7)$$

Pilot fuel requirement:

In order to account for the amount of pilot fuel required for the options LNG, methanol and ethanol, a percentage was assumed as follows:

- 5% of total energy is supplied by MGO pilot fuel in all pilot fuelled options. It is noted LNG may be 3% mass based [59].

This percentage is subsequently also subtracted from the total energy as it would be delivered by MGO.

Fuel cost for each case was then calculated as follows:

$$Cost_{fuel} = m_{fuel} \cdot Price_{fuel} + m_{Pilot} \cdot Price_{Pilot} \quad (8)$$

The energy cost for scrubber operation in the HFO compliance option was included in scrubber operational cost and not in total fuel cost.

Using the method described above, fuel costs were calculated for each of the three case study ships. Tables 13, 14 and 15 show the results of the fuel cost calculations for each ship type operating 100% of the time on the designated fuel.

Table 13: Annual fuel costs for each ship type for the average fuel price scenario

Annual fuel costs for average fuel price scenario (in million $)					
	HFO	MGO	LNG	Methanol	Ethanol
Ferry	10.3	14.3	10.9	12.0	15.2
Chemical Tanker	6.5	9.1	6.9	7.6	9.6
Cruise Ship	11.7	16.3	12.5	13.7	17.3

Table 14: Annual fuel costs for each ship type for the high oil fuel price scenario

Annual fuel costs for best case (high oil) fuel price scenario (in million $)					
	HFO	MGO	LNG	Methanol	Ethanol
Ferry	12.6	21.5	11.6	12.0	14.4
Chemical Tanker	8.0	13.7	7.4	7.7	9.1
Cruise Ship	14.3	24.5	13.2	13.7	16.4

Table 15: Annual fuel costs for each ship type for the low oil fuel price scenario

Annual fuel costs for worst case (low oil) fuel price scenario (in million $)					
	HFO	MGO	LNG	Methanol	Ethanol
Ferry	5.7	9.6	8.3	11.4	11.7
Chemical Tanker	3.6	6.1	5.3	7.2	7.4
Cruise Ship	6.5	11.0	9.4	13.0	13.3

2.5.2.4 Payback Analysis and Results

A payback time was calculated for each of the three case study ships using the investment costs, operating costs, and fuel costs as described previously. The approach was similar to that followed in the EMSA report on 0.1% sulphur requirement [79], as follows:

$$Payback\ time = \frac{Cost\ of\ installation}{fuel\ cost\ saving} \qquad (9)$$

Different types of trade representing operation time within coastal or deep sea areas were considered for the case study ships as shown in Table 16.

Table 16: Operational areas considered for each of the case study ships

Ship	Operational Profile
Ferry	100% in ECA (1) and 100% outside ECA (2)
Chemical Tanker	100% ECA (1) and 50% outside ECA (2)
Cruise Ship	100% ECA (1) and 75% outside ECA 25% in ECA (2)

Table 17 summarizes the results of the payback time calculation for the average fuel price scenario, for both new and retrofit investments for the three case study ships. It is assumed that the ships operate on the alternative fuel both within and outside of ECA. The comparator used when the ship is 100% within ECA is a ship operating 100% on MGO. The comparator when the ship operates outside of ECA is the ship operating on HFO without after-treatment system installed. For cases operating partially outside of ECA the comparator is a ship that operates on MGO within ECA and on HFO outside ECA, and that has not invested in a scrubber. For the operational profiles partially within ECA the assumptions were as follows:

- Chemical tanker 50% within ECA – the comparator ship operated on MGO for 50% of the operational time and HFO for 50% of the time, with no investment cost for a scrubber. The LNG, methanol, and ethanol ships were assumed to operate on the alternative fuel both inside and outside of the ECA area.
- Cruise Ship 25% within ECA: The comparator ship operated on MGO for 25% of the time and HFO for 75% of the time. There was no investment for a scrubber installation. The LNG, methanol, and ethanol ships were assumed to operate on the alternative fuel both inside and outside of the ECA area.

Table 17: Payback time summary for case ships using the average fuel price scenario

Ship Type and Operating Locations	Payback Time (years)							
	Retrofit				Newbuild			
	HFO + scrubber +SCR	LNG	Methanol	Ethanol	HFO + scrubber +SCR	LNG	Methanol	Ethanol
Ferry 100% in ECA	2.2	3.8	3.1	Never	2.0	4.6	2.6	Never
Ferry 0 % ECA	NA	Never	Never	Never	NA	Never	Never	Never
Chem. Tanker 100% ECA	1.7	3.0	2.4	Never	1.5	3.6	2.1	Never
Chem. Tanker 50% ECA	3.4	7.5	21.2	Never	3.1	9.1	18.0	Never
Cruise Ship 100% in ECA	2.3	3.6	2.9	Never	2.1	4.4	2.5	Never
Cruise Ship 25% in ECA	9.0	36.2	Never	Never	8.2	44.2	Never	Never

Both the methanol and HFO with scrubber and SCR compliance options resulted in payback times between 1.5 to 3.1 years for all case study ships when operating 100% within an ECA area. LNG also resulted in reasonable payback times for ships operating within ECA areas, with slightly longer times of 3.4 to 4.6 years depending on ship type. The fuel and operational costs for methanol and LNG were similar but LNG has a higher investment cost for retrofit and new build solutions. For longer periods of time outside of the ECA area, the payback times were relatively long. For the ferry operating 100% of the time outside ECA, the methanol, ethanol, and LNG alternatives did not pay back the investment cost because the annual fuel prices were above the HFO annual fuel cost (see Table 13).

Tables showing details of all payback time calculations are provided in Appendix IV.

1.5% Sulphur limits: From 1 January 2015 to 1 January 2020, passenger ships on regular services operating in EU waters outside SECA areas must use marine fuels with a maximum sulphur content of 1.5%. Other ships may use up to a maximum 3.5% S, as indicated in Table 18.

Table 18: EU Limits for the maximum sulphur content by mass in marine fuels for the period 1 January 2015 to 1 January 2020 (source: EMSA [80])

Ship type and operating area	Inside EU SECA	Outside EU SECA
At berth/anchor	0.10%	0.10% (not if < 2 hrs or shoreside electricity)
Passenger ships on regular service		1.50%
Other ships		3.50%

Fuel with a sulphur content of 1.5% will be HFO or IFO – as a residual fuel oil blend in the same manner as most of the 1% S used to be. Initial enquiry with a bunker trader shows that most fuels being supplied to fit this requirement will likely be a 1% S or a higher sulphur fuel oil blended with a 1%. In the Mediterranean 1.5% fuel is not supplied any longer. At the start of the year 2015 a ferry company in the Irish Sea was paying about 245 USD/tonne for 1.5% HFO versus 486 USD/tonne for MGO (margin of 240 USD). In recent months (end of 2015) the margin compared to 0.1% decreased and the price is about 160 USD/tonne for 1.5% compared to 315 USD/tonne. The price of 1.5% sulphur fuel is therefore judged not too dissimilar from the price of high sulphur residual. Thus the payback times would be similar to those estimated for the high sulphur residual.

0.5% Global Sulphur Cap from 2020: From the year 2020, all fuel used within the European territorial waters and economic zones shall have a maximum sulphur content of 0.5%, except for the ECAs where the lower limit of 0.1% sulphur applies. In international waters, IMO's MARPOL Annex VI specifies a reduction of the maximum sulphur content in fuel from 3.5% to 0.5% by 2020, with a possible extension to 2025 to be determined after a review in 2018. The characteristics and prices of the fuels that will be used to meet these 0.5% sulphur guidelines is uncertain. They may be similar to the ultra low sulphur marine fuel oil (ULSMFO) 0.1% residual fuel oils that are offered in some regions today. These have a price which is close to, but still lower than, the distillate fuel oil prices (MGO/MDO). The implementation of the 0.5% sulphur cap will likely shorten pay back times for operation of vessels outside of ECAs, because the 0.5% S fuel will cost more than the 3.5% S fuels allowed today.

To get a rough indication of the possible effect of the 0.5% sulphur cap on payback times, the case of a ro-ro ferry operating 100% in an area with a 0.5% sulphur fuel cap was considered. For this calculation, a price of 900 USD/tonne for 0.5% sulphur residual fuel oil was assumed as the comparator rather than MGO. As noted above, this price is considered very uncertain. Using the "average" scenario for the other fuel prices, the payback times are estimated as shown in Table 19.

Table 19: Payback time estimate compliance strategies using a comparator of 0.5% S Fuel Oil with assumed price of 900 USD/tonne

	0.5%S Fuel oil	HFO scrubber and SCR	LNG	Methanol	Ethanol
Assumed fuel cost USD/ tonne	900	711	931	412	737
Payback time (years) New Build	0 (comparator)	3.0	7.5	6.2	never
Payback time (years) Retrofit	0 (comparator)	3.3	6.2	7.3	never

As shown in Table 19, the HFO with scrubber and SCR has a reasonable payback time and LNG and methanol are about twice as long. The relative price differences between the fuels are quite uncertain, however. With a greater fuel price differential the methanol and LNG options would have shorter payback times.

Summary: The payback time analysis results indicate that methanol can be competitive with other fuels and emissions compliance strategies depending on the fuel price differentials. Ethanol is currently not an attractive option from a financial perspective due to higher fuel costs. Investment costs for both methanol and ethanol retrofit and new build solutions are estimated to be in the same range as costs for installing exhaust gas after treatment (scrubber and SCR) for use with heavy fuel oil, and below the costs of investments for LNG solutions. The estimates for investment and operational costs for the methanol and ethanol options are based on limited experience as there is currently only one installation in existence. The investment cost is anticipated to decrease with more experience and statutory and classification requirements appearing. This will shorten payback times in the future.

Costs of the alternative fuels must be below MGO fuel costs on an energy basis to show a payback compared with this option. Methanol and LNG fuel costs were similar in this analysis, but methanol showed a shorter payback time for operations within ECA areas due to lower investment costs.

3 Standards/regulations/guidelines related to bunkering and use of ethyl and methyl alcohol

Regulations pertaining to both the ship board use of methyl and ethyl alcohol fuels and to the land-based provisions regarding bunkering (market, storage, distribution to ships) are described below.

3.1 Ship-side regulations

The review of ship side standards/regulations/guidelines for use of methyl and ethyl alcohol fuels included the following main source categories:

- International Regulations
- Classification society rules such as Lloyd's Register's Provisional Rules for the Classification of Methanol Fuelled Ships (January 2015) [81] and DNV's Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations [82]
- National Rules and other identified standards/regulations/guidelines

A discussion of the regulations is included in the following sub-sections.

3.1.1 International Regulations IMO:

SOLAS Chapter II-2 Part B Reg. 4.2 [83] deals with the flash point of oil fuel:

This regulation requires that fuels shall have a flashpoint of 60°C or higher with some exceptions. This provides for the assumption that the following regulations can be assumed effective in protecting the vessel from fire.

Further guidance on reducing risk in fuel systems is provided in the Guidelines to minimize leakage from flammable liquid systems (MSC/Circ.647) [84], the Guidelines on engine-room oil fuel systems (MSC/Circ.851) [85] and the Guidelines for measures to prevent fires in engine-rooms and cargo pump-rooms (MSC.1/Circ.1321) [86], which are referenced in SOLAS.

SOLAS Chapter II-2 Part F Reg. 17 [83] currently provides the only path to facilitate use of a fuel which has a flash point differing from the above requirement; "When fire safety design or arrangements deviate from the prescriptive requirements of this chapter, engineering analysis, evaluation and approval of the alternative design and arrangements shall be carried out in accordance with this regulation." (2.2.2)

The IMO International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) [87] and draft technical provisions for ships using ethyl/methyl alcohol as fuel [88], which are currently under development. The following provides the status as of September 2015.

The International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF CODE) has been developed in order to facilitate the use of such fuels onboard ships that are not carrying these substances as a cargo. It originated from MSC 78, which had instructed the BLG, DE (co-ordinator) and FP Sub-Committees to develop appropriate draft guidelines for gas-fuelled ships, with a view to establishing an international standard for the installation and operation of internal combustion engine installations using gas as fuel in all types of ships other than LNG carriers and included a high priority item on "Development of provisions for gas-fuelled ships" in the Sub-Committee's work programme and provisional agenda for BLG 9 with a target completion date of 2007. It was noted that United States (DE 48/19/1) proposed to expand their scope to also cover other potential gas fuels such as hydrogen and propane, and it was agreed, in principle, that the provisions to be developed should not only consider natural gas, but also other potential gas fuels such as hydrogen and propane, but that this should be further considered at a later stage. At BLG 9 a Correspondence Group was instated.

In November 2012 the correspondence group on the "Development of International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels" reported a proposal by Sweden to include ethyl and methyl alcohol and in February 2013 Interferry gave a presentation at IMO about methyl alcohol and its implications for the IGF Code.

The risk analysis carried out for the SPIRETH project served as a basis for some of the IMO's IGF methanol (methyl alcohol) guideline development work.

IMO Submissions BLG 17/8/3 and BLG 17/INF.10 (Additional information on Methyl/Ethyl as marine fuel - Risk management plan and GAP-analysis) by Sweden were received at BLG and the decision was taken that due to the fact that ships were using LNG as fuel already, the working group was to consider these with the understanding that priority was to be given to the technical provisions for LNG so that the Code could be finalized in 2014.

The draft IGF was developed by the Correspondence Group on the Development of the IGF Code established at IMO's BLG 17. The report presented to the Sub-committee on Carriage of Cargo and Containers at the first session in September 2014 included Annex 4 (Specific Requirements for Ships Using Ethyl or Methyl Alcohol as Fuel) of CCC 1/4: "Development of International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code). Annex 4 is being developed as "Part A-2" of the IGF Code.

Meanwhile the first version of the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) was adopted by resolution MSC.391 (95), which will enter into force on 1 January 2017. (There are associated amendments to SOLAS and the 1978 and 1988 Protocols, adopted by resolutions MSC.392(95), MSC.394(95) and MSC.395(95), respectively). This code applies to gas as fuel.

The second session of the CCC was held 14-18 September 2015, with the provisional agenda showing Item 3 on Amendments to the IGF code.

Developments at CCC2 included the following:

- Amendments to the IGF Code and development of guidelines for low-flash point fuels: Draft Technical Provisions for ships using Methyl/Ethyl alcohol as fuel
- Nature of technical requirement: there was as discussion whether to develop a set of technical requirements as non-mandatory interim guidelines or develop text as a part of the IGF Code. After an in-depth discussion, CCC2 agreed not to discuss a set of technical requirements as non-mandatory interim guidelines and the correspondence group and document was renamed as "Technical Provisions".

Further technical elements in the technical provisions that were discussed:

- *Fuel tank protection:* Integral tanks are required to have cofferdams on all surfaces (i.e. boundaries) except those bound by (a) bottom shell plating, (b) other alcohol fuel tanks and /or (c) fuel pump/preparation rooms. The provisions do not require protective cofferdams for independent tanks. The code does not cover separation and/or cofferdam provisions between methyl/ethyl alcohol fuel tanks and cargo tanks when located in the cargo areas of chemical tankers. It was confirmed that portable tanks should be securely fixed to the ships' structure and connected to the ship's safety systems, etc.

- *Inerting:* The need for mandatory provision to inert fuel tanks was questioned. No conclusion was reached but strong views were expressed to maintain this provision and to use a risk assessment to justify applications where inerting is not required.
- *Emergency Shut Down (ESD) protected machinery spaces as defined in the IGF Code:* No conclusion was reached on the applicability of ESD protection for machinery spaces using methyl/ethyl alcohol. However most were of the opinion that ESD protection is inappropriate.

The correspondence group was re-established to work on this subject.

IBC Code - International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, Amended by Resolution MEPC.225(64) [89]

The compliance with this code is stipulated by MARPOL Annex II [90]. Whereas not applicable to the combustion of low flash point fuels, in liquid state, this code contains design requirements for the carriage of cargoes derived from properties of the cargo. GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environment Protection) has Working Group 1 on the Evaluation of the Hazards of Harmful Substances Carried by Ships. This delivers the assessments of the properties to IMO.

Both methyl alcohol and ethyl alcohol are contained in the code. Ethyl alcohol is listed in Chapter 18 "List of products to which the Code does not Apply" with Pollution Category Z, indicating that only MARPOL Annex II applies.

Methyl alcohol is listed in Chapter 17 "Summary of minimum requirements", indicating that specific requirements from the IBC code apply in addition to MARPOL Annex II. IBC Chapter 17 lists the ship type for methanol as Ship Type 3. Ship Type defines, amongst other requirements, where the tank carrying the product can be located. Ship type 3 has no distance requirements for the tank location from the outer hull.

Other Related Codes and Documents:

The following documents are relevant as they were used as sources for the first draft text of the IGF Code. Furthermore, the IGC Code was historically the only document allowing for the combustion of cargo gas as fuel. This has recently been extended to include more products for such a use.

- International Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) and amendments [91].
- IMO document MSC 86/26/Add.1 Annex II Interim Guidelines for Natural Gas-Fuelled engine installations in ships [92.

Other International Standards:

- IEC 60079-1: Electrical apparatus for explosive gas atmospheres – Part 10: Classification of Hazardous areas [93].
- IEC 60092: Electrical installations in ships – Part 502: Tankers-Special and IEC 60092-506 is for ships carrying specific dangerous goods and materials hazardous only in bulk [94].

3.1.2 Classification Society Rules

At present only two ship classification societies have requirements for methyl alcohol as a fuel – Lloyds' Register and DNV. It is expected that in 2015 the classification society ClassNK may also issue rules related to methyl alcohol fuel.

Lloyd's Register Provisional Rules - Provisional Rules for the Classification of Methanol Fuelled Ships [81]

Lloyd's Register published its provisional rules for methanol fuelled ships in January 2015.

Prior to these provisional rules, LR required any ship where methyl alcohol was proposed as a fuel to comply **specifically with Pt7, Chapter 16 Rules for Systems of Unconventional Design** in addition to the **Rules and Regulations for Ships.** This necessitated the provision of a risk assessment for the specific fuel installation.

Whilst the provisional rules do not remove the requirement to risk assess the design completely, they were aligned with the approach taken for the existing Rules for Natural Gas fuelled Ships and for the purposes of consistency, commonality of core requirements and Rules structure is used wherever possible.

Nevertheless, some of the hazards of methanol differ from LNG. A key difference is that methanol does not have the hazards associated with a cryogenic liquid as it is stored at ambient temperatures. Consequently, whilst many design principles such as tank construction might be similar to those of oil fuel, it still presents the same low flashpoint fuel hazards but also brings with it hazards associated with toxicity, corrosion and solvency. The requirements of these rules therefore incorporate, or refer out to requirements from other LR Rule sets in combination with learnings from a variety of other sources as follows:

- Many requirements for example have evolved from LR work being undertaken on the methanol-fuelled RoPax project and other methanol related research projects with learnings from hazard identification studies being incorporated.
- Tank construction requirements principally reference those of the *Rules for Ships for the Carriage of Liquid Chemicals in Bulk* as they take into account not only the structural requirements for the rules for ships, but also address hazards associated with the potentially corrosive nature of the fuel.
- Other requirements have been developed from the draft Part A-2 of the IGF Code currently under development.

Further sources of information and requirements include:

- Methanol Safe Handling Manual published by the Methanol Institute [32]
- IEC 60092-502 Electrical installations in ships – Part 502: Tankers – Special Features [95].
- Involvement in industry working groups such as the Society for Gas as a Marine Fuel (SGMF).

Whilst the basis of the proposal is therefore a set of prescriptive Rules to address known hazards, as with the rules for natural gas fuelled ships, these are supported by a risk based approach which requires an assessment of methanol fuel system designs and installations. The risk based studies are intended to be proportionate in scope, calling on prior experience of system and installation design as appropriate.

Through LR's continuing involvement in methanol related projects, including assessments of methanol fuelled machinery and systems design and active participation in industry working groups, typical solutions for mitigating the hazards will be captured and more prescriptive requirements will be developed, reducing the reliance on the risk based studies.

DNV PART 6 CHAPTER 3, Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations [82]

DNV published the above rules in 2013. The rationale for the development of these rules is not known to the authors. The content of the rules envelops similar areas as discussed in the LR section.

3.1.3 Comparison of developing requirements

The IMO Draft Technical Provisions for the Safety of Ships Using Methyl/Ethyl alcohol as fuel [88] (CCC2 – WP. 3 Annex 1) was reviewed in comparison with the LR and DNV Rules. Although the documents are structured differently, a high level comparison could be carried out as shown in Table 20.

Table 20: High-level comparison of Rules and IGF Draft relating to methyl and ethyl alcohol

<table>
<tr><th colspan="3">Current Methyl Alcohol and Ethyl Alcohol Provisions and Rule Requirements as Ship Fuel</th></tr>
<tr><th>Draft Technical Provisions for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel</th><th>LR Rule Jan. 2015</th><th>DNV - Rule July 2013</th></tr>
<tr><td>1 Preamble</td><td rowspan="3">Section 1 General 1.1 Purpose and Scope</td><td rowspan="3">Section 1 A. Introduction A100 Objective A200 Scope</td></tr>
<tr><td>2 GENERAL</td></tr>
<tr><td>3 GOAL AND FUNCTIONAL REQUIREMENTS</td></tr>
<tr><td>4 GENERAL REQUIREMENTS</td><td>Section 3 Risk Based Studies</td><td rowspan="3"></td></tr>
<tr><td>4.2 Risk assessment</td><td>3.2 System safety risk assessment
3.3 System dependability assessment
3.4 Failure modes and effects analysis (FMEA) of the critical system elements
3.5 Hazardous areas classification study
3.6 System hazard & operability study (HAZOP)
3.7 Bunkering safety study
3.8 Other risk-based studies</td></tr>
<tr><td>4.3 Limitation of explosion consequences</td><td></td></tr>
</table>

Current Methyl Alcohol and Ethyl Alcohol Provisions and Rule Requirements as Ship Fuel		
Draft Technical Provisions for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel	**LR Rule Jan. 2015**	**DNV - Rule July 2013**
5 SHIP DESIGN AND ARRANGEMENT	Section 5 Location and arrangement of spaces 5.2 Methanol bunkering station 5.3 Fuel storage tanks 5.4 Fuel supply equipment 5.5 Methanol-fuelled consumer equipment 5.8 Hazardous areas	SECTION 3 ARRANGEMENT AND DESIGN SECTION
6 FUEL CONTAINMENT SYSTEM	6.3 Fuel storage tanks 6.4 Cofferdams	SECTION 3 B. Fuel Storage
6.4 Inerting and atmospheric control within the fuel storage system 6.5 Inert gas production on board	6.8 Inert gas system	SECTION 3 G. Nitrogen Installations
7 MATERIAL AND GENERAL PIPE DESIGN	Section 4 Materials, components and equipment	SECTION 2 MATERIALS
8 BUNKERING	3.7 Bunkering safety study 6.2 Methanol bunkering system 8.6 Bunkering system	SECTION 3 F. Fuel Bunkering
9 FUEL SUPPLY TO CONSUMERS	6.5 Methanol supply system Section 7 Piping	C. Fuel Transfer and Supply
10 POWER GENERATION INCLUDING PROPULSION AND OTHER ENERGY CONVERTERS	6.6 Methanol-fuelled reciprocating internal combustion engines and turbines 6.7 Methanol-fuelled boilers	SECTION 6 D. Engine Monitoring SECTION 7 ENGINES AND PUMPS
11 FIRE SAFETY	8.4 Methanol vapour detection 8.5 Fire detection and alarm system Section 10 Fire safety 10.2 Structural fire protection 10.3 Fire main 10.4 Deck-fixed pressure water-spraying system 10.5 Deck foam fire-extinguishing system 10.6 Fire-extinguishing arrangements in machinery spaces	SECTION 4 FIRE SAFETY B. Containment of Fire C. Fire Fighting

Current Methyl Alcohol and Ethyl Alcohol Provisions and Rule Requirements as Ship Fuel		
Draft Technical Provisions for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel	**LR Rule Jan. 2015**	**DNV - Rule July 2013**
[12 EXPLOSION [PREVENTION] AND [AREA CLASSIFICATION]	Section 9 Electrical	SECTION 5 B. Area Classification
13 VENTILATION	5.7 Ventilation and pressurisation 5.8 Hazardous Areas	SECTION 3 E. Ventilation
14 ELECTRICAL INSTALLATIONS	Section 9 Electrical	SECTION 5 ELECTRICAL SYSTEMS
15 CONTROL, MONITORING AND SAFETY SYSTEMS	Section 8 Control, alert and safety systems	SECTION 6 CONTROL, MONITORING AND SAFETY SYSTEMS
	Section 2 Submission requirements	SECTION 1 C Procedural Requirements
2.3 Alternative design	Section 11 Testing and trials	SECTION 5 C. Inspection and testing SECTION 8 Manufacture, Workmanship and Testing
2.3 Alternative design *4.2 Risk assessment*	*Section 2 Submission requirements* *Section 3 Risk Based Studies*	SECTION 9 Operational Instructions
2.3 Alternative design *4.2 Risk assessment*	*Section 2 Submission requirements* *Section 3 Risk Based Studies*	SECTION 10 Personnel Protection
2.3 Alternative design *4.2 Risk assessment*	*Section 2 Submission requirements* *Section 3 Risk Based Studies*	SECTION 11 Ship Type Considerations

The green highlighted fields give an indication of commonalities, whereas some details may still differ.

The pink highlighted areas shown in the table indicate some missing subjects:

- Certification: not directly covered, CCC2/WP.3 Annex 1
- Submission: not directly covered, CCC2/WP.3 Annex 1

  Both DNV and LR have sections covering requirements for submission and certification. The current draft text CCC2-WP3 Annex 1 does not consider submission requirements as this will be determined by the Flag States.
- Risk: not covered DNV Rule

  Both LR Rule and CCC2-WP3 Annex 1 have a section which requires risk assessment. This section covers implicitly operational requirements and other specific considerations. The DNV rule does not include risk assessment but instead includes specific ship type considerations, which are not directly covered in CC2/WP.3 Annex 1 and the LR Rule.

In addition to the gaps shown in the table above, the following items are gaps for both sets of rules and the draft IGF code for low flashpoint fuels:

- Bunkering landside: not considered, all
- Bunkering Ship to ship: not considered, all

None of the documents, which were compared, provide guidance regarding the delivery side of the bunkering operation. This means that land side guidance and guidance for a bunker vessel do not currently exist. It is though noted that this is not usually within the scope of Class Rules or IMO documentation.

Lastly, methyl and ethyl alcohol quality requirements as fuel and for sulphur compliance are not considered.

3.1.3.1 Knowledge Gaps

The areas of greatest difference are listed in Table 21. These subjects also provide an indication of where current gaps in knowledge lie.

Table 21: Sections of Rules and IGF Draft relating to methyl and ethyl alcohol with highest degree of variance

LR Chapter on Risk based studies	DNV -	CCC2-3-1 Subsection in General deals with Risk assessment
Fire safety General Structural fire protection Fire main Deck-fixed pressure water-spraying system Deck foam fire-extinguishing system Fire-extinguishing arrangements in machinery spaces	FIRE SAFETY A. General B. Containment of Fire C. Fire Fighting C 100 Foam fire extinguishing on open deck C 200 Fire extinguishing of the pump room C 300 Fire extinguishing of engine room C 400 Portable firefighting equipment and fire fighter's outfits	FIRE SAFETY Functional requirements General requirements Regulation for fire protection Regulation for fire main Regulation for firefighting Regulation for fire extinguishing of engine-room and pump-room
Control, alert and safety systems General Control, alarm and safety functions Pressurisation Methanol vapour detection Fire detection and alarm system Bunkering system	CONTROL, MONITORING AND SAFETY SYSTEMS A. General A 100 System arrangement A 200 Engine shutdown prevention system B. Control System B 100 General B 200 Field instrumentation B 300 Bunkering and tank monitoring B 400 Fuel supply monitoring C. Safety System C 100 General C 200 Bunkering and tank safety C 300 Gas detection C 400 Liquid leakage detection C 500 Ventilation C 600 Manual shutdown buttons C 700 Safety actions	CONTROL, MONITORING AND SAFETY SYSTEMS Goal Functional requirements General requirements Requirements for bunkering and fuel tank monitoring Requirements for bunkering control Requirements for pump monitoring Requirements for engine monitoring Requirements for gas fuel vapour detection Requirements for fire detection Requirements for ventilation
Chapter on Trials and Testing	Chapter on Manufacture, workmanship and Testing	-
Ventilation is dealt with in Location and arrangement of Spaces	Ventilation is dealt with in Arrangement and Design	Dedicated section on VENTILATION
-	SHIP TYPE CONSIDERATIONS	-

These differences also indicate the areas of greatest uncertainty in knowledge and experience that is required in order to develop requirements.

Some observations can be made relating to the detailed requirements and gaps in current knowledge and experience on how to deal appropriately with the risks posed by methyl and ethyl alcohol used as fuel.

- GAP 1: Fire detection and extinction

  The current draft is to revisit most of the requirements in the relevant section. Due to the properties of a methyl alcohol fire it is currently not known whether currently prescribed detection methods are effective. Equally, the extinction of a methanol fire may pose specific issues such as the ability of the person extinguishing a fire not being able to see the flame or the possibility that extinction may not be effective. Issues for specific fire suppression systems are as follows:

  - Alcohol resistant foam: may not cover the edges of a fire and continue to burn.
  - CO_2: Re-ignition after space ventilation is distinctly possible if surfaces have not been cooled sufficiently.
  - Water based systems: in order to use the dilution effect to make the material non-flammable large quantities are needed.

  Regarding structural fire protection and fire extinguishing the requirements in CCC2/WP.3 Annex 1 are shown in Tables 22 and 23.

Table 22: Structural fire protection in CCC2-WP3 Annex 1

y x	Accommodation	Service Spaces	Control Stations	Machinery Spaces	Machinery Spaces Cat. A	High Risk Area	Escape Routes	Cargo Area
FPR* (x boundaries toward y)	A-60		A-60					A-60
Tank on open deck (y boundaries facing x)	A-60	A-60	A-60	A-60	A-60		A-60	A-60
Integral tank cofferdam (x boundaries facing y)				A-60	A-60	A-60		
Bunkering Station (x boundaries adjacent to y)	A-60		A-60		A-60	A-60		

* FPR is an abbreviation for fuel process room which includes spaces containing fuel pumps, heat exchangers, pressure vessels, etc. For the purpose of application of the SFP requirements of SOLAS Chapter II/2 Regulation 9, these spaces should be considered as machinery space of category A.

**(up to bridge windows which can be A-0).

Table 23: Fire extinguishing requirements in CCC2-WP3 Annex 1

Protected Space	Fixed Fire Extinguishing System (FES) Requirement
Main ER and Pump Room	FES approved for machinery space of Cat. A as given in SOLAS Chapter II/2 Reg. 10. In addition an approved alcohol resistant (AR) foam system covering tank top and bilge area *
Tank on open deck	AR foam system covering the area below the tank. In addition a fixed water spray system covering exposed parts of the fuel tank.
Bunker Station	AR foam system.

* CCC2-WP 3: 11.6.5 contradicts 11.7.1. 11.7.1 is reflected in this table only.

- GAP 2: Vapour Detection

  Vapour detection could be considered the last protective measure before a potential ignition and fire. Standards for such systems are in existence (EN 60079 series). As these systems are highly dependent on calibration, the opportunity exists to provide detailed calibration guidance, for systems under this code due to the fact that the substance to be detected is only one as opposed to a multitude possible when thinking about cargo carriage. Another question related to vapour detection is the reliability of detection under high air flow conditions.

  Note: there is already guidance on detection systems in the FSS Code - Fire Safety Systems – Resolution MSC.98 (73) - Annex - International Code For Fire Safety Systems - Chapter 16 - Fixed Hydrocarbon Gas Detection Systems [96].

- GAP 3: Ventilation

  The knowledge about how a leak of methyl or ethyl alcohol will evaporate and propagate throughout mechanically ventilated space is limited. This knowledge also affects the requirements for air changes, placement of detection systems and location of ventilation outlets. A full answer is not available as to how vapour detection and ventilation will interact.

- GAP 4: shore connection

  An understanding of the availability of “drip free connections” on the market (ref CCC2_3_1 5.3.13).

- GAP 5: Spark ignition engines are currently a theoretical proposition for marine use of methanol, but the Code should account for a potential option, e.g. ref CCC2/3/1 10.3.8 and CCC2/3/1 10.2.1.1.

Some detailed specific thoughts regarding the current draft texts:

- Statutory requirements from other codes or conventions should not be repeated as it would necessitate “knock-on” changes should these be changed, e.g. the FSS Code already contains requirements for inert gas production systems.

- The current definitions in CCC2/3/1 of methyl and ethyl alcohol are very restrictive and could force a very high specification of these products as a fuel and therefore be expensive.
- The Code draft raises a general question regarding the rationale for airlock requirements. It is unclear as to why a maximum distance is required. (ref CCC2_3_1 5.12.3)

Lastly, it is possible to comment the general structure of the document. As the original brief for the correspondence group on low flash point fuel was not limited to one fuel, but specifically sought “not only to consider natural gas, but also other potential gas fuels such as hydrogen and propane, but that this should be further considered at a later stage” it is now conceivable that in future, other fuels could become commercially interesting for shipping. Methyl and ethyl alcohol are the first of such fuels currently being evaluated for their risks with mitigations being sought for incorporation into the IGF Code in an appropriate manner. In addition discussions regarding the use of automotive diesel (with flashpoints lower than marine fuel oils) were added to the agenda. These new fuels may differ significantly in their properties from existing fuels and from each other. For that reason it is prudent that any requirements on such fuels should be as specific as possible in respect to the fuel.

