TECHNICAL REPORT

OPTIMISED ENVIRONMENTAL TECHNOLOGIES
FOR
CRUISE AND FERRY VESSELS

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TECHNICAL REPORT

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Summary:

The object of this report is to highlight the main pollutants generated from Cruise vessels and passenger ferries. The impact the different pollutants have on the environment, which rules and regulations govern and will govern in the near future and what type of technology is available on the market and the consequences of their use.

The report is ordered and financed by Troms Fylkes Dampskibsselskap together with Norsk Forskningsråd.

The report does not cover operational aspects and comfort aspects with regards, noise and vibrations nor choice of environmental friendly materials with regards to design and operation of cruise and passenger vessels.

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1 INTRODUCTION

This report describes a study ordered and financed by Troms Fylkes Dampskibsselskap in co-operation with Norsk Forskningsråd and shall highlight the different systems within a cruise or ferry vessel with regards to environmental impact, the different systems available on the market and the consequences of their use.

Over the past years the importance of preventing or reducing operational and accidental emissions to air and discharges to sea has been increasingly highlighted both in national and international agreements and legislation. The growing general awareness of pollution, be it to sea or air is becoming more apparent and public opinion is finding pollution increasingly unacceptable. Especially for the cruise and ferry industry, public opinion is in fact customer's opinion. Environmental awareness is a big issue in for the industry and environmental image is important.

Both national and international regulations in this field are becoming stricter. What was acceptable last year will not necessary be acceptable next year, and the legislation is and will in the future also affect existing vessel. With this regard it is important for cruise and ferry lines to adopt their own environmental policy. What level of environmental awareness should they adopt? Is it possible to plan design for future requirements be it from public/customer or national/international bodies?

This report highlights the different pollutants a ship generates, which legislation's are applicable, future requirements and generally what can be done to reduce the impact on the environment with the current available technology.

The main areas covered are:

- Discharges to sea
- Emissions to air
- Garbage
- Preventive design

Discharges to sea include sewage and grey water from passenger and crew, bilge and cooling water from machinery spaces and ballast water. All these may have an impact on the surrounding environment and all deliver some type of pollution in the surrounding water. The underwater paint system (antifouling) is normally not thought of as discharging to sea, but nontheless deliver pollutants to the sea.

Emissions to air are generally exhaust products generated by the propulsion, auxiliary or incinerator plants located on board. The main pollutants are NO_x, SO_x, CO_2 and ash. Ash is not covered in this report.

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Garbage handling for cruise and ferry vessels can range from a garbage container to a whole industry in itself. For the larger cruise vessels the number of passengers are several thousand. Garbage and waste handling for these large vessels are comparable with a small community. There are several ways to treat garbage, store it and deliver it ashore and incineration. Procedures, education and awareness of crew and management within the company's organisation are necessary aspects for good waste handling. The human aspects are not covered in this report.

Preventive design covers aspects to reduce likelihood of accidents and to minimise pollution in the event of an accident.

There are a number of other environmental concerns with regards to design and operation of cruise and ferry vessels not covered by this report. Some of them are:

- Design and selection of environmental friendly materials in the interior of the vessels.
- Selection of environmental friendly consumables, such as oils, chemicals, packing materials etc.
- Noise and vibrations, both internally and externally.
- Design and operation with regards to energy economising aspects.
- Ash and particulates from exhaust emissions.

Except for the ash emissions these items have to be individually discussed for each organisation and project as there will be different requirements with regards to trade routs, culture and organisation aspects.

For the same reasons of individual aspects that will govern the correct environmental selections of equipment or design the report has to a large part refrained from concluding on the best environmental friendly solution. Different regions will have different requirements and the consequences on the environment will be different. For example the emission of NO_x and SO_x has a larger impact on Scandinavian environment with its lime-deficient nature, compared to the Mediterranean with its lime-enriched soil. The effect of discharging sewage will be different off the coast of Norway with only a handful of ships calling at any given port compared with a port like Rotterdam, where thousand of ships call every year.

2 DISCHARGE TO SEA

2.1 Sewage System

2.1.1 General

The amount of sewage and also the composition of the content from sewage depend upon the type and characteristics of the vessel. The complexity as well as the volume of sewage increases by the number of crew and passengers onboard. For cruise vessels and ferries these systems are of utmost importance for the trade.

The vessels may have different toilet flushing systems installed:

- A conventional sewage system (gravitation system) uses about 6 litres of water on each rinse. Normal consumption of 100 l/person/24 hours is used (this includes black water and a part of the grey water since some vessels mix the black and grey water).
- A vacuum sewage system uses under pressure to transport the sewage and uses in average about 1.2 litres of water on each rinse. Normal consumption of 50 l/person/24 hours is used (this includes black water and a part of the grey water since some vessels mix the black and grey water). Vacuum systems are normally used on passenger vessels. After 1990 almost all passenger vessels have vacuum systems.

Vessels that have a sewage treatment system produce about 2 litres of sludge/person/24 hours.

2.1.2 Impact On The Environment

The compounds of sewage might include those being in organic as well as organic. The potential environmental impacts will depend upon the composition of sewage. Commonly, the following is found from sample analysis:

- Organic compounds
- Nitrogen (N)
- Phosphorous (P)
- Bacteria
- Environmental hazards (PCBs, PAH and heavy metals)
- Visual pollution

Organic compounds will typically discolour the water and reduce visibility in the water. The discharge of organic compounds will result in an increased consumption of oxygen. In some areas, the reduction of present oxygen in the water column may be critical causing anaerobic conditions. Organic compounds in the sewage mainly originate from toilets. The biological oxygen demand is a measuring unit for the amount of oxygen that the micro-organisms are using when they are degrading organic compounds. In Norway the oxygen demand is measured after 7 days (BOD_7), while in Europe the oxygen demand is measured after 5 days (BOD_5). The BOD_7 in sewage from vessels is typically given at 20 gram/person/24 hours.

Nitrogen and phosphorous are nutrient salts that may give input of nutrient salts to the sea. This may result in eutrophication, which again may result in high algae production. Nitrogen in the sewage mainly originates from faecal and urine, while phosphorous mainly originates from faecal and synthetic detergents. The total nitrogen content in sewage from vessels has been estimated to be in the region 11 gram/person/24 hours, while the total phosphorous content in sewage from vessels may be estimated to be in the region 1.3 gram/person/24 hours (adopted norms referred to in literature).

Bacteria may result in infections. The concentration of bacteria in sewage from vessels will depend on the system that is used (conventional system or vacuum system). Sewage from households normally has a content of $5x10^6$ termostable coli-bacterias for each 100 ml of sewage. Discharged sewage from vessels will be diluted and many micro-organisms will die in relatively short time. Some organisms may live for a long time in the seawater while other organisms may also be reproduced in the water. The bacteria that survive may result in infections.

The environmental hazards represented by the discharge of sewage can be divided into three main groups:

- Chlororganic compounds such as DDT, PCB and dioxins
- Polycyclic aromatic hydrocarbons (PAH)
- Heavy metals such as mercury, cadmium and lead.

Environmental hazards may result in damages even when appearing at low concentrations. The environmental hazards might be slowly degradable (depending upon the presence of living organisms) or they may be totally stable. If the supply of these species exceed the amount that is degraded, the species will accumulate and may reach critical levels. For other hazardous materials the dangerous effects will not arise until repeated influences have occurred. The hazards may have the following qualities:

- High acute or chronic toxicity
- Mutagenic (changes in mutation)
- Cancerogenic (give cancer)
- Teratogenic (give damage to embryos)

Visual pollution may constitute of "garbage." Garbage found in sewage discharge can be toilet paper, sanitary towels, plastics, etc. This is the most visual part of the sewage pollution and due to its nature the plastic is often regarded as the most problematic part of the garbage.