It has been seen that LNG and methanol differ in physical state and this will be the same with other potential fuels. Therefore it is prudent to ensure a guiding principle of one fuel one rule. In considering this and conceiving a possible future of many different fuel products with significantly differing properties, it is possible that the IGF Code could become a very large document. In order to ensure the size of the Code stays manageable and ensure that every potential fuel is considered appropriately, a modular approach, along the lines of IBC, where the properties are used to select the relevant design requirements, could be a solution.

3.1.4 Conclusions

In conclusion it can be said that the development of the new part of IGF related to methyl and ethyl alcohol can be embraced, as it facilitates the use of new fuels with flash points lower than the SOLAS stipulated 60°C minimum to be introduced to the marine stage.

3.2 Shore side regulations

Shore side factors such as infrastructure for fuel storage, handling by port personnel, and land transport of the fuels if applicable are governed by a mix of national and regional regulations, with some examples given in Table 24. Provisions for transport and storage of methanol and ethanol are often the same as for other flammable liquids with similar characteristics such as gasoline, jet fuel, and other distillates.

Table 24: Examples of onshore regulations for methanol and ethanol transport and storage

Activity	Relevant standard or rule	Regulating body
Methanol and ethanol cargo transport by road	ADR	UNECE
Methanol and ethanol cargo transport by rail	RID	Convention concerning international carriage by rail (COTIF)
Methanol and ethanol storage	ICC International guidance	International Code Council (ICC) provides guidance on above ground storage tanks containing flammable liquids (including methanol)
Methanol and ethanol storage	National regulations regarding storage	Examples include *Bundes Immisions Schutzgesetz* in Germany, UK HSE, and Swedish MSB requirements regarding standards for storage sites, pertaining to safety and environmental protection

3.2.1 Fuel storage

Methanol and ethanol are Class 3 flammable liquids (UN dangerous goods classification), which is the same class as many other liquid fuels such as gasoline and petroleum distillates, and thus share similarities with storage and distribution procedures. Examples of regulations that apply to storage on land and that are implemented at a national level include:

- Germany: In Germany *Bundes Immisions Schutzgesetz* is relevant for tanks.
- UK: the Health and Safety Executive (HSE) is responsible for shore side installations, and have described requirements in the report "Safety and environmental standards for fuel storage sites" [97]. In this guidance liquid dangerous substances are considered to be gasoline and other hazardous liquids including methanol and ethanol.
- Sweden: The Swedish Civil Contingencies Agency (MSB) is the regulatory government agency that is responsible for land-based handling and storage of inflammable liquids. Accredited inspection bodies verify that storage tanks meet the requirements regarding wall thickness and spill containment construction.

Methanol storage at docks and marine terminals is typically within floating roof tanks which are dedicated for methanol handling [32]. Internal floating roofs are stated to be preferred to avoid contamination. Safety equipment often includes leak detection and alarms. Local and national regulations as noted above will include requirements regarding containment in the event of tank failure.

3.2.2 Land Transport

For road and rail transport of ethanol and methanol, ADR and RID European requirements must be followed for the transport of methanol and ethanol by road or rail. For the SPIRETH project, methanol was delivered by road tanker truck and the driver had safety equipment and procedures as specified by ADR-S, the Swedish national variation of ADR. Additional procedures were developed by the SPIRETH project for the ship crew and reviewed with the driver prior to delivery.

3.2.3 Bunkering

Potential bunkering scenarios for methanol and ethanol include the following:

- Ship to ship bunkering
- Truck to ship bunkering
- Land storage tank to ship bunkering.

If ship-to-ship bunkering is carried out, it is likely existing small product tanker bunkering vessels would be suitable. Most bunkering vessels are classified as product tankers and could be used for carrying methanol and ethanol. Conversion cost of a bunker barge for methanol was estimated to be a relatively low cost of EUR 1.5 million [77].

Regarding bunkering from a road tanker from land side, "IP Area Classification Code for Installations Handling Flammable Liquids" can provide guidance regarding safety zones and procedures.

Occupational exposure limits as described in Section 2.2.3 could be applicable to shore side personnel, but appropriate design of the bunkering system and bunkering procedures involving "no drip" couplings should limit exposure.

Land storage tank to ship bunkering is similar to loading of product tankers that transport methanol. This is done on a routine basis and there are procedures and guidelines for guidance. The cost of constructing a 20,000 m^3 methanol storage tank, including installations for loading the methanol from a product tanker vessel to the storage tank, and for transferring methanol from the storage tank to a bunker vessel, was estimated at approximately EUR 5 million [77]. Construction of an LNG terminal was stated to be 10 times more expensive than an equivalent methanol terminal and larger volumes are needed to justify costs for these facilities [77].

The *Stena Germanica* bunkering in Gothenburg is the only example of methanol bunkering to a ship being carried out today. Bunkering is carried out from the quayside using a specially built pump station. The cost of this small unit was estimated to be EUR 400,000 [77]. No storage for methanol was constructed for this project. Road tanker trucks provide methanol which is pumped on board using the pumps on the quay. A Manntek "drip free" coupling is used for the connection to the ship. A bunkering checklist was developed for the bunkering operation. Previous research projects SPIRETH and METHAPU also used road tanker trucks for bunkering. These projects required smaller volumes of methanol and thus no land side pumping installation was provided. For SPIRETH the methanol tanker truck's own pump was used.

3.2.4 Potential need for treatment, fuel standards, and additives of ethanol and methanol fuels.

Methanol: For the chemical industry, methanol is supplied as a bulk product at 99.85% purity on a weight basis according to the International Methanol Consumers and Producers Association (IMPCA) methanol standard [21]. Methanol sold is subject to testing and analysis with methods recommended by IMPCA [21]. Although methanol with higher water content would likely be acceptable for use in some marine diesel engines, there is currently not any "lower quality" methanol produced and sold for fuel uses, except in China's internal market for automobile fuel. Thus for the initial use of methanol in ships, the IMPCA grade methanol should be assumed. For the SPIRETH project testing, there were no additives used for the methanol. For some applications, however, it could be recommended that a bitterant is added to discourage oral ingestion.

Ethanol: Scania alcohol combustion ignition engines use an ethanol fuel called ED95, produced by SEKAB, which has a composition as follows:

- Ethanol 95% by volume (92.2% by weight)
- Ignition improver 5% by weight (Beraid 3555, poly-ethylene-glycol, Akzo Nobel)
- MTBE + isobutyl alcohol 2.8% by weight

From [18].

3.3 Regulatory Environment Summary

The handling, transport, and use of methanol and ethanol is a long established practise in the chemical industry and there are well established regulations, guidelines, and best practices in place. On the marine side, there is a lot of experience with transporting methanol and ethanol as cargo and with using methanol in the offshore industry to prevent blocking and restriction of flow lines from the well head to the water surface. Their use as a marine fuel, however, is new and the development of regulations in this area can benefit from the experience in other sectors. Table 25 provides a summary of the main relevant regulations to be considered on ship side and shore side regarding the use of methanol as fuels, and identifies some areas where development may be required.

Table 25: Overview of standards and regulations and their status

Item	Methanol	Ethanol	Status Comment
Use as Ship Fuel			
IMO requirement	SOLAS Alternative Design		Existing
IMO requirement	IGF draft	IGF draft	Under development
Class Rules	DNV, LR	DNV	All in provisional or draft status: for more detail see section 3.1 of this report.
Ship Cargo Carriage Rules			
IMO regulations for carriage of chemicals in bulk	MARPOL Annex II and IBC Code	MARPOL Annex II	Sets out design and construction standards for ships carrying dangerous cargo.
IMO regulations for carrying packaged dangerous goods	IMDG Code	IMDG Code	Covers packing, container traffic, stowage, and segregation of goods.
Inland Waterways Ship Cargo Carriage Rules			
European regulations on carriage of dangerous goods	ADN	ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways.

Item	Methanol	Ethanol	Status Comment
		Bunkering	
Bunkering Ship	MARPOL Annex II and IBC Code	MARPOL Annex II	Specifies requirements for carriage of cargo; Ship to Ship connection not defined; metering
Bunkering truck	ADR	ADR	Existing European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)
Ship Side operations	ISM	ISM	Does not specifically consider fuelling with the proposed products
		Fuel Quality Standard	
Quality Standard	IMPCA Methanol Reference Specifications and/or ASTM D-1152/97	EN 15376 or ASTM D 4806 Standard Spec. for Denatured Fuel Ethanol for Blending	No marine fuel standard in existence. IMPCA standards used for current applications.

4 Safety Assessment of Methanol and Ethanol Fuelled Ships

The safety regulations for the use of methanol and ethanol as marine fuels are still under development, as described in the previous chapter. As part of this study a safety assessment was carried out for generic ship types to help contribute to discussions regarding safety and risk management of methanol and ethanol fuelled ships.

4.1 Previous risk assessment work

The few previous, existing, and planned installations for methanol fuel systems on board ships had case specific risk assessments to show that the designs and safety measures provide a similar level of safety to conventional fuel systems. This demonstration of "equivalent safety" is a requirement of IMO's SOLAS regulations in the absence of agreed requirements for the use of methanol as fuel. The following marine methanol projects underwent risk assessments and were approved by the relevant ship flag States and Classification Societies:

- METHAPU project: This pilot project was stated to be successful in demonstrating that the on-deck methanol tank and fuel cell system did not present any greater risk to the ship, occupants, or environment than that associated with conventional fuels [1].
- SPIRETH project: The test installation for this project also included an on-deck methanol tank, but in this case supplying fuel to an "on-board alcohol to ether" fuel conversion plant located below deck. The installation was approved by the Classification Society and flag State (the Swedish Transport Agency) for a ship trial.
- *Stena Germanica*: As of 2015 this is the only installation involving an integral methanol fuel tank and conversion of main engines to dual-fuel methanol/MGO operation. Risk assessment work includes hazard and operability studies for the fuels system and main engines as well as a specific fire risk assessment. This work was considered to show equivalent safety and was approved by both Lloyd's Register as Classification Society and the Swedish Transport Agency as flag State.
- Waterfront Shipping Chemical Tankers: These new tankers also include integral tanks for the methanol fuel. New dual-fuel engines are being installed and the ships are scheduled for delivery in 2016. The designs have undergone risk assessments by Classification Society.

The above projects demonstrate that safety considerations have not been a barrier to the use of methanol fuel systems on ships. Although there are no installations of ethanol fuel systems on ships, to the authors' knowledge, it is expected that safety considerations will not be a barrier for the use of this as fuel either. However, given the limited experience with these fuels and only a few designs to date, further assessment of safety for other ship types and installations will be useful for future projects.

For the work carried out in this study, a high level safety assessment was carried out for two generic ship types. This work generated some insights and safeguards to be considered for future specific applications and regulatory development. The safety assessment and results are discussed in the following sub-sections, which include excerpts from the full safety assessment report included in Appendix V.

4.2 Safety Assessment for Generic Passenger and Cargo Ships

The principal part of the safety assessment was a workshop facilitated by LR and attended by representatives from industry. The safety assessment considered two generic ship types: a passenger ship and a cargo ship. Differences for these ship types were noted between short-sea (coastal) and deep-sea trade for both methanol and ethanol as fuel. For the passenger ship, the scope covered generic designs for a Ro-Pax and cruise ship, and for the cargo ship, a generic chemical tanker served as the assessment example.

Different design possibilities regarding the fuel tanks were covered for each ship type. These included integral and independent fuel tanks and fuel tanks located above and below deck. For the cargo ship, fuel tanks located in cargo areas were also considered. Various operational possibilities were also considered where applicable, such as passengers embarking and disembarking, loading and unloading of vehicles, provisions and cargo, and bunkering from a shore facility, road truck, or barge.

A HAZID type technique in line with ISO 31010 [98] was used for the safety assessment, with indicative risk rating based on expert judgement and reference to incident and failure data. This helped to determine the adequacy of safeguards and whether the safety risks could be considered to be 'mitigated as necessary' as described in the IGF code [87].

4.2.1 Objective

The objective of the safety assessment was to evaluate the safety-risks to persons from the use of methanol/ethanol as fuel for ships. This was achieved by:

1. identifying and recommending safeguards that could reduce risk; and,
2. rating risks so as to test if they could be considered 'mitigated as necessary' as described in the IGF Code.

4.2.2 Scope

The safety assessment considered two generic ship types, a passenger ship and a cargo ship. For the passenger ship, the scope covered both a Ro-Pax and cruise ship, and for the cargo ship, a chemical tanker.

For both generic ship types the fundamental functional groups for investigation were taken as:

A. bunkering of fuel;

B. storage of fuel;

C. transfer (and preparation4) of fuel; and,

D. use of fuel.

These functional groups and their generic arrangement are illustrated and further detailed in Figures 15 and 16 together with a full listing of scope considerations. A simplified presentation of the functional groups is shown in the diagram below:

Figure 14: Functional groups (nodes)

Functional Groups

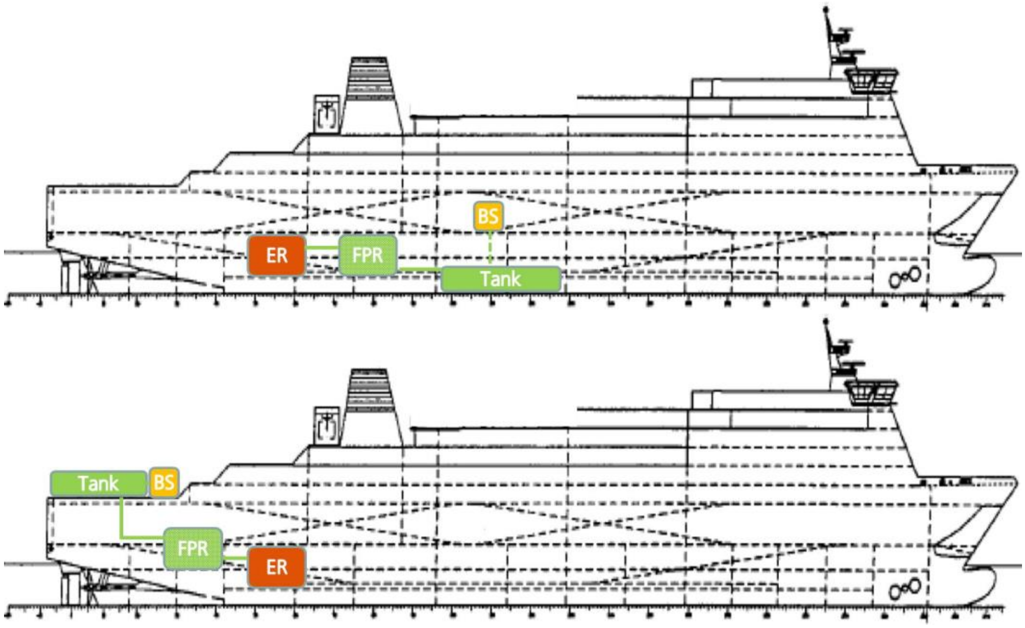
A. Bunkering of fuel.
A bunker station (on-deck, below deck, enclosed, semi-enclosed or open), typical equipment (e.g. hose, manifold, connectors) and delivery by shore facility, road truck or bunker barge.

B. Storage of fuel.
Independent fuel tanks located on-deck or below deck in a Fuel Storage Hold Space (FSHS), integral/structural tanks located below deck, and associated equipment (e.g. instrumentation).

C. Transfer (and preparation) of fuel.
Pumps, preparation equipment and pipework located in a dedicated Fuel Preparation Room (FPR - Pump Room including pressure regulation and process monitoring equipment, etc.) below deck or on-deck, and pipework from the fuel tank via the FPR to the ships' engines.

D. Use of fuel.
Engines and fuel pipework located in a dedicated machinery space (Engine Room) below deck.

Generic Arrangement of Functional Groups



General Design & Operational Considerations for Safety Assessment

1. Ro-Pax / Cruise Ship
2. Methanol / Ethanol.
3. Short sea (coastal) Ro-Pax / Deep sea Cruise ship.
4. Integral/structural fuel tanks / Independent fuel tanks.
5. Fuel tanks above deck / Fuel tanks below deck.
6. Passengers embarking / Passengers disembarking.
7. Vehicles - Loading / Unloading (Ro-Pax only).
8. Loading provisions.
9. Bunkering - Shore facility (Port-to-Ship, PTS) / Road truck (Truck-to-Ship, TTS) / Barge (Ship-to-Ship, STS).

Figure 15: Passenger Ship Generic

Functional Groups

A. Bunkering of fuel.
A bunker station (on-deck, below deck, enclosed, semi-enclosed or open), typical equipment (e.g. hose, manifold, connectors) and assumed delivery by established cargo loading (and if not available, by shore facility, road truck or bunker barge).

B. Storage of fuel.
Independent fuel tanks located on-deck, in the cargo area or below deck in a Fuel Storage Hold Space (FSHS), integral/structural tanks located below deck, and associated equipment (e.g. instrumentation). Configuration might include storage in a dedicated cargo tank or slop tank with a connection to a service tank (S tank, on or below deck).

C. Transfer (and preparation) of fuel.
Pumps, preparation equipment and pipework located in a dedicated Fuel Preparation Room (FPR - Pump Room including pressure regulation and process monitoring equipment, etc.) below deck, on-deck or within cargo area, and pipework from the fuel tank/service tank via the FPR to the ships' engines.

D. Use of fuel.
Engines and fuel pipework located in a dedicated machinery space (Engine Room) below deck.

Generic Arrangement of Functional Groups

General Design & Operational Considerations for Safety Assessment

1. Chemical Tanker
2. Methanol / Ethanol.
3. Short sea (coastal) / Deep sea.
4. Integral fuel tanks / Independent fuel tanks.
5. Fuel tanks above deck / Fuel tanks below deck.
6. Fuel tanks within cargo area.
7. Loading / Unloading cargo.
8. Loading provisions.
9. Bunkering – Established cargo loading / Shore facility (Port-to-Ship, PTS) / Road truck (Truck-to-Ship, TTS) / Barge (Ship-to-Ship, STS).

Figure 16: Cargo Ship – Chemical Tanker Generic

4.2.3 Approach - Assessment Technique

The safety assessment consisted of four distinct areas:

1. a principal workshop using a HAZID type technique in line with ISO 31010 [98]
2. indicative risk rating based upon expert judgement and data;
3. a subsequent workshop to complete item (1); and,
4. expert review and additions to workshop findings and risk ratings.

The principal workshop was facilitated by LR and consisted of a team collectively knowledgeable in design, operation and regulations pertaining to methanol/ethanol fuelled ships. This included part development of risk ratings. The subsequent workshop was undertaken entirely by LR together with completion of risk ratings.

The expert review of the findings from both workshops and additional comments were undertaken by members of the principal workshop teams and experts from two ship builders/designers. Draft versions of the report were circulated on two occasions for review by the external contributors. Detail on team members and the full report can be found in Appendix V.

The assessment technique used in the workshops is fully described in Tables 26 to 28. In summary, the workshop teams undertook a facilitated identification of how fuel could leak and cause harm. They then identified and considered safeguards that could eliminate or minimise these causes, referred to as prevention safeguards. Assuming failure of these safeguards, the team then identified and considered:

- firstly, mitigation safeguards to contain, detect and prevent ignition of a leak; and
- secondly, mitigation safeguards to further contain a leak (given failure of the first containment safeguard), and given ignition, contain and prevent the spread of fire, protect from thermal radiation and explosion, and detect and extinguish a fire.

To help promote inherently safer designs and arrangements, when considering safeguards the team firstly considered engineering solutions in preference to procedural controls and passive safeguards in preference to active safeguards. For example, a passive measure is one where no manual or automated action is required for it to function on demand and as intended. Whereas, an active measure requires some means of activation for it to operate.

Finally, the likelihood and consequences of harm were considered by the team and a risk rating determined using the risk matrix/criteria given in Table 28. Acknowledging the difficulty in appraising incident/failure data during a workshop and estimating the likelihood of 'rare' events, a number of the risk ratings were determined following the workshops so as to maximise effort in identifying and examining safeguards.

All causes, safeguards and risk ratings were recorded using a worksheet format as shown in Appendix V.

Prior to the principal workshop, a Terms of Reference (ToR) document [99] was issued. The purpose of this was to: help the team familiarise with the objectives, scope and intended approach; inform the team of the proposed schedule and team members; and remind the team of the properties and hazards of methanol/ethanol. It also provided an opportunity to comment and seek clarifications prior to the workshop. The properties and hazards of methanol and ethanol have been described in Chapter 2. Finally, on commencement of the workshops the facilitator summarised the objectives, scope and approach.

Table 26: Assessment Technique

1. With reference to Figure 15 and 16, for a functional group (e.g. storage) identify a cause (threat) that could result in a release (leak) of methanol/ethanol[a].
2. List the safeguards (barriers) that eliminate or minimise the likelihood of that cause. These safeguards are commonly referred to as 'preventative' or 'Prevention Safeguards'.
3. Assuming failure of the Prevention Safeguards listed in 2, such that there is a release of fuel, identify safeguards to:
   a. contain the release[b];
   b. detect the release; and
   c. prevent ignition of the release.

   These safeguards are 'mitigation' safeguards, and are referred to here as 'Mitigation Safeguards A'.
4. Assuming failure of the mitigation safeguards listed in 3, such that there is an uncontained release of fuel and/or there is a fuel fire, identify mitigation safeguards to:
   a. further contain the release[b];
   b. contain the fire and protect from thermal radiation/explosion;
   c. detect the fire; and
   d. extinguish the fire.

   These mitigation safeguards are referred to here as 'Mitigation Safeguards B'. The safeguards in 2, 3 and 4 should not be restricted to safeguards noted within existing and draft regulations, standards and guidelines.
5. For each functional group (or sub-group, as appropriate) judge the likelihood and consequences of harm to provide a risk 'rating' (refer to Table 27). In developing the rating consider the adequacy of the prevention and mitigation safeguards identified in 2, 3 and 4. The rating can be performed with and without additional/alternative safeguards.
6. Repeat 1 to 5 until all functional groups have been examined, and note any differences related to the general considerations listed in Figures 15 and 16.

Notes:

(a) as a minimum, the release cause categories listed in Table 26 will be considered

(b) 'contain' includes safeguards such as, safely collecting a release (e.g. using a holding tank), directing a release to a safe location (e.g. via a vent) and rendering a release harmless (e.g. by dilution with water)

Table 27: Release Cause Categories

1. Ship Collision, Contact and Grounding.

   This includes collision where the subject ship is the struck ship or the striking ship and impacts with other floating and fixed objects/structures (e.g. a harbour wall).

2. External Impact.

   This includes dropped objects (e.g. from crane operations) and impacts during loading (e.g. loading of cars and trucks).

3. External Fire.

   This covers flame impingement and thermal radiation from fires external to spaces and equipment dedicated to methanol/ethanol bunkering, storage, transfer & use.

4. Mechanical Failure.

   This covers failure of fuel containing equipment from wear, erosion, corrosion, fatigue, stress, etc. as a result of vibration, cyclic loads and heat/cold, etc.

5. Control Failure.

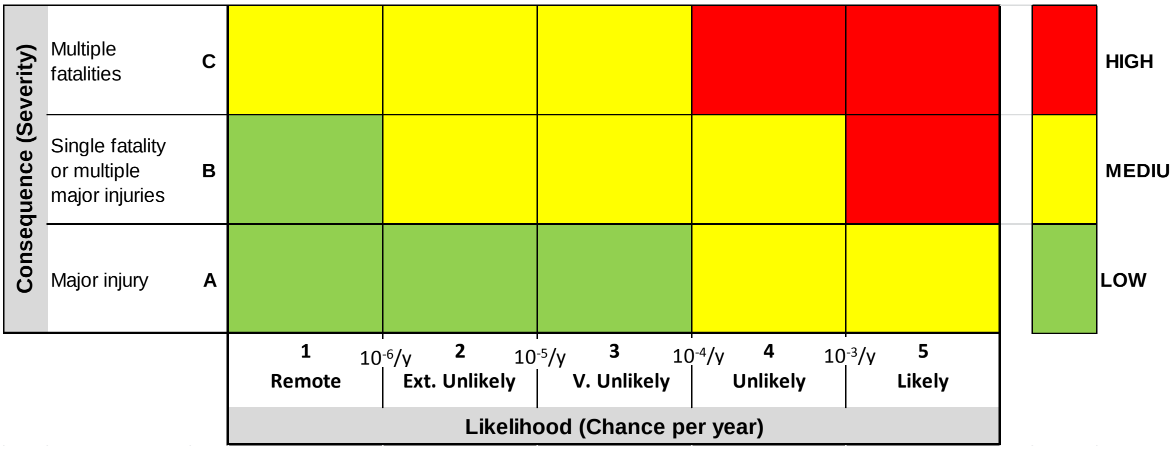
   This covers failure of instrumentation and process controls resulting in operation outside of the design intent.

6. Utilities Failure.

   This includes loss of power supply, heating, lighting and supporting services (e.g. inert gas supply).

Table 28: Risk Matrix / Criteria and Consequence / Likelihood Categories

Risk Matrix



Consequence Category

A. Major injury - long-term disability / health effect

B. Single fatality or multiple major injuries - one death or multiple individuals suffering long-term disability / health effects

C. Multiple fatalities - two or more deaths

Likelihood Category

1. Remote - 1 in a million or less per year
2. Extremely Unlikely - between 1 in a million and 1 in 100,000 per year
3. Very Unlikely - between 1 in 100,000 and 1 in 10,000 per year
4. Unlikely - between 1 in 10,000 and 1 in 1,000 per year
5. Likely - between 1 in 1,000 and 1 in 100 per year

The likelihood categories can be related to a ship life. For example, assuming a ship lifetime is 25 years, then for a scenario with an annual likelihood of 1 in a million (i.e. rating 1 Remote) the probability of occurrence in the ship's lifetime is 1 in 40,000 (i.e. 1/(10-6 x 25)).

Risk Rating and Risk Criteria Guidance

Low Risk – A1, A2, A3 & B1

The risk can be accepted as 'mitigated as necessary'. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.

Medium Risk – A4, A5, B2, B3, B4, C1, C2 & C3

The risk is tolerable and considered 'mitigated as necessary'. This assumes implementation of all reasonably practicable mitigation measures.

High Risk – B5, C4 & C5

The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

Mitigated as necessary: This is the wording used within the IGF Code and is akin to the phrase 'As Low As Reasonably Practicable', commonly referred to as ALARP.

4.2.4 Results

A complete record of the prevention and mitigation safeguards identified and the indicative risk ratings developed is given in Appendix V (see Annex A and Annex B for passenger ships and cargo ships, respectively).

A large number of safeguards were identified and a significant proportion of these are additional to those noted in the developing IGF Code for methanol/ethanol. These additional safeguards are shaded in green in Annexes A and B of the full report in Appendix V. It is important to note that not all safeguards will be applicable to all ships and neither will they be applicable to all fuel designs and arrangements. Some are obviously practical and of benefit but others may require further investigation as to their merits and feasibility. However, they are all listed for consideration and may help to inform prescriptive requirements and develop inherently safer designs and arrangements.

Importantly, the additional safeguards have contributed to further risk reduction, and in all cases the risks are judged 'low' to 'medium' and could be considered 'mitigated as necessary'[1]. The additional safeguards identified by the team are also summarised below in sections 4.2.4.1 and 4.2.4.2 for passenger ships and cargo ships, respectively. They are listed by the categories 'prevention' and 'mitigation. That is, those that could:

- prevent a release of fuel – referred to as '**Prevention Safeguards**';
- contain, detect and prevent ignition of a release of fuel. These are initial post-leak mitigations – referred to as **Mitigation Safeguards A**; and
- further contain a release of fuel, contain and protect from fire, and
- detect and extinguish fire[2]. These are secondary post-leak mitigations – referred to as **Mitigation Safeguards B**.

Figure 17 identifies how the safeguards relate to each other, in a timeline sequence of events.

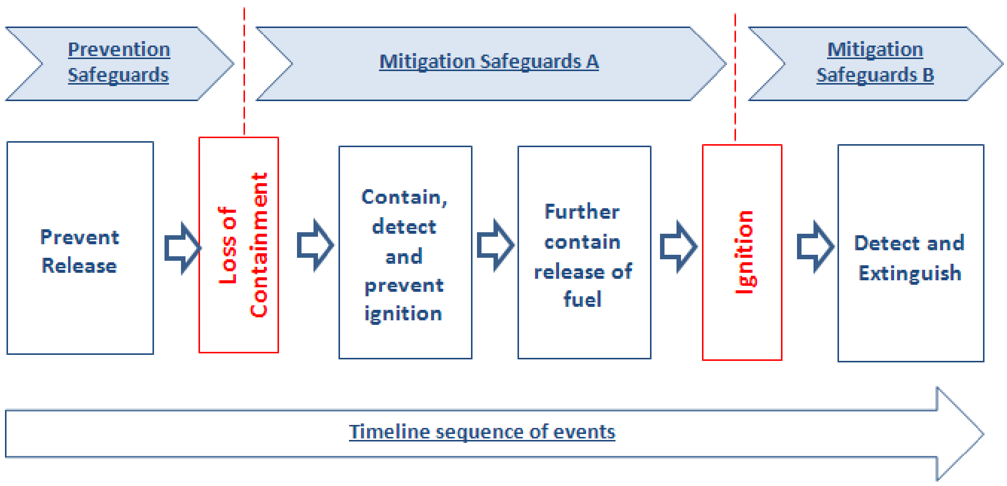


Figure 17: Safeguards considered, according to the logical hazard timeline of events

The references in brackets at the end of each listed safeguard refer to the worksheets in Annexes A and B of the full report in Appendix V, as appropriate. The references denote each

[1] The risk ratings are based on generic ship types. Specific ship designs could have different risk ratings.

[2] A fuller explanation of the safeguards is given in Table 25.

safeguards' first use for each functional group and release cause category (refer to Figures 15 and 16 and Table 26). For example, B-4-3 refers to 'storage (B) - mechanical failure (4) – third listed safeguard (3)'.

4.2.4.1 Safeguards Passenger Ships

There are a total of 45 additional safeguards:

- 28 Prevention Safeguards;
- 10 Mitigation Safeguards A; and
- 7 Mitigation Safeguards B.

From an inherently safer design perspective, it is important to note that nearly two thirds of the safeguards are focused on prevention (approximately 62%) and four of these are also included within the mitigation safeguards.

Interestingly none of the additional mitigation safeguards refer to fire extinguishment. This could be taken to mean that the existing (including currently proposed) fire-fighting measures are considered adequate or there is a lack of knowledge in this area on what improvements could be made specific to methanol/ethanol[3].

Methanol – Ethanol

The workshop team did not specifically distinguish between methanol and ethanol, and the safeguards are judged to be relevant to both fuels. This is because the principal hazard is that of fire and methanol/ethanol characteristics are similar, and for the vast majority of scenarios the toxicity differences are not a significant factor in identifying the provision of safeguards and estimating a risk rating. However, differences in properties and characteristics could result in differing detailed design requirements for certain safeguards, for example: means/setting of vapour detection; location of vapour detectors; and protection from toxic aspects where it might be possible for persons to come into contact with the fuel.

Ro-Pax Ships – Cruise Ships

The different operational profiles and designs of Ro-Pax ships and cruise ships could influence the likelihood and/or consequences of an incident involving methanol/ethanol. Considerations include, for example:

- Greater number of persons is potentially exposed on a cruise ship. However, this will be dependent upon the location of a potential spill/fire and the protection afforded;
- Coastal operation of a Ro-Pax between dedicated ports may reduce the likelihood of collision due to route experience. However, a Ro-Pax may be more likely to operate in congested waters or routes, increasing the likelihood of collision;
- Cruise ships are likely to store more fuel and so increase potential fire duration. However, there is a threshold above which increased fire duration will not necessarily result in more persons being harmed. This is because, for example, persons have sufficient time to evacuate to a safe location;
- The amount of fuel stored, however, and the complexity of fuel systems, directly depending on the number of methanol/ethanol consumers, will very likely dictate the design of detection and firefighting systems, such as deluge equipment which will have

[3] Research work is currently on-going in this area. For example, 'preFLASH - Preliminary study of protection against fire in low flashpoint, fuel', SP Technical Research Institute of Sweden, SP Report 2015:51.

a capacity proportional to the expected maximum amount of fuel expected to be released following an accidental loss of containment/ spillage.

- Ro-Pax is likely to bunker more often increasing the likelihood of a methanol/ethanol spill. However, bunkering might take place at night away from areas where persons can be expected and with no one on board other than bunkering personnel – thus, reducing the potential for harm.

It is clear from the above examples that the risk will be dependent upon the specific operational profile and design of the ship and it is not simply characterised by whether a ship is a Ro-Pax or a cruise ship. As such, the safeguards listed in tables 28 to 32 are generally applicable to both Ro-Pax ships and cruise ships with the exception that Protection Safeguard S7 refers to protection from vehicle impact. In addition, Prevention Safeguards S8, S9, S10, S16 and S25 and Mitigation Safeguard S36 include protection to/from vehicles.

Finally, although most fuel tanks might be located below deck, Ro-Pax ships are more likely to have fuel tanks and fuel containing equipment on open-deck compared to cruise ships. The following safeguards specifically refer to open-deck measures (also referred to as on-deck): Prevention Safeguards S8, S17 and S26; and, Mitigation Safeguards S29, S30, S32, S36, S40 and S41.

Table 29: Prevention Safeguards – Passenger Ship

Prevention Safeguards – Passenger Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SP1	Contain	The cofferdam around an integral fuel tank could contain water. In the event of a leak from the tank to the cofferdam the water would dilute the fuel and help minimise potential ignition.	B-1-2
SP2	Contain	Provide a secondary barrier around an independent fuel tank to safely contain a leak from failure of the fuel tank's primary barrier. This safeguard could also provide some protection from external impact and from thermal radiation and flame impingement.	B-1-3 B-3-4
SP3	Prevent release	Increase impact resistance of shell plating, hull girder and/or local structure in way of the fuel tank to provide additional protection from collisions and groundings.	B-1-4
SP4	Prevent release	Locate integral fuel tanks below the waterline so that given a release to sea, the leak is diluted to minimise potential ignition and toxicity	B-1-5
SP5	Prevent release	Design the fuel tank to deform without loss of integrity for specified impacts. This would provide additional protection against accidental impacts (such as dropped loads) and possibly protection from some from collisions and groundings	B-1-8 B-2-6
SP6	Prevent release	Provide the fuel tank with an internal flexible and expandable bag (liner or bladder). This would provide additional protection against accidental impacts such as dropped loads, collisions and groundings.	B-1-9 B-2-7

Prevention Safeguards – Passenger Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SP7	Prevent release	Install crash barriers/bollards around fuel tanks, FSHSs and FPRs that are located on decks where vehicles could be present.	B-2-1 C-2-3
SP8	Prevent release	In the vicinity of a fuel tank and FPR (e.g. on-deck) prevent lifting, maintenance, loading, laydown and vehicle activity without additional safeguards and an appropriate permit-to- work. This is to limit the likelihood of impact.	B-2-4, C-2-5
SP9	Prevent release	Provide physical separation between fuel tanks (and FSHSs/FPRs) and vehicles/other sources of fire. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement. This safeguard could be combined with SP10 to reduce or eliminate the separation distance.	B-3-1 C-3-5
SP10	Prevent release	Provide an appropriate rated class division between fuel tanks (and FSHSs/FPRs) and vehicles/other sources of fire. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement. This safeguard could be combined with SP9 to optimise the class division.	B-3-2 C-3-5
SP11	Prevent release	Minimise penetrations, fittings and connections. This is fundamental to inherently safer design and reduces the likelihood of a fuel release.	A-4-3 B-4-3 C-4-3 D-4-3
SP12	Prevent release	Ensure that the safety control system is separate and independent from the fuel control system. This is good engineering practice to eliminate common cause failures and increase the likelihood of safe shutdown. This safeguard is noted in Part A-1 (LNG) of the IGF Code (15.2.4) but is not within the developing sections for methanol/ethanol.	A-5-2 B-5-3 C-5-2 D-5-1
SP13	Prevent release	For dual-fuel engines, change-over to fuel oil if utilities supporting the safety control system fail, and consider change-over to fuel oil if utilities for the fuel control system fail. Utilities include electrical power, hydraulics, compressed air and inert gas.	B-6-2 B-6-4 C-6-2 D-6-2
SP14	Prevent release	Given sufficient warning and time, for dual-fuel engines, change-over to fuel oil. This would close the TMIV. The purpose of this is to reduce leak inventory of equipment and pipework downstream of the TMIV.	C-1-3 D-1-1 D-3-1
SP15	Prevent release	Within the FPR and ER prevent lifting, maintenance and inspection activity without additional safeguards (e.g. equipment is purged/ Inerted) and an appropriate permit-to-work. This is to limit the likelihood of impact.	C-2-1 D-2-3
SP16	Prevent release	Locate fuel pipework/lines within trunks, beyond the operational envelope of lifting operations, and/or behind structure to protect from mechanical damage and external	C-2-7, D-2-2

Prevention Safeguards – Passenger Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
		fires (especially to protect against potential vehicle impact and vehicle fires on ro-ro decks)	
SP17	Prevent release	Locate fuel preparation equipment within an FPR even when on-deck. This could be a protective box, cover or room. The purpose of this is to provide protection from external fire. It would also provide protection against external impact (e.g. dropped loads).	C-3-2
SP18	Prevent release	For dual-fuel engines, on change-over to fuel oil given failure of utilities supporting the safety control system, methanol/ethanol fuel should be recycled to a safe location (e.g. the fuel tank).	D-5-3
SP19	Prevent release	Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release.	A-1-1, A-2-4, A-3-1
SP20	Prevent release/ Contain/ Detect	The bunkering of fuel should be a manned operation with a dedicated 'watchman' to warn of potential events and the need to shutdown transfer. The purpose of this is to provide early warning, the opportunity to take early prevention or mitigation actions, and as a safeguard against failure of detection/shutdown systems	A-1-2, A-2-5, A-3-2
SP21	Prevent release/ Contain	The bunkering location in port should be selected to minimise exposure to harbour/ship traffic. The purpose of this is to limit the potential for third parties to initiate an accidental release of fuel, to minimise the chances of ignition, and to protect persons and property from harm in the event of a fuel release.	A-1-3
SP22	Prevent release	Delivery hose/arm independently supported at source and on the receiving ship. The purpose of this is to minimise excess movement and stress/strain on manifolds and the hose that could result in an accidental release of fuel (e.g. from the manifold connection of the receiving ship).	A-1-4
SP23	Prevent release	Establish a safe operational envelope for bunkering operations. This would include weather conditions (including electrical storms, wind, snow, ice and sea state, etc.).	A-1-5
SP24	Prevent release	Locate the Bunker Station beyond the operational envelop of lifting operations.	A-2-1
SP25	Prevent release	During bunkering, prevent lifting, loading, maintenance, laydown and vehicle activity in the vicinity of the BS unless additional safeguards are taken (e.g. BS is beyond the	A-2-2

Prevention Safeguards – Passenger Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
		operating envelope of lifting activities and embarking/disembarking passengers and vehicles are beyond the exclusion/safety zone and at a distance where they would not be directly harmed by a ignited or unignited spill).	
SP26	Prevent release/ Contain	For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages.	A-3-5
SP27	Prevent release	During bunkering provide a means of vapour management (such as vapour return to the supply). This is because during bunkering and unless necessary for safety, fuel vapour should not be released to atmosphere (IGF Code developing methanol/ethanol Section 3.2.9).	A-5-4
SP28	Prevent release	Shutdown of bunker transfer is expected given failure of utilities that support operation of the ESD-link (between bunker supply and receiving ship) and other safety controls. Utilities include electrical power, hydraulics, compressed air and inert gas, as appropriate.	A-6-2

Impact protection as a safeguard is noted within the developing methanol/ethanol section of the IGF Code in a generic way: e.g. "5.3.4 Fuel tanks located on open deck shall be protected against mechanical damage". The prevention measures above provide more specific considerations on such protection for fuel tanks and other fuel containing equipment (SP2, SP5, SP6, SP7, SP8, SP17 and SP26).

Table 30: Mitigation Safeguards "A" – Passenger Ship

Mitigation Safeguards A			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SP29	Contain	In the event of a fuel release on-deck, inlets/outlets to spaces where persons can be expected (e.g. accommodation) should be closed to prevent ingress of vapour.	B-2-8
SP30	Contain	Additional intermediate coamings to be provided for fuel tanks located on-deck or reduce coaming extent and increase coaming height. The purpose of this is to minimise the surface area of a spill and so limit evaporation and formation of vapour.	B-4-6
SP31	Contain	All inlets/outlets to the ship that are located within the bunkering exclusion/safety zone should be closed to prevent ingress of vapour.	A-1-8
SP32	Contain	For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages.	A-1-7, this is also a Prevention Safeguard SP26
SP33	Detect	As part of fuel tank instrumentation, provide an alarm to warn when the liquid level decreases at a rate beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system.	B-1-14
SP34	Detect	As part of fuel tank instrumentation, provide an alarm to warn when the liquid flow-rate from the tank is beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system.	B-1-15
SP35	Detect	Provide liquid level detection in drip trays to warn of a spill.	C-2-12
SP36	Prevent Ignition	Water deluge, water spray or foam systems could be activated to help prevent ignition within the FSHS, FPR, and enclosed BS, or within the vicinity of fuel tanks/BS located on-deck. Water deluge would provide dilution whilst foam would limit evaporation. Consideration would need to be given to limiting avoiding 'spreading' of a spill on-deck.	A-1-15, A-1-16, B-1-19
SP37	Prevent ignition	Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release.	A-1-14, this is also a Prevention Safeguard SP19
SP38	Prevent ignition	Establish a safe operational envelope for bunkering operations. This would consider, for example, weather and meteorological conditions (i.e. electrical storms, wind, snow, ice and sea state, etc.).	A-1-18, this is also a Prevention Safeguard SP23

Table 31: Mitigation Safeguards "B" – Passenger Ship

Safeguard	Objective	Description	Type (see Appendix V – Safety Assessment)
Mitigation Safeguards B			
SP39	Contain	Locate fuel tanks (and FSHS/FPR/BS) away from accommodation and areas/spaces where persons are normally expected, and away from areas/spaces with flammable materials (e.g. vehicles). Appropriate separation from such areas/spaces needs to be determined. The purpose of this is to protect areas/spaces from thermal radiation and flame impingement and limit escalation of fire. Part A-1 of the IGF Code suggests 10 m (11.5.2) but this may not be appropriate for methanol/ethanol fires.	A-1-22 B-1-26 B-1-27 C-1-14
SP40	Contain	Provide an appropriate rated class division between fuel tanks on-deck (and FSHSs/FPRs) and areas/spaces where persons are normally expected. This would provide some protection from thermal radiation and direct flame impingement.	B-3-17, C-2-24, this is also a Prevention Safeguard similar to SP10
SP41	Contain	Provide deluge/spray on accommodation and control station boundaries, etc. within a determined distance from a FSHS/FPR that is located on-deck. This would provide some protection from thermal radiation and direct flame impingement.	C-2-25
SP42	Contain	Provide water cooling/deluge to protect the hull from potential fires in the BS.	A-1-28
SP43	Detect	Provide fixed and/or portable IR cameras to detect fires/flames. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye.	A-1-23 B-1-28 C-1-15 D-1-12
SP44	Detect	Provide CCTV with IR capability. This would enable fires to be viewed remotely and provide information to help with emergency actions.	A-1-24 B-1-29 C-1-16 D-1-13
SP45	Detect	Provide temperature instrumentation to detect fire. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye.	A-1-26 B-1-31 C-1-18 D-1-15

4.2.4.2 Safeguards for Cargo Ships

There are a total of 40 additional safeguards:

- 22 Prevention Safeguards;
- 11 Mitigation Safeguards A; and
- 7 Mitigation Safeguards B.

From an inherently safer design perspective, it is important to note that more than half of the safeguards are focused on prevention (55%). As noted previously not all safeguards will be applicable to all ships or to all fuel designs and arrangements.

As per the passenger ship work reported in Section 4.2.4.1, none of the additional mitigation safeguards refer to fire extinguishment. This could be taken to mean that the existing (including currently proposed) fire-fighting measures are considered adequate or there is a lack of knowledge in this area on what improvements could be made specific to methanol/ethanol[4].

Methanol – Ethanol

In keeping with the passenger workshop, the cargo workshop team did not specifically distinguish between methanol and ethanol, and the safeguards were judged to be relevant to both fuels. This is because the principal hazard is that of fire and methanol/ethanol characteristics are, in that regard, similar, and for the vast majority of scenarios the toxicity differences are not a significant factor in identifying the provision of safeguards and estimating a risk rating.

However, differences in properties and characteristics could result in differing detailed design requirements for certain safeguards, for example: means/setting of vapour detection; location of vapour detectors; and protection from toxic aspects where it might be possible for persons to come into contact with the fuel.

Short Sea (coastal) – Deep Sea

The different operational profiles and designs of coastal and deep sea vessels could influence the likelihood and/or consequences of an incident involving methanol/ethanol. Considerations include, for example:

- coastal operation between dedicated ports may reduce the likelihood of collision due to route experience. However, coastal operations might experience more congested waters or routes, increasing the likelihood of collision;
- deep sea ships are likely to store more fuel and so increase potential fire duration. However, there is a threshold above which increased fire duration will not necessarily result in more persons being harmed. This is because, for example, persons have sufficient time to evacuate to a safe location;
- the amount of fuel stored, however, and the complexity of fuel systems, directly depending on the number of methanol/ethanol consumers, will very likely dictate the design of detection and firefighting systems, such as deluge equipment which will have a capacity proportional to the expected maximum amount of fuel expected to be released following an accidental loss of containment/ spillage;
- a ship designed for coastal operation is likely to bunker more often increasing the likelihood of a methanol/ethanol spill. However, bunkering might take place at night away from areas where persons can be expected and with no one on board other than bunkering personnel - thus, reducing the potential for harm.

It is clear from the above examples that the risk will be dependent upon the specific operational profile and design of the ship and it is not simply characterised by whether a ship

[4] Research work is currently on-going in this area. For example, 'preFLASH - Preliminary study of protection against fire in low flashpoint, fuel', SP Technical Research Institute of Sweden, SP Report 2015:51.

is designed for coastal or deep sea operations. As such, the safeguards listed below are generally applicable to both operational modes.

Many of the safeguards listed in the tables below are similar or identical to those listed for passenger ships in Chapter 4.5.1 and these 'passenger' safeguards are denoted by the abbreviation SP.

Table 32: Prevention Safeguards – Cargo Ship

Prevention Safeguards – Cargo Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SC1	Contain/ Prevent ignition	The cofferdam around an integral fuel tank could contain water. In the event of a leak from the tank to the cofferdam the water would dilute the fuel and help minimise potential ignition.	(B-1-2) SP1
SC2	Prevent release	Increase impact resistance of shell plating, hull girder and/or local structure in way of the fuel tank to provide additional protection from collisions and groundings.	(B-1-7) SP3
SC3	Prevent release	Locate integral fuel tanks below the waterline so that given a release to sea, the leak is diluted to minimise potential ignition and toxicity.	(B-1-8) SP4
SC4	Prevent ignition	Emergency discharge of fuel to a safe location, such as a holding tank or direct to sea.	(B-1-10)
SC5	Prevent release	Design the fuel tank to deform without loss of integrity for specified impacts. This would provide additional protection against accidental impacts (such as dropped loads) and possibly protection from some from collisions and groundings.	(B-1-11) SP5
SC6	Prevent release	Provide the fuel tank with an internal flexible and expandable bag (liner or bladder). This would provide additional protection against accidental impacts such as dropped loads, collisions and groundings.	(B-1-12) SP6
SC7	Procedural Measure	Area accessible only to authorised crew.	(B-2-4, C-2-5)
SC8	Prevent release	In the vicinity of a fuel tank and FPR, and in the vicinity of a BS during bunkering, prevent lifting, maintenance, loading and laydown without additional safeguards and an appropriate permit-to-work. This is to limit the likelihood of impact.	(A-2-2, B-2-3, C-2-4) SP8
SC9	Prevent release	Provide physical separation between fuel tanks (and FSHSs/FPRs) and other sources of fire, or separate from cargo areas. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement.	B-3-1 C-3-5 Same as SP9
SC10	Prevent release	Minimise penetrations, fittings and connections. This is fundamental to inherently safer design and reduces the likelihood of a fuel release.	B-4-3 C-4-3 D-4-3 Same as SP11

Prevention Safeguards – Cargo Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SC11	Procedural Measure/ Prevent release	For dual-fuel engines, change-over to fuel oil if utilities supporting the safety control system fail, and consider change-over to fuel oil if utilities for the fuel control system fail. Utilities include electrical power, hydraulics, compressed air and inert gas.	A-6-2 B-6-2 C-6-2 D-6-2 A-6-4 B-6-4 C-6-4 D-6-4 Same as SP13
SC12		Given sufficient warning and time, for dual-fuel engines, change-over to fuel oil. This would close the TMIV. The purpose of this is to reduce leak inventory of equipment and pipework downstream of the TMIV.	C-1-3 D-1-1 Same as SP14
SC13	Prevent ignition	Provide an appropriate rated class division between the ER and FPR. This is to protect from thermal radiation and direct flame impingement.	C-1-5
SC14	Prevent release	Within the FPR and ER prevent lifting, maintenance and inspection activity without additional safeguards (e.g. equipment is purged/ Inerted) and an appropriate permit-to-work. This is to limit the likelihood of impact.	C-2-1 D-2-3 Same as SP15
SC15	Prevent release	Locate fuel pipework/lines within trunks, beyond the operational envelope of lifting operations, and/or behind structure to protect from mechanical damage and external fires.	C-2-6 D-2-2 Same as SP16
SC16	Procedural Measure/ Prevent release	Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release.	A-1-1 Same as SP19
SC17	Procedural Measure/ Prevent release/ Contain	The bunkering of fuel should be a manned operation with a dedicated 'watchman' to warn of potential events and the need to shutdown transfer. The purpose of this is to provide early warning, the opportunity to take early prevention or mitigation actions, and as a safeguard against failure of detection/shutdown systems.	A-1-2 Same as SP20
SC18	Procedural Measure/ Prevent release/ Contain	The bunkering location in port should be selected to minimise exposure to harbour/ship traffic. The purpose of this is to limit the potential for third parties to initiate an accidental release of fuel, to minimise the chances of ignition, and to protect persons and property from harm in the event of a fuel release.	A-1-3 Same as SP21

Prevention Safeguards – Cargo Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SC19		Delivery hose/arm independently supported at source and on the receiving ship. The purpose of this is to minimise excess movement and stress/strain on manifolds and the hose that could result in an accidental release of fuel (e.g. from the manifold connection of the receiving ship).	A-1-4 Same as SP22
SC20		Establish a safe operational envelope for bunkering operations. This would include weather conditions (including electrical storms, wind, snow, ice and sea state, etc.).	A-1-6 Same as SP23
SC21		During bunkering provide a means of vapour management (such as vapour return to the supply). This is because during bunkering and unless necessary for safety, fuel vapour should not be released to atmosphere (IGF Code developing methanol/ethanol Section 3.2.9).	A-5-4 Same as SP27
SC22		Shutdown of bunker transfer is expected given failure of utilities that support operation of the ESD-link (between bunker supply and receiving ship) and other safety controls. Utilities include electrical power, hydraulics, compressed air and inert gas, as appropriate.	A-5-2 Same as SP28

Table 33: Mitigation Safeguards "A" – Cargo Ship

Safeguards A – Cargo Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SC23	Contain	For fuel tanks located on-deck provide additional intermediate coamings or reduce coaming extent and increase coaming height. The purpose of this is to minimise the surface area of a spill and so limit evaporation and formation of vapour.	B-4-7 Same as SP30
SC24	Contain	For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages.	A-1-8 Same as SP32
SC25	Contain	All inlets/outlets to accommodation closed on leak detection within vicinity of leak.	B-2-8 C-2-9
SC26	Contain	All inlets/outlets to the ship that are located within the bunkering exclusion/safety zone should be closed to prevent ingress of vapour.	A-1-9 Same as SP31
SC27	Contain/direct	Provide explosion relief in exhaust vented to a safe location.	D-5-4
SC28	Prevent ignition	Emergency discharge of fuel to a safe location, such as a holding tank or direct to sea (in the event of a BS release).	A-1-11
SC29	Detect	Provide liquid level detection in drip trays to warn of a spill.	C-2-11 Same as SP35
SC30	Detect	As part of fuel tank instrumentation, provide an alarm to warn when the liquid level decreases at a rate beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system.	B-1-19, C-1-7, D-1-4 Same as SP33
SC31	Detect	As part of fuel tank instrumentation, provide an alarm to warn when the liquid flow-rate from the tank is beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system.	B-1-20, C-1-8, D-1-5 Same as SP34
SC32	Prevent ignition	Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release.	A-1-15, this is also a Prevention Safeguard SC16 – Same as SP19
SC33	Prevent ignition	Establish a safe operational envelope for bunkering operations. This would consider, for example, weather and meteorological conditions (i.e. electrical storms, wind, snow, ice and sea state, etc.).	A-1-19, this is also a Prevention Safeguard SC20) Same as SP38

Table 34: Mitigation Safeguards B – Cargo Ship

Mitigation Safeguards B – Cargo Ship			
Safeguard	**Objective**	**Description**	**Type** (see Appendix V – Safety Assessment)
SC34	Contain/ protect	Locate lifeboats and emergency routes at a distance where thermal radiation will not impair use.	B-1-37
SC35	Contain	Locate fuel tanks (and FSHS/FPR/BS) away from accommodation and areas/spaces where persons are normally expected, and away from areas/spaces with flammable materials. Appropriate separation from such areas/spaces needs to be determined. The purpose of this is to protect areas/spaces from thermal radiation and flame impingement and limit escalation of fire. Part A-1 of the IGF Code suggests 10 m (11.5.2) but this may not be appropriate for methanol/ethanol fires.	A-1-23 B-1-32 C-1-15 Same as SP39
SC36	Contain	Provide water cooling/deluge to protect the hull from potential fires in the BS.	A-1.29 Same as SP42
SC37	Detect	Provide fixed and/or portable IR cameras to detect fires/flames. Fuel fires are not always easy to detect because methanol/ ethanol flames are difficult to see with the naked eye.	A-1-24 B-1-33 C-1-17 D-1-12 Same as SP43
SC38	Detect	Provide CCTV with IR capability. This would enable fires to be viewed remotely and provide information to help with emergency actions.	A-1-25 B-1-34 C-1-18 D-1-13 Same as SP44
SC39	Detect	Provide sea water/water detection within the fuel tanks	B-1-38
SC40	Detect	Provide temperature instrumentation to detect fire. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye. (A-1-27, B-1-36,	C-1-20 D-1-15 Same as SP45

4.2.4.3 Risk Rank Matrices

The safeguards presented in the previous section are the result of the safety assessment exercise, not only with the contribution of experts during the safety meeting but also as a result from further consultation, where different contributions have been taken into account to define a comprehensive list of different measures (either for hazard prevention or mitigation) that could be relevant for ships using methanol/ethanol as fuel.

In addition to the definition of the presented safeguards, risk ranking was discussed and attempted. As defined in Table 27, where the key risk-matrix is presented, the objective was to display graphically how each considered release event would qualify, first without safeguards or safety controls and, secondly, how would these prevention/mitigation measures succeed in mitigating risk.

The lack of information on methanol/ethanol fuel incident data, and the generic knowledge of possible release/ignition consequences, would have made it difficult to have any type of quantitative approach to risk. The discussions however have seen the sharing of different professional experiences (see Appendix V for HAZID Team composition) and have developed towards the drafting of risk matrices for each "functional group" and "release scenario" presented in Table 26. The risk ranking is then agreed for each scenario, depending on the release cause considered and on the potential effect of the proposed safeguards.

Each presented risk matrix, as presented from Figures 18 to 21, includes a substantial amount of uncertainty and the graphical presentation is intended mostly to provide a representation on how methanol/ethanol related hazards, more specifically release events, can be qualitatively considered from a safety perspective.

For each individual risk matrix a small legend is provided so as to highlight the differences in the ranks contained in the matrix cells and, also, to have a short indication on how different safeguards impact the risk ranking for a given release scenario.

Figure 18: Indicative Risk Ratings – Passenger Ships

D. Use of Fuel

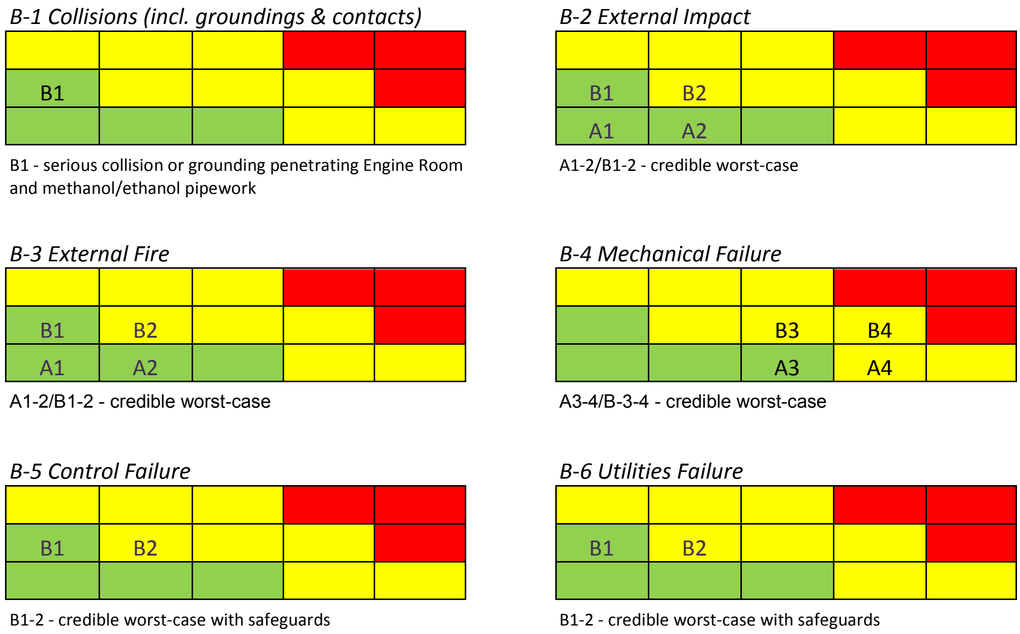


Figure 18 continued: Indicative Risk Ratings – Passenger Ships

Figure 19 Indicative Risk Ratings – Cargo Ships

Figure 19 continued: Indicative Risk Ratings – Cargo Ships

4.2.5 Findings of the safety assessment

A large number of safeguards were identified, many of which were additional to those noted in the developing IGF Code for methanol/ethanol. The safeguards will not be applicable to all designs and operations but they can provide useful input when deliberating prescriptive requirements and considering inherently safer designs and arrangements.

It is concluded that safeguards can be provided to ensure the safety risk from methanol/ethanol as marine fuel is 'mitigated as necessary', as required by the IGF Code [87].

4.2.6 Findings requiring further investigation

1. Definition of ***separation distances*** from tanks or vent outlets could benefit from further investigation, regarding the protection the distances provide in case of methanol or ethanol release. Especially as for methyl alcohol the distance requirement from tank vents is currently under discussion for the carriage as a cargo and could change to 15 m. This subject relates to SP 39 and SC 35: "Locate fuel tanks (and FSHS/FPR/BS) away from accommodation and areas/spaces where persons are normally expected, and away from areas/spaces with flammable materials. Appropriate separation from such areas/spaces needs to be determined. The purpose of this is to protect areas/spaces from thermal radiation and flame impingement and limit escalation of fire. Part A-1 of the IGF Code suggests 10 m (11.5.2) but this may not be appropriate for methanol/ethanol fires. (A-1-23, B-1-32,C-1-15)"

2. Further investigation on the appropriate ***distribution of methanol and ethanol vapours*** may be beneficial. Ventilation was discussed, whereas the draft code contains requirements, these differ from the IBC requirements, the following was noted: Regarding the air change requirements some discussion has been had, the current IBC requirement is: pump room 20 air changes/h, for spaces normally entered by staff; 30 air changes/h, not normally entered

spaces; 16 air changes/h. Ventilation rates in the engine room should consider the health aspect of the materials. See worksheets.

3. ***IR*** and ***CCTV*** should be evaluated for their cost benefit. SP44/SP43, SC38/SC37. These recommendations were identified for every functional node and the vessel may benefit from uptake of these technologies, if they are found to be available and reliable sufficiently in the conditions when they will be required.

4. The efficacy of traditional ***fire extinguishing systems*** in the case of methanol or ethanol fires should be further evaluated. The fire extinguishing system was discussed whereas the draft code contains requirements; water mist, fixed water-spray (as water can dilute but may spread the fire and still continue to burn), foam or gas based system (gas based systems may be less effective to extinguish, as they may not cool sufficiently and as methyl and ethyl alcohol provide an inherent oxygen, so that re-ignition may be possible, it could also add delays in releasing), but a two stage extinction system comprising water and then gas may be most effective.

4a. Furthermore some work on the ***test chamber sizes or improved scaling methods*** may be of use as it appears that the availability of water mist system for Mach. Space cat. A and cargo pump room having "large" volumes or height may be limited. This limitation is derived by the test conditions used during the test and not from the technology used, in particular the height limit issue can be solved by installing an additional row of nozzles with the right spacing and the volume of the protected space can be scaled to two times the volume tested if the conditions of MSC.1/Circular.1385 – Scientific Methods on Scaling of Test Volume for Fire Test on Water-Mist Fire-Extinguishing Systems – (10 December 2010) are satisfied. It is noted that a "typical" water mist system is approved up to 3300 m^3, bigger volumes would require bigger (and expensive) test chambers.

4b. Water Mist Fixed Fire Fighting System (FFES) for "methanol" Mach. Space cat. A and Cargo pump room, this system should be generally tested in accordance with ***MSC/Circular.1165*** – (Revised Guidelines for the Approval of Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces and Cargo Pump-Rooms - (10 June 2005)) however the ***methanol/ethanol fuel should be included*** in the fire scenarios indicated in this circular.

5. The ***switch-over conditions for dual fuel*** vessels need to be developed further in the IGF Code. The findings in the HAZID for dual fuelled vessel switch over conditions were: SP13. SC 11. For dual-fuel engines, change-over to fuel oil if utilities supporting the safety control system fail, and consider change-over to fuel oil if utilities for the fuel control system fail. Utilities include electrical power, hydraulics, compressed air and inert gas. (B-6-2, B-6-4, C-6-2, D-6-2) , SP14. SC 12 Given sufficient warning and time, for dual-fuel engines, change-over to fuel oil. This would close the TMIV. The purpose of this is to reduce leak inventory of equipment and pipework downstream of the TMIV. (C-1-3, D-1-1, D-3-1), SC 39 Water sensing in tank, Collision detection: Chemical Tanker B-1.21.

6. The current rules and IGF draft refer to cofferdam on the ship internal side to protect the storage tank. Further work could be of benefit in order facilitate alternative solutions as a ***Secondary barrier SP1, SP2*** such as the ballast tank solution of *Stena Germanica* or the bladder found in ***SP 6.*** The same applies to considerations regarding the ship's external side. ***SP 5, SP6.***

7. ***Bunkering guidance*** should be developed, specifically for the passenger ship scenarios this may be more prudent than the chemical tanker(s) as there the loading of methyl and ethyl alcohol is a known on-board process. The following HAZID findings should be considered:

- SP24, SP25, SP26
- manned operation SP 20
- weather conditions (discussed, but for chemical tankers loading is already a weather dependent action), SP23, SP38
- exclusion zones SP19, SP21
- open deck collection of drips, SP 32
- shutdown conditions and method
- protocol for communications SP28
- the conditions of air inlets to the ship SP31, SC25
- PPE (discussed),
- hose handling SP22, Dry break couplings SP22, SC19 should be evaluated for their cost benefit regarding ship type specific applicability.
- prevention of static build up (in code),
- emergency plan (discussed). SP28, SP43, SP 42

4.2.7 Recommendations for further assessment

It is important to note that not all safeguards identified in the previous section will be applicable to all ships and neither will they be applicable to all fuel designs and arrangements. Some are obviously practical and of benefit but others may require further investigation as to their merits and feasibility. In addition, there may be alternative safeguards that could provide equivalent prevention or mitigation. Further assessment is therefore required for additional designs to select the safeguards that may be most appropriate. In addition the study team did not distinguish between methanol and ethanol on a detailed level because the principal hazard of both is that of fire and in the vast majority of scenarios the toxicity of methanol was not a significant factor in identifying the provision of safeguards and estimating a risk rating. However, differences in properties and characteristics could result in differing detailed design requirements for certain safeguards such as means/setting of vapour detection; location of vapour detectors; and protection from toxic aspects where it might be possible for persons to come into contact with the fuel. These should be considered in further assessments.

The safeguards identified are indiscriminate of whether or not they are cost effective. Selection of what is to be done for a specific design or developing regulation should be on the basis of a cost benefit analysis for a specific mitigation measure in a specific project. This was not within the scope of the high level assessment carried out for this project.

Six subject areas requiring further work or investigation were identified from these findings:

- Separation distances as a prevention measure
- The distribution of methanol and ethanol vapours,
- Fire extinguishing and detection systems, specifically IR and CCTV
- Defined switch-over conditions for dual fuel
- Alternatives to cofferdams as secondary barrier
- The need for bunkering guidance.

5 Conclusions

This study assessed the potential of methanol and ethanol as alternative fuels in shipping to comply with low sulphur fuel requirements. The main areas covered by this evaluation included:

- Technical and operational factors, including technology readiness of engines and associated equipment, and experience with previous marine projects;
- Availability and supply of methanol and ethanol;
- Environmental impacts including fuel production and supply, emissions from combustion, and impacts on receiving waters from accidental spills;
- Safety and regulations pertaining to use as a ship fuel;
- Costs and economic considerations including operational costs and investment costs for both retrofit and new build ship installations.

For each of these main areas, both benefits and potential barriers were identified and compared with conventional fuels and LNG as described below.

Technical and operational readiness / experience with previous and current projects

Methanol has been tested as a fuel in marine engines in laboratories in a few projects and in one full scale installation on board the *Stena Germanica* Ro-Pax ferry in 2015. Engine performance was shown to be as good as with conventional fuels for these tests and emissions were found to be lower. Methanol has been tested in heavy duty diesel engines in land based applications with good results. For the marine market, in addition to the *Stena Germanica* conversion seven new chemical tankers with dual fuel methanol engines were commissioned by Waterfront Shipping to be delivered in 2016. Although results have been good, the limited experience with methanol on ships may be perceived as a barrier. Additional projects and longer term operational experience should help build confidence and acceptance of this fuel.