2.1.3 Rules & Regulations

Sewage is regulated through the MARPOL Convention in an independent Annex:

- Annex IV Regulation for the Prevention of Pollution by Sewage from Ships.

Annex IV is at present not ratified, hence there are at present no international mandatory legal instrument regulating the discharge of sewage.

According to MARPOL Annex IV sewage is:

- *drainage and other waste from any form of toilets, urinals, and WC scuppers;*
- *drainage from medical premises (dispensary, sick bay, etc.) via wash basins, wash tubs and scuppers located in such premises;*
- *drainage from spaces containing living animals; or*
- *other waste waters when mixed with the drainage's defined above.*

MARPOL distinguish between "black water" (being sewage as defined above) and "grey water". "Grey water" represents discharges from galley, laundries, bathrooms, swimming pools, photo laboratory chemicals etc. In this report, grey water is discussed in section 2.2.
It should be noted that in many cases the black and grey water is mixed. This may in particular apply to new build cruise vessels and ferries, where the mixture is processed in a treatment plant.

Details Of MARPOL Annex IV
Table summarises the MARPOL requirements concerning discharge of the sewage to sea. Regulation 8 in MARPOL, Annex IV is regulating the discharge of sewage to the sea. When sewage is mixed with waters or waste water having different discharge requirements, the more stringent requirements shall apply.

Table 2.1.3-1: MARPOL requirements with regard to discharge of sewage (MARPOL 73/78, 1992).

Ocean Area	MARPOL Regulations
< 4 nautical miles from the nearest land	Prohibited
> 4 nautical miles and < 12 nautical miles from the nearest land	Permitted if sewage is comminuted and disinfected using a system approved by the Administration[1]
> 12 nautical miles from the nearest land	Permitted for not comminuted and disinfected sewage provided in any case, that the sewage stored in holding tanks shall not be discharged instantaneously but at a moderate rate when the ship is en route and proceeding by not less than 4 knots. The rate of discharge shall be approved by the Administration[1]
All areas	Permitted if the ship has in operation an approved sewage treatment plant which has been certified by the Administration[1] to meet the operational requirements given in MARPOL, Annex IV
The waters under the jurisdiction of a State	Permitted if the ship is discharging sewage in accordance with such less stringent requirements as may be imposed by such State

[1]: "Administration" means the Government of the state under whose authority the ship is operating. With respect to a ship entitled to fly a flag of any State, the Administration is the Government of the State.

The MARPOL convention gives possibilities for each convention state to establish their own discharge rules. These discharge rules shall however not be less stringent than the rules of MARPOL.

Existing Rules & Regulations
Due to the lack of international mandatory regulations, the introduction of numerous local and regional regulations have been introduced.

The nature of the areas frequently visited by larger cruise vessels can be generalised as particularly valuable areas from an environmental point of view. They are particularly sensitive not only environmentally but also financially.

Future Rules & Regulations
Despite the Annex being developed in the 1970's it has still not been ratified. Annex IV will not enter into force until a minimum of 15 nations representing a share of 50% or more of the world fleet has ratified it. At present, the requirement related to the number of nations is satisfied. However, these nations represent only some 43-44% of the world fleet.

Recent initiatives by IMO member countries have resulted in an ongoing evaluation of the Annex aiming at identifying changes that may provide for sufficient ratification. It is stated that the strict requirements associated to reception facilities as defined by the Annex, make it difficult for many nations to comply to as they may be scarcely populated and not have any facilities at all. The ongoing considerations is believed to result in changes to the Annex that will speed up the ratification process and hence provide international mandatory requirements on the discharge of sewage.

2.1.4 Technology

There are mainly 3 different solutions to the vessel sewage problem. These are:

- Use of a sewage treatment plant
- Use of a system to comminute and disinfect the sewage
- Use of a holding tank

In addition the vessels have to be equipped with a system that makes the vessel able to discharge the sewage or sludge ashore. Also incineration of sludge from sewage may be a solution. These options are described in sections 4.1.

Sewage Treatment Plant
A sewage treatment plant may consist of a biological or chemical treatment plant.

<u>Biological treatment</u>
Biological treatment is the most commonly used treatment method for sewage on vessels, with about 70 % share of the market in Europe. There are 5-6 large manufacturers of biological treatment plants in Europe e.g. Hamworthy (England), Aquamar and Saltzkotten (Germany), Isir (Italy) and Scanship Engineering, Tønsberg.

A biological treatment plant implies that particles and soluble substances in the sewage is used by micro-organisms to make less complex substances and produce new cell mass. These are then separated from the water as biological sludge. Biological treatment is used to remove small and larger sludge particles as well as organic matter. The removal of phosphor is moderate. Biological treatment may also provide efficient removal of nitrogen.

All the above mentioned manufactures of biological treatment plants are supplying the market with so-called aerobic treatment plants where air is introduced into the sewage in order to accelerate the degradation of the sewage. The sludge that is produced is more or less free of bacteria and may be discharged where allowed or taken ashore and deposited. The sludge may also be incinerated onboard provided the vessel is fitted with an appropriate incineration plant. However this is not a frequently used method for treatment of the sludge from sewage. The purified water is normally treated with chlorine and is thereafter discharged into the sea. However the introduction of chlorine is not always carried out. In some plants the use of Ultra violet (UV) irradiation has also been used to disinfect the water. This may be used at places where chemical treatment with chlorine is not allowed.

Biological treatment plants are the most commonly used plants on cruise vessels and ferries.

Chemical treatment
Onshore a chemical treatment plant implies that chemicals are used in order to achieve a particular consistency enabling the separation of water by use of sedimentation. However based on the volumes that these plants require, chemical treatment plants in this meaning be not used on vessels.

When the terminology chemical treatment plants is used to describe sewage treatment plants on vessels it implies plants that in some way are using chlorine to treat the sewage. Today there are 2-3 manufacturers of chemical treatment plants in the world i.e. Omnipure (USA), Orca (USA) and Haman in Germany. The latest one is the largest one. The technology used is firstly grinding of the sewage, thereafter dilution with seawater followed by the addition of chlorine before the sewage is discharged into the sea. The method gives some sludge that is also discharged overboard.

It should be emphasised that the use of chemical treatment have been prohibited or restricted in some areas by national regulation. In Canada (the Great Lakes), the use of these plants have been prohibited, whilst German authorities (Seeberufsgenossenschaft) have stopped to approve such plants.

It should be emphasised that for all sewage treatment plants MARPOL states that: *"when the ship is equipped with a sewage treatment plant the plant shall meet operational requirements based on standards and the test methods developed by the Organisation"*.

Comminuting and disinfecting the sewage
Comminuting of the sewage is done by the use of a system that comminutes the larger particles of the sewage. This is as described before also used in the chemical method from Haman.
Disinfection of the sewage may be undertaken by adopting the methods of:

- Chlorination
- Ozonation
- Ultra violet (UV) irradiation

Chlorination is the most frequently adopted method. Chlorine in gas (Cl_2) or solid form is used to disinfect the pathogenic organisms. Chlorination is mostly used as a chemical treatment method.

Ozone (O_3) is a blue coloured gas that is used among other to disinfect the sewage and to reduce the smell of the sewage. Ozone has to be produced where it is intended to be used. This requires the introduction of an ozone-generating unit that may incur significant costs. Early ozone generating plants were complicated and gave concerns related to occupational safety. Modern generators are more efficient, safer and offered at reduced prices. The method at present is rarely adopted.