For ethanol, there were no projects identified for testing in marine diesel engines but there is long term experience with smaller heavy duty engines for land transport. It is expected that ethanol would have similar good performance in marine engines and there are no technical barriers foreseen but the lack of previous tests and conversions may be considered a relative disadvantage for ethanol.

Regarding ship board installations for fuel storage and transfer, considerations need to be given to material choices due to higher corrosivity of methanol and ethanol as compared to conventional fuels. Both methanol and ethanol have an energy density that is approximately half that of conventional fuels. This requires larger storage volumes or more frequent bunkering, and could be a barrier for some ship applications. In the case of the *Stena Germanica* conversion, existing ballast tanks were converted for methanol fuel storage.

Availability and supply of methanol and ethanol

Methanol is widely available on both a global and European basis as it is used extensively in the chemical industry. It is available at major ports, with large bulk storage terminals in both Rotterdam and Antwerp, and it is transported in deep sea and short sea shipping and via inland waterways to customers. For the current and past projects that have used methanol as ship fuel, bunkering has been done by truck. The availability of terminals for marine fuel and bunkering vessels would be important for encouraging uptake of the fuel. Terminals for methanol fuel would be similar to those for liquid oil fuels and construction costs are relatively low, particularly as compared to LNG. Conversion of existing bunkering vessels for methanol use was considered to be feasible and relatively low cost. This is an advantage compared to LNG, but an area that needs some development as compared to conventional fuels where there are terminals and bunkering systems already in existence.

Ethanol can also be found at most large chemical storage hubs in Europe. It is the most widely used biofuel in land based transportation but is primarily used blended with gasoline. Bunkering and fuel storage facilities would be very similar to methanol. Thus there is also some cost advantage as compared to LNG but need for development of marine facilities.

Environmental Impacts

Both methanol and ethanol have many advantages regarding environmental impacts as compared to conventional fuels. Methanol and ethanol do not contain sulphur so their use ensures compliance with sulphur limits in emission control areas. When a pilot fuel ignition concept is used a small amount of sulphur oxides will be produced depending on the amount and sulphur content of pilot fuel used. Tests of methanol marine engines have shown low NO_x emissions and also very low particulate emissions as compared to use of oil fuels. Although there are currently no regulations regarding particulate emissions, they have been shown to have adverse impacts on human health and the environment. The choice of methanol or ethanol fuel would ensure compliance with any future particulate emission regulations that may be brought in for shipping.

When a life cycle approach to assessing environmental impacts of fuels is taken, impacts from both production and use of the fuel should be considered. For methanol, the environmental impact of production and use “well to wake”, using greenhouse gas equivalents as an indicator of global warming potential, varies according to the feedstock. The majority of methanol available on the market is produced from natural gas. Renewable methanol is produced from pulp mill residue in Sweden, waste in Canada, and from CO_2 emissions at a small commercial plant in Iceland. Methanol produced using natural gas as a feedstock has “well to tank” emissions similar to other fossil fuels such as LNG and MDO. Bio-methanol produced from second generation biomass such as waste wood has a much lower global warming potential than fossil fuels and is lower than ethanol by most production methods. “Well to wake” emissions from ethanol are lower than fossil fuels but the amount varies with production methods and feedstock. For example the ethanol produced in Brazil and in Sweden has much lower “well to tank” greenhouse gas emissions than that produced from corn in the US.

The behaviour of methanol and ethanol fuels when spilled to the aquatic environment is also important from an environmental performance perspective as ship accidents such as collisions, groundings and foundering may result in fuel and cargo spills. Both methanol and ethanol dissolve readily in water, are biodegradable, and do not bioaccumulate. They are not rated as toxic to aquatic organisms.

Safety and Regulations

The handling, transport, and use of methanol and ethanol is a long established practice in the chemical industry and there are well established regulations, guidelines, and best practices in place for safety. On the marine side, there is a lot of experience with transporting methanol and ethanol as cargo and with using methanol in the offshore industry. The use of methanol and ethanol as a marine fuel, however, is new and the safety regulations for this application are still under development. The flashpoints of methanol and ethanol are both below the minimum flashpoint for marine fuels specified in the International Maritime Organization’s

(IMO) Safety of Life at Sea Convention (SOLAS), which means that a risk assessment or evaluation must be carried out for each case demonstrating fire safety equivalent to conventional fuels. Guidelines have been drafted on the use of methanol and ethanol fuels on ships, for future incorporation in the newly adopted International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF CODE). This will facilitate the use of these fuels on board ships. The previously described *Stena Germanica* and Waterfront shipping chemical tanker projects both carried out risk assessments and were approved for installation, demonstrating that safety considerations are not a barrier to the use of methanol fuel systems on ships. The requirements for carrying out a risk assessment, however, may be onerous for smaller ships and applications, so the adoption of international codes and guidelines and more work in this area may encourage more to consider use of these fuels.

Cost and economic considerations

Methanol prices were below the price of low sulphur marine gas oil (MGO) on an energy basis for two years from 2011 to 2013, prior to the recent oil price crash, making it an attractive sulphur compliance option during that time. With the low oil prices in 2014 and early 2015, methanol was comparatively more expensive but in late 2015 the price of methanol has started to move closer to the levels of MGO again. Cheap natural gas, a primary feedstock for producing methanol, contributes to lower production costs and can make methanol economically attractive again against conventional fuel alternatives. Ethanol prices have been higher than MGO traditionally, similar to other types of biofuels. Fuels from non-fossil feedstock, including bio-methanol, tend to have a higher price than fossil fuels. The alternative fuels must have a price below MGO on an energy basis to be competitive from an economic perspective.

Investment costs for both methanol and ethanol retrofit and new build solutions are estimated to be in the same range as costs for installing exhaust gas after treatment (scrubber and SCR) for use with heavy fuel oil, and below the costs of investments for LNG solutions. Operating costs are primarily fuel costs. Fuel costs for LNG and methanol as delivered to the ship were comparable. Ethanol fuel costs are considerably higher. The payback time analysis carried out for this study showed methanol to have shorter payback times than LNG due to the lower investment costs required for both retrofit and new build solutions. Methanol can be competitive with other fuels and emissions compliance strategies, but this depends on the fuel price differentials. The alternative fuels must have a price below MGO on an energy basis to be competitive from an economic perspective for compliance with sulphur emission control regulations.

Summary

In summary, both methanol and ethanol are very attractive fuel choices from an environmental perspective because they are clean-burning, contain no sulphur, and can be produced from renewable feedstocks. Regarding engine technology, both have been shown to work well in heavy duty diesel engines, but there is limited experience with marine applications. Methanol has been used in a full scale ferry installation in 2015 and is being installed in new build chemical tankers for delivery in 2016. More projects and experience with different ship applications would be beneficial for demonstrating the potential of the fuels. Considering availability and supply, methanol and ethanol are both widely available globally but no specific infrastructure for marine fuel is in place. However, the costs for developing this are considered low in comparison to the equivalent LNG infrastructure and it can be done economically on a small scale. From a cost perspective, methanol is competitive with MGO only when the price on an energy basis is lower, as was the case during 2011 to 2013, to allow reasonable payback times for investment costs. Retrofit and new build investment costs for methanol are similar to those for exhaust gas after treatment (scrubber and SCR option) and below investments required for LNG.

References

[1] Fort, E. 2011. Sustainable Marine Power – the METHAPU Project. Paper 15. Lloyds Register Technology Days 2011. Available: http://vk.od.ua/ufiles/MethapuProject.pdf [Accessed 20150414].

[2] Fagerlund, P., and B. Ramne. 2013. WP9 Summary Report. EffShip Project Summary and Conclusions. Gothenburg: SSPA Sweden.

[3] Stenhede, T. 2013. EffShip WP2 Present and Future Maritime Fuels Report. Gothenburg: SSPA.

[4] Ellis, J., Ramne, B., Falk, T., Nilsson, M, Stefenson, P., Folic, M., Kotur, N., Tanneberger, K., Freudendal, U., Stenhede, T., and L. Haraldson. 2014. SPIRETH – Alcohol (Spirits) and Ether as Marine Fuel. Final Project Report.

[5] Haraldson, L. 2015. Methanol as Fuel. Presentation at the International Workshop “Methanol as Fuel & Energy Storage”, 17 March 2015, Lund, Sweden. Available: http://www.lth.se/fileadmin/mot2030/filer/12._Haraldsson_-_Methanol_as_fuel.pdf [Accessed 19.03.2015].

[6] Stena Line. 2015. Stena Line Launches the World’s First Methanol Ferry. [Press Release]. Available: http://news.stenaline.co.uk/pressreleases/stena-line-launches-the-world-s-first-methanol-ferry-1137516 [accessed 20150331].

[7] Lloyds Register Marine. 2015a. LR Project studies new generation of methanol-powered passenger ships. January 2015. Horizons. Issue 42. Available: http://www.lr.org/en/_images/213-48700_LR_Horizons_January_2015_spreads.pdf [accessed: 20150418].

[8] Methanex. 2013. Waterfront Shipping to Commission New Ships Built With Flex-Fuel Engines. [Press release]. Available: https://www.methanex.com/news/waterfront-shipping-commission-new-ships-built-flex-fuel-engines [accessed: 20150629].

[9] MAN, 2014. MAN B&W Dual Fuel Engines – Starting a New Era in Shipping. Copenhagen: MAN Diesel & Turbo. Available: http://marine.man.eu/docs/librariesprovider6/technical-papers/the-man-b-amp-w-duel-fuel-engines-starting-a-new-era-in-shipping.pdf?sfvrsn=6 [accessed: 20151007].

[10] The Motorship. 2015. MAN demonstrates two-stroke methanol engine. On-line article. Available: http://www.motorship.com/news101/engines-and-propulsion/man-demonstrates-two-stroke-methanol-engine [accessed 20150817].

[11] Damen. 2015. Damen coordinating European Innovation Project LeanShips. http://www.damen.com/en/news/2015/06/damen_coordinating_european_innovation_project_leanships. [press release]. [accessed: 20150615].

[12] Verhelst, S. 2015. LeanShips - A ‘Mobility for Growth’ European Innovation project - call “Towards the energy-efficient and very low emission vessel”. Presentation at the 2015 European Methanol Policy Form, 13-14 October 2015, Brussels. Available: https://eu-ems.com/practical.asp?event_id=269&page_id=2551 [Accessed 27.10.2015].

[13] Evegren, F. 2015. The World’s First Ship with Fire Safety Adapted to Methanol. International Fire Fighter Magazine E-Newswire June 2015. Available:

http://iffmag.mdmpublishing.com/the-worlds-first-ship-with-fire-safety-adapted-to-methanol-2/ [accessed: 20150629].

[14] Evegren, F. 2015. Stena Germanica meets methanol challenge. The Naval Architect. May 2015.

[15] LR pers. communication, 2015.

[16] Richards, B.G. 1990. Methanol-Fueled Caterpillar 3406 Engine Experience in On-Highway Trucks. SAE Technical Paper 902160, doi:10.4271/902160.

[17] Nakamura, Y., Ozu, T., Yamashita, H., Kakayama, N. and T. Fujii. 1992. Research on Methanol-fueled Marine Diesel Engine. Bulletin of the M.E.S.J., Vol. 20, No. 2.

[18] Stålhammar, P. 2015. SCANIA – ED95 development Alcohol CI combustion. Presentation at the International Workshop "Methanol as Fuel & Energy Storage", 17 March 2015, Lund, Sweden. Available: http://www.lth.se/fileadmin/mot2030/filer/11._Stalhammar_-_Scania_ED95_development.pdf [Accessed 19.03.2015].

[19] Ansell, D.V., Dicks, B., Guenette, C.C., Moller, T.H., Santner, R.S., and I.C. White. 2001. A Review of the Problems Posed by Spills of Heavy Fuel Oils. Paper presented at 2001 International Oil Spill Conference, March 26-29, Tampa, Florida.

[20] ISO. 2012. ISO 8217:2012, Petroleum Products – Fuels (class F) – Specifications of Marine Fuels. International Organization for Standardization.

[21] IMPCA. 2008. IMPCA Methanol Reference Specifications. Brussels: International Methanol Producers and Consumers Association. Available: http://www.methanol.org/Technical-Information/Resources/Technical-Information/Methanol-Specifications-(IMPCA).aspx [Accessed 20130226].

[22] IRENA. 2013. Road transport: The cost of renewable solutions. IRENA report preliminary findings. Available: http://www.irena.org/DocumentDownloads/Publications/Road_Transport.pdf [accessed: 20150814].

[23] Foss, M.M. 2007. Introduction to LNG. Center for Energy Economics. Available: http://www.beg.utexas.edu/energyecon/lng/documents/CEE_INTRODUCTION_TO_LNG_FINAL.pdf [accessed 20150819].

[24] Lloyd's Register Marine. 2015b. FOBAS fuel management toolkit. Available: http://www.lr.org/en/marine/consulting/fobas/FuelManagementToolkit.aspx

[25] ISO. 2006. ISO 12156-1:2006, Diesel fuel -- Assessment of lubricity using the high-frequency reciprocating rig (HFRR) -- Part 1: Test method. International Organization for Standardization.

[26] Methanol Institute. Undated. Using Physical and Chemical Properties to Manage Flammable Liquid Hazards Part Two of a Three Part Series. Available: http://www.methanol.org/Health-And-Safety/Technical-Bulletins.aspx

[27] Robin, J.-Y. and Demoury, V. 2012. The lng industry in 2012. Technical report, International Group of Liquefied Natural Gas Importers. Available: http://www.giignl.org/system/files/publication/giignl_the_lng_industry_2012.pdf

[28] Canadian Centre for Occupational Safety and Health. 1997. OSH Answers Fact Sheets. Flammable & Combustible Liquids – Hazards. Available: http://www.ccohs.ca/oshanswers/chemicals/flammable/flam.html. [accessed: 20150804].

[29] ISO 8217:2012. Petroleum products - Fuels (class F) - Specifications of marine fuels. Geneva: International Organization for Standardization.

[30] Toups, H.J. 2003. Fires and Explosions - Fundamentals and Design Considerations. AIChE SACHE Faculty Workshop. Available: http://www.mpri.lsu.edu/workshop/Presentations.htm

[31] Brynolf, S., Fridell, E., and K. Andersson. 2014. Environmental assessment of marine fuels: liquefied natural gas, liquiefied biogas, methanol and bio-methanol. Journal of Cleaner Production.

[32] Methanol Institute. 2013. Methanol Safe Handling Manual. Available: www.methanol.org [accessed: 20150815].

[33] DOE. 2013. Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends. DOE/GO-102013-3861. Report prepared for the US Department of Energy. Available: http://www.afdc.energy.gov/uploads/publication/ethanol_handbook.pdf [accessed: 20150817].

[34] Martini, G., Manfredi, U., Krasenbrink, A., Stradling, R., Zemroch, P.J., Rose, K.D., Hass, H., and H. Maas. 2013. Effect of oxygenates in gasoline on fuel consumption and emissions in three Euro 4 passenger cars. Reference Report by the Joint Research Centre of the European Commission. Available: http://iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu.about-jec/files/documents/jec_ethanol_report_online_final_v2.pdf [accessed: 20150929].

[35] World Health Organization. 1997. Environmental Health Criteria 196, Methanol. International Programme on Chemical Safety (IPCS), Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. Geneva. Available: http://www.inchem.org/documents/ehc/ehc/ehc196.htm

[36] OECD SIDS. 2004. CAS N°: 64-17-5 Ethanol. SIDS Initial Assessment Report for SIAM 19. UNEP Publications. Available: http://www.inchem.org/documents/sids/sids/64175.pdf

[37] American Petroleum Institute. 2011. Heavy Fuel Oils Category Analysis and Hazard Characterization. Report submitted to the US EPA. Available: http://www.epa.gov/hpv/pubs/summaries/heavyfos/c15368hc.pdf

[38] Prasad, S., Zhao, L. and J. Gomes. 2011. Methane and Natural Gas Exposure Limits. Epidemiology. Volume 22, Issue 1.

[39] European Chemicals Agency. (http://www.echa.europa.eu/) Registered substances.

[40] International Labour Organization, 2011. Chemical Exposure Limits. Available: http://www.ilo.org/safework/info/publications/WCMS_151534/lang--en/index.htm#P158_12821 [accessed: 20150811].

[41] Council Directive 2000/39/EC establishing a First List of Indicative Occupational Exposure Limit Values at European Community level in implementation of council directive 98/24/EC on the protection of the health and safety of workers from the risks related to chemical agents at work.

[42] Council Directive 2006/15/EC establishing a second list of indicative occupational exposure limit values in implementation of Council Directive 98/24/EC and amending Directives 91/322/EEC and 2000/39/EC

[43] Health and Safety Executive. 2011. EH40/2005 Workplace Exposure Limits. Second Edition. Available: http://www.hse.gov.uk/pUbns/priced/eh40.pdf [accessed 20150810].

[44] Swedish Work Environment Authority. 2005. Occupational Exposure Limit Values and Measures Against Air Contaminants. Provisions of the Swedish Work Environment Authority on Occupational Exposure Limit Values and Measures against Air Contaminants, together with General Recommendations on the implementation of the Provisions. AFS 2005:17. Available: http://www.av.se/dokument/inenglish/legislations/eng0517.pdf

[45] COWI. 2015. State of the Art on Alternative Fuels Transport Systems in the European Union. Available: http://ec.europa.eu/transport/themes/sustainable/studies/doc/2015-07-alter-fuels-transport-syst-in-eu.pdf

[46] Law, K., Rosenfeld, J., and M. Jackson. 2013. Methanol as a renewable resource. White paper prepared for the Methanol Institute. Available from: http://www.methanol.org/getdoc/300af053-04bd-4b2a-8dce-f6a3e4c4d4ce/MI-Renewable-Methanol-Pathways-White-Paper_final.aspx

[47] Lloyds Register Marine and University College London. 2014. Global Marine Fuel Trends 2030. Available: http://www.lr.org/en/marine/projects/global-marine-fuel-trends-2030.aspx [Accessed 26.03.2014].

[48] Posti, A. and J. Häkkinen, 2012 . Survey of Transportation of Liquid Bulk Chemicals in the Baltic Sea. Available: http://www.merikotka.fi/chembaltic/Files/Posti_and_Hakkinen_2012_-_Survey_of_transportation_of_liquid_bulk_chemicals_in_the_Baltic_Sea_UPDATED.pdf

[49] Sucden, 2015.World Ethanol Market. Available: http://www.sucden.com/statistics/10_world-ethanol-market [accessed 20150820].

[50] Florentinus, A., Hamelinck, C., van den Bos, A., Winkel, R., and M. Cuijpers. 2012. Potential of biofuels for shipping. Final Report. Report prepared by Ecofys for the European Maritime Safety Agency. Available: http://www.ecofys.com/files/files/ecofys_2012_potential_of_biofuels_in_shipping_02.pdf.

[51] Wesoff, E. 2014. LanzaTech, a Waste-Gas-to-Fuel Startup, Tops Off a $112M Funding Round. From: http://www.greentechmedia.com/articles/read/Can-Lanza-Khosla-Solve-the-Biofuels-Conversion-Riddle [accessed 20150805].

[52] Smith, T. W. P.; Jalkanen, J. P.; Anderson, B. A.;Corbett, J. J.; Faber, J.; Hanayama, S.; O'Keeffe, E.; Parker, S.; Johansson, L.; Aldous, L.;Raucci, C.; Traut, M.; Ettinger, S.; Nelissen, D.; Lee, D. S.; Ng, S.; Agrawal, A.; Winebrake, J.J.; Hoen, M.; Chesworth, S.; Pandey, A.

2014. Third IMO GHG Study 2014. International Maritime Organization (IMO) London, UK, June 2014.

[53] Edwards, R., Larivé, J.-F., Rickeard, D., and W. Weindorf. 2014a. JEC - Joint Research Centre-EUCAR-CONCAWE collaboration, WELL-TO-TANK Appendix 4 (Version 4a) Description, results and input data per pathway. JRC Technical report of study carried out jointly by JRC, EUCAR, and CONCAWE. Luxembourg: Publications Office of the European Union.

[54] Edwards, R., Larivé, J.-F., Rickeard, D., and W. Weindorf. 2014b. JEC - Joint Research Centre-EUCAR-CONCAWE collaboration, WELL-TO-TANK Appendix 4 (Version 4a) Conversion factors and fuel properties. JRC Technical report of study carried out jointly by JRC, EUCAR, and CONCAWE. Luxembourg: Publications Office of the European Union.

[55] Bengtsson, S., Fridell, E., and K. Andersson. 2012b. Environmental assessment of two pathways towards the use of biofuels in shipping. Energy Policy 44: 451-463.

[56] Stojcevski, T. 2015. Personal communication.

[57] Arcadis, Geraghty, & Miller Inc. 1998. Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations. Transit Cooperative Research Program Report 38. Transportation Research Board. Washington: National Academies Press.

[58] Olofsson, M. 2009. SEKAB – Polish Bioethanol as a clean alternative for urban heavy transport. Available: https://stockholm.trade.gov.pl/pl/download/file/f,4009.

[59] MAN, 2015. Marine Engine IMO Tier ll and Tier lll Programme 2015. MAN Diesel and Turbo. Available: http://marine.man.eu/docs/librariesprovider6/marine-engine-programmes/4510-0014-00d9d156f0bf5969569b45ff0200499204.pdf?sfvrsn=4 [accessed: 20151008].

[60] Lloyds Register. 2012. Understanding exhaust gas treatment systems – Guidance for ship owners and operators. London: Lloyd’s Register.

[61] GESAMP. 2013. Revised GESAMP Hazard Evaluation Procedure for Chemical Substances Carried by Ships (IMO/FAO/UNESCO-IOC/WMO/ IAEA/UN/UNEP/UNIDO/UNDP) Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud. GESAMP No. 64.

[62] EMSA. 2009. Manual on the Applicability of Oil Spill Dispersants. Manual initially prepared as part of EMSA contract EMSA 05-679-RES/04/2005 and updated under EMSA contract EMSA/146/2008.

[63] GESAMP. 2014. Revised GESAMP Hazard Evaluation Procedure for Chemical Substances Carried by Ships (IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO/UNDP) Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud. GESAMP No. 64.

[64] COWI. 2011. #14 BRISK Sub-Regional Risk of Spill of Oil and Hazardous Substances in the Baltic Sea. Summary Report.

[65] Webber, D.M, Gant, S.E., Ivings, M.J. and S.F. Jagger. 2010. LNG source term models for hazard analysis. Report prepared for the Health and Safety Executive. Research Report RR789.

[66] Meech, R. 2015. "Choices: So you're complying – but is this minimising costs and maintaining safety now and in the future?" Presentation to the 36th International Bunker Conference. 22-24 April 2015, Oslo.

[67] Lng24. 2015. What does LNG bunkering cost? Available: www.lng24.com/en /lng-sailing/lng-price/ [Accessed: 14.08.2015].

[68] Bengtsson, S., Andersson, K., Ellis, J., Haraldsson, L., Ramne, B., and P. Stefenson. 2012. Criteria for Future Marine Fuels. Proceedings from the IAME 2012 Conference, 6-8 September 2012, Taipei, Taiwan.

[69] www.methanex.com 2015

[70] EIA. 2015. Annual Energy Outlook 2015 with projections to 2040. Washington, D.C.: US Energy Information Administration. Available from: http://www.eia.gov/forecasts/aeo/ [Accessed: 14.08.2015].

[71] EIA. 2012. Biofuels Issues and Trends. Washington, D.C.: US Energy Information Administration. Available from: http://www.eia.gov/biofuels/issuestrends/ [Accessed: 29.06.2015].

[72] World Bank Group. 2015. Commodity Markets Outlook. April 2015. Available: www.worldbank.org/prospects/commodities [Accessed 12.08.2015].

[73] Buhaug, Ø., J. J. Corbett, Ø. Endresen, V. Eyring, J. Faber, S. Hanayama, D. S. Lee, D. Lee, H. Lindstad, A. Z. Markovska, A. Mjelde, D. Nelissen, J. Nilsen, C. Pålsson, J. J. Winebrake, W. Wu and K. Yoshida (2009). Second IMO GHG Study 2009. London, UK, International Maritime Organization.

[74] Wärtsilä. 2015. http://www.wartsila.com/products/marine-oil-gas/engines-generating-sets/diesel-engines/wartsila-38.

[75] LR Marine. 2015. Unpublished private data source.

[76] Danish Maritime Authority. 2012. North European LNG Infrastructure Project – A feasibility study for an LNG filling station infrastructure and test of recommendations. Appendix 3 Ship Cost Analysis. Copenhagen: Danish Maritime Authority.

[77] Andersson, K., Marquez Salazar, C. 2015. Methanol as a Marine Fuel. London: FCBI Energy.

[78] Shu, S.-T. 2012. A Life Cycle Cost Analysis of Marine Scrubber Technologies. Master Thesis presented in partial fulfillment of the requirements for the double degree: "Advanced Master in Naval Architecture" conferred by University of Liege and "Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetic and Propulsion" conferred by Ecole Centrale de Nantes.

[79] European Maritime Safety Agency. 2010. The 0.1% sulphur in fuel requirement as from 1 January 2015 in SECA s- An assessment of available impact studies and alternative means of compliance. Available: http://ec.europa.eu/environment/air/transport/pdf/Report_Sulphur_Requirement.pdf

[80] European Maritime Safety Agency. 2015. New Limits for the sulphur content of marine fuels. Lisbon: European Maritime Safety Agency. Available: http://emsa.europa.eu/publications/information-leaflets-and-brochures.html

[81] Lloyd's Register. 2015. Lloyd's Register's Provisional Rules for the Classification of Methanol Fuelled Ships.

[82] DNV. 2013. Tentative Rules for Low Flashpoint Liquid Fuelled Ship Installations.

[83] IMO. 1974. SOLAS - International Convention for the Safety of Life at Sea, as amended.

[84] IMO MSC. 1994. MSC/Circular.647 – Guidelines to Minimize Leakages from Flammable Liquid Systems (Adopted on 6 June 1994). London: IMO.

[85] IMO MSC. 1998. MSC/Circular.647 – Guidelines to Minimize Leakages from Flammable Liquid Systems – (Adopted on 6 June 1994). London: IMO.

[86] IMO MSC. 2009. MSC.1/Circular.1321 – Guidelines for Measures to Prevent Fires in Engine-Rooms and Cargo Pump-Rooms – (11 June 2009). London: IMO.

[87] IMO MSC. 2015. Adoption of the International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF CODE). Annex 1, Resolution MSC.391 (95) (adopted on 11 June 2015). London: IMO.

[88] IMO Sub-Committee on Carriage of Cargoes and Containers (CCC). 2015. AMENDMENTS TO THE IGF CODE AND DEVELOPMENT OF GUIDELINES FOR LOW-FLASHPOINT FUELS, Report of the Working Group. Submitted as Agenda Item 3, CCC 2/WP .3. London: IMO.

[89] IMO. 2012. IBC Code - International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, Amended by Resolution MEPC.225 (64). London: IMO.

[90] IMO. 1974/78 MARPOL - International Convention for the Prevention of Pollution from Ships as amended. London: IMO.

[91] IMO. 1983. IGC Code - International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk as amended. London: IMO.

[92] IMO. 1986. IMO document MSC 86/26/Add.1 Annex II Interim Guidelines for Natural Gas-Fuelled engine installations in ships. London: IMO.

[93] IEC. 2014. IEC 60079-1: Electrical apparatus for explosive gas atmospheres – Part 10: Classification of Hazardous areas. Geneva: IEC.

[94] IEC. 2003. IEC 60092: Electrical installations in ships – Part 502: Tankers-Special and IEC 60092-506 is for ships carrying specific dangerous goods and materials hazardous only in bulk. Geneva: IEC.

[95] IEC. 1999. IEC 60092-502 Electrical installations in ships - Part 502: Tankers – Special Features. Geneva: IEC.

[96] IMO. 2000. Resolution MSC.98 (73) - Adoption of the International Code for Fire Safety Systems - (Adopted on 5 December 2000). London: IMO.

[97] Health and Safety Executive. 2009. Safety and environmental standards for fuel storage sites. Available: http://www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf

[98] ISO. 2009. IEC 31010:2009, Risk management -- Risk assessment techniques. International Electrotechnical Commission, International Organization for Standardization (Joint IEC/ISO).

[99] Lloyd’s Register Marine. 2015. Terms of Reference (ToR): Safety Assessment of Methanol and Ethanol Fuelled Ships. Lloyd’s Register Marine. 18th September 2015. Rev01.

Appendix I: ISO 8217:2012 Residual Marine Fuels

			RMA 10 a	RMB 30	RMD 80	RME 180	RMG 180	RMG 380	RMG 500	RMG 700	RMK 380	RMK 500	RMK 700
Kinematic viscosity at 50°C b	mm^2/s	max.	10.00	30.00	80.00	180.0	180.0	380.0	500.0	700.0	380.0	500.0	700.0
Density at 15°C	kg/m^3	max.	920.0	960.0	975.0	991.0	991.0				1010.0		
CCAI	—	max.	850	860	860	860	870				870		
Sulfur c	mass %	max.	Statutory Requirements										
Flash point	°C	min.	60.0	60.0	60.0	60.0	60.0				60.0		
Hydrogen sulfide	mg/kg	max.	2.00	2.00	2.00	2.00	2.00				2.00		
Acid number d	mg KOH/g	max.	2.5	2.5	2.5	2.5	2.5				2.5		
Total sediment aged	mass %	max.	0.10	0.10	0.10	0.10	0.10				0.10		
Carbon residue: micro method	mass %	max.	2.50	10.00	14.00	15.00	18.00				20.00		
Pour point (upper) e													
summer quality	°C	max.	6	6	30	30	30				30		
winter quality	°C	max.	0	0	30	30	30				30		
Water	volume %	max.	0.30	0.50	0.50	0.50	0.50				0.50		
Ash	mass %	max.	0.040	0.070	0.070	0.070	0.100				0.150		
Vanadium	mg/kg	max.	50	150	150	150	350				450		
Sodium	mg/kg	max.	50	100	100	50	100				100		
Aluminium plus silicon	mg/kg	max.	25	40	40	50	60				60		

a This category is based on a previously defined distillate DMC category that was described in ISO 8217:2005, Table 1. ISO 8217:2005 has been withdrawn.
b 1 mm^2/s = 1cSt.
c The purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See 0.3 and Annex C.
d See Annex H.
e Purchasers shall ensure that this pour point is suitable for the equipment on board, especially if the ship operates in cold climates.

Appendix II: ISO 8217:2012 Distillate Marine Fuels

			DMX	DMA	DMZ	DMB
Kinematic viscosity at 40 °C a	mm^2/s	max.	5.500	6.000	6.000	11.00
		min.	1.400	2.000	3.000	2.00
Density at 15 °C	kg/m^3	max.	—	890.00	890.00	900.00
Cetane index	—	min.	45.00	40.00	40.00	35.00
Sulfur b	mass %	max.	1.00	1.50	1.50	2.00
Flash point	°C	min.	43	60	60	60
Hydrogen sulfide	mg/kg	max.	2.00	2.00	2.00	2.00
Acid number	mg KOH/g	max.	0.5	0.5	0.5	0.5
Total sediment by hot filtration	mass %	max.	—	—	—	0.10 d
Oxidation stability	g/m^3	max.	25	25	25	25 e
Carbon residue: micro method on the 10 % volume distillation residue	mass %	max.	0.30	0.30	0.30	—
Carbon residue: micro method	mass %	max.	—	—	—	0.30
Cloud point	°C	max.	−16	—	—	—
Pour point (upper)						
summer quality	°C	max.	—	0	0	6
winter quality	°C	max.	—	− 6	− 6	0
Appearance	—	—	Clear and bright	Clear and bright	Clear and bright	d,e,f
Water	volume %	max.	—	—	—	0.30 d
Ash	mass %	max.	0.01	0.01	0.01	0.01
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C h	µm	max.	520	520	520	520 g

a 1 mm2/s = 1 cSt.
b Notwithstanding the limits given, the purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See Annex C.
c Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the ship operates in cold climates.
d If the sample is not clear and bright, the total sediment by hot filtration and water tests shall be required, see 7.4 and 7.6.
e If the sample is not clear and bright, the test cannot be undertaken and hence the oxidation stability limit shall not apply.
f If the sample is not clear and bright, the test cannot be undertaken and hence the lubricity limit shall not apply.
g This requirement is applicable to fuels with a sulfur content below 500 mg/kg (0,050 mass %).
h If the sample is dyed and not transparent, then the water limit and test method as given in 7.6 shall apply.

Appendix III: Selected Chemical and Physical Properties of Ethanol, Methanol, LNG, MGO, and HFO with reference sources

Properties	HFO	MGO	LNG	Methanol	Ethanol
Boiling Temperature at 1 bar [°C]	-	175-650 [10]	-161.48 [9]	65 [1,20]	77.85 [14] 78 [1] 78.4 [11] 78.3 [13]
Density at 15°C [kg/m^3]	989 [10]	855.6 [10] max. 900 [3]	423.11 [9] (-162°C, 1 bar Methane) 0.67 [9] (-15°C ,1 bar, Methane) 448.39[22](-162°C, 1 bar, LNG)	795.5 [1]	792 [15]
Dynamic Viscosity at 40°C [cSt]	-	3.5[10] 2.72 [2]	-	0.58 [2] (25°C)	1.082 [12] 1.13 [15]
Lower Heating Value [MJ/kg]	40 [10] 40.4 [17]	42.7 [8,10]	50.114 [9] (162°C and 1 bar) 48.5[16]	19.5[1] 20 [16]	26.9 [1] 28 [14]
Lubricity WSD [µm]	-	280-400 [4] <520 [3] (0.05 % sulphur) 374 [10]	-	1100 [2]	632 [15] 1057 [2]
Vapour Density air=1		Heavier than air >5 [18]	Lighter than air 0.55[18]	1.1[18] 1.01 [20]	1.6[21]
Flash Point (TCC) [°C]	>60 [3]	70.1 [10] >60 [3]	-175 [18]	12 [1,18]	17 [5]
Auto Ignition Temperature [°C]	-	250-300 [18]	540 [23]	470 [1] 464[20]	363[21]
Flammability Limits [by % Vol of Mixture]	-	0.5 - 5 [18] 0.3 -10 [7]	5 - 15 [7,18]	6 – 36 [2,18] 5.5 - 44 [20]	3.3-19 [7]
min. ignition energy at 25°C [mJ]	-	20 [18]	0.3 [6] 0.25 [18]	0.14 [8,9,18]	0.4 [6]
Heat of evaporation [kJ/kg]	-	-	510[24]	1100 [19]	840 [11]

References for Appendix III Table

(References for the full report are listed elsewhere)

[1] Methanex. 2006. Technical Information & safe handling guide for methanol. Version 3.0. September 2006

[2] Lapuerta M. et al. Stability, Lubricity, Viscosity, and Cold-Flow Properties of Alcohol−Diesel Blends, Energy Fuels, 2010, 24 (8), pp 4497–4502, DOI: 10.1021/ef100498u

[3] ISO, 2010, ISO 8217:2010

[4] Intertek lintek, Lubricity Characteristics of Marine Distillate Fuels 2012 , Available: http://www.lintec-group.com/pressreleases/2012_08_Innospec_Intertek_Lintec_MTZ_Industrial.pdf

[5] http://www.engineeringtoolbox.com/flash-point-fuels-d_937.html

[6] Thomas H. Pratt, Electrostatic Ignitions of Fires and Explosions, 1997

[7] Sara McAllister, Jyh-Yuan Chen, A. Carlos Fernandez-Pello, Fundamentals of Combustion Processes, 2011

[8] Wartsila,accessed 2015 http://www.wartsila.com/products/marine-oil-gas/engines-generating-sets/dual-fuel-engines/definitions-and-notes

[9] National Institute of Standards and Technology (NIST) v.9

[10] FOBAS, 2014 average MGO, DMA

[11] Michael Wächter Tabellenbuch der Chemie: Daten zur Analytik, Laborpraxis und Theorie, 2012

[12} ECHA, 2015, registered substances :search ethanol http://www.echa.europa.eu/

[13] Component plus ProSim, unknown version

[14] Tran et al. (2012) , Tran L. S., Sirjean B., Glaude P. A., Fournet R. and Battin-Leclerc F., (2012) Progress in Detailed Kinetic Modeling of the Combustion of Oxygenated Components of Biofuels, Energy, 43, pp. 4-18. Available: https://tel.archives-ouvertes.fr/tel-00909646/document

[15] The lubricity of ethanol-gasoline fuel blends La lubricidad de las mezclas etanol-gasolina John Agudelo1,* Álvaro Delgado1, Pedro Benjumea2 1 Facultad de Ingeniería. Universidad de Antioquia. Calle 67 N.° 53-108. Medellín, Colombia 2 Alternative fuels group. Institute of energy. Faculty of Mines. Universidad Nacional de Colombia sede Medellín, Colombia (Recibido el 15 de febrero de 2010. Aceptado el 19 de agosto de 2010)

[16] Report prepared for the California Energy Commission, FULL FUEL CYCLE ASSESSMENT WELL TO TANK ENERGY INPUTS, EMISSIONS, AND WATER IMPACTS, 2007 : TIAX LLC, 2007. Full Fuel Cycle Assessment Well to Tank Energy Inputs, Emissions, and Water Impacts. Available: http://www.energy.ca.gov/2007publications/CEC-600-2007-004/CEC-600-2007-004-F.PDF

[17] Bengtsson, S., Andersson, K. & E. Fridell. 2011. A comparative life cycle assessment of marine fuels: liquefied natural gas and three other fossil fuels. Proceeding of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 225, 97-110

[18] IMO Sub-Committee on Bulk Liquids and Gases. 2011. BLG16/6/3 Development of Code of Safety for Ships Using Gases or Other low-flash Point Fuels – Properties and hazards of low-flash point fuels. London: IMO.

[19] FIRE SAFETY SCIENCE-PROCEEDINGS OF THE FIFTH INTERNATIONAL SYMPOSIUM, pp 499-510

[20] ILO ICSC 0057

[21] International Program on Chemical Safety, Chemical Safety for Intergovernmental Organizations, Available: International Chemical Safety Cardshttp://www.inchem.org/documents/icsc/icsc/eics0044.htm

[22] Robin, J.-Y. and Demoury, V. 2012. The lng industry in 2012. Technical report, International Group of Liquefied Natural Gas Importers. Available: http://www.giignl.org/system/files/publication/giignl_the_lng_industry_2012.pdf

[23] Mokhatab S, et al.,Handbook of Liquefied Natural Gas, Gulf Professional Publishing, 2013

[24] US Coast Guard Chemical Hazards Response Information System. 1999. Liquefied Natural Gas. http://cameochemicals.noaa.gov/chris/LNG.pdf

Appendix IV: Payback time tables

IC refers to investment cost and MC refers to maintenance cost.

Table AIV1: Payback time Ferry Retrofit, High Oil Price Scenario, 100% in ECA

Ferry Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.4	0.0	11.9	6.4	6.4
MC [million$]	0.6	0.0	0.9	0.6	0.6
Fuel Cost [million$]	12.6	21.5	11.6	12.0	14.4
Fuel Saving [million$]	8.9	0.0	9.9	9.4	7.1
Payback time [years]	1.0	comparator	1.3	0.7	1.0

Table AIV2: Payback time Ferry Retrofit, Average Price Scenario, 100% in ECA

Ferry Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.4	0.0	11.9	6.4	6.4
MC [million$]	0.6	0.0	0.9	0.6	0.6
Fuel Cost [million$]	10.3	14.3	10.9	12.0	15.2
Fuel Saving [million$]	4.1	0.0	3.4	2.3	-0.8
Payback time [years]	2.2	comparator	3.8	3.1	never

Table AIV3: Payback time Ferry Retrofit, Low Oil Price Scenario, 100% in ECA

Ferry Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.4	0.0	11.9	6.4	6.4
MC [million$]	0.6	0.0	0.9	0.6	0.6
Fuel Cost [million$]	5.7	9.6	8.3	11.4	11.7
Fuel Saving [million$]	4.0	0.0	1.4	-1.8	-2.0
Payback time [years]	2.3	comparator	9.3	never	never

Table AIV4: Payback time Ferry New Construction, Average Scenario, 100% in ECA

Ferry New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	7.6	0.0	14.5	5.3	5.3
MC [million$]	0.6	0.0	0.9	0.6	0.6
Fuel Cost [million$]	10.3	14.3	10.9	12.0	15.2
Fuel Saving [million$]	4.1	0.0	3.4	2.3	-0.8
Payback time [years]	2.0	comparator	4.6	2.6	never

Table AIV5: Payback time Chemical Tanker New Construction, High Oil Price Scenario, 100% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	8.0	13.7	7.4	7.7	9.1
Fuel Saving [million$]	5.7	0.0	6.3	6.0	4.5
Payback time [years]	0.7	comparator	1.2	0.5	0.7

Table AIV6: Payback time Chemical Tanker New Construction, Average Scenario, 100% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	6.5	9.1	6.9	7.6	9.6
Fuel Saving [million$]	2.6	0.0	2.1	1.5	-0.5
Payback time [years]	1.5	comparator	3.6	2.1	never

Table AIV7: Payback time Chemical Tanker New Construction, Low Oil Price Scenario, 100% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	3.6	6.1	5.3	7.2	7.4
Fuel Saving [million$]	2.5	0.0	0.9	-1.1	-1.3
Payback time [years]	1.6	comparator	8.9	never	never

Table AIV8: Payback time Chemical Tanker Retrofit, Average Case, 100% in ECA

Chemical Tanker Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	4.1	0.0	5.9	3.1	3.1
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	6.5	9.1	6.9	7.6	9.6
Fuel Saving [million$]	2.6	0.0	2.1	1.5	-0.5
Payback time [years]	1.7	comparator	3.0	2.4	never

Table AIV9: Payback time Chemical Tanker New Construction, High Oil Price Scenario, 50% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	8.0	10.8	7.4	7.7	9.1
Fuel Saving [million$]	2.8	0.0	3.4	3.2	1.7
Payback time [years]	1.4	comparator	2.3	0.9	1.8

Table AIV10: Payback time Chemical Tanker New Construction, Average Scenario, 50% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	6.5	7.8	6.9	7.6	9.6
Fuel Saving [million$]	1.3	0.0	0.9	0.2	-1.8
Payback time [years]	3.1	comparator	9.1	18.0	never

Table AIV11: Payback time Chemical Tanker New Construction, Low Oil Price Scenario, 50% in ECA

Chemical Tanker New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	3.7	0.0	7.2	2.6	2.6
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	3.6	4.9	5.3	7.2	7.4
Fuel Saving [million$]	1.3	0.0	-0.4	-2.4	-2.5
Payback time [years]	3.1	comparator	never	never	never

Table AIV12: Payback time Chemical Tanker Retrofit, Average Scenario, 50% in ECA

Chemical Tanker Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	4.1	0.0	5.9	3.1	3.1
MC [million$]	0.2	0.0	0.6	0.4	0.4
Fuel Cost [million$]	6.5	7.8	6.9	7.6	9.6
Fuel Saving [million$]	1.3	0.0	0.9	0.2	-1.8
Payback time [years]	3.4	comparator	7.5	21.2	never

Table AIV13: Payback time Cruise Ship New Construction, High Oil Price Scenario, 100% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	14.3	24.5	13.2	13.7	16.4
Fuel Saving [million$]	10.2	0.0	11.3	10.8	8.1
Payback time [years]	0.9	comparator	1.5	0.6	0.8

Table AIV14: Payback time Cruise Ship New Construction, Average Scenario, 100% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	11.7	16.3	12.5	13.7	17.3
Fuel Saving [million$]	4.6	0.0	3.9	2.6	-1.0
Payback time [years]	2.1	comparator	4.4	2.5	never

Table AIV15: Payback time Cruise Ship New Construction, Low Oil Price Scenario, 100% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	6.5	11.0	9.4	13.0	13.3
Fuel Saving [million$]	4.5	0.0	1.6	-2.0	-2.3
Payback time [years]	2.1	comparator	10.9	never	never

TableAIV16: Payback time Cruise Ship Retrofit, Average Scenario, 100% in ECA

Cruise Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	9.7	0.0	13.7	7.4	7.4
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	11.7	16.3	12.5	13.7	17.3
Fuel Saving [million$]	4.6	0.0	3.9	2.6	-1.0
Payback time [years]	2.3	comparator	3.6	2.9	never

Table AIV17: Payback time Cruise Ship New Construction, High Oil Price Scenario, 25% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	14.3	16.9	13.2	13.7	16.4
Fuel Saving [million$]	2.5	0.0	3.6	3.1	0.4
Payback time [years]	3.7	comparator	4.7	2.1	14.3

Table AIV18: Payback time Cruise Ship New Construction, Average Scenario, 25% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	11.7	12.8	12.5	13.7	17.3
Fuel Saving [million$]	1.2	0.0	0.4	-0.9	-4.4
Payback time [years]	8.2	comparator	44.2	never	never

Table AIV19: Payback time Cruise Ship New Construction, Low Oil Price Scenario, 25% in ECA

Cruise New	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	8.7	0.0	16.7	6.2	6.2
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	6.5	7.6	9.4	13.0	13.3
Fuel Saving [million$]	1.1	0.0	-1.8	-5.4	-5.7
Payback time [years]	8.4	comparator	never	never	never

Table AIV20 Payback time Cruise Ship Retrofit, Average Scenario, 25% in ECA

Cruise Retrofit	HFO scrubber and SCR	MGO	LNG	Methanol	Ethanol
IC total [million$]	9.7	0.0	13.7	7.4	7.4
MC [million$]	0.8	0.0	0.4	0.3	0.3
Fuel Cost [million$]	11.7	12.8	12.5	13.7	17.3
Fuel Saving [million$]	1.2	0.0	0.4	-0.9	-4.4
Payback time [years]	9.0	comparator	36.2	never	never

Appendix V: Report on Safety Assessment of Methanol and Ethanol Fuelled Ships

Lloyd's Register Marine

Working together
for a safer world

Safety Assessment

Methanol and Ethanol Fuelled Ships

FINAL REPORT

3rd December 2015 Rev03 EMSA

Prepared by

Dr Paul Davies
Technical Manager, Risk Assessment, LNG & Alternative Fuels
Lloyd's Register Global Technology Centre, UK

T: +44 (0)1625 538 928
Email: paul.davies@lr.org

Reviewed and approved by

Kim Tanneberger
Lead Specialist, Strategic Research Group
Lloyd's Register Global Technology Centre, UK

T: +44 (0)3304140218
Email: kim.tanneberger@lr.org

1. Introduction

This document is a record of a risk-based safety assessment on the use of methyl alcohol (methanol) and ethyl alcohol (ethanol) as marine fuel. It was undertaken by Lloyd's Register Marine (LR) as part of a study for the European Maritime Safety Agency (EMSA).

The principal part of the safety assessment was a workshop facilitated by LR and attended by representatives from:

- SSPA Sweden;
- Swedish Transport Agency;
- Methanex;
- Stena;
- Marinvest Shipping;
- SP Fire Research;
- Scandinaos; and
- EMSA.

Additional input and review was provided by individuals interested in the design of methanol fuelled ships at Meyer Werft and Flensburger Schiffbau Gesellschaft.

Two generic ship types were the focus of the study; a passenger ship and a cargo ship, with differences noted between short-sea (coastal) and deep-sea trade for both methanol and ethanol as fuel. For the passenger ship, Ro-Pax and cruise ship generic designs were assessed and for the cargo ship, a generic chemical tanker was taken as representative.

To encompass design possibilities the assessment of each ship type included: integral and independent fuel tanks; fuel tanks located above and below deck; and for the cargo ship only, fuel tanks located in cargo areas. In addition, and where applicable, to cover operational possibilities consideration was given to: passengers embarking and disembarking; loading and unloading of vehicles, provisions and cargo; and bunkering from a shore facility, road truck and barge.

The safety assessment used a HAZID type technique in line with ISO 31010[1] and an indicative risk rating based upon expert judgement and reference to incident and failure data[2]. This helped determine the adequacy of safeguards and whether the safety risks could be considered 'mitigated as necessary' as described in the IGF Code[3].

1. ISO 31010: 2010, Risk Management – Risk Assessment Techniques.
2. Formal Safety Assessments of Ships as part of SAFEDOR and reported in MSC 83/21/2, MSC 83/INF.8, MSC 85/17/1, MSC 85/INF.2, MSC 85/17/2, MSC 85/INF.3, etc. Intl. Association of Oil & Gas Producers, 1 March 2010, Risk Assessment Data Directory – Process Release Frequencies, Report No. 434 – 1. Health and Safety Executive, 1992-2006, Hydrocarbon Releases (HCR) System. LNG as a Marine Fuel - Likelihood of LNG Releases, Journal of Marine Engineering & Technology, 12, 3, 2013.
3. International Code for Safety of Ships Using Gases or Other Low-flashpoint Fuels (IGF Code), para. 4.2.3 (as of 10 June 2015).

2. OBJECTIVE

The objective of the safety assessment was to evaluate the safety-risks to persons from the use of methanol/ethanol as fuel for ships. This was achieved by:

1. identifying and recommending safeguards that could reduce risk; and,
2. rating risks so as to test if they could be considered '*mitigated as necessary*' as described in the IGF Code.

3. SCOPE

The safety assessment considered two generic ship types, a passenger ship and a cargo ship. For the passenger ship, the scope covered both a Ro-Pax and cruise ship, and for the cargo ship, a chemical tanker.

For both generic ship types the fundamental functional groups for investigation were taken as:

A. bunkering of fuel;
B. storage of fuel;
C. transfer (and preparation[4]) of fuel; and,
D. use of fuel.

These functional groups and their generic arrangement are illustrated and further detailed in Tables 3.1 and 3.2 together with a full listing of scope considerations.

4. Preparation of fuel covers, for example, pumps and pressure regulation and process monitoring equipment.

Table 3.1: Passenger Ship Scope

Functional Groups

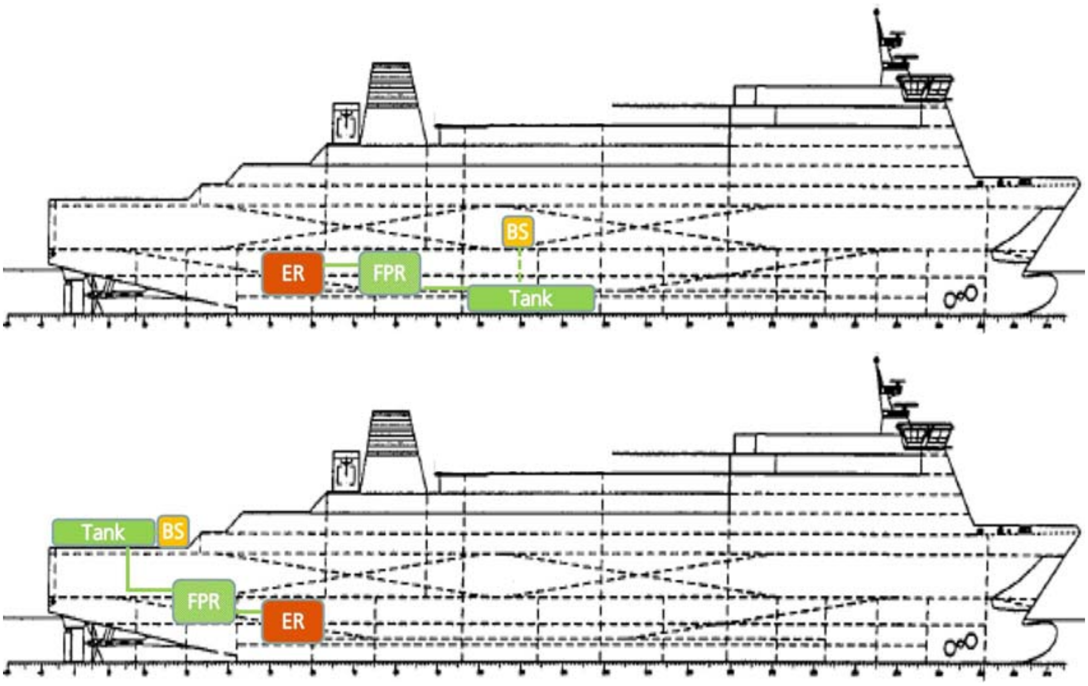
A. Bunkering of fuel.
A bunker station (on-deck, below deck, enclosed, semi-enclosed or open), typical equipment (e.g. hose, manifold, connectors) and delivery by shore facility, road truck or bunker barge.

B. Storage of fuel.
Independent fuel tanks located on-deck or below deck in a Fuel Storage Hold Space (FSHS), integral/structural tanks located below deck, and associated equipment (e.g. instrumentation).

C. Transfer (and preparation) of fuel.
Pumps, preparation equipment and pipework located in a dedicated Fuel Preparation Room (FPR - Pump Room including pressure regulation and process monitoring equipment, etc.) below deck or on-deck, and pipework from the fuel tank via the FPR to the ships' engines.

D. Use of fuel.
Engines and fuel pipework located in a dedicated machinery space (Engine Room) below deck.

Generic Arrangement of Functional Groups



General Design & Operational Considerations for Safety Assessment

1. Ro-Pax / Cruise Ship
2. Methanol / Ethanol.
3. Short sea (coastal) Ro-Pax / Deep sea Cruise ship.
4. Integral/structural fuel tanks / Independent fuel tanks.
5. Fuel tanks above deck / Fuel tanks below deck.
6. Passengers embarking / Passengers disembarking.
7. Vehicles - Loading / Unloading (Ro-Pax only).
8. Loading provisions.
9. Bunkering - Shore facility (Port-to-Ship, PTS) / Road truck (Truck-to-Ship, TTS) / Barge (Ship-to-Ship, STS).

Table 3.2: Cargo Ship Scope

Functional Groups

A. Bunkering of fuel.
A bunker station (on-deck, below deck, enclosed, semi-enclosed or open), typical equipment (e.g. hose, manifold, connectors) and assumed delivery by established cargo loading (and if not available, by shore facility, road truck or bunker barge).

B. Storage of fuel.
Independent fuel tanks located on-deck, in the cargo area or below deck in a Fuel Storage Hold Space (FSHS), integral/structural tanks located below deck, and associated equipment (e.g. instrumentation). Configuration might include storage in a dedicated cargo tank or slop tank with a connection to a service tank (S tank, on or below deck).

C. Transfer (and preparation) of fuel.
Pumps, preparation equipment and pipework located in a dedicated Fuel Preparation Room (FPR - Pump Room including pressure regulation and process monitoring equipment, etc.) below deck, on-deck or within cargo area, and pipework from the fuel tank/service tank via the FPR to the ships' engines.

D. Use of fuel.
Engines and fuel pipework located in a dedicated machinery space (Engine Room) below deck.

Generic Arrangement of Functional Groups

General Design & Operational Considerations for Safety Assessment

1. Chemical Tanker
2. Methanol / Ethanol.
3. Short sea (coastal) / Deep sea.
4. Integral fuel tanks / Independent fuel tanks.
5. Fuel tanks above deck / Fuel tanks below deck.
6. Fuel tanks within cargo area.
7. Loading / Unloading cargo.
8. Loading provisions.
9. Bunkering – Established cargo loading / Shore facility (Port-to-Ship, PTS) / Road truck (Truck-to-Ship, TTS) / Barge (Ship-to-Ship, STS).

4. Approach – Assessment Technique

The safety assessment consisted of four distinct areas:

1. a principal workshop using a HAZID type technique in line with ISO 31010[5];
2. indicative risk rating based upon expert judgement and data;
3. a subsequent workshop to complete item (1); and,
4. expert review and additions to workshop findings and risk ratings.

The principal workshop was facilitated by LR and consisted of a team collectively knowledgeable in design, operation and regulations pertaining to methanol/ethanol fuelled ships. This included part development of risk ratings. The subsequent workshop was undertaken entirely by LR together with completion of risk ratings.

The expert review of the findings from both workshops and additional comments were undertaken by members of the principal workshop teams and experts from two ship builders/designers. All team members and contributors are noted in Section 5.

The assessment technique used in the workshops is fully described in Tables 4.1 to 4.3. In summary, the workshop teams undertook a facilitated identification of how fuel could leak and cause harm. They then identified and considered safeguards that could eliminate or minimise these causes, referred to as prevention safeguards. Assuming failure of these safeguards, the team then identified and considered;

- firstly, mitigation safeguards to contain, detect and prevent ignition of a leak; and
- secondly, mitigation safeguards to further contain a leak (given failure of the first containment safeguard), and given ignition, contain and prevent the spread of fire, protect from thermal radiation and explosion, and detect and extinguish a fire.

To help promote inherently safer designs and arrangements, when considering safeguards the team firstly considered engineering solutions in preference to procedural controls and passive safeguards in preference to active safeguards. For example, a passive measure is one where no manual or automated action is required for it to function on demand and as intended. Whereas, an active measure requires some means of activation for it to operate.

Finally, the likelihood and consequences of harm were considered by the team and a risk rating determined using the risk matrix/criteria given in Table 4.3. Acknowledging the difficulty in appraising incident/failure data during a workshop and estimating the likelihood of 'rare' events, a number of the risk ratings were determined following the workshops so as to maximise effort in identifying and examining safeguards.

All causes, safeguards and risk ratings were recorded using the worksheet illustrated in Figure 4.1.

Prior to the principal workshop, a Terms of Reference (ToR) document was issued[6]. The purpose of this was to: help the team familiarise with the objectives, scope and intended approach; inform the team of the proposed schedule and team members; and remind the team of the

5. ISO 31010: 2010, Risk Management – Risk Assessment Techniques.
6. Terms of Reference (ToR): Safety Assessment of Methanol and Ethanol Fuelled Ships. Lloyd's Register Marine. 18th September 2015. Rev01.

properties and hazards of methanol/ethanol. It also provided an opportunity to comment and seek clarifications prior to the workshop. Table 4.4 summarises the properties and hazards of methanol and ethanol.

Finally, on commencement of the workshops the facilitator summarised the objectives, scope and approach.

Table 4.1: Assessment Technique

1. With reference to Tables 3.1 & 3.2, for a functional group (e.g. storage) identify a cause (threat) that could result in a release (leak) of methanol/ethanol[(a)].
2. List the safeguards (barriers) that eliminate or minimise the likelihood of that cause. These safeguards are commonly referred to as 'preventative' or 'Prevention Safeguards'.
3. Assuming failure of the Prevention Safeguards listed in 2, such that there is a release of fuel, identify safeguards to:
    a. contain the release[(b)];
    b. detect the release; and
    c. prevent ignition of the release.

    These safeguards are 'mitigation' safeguards, and are referred to here as 'Mitigation Safeguards A'.
4. Assuming failure of the mitigation safeguards listed in 3, such that there is an uncontained release of fuel and/or there is a fuel fire, identify mitigation safeguards to:
    a. further contain the release[(b)];
    b. contain the fire and protect from thermal radiation/explosion;
    c. detect the fire; and
    d. extinguish the fire.

    These mitigation safeguards are referred to here as 'Mitigation Safeguards B'.

    The safeguards in 2, 3 and 4 should not be restricted to safeguards noted within existing and draft regulations, standards and guidelines.
5. For each functional group (or sub-group, as appropriate) judge the likelihood and consequences of harm to provide a risk 'rating' (refer to Table 4.3). In developing the rating consider the adequacy of the prevention and mitigation safeguards identified in 2, 3 and 4. The rating can be performed with and without additional/alternative safeguards.
6. Repeat 1 to 5 until all functional groups have been examined, and note any differences related to the general considerations listed in Tables 3.1 & 3.2.

(a) as a minimum, the release cause categories listed in Table 4.2 will be considered

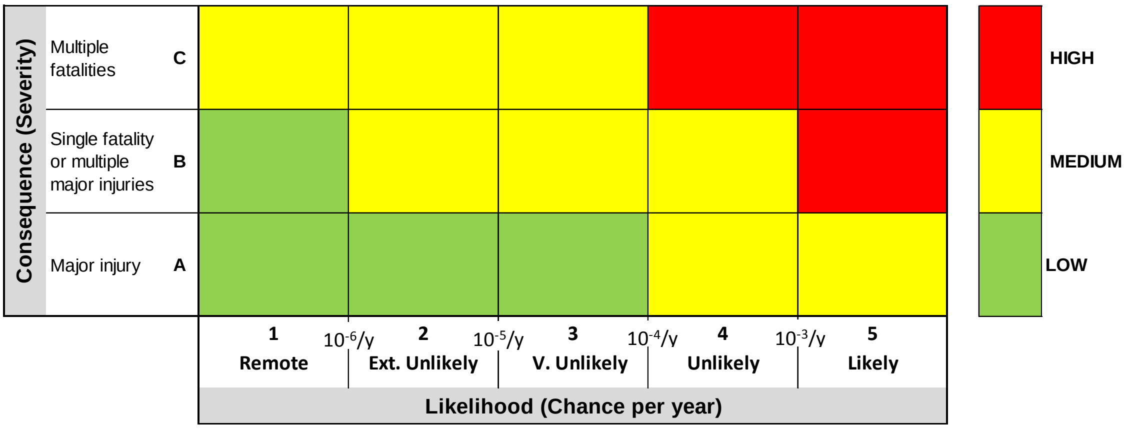
(b) 'contain' includes safeguards such as, safely collecting a release (e.g. using a holding tank), directing a release to a safe location (e.g. via a vent) and rendering a release harmless (e.g. by dilution with water)

Table 4.2: Release Cause Categories

1. Ship Collision, Contact and Grounding.
   This includes collision where the subject ship is the struck ship or the striking ship and impacts with other floating and fixed objects/structures (e.g. a harbour wall).
2. External Impact.
   This includes dropped objects (e.g. from crane operations) and impacts during loading (e.g. loading of cars and trucks).
3. External Fire.
   This covers flame impingement and thermal radiation from fires external to spaces and equipment dedicated to methanol/ethanol bunkering, storage, transfer & use.
4. Mechanical Failure.
   This covers failure of fuel containing equipment from wear, erosion, corrosion, fatigue, stress, etc. as a result of vibration, cyclic loads and heat/cold, etc.
5. Control Failure.
   This covers failure of instrumentation and process controls resulting in operation outside of the design intent.
6. Utilities Failure.
   This includes loss of power supply, heating, lighting and supporting services (e.g. inert gas supply).

Table 4.3: Risk Matrix/Criteria and Consequence/Likelihood Categories

Risk Matrix



Consequence Category

A. Major injury - *long-term disability / health effect*

B. Single fatality or multiple major injuries - *one death or multiple individuals suffering long-term disability / health effects*

C. Multiple fatalities - *two or more deaths*

Likelihood Category

1. Remote - *1 in a million or less per year*
2. Extremely Unlikely - *between 1 in a million and 1 in 100,000 per year*
3. Very Unlikely - *between 1 in 100,000 and 1 in 10,000 per year*
4. Unlikely - *between 1 in 10,000 and 1 in 1,000 per year*
5. Likely - *between 1 in 1,000 and 1 in 100 per year*

The likelihood categories can be related to a ship life. For example, assuming a ship lifetime is 25 years, then for a scenario with an annual likelihood of 1 in a million (i.e. rating 1 Remote) the probability of occurrence in the ship's lifetime is 1 in 40,000 (i.e. $1/(10^{-6} \times 25)$).

Risk Rating and Risk Criteria Guidance

Low Risk – A1, A2, A3 & B1
The risk can be accepted as 'mitigated as necessary'. Where practical and cost-effective it is good practice to implement mitigation measures that would further reduce the risk.

Medium Risk – A4, A5, B2, B3, B4, C1, C2 & C3
The risk is tolerable and considered 'mitigated as necessary'. This assumes implementation of all reasonably practicable mitigation measures.

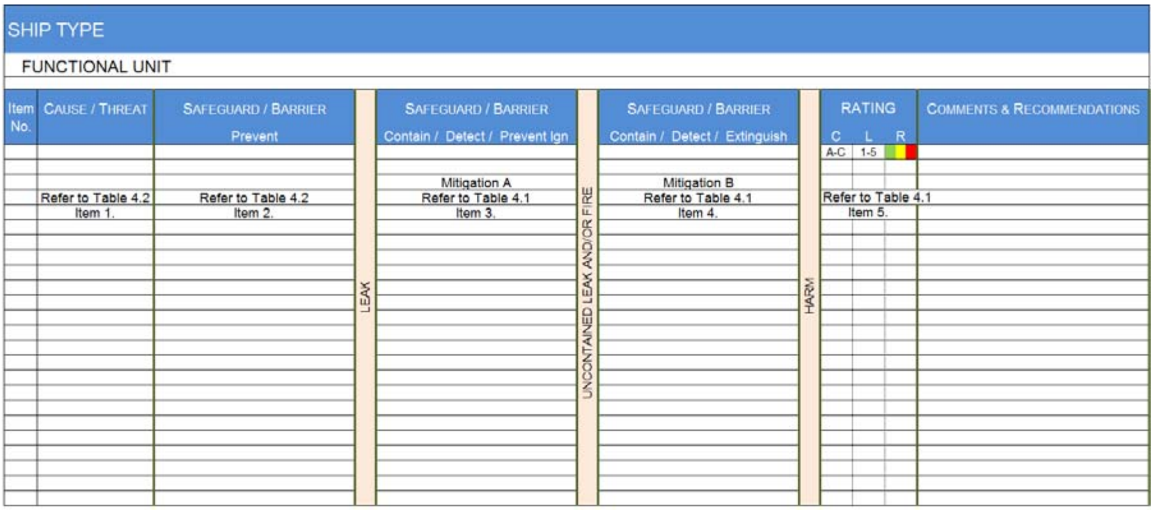
High Risk – B5, C4 & C5
The risk is unacceptable and is not 'mitigated as necessary'. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.

Mitigated as necessary
This is the wording used within the IGF Code and is akin to the phrase 'As Low As Reasonably Practicable', commonly referred to as ALARP.

Table 4.4: Properties and Characteristics of Methanol and Ethanol

	Methanol	Ethanol
Flammability Limits (vol. % in air)	6 – 36	3.3 – 19
Flash Point (deg. C)	12	17
Boiling Point at 1 bar (deg. C)	65	78
Auto-ignition Temperature (deg. C)	440 – 470	363
Vapour Density (air = 1)	1.1	1.6
Liquid Density (water = 1)	0.8	0.79
Combustion	burns with a clear/blue flame	burns with a clear/blue or slight visible orange flame
Liquid	colourless, toxic, water soluble and flammable at concentrations of 25% or more in water	colourless, water soluble and flammable at concentrations of 17% or more in water

Figure 4.1: Worksheet Example



5. TEAM AND WORKSHOP SCHEDULES

The principal and subsequent workshops were facilitated and recorded by LR and attended by the individuals listed in Tables 5.1 and 5.2. Collectively the team was knowledgeable in design, operation and regulations pertaining to methanol/ethanol fuelled ships.