Ultraviolet irradiation utilises the spectrum of light with wavelength in the area 100-4,000 Ångstrøm (1 Ångstrøm 10^{-10}m). UV irradiation may have a disinfecting effect. However the method is not much used.

Following treatment by one of these methods, the sewage can be discharged into the sea.

Holding Tank
Many ships have installed holding tanks for sewage storage until arrival in port for delivery to reception facility. The holding tank should be equipped so that the content level can be monitored.

A holding tank arrangement require a discharge arrangement suitable for delivery to shorebased reception facilities. These reception facilities may be stationary or mobile.

Most sewage treatment facilities will enable the vessel to discharge “clean” water to sea and hence remove the requirement of reception facilities. However, other approaches (using elements of technologies discussed above), may only reduce the volume of sewage.

2.2 Grey Water System

Cruise vessels and ferries are large producers of grey water and there is more and more concern of the problems that the grey water is giving.

2.2.1 General

Grey water include discharges from galley, laundries, bathrooms, swimming pools, etc. The discharges from these sources may contain wash detergents, remains of human skin, hair, cosmetic remains, fat and water treatment chemicals.

There are different ways of taking care of the grey water:

- Discharge into the sea (as allowed by Marpol).
- Collection into a holding tank in coastal waters followed by discharge in open sea or delivery ashore.
- Treatment in the black water treatment plant.
- Separate grey water treatment plant.

The first method is the most commonly used method, at present but more and more vessels are switching to more environmentally friendly methods.

2.2.2 Impact On The Environment

The main potential pollution-contributing element of grey water will be that of washing detergents. This will contribute to the discharge of phosphor. Other contributors that should be mentioned are those of fat and water treatment chemicals. Grey water will also include nitrogen and organic matter, but in a much lower concentration than the black water.

2.2.3 Rules & Regulations

MARPOL Annex IV does not provide for the discharge of grey water. The discharges of grey water are not regulated by any international legal instrument. MARPOL Annex IV distinguishes between "black water" and "grey water" but does not apply any provisions as to the discharge of "grey water". However, any convention state may establish own regulations.

Existing Rules & Regulations
However some of the local and regional requirements applying to the discharge of sewage also include grey water. In these cases, sewage and grey water are normally treated as one substance.

2.2.4 Technology

Grey water may be treated by the same methods as those for of sewage treatment. However, since the composition of grey water it is mostly particular, (hair, skin etc.) but also liquid from film and x-ray development together with grease. Filtration and grease sorting may be sufficient. This provided that the use phosphorous free washing detergents have been adopted.

Chemical water treatment is associated to water used in swimming pools. Water originating from such can be dechlorinated.

An increasing awareness concerning the potential spread of diseases through grey water has also introduced a focus on bacteria and virus originating from grey water. Treatment by ozonation has been suggested ensuring against this threat.

2.2.5 Consequence Of Use Of Different Technologies

As grey water can be treated together with black water, the same consequences apply. Installation of filtration systems will require these to undergo regular cleaning. This can be automated. The remains following filter cleaning can be incinerated or delivered to shore reception facilities. This also apply for fat remains produced following fat sorting.

2.3 Bilge Water System

2.3.1 General

Water and other spill from various operational sources are drained to the lowest areas, the bilge. Normally the bilge water from the machinery spaces consist of:

- Leakage from operational sources; such as condensation, shaft seals, evaporators, separators and other equipment or machinery
- Leakage of water, oil or chemicals from various valves, pumps or pipes
- Water or chemicals from cleaning
- Spill during maintenance

In addition rain water from hatches or opening and leakage from storage and dry cargo compartments are collected and led to the bilge. Rain, seawater and other spill on open decks are normally led overboard by an open drain piping system. The open drain system is not treated in this report.

All vessels must have a bilge system for draining and pumping out any watertight compartment (except tanks with separate pumping systems). Normally the bilge water is pumped from bilge wells in the lowest parts of the compartments to a bilge tank. From the tank the liquid can be delivered ashore or be pumped overboard via dedicated filtering and separating equipment.

On vessels that carry cars the decks are normally drained directly overboard in the same way as open decks, and no bilge water is collected from here. For cruise vessels only open decks are normally drained directly overboard.

Water from all enclosed compartments is drained to the bilge water tank. For some compartments however, such as for example the cargo areas on ferry vessels, the bilge collecting system can be bypassed and water drained directly overboard during washing.

Finally in case of a serious accident, for example grounding with hull penetration or breakage of a pipe, there is an arrangement for pumping water directly overboard from the engine room.

2.3.2 Impact On The Environment

Contaminated water has a negative impact on the environment depending on the type of contamination, oil, chemicals or other. Oil spill can result in oil smearing of birds and marine mammals and may be toxic to marine life if ingested. Smothering of coastal communities and habitats occurs when oil is spilt near to shore and tainting of commercial fisheries may occur. Chemical spills may be toxic, both acutely and chronically. Some chemicals have the ability to cause sub-lethal effects, interfering with animal and human reproductive capability.

During normal operation the environmental impact from bilge water is generally considered low, as the spill is either collected onboard or discharged after filtering and separation. However recent research studies have shown that discharge of contaminated water may meet requirements in the regulations but they do have an adverse effect on the eco-system in the local environment.

The amount of oil discharged through bilge water as a function of the ship size may be estimated by the following equation:

$$B_{year} = C_0 \cdot (0{,}22 \cdot grt + 58) \cdot d$$

Where:

B_{year} = Quantity of bilge water generated each year (litres/year)

C_0 = Average concentration of oil in the bilge water (estimated to 258 ppm)

grt = Gross tonnage of the ship

d = Days in service each year

The actual oil discharge can for many vessels be considerably larger as under practical operational conditions the required maximum oil content in the effluent after the separators is often not achieved. Then the bilge water is re-circulated to the holding tank and no discharge can take place or in worst case discharged with too high oil content. Further there is the risk of accidental discharge from spill or neglected operational procedures. This added to the fact that cruise and ferry vessels operate mainly in coastal or enclosed waters motivates the high attention on the discharge of bilge water and the environmental impact.

The operator's management of oily wastes and chemicals onboard is important for the environmental impact. International regulations (see section 2.3.3) require that the filtered and separated bilge water be only discharged while underway. To ensure minimal impact on the environment the operational procedures should restrict discharge in coastal or enclosed waters. Further the procedures should ensure that contaminated water is not drained overboard especially from car decks or cargo areas in ferry vessels if the bilge system can be bypassed.

Finally the operator's policies and operational procedures should specify the use of cleaners, detergents and chemicals to be minimised and that they be of environmental friendly type were available.

2.3.3 Rules & Regulations

Pollution of the sea by oil was one of the earliest areas were the need for international control was recognised and now the discharge of oil-contaminated water is governed by strict international regulations. International conventions have been arranged since the 1920s. In 1954 the International Convention for the prevention of Pollution of the Sea by Oil was adopted. The current MARPOL 73/78 with annexes and amendments has now superseded it.

Existing Rules & Regulations
Basically the existing international rules and regulations require that bilge water is collected and not discharged unless the oil content in the effluent is below 15 ppm. Details are given below.

The following international rules and regulations apply:

- SOLAS, Chapter II-1, Regulation 21 requires that a bilge system be provided. Various detailed requirements to the system are given; for example for passenger ships three or four bilge pumps (depending on the size of the ship) and direct emergency bilge suction from the engine room are required.
- IMO MARPOL, Annex I, Regulations 10 & 16 requires that oil filtering equipment and arrangements for an alarm and automatic stopping of discharge when the oil content in the effluent exceeds 15 ppm is installed and that discharge only takes place when proceeding en route. Further various detailed requirements to the filtering equipment are given.
- IMO MARPOL, Annex I, Regulations 20 requires that the vessel be provided with an Oil Record Book where discharge, included filtered bilge water, is reported.

In addition the Classification Societies have rules with various detailed requirements to the bilge system incorporating the SOLAS and MARPOL regulations.

Further there are local requirements in some areas denying all discharge whatsoever or setting stricter limits to oil content in the effluent. For example is all discharge forbidden (even below 15 ppm) in the Great Barrier Reef National Park Australia, in some coastal waters in the Caribbean and in some Asian harbour areas.
Finally many ship owners have made their own stricter requirements. For example some cruise vessel operators have internal requirement of maximum 5 ppm oil content in the effluent.

Future Rules & Regulations
We are not aware of any further international rules or regulations under way. However it is likely that some local authorities will come with stricter requirements, aiming at zero discharge for coastal areas.

Reference to part of this report which may lead to misinterpretation is not permissible.

2.3.4 Technology

The most environmental friendly technology is to collect all bilge water and pump it to shore. This requires that the necessary shore facilities to receive and treat the contaminated water are available. This is however often not the case and in addition is deliverance to shore often costly and not practical.

For treating the bilge water onboard there are two main types of bilge water separators based on either static or centrifugal separating process.

Static Separation Process
This is normally a three-step separation process using emulsion breaking chemicals, settling and coalescence effects. Traditionally bilge water separators of the static type are installed in all kind of vessels. The separators are tested and certified to oil content in the effluent of maximum 15 ppm. Experience has however shown that this is often not achieved under practical operating conditions. The reason is often being that the oil is emulsified due to washing chemicals, lubricating oil additives or particles, and therefore difficult to separate.

Newer types of static separators (w/ preheating, settling, chemicals, flocculation, filtering) have shown much better results. These have mainly been installed in large cruise liners and show good results under practical operating conditions. Experience show that it is possible to keep the oil content in the effluent below 5 ppm.

Centrifugal Separating Process
This is based on modern self-cleaning separator technology with preheating and can also be in combination with emulsion breaking chemicals. These separators show good results and have an advantage in tackling large variations in oil content in the bilge water.

System solutions
An optimal and sophisticated system might be different types of separators in combination.

Some large passenger ferries and other vessels have installed a system where the bilge water, together with sludge, is separated in a centrifuge. Thereafter the water is led to a treatment tank and circulated while adding chemicals before a final settling. Experience with this system is that it is possible to keep the oil content below 10 ppm under practical operational conditions.

“State of the art” technology for new large cruise liners involves settling in tanks after a centrifuge or a traditional static bilge water separator (max. 15 ppm), then further cleaning in a new type of static separators (max. 5 ppm) before pumping to holding tanks for clean bilge water. From these tanks the bilge water with max. 5 ppm can be pumped overboard. The sludge oil may be burnt in the incinerator.

Reference to part of this report which may lead to misinterpretation is not permissible.

2.3.5 Consequence of use of Different Technologies

The consequence of a sub-optimal system can be:

- Discharge of contaminated water
- That bilge water must be stored onboard and eventually delivered ashore.
  This because the water is re-circulated due to a too high oil content in the effluent.

The investment cost of a system based on the newer types of separators can be more than five times higher than a system based on a simple, traditional system. There are large variations depending on the actual suppliers and the chosen system design.

The operational, environmental and image benefits can however be substantial when installing a sophisticated and more expensive system. This can be especially beneficial for cruise and ferry vessels, which operate in fragile coastal eco-systems and have a high public profile.

2.4 Cooling Water Systems

2.4.1 General

Typically any modern vessel will have a central cooling water system i.e. a sea water system pumping from sea chests on each side of the vessel, through central fresh water coolers and over board. Further there is a closed circuit low temperature fresh water system, cooled by seawater in the central coolers, distributing fresh water for cooling of various components in the engine room. Finally there is a closed circuit high temperature fresh water system, cooled by the low temperature water, cooling for example the diesel engine tops. This high temperature circuit is often also used for heating air conditioning systems and some tanks.

2.4.2 Impact On The Environment

The fresh water systems are treated with chemicals to reduce the risk of corrosion and formation of deposits. Normally nitrite-borate inhibitors are used. Since the concentration of chemicals is very low and the system is closed circuit the environmental impact is considered very low or negligible. This is however depending on the management of chemicals onboard, the awareness of the crew and the operational procedures which should ensure that the treated water is taken care of and not spilled overboard during exchange of the treated water or maintenance work.

The seawater intakes and piping system can quickly get constrained or clogged by marine growth if unprotected. Therefore there is normally a marine growth prevention system installed, with injection of a marine growth preventing substance into the sea chests. The most commonly used systems for cruise and ferry vessels involves discharge of chlorine, copper or chemicals. The different systems are described more in detail in section 2.4.4 Technology.

The impact on the environment depends on the active substance used:

Chlorine
Chlorine is found naturally in seawater in high concentrations as chloride (Cl^-). Active chlorine is a toxin that kills marine growth organisms. Further chlorine is an oxidant that will quickly react with organic compounds and dissolve in the seawater; the environmental effects are therefore very limited.

Local negative environmental effects can however occur for example at a quay or in enclosed waters, such as a harbour area.

Chemicals
Various chemicals are toxins that that kill marine growth organisms. When relative small quantities are discharged over a large area the environmental effects are limited, but if for example a small area is exposed continuously there may be local negative effects on the environment.

Copper
Copper is very toxic, especially for organisms in water. When relative small quantities are discharged over a large area the environmental effects are limited, but if for example a local area is exposed continuously the effects could be significant. The copper will bio-accumulate in several groups of organisms and can therefore cause an increasing problem over time, possibly interfering with marine life reproductive capability.

2.4.3 Rules & Regulations

Existing Rules & Regulations
There are no international rules or regulations setting requirements to discharge from marine growth prevention systems. Some local authorities however put limitations to discharge such that the sea chest injection must be stopped in harbours or special areas. For example is discharge of chlorine prohibited in the Great Barrier Reef National Park, Australia and in some enclosed waters in the Caribbean.

Future Rules & Regulations
At present no further international rules or regulations are known to be under way.

In Europe most countries have signed the “OSPAR”-convention concerning pollution threatening the marine environment, and EU has “The Dangerous Substance Directive” (76/464/EEC). Both these list various chemicals and toxic substances, among which copper and chlorine, where discharges are to be reduced. It is likely that local authorities may come with stricter requirements, possibly based on the above, concerning chlorine and copper discharges from vessels.

Reference to part of this report which may lead to misinterpretation is not permissible.

2.4.4 Technology

As mentioned above the most commonly used systems for marine growth prevention on cruise and ferry vessels are based on chlorine, chemicals or copper.

Different ship operators have different experiences and therefor preferences for which system to use.

Chlorine
Chlorine in the form of sodium hypochlorite is injected into the sea chests by a dedicated pump. The sodium hypochlorite is either mixed from granulates in a separate tank or produced onboard from seawater in electrolytic cells.

Typical concentration of chlorine: 2 ppm ($^{vol}/_{vol}$).

Chemicals
Special chemicals ("sperse-oil") are added in a separate tank and injected into the sea chests by a dedicated pump. The injected substance sticks to the marine growth, hindering organisms uptake of oxygen and thereby preventing further growth and fouling.

Typical concentration of "oil": 6 ppm ($^{vol}/_{vol}$).