Additional comment and review was provided by Meyer Werft and Flensburger Schiffbau Gesellschaft[7].

The principal workshop was held at SSPA, Göteborg, Sweden, over two days on the 30th September and 1st October 2015. The workshop commenced at 10:00 and ended at 18:15 on day 1, and commenced at 09:00 and end at 15:15 on day 2.

The subsequent workshop was held at LR's Global Technology Centre on 8th October 2015 between 09:00 and 16:00.

Table 5.1: Principal Workshop Team

Name & Organisation	Position / Job Title	Qualifications & Experience
Paul Davies [Facilitator] LR Marine	Technical Manager, Risk Assessment & Alternative Fuels	PhD, Risk Assessment. BEng. Mech. Eng. CEng. Risk analyst - major accident hazards (25 years incl. HAZID facilitation). Technical lead for gas fuelled rules. Support to UK MCA in development of the IGF Code. Development of LR's assessment of risk based designs.
Kim Tanneberger [Scribe] LR Marine	Lead Specialist, Strategic Research	Dipl . Ing. (FH) Chemical Engineering. LR Strategic Research Group since 2008. Numerous projects on alternative fuels for ships: methanol, biodiesel, LNG, & glycerine. Includes the SPIRETH and Germanica projects. Experienced HAZID scribe.
Fabio Fantozzi LR Marine	Senior Specialist Fire & Safety	Bachelor Honours Degree, Safety Engineering. Safety Specialist for Energy, Oil & Gas and Marine projects, On-Shore/Off-Shore, EMEA and Middle America (9 years).
Anders Höfnell LR Marine	Business Development Manager, Scandinavia & Baltic	BSc, ESLog, Mariner and Engineer. Business development for several recent, local projects on alternative fuels for ships: methanol and LNG. Includes the SPIRETH and Germanica projects.
Gary Pogson LR Marine	Lead Specialist, Engineering Systems	MEng. Mechanical Eng. CEng. Systems Eng., product development & QA in defence, aerospace & marine sectors (>16 years). Development of gas fuelled rules & LR lead on provisional rules for regasification systems & methanol fuelled ships.
Karel Vinke LR Marine	Principal Specialist, Marine Design Support	Ing. / Operations Manager / Fleet Manager. Over 30 years' experience in chemical tanker operations. LR chemical tanker expert, including new buildings and upgrades.
Joanne Ellis SSPA Sweden AB	Project Manager	PhD. Experience in risk, safety and environmental assessment of marine transport. Includes research on dangerous goods and alternative fuels for ships: LNG, methanol (SPIRETH). SSPA 16 years, 25 years overall experience.
Björn Forsman SSPA Sweden AB	Project Manager	MSc. Mech. Eng. Over 30 years' consultancy experience in maritime safety assessment and risk analysis. Expert experience from several QRA/FSA risk assessment projects related to LNG as ship fuel and LNG bunkering.
Maria Bännstrand SSPA Sweden AB	Project Manager	MSc. Master Mariner. Experience with projects in the areas of alternative fuels for marine use and related infrastructure, ports and fairways, platform and vessel technical safety. 20 years within the shipping industry.
Roger Karlsson SSPA Sweden AB	Project Manager, Ship Design	MSc. Naval Architecture. Over 35 years' in shipping operations and design. Technical Director (10 years) of a tanker company (incl. methanol transport). SSPA projects & risk assessments for alternative fuels, tanker operations.

7. Meyer Werft and Flensburger Schiffbaugesellschaft'. (18-Nov-15). Two documents received 20-Nov-15: 'Remarks by Meyer Werft and Flensburger Schiffbaugesellschaft' and 'Remarks to EMSA Report working draft of the 'Safety Assessment – Methanol and Ethanol fuelled Ships'.

Name & Organisation	Position / Job Title	Qualifications & Experience
Ricardo Batista EMSA	Project Officer, Marine Environment, Environment and Enforcement	MSc. Naval Architecture. BEng. Marine Eng. European Commission support with alternative fuels (IGF Code, LNG bunkering) and abatement methods. Onboard experience (5 years) as propulsion, power production, safety & damage control officer.
Saeed Mohebbi Swedish Transport Agency, Maritime & Civil Aviation Dept.	Senior Adviser Electrical Safety and Alternative Fuels	Marine engineer and electro-technician working in electrical safety, machinery and alternative fuels (IGF Code working and correspondents groups for LNG and methanol). STA since 2008.
Kristoffer Tyvik MARINVEST Shipping AB	Senior Project Manager	MSc. Naval Architecture, IWE. Management of newbuilding projects, including LFL fuelled methanol tankers and fleet improvement projects. HAZID / FMECA and survey and piping systems approval experience (3 years Marinvest, 7 years DNV).
Michel Hamrouni Methanex	Manager, Market Development & Regulatory Affairs	MSc. Electronic Eng., MBA Finance & Strategic Marketing. Responsible for commercialising methanol energy applications in Europe, Central Asia and Middle East. Working with the global Methanex team with global responsibility for coordinating and executing renewable methanol strategy.
Per Stefenson Stena Teknik	Marine Standards Advisor	MSc. Naval Architecture. Expertise in: IMO/EU standards & regulations development, RTD/project management of lightweight design & naval craft; & methanol as fuel (eg. SPIRETH & coordinator of *Methanol: the marine fuel of the future*.
Lisa Gustin Stena Teknik	Project Manager	M.Sc. Naval Architecture, Officer (Royal Swedish Navy). Recently appointed PM for Stena RoRo-RoPax fire safety project. Structural design, light weight structures and exhaust gas cleaning. Onboard experience (military ships).
Ulf Freudendahl MARU Teknik AB	Naval Architect	MSc. Naval Architecture. Experience in shipyards/classification of ships since 1971, both new-build, ships in operation and LNG and methanol as fuel. Extensive involvement in drafting interim guidelines for methanol/ ethanol as fuel at IMO and member of the IGF Code Correspondence Group.
Franz Evegren SP Fire Research	Senior Research Scientist	MSc. Risk Management & Systems Safety. BSc. Fire Safety Eng. Risk-based approaches to assess fire safety of alternative ship designs since 2010. Assisted Swedish Flag: fire safety of low-flashpoint fuel installations; FRP composites. Fire safety assessment/design for Germanica
All individuals attended full-time both days with the exception of: Per Stefenson (attended day 1 only 10:00-14:00), Franz Evergren (attended day 1 only until 18:00), Björn Forsman (left day one 18:00), Maria Bännstrand (left day 1 18:00 and day 2 15:00), and Roger Karlsson (left day 2 13:30).		

Table 5.2: Subsequent Workshop Team

Name & Organisation	Position / Job Title	Qualifications & Experience
Paul Davies [Facilitator] LR Marine	Technical Manager, Risk Assessment & Alternative Fuels	As per Table 5.1.
Kim Tanneberger [Scribe] LR Marine	Lead Specialist, Strategic Research	As per Table 5.1.
Fabio Fantozzi LR Marine	Senior Specialist Fire & Safety	As per Table 5.1.
Gary Pogson LR Marine	Lead Specialist, Engineering Systems	As per Table 5.1.
Karel Vinke LR Marine	Principal Specialist, Marine Design Support	As per Table 5.1.
Francesco Sandrelli LR Marine	Senior Specialist. MARPOL, Marine Design Support	MSc, PGDip (Law). LR Marpol since 2012. Numerous projects on Chemical and Gas Vessel covering existing, conversion and upgrading.
Jonathan Morley LR Marine	Lead Specialist. MARPOL, Marine Design Support	BSc. Naval Architecture & Shipbuilding. Fellow of: RINA, CILT, IMarEST, SNAME, CIWEM. Over 30 years MARPOL experience representing LR at IMO. Hon. Sec. of RINA London Branch 2000-05, President 2005-11, and current vice-President. Experience includes surveying and chemicals/gas.
All individuals attended full-time with the exception of: Gary Pogson (attended 08:30-12:00) and Francesco Sandrelli (attended 11:00-15:00)		

6. RESULTS

A complete record of the prevention and mitigation safeguards identified and the indicative risk ratings developed is given in Annex A and Annex B for passenger ships and cargo ships, respectively.

A large number of safeguards were identified and a significant proportion of these are additional to those noted in the developing IGF Code for methanol/ethanol. That is, they are not currently within the Code. These additional safeguards[8] are shaded in green in Annexes A and B.

Importantly, the additional safeguards could contribute to further risk reduction, and in all cases the risks are judged 'low' to 'medium' and could be considered 'mitigated as necessary'[9].

It is important to note that not all safeguards will be applicable to all ships and neither will they be applicable to all fuel designs and arrangements. Some are obviously practical and of benefit but others may require further investigation as to their merits and feasibility. In addition, there may be alternative safeguards that could provide equivalent prevention or mitigation. However, all identified safeguards are listed for consideration and these may help inform prescriptive requirements and develop inherently safer designs and arrangements.

The additional safeguards identified by the team are summarised in Section 6.1 and Section 6.2 for passenger ships and cargo ships, respectively. They are listed by the categories 'prevention' and 'mitigation. That is, those that could:

- prevent a release of fuel – referred to as '<u>Prevention Safeguards</u>';
- contain, detect and prevent ignition of a release of fuel. These are initial post-leak mitigations – referred to as <u>Mitigation Safeguards A</u>; and
- further contain a release of fuel, contain and protect from fire, and detect and extinguish fire[10]. These are secondary post-leak mitigations – referred to as <u>Mitigation Safeguards B</u>.

The references in brackets at the end of each listed safeguard refer to the worksheets in Annexes A or B, as appropriate. The references denote each safeguard's <u>first</u> use for each functional group and release cause category (refer to Tables 3.1, 3.2 and 4.2). For example, B-4-3 refers to 'storage (B) - mechanical failure (4) – third listed safeguard (3)'.

Abbreviations, terms and acronyms used in the listing of safeguards / risk ratings

BS	Bunker Station	IR	infra-red
CCTV	Closed Circuit Television	on-deck	i.e. open-deck
ESD	Emergency Shutdown	QCDC	quick connect disconnect coupling
FPR	Fuel Preparation Room	SP	safeguard for a Passenger Ship
FSHS	Fuel Storage Hold Space	SC	safeguard for a Cargo Ship
		TMIV	Tank Master Isolation Valve

8. Marinvest Shipping is of the view that the safety considerations noted in this report (that are additional to the developing IGF Code) may give the impression that methanol/ethanol presents greater safety risks than other alternative fuel options, such as LNG and therefore distance themselves from this report. This impression should not be drawn from this report since the scope of work did not cover safety comparisons with other alternative fuels.
9. The risk ratings are based on generic ship types. Specific ship designs could have different risk ratings.
10 A fuller explanation of the safeguards is given in Table 4.1.

6.1 Safeguards – Passenger Ships

There are a total of 45 additional safeguards:

- 28 Prevention Safeguards;
- 10 Mitigation Safeguards A; and
- 7 Mitigation Safeguards B.

From an inherently safer design perspective, it is important to note that nearly two thirds of the safeguards are focused on prevention (approximately 62%) and four of these also provide mitigation.

Interestingly none of the additional mitigation safeguards refer to fire extinguishment. This could be taken to mean that the existing (including currently proposed) fire-fighting measures are considered adequate or there is a lack of knowledge in this area on what improvements could be made specific to methanol/ethanol[11].

Methanol – Ethanol

The workshop team did not specifically distinguish between methanol and ethanol, and the safeguards are judged to be relevant to both fuels. This is because the principal hazard is that of fire and methanol/ethanol characteristics are similar, and for the vast majority of scenarios the toxicity differences are not a significant factor in identifying the provision of safeguards and estimating a risk rating. However, differences in properties and characteristics could result in differing detailed design requirements for certain safeguards, for example: means/setting of vapour detection; location of vapour detectors; and protection from toxic aspects where it might be possible for persons to come into contact with the fuel.

Ro-Pax Ships – Cruise Ships

The different operational profiles and designs of Ro-Pax ships and cruise ships could influence the likelihood and/or consequences of an incident involving methanol/ethanol. Considerations include, for example:

- a greater number of persons are potentially exposed on a cruise ship. However, this will be dependent upon the location of a potential spill/fire and the protection afforded;
- coastal operation of a Ro-Pax between dedicated ports may reduce the likelihood of collision due to route experience. However, a Ro-Pax may be more likely to operate in congested waters or routes, increasing the likelihood of collision;
- cruise ships are likely to store more fuel and so increase potential fire duration. However, there is a threshold above which increased fire duration will not necessarily result in more persons being harmed. This is because, for example, persons have sufficient time to evacuate to a safe location; and
- a Ro-Pax is likely to bunker more often increasing the likelihood of a methanol/ethanol spill. However, bunkering might take place away from areas where persons can be expected and with no one on board other than bunkering personnel – thus, reducing the potential for harm.

11. Research work is currently on-going in this area. For example, 'preFLASH - Preliminary study of protection against fire in low-flashpoint fuel', SP Technical Research Institute of Sweden, SP Report 2015:51.

It is clear from the above examples that the risk will be dependent upon the specific operational profile and design of the ship and it is not simply characterised by whether a ship is a Ro-Pax or a cruise ship. As such, the safeguards listed below are generally applicable to both Ro-Pax ships and cruise ships with the exception that Protection Safeguard S7 refers to protection from vehicle impact. In addition, Prevention Safeguards S8, S9, S10, S16 and S25 and Mitigation Safeguard S36 include protection to/from vehicles.

Finally, although most fuel tanks might be located below deck, Ro-Pax ships are more likely to have fuel tanks and fuel containing equipment on open-deck compared to cruise ships. The following safeguards specifically refer to open-deck measures (also referred to as on-deck): Prevention Safeguards S8, S17 and S26; and, Mitigation Safeguards S29, S30, S32, S36, S40 and S41.

Prevention Safeguards

SP1. The cofferdam around an integral fuel tank could contain water. In the event of a leak from the tank to the cofferdam the water would dilute the fuel and help minimise potential ignition. (B-1-2)

SP2. Provide a secondary barrier around an independent fuel tank to safely contain a leak from failure of the fuel tank's primary barrier. This safeguard could also provide some protection from external impact and from thermal radiation and flame impingement. (B-1-3, B-3-4)

SP3. Increase impact resistance of shell plating, hull girder and/or local structure in way of the fuel tank to provide additional protection from collisions and groundings. (B-1-4)

SP4. Locate integral fuel tanks below the waterline so that given a release to sea, the leak is diluted to minimise potential ignition and toxicity. (B-1-5)

SP5. Design the fuel tank to deform without loss of integrity for specified impacts. This would provide additional protection against accidental impacts (such as dropped loads) and possibly protection from some from collisions and groundings. (B-1-8, B-2-6)

SP6. Provide the fuel tank with an internal flexible and expandable bag (liner or bladder). This would provide additional protection against accidental impacts such as dropped loads, collisions and groundings. (B-1-9, B-2-7)

SP7. Install crash barriers/bollards around fuel tanks, FSHSs and FPRs that are located on decks where vehicles could be present. (B-2-1, C-2-3)

SP8. In the vicinity of a fuel tank and FPR (e.g. on-deck) prevent lifting, maintenance, loading, laydown and vehicle activity without additional safeguards and an appropriate permit-to-work. This is to limit the likelihood of impact. (B-2-4, C-2-5)

SP9. Provide physical separation between fuel tanks (and FSHSs/FPRs) and vehicles/other sources of fire. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement. This safeguard could be combined with SP10 to reduce or eliminate the separation distance. (B-3-1, C-3-5)

SP10. Provide an appropriate rated class division between fuel tanks (and FSHSs/FPRs) and vehicles/other sources of fire. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement. This safeguard could be combined with SP9 to optimise the class division. (B-3-2, C-3-5)

SP11. Minimise penetrations, fittings and connections. This is fundamental to inherently safer design and reduces the likelihood of a fuel release. (A-4-3, B-4-3, C-4-3, D-4-3)

SP12. Ensure that the safety control system is separate and independent from the fuel control system. This is good engineering practice to eliminate common cause failures and increase the likelihood of safe shutdown. This safeguard is noted in Part A-1 (LNG) of the IGF Code (15.2.4) but is not within the developing sections for methanol/ethanol. (A-5-2, B-5-3, C-5-2, D-5-1)

SP13. For dual-fuel engines, change-over to fuel oil if utilities supporting the safety control system for methanol/ethanol fail, and consider change-over to fuel oil if utilities for the fuel control system for methanol/ethanol fail. Utilities include electrical power, hydraulics, compressed air and inert gas. (B-6-2, B-6-4, C-6-2, D-6-2)

SP14. Given sufficient warning and time (of collision/fire in vicinity of fuel tank), for dual-fuel engines, change-over to fuel oil. This would close the TMIV. The purpose of this is to reduce leak inventory of equipment and pipework downstream of the TMIV. (C-1-3, D-1-1, D-3-1)

SP15. Within the FPR and ER prevent lifting, maintenance and inspection activity without additional safeguards (e.g. equipment is purged/inerted) and an appropriate permit-to-work. This is to limit the likelihood of impact. (C-2-1, D-2-3)

SP16. Locate fuel pipework/lines within trunks, beyond the operational envelope of lifting operations, and/or behind structure to protect from mechanical damage and external fires (especially to protect against potential vehicle impact and vehicle fires on ro-ro decks). (C-2-7, D-2-2)

SP17. Locate fuel preparation equipment within an FPR even when on-deck. This could be a protective box, cover or room. The purpose of this is to provide protection from external fire. It would also provide protection against external impact (e.g. dropped loads). (C-3-2)

SP18. For dual-fuel engines, on change-over to fuel oil given failure of utilities supporting the safety control system, methanol/ethanol fuel should be recycled to a safe location (e.g. the fuel tank). (D-5-3).

SP19. Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release. (A-1-1, A-2-4, A-3-1)

SP20. The bunkering of fuel should be a manned operation with a dedicated 'watchman' to warn of potential events and the need to shutdown transfer. The purpose of this is to provide early warning, the opportunity to take early prevention or mitigation actions, and as a safeguard against failure of detection/shutdown systems. (A-1-2, A-2-5, A-3-2)

SP21. The bunkering location in port should be selected to minimise exposure to harbour/ship traffic. The purpose of this is to limit the potential for third parties to initiate an accidental release of fuel, to minimise the chances of ignition, and to protect persons and property from harm in the event of a fuel release. (A-1-3)

SP22. Delivery hose/arm independently supported at source and on the receiving ship. The purpose of this is to minimise excess movement and stress/strain on manifolds and the hose that could result in an accidental release of fuel (e.g. from the manifold connection of the receiving ship). This also needs to consider 'dry breakaway' couplings used to prevent spills in the event of excess movement. (A-1-4)

SP23. Establish a safe operational envelope for bunkering operations. This would include weather conditions (including electrical storms, wind, snow, ice and sea state, etc.). (A-1-5)

SP24. Locate the Bunker Station beyond the operational envelop of lifting operations. (A-2-1)

SP25. During bunkering, prevent lifting, loading, maintenance, laydown and vehicle activity in the vicinity of the BS unless additional safeguards are taken (e.g. BS is beyond the operating envelope of lifting activities and embarking/disembarking passengers and vehicles are beyond the exclusion/safety zone and at a distance where they would not be directly harmed by a ignited or unignited spill). (A-2-2)

SP26. For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages. (A-3-5)

SP27. During bunkering provide a means of vapour management (such as vapour return to the supply). This is because during bunkering and unless necessary for safety, fuel vapour should not be released to atmosphere (IGF Code developing methanol/ethanol Section 3.2.9). (A-5-4)

SP28. Shutdown of bunker transfer is expected given failure of utilities that support operation of the ESD-link (between bunker supply and receiving ship) and other safety controls. Utilities include electrical power, hydraulics, compressed air and inert gas, as appropriate. (A-6-2)

Impact protection as a safeguard is noted within the developing methanol/ethanol section of the IGF Code in a generic way: e.g. "5.3.4 Fuel tanks located on open deck shall be protected against mechanical damage". The prevention measures above provide more specific considerations on such protection for fuel tanks and other fuel containing equipment (SP2, SP5, SP6, SP7, SP8, SP17, SP26).

Mitigation Safeguards A

SP29. Contain – In the event of a fuel release on-deck, inlets/outlets to spaces where persons can be expected (e.g. accommodation) should be closed to prevent ingress of vapour. This refers to those inlets/outlets to which it is determined vapour can disperse/reach. (B-2-8)

SP30. Contain – For fuel tanks located on-deck provide additional intermediate coamings or reduce coaming extent and increase coaming height. The purpose of this is to minimise the surface area of a spill and so limit evaporation and formation of vapour. (B-4-6)

SP31. Contain – All inlets/outlets to the ship that are located within the bunkering exclusion/safety zone should be closed to prevent ingress of vapour. (A-1-8)

SP32. Contain – For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages. (A-1-7, this is also a Prevention Safeguard SP26)

SP33. Detect – As part of fuel tank instrumentation, provide an alarm to warn when the liquid level decreases at a rate beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system. (B-1-14)

SP34. Detect - As part of fuel tank instrumentation, provide an alarm to warn when the liquid flow-rate from the tank is beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system. (B-1-15)

SP35. Detect – Provide liquid level detection in drip trays to warn of a spill. (C-2-12)

SP36. Prevent Ignition – Water deluge, water spray or foam systems could be activated to help prevent ignition within the FSHS, FPR, and enclosed BS, or within the vicinity of fuel tanks/BS located on-deck. Water deluge would provide dilution whilst foam would limit evaporation. Consideration would need to be given to limiting avoiding 'spreading' of a spill on-deck. (A-1-15, A-1-16, B-1-19)

SP37. Prevent ignition – Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release. (A-1-14, this is also a Prevention Safeguard SP19)

SP38. Prevent ignition – Establish a safe operational envelope for bunkering operations. This would consider, for example, weather and meteorological conditions (i.e. electrical storms, wind, snow, ice and sea state, etc.). (A-1-18, this is also a Prevention Safeguard SP23)

Mitigation Safeguards B

SP39. Contain – Locate fuel tanks (and FSHS/FPR/BS) away from accommodation and areas/spaces where persons are normally expected, and away from areas/spaces with flammable materials (e.g. vehicles). Appropriate separation from such areas/spaces needs to be determined based on fire load and intervening boundaries. The purpose of this is to protect areas/spaces from thermal radiation and flame impingement and limit escalation of fire. Part A-1 of the IGF Code suggests 10 m (11.5.2) but this may not be appropriate for methanol/ethanol fires. (A-1-22, B-1-26, B-1-27, C-1-14)

SP40. Contain – Provide an appropriate rated class division between fuel tanks on-deck (and FSHSs/FPRs) and areas/spaces where persons are normally expected. This would provide some protection from thermal radiation and direct flame impingement. (B-3-17, C-2-24, this is also a Prevention Safeguard similar to SP10)

SP41. Contain – Provide deluge/spray on accommodation and control station boundaries, etc. within a determined distance from a FSHS/FPR that is located on-deck. This would provide some protection from thermal radiation and direct flame impingement. (C-2-25)

SP42. Contain – Provide water cooling/deluge to protect the hull from potential fires in the BS. (A-1-28)

SP43. Detect – Provide fixed and/or portable IR cameras to detect fires/flames. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye. (A-1-23, B-1-28, C-1-15, D-1-12)

SP44. Detect – Provide CCTV with IR capability. This would enable fires to be viewed remotely and provide information to help with emergency actions. (A-1-24, B-1-29, C-1-16, D-1-13)

SP45. Detect – Provide temperature instrumentation to detect fire. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye. (A-1-26, B-1-31, C-1-18, D-1-15)

6.2 Safeguards – Cargo Ships

There are a total of 40 additional safeguards:

- 22 Prevention Safeguards;
- 11 Mitigation Safeguards A; and
- 7 Mitigation Safeguards B.

From an inherently safer design perspective, it is important to note that more than half of the safeguards are focused on prevention (55%).

As per the passenger ship work reported in Section 6.1, none of the additional mitigation safeguards refer to fire extinguishment. This could be taken to mean that the existing (including currently proposed) fire-fighting measures are considered adequate or there is a lack of knowledge in this area on what improvements could be made specific to methanol/ethanol[12].

Methanol – Ethanol

In keeping with the passenger workshop, the cargo workshop team did not specifically distinguish between methanol and ethanol, and the safeguards are judged to be relevant to both fuels. This is because the principal hazard is that of fire and methanol/ethanol characteristics are similar, and for the vast majority of scenarios the toxicity differences are not a significant factor in identifying the provision of safeguards and estimating a risk rating. However, differences in properties and characteristics could result in differing detailed design requirements for certain safeguards, for example: means/setting of vapour detection; location of vapour detectors; and protection from toxic aspects where it might be possible for persons to come into contact with the fuel.

12. Research work is currently on-going in this area. For example, 'preFLASH - Preliminary study of protection against fire in low-flashpoint fuel', SP Technical Research Institute of Sweden, SP Report 2015:51.

Short Sea (coastal) – Deep Sea

The different operational profiles and designs of coastal and deep sea vessels could influence the likelihood and/or consequences of an incident involving methanol/ethanol. Considerations include, for example:

- coastal operation between dedicated ports may reduce the likelihood of collision due to route experience. However, coastal operations might experience more congested waters or routes, increasing the likelihood of collision;
- deep sea ships are likely to store more fuel and so increase potential fire duration. However, there is a threshold above which increased fire duration will not necessarily result in more persons being harmed. This is because, for example, persons have sufficient time to evacuate to a safe location; and
- a ship designed for coastal operation is likely to bunker more often increasing the likelihood of a methanol/ethanol spill. However, bunkering might take place at night away from areas where persons can be expected and with no one on board other than bunkering personnel - thus, reducing the potential for harm.

It is clear from the above examples that the risk will be dependent upon the specific operational profile and design of the ship and it is not simply characterised by whether a ship is designed for coastal or deep sea operations. As such, the safeguards listed below are generally applicable to both operational modes.

Many of the safeguards listed below are similar or identical to those listed for passenger ships in Section 6.1 and these 'passenger' safeguards are denoted by the abbreviation SP.

Prevention Safeguards

SC1. The cofferdam around an integral fuel tank could contain water. In the event of a leak from the tank to the cofferdam the water would dilute the fuel and help minimise potential ignition. (B-1-3) SP1

SC2. Increase impact resistance of shell plating, hull girder and/or local structure in way of the fuel tank to provide additional protection from collisions and groundings. (B-1-7) SP3

SC3. Locate integral fuel tanks below the waterline so that given a release to sea, the leak is diluted to minimise potential ignition and toxicity. (B-1-8) SP4

SC4. Emergency discharge of fuel to a safe location, such as a holding tank or direct to sea. (B-1-10).

SC5. Design the fuel tank to deform without loss of integrity for specified impacts. This would provide additional protection against accidental impacts (such as dropped loads) and possibly protection from some from collisions and groundings. (B-1-11) SP5

SC6. Provide the fuel tank with an internal flexible and expandable bag (liner or bladder). This would provide additional protection against accidental impacts such as dropped loads, collisions and groundings. (B-1-12) SP6

SC7. Area accessible only to authorised crew. (B-2-4, C-2-5)

SC8. In the vicinity of a fuel tank and FPR, and in the vicinity of a BS during bunkering, prevent lifting, maintenance, loading and laydown without additional safeguards and an appropriate permit-to-work. This is to limit the likelihood of impact. (A-2-2, B-2-3, C-2-4) SP8

SC9. Provide physical separation between fuel tanks (and FSHSs/FPRs) and other sources of fire, or separate from cargo areas, as appropriate. This is to protect fuel tanks (and FSHSs/FPRs) from thermal radiation and direct flame impingement. (B-3-1, C-3-5) SP9

SC10. Minimise penetrations, fittings and connections. This is fundamental to inherently safer design and reduces the likelihood of a fuel release. (B-4-3, C-4-3, D-4-3) SP11

SC11. For dual-fuel engines, change-over to fuel oil if utilities supporting the safety control system fail, and consider change-over to fuel oil if utilities for the fuel control system fail. Utilities include electrical power, hydraulics, compressed air and inert gas. (A-6-2, B-6-2, C-6-2, D-6-2, A-6-4, B-6-4, C-6-4, D-6-4) SP13

SC12. Given sufficient warning and time (of collision/fire in vicinity of fuel tank), for dual-fuel engines, change-over to fuel oil. This would close the TMIV. The purpose of this is to reduce leak inventory of equipment and pipework downstream of the TMIV. (C-1-3, D-1-1) SP14

SC13. Provide an appropriate rated class division between the ER and FPR. This is to protect from thermal radiation and direct flame impingement. (C-1-5).

SC14. Within the FPR and ER prevent lifting, maintenance and inspection activity without additional safeguards (e.g. equipment is purged/inerted) and an appropriate permit-to-work. This is to limit the likelihood of impact. (C-2-1, D-2-3) SP15

SC15. Locate fuel pipework/lines within trunks, beyond the operational envelope of lifting operations, and/or behind structure to protect from mechanical damage and external fires. (C-2-6, D-2-2) SP16

SC16. Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release. (A-1-1) SP19

SC17. The bunkering of fuel should be a manned operation with a dedicated 'watchman' to warn of potential events and the need to shutdown transfer. The purpose of this is to provide early warning, the opportunity to take early prevention or mitigation actions, and as a safeguard against failure of detection/shutdown systems. (A-1-2) SP20

SC18. The bunkering location in port should be selected to minimise exposure to harbour/ship traffic. The purpose of this is to limit the potential for third parties to initiate an accidental release of fuel, to minimise the chances of ignition, and to protect persons and property from harm in the event of a fuel release. (A-1-3) SP21

SC19. Delivery hose/arm independently supported at source and on the receiving ship. The purpose of this is to minimise excess movement and stress/strain on manifolds and the hose that could result in an accidental release of fuel (e.g. from the manifold connection of the receiving ship). This also needs to consider 'dry breakaway' couplings used to prevent spills in the event of excess movement. (A-1-4) SP22

SC20. Establish a safe operational envelope for bunkering operations. This would include weather conditions (including electrical storms, wind, snow, ice and sea state, etc.). (A-1-6) SP23

SC21. During bunkering provide a means of vapour management (such as vapour return to the supply). This is because during bunkering and unless necessary for safety, fuel vapour should not be released to atmosphere (IGF Code developing methanol/ethanol Section 3.2.9). (A-5-4) SP27

SC22. Shutdown of bunker transfer is expected given failure of utilities that support operation of the ESD-link (between bunker supply and receiving ship) and other safety controls. Utilities include electrical power, hydraulics, compressed air and inert gas, as appropriate. (A-5-2) SP28

Mitigation Safeguards A

SC23. Contain – For fuel tanks located on-deck provide additional intermediate coamings or reduce coaming extent and increase coaming height. The purpose of this is to minimise the surface area of a spill and so limit evaporation and formation of vapour. (B-4-7) SP30

SC24. Contain – For a BS on-deck, provide an enclosure to protect from accidental impacts and to help contain any spillages. (A-1-8) SP32

SC25. Contain – All inlets/outlets to accommodation closed on leak detection within vicinity of leak. This refers to those inlets/outlets to which it is determined vapour can disperse/reach (B-2-8, C-2-9)

SC26. Contain – All inlets/outlets to the ship that are located within the bunkering exclusion/safety zone should be closed to prevent ingress of vapour. (A-1-9) SP31

SC27. Contain/direct – Provide explosion relief in exhaust vented to a safe location. (D-5-4)

SC28. Emergency discharge of fuel to a safe location, such as a holding tank or direct to sea (in the event of a BS release). (A-1-11).

SC29. Detect – Provide liquid level detection in drip trays to warn of a spill. (C-2-11) SP35

SC30. Detect – As part of fuel tank instrumentation, provide an alarm to warn when the liquid level decreases at a rate beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system. (B-1-19, C-1-7, D-1-4) SP33

SC31. Detect – As part of fuel tank instrumentation, provide an alarm to warn when the liquid flow-rate from the tank is beyond normal operating parameters. The purpose of this is to indicate a potential leak from the system. (B-1-20, C-1-8, D-1-5) SP34

SC32. Prevent ignition – Establish an exclusion/safety zone around the bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled. The purpose of this is to limit the potential for accidental releases of fuel, minimise the chances of ignition, and protect persons from harm in the event of a fuel release. (A-1-15, this is also a Prevention Safeguard SC16) SP19

SC33. Prevent ignition – Establish a safe operational envelope for bunkering operations. This would consider, for example, weather and meteorological conditions (i.e. electrical storms, wind, snow, ice and sea state, etc.). (A-1-19, this is also a Prevention Safeguard SC20) SP38

Mitigation Safeguards B

SC34. Contain/protect – Locate lifeboats and emergency routes at a distance where thermal radiation will not impair use. (B-1-37)

SC35. Contain – Locate fuel tanks (and FSHS/FPR/BS) away from accommodation and areas/spaces where persons are normally expected, and away from areas/spaces with flammable materials. Appropriate separation from such areas/spaces needs to be determined based on fire load and intervening boundaries. The purpose of this is to protect areas/spaces from thermal radiation and flame impingement and limit escalation of fire. Part A-1 of the IGF Code suggests a 10 m (11.5.2) separation from LNG fires but this may not be appropriate for methanol/ethanol fires. (A-1-23, B-1-32, C-1-15) SP39

SC36. Contain – Provide water cooling/deluge to protect the hull from potential fires in the BS. (A-1.29) SP42

SC37. Detect – Provide fixed and/or portable IR cameras to detect fires/flames. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye. (A-1-24, B-1-33, C-1-17, D-1-12) SP43

SC38. Detect – Provide CCTV with IR capability. This would enable fires to be viewed remotely and provide information to help with emergency actions. (A-1-25, B-1-34, C-1-18, D-1-13) SP44

SC39. Detect – Provide sea water/water detection within the fuel tanks. (B-1-38)

SC40. Detect – Provide temperature instrumentation to detect fire. Fuel fires are not always easy to detect because methanol/ethanol flames are difficult to see with the naked eye. (A-1-27, B-1-36, C-1-20, D-1-15) SP45

6.3 Risk Ratings

The risk ratings with respect to the functional groups and release cause categories are detailed in Annex A and Annex B for passenger ships and cargo ships, respectively. These ratings are also illustrated below in Figure 6.1 for passenger ships and Figure 6.2 for cargo ships.