Copper
Copper anodes with impressed current are placed directly in the sea chests releasing copper ions for prevention of marine growth. Normally a combination of copper and/or iron/aluminium anodes are used (depending on the material of the piping system), where the function of the iron/aluminium is corrosion prevention in the pipes (aluminium anodes in case of steel pipes). Size and number of anodes are normally dimensioned for a lifetime of 2-3 years (docking interval).

The consumption of copper varies with the cooling water pumps' capacity. For a ferry vessel typically approximately 20-50 kg copper are discharged to the sea per year pr. vessel, whereas for the largest cruise liners this figure can be in excess of 120 kg.

2.4.5 Consequence of use of Different Technologies

A system based on chemicals are the least costly, this is most commonly used on very small ferries and other smaller coastal vessels.

There are no significant differences in installation price or operating cost between systems based on copper or chlorine. Operators have different preferences but the most commonly used system for cruise and ferry vessels is copper anodes.

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Today normal practice is to run these systems continuously. It would however be an advantage for the environment to stop operation of the systems in harbours or enclosed waters and to hinder local negative effects.

2.5 Ballast Water System

2.5.1 General

Ballast water is water (fresh, brackish or marine) and associated sediment brought on board the vessel in "departure" ports and discharged in other ports. Safety, weather conditions, loading conditions and parameters related to the nature of the respective trade, are primary concerns for determining in what scale ballasting is required.

Due to the nature of the cruise and ferry segment, these vessels are minor users of ballastwater. Often, ballast is used in order to compensate for trim in harbour or for weather-induced heeling. Ballast water might also be used for reasons of reducing vessel movement (comfort) and stability.

Transport of large volumes of water containing organisms from shallow, coastal waters across natural oceanic barriers can cause massive invasions of neritic marine organisms. Because ballast water is usually taken from bays and estuaries with water rich in animal and plant life, most ships carry a diverse assemblage of organisms in their ballast water. Viable organisms isolated from ballast water include fish, crustaceans, molluscs, polychaete worms, arrowworms, coelentarates, sea squirts, toxic dinoflagellates, diatoms and bacteria.

All sites that receive new invasions become new potential donor areas/regions.

The transfer of organisms via ballast water can be looked on in stages:

1) Ballasting.

   Ballast water is brought on board through the sea chest located on the side or bottom of the ship below the waterline with ballast pumps or by gravity feed. To prevent the intake of large foreign objects, grates and/ or strainer plates are in use. Water entering a tank in the ***donor area*** can include a variety of organisms living in the water column and (already present) sediment (nekton, holoplankton, meroplankton, and demersal zooplankton or benthic species).

2) Transfer.

   The conditions under which these organisms live in the ballast tank varies among other factors with ballast water systems, air space above ballast water (surface area), temperature variations during voyage etc. The transfer of organisms is dependent on the survival under these conditions.

3) De-ballasting.

   Organisms, which have survived the voyage in ballast tanks, are discharged in the ***recipient area.*** Successful establishment of organisms is dependent on their ability to adapt to the "new" environment (physical/chemical conditions, competition etc.) in the recipient area.

Another related pathway is the transfer of organisms via fouling on the vessel hull. Although modern antifouling paints are extremely efficient, hull fouling occurs on all vessels over time. However, this pathway is assumed to have become less important compared to the ballast water pathway by the introduction of efficient antifouling paints and greater ship speed. However, this might be effected by the introduction of stricter requirements to antifouling products (e.g. the ban of TBT to be introduced in 2003).

The large consumers of ballast water representing the highest risk of causing the transfer of unwanted aquatic organisms are typically tankers and bulk carriers moving between biological regions carrying large amounts of ballast. Cruise and passenger vessels/ ferries rearly carry such extensive amounts of ballast water nor do they operate on longer routes in the same scale. However, in some cases one can foresee these vessels being operated in a manner making them a potential source for unwanted transfer.

Cruise, passenger vessels and ferries are likely to use ballast water in conjunction with adjustments of trim/ heel rather that securing stability for safety reasons. Ballasting might be undertaken in a number of ports in a rapid sequence making the individual voyages between ports "safe" from a biological point of view. However, this pattern of operation will enable a complex build-up of sedimentation in the tanks used for ballasting. Organisms can survive in such sediments for a long period of time (years). The tank sediments themselves might therefor represent the most potential source of biological transfer.

2.5.2 Impact On The Environment

Transfer of living organisms (aquatic plants, animals and pathogens) via ballast water has been known since the beginning of the 20th century. The extent of this transfer has since increased with growing maritime activity and larger and faster vessels.

Undesirable spreading of exotic organisms has been described as the biggest threat to biodiversity and as the next big pollution challenge for the shipping industry causing irreversible processes effecting human health and industrial activities as well as the ecological balance of the seas.

In several cases the introduction of non-indigenous species have caused great economic consequences, and there is an increasing realisation of the ecological costs of biological invasions in the irretrievable loss of native biodiversity.

The total volume of ballast water carried in transoceanic shipping is not known. In Australia, however, about 150 million tonnes of ballast water are discharged into 64 ports by 10,000 vessels from 300 overseas ports each year (AQIS 1998). In addition, domestic shipping each year from one Australian port to another moves millions of tonnes. In 1991 United States received 79 million tonnes of ballast water (Shipping Study 1991). Recent work carried out in the Netherlands, suggest that Rotterdam represents the largest ballast water export port of the world at some 14 million tonnes annually.

It has been estimated that more than 3,000 species may be in motion around the world in ballast of ocean-going vessels (Carlton & Geller 1993) at all time. Some numbers from the literature are listed in the following:

- Approximately 30 % of the aquatic species introduced to the Great Lakes are considered to be ballast water introductions (Wiley & Hall 1996).
- At least 367 different aquatic plants and animals have been found in the ballast water of ships arriving in Oregon from Japan alone (Carlton, J.T. & J. Geller. 1993).
- Over a period of three years, approximately 300 vessels calling at German ports were inspected. About 350 botanical and zoological taxa were found, of which roughly 30 percent comprised foreign organisms, non-indigenous to the Baltic and North Sea (Gollasch et al. 1995).
- Marine aquaculture farming is threatened by the worldwide transport of toxic phytoplankton species in ballast water tanks, especially the cyst-forming dinoflagellates that are able to survive long periods of unfavourable conditions (Hallegraeff et al.1990).
- In Australia, there have been at least fourteen well established species known with reasonable certainty to have been introduced in ballast water (Rigby et al. 1993).

Several examples of new ballast-mediated invasions are recorded since the 1970s.

- The toxic dinoflagellate Gymnodinium catenatum is assumed introduced to an Australian port after 1980 with a cargo vessel originating from Japan or Korea. It is now well established in the port of Hobart and has been responsible for the closure of shellfish harvesting in this area on several occasions. As a result, the Tasmanian health and fisheries authorities have had to implement a costly shellfish toxin monitoring programme to ensure the quality of commercial shellfish products and to protect public health (Rigby, G. & G. Hallegraeff 1994).
- It is estimated that it will cost U.S. $500 million over the next ten years to repair and control the damage (clogging pipes in pumping discharge systems) by the zebra mussel (Dreissena polymorpha) in the Great Lakes (non-indigenous Aquatic Nuisance Prevention and Control Act of 1990).
- The introduction of the ctenophore Mnemiopsis leidy in the Black and Azov seas in the early 1980s has resulted in a dramatic decline in the region's anchovy and sprat fisheries which used to have a turnover of about U.S. $ 200 mill./year (Botnen 1997). This north-western Atlantic “comb jelly” has become a dominant member of the carnivorous zooplankton in the Black Sea ecosystem, affecting the recruitment of commercial fish stocks by predation on fish larvae and their prey organisms (Harbison & Volovik 1993).

- Another North American species, the spionid polychaete Marenzellaria viridis, has established itself in the Baltic Sea (Norrko et al. 1993) and almost entirely replaced the indigenous polychaete Nereis diversicolor in some areas (Zmudzinski 1993).
- The Northern Pacific sea star, Asterias amurensis, which was introduced to Australia (by ballast water from Japan) in the early 1980's, has since then caused severe damage to aquaculture and fishing industries. The introduction has been thought likely to cost millions of dollars annually (CRIMP 1997). The sea star, a prolific breeder, grows very large and is a voracious predator. It has proved impossible to eradicate.
- Some scientists believe that a massive cholera epidemic in Peru in 1991 resulted from the discharge of ballast water infected with the organism Vibrio cholerae (Food and Nutrition Digest 1997).
- The catadromous, burrowing Chinese mitten crab (Eriocheir sinensis) became phenomenally abundant in the rivers and upper estuaries of Germany in the 1930s, causing damage to trap and net fisheries and to riverbanks. This lead to a government-sponsored control programs that, at its peak, trapped and destroyed tens of millions of crabs per year. The mitten crab became established in San Francisco Bay in the 1990s (Cohen & Carlton 1995), and is now a found in density exceeding 10,000 individuals per square meter (NOAA 1994).

The above examples represent species about which there is a good history or taxonomic research and expertise available within the receiving country to be able to record their dates of introduction. In locations where the marine fauna is less investigated and/or taxonomic science is not so experienced, it is likely that many introduced species are unrecorded.

2.5.3 Rules & Regulations

The legally binding Convention on Biological Diversity (CBD) was the first international agreement obligating governments to conserve and sustainable use their biological resources and ensure the equitable sharing of their benefits. The Convention was opened for signature on 5 June 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit"). By 4 June 1993 it had received 168 signatures. The Convention entered force on 29 December 1993.

The second meeting of the Conference of the Parties (COP-2) to the CBD was held in Jakarta, Indonesia in November 1995. The meeting marked the first time the international community addressed in a comprehensive way the urgent global problem of marine and coastal biodiversity loss. The decisions taken on this topic were referred to collectively in the Ministerial Statement issued at COP-2 as the Jakarta Mandate on Marine and Coastal Biodiversity (Jakarta Mandate).

At the international level, institutional mechanisms are set up under the CBD to assist the Parties in their implementation efforts (including financial mechanisms to provide assistance to developing countries; an information clearinghouse; an advisory body on

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scientific and technical matters (the Subsidiary Body on Scientific, Technical and Technological Advice, or SBSTTA)). In supporting the SBSTTA recommendations, the COP in effect recommended a "checklist" of actions that Parties should take to fulfil their obligations under the CBD in marine and coastal environments. These recommendations cover, in particular, five thematic areas:

Integrated marine and coastal area management (IAM)	Marine protected areas (MPAs)
Coastal and marine living marine resources (CLMR)	Alien Species
Mariculture	

Several of these thematic areas include to a lesser or higher degree elements of the "ballast water problem". However, the thematic area of "alien species" is in particular interesting in this context.

Existing Rules & Regulations
At present, there are no mandatory binding regulations addressing the prevention of biological transfer of organisms from ballast water. However, there are several initiatives already enforced that might be described as "steps in the process."

IMO have developed a guideline (IMO Ass. res. A 868 (20)) outlining precautions prior to arrival in order to reduce the potential of causing biological transfer. The IMO initiative rest upon the assumption that exchanging ballastwater during the voyage is the only method at present offering a practical option to reduce the number of organisms carried. The method is based on the assumptions that organisms taken on board a ship in coastal areas will not survive when released in oceanic areas, and vice versa, and that mid-ocean water contains relatively few species. IMO Guidelines recommend mid-ocean exchange, with mid-ocean being at least 200 nautical miles from the coast, at a minimum depth of 500 m. In recognising that the exchange of ballast water introduces a number of issues related to both stability and strength, the guideline require a Ballast Water Management plan to be established. Further, it addresses alternative methods to some detail (sequential exchange/ flush through method).

A number of nations have developed recommendations in relation to ballast water exchange. Most of these adopt the philosophy of the IMO resolution.

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Table 2.5.3-1: Summary on existing national, regional or local quarantine requirements for ballast water

Country	Authority	Ports/ ships affected	Implemen-tation	Methods	Sampling	Reference/ Further
Argentina	*Direccion National de Sanidad de Fronteras, del Ministro de Salud Publica*	*Buenos Aires/ Ships arriving from areas where cholera is epidemic*	*Mandatory(1990)*	*In tank treatment by adding chlorine to ballast water through air pipes.*	*Random, by authorities*	*New regulations are imposed under Ordinance No. 12. 12-97 dated 7th. January 1998 (Rules for the Protection of the Environment)t*
Australia	*AQIS (Australian Quarrantine and Inspection Service)*	*All/All*	*Voluntary compliance, mandatory reporting (1992)*	*Exchange, deep ocean areas*	*Target/ random / mandatory supervised by AQIS*	*AQIS Australian Ballast Water Management Guidelines http://www.aqis.gov.au*
Canada	*CCG (Canadian Coast Guard)*	*All vessels transiting the Eastern Canada vessel traffic services Zones that are proceeding towards St. Lawrence*	*Voluntary (1989)*	*Exchange deep ocean areas (greater than 2000 m.) (some exceptions)*	*None required by ship*	*Voluntary guidelines for the control of ballast water discharges from ships…(CCG). Note that special rules apply to ships departing from ports in Lake Superior, with ballast that have been taken in Lake Superior*
Canada	*Vancouver*	*All ships in ballast*	*Mandatory application*	*Exchange deep ocean areas*	*Not specified*	*Vancouver Port Corporation announcement dated 10th. February 1997.*

Chile	*Chilean Navy*	*All/ All ships coming from abroad, ballasted with sea water.*	*Mandatory application (1995)*	*Exchange, deep ocean areas.*	*Not defined*	*Chilean declaration DGTM. And MM.ORD.NO. 12600/228 VRS. Order for Preventive Measures to Avoid Transmission of Harmful Organisms and Epidemics by Ballast Water. 10th. August 1995.*
Israel	*Ministry of transport*	*All/ All*	*Mandatory application (1994)*	*Exchange, deep ocean areas. Ships bound for Eilat must exchange outside of the Red Sea when practical. +*	*Not defined*	*Israel notice to Mariners No. 4/96 dated 19th. April 1996.*
New Zealand	*New Zealand Ministry of Fisheries*	*All/ All ships entering New Zealand territorial waters loaded with territorial water of another country*	*Compliance with guidelines. Import health standard for ballast water came into force on April 30. 1998.*	*Exchange, deep ocean areas/ use of fresh water/ use of approved on-shore treatment facility/ Use of approved in-tank treatment/ discharge into approved non-risk zone.*	*Not defined*	*New Zealand Import Health Standard for Ballast water from all Countries. New Zealand Ballast Water and Ships Hull de-fouling, January 1998*