Following inclusion of safeguards all risk ratings were judged 'low' to 'medium' and the safety risk could be considered 'mitigated as necessary'[13].

The 'blue dots' in Figures 6.1 and 6.2 cover the range of risk ratings discussed by the team, and also illustrate the uncertainty inherent in estimating consequences and likelihoods based on: non-specific designs and operation; and minimal operational experience and data.

Methanol – Ethanol

The risk ratings do not distinguish between methanol and ethanol, and are judged to be indicative of both fuels. However, the overall safety risk will be dependent in some respects on fuel properties and characteristics, as noted in Sections 6.1 and 6.2 'Methanol - Ethanol'.

Ro-Pax Ships – Cruise Ships

No distinction is made between Ro-Pax ships and cruise ships, and the risk ratings are judged to be indicative of both passenger ship types. However, the overall safety risk will be dependent upon design and operational specifics, as noted in Section 6.1 'Ro-Pax Ships – Cruise Ships'.

Short Sea (coastal) – Deep Sea

No distinction is made between coastal and deep sea vessels, and the risk ratings are judged to be indicative of both. However, the overall safety risk will be dependent upon operational profiles and design, as noted in Section 6.2 'Short Sea (coastal) – Deep Sea'.

13. The risk ratings are based on generic ship types. Specific ship designs could have different risk ratings.

Figure 6.1: Indicative Risk Ratings – Passenger Ships

KEY (for detail refer to Table 4.3)

Cons						
	C					
	B					
	A					
Likelihood		1	2	3	4	5

High
Med
Low

A. BUNKERING OF FUEL

A-D All Causes

	C2		C4	
B1		B3		

B1-3 - credible worst-case, loading/unloading of passengers and/or vehicles, with ESD link, QCDC and exclusion zone
C2-4 - as B1-3 but no ESD link/QCDC and no exclusion zone

B. STORAGE OF FUEL

B-1 Collisions (incl. groundings & contacts)

		C3		
		B3		
		A3	A4	

A3 - serious collision in way of tank located below waterline
A3-4 - serious grounding in way of tank
A3/B3 - as A3-4 resulting in tank damage but intact hull
B3/C3 - serious collision in way of tank located above waterline

B-2 External Impact

		C3		
		B3		

B3/C3 - dropped objects or other impacts

B-3 External Fire

C1	C2	C3		
B1	B2			

B1-2/C1-2 - some shielding to/from tank on-deck but PRV does not prevent over-pressurisation
C2-3 - as B1-2/C1-2 but no shielding

B-4 Mechanical Failure

	C2			
B1	B2			
	A2			

A2 - integral tank
B1-2 - independent tank below deck or on-deck with shielding
B2/C2 - credible worst-case

B-5 Control Failure

C1	C2			
B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case with safeguards
B1-2/C1-2 - credible worst-case without safeguards

B-6 Utilities Failure

C1	C2			
B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case with safeguards
B1-2/C1-2 - credible worst-case without safeguards

C. TRANSFER (AND PREPARATION) OF FUEL

B-1 Collisions (incl. groundings & contacts)

	A2	A3		

A2-3 - serious collision or grounding in way of FPR

B-2 External Impact

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-3 External Fire

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-4 Mechanical Failure

	C2	C3	C4	
	B2	B3		

B2-3/C2-3 - credible worst-case with safeguards
C4 - credible worst-case without safeguards

B-5 Control Failure

C1	C2			
B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case with safeguards
B1-2/C1-2 - credible worst-case without safeguards

B-6 Utilities Failure

C1	C2			
B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case with safeguards
B1-2/C1-2 - credible worst-case without safeguards

Figure 6.1 continued: Indicative Risk Ratings – Passenger Ships

D. Use of Fuel

B-1 Collisions (incl. groundings & contacts)

B1				

B1 - serious collision or grounding penetrating Engine Room and methanol/ethanol pipework

B-2 External Impact

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-3 External Fire

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-4 Mechanical Failure

		B3	B4	
		A3	A4	

A3-4/B-3-4 - credible worst-case

B-5 Control Failure

B1	B2			

B1-2 - credible worst-case with safeguards

B-6 Utilities Failure

B1	B2			

B1-2 - credible worst-case with safeguards

Figure 6.2: Indicative Risk Ratings – Cargo Ships

KEY (for detail refer to Table 4.3)

Cons						
	C					
	B					
	A					
Likelihood		1	2	3	4	5

High
Med
Low

A. BUNKERING OF FUEL

A-D All Causes

	C2		C4	
B1	B2	B3	B4	

B1-3 - credible worst-case, loading/unloading activities, with ESD link, QCDC and exclusion zone
B2-4/C2-4 - as B1-3 but no ESD link/QCDC and no exclusion zone

B. STORAGE OF FUEL

B-1 Collisions (incl. groundings & contacts)

		C3		
		B3		
		A3	A4	

A3 - serious collision in way of tank located below waterline
A3-4 - serious grounding in way of tank
A3/B3 - as A3-4 resulting in tank damage but intact hull
B3/C3 - serious collision in way of tank located above waterline

B-2 External Impact

	C2		C4	
	B2		B4	

B2-4/C2 - credible case with safeguards
C4 - credible worst-case without safeguards

B-3 External Fire

C1	C2	C3		
B1	B2			

B1-2/C1-2 - some shielding to/from tank on-deck but PRV does not prevent over-pressurisation
C2-3 - as B1-2/C1-2 but no shielding

B-4 Mechanical Failure

B1	B2			
	A2			

A2 - integral tank
B1-2 - dedicated cargo tank

B-5 Control Failure

C1	C2	C3		
B1	B2	B3		

B1-2/C1-2 - credible worst-case with safeguards
B2-3/C2-3 - credible worst-case without safeguards

B-6 Utilities Failure

C1	C2	C3		
B1	B2	B3		

B1-2/C1-2 - credible worst-case with safeguards
B2-3/C2-3 - credible worst-case without safeguards

C. TRANSFER (AND PREPARATION) OF FUEL

B-1 Collisions (incl. groundings & contacts)

	A2	A3		

A2-3 - serious collision or grounding in way of FPR

B-2 External Impact

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-3 External Fire

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-4 Mechanical Failure

	C2	C3	C4	
	B2	B3		

B2-3/C2-3 - credible worst-case with safeguards
C4 - credible worst-case without safeguards

B-5 Control Failure

B1	B2	B3		

B1-2 - credible worst-case with safeguards
B2-3 - credible worst-case without safeguards

B-6 Utilities Failure

C1	C2	C3		
B1	B2	B3		

B1-2/C1-2 - credible worst-case with safeguards
B2-3/C2-3 - credible worst-case without safeguards

Figure 6.2 continued: Indicative Risk Ratings – Cargo Ships

D. Use of Fuel

B-1 Collisions (incl. groundings & contacts)

B1				

B1 - serious collision or grounding penetrating Engine Room and methanol/ethanol pipework

B-2 External Impact

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-3 External Fire

B1	B2			
A1	A2			

A1-2/B1-2 - credible worst-case

B-4 Mechanical Failure

		B3	B4	
		A3	A4	

A3-4/B-3-4 - credible worst-case

B-5 Control Failure

B1	B2			

B1-2 - credible worst-case with safeguards

B-6 Utilities Failure

B1	B2			

B1-2 - credible worst-case with safeguards

7. CONCLUSIONS

A large number of safeguards have been identified, many of which are additional to those noted in the developing IGF Code for methanol/ethanol. The safeguards will not be applicable to all designs and operations but they can provide useful input when deliberating prescriptive requirements and considering inherently safer designs and arrangements.

It is concluded that safeguards can be provided to ensure the safety risk from methanol/ethanol as marine fuel is 'mitigated as necessary', as required by the IGF Code.

ANNEX A

Worksheets – Passenger Ships

RoPAX ----- Cruise Ship | DRAFT FOR COMMENT

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
								C	2/4		Credible worst-case (assuming all causes) with loading/unloading passengers and/or vehicles and no ESD link/QCDC and no appropriate exclusion zone
								B	1/3		Credible worst-case (assuming all causes) with loading/unloading passenger and/or vehicles and with ESD link, QCDC and appropriate exclusion zone
											A safe bunkering operational envelope should be develop considering: wind, weather and sea state; required exclusion/safety zone extent; harbour, port and ship traffic; and simultaneous operations (e.g. loading of vehicles and passengers)
A-1	**Collision (incl. grounding & contacts)**	1. Exclusion/safety zone around bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled		6. Contain - Drip tray beneath bunker manifold		19. Contain/Extinguish - B-1-20. Fixed fire-fighting system (water, foam as appropriate)					Setting the extent of the exclusion/safety zone needs to consider: (a) supply hose/arm diameter and length (i.e. potential 'locked-in' inventoty); delivery flow rate; weather conditions; and spill surface (i.e. land, sea, ship, barge).
		2. Manned operation with dedicated 'watchman' to warn of potential events and need to shutdown transfer		7. Contain - BS completely enclosed from ship by bulkheads when below deck - consider bulkheads for on-deck BS		20. Contain/Extinguish - B-1-21. Portable fire-fighting appliances					
		3. Bunkering location selected to minimise exposure to harbour/ship traffic		8. Contain - All ship inlets/outlets closed within exclusion/safety zone		21. Contain - A-60 BS bulkheads (unless on open deck) - condsider A-60 on open deck					
		4. Delivery hose/arm independently supported on ship		9. Contain /direct to safe location - C-2-8. Liquid to drain wells and bilge holding tank with non-return valve (tank may contain water to dilute spill below flammable range)		22. Contain - locate BS away from accommodation, areas where persons are normally expected and cargo/vehicle loading activities					
		5. Safe operating envelope - weather, etc.		10. Contain /direct to safe location - direct spill to sea		23. Detect - B-1-28. Fixed and/or portable IR cameras					

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
				11. Contain/minimise release - Linked ESD with QCDC (quick connect disconnect coupling) between ship and shore/truck/barge halting delivery and resulting in closure of valves to reduce leak inventory and possibly disconnection of delivery hose/arm (and potential for truck/barge to move away from ship)		24. Detect - B-1-29. CCTV with IR capability					
				12. Contain/minimise release - Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of valves to reduce leak inventory		25. Detect - B-1-30. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
				13. Detect - Leak detection (liquid and/or vapour detection) within BS		26. Detect - B-1-31. Temperature detectors					CCTV could also be used.
				14. Prevent Ign - Ex protected equipment in BS and exclusion/safety zone (hazardous area classification)		27. Contain/minimise release/prevent ignition - A-1-9					
				15. Prevent Ign - Deluge within BS		28. Contain - Consider water cooling/deluge on hull to protect from fire					
				16. Prevent Ign - water sprays, monitors and/or deluge at bunker supply							
				17. Prevent Ign - supply (e.g. truck) electrically isolated from ship							Even if 'earthed' on either side a spark is still possible on disconnection.
				18. Prevent Ign - no bunkering during electrical storms							
A-2	**External Impact**	1. BS located outside envelope of crane lifting operations		6. Contain - A-1-6		19. Contain/Extinguish - A-1-19					
		2. No lifting, maintenance, loading, laydown or vehicle activity within vicinity of BS		7. Contain - A-1-7		20. Contain/Extinguish - A-1-20					
		3. BS inaccessible to passengers and unauthorised crew		8. Contain - A-1-8		21. Contain - A-1-21					
		4. A-1-1		9. Contain /direct to safe location - A-1-9		22. Contain - A-1-22					
		5. A-1-2		10. Contain /direct to safe location - A-1-10		23. Contain - A-60 boundaries for accommodation and control stations, etc. within 10 m of BS on-deck					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	L	R	COMMENTS & RECOMMENDATIONS
				11. Contain/minimise release - A-1-11		24. Contain - Deluge on accommodation and control stations boundaries, etc. within 10 m of BS on-deck					
				12. Contain/minimise release - A-1-12		25. Contain - 10 m separartion from ER on-deck					
				13. Detect - A-1-12		26. Detect - A-1-23					
				14. Prevent Ign - A-1-14		27. Detect - A-1-24					
				15. Prevent Ign - A-1-15		28. Detect - A-1-25					
				16. Prevent Ign - A-1-16		29. Detect - A-1-26					
				17. Prevent Ign - A-1-17		30. Contain/minimise release/prevent ignition - A-1-9					
				18. Prevent Ign - A-1-18		31. Extinguish - A-1-28					
A-3	**External Fire**	1. A-1-1		6. Contain - A-1-6		12. Contain/Extinguish - A-1-19					
		2. A-1-2		7. Contain - A-1-7		13. Contain/Extinguish - A-1-20					
		3. A-1-3		8. Contain - A-1-8		14. Contain - A-1-21					
		4. C-3-4. Fire detection and extinguishment in areas external to FPR		9. Contain/minimise release - A-1-11		15. Contain - A-1-22					
		5. A-1-7		10. Contain/minimise release - A-1-12		16. Contain - A-2-24					
				11. Detect - A-1-13		17. Contain - A-2-25					
						18. Contain - A-2-26					
						19. Detect - A-1-23					
						20. Detect - A-1-24					
						21. Detect - A-1-25					
						22. Detect - A-1-26					
						23. Contain - A-1-28					
A-4	**Mechanical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		4. Contain - A-1-6		17. Contain/Extinguish - A-1-19					
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		5. Contain - A-1-7		18. Contain/Extinguish - A-1-20					
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		6. Contain - A-1-8		19. Contain - A-1-21					
				7. Contain /direct to safe location - A-1-9		20. Contain - A-1-22					
				8. Contain /direct to safe location - A-1-10		21. Contain - A-2-24					
				9. Contain/minimise release - A-1-11		22. Contain - A-2-25					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	L	R	COMMENTS & RECOMMENDATIONS
				10. Contain/minimise release - A-1-12		23. Contain - A-2-26					
				11. Detect - A-1-13		24. Detect - A-1-23					
				12. Prevent Ign - A-1-14		25. Detect - A-1-24					
				13. Prevent Ign - A-1-15		26. Detect - A-1-25					
				14. Prevent Ign - A-1-16		27. Detect - A-1-26					
				15. Prevent Ign - A-1-17		28. Contain - A-1-28					
				16. Prevent Ign - A-1-18		29. Contain/minimise release/prevent ignition - A-1-9					
A-5	**Control Failure**	1. B-5-2. Valves fail to safe position		No additional safeguards identified		No additional safeguards identified					
		2. B-5-3. Safe shutdown on failure of control/ESD link - safety system is separate and independent from control system									
		3. Safe shutdown on tank overfill (high-high alarm)									
		4. Consider vapour return/management									
		5. System designed to withstand maximum pump pressure									
		6. Pump with recycle on closed valve and/or shutdown/ESD									
A-6	**Utilities Failure**	1. Power restored through emergeny generator and board on ship, via, shore or bunker barge	LEAK	No additional safeguards identified	UNCONTAINED LEAK AND/OR FIRE	No additional safeguards identified	HARM				
		2. Electrical failure (utilities failure) will result in shutdown of bunker transfer - ESD link									
		3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. Compressed air or hydraulic failure (utilities failure A-6-2) will result in shutdown of bunker transfer									
		5. A-1-2									

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	Cause / Threat	Safeguard / Barrier Prevent		Safeguard / Barrier Contain / Detect / Prevent Ign		Safeguard / Barrier Contain / Detect / Extinguish		Rating C	Rating L	Rating R	Comments & Recommendations
B-1	**Collision (incl. grounding & contacts)**	1. Independent tank located in-board of shell plating in FSHS (min. 800 mm)	LEAK	11. Contain - Secondary barrier (FSHS, cofferdam, coaming if on-deck)	UNCONTAINED LEAK AND/OR FIRE	20. Contain/Extinguish - Fixed fire-fighting system (water, foam, CO2 as appropriate)	HARM	A	3		Rating for serious collision in way of tank and tank located below waterline
		2. Integral tank with protective cofferdam (maybe water filled)		12. Contain - Transfer of fuel to safe location (e.g. holding tank, dedicated bilge tank with inert blanket with/without water for dilution, or transfer to sea)		21. Contain/Extinguish - Portable fire-fighting appliances		B/C	≤ 3		Rating for serious collision in way of tank and tank located above waterline
		3. Tank surrounded by a secondary barrier		13. Detect - Leak detection (liquid, liquid level and/or vapour detection) in cofferdams and otherspaces surrounding the tank		22. Contain - A-60 FSHS bulkheads		A	3-4		Rating for serious grounding in way of tank
		4. Increased strength/resistance to impact of shell plating and structure in way of tank		14. Detect - Tank level indication (excessive decrease in liquid level)		23. Contain - Cofferdam around integral tank		A/B	3		Rating for serious grounding in way of tank resulting in tank damage but intact hull
		5. Tank located below waterline (SLL) [Tanks located above waterline for protection against grounding only)		15. Detect - Indication of excess flow from tank.		24. Contain - A-60 boundaries for accommodation and control stations, etc. within 10 m of on-deck tank					
		6. Tank located in areas less prone to impact (e.g. away from the bow)		16. Detect - Auto change-over to fuel oil for dual-fuel vessels		25. Contain - Deluge on accommodation and control stations boundaries, etc. within 10 m of on-deck tank					Means of escape should not be routed within in vicinity of the tank.
		7. Emergency discharge of fuel to a safe location (e.g. holding tank or sea)		17. Prevent Ign - Inert blanket		26. Contain - 10 m separartion from tank on-deck - A-1-27					
		8. Tank designed for deformation		18. Prevent Ign - Ex protected equipment in FSHS and in areas on-deck (hazardous area classification)		27. Contain - locate tanks away from accommodation and areas where persons are normally expected					
		9. Tank with internal flexible and expandable bag, liner or bladder		19. Prevent Ign - Deluge and/or foam for FSHS and on-deck tank		28. Detect - Fixed and/or portable IR cameras					
		10. Independent tank secured to deck with anti-floation in the event of flooding				29. Detect - CCTV with IR capability					
						30. Detect - Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
						31. Detect - Temperature detectors					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
B-2	**External Impact**	1. Bollardsand/or crash barriers to prevent collision of vehicles: directly with tank on-deck; or with bulkhead/FSHS for tanks located below deck or located on ro-ro decks		8. Contain - Closure of inlets/oulets to accommodation etc		19. B-1-20		B/C	3		Assumes all safeguards for a Ro-pax with tank located on vehicle deck
		2. Physical protection for tank on-deck in way of crane lifting operations		9. Contain/minimise release - Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation valve and hence reduction in leak inventory.		20. B-1-21					
		3. Tank on-deck located outside envelope of crane lifting operations		10. B-1-11		21. B-1-22					
		4. No lifting, maintenance (except for tank), loading, laydown or vehicle activity within vicinity of tank		11. B-1-12		22. B-1-23					
		5. Area inaccessible to passengers and unauthorised crew		12. B-1-13		23. B-1-24					
		6. B-1-8		13. B-1-14		24. B-1-25					
		7. B-1-9		14. B-1-15		25. B-1-26					
				15. B-1-16		26. B-1-27					
				16. B-1-17		27. B-1-28					
				17. B-1-18		28. B-1-29					
				18. B-1-19		29. B-1-30					
						30. B-1-31					
B-3	**External Fre**	1. Physical distance from vehicles and other sources of fire (increased distance for road trucks and vehicles containing flammable cargo)		7. B-1-11		17. B-3-2 (The A-60 structure will offer some screening/protection in the event of a methanol/ethanol fire)		C	2/3		Assumes no shielding (ie. FSHS) to/from tank on-deck and PRV does not prevent over-pressurisation
		2. Open-ended A-60 FSHS for tanks on-deck with A-60 facing vehicles and/or other fire sources		8. B-1-12		18. B-1-20		B/C	1/2		Assumes some shielding to/from tank on-deck but PRV does not prevent over-pressurisation
		3. Pressure relief valve (PRV) on tank to prevent tank over-pressurisation - PRV outlet routed to safe location		9. B-1-13		19. B-1-21					With shielding of the tankon deck (i.e. tank withgin a FSHS) it may not be possible to use external fire-fighting systems/appliances
		4. B-1-3		10. B-1-14		20. B-1-22					With shielding of the tankon deck (i.e. tank withgin a FSHS) it may not use be possible to use externally located CCTV and IR cameras
		5. B-1-7		11. B-1-15		21. B-1-23					
		6. B-2-5		12. B-1-16		22. B-1-24					
				13. B-1-17		23. B-1-25					
				14. B-1-18		24. B-1-26					
				15. B-1-19		25. B-1-27					
				16. B-2-10		26. B-1-28					

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	Cause / Threat	Safeguard / Barrier Prevent		Safeguard / Barrier Contain / Detect / Prevent Ign		Safeguard / Barrier Contain / Detect / Extinguish		Rating C	L	R	Comments & Recommendations
						27. B-1-29					
						28. B-1-30					
						29. B-1-31					
B-4	**Mechanical Failure**	1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		4. Contain /direct to safe location - Ventilation of FSHS (for independent tanks) with outlet led to a safe location		19. B-1-20		B	1/2		Independent tank below deck or on-deck with shielding
		2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		5. Contain - Drip trays under fittings/connections		20. B-1-21		A	2		Integral tank
		3. Minimise penetrations, fittings and connections		6. Contain - Additional/intermediate coamings for tanks on-deck		21. B-1-22		B/C	2		credible worst-case
				7. Contain /direct to safe location - Direct release over-board to the sea		22. B-1-23					
				8. B-1-11		23. B-1-24					
				9. B-1-12		24. B-1-25					
				10. B-1-13		25. B-1-26					
				11. B-1-14		26. B-1-27					
				12. B-1-15		27. B-1-28					
				13. B-1-16		28. B-1-29					
				14. B-1-17		29. B-1-30					
				15. B-1-18		30. B-1-31					
				16. B-1-19							
				17. B-2-8							
			LEAK	18. B-2-10	UNCONTAINED LEAK AND/OR FIRE		HARM				
B-5	**Control Failure**	1. Vacuum relief on tank		No additional safeguards identified		No additional safeguards identified		B/C	1/2		credible worst-case without safeguards
		2. Valves fail to safe position						A/B	1/2		credible worst-case with safeguards
		3. Safe shutdown on failure of control - safety system is separate and independent from control system									
B-6	**Utilities Failure**	1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B/C	1/2		credible worst-case without safeguards
		2. Electrical failure (utilities failure) will result in auotmatic change-over to fuel oil for dual-fuel vessel						A/B	1/2		credible worst-case with safeguards
		3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. Compressed air or hydraulic failure (utilities failure B-6-2) will result in auotmatic change-over to fuel oil for dual-fuel vessel									

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	 L	 R	COMMENTS & RECOMMENDATIONS
C-1	**Collision (incl. grounding & contacts)**	1. FPR typically located 2 or more metres in-board		5. Detect - Leak detection (liquid and/or vapour detection) within FPR		11. Contain/Extinguish - B-1-20. Fixed fire-fighting system (water, foam, CO2 as appropriate)		A	2/3		Rating for serious collision or grounding in way of FPR
		2. All pipework is located in-board of shell plating (min. 800 mm)		6. Detect - B-1-14. Tank level indication (excessive decrease in liquid level)		12. Contain/Extinguish - B-1-21. Portable fire-fighting appliances					Water can dilute below flammable range. CO2 may not provide sufficient cooling to prevent re-ignition.
		3. Given sufficient warning, activate shutdown/purge and change-over to fuel oil for dual fuel ships. This closes Tank Master Isolation Valve and would eliminate/reduce leak inventory		7. Detect - B-1-15. Indication of excess flow from tank.		13. Contain - A-60 FPR bulkheads					It would be prudent to consider A-60 protection towards any spaces that contain combustibiles or where persons might be present.
		4. FPR consists of steel bulkeads surrounding all equipment		8. Detect - B-1-16. Auto change-over to fuel oil for dual-fuel vessels		14. Contain - locate FPR away from accommodation and areas where persons are normally expected - B-1-					All FPR equipment should be within a structural FPR - if on-deck this should be a 'pump box'.
				9. Prevent Ign - Ex protected equipment in FPR (hazardous area		15. Detect - B-1-28. Fixed and/or portable IR cameras					
				10. Prevent Ign - Deluge, foam and/or CO2 within FPR		16. Detect - B-1-29. CCTV with IR capability					Given fire, watermist might be preferable to water deluge. This is because deluge may spread the fire. CO2 provides no cooling ans so reignition may be possible.
						17. Detect - B-1-30. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
						18. Detect - B-1-31. Temperature					
C-2	**External Imapct**	1. All maintenance/lifting/inspection activities within FPR covered by permit-to-work system. Therefore, equipment is likely to be purged/inerted during such activity		8. Contain /direct to safe location - Liquid to drain wells and bilge holding tank with non-return valve (tank may contain water to dilute spill below flammable range)		20. Contain/Extinguish - C-1-11		A/B	1/2		Credible worst-case
		2. C-1-4		9. Contain /direct to safe location - B-4-4. Ventilation of FPR with outlet led to a safe location		21. Contain/Extinguish - C-1-12					Size drain well/bilge/holding tank for credible worst case leak and time to detect and close valves to limit leak inventory.
		3. B-2-1. Bollards and/or crash barriers to prevent collision of vehicles with FPR if located on deck or on ro-ro		10. Contain - B-2-8. Closure of inlets/oulets to accommodation etc		22. Contain - C-1-13					
		4. B-2-3. FPR located outside envelope of crane lifting operations		11. Contain/minimise release - B-2-9. Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation Valve and hence reduction in leak inventory		23. Contain - C-1-14					
		5. B-2-4. No lifting, maintenace (except for FPR), loading, laydown or vehicle activity within vicinity of FPR		12. Detect - Spill liquid level detection in drip trays		24. Contain - Consider A-60 boundaries for accommodation and control stations, etc. within 10 m of FPR					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
		6. B-2-5. Area inaccessible to passengers and unauthorised crew		13. Detect - Liquid level detection in drain/bilge/bilge tank		25. Contain - Consider deluge on accommodation and control stations boundaries, etc. within 10 m of FPR on-deck					
		7. Consider locating transfer pipework/lines to users within trunk to protect from mechanical damage and external fires (especially on ro-ro		14. Detect - C-1-5		26. Contain - Consider 10 m separartion from FPR on-deck - C-2-24					
				15. Detect - C-1-6		27. Detect - C-1-15					
				16. Detect - C-1-7		28. Detect - C-1-16					
				17. Detect - C-1-8		29. Detect - C-1-17					
				18. Prevent Ign - C-1-9		30. Detect - C-1-18					
				19. Prevent Ign - C-1-10.							
C-3	**External Fire.**	1. C-1-3		8. Contain - C-2-10		18. Contain/Extinguish - C-1-11		A/B	1/2		Credible worst-case
		2. C-1-4.		9. Contain/minimise release - C-2-11		19. Contain/Extinguish - C-1-12					
		2. C-1-13		10. Detect - C-2-12		20. Contain - C-1-14					
		4. Fire detection and extinguishment in areas external to FPR		11. Detect - C-2-13		21. Detect - C-1-15					
		5. B-3-2. Physical distance from vehicles and other sources of fire (increased distance for road trucks and vehicles containing flammable cargo)		12. Detect - C-1-5		22. Detect - C-1-16					
		6. Pressure relief valvefor locked-in lines and equipment to prevent over-pressurisation - PRV outlet routed to safe location		13. Detect - C-1-6		23. Detect - C-1-17					
		7. C-2-6		14. Detect - C-1-7		24. Detect - C-1-18					
				15. Detect - C-1-8							
				16. Prevent Ign - C-1-9							
				17. Prevent Ign - C-1-10							
C-4	**Mechanical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		4. Contain /direct to safe location - C-2-8		16. Contain/Extinguish - C-1-11		C	4		Credible worst-case without safeguards
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		5. Contain /direct to safe location - C-2-9		17. Contain/Extinguish - C-1-12		B/C	2/3		Credible worst-case with safeguards
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		6. Contain - C-2-10		18. Contain - C-1-13					Typically 10% inspection for fully welded pipe reverting 100% if defect is found.
				7. Contain/minimise release - C-2-11		19. Contain - C-1-14					Consider 100% inspection to high pressure pipes or 'large' diameterr pipes.
				8. Detect - C-2-12		20. Detect - C-1-15					
				9. Detect - C-2-13		21. Detect - C-1-16					
				10. Detect - C-1-5		22. Detect - C-1-17					
				11. Detect - C-1-6		23. Detect - C-1-18					
				12. Detect - C-1-7		24. Contain - C-2-24					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
				13. Detect - C-1-8		25. Contain - C-2-25					
				14. Prevent Ign - C-1-9		26. Contain - C-2-26					
				15. Prevent Ign - C-1-10.							
C-5	**Control Failure**	1. B-5-2. Valves fail to safe position		No additional safeguards identified		No additional safeguards identified		B/C	1/2		credible worst-case without safeguards
		2. B-5-3. Safe shutdown on failure of control - safety system is separate and independent from control system						A/B	1/2		credible worst-case with safeguards
		3. Pressure relief on equipment and isolable pipework/lines									
C-6	**Utilities Failure**	1. B-6-1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B/C	1/2		credible worst-case without safeguards
		2. B-6-2. Electrical failure (utilities failure) will result in auotmatic change-over to fuel oil for dual-fuel vessel						A/B	1/2		credible worst-case with safeguards
		3. B-6-3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. B-6-4. Compressed air or hydraulic failure (C-6-2 utilities failure) will result in auotmatic change-over to fuel oil for dual-fuel vessel									

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

D. Use of Fuel ~ Engine Room (ER)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
D-1	**Collision (incl. grounding & contacts)**	1. C-1-3. Given sufficient warning, activate shutdown/purge and change-over to fuel oil for dual fuel ships. This closes Tank Master Isolation Valve and would eliminate/reduce leak inventory		3. Detect - Leak detection (liquid and/or vapour detection) within double walled pipework		9. Contain/Extinguish - B-1-20. Fixed fire-fighting system (water, foam, CO2 as appropriate)		B	1		Rating for serious collision or grounding penetrating ER and methanol/ethanol resulting in harm
		2. ER consists of steel bulkeads surrounding all equipment		4. Detect - B-1-14. Tank level indication (excessive decrease in liquid		10. Contain/Extinguish - B-1-21. Portable fire-fighting appliances					Consider PPE
				5. Detect - B-1-15. Indication of excess flow from tank.		11. Contain - A-60 ER bulkheads					
				6. Detect - B-1-16. Auto change-over to fuel oil for dual-fuel vessels		12. Detect - B-1-28. Fixed and/or portable IR cameras					
				7. Contain/minimise release - B-2-9. Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation Valve and 'Fuel Master Isolation Valve' and hence reduction in leak inventory.		13. Detect - B-1-29. CCTV with IR capability					
				8. Prevent Ign - Deluge, foam and/or CO2 within ER		14. Detect - B-1-30. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
						15. Detect - B-1-31. Temperature					
D-2	**External impact**	1. Methanol/ethanol pipework is double walled		4. Detect - D-1-3		11. Contain/Extinguish - D-1-9		A/B	1/2		Credible worst-case
		2. C-2-7. Route methanol/ethanol pipework outside 'lifting' areas		5. Detect - D-1-4		12. Contain/Extinguish - D-1-10					
		3. C-2-1. All maintenance, lifting and certain inspection activities within ER covered by permit-to-work system. Therefore, methanol/ethanol pipework is likely to be purged/inerted during such activity		6. Detect - D-1-5		13. Contain - D-1-11					
				7. Detect - D-1-6		14. Detect - D-1-12					
				8. Detect - C-2-12. Spill liquid level detection in drip trays		15. Detect - D-1-13					
				9. Contain/minimise release - D-1-7		16. Detect - D-1-14					
				10. Prevent Ign - D-1-8		17. Detect - D-1-15					
D-3	**External Fire**	1. D-1-1		5. Detect - D-1-3		12. Contain/Extinguish - D-1-9		A/B	1/2		Credible worst-case
		2. D-1-2		6. Detect - D-1-4		13. Contain/Extinguish - D-1-10					
		3. D-2-1		7. Detect - D-1-5		14. Contain - D-1-11					
		4. D-1-11		8. Detect - D-1-6		15. Detect - D-1-12					
				9. Detect - C-2-12. Spill liquid level detection in drip trays		16. Detect - D-1-13					Explosion relief in exhaust
				10. Contain/minimise release - D-1-7		17. Detect - D-1-14					
				11. Prevent Ign - D-1-8		18. Detect - D-1-15					