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United Kingdom	*Orkney Island Council*	*All ships visiting Flotta Terminal in ballast. Exemption , Liquefied gas carriers.*	*Mandatory application (1998)*	*Discharge to shore reception facility*	*None*	*Flotta Terminal Port information Book (ELF, UK plc.)*
USA	*USCG (US Coast Guard).*	*All / All*	*Mandatory in Great Lakes and Hudson River (North of George Washington bridge), Voluntary elsewise (for 3 years from 1998.)*	*Complete exchange outside US EEZ on depth of 2000 m. or deeper/ Retain ballast water on board/ Complete exchange in alternative designated areas/ Alternative ballast water managemen t practises approved in advance by USCG.*	*USCG might sample ballast water and sedime nts.*	*US Code of Federal Regulations (33 CFR Part 151, Subpart C./ US No0ndigenous Aquatic Nuisance Prevention and Control Act (16 US Code 4701, et sec. US Invasive Species Act 1996 Commandant, Office of Response (G-Mor); United States Coast Guard 2100 2nd. Street, Southwest, Room 2100, Washington DC 20593-0001 http://www.uscg.mil/hq/g-m/mso4/bib.htm Interim Rule, July 1st. 1999*
		Oakland, California	*Mandatory (1999)*	*Complete deep ocean exchange*		

US, in General	*USCG*			*Exchange ballastwater outside EEZ prior to entry, exchange in "other areas where no threat on infestation or spread of aquatic nuisance species is posed, use environmentally sound ballast water management methods, make provisions for sampling to ensure compliance "*		*Interim Rule, National guideline*

* California: California state bill (1999) ban discharge of ballast water into state waters unless the vessel concerned has a ballast water discharge permit. From 1 st. April 2000, Master must submit a ballast water report when entering state waters. From December 2002, no ballast water that contain "live exotic ballast water organisms" may be discharged into state waters (exemption rel to safety). After January 2003 terminals are required to start building treatment facilities. (further reading; California Water Resources Control Board)

Future Rules & Regulations

International efforts are at present focusing on the ballast issue through IMO. A working group reporting to the MEPC has been established and are preparing regulations including a code for Ballast Water Management. New regulations will be introduced through a new free standing convention to be adopted at a conference to be held in year 2003.

In the meantime the present IMO guidelines (voluntary and not legally binding) might encourage states to take unilateral domestic action as already seen (ref. table 2.5.3-1).

2.5.4 Technology

A range of options and possible solutions have been proposed and investigated to minimise the transfer of organisms in ballast water. Table 2.5.4-1 summarises some of those most often referred to as perusable (Carlton, Reid & van Leeuwen, (1995)).

Biocidal techniques, mechanical and physical treatments are claimed not attractive on cost, practicality, environmental or on effectiveness grounds. (AQIS, 1997).

For the time being reballasting/ballast water exchange in open seas are the only methods applied on a routine basis. This measure is required by a number of nations in order to provide a minimum of protection. However, the effectiveness of the method is a function of a number of factors and not sufficiently documented.

Table 2.5.4-1: Perusable options

Treatment method	**Evaluation**
Port provide *city fresh* water	Useful for vessels on defined regional routes serving a few cities, where specific arrangements could be made with the port authorities involved
No ballasting in "Global Hot Spots"	Emphasised by the IMO guidelines, but there is a danger that other waters are thought of as "safe" or "clean"
No ballasting in sediment loads areas	Taking on ballast water higher in the water column could increase the intake of organisms in this layer of water
No ballasting in certain areas at certain times of year.	Specific advisories could identify the times when "blooms" are in progress, and update on a regular basis
No ballasting at night	Vertical migration cause several groups of organisms to rise up in the water column at night, and daytime ballasting could reduce the uptake of such organisms
Filtration	Macrofiltration: extended utilisation is conceivable. Microfiltration: automatic self-cleaning microfilters presents future options for ballast water management with vessel retrofitting or redesign
UV	Remains a possibility, especially in conjunction with other control options such as microfiltration. Effectiveness depends on clarity of water, but it could also have some limited depth penetration in sediments
Heat	Well known effects; is a marginally pursuable option, perhaps applicable to new vessel design; costs of retrofitting would be high, thermodynamics is poorly understood, great heat loss, even heating is difficult, can not be used on cargo holds, environmental regulations could prevent discharge of heated water, heat levels necessary is not known
Filtration/ UV/ Ultrasonics en route	Pursuable option if in situ treatment while the vessel is on the way is more effective than treatment during ballasting

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Partial exchange	Potential usefulness if a vessel finds itself in water of distinctly different salinity
Exchange	There is no minimum amount of original water which, when mixed with exchange site water, “guarantees” the absence of organisms from the original ballasting site
Sediment removal, disposal at sea	Limited time and access, air quality problems. The product “Mud Conditioner” leaves minimal health risks
Deballasting only	Potential option under limited circumstances for certain vessels
Discharge to reception vessel	Technically not difficult, but vessels have to be dedicated to the task and themselves undergo treatment; cost effectiveness needs to be checked, but the option bears pursuit and study; the discharge-treatment facility could come to a vessel in question rather than the other way around
Sediment removal and on shore disposal	Time-consuming but likely to be efficient.
Return to sea for exchange	The only option if no onshore facilities/lightening vessel is available, or if it is less expensive than the alternatives; cost can not be estimated because of the variety of vessels, amounts of water, distances, etc.

Ballast water exchange, filtration, heat and some chemical methods are the techniques that provide the most promising results. This might reflect that these methods have undergone the most focusing in work carried out. Hence, the availability of information on other methods are more restricted. A vast amount of alternative options are not considered very practical. This is often because they compromise safety (like chemical treatment in general) or are not proven effective.

Many new techniques have recently emerged and some may prove to be better options than the existing ones.

Ballast Water Exchange/ Re-ballasting

Exchanging ballast water when crossing deep open oceans will reduce the risk of spreading estuarine and neritic plankton species between areas, as clear nutrient-exhausted open ocean water is usually characterised by a sparse plankton community. However, it may not be quite so effective with benthic organisms. Table 2.5.4-2 summarises some benefits and concerns related to ballast water exchange.

In many cases, completely emptying and refilling ballast tanks in open sea (sequential reballasting) represents a safety hazard regarding aspects such as the ships stability but also in association to the imposed structural load. This applies in general but are normally not relevant for cruise vessels and/ or ferries.

An alternative method is continuous flushing of ballast tanks (flush through method/ Brazilian dilution method) to replace the original water, i.e. the ballast tanks remain full at all times. This might be applicable for some vessels, but might require modifications to tank piping and ballast water arrangements for others. These methods might cause strength-related concerns. This method might for practical purposes not be feasible for cruise and/ or ferries.

Measurements comparing these methods have been carried out, but the results are not unambiguous. However, re-ballasting/ballast exchange takes time and is therefore associated with a cost element.

Table 2.5.4-2: Benefits and concerns associated to ballast water exchange

BENEFITS **Operational** 1) *General applicabiliy*: Most vessels can currently undertake some measures of exchange, by some means, without retrofitting costs. For many vessels, weather permitting, exchange can normally be completed in less time that required for transoceanic crossings. 2) *Part of standard operating procedure*: For some vessels, the cost of operation for ballast water exchange will not be a new cost, when deballasting and reballasting already occur as a part of standard operating procedures. 3) *Cost acceptable*: For many vessels, the overall cost of operation may be acceptable, in terms of equipment, wear, fuel costs, crew time, fatigue and transit delays. **Biological** 4) *Effective in removing and killing freshwater organisms:* Saltwater exchange is likely to be highly effective in removing and killing fresh water organisms. 5) *Effective in removing brackish water and salt water organisms:* Salt water exchange may be very important in reducing the abundance and diversity of original brackish and salt water organisms.
CONCERNS **Operational** 1) *Forces upon the ship:* The larger the vessel, the greater the potential problems related to stresses (shear forces, bending moments). Exchange might create unacceptable free surface tank conditions jeopardising vessel stability and further lead to unacceptable ship beam stresses. Under severe sea states, many vessels will be unable to perform exchange. 2) *Cost not acceptable*: For many vessels, the overall costs associated to exchange may be unacceptable in terms of equipment, wear, fuel costs, crew time, fatigue and transit delays. **Biological** 3) *Sediments and organisms often remain*: In most vessels, will not free up and flush out larger sediment loads, potentially leaving large numbers of organisms remaining in the ballast. 4) *Not efficient in removing and killing fresh water organisms*: Salt water exchange may not eliminate the resistant stages of many fresh water organisms. *Not effective in removing all brackish water and salt water organisms*: For many vessels, complete exchange may always be impossible (residual water remains even after pumps lose suction). Residual organisms will remain. Thus salt water exchange will not eliminate all original brackish and salt water organisms.

Filtration

Filtration is mentioned positively by a number of relevant references. Filtration has been divided into different "sub-groups" in different studies. Carlton et al. (1995) separated between macro- and microfiltration, Gollasch (1997) considered self-cleaning filtration, microfiltration and granular filtration, and AquaSense (1998) added jet filtration.

Gollasch' self-cleaning filtration is identical with the project on board the *Algonorth* (Cangelosi 1997) and has the advantages of being effective, and safe for the ship, crew, and the environment. The sediment problem is addressed by this method, and backwash is possible.

Microfiltration opens up for a use of combinations of filters with different mesh sizes. Automatic self-cleaning is always a necessity because of rapid clogging and fouling of filters. It is predicted that pump capacity might be reduced because of such clogging (Gollasch 1997). Larger filter areas can reduce clogging as high flow rates are important during ballasting. A recirculation system for on board treatment could also solve the problem (Laughton et al. 1992).

The jet filtration, uses centrifugal force to separate the sediment and organisms from the water (AquaSense 1998). Post-treatment with UV increases the efficiency.

Heat

Heat renders a long list of disadvantages, but is yet considered positively in many studies studies carried out. (AquaSense 1998, Carlton et al. 1995, Committee on Ships' Ballast Operations et al. 1996, Gollasch 1997), which seems mainly to reflect upon the method characteristics associated to safety, effectiveness for plankton, and operational costs.

The drawbacks mentioned are: the necessary heat levels are not known, lower organisms may survive, even heat is difficult to achieve and heat loss is great, release of hot water might not be environmentally sound, not possible for use in cargo holds, may cause bacterial growth, negative effects on pipes, pumps, and coatings, high costs of retrofitting, constraints on volume treated, length of voyage limits time for treatment, and large energy requirements. Many of these claimed disadvantages have been refuted (see Anonymous 1997, Bolch & Hallegraeff 1993, Hallegraeff et al. 1997, Rigby et al. 1997, 1998).

Chemical Alternatives

The method of ozone is addressed separately as it is considered an exception in the group of chemical methods in that it does not have serious by-products effecting the environment.

Oemcke & van Leeuwen (1998) investigated ozone for ballast water treatment, and reviewed different literature for comparisons. These stress the fact that ozonation of seawater is different from that of ozonation of freshwater. Results of treatment of dinoflagellate hypnocysts were one of the objects of the study, but indicator organisms were used in stead. Treatment in transit, during ballasting, and at shorebased facilities were evaluated.

2.5.5 Consequence Of Use Of Different Technologies

The introduction of procedures, either re-ballasting or onboard treatment, aiming at reducing the content of aquatic species in ballastwater will introduce additional energy consume, new operational procedures and in some cases an investment requirement.

Energy Requirement
Re-ballasting will require additional pumping to be undertaken and might require the voyage to be extended in order to achieve the requirements of the IMO guidelines. New onboard installations will also require energy. An increased use of fuel will increase specific emission of CO2 from the vessel. Due to the limited ballastwater requirement of cruise vessels and ferries, it is assumed that the increased fuel consumption will be marginal.

Operational Procedures
Re-ballasting in open seas introduces a number of safety-related concerns. Procedural error might have severe consequences. From reports on incidents, some examples have been identified:

- Capsize due to ballasting error (3/96)
- Damage to ballast hold during de-ballasting (5/94)
- Overpressurising of tank due to operational error causing hull damage (4/94)
- Overpressurising of top side tanks causing hull damage (5/93)

Alternative measures might also introduce an occupational safety aspect. The operation of equipment or handling of chemicals require training and should be addressed accordingly.

Investment Requirement
Most vessels are thought to enable being re-ballasted without any major modifications. However, operational procedures and training of crew will introduce a level of cost. Treatment of ballastwater will in most cases require high capacity plants and hence increase the level of cost. However, the limited ballasting capacity of cruise vessels and ferries, will limit the capacity requirement. Level of cost will vary considerably depending upon treatment alternative chosen.

Reference to part of this report which may lead to misinterpretation is not permissible.

2.6 Antifouling Systems

2.6.1 General

The main function of an antifouling paint is to prevent the settling of organisms on the submerged parts of vessels. Fouling roughens the hull, resulting in increased friction, and thereby increasing the ship's fuel oil consumption or in loss of speed.

Fouling can be classified in two groups, according to potential size of the fully-grown specimen:

- Macro-fouling, which includes animals (barnacles, tubeworms, hydroids, molluscs, etc.) and plants (green algae, brown algae, etc.)
- Micro-fouling, which includes bacteria and diatoms (slime).

It is estimated that up to 5000 different species are involved in fouling ship surfaces.

Paint manufactures view their antifouling as pest control. Normal pest control is directed against one specific specie, while antifouling battle against a multitude of species.

Antifouling paints employ biocides for fouling control. In order to cover the large variety of species the antifouling paint has to be fairly toxic for the full lifetime of the paint system. One way of keeping the toxic levels at a determined level is to use self-polishing paints. As time goes by the upper layers of the paint become less toxic as it is washed out of the paint. The paint is designed to let the sea slowly wash off the uppermost layer of the paint. Any organisms that have fastened to the hull will lose its grip as the upper layer of the paint lets go. The new exposed layer of paint below will be smooth and its toxic level will be at the determined level again. Modern self-polishing antifouling paints have a lifetime of up to about 5 years.

The organotin-based (Tribultytin or TBT) antifouling have been very successful in keeping the underwater surfaces from fouling. Thus, resulting in lower fuel consumption and less emissions to the atmosphere. Since the hull wetted surface is toxic and is designed to be so for a long period of time constant leaching of the toxins take place and consequently pollute the surrounding environment.

Organotin-based toxins such as TBT have been very popular in the industry the last 30 years. These metal-based toxins have a very slow deterioration rate and thereby they will build up in the food chain. Alarming amounts of tin-based toxins have been registered in sea creatures.

2.6.2 Impact On The Environment

Antifouling paints that are based on leaching biocides to the environment contain as a rule toxins that are washed out into the sea, they do have a negative effect on the environment. The antifouling's mechanism is to keep the vessel's submerged surface toxic for as long as possible in order to keep organisms from fastening. When these toxins are washed out they will pollute the environment.

The main biocides used are:

- Tribultytin or TBT
- Copper compounds

The biocides after leaching out of the paint and into the water will be:

- Degenerated (biological, hydrolysis and UV degeneration)
- Partitioned into the sediments
- Absorbed by aquatic organisms (bio-accumulated)

Degeneration:
Degeneration time of the free biocides in the water will generally determine how toxic the biocides are.

Typically half-life of the two biocides mentioned above are for TBT - a few months and Copper compounds down to a few hours
The half-life time is a direct factor for the concentration of the toxin within the environment.

Sediment Partitioning:
When toxins leach from a ship it will have the desire to either remain in the water or partition into the sediments. It is normally considered that the better a toxin's ability to rapidly partition into the sediments, the more environmental friendly it is.

Both the TBT and Copper based biocides have good partitioning capabilities.

This results in higher toxin concentrations in the sediments