RoPAX ----- Cruise Ship DRAFT FOR COMMENT

D. Use of Fuel ~ Engine Room (ER)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
D-4	**Mechnical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		5. Detect - D-1-3		12. Contain/Extinguish - D-1-9		A/B	3/4		Credible worst-case
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		6. Detect - D-1-4		13. Contain/Extinguish - D-1-10					
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		7. Detect - D-1-5		14. Contain - D-1-11					
		4. D-2-1		8. Detect - D-1-6		15. Detect - D-1-12					Double walled pipe should apply to methanol/ethanol supply pipework and return/recycle pipework
				9. Detect - C-2-12. Spill liquid level detection in drip trays		16. Detect - D-1-13					
				10. Contain/minimise release - D-1-7		17. Detect - D-1-14					
				11. Prevent Ign - D-1-8		18. Detect - D-1-15					
D-5	**Control Failure**	1. B-5-3. Safe shutdown on failure of control - safety system is separate and independent from control system		4. Contain/direct to safe location - explosion relief in exhaust		No additional safeguards identified		B	1/2		credible worst-case with safeguards
		2. Misfire detection									
		3. Unused fuel recycled to tank or safe location									
D-6	**Utilities Failure**	1. B-6-1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B	1/2		credible worst-case with safeguards
		2. B-6-2. Electrical failure (utilities failure) will result in auotmatic change-over to fuel oil for dual-fuel vessel									
		3. B-6-3. Additional inert gas bottles									
		4. B-6-4. Compressed air or hydraulic failure (utilities failure D-6-2) will result in auotmatic change-over to fuel oil for dual-fuel vessel									

ANNEX B

Worksheets – Cargo Ships

Cargo Ship ----- Chemical Tanker | DRAFT FOR COMMENT

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
								B/C	2/4		Credible worst-case (assuming all causes) with loading/unloading activites and no ESD link/QCDC and no appropriate exclusion zone
								B	1/3		Credible worst-case (assuming all causes) with loading/unloading activities and with ESD link, QCDC and appropriate exclusion zone
											A safe bunkering operational envelope should be develop considering: wind, weather and sea state; required exclusion/safety zone extent; harbour, port and ship traffic; and simultaneous operations (e.g. loading of activities)
A-1	**Collision (incl. grounding & contacts)**	1. Exclusion/safety zone around bunkering activity within which only essential personnel are allowed and potential ignition sources and port/ship traffic is controlled		7. Contain - Drip tray beneath bunker manifold		20. Contain/Extinguish - B-1-25. Fixed fire-fighting system (water, foam as appropriate) this only if enclosed if on deck					Setting the extent of the exclusion/safety zone needs to consider: (a) supply hose/arm diameter and length (i.e. potential 'locked-in' inventoty); delivery flow rate; weather conditions; and spill surface (i.e. land, sea, ship, barge).
		2. Manned operation with dedicated 'watchman' to warn of potential events and need to shutdown transfer		8. Contain - consider BS completely enclosed from ship by bulkheads when below deck - consider bulkheads for on-deck BS		21. Contain/Extinguish - B-1-26. Portable fire-fighting appliances					
		3. Bunkering location selected to minimise exposure to harbour/ship traffic		9. Contain - All ship inlets/outlets closed within exclusion/safety zone Accomodation ventilation on		22. Contain - A-60 BS bulkheads (unless on open deck) - condsider A-60 on open deck					
		4. Delivery hose/arm independently supported on ship		10. Contain /direct to safe location - C-2-7. Liquid to drain wells and bilge holding tank with non-return valve (tank may contain water to dilute spill below flammable range) If BS is on deck: drips would be caught in drip tray , large leak would spill on deck and be collected in the scuppers for later manual removal to holding		23. Contain - locate BS away from accommodation, areas where persons are normally expected					
		5. Emergency stop		11. Contain /direct to safe location - direct spill to sea		24. Detect - B-1-33. Fixed and/or portable IR cameras					

Cargo Ship ----- Chemical Tanker											DRAFT FOR COMMENT
A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)											
Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	L	R	COMMENTS & RECOMMENDATIONS
		6. Bunkering procedure includes for example:communications barge - ship - other authorities. Safe operating envelope - weather, etc.		12. Contain/minimise release - Linked ESD with QCDC (quick connect disconnect coupling) between ship and shore/truck/barge halting delivery and resulting in closure of valves to reduce leak inventory and possibly disconnection of delivery hose/arm (andpotential for truck/barge to move away from ship) - Consider ESD further.		25. Detect - B-1-34. CCTV with IR capability					Consider if this requirement is required for a chemical tanker: A) large exposure possible from flanged cargo hoses anyway B)Flanges do not break as easily C) no passenger exposure to consider D)Disconnection QCDC under pressure can release liquid underpressure E)spark when it accidentally hits the deck. Linked ESD IWW only?
				13. Contain/minimise release - Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of valves to reduce leak		26. Detect - B-1-35. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					typically no smoke or Temp sensors
				14. Detect - Leak detection (liquid and/or vapour detection) within BS		27. Detect - B-1-36. Temperature detectors					12 portable or fixed. May be impossible to achieve
				15. Prevent Ign - Ex protected equipment in BS and exclusion/safety zone (hazardous area classification)		28.. Contain/minimise release/prevent ignition - A-1-10					hazardous area analysis around flanges?
				16. Prevent Ign - consider Deluge within BS		29. Contain - Consider water cooling/deluge on hull to protect from					normally, foam monitos an fire hoses
				17. Prevent Ign - water sprays, monitors and/or at bunker supply							Operational requirements for chemical tankers: ship isolated no thunderstorm ops… Does not to be said to chem tankers.
				18. Prevent Ign - supply (e.g. truck) electrically isolated from ship							
				19. Prevent Ign - no bunkering during electrical storms							
A-2	**External Impact**	1. BS located outside envelope of crane lifting operations		8. Contain - A-1-7		21. Contain/Extinguish - A-1-20					
		2. No lifting, maintenace, loading, laydown activity within vicinity of BS	LEAK	9. Contain - A-1-8	UNCONTAINED LEAK AND/OR FIRE	22. Contain/Extinguish - A-1-21	HARM				
		3. BS inaccessible to unauthorised		10. Contain - A-1-9		23. Contain - A-1-22					
		4. A-1-1		11. Contain /direct to safe location - A-		24. Contain - A-1-23					
		5. A-1-2		12. Contain /direct to safe location - A-1-11		25. Contain - A-60 boundaries for accommodation and control stations, etc. within 10 m of BS on-deck					
		6. A-1-5		13. Contain/minimise release - A-1-12		25. Contain - Deluge on accommodation and control stations boundaries, etc. within 10 m of BS on-					
		7. A-1-6		14. Contain/minimise release - A-1-13		26. Contain - 10 m separartion from ER on-deck					
				15. Detect - A-1-14		27. Detect - A-1-24					

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	L	R	COMMENTS & RECOMMENDATIONS
				16. Prevent Ign - A-1-15		28. Detect - A-1-25					
				17. Prevent Ign - A-1-16		29. Detect - A-1-26					
				18. Prevent Ign - A-1-17		30. Detect - A-1-27					
				19. Prevent Ign - A-1-18		31. Contain/minimise release/prevent ignition - A-1-10					
				20. Prevent Ign - A-1-19		32. Contain - A-1-29					
A-3	**External Fire**	1. A-1-1		8. Contain - A-1-7		15. Contain/Extinguish - A-1-20					
		2. A-1-2		9. Contain - A-1-8		16. Contain/Extinguish - A-1-21					
		3. A-1-3		10. Contain - A-1-9		17. Contain - A-1-22					
		4. C-3-4. Fire detection and extinguishment in areas external to BS		11. Contain /direct to safe location - A-1-10		18. Contain - A-1-23					
		5. A-1-8		12. Contain/minimise release - A-1-12		19. Contain - A-2-25					
		6. A-1-5		13. Contain/minimise release - A-1-13		20. Contain - A-2-26					
		7. A-1-6		14. Detect - A-1-14		18. Contain - A-2-25					
						21. Detect - A-1-24					
						22. Detect - A-1-25					
						23. Detect - A-1-26					
						24. Detect - A-1-27					
						25. Contain - A-1-29					
A-4	**Mechanical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		6. Contain - A-1-7		19. Contain/Extinguish - A-1-20					
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.	LEAK	7. Contain - A-1-8	UNCONTAINED LEAK AND/OR FIRE	20. Contain/Extinguish - A-1-21	HARM				
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		8. Contain - A-1-9		21. Contain - A-1-22					
		4. A-1-5		9. Contain /direct to safe location - A-1-		22. Contain - A-1-23					
		5. A-1-6		10. Contain /direct to safe location - A-		23. Contain - A-2-25					
				11. Contain/minimise release - A-1-12		24. Contain - A-2-26					
				12. Contain/minimise release - A-1-13		25. Contain - A-2-27					
				13. Detect - A-1-14		26. Detect - A-1-24					
				14. Prevent Ign - A-1-15		27. Detect - A-1-25					
				15. Prevent Ign - A-1-16		28. Detect - A-1-26					
				16. Prevent Ign - A-1-17		29. Detect - A-1-27					
				17. Prevent Ign - A-1-18		30. Contain - A-1-29					
				18. Prevent Ign - A-1-19		31 Contain/minimise release/prevent ignition - A-1-10					

Cargo Ship ----- Chemical Tanker											DRAFT FOR COMMENT
A. BUNKERING (transfer of fuel from shore, road tanker or bunker barge) ~ Bunker Station (BS)											
Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	L	R	COMMENTS & RECOMMENDATIONS
A-5	**Control Failure**	1. B-5-2. Valves fail to safe position	LEAK	No additional safeguards identified	UNCONTAINED LEAK AND/OR FIRE	No additional safeguards identified	HARM				
		2. Safe shutdown on failure of control/ESD link - safety system is separate and independent from control system									unliklely to be a link, but to be human comms with two buttons.
		3. Safe shutdown on tank overfill (high-high alarm)									Chemical tankers have vapour return facility, but often do not use it and blow PV valve during loading. It is undetermined as to vapour retun being practical when fuelling a chemical tanker - smaller volumes in comparison.
		4. Consider vapour return/management									For IWW vapour return for cargo ops will become manadatory in 2 years
		5. System designed to withstand maximum pump pressure									
		6. Pump with recycle on closed valve and/or shutdown/ESD									
A-6	**Utilities Failure**	1. Power restored through emergeny generator and board on ship, via, shore or bunker barge		No additional safeguards identified		No additional safeguards identified					
		2. Electrical failure will result in shutdown of bunker transfer									
		3. Additional inert gas bottles and/or inert gas generator if purge/inert									
		4. Compressed air or hydraulic failure air failure will result in shutdown of bunker transfer									
		5. A-1-2									

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	 L	 R	COMMENTS & RECOMMENDATIONS
B-1	**Collision (incl. grounding & contacts)**	1. Independent tank located in-board of shell plating in FSHS (min. 800 mm)		15.Contain - Secondary barrier (FSHS, cofferdam, coaming if on-deck)		25. Contain/Extinguish - Fixed fire-fighting system (water, foam, CO_2 as appropriate) and Deck monitors AR foam in cargo area, to also be able to cover the indepentent deck tank. FSHS Waterbased system and AR foam bilges		A	3		Rating for serious collision in way of tank and tank located below waterline
		2.Independent tank located on deck in-board of side shell (min. 800 mm)		16. Contain - drip tray under independent tank		26. Contain/Extinguish - Portable fire-fighting appliances		B/C	≤ 3		Rating for serious collision in way of tank and tank located above waterline
		3. Integral tank with protective cofferdam (maybe water filled)		17. Contain - Transfer of fuel to safe location (e.g. holding tank, dedicated bilge tank with inert blanket with/without water for dilution, or transfer to sea) B-1.10		27. Contain - A-60 FSHS bulkheads		A	3-4		Rating for serious grounding in way of tank
		4. Cargo Tank located as per IBC: at side shell and at bottom (above and below WL)		18. Detect - Leak detection (liquid, liquid level and/or vapour detection) in cofferdams and otherspaces surrounding the tank		28. Contain - Cofferdam around integral tank only fuel tank cargo tank as before as it is isolated most of the time		A/B	3		Rating for serious grounding in way of tank resulting in tank damage but intact hull
		5. Isolation between cargo and service tank after filling. Service tank may need different protection to provide ongoing power…."Get you home volume."		19. Detect - Tank level indication (excessive decrease in liquid level)		29. Contain - A-60 boundaries for accommodation and control stations, etc. within 10 m of on-deck tank Cargo areas (IBC) 10 m? SOURCE Gas? Is this actual applicable to Methanol - Proflash check					CO_2 might not be a preferred option as its cooling and dilution effect is limited, therefore it cannot be used as a preventative measure. Water can dilute below flammable range. CO_2 may not provide sufficient cooling to prevent re-ignition. Deluge to cool tank SOLAS II/2 Reg. 10.8 requires tankers to have a deck foam fire-fighting extinguishing system (fixed type if >=20000t). This delivers foam to the entire cargo tanks deck area as well as any cargo tank on-deck. Thisz system could be used to protect the fuel tank on the open deck. Consider starting prior to ignition. Monitors at distance. (In SOLAS ANYWAY< if not required for CC yet , should be additional requirement) Deluge volumes? Check? If for external fire and internal fire may need to be diffferent? 10L/m2 min IGC, IBC for 15.8.29
		6. FUEL Tank surrounded by a secondary barrier		20. Detect - Indication of excess flow from tank.		30. Contain - Deluge on accommodation and control stations boundaries, etc. within 10 m of on-deck tank					
		7. Increased strength/resistance to impact of shell plating and structure in way of tank		21. Detect - Auto change-over to fuel oil for dual-fuel vessels		31. Contain - 10 m separartion from tank on-deck					

Cargo Ship ----- Chemical Tanker											DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	L	R	COMMENTS & RECOMMENDATIONS
		8. integral/independent fuel Tank located below waterline (SLL) [Tanks located above waterline for protection against grounding only)		22. Prevent Ign - Inert blanket		32 . Contain - locate tanks away from accommodation, cargo and areas where persons are normally expected					
		9. Tank located in areas less prone to impact (e.g. away from the bow)		23. Prevent Ign - Ex protected equipment in FSHS and in areas on-deck (hazardous area classification) and cargo areas (IBC)		33. Detect - Fixed and/or portable IR cameras					
		10. Emergency discharge of fuel to a safe location (e.g. holding tank or sea)		24. Prevent Ign - Deluge **and f**oam for FSHS and on-deck tank and cargo block / area		34. Detect - CCTV with IR capability					
		11 .Tank designed for deformation				35. Detect - Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
		12. Tank with internal flexible and expanable bag, liner or bladder				36. Detect - Temperature detectors					
		13 . Independent tank secured to deck with anti-floation in the event of flooding				37. Contain/protect - Lifeboat locations and Emergency routes need to be located away from tank - 10m					
		14 Single fuelled option: SOLAS? 2 tanks? Double check.				38. Detect - Water sensing in tank. Density or conductibity Switch over.					
B-2	**External Impact**	1. Physical protection for tank on-deck in way of crane lifting operations PTW, ensure routes are appropriate		8. Contain - Closure of inlets/oulets to accommodation etc		19. B-1-25		B/C	2/4		Credible worst and best case with/without safeguards
		2. Tank on-deck located outside envelope of crane lifting operations		9. Contain/minimise release - Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation valve and hence reduction in leak inventory.		20. B-1-26					tank in aft peak stores may impact. No loaction in this area guarding against anchor and mooring line handling.
		3. No lifting, maintenace (except for tank), loading or laydown activity within vicinity of tank		10. B-1-15		21. B-1-27					
		4. Area inaccessible to unauthorised crew		11. B-1-17		22. B-1-28					
		5. B-1-8		12. B-1-18		23. B-1-29					
		6.. B-1-9		13. B-1-19		24. B-1-30					
		7. Single fuelled option: SOLAS? 2 tanks? Double check.		14. B-1-20		25. B-1-31					
				15. B-1-21		26. B-1-32					
				16. B-1-22		27. B-1-33					
				17. B-1-23		28. B-1-34					
				18. B-1-24		29. B-1-35					

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
						30. B-1-36					
						31. B-1-37					
B-3	**External Fre**	1. Physical distance from cargo and other sources of fire. All fuell tanks not loacted in cargo area		7. B-1-15		17. B-3-2 (The A-60 structure will offer some screening/protection in the event of a methanol/ethanol fire)		C	2/3		Assumes no shielding to/from tank on-deck and PRV does not prevent over-pressurisation
		2. independentl tank in cargo area: FSHS and A60		8. pressure detection to alert prior to PV venting		18. B-1-25		B/C	1/2		Assumes some shielding to/from tank on-deck but PRV does not prevent over-pressurisation
		3. integral tank in cargo area: cofferdam and ~~A60~~ check		9. B-1-17		19. B-1-26					With shielding of the tankon deck (i.e. tank withgin a FSHS) it may not be possible to use external fire-fighting systems/appliances
		4. FSHS for tanks on-deck with A-60 facing cargo and other fire sources		10. B-1-18		20. B-1-27					With shielding of the tankon deck (i.e. tank withgin a FSHS) it may not use be possible to use externally located CCTV and IR cameras
		5. Pressure relief valve (PRV) on tank to prevent tank over-pressurisation - PRV outlet routed to safe location		11. B-1-19		21. B-1-28					UR Should integral fuel tanks be in cargo area?
		6. B-1-6	LEAK	12. B-1-20	UNCONTAINED LEAK AND/OR FIRE	22. B-1-29	HARM				
		7. B-1-10		13. B-1-21		23. B-1-30					
				14. B-1-22		24. B-1-31					
				15. B-1-23		25. B-1-32					
				16. B-1-24		26. B-1-33					
						27. B-1-34					
						28. B-1-35					
						29. B-1-36					
						30. B-1-37					
B-4	**Mechanical Failure**	1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		5. Contain /direct to safe location - Ventilation of FSHS (for independent tanks) with outlet led to a safe location		19. B-1-25		B	1/2		Dedicated cargo tank
		2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		6. Contain - Drip trays under fittings/connections		20. B-1-26		A	2		Integral tank
		3. Minimise penetrations, fittings and connections.		7. Contain - Additional/intermediate coamings for tanks on-deck		21. B-1-27					

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

B. STORAGE ~ Fuel Storage Hold Space (FSHS)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
		4. consider appropriate design for the environemet it is tobe used in (Polar region?) In polar regions Cargo tank location has to be away from side shell)		8. Contain /direct to safe location - Direct release over-board to the sea		23 B-1-28					
				9 . B-1-15		23. B-1-29					
				10. B-1-17		24. B-1-30					
				11. B-1-18		25. B-1-31					
				12 B-1-19		26. B-1-32					
				13. B-1-20		27. B-1-33					
				14 B-1-21		28. B-1-34					
				15. B-1-22		29. B-1-35					
				16. B-1-23		30. B-1-36					
				17. B-1-24		31. B-1-37					
				18. B-2-8							
B-5	**Control Failure**	1. Vacuum relief on tank		No additional safeguards identified		No additional safeguards identified		B/C	2/3		credible worst-case without safeguards
		2. Valves fail to safe position						B/C	1/2		credible worst-case with safeguards
		3. Safe shutdown on failure of control - safety system is separate and independent from control system									
B-6	**Utilities Failure**	1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B/C	2/3		credible worst-case without safeguards
		2. Electrical failure will result in auotmatic change-over to fuel oil for dual-fuel vessel						B/C	1/2		credible worst-case with safeguards
		3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. Compressed air or hydraulic failure air failure will result in auotmatic change-over to fuel oil for dual-fuel vessel									

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
C-1	**Collision (incl. grounding & contacts)**	1. FPR typically located 2 or more metres in-board		6. Detect - Leak detection (liquid and/or vapour detection) within FPR		12. Contain/Extinguish - B-1-20. Fixed fire-fighting system (water, foam, CO2 as appropriate)		A	2/3		Rating for serious collision or grounding in way of FPR
		2. All pipework is located in-board of shell plating (min. 800 mm)		7. Detect - B-1-19. Tank level indication (excessive decrease in liquid level)		13. Contain/Extinguish - B-1-21. Portable fire-fighting appliances					
		3. Given sufficient warning, activate shutdown/purge and change-over to fuel oil for dual fuel ships. This closes Tank Master Isolation Valve and would eliminate/reduce leak inventory		8. Detect - B-1-20 Indication of excess flow from tank. Pressure and flow measurement on pipework		14.Contain - A-60 FPR bulkheads					It would be prudent to consider A-60 protection towards any spaces that contain combustibiles or where persons might be present.
		4. FPR consists of steel bulkeads surrounding all equipment		9. Detect - B-1-16. Auto change-over to fuel oil for dual-fuel vessels		15. Contain - locate FPR away from accommodation and areas where persons are normally expected					All FPR equipment should be within a structural FPR - if on-deck this should be a 'pump box'.
		5. consider additional protection between ER and FPR in case of fire		10. Prevent Ign - Ex protected equipment in FPR (hazardous area classification)		16. B-1-25 Contain/Extinguish - Fixed fire-fighting system (water, foam, CO2 as appropriate) and Deck monitors AR foam in cargo area, to also be able to cover the indepentent deck tank. FSHS Waterbased system and AR foam bilges					applies to all Mach /Mach Spce Boundary is only steel. A0, translation for Paul: Between FPR and ER no need for A60 as per IGF and SOLAS see C-1-5
				11 . Prevent Ign - Deluge, foam and/or CO2 within FPR		17. Detect - B-1-33. Fixed and/or portable IR cameras					
						18. Detect - B-1-34. CCTV with IR capability					
						19. Detect - B-1-35. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
						20. Detect - B-1-36. Temperature detectors					
						21. B-1-37 Deal with disaster - Lifeboat locations and Emergency routes need to be located away from					
C-2	**External Imapct**	1. All maintenance/lifting/inspection activities within FPR covered by permit-to-work system. Therefore, equipment is likely to be purged/inerted during such activity		7. Contain /direct to safe location - Liquid to drain wells and bilge holding tank with non-return valve (tank may contain water to dilute spill below flammable range)		19. Contain/Extinguish - C-1-12		A/B	1/2		Credible worst-case
		2. C-1-4		8. Contain /direct to safe location - B-4 5. Ventilation of FPR with outlet led to a safe location		20. Contain/Extinguish - C-1-13					Size drain well/bilge/holding tank for credible worst case leak and time to detect and close valves to limit leak inventory.
		3. B-2-2. FPR located outside envelope of crane lifting operations		9. Contain - B-2-8. Closure of inlets/oulets ON accommodation , which may be affected - in or near vent outlets from FPR		21. Contain - C-1-14					Debate on ventilation rates MAY BE IMPORTANT IBVC requires 20 airchanges or 16 only. LR Rules: 15 airchanges normally and on detection 30 airchanges

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	L	R	COMMENTS & RECOMMENDATIONS
		4. B-2-3. No lifting, maintenace (except for FPR), loading, laydown or vehicle activity within vicinity of FPR		10. Contain/minimise release - B-2-9. Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation valve and hence reduction in leak inventory		22. Contain - C-1-15					Waterbased and foam for bilge FSS Chapter 6 Foam conc MSC Circ 1312 monitors coverage should include Fuel tank and pumproom area.
		5. B-2-4. Area inaccessible to unauthorised crew		11. Detect - Spill liquid level detection in drip trays		23. Contain - Consider A-60 boundaries for accommodation and control stations, etc. within 10 m of FPR on-deck 10 m in IGF also waterspray					
		6. Consider locating transfer pipework/lines to users within trunk to protect from mechanical damage and external fires		12. Detect - Liquid level detection in drain/bilge/bilge tank		24. Contain - Consider deluge on accommodation and control stations boundaries, etc. within 10 m of FPR on-deck					
				13. Detect - C-1-6		25. Contain - Consider 10 m separartion from FPR on-deck					
				14. Detect - C-1-7		26. Detect - C-1-16					
				15. Detect - C-1-8		27. Detect - C-1-17					
				16. Detect - C-1-9		28. Detect - C-1-18					
				17. Prevent Ign - C-1-10		29. Detect - C-1-19					
				18. Prevent Ign - C-1-11		30. Detect - C-1-20					
						31. Detect - C-1-21					
C-3	**External Fire.**	1. C-1-3		10. Contain - C-2-9		21. Contain/Extinguish - C-1-12		A/B	1/2		Credible worst-case
		2. C-1-4.		11. Contain/minimise release - C-2-10		22. Contain/Extinguish - C-1-13					
		3. C-1-14		12. Detect - C-2-11		23. Contain - C-1-15					
		4. Fire detection and extinguishment in areas external to FPR		13. Detect - C-2-12		24. Detect - C-1-16					
		5. Physical distance from cargo and other sources of fire		14. Detect - C-1-6		25. Detect - C-1-17					
		6. Pressure relief valve for locked-in lines and equipment to prevent over-pressurisation - PRV outlet routed to safe location		15. Detect - C-1-7		26. Detect - C-1-18					
		7. C-2-5		16. Detect - C-1-8		27. Detect - C-1-19					
		8. C-2 23		17. Detect - C-1-9							
		9. C-2 24		18. Detect - B-3-8 pressure detection to alert priot to PV venting isolate able sections should be minimised. …….reliefto where?							
				19. Prevent Ign - C-1-10							
				20. Prevent Ign - C-1-11							

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

C. TRANSFER (and preparation) ~ Fuel Preparation Room (FPR) / Pump Room

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	E	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	RATING L	RATING R	COMMENTS & RECOMMENDATIONS
C-4	**Mechanical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements		4. Contain /direct to safe location - C-2-7		17. Contain/Extinguish - C-1-12		C	4		Credible worst-case without mitigations
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		5. Contain /direct to safe location - C-2-8		18. Contain/Extinguish - C-1-13		B/C	2/3		Credible worst-case with mitigations
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		6. Contain - C-2-9		19. Contain - C-1-14					Typically 10% inspection for fully welded pipe reverting 100% if defect is found.
				7. Contain/minimise release - C-2-10		20. Contain - C-1-15					Consider 100% inspection to high pressure pipes or 'large' diameterr pipes.
				8 Contain - incrase ventilation rate, if not removed close vent inlets and out lets to FPR							See debate on airchanges.
				9. Detect - C-2-11		21. Detect - C-1-16					
				10. Detect - C-2-12		22. Detect - C-1-17					
				11. Detect - C-1-6		23. Detect - C-1-18					
				12. Detect - C-1-7		24. Detect - C-1-19					
				13. Detect - C-1-8		25.Contain - C-2-23					
				14. Detect - C-1-9		26. Contain - C-2-24					
				15. Prevent Ign - C-1-10		27. Contain - C-2-25					
				16. Prevent Ign - C-1-11							
C-5	**Control Failure**	1. B-5-2. Valves fail to safe position		No additional safeguards identified		No additional safeguards identified		B	2/3		credible worst-case without safeguards
		2. B-5-3. Safe shutdown on failure of control - safety system is separate and independent from control system						B	1/2		credible worst-case with safeguards
		3. Pressure relief on equipment and isolable pipework/lines									
C-6	**Utilities Failure**	1. B-6-1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B/C	2/3		credible worst-case without safeguards
		2. B-6-2. Electrical failure will result in auotmatic change-over to fuel oil for dual-fuel vessel						B/C	1/2		credible worst-case with safeguards
		3. B-6-3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. B-6-4. Compressed air or hydraulic failure air failure will result in auotmatic change-over to fuel oil for dual-fuel									

D. Use of Fuel ~ Engine Room (ER)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent	LEAK	SAFEGUARD / BARRIER Contain / Detect / Prevent Ign	UNCONTAINED LEAK AND/OR FIRE	SAFEGUARD / BARRIER Contain / Detect / Extinguish	HARM	RATING C	L	R	COMMENTS & RECOMMENDATIONS
D-1	**Collision (incl. grounding & contacts)**	1. C-1-3. Given sufficient warning, activate shutdown/purge and change-over to fuel oil for dual fuel ships. This closes Tank Master Isolation Valve and would eliminate/reduce leak inventory		3. Detect - Leak detection (liquid and/or vapour detection) within double walled pipework		9. Contain/Extinguish - B-1-20. Fixed fire-fighting system (water, foam, CO2 as appropriate)		B	1		Rating for serious collision or grounding penetrating ER and methanol/ethanol resulting in harm
		2. ER consists of steel bulkeads surrounding all equipment		4. Detect - B-1-19. Tank level indication (excessive decrease in liquid		10. Contain/Extinguish - B-1-21. Portable fire-fighting appliances					
				5. Detect - B-1-20 Indication of excess flow from tank.		11. Contain - A-60 ER bulkheads					
				6. Detect - B-1-16. Auto change-over to fuel oil for dual-fuel vessels		12. Detect - B-1-33. Fixed and/or portable IR cameras					
				7. Contain/minimise release - B-2-9. Manual and/or automatic shutdown on leak/vapour/fire detection resulting in closure of Tank Master Isolation Valve and 'Fuel Master Isolation Valve' and hence reduction in leak inventory.		13. Detect - B-1-34. CCTV with IR capability					
				8. Prevent Ign - Deluge, foam and/or CO2 within ER		14. Detect - B-1-30. Smoke detectors (may only be useful if other materials combust e.g. paintwork)					
						15. Detect - B-1-31. Temperature					
D-2	**External impact**	1. Methanol/ethanol pipework is double walled		4. Detect - D-1-3		11. Contain/Extinguish - D-1-9		A/B	1/2		Credible worst-case
		2. Route methanol/ethanol pipework outside 'lifting' areas		5. Detect - D-1-4		12. Contain/Extinguish - D-1-10					
		3. All maintenance, lifting and certain inspection activities within ER covered by permit-to-work system. Therefore, methanol/ethanol pipework is likely to be purged/inerted during such activity		6. Detect - D-1-5		13. Contain - D-1-11					
				7. Detect - D-1-6		14. Detect - D-1-12					
				8. Detect - C-2-12. Spill liquid level detection in drip trays		15. Detect - D-1-13					
				9. Contain/minimise release - D-1-7		16. Detect - D-1-14					
				10. Prevent Ign - D-1-8		17. Detect - D-1-15					
D-3	**External Fire**	1. D-1-1		5. Detect - D-1-3		12. Contain/Extinguish - D-1-9		A/B	1/2		Credible worst-case
		2. D-1-2		6. Detect - D-1-4		13. Contain/Extinguish - D-1-10					
		3. D-2-1		7. Detect - D-1-5		14. Contain - D-1-11					
		4. D-1-11		8. Detect - D-1-6		15. Detect - D-1-12					
				9. Detect - C-2-12. Spill liquid level detection in drip trays		16. Detect - D-1-13					
				10. Contain/minimise release - D-1-7		17. Detect - D-1-14					
				11. Prevent Ign - D-1-8		18. Detect - D-1-15					

Cargo Ship ----- Chemical Tanker DRAFT FOR COMMENT

D. Use of Fuel ~ Engine Room (ER)

Item No.	CAUSE / THREAT	SAFEGUARD / BARRIER Prevent		SAFEGUARD / BARRIER Contain / Detect / Prevent Ign		SAFEGUARD / BARRIER Contain / Detect / Extinguish		RATING C	L	R	COMMENTS & RECOMMENDATIONS
D-4	**Mechnical Failure**	1. B-4-1. Maintenance, inspection, materials and construction as per class, manufacturing and flag requirements	LEAK	5. Detect - D-1-3	UNCONTAINED LEAK AND/OR FIRE	12. Contain/Extinguish - D-1-9	HARM	A/B	3/4		Credible worst-case
		2. B-4-2. Arrangements to minimise failure due to slamming/loading, vibration and/or heat induced fatigue, stress, strain, etc.		6. Detect - D-1-4		13. Contain/Extinguish - D-1-10					
		3. B-4-3. Minimise equipment, penetrations, fittings and connections		7. Detect - D-1-5		14. Contain - D-1-11					
		4. D-2-1		8. Detect - D-1-6		15. Detect - D-1-12					Double walled pipe should apply to methanol/ethanol supply pipework and return/recycle pipework
				9. Detect - C-2-12. Spill liquid level detection in drip trays		16. Detect - D-1-13					
				10. Contain/minimise release - D-1-7		17. Detect - D-1-14					
				11. Prevent Ign - D-1-8		18. Detect - D-1-15					
D-5	**Control Failure**	1. B-5-3. Safe shutdown on failure of control - safety system is separate and independent from control system		4. Contain/direct to safe location - explosion relief in exhaust		No additional safeguards identified		B	1/2		credible worst-case with safeguards
		2. Misfire detection									
		3. Unused fuel recycled									
D-6	**Utilities Failure**	1. B-6-1. Power restored through emergeny generator and board		No additional safeguards identified		No additional safeguards identified		B	1/2		credible worst-case with safeguards
		2. B-6-2. Electrical failure will result in auotmatic change-over to fuel oil for dual-fuel vessel									
		3. B-6-3. Additional inert gas bottles and/or inert gas generator if purge/inert capacity is lost									
		4. B-6-4. Compressed air or hydraulic failure air failure will result in auotmatic change-over to fuel oil for dual-fuel									

Contact for further information:
Kim Tanneberger
Lead Specialist, Strategic Research Group
Lloyd's Register Global Technology Centre, Southampton, SO16 7QF, UK

T: +44 (0)3304140218
E: kim.tanneberger@lr.org
W: www.lr.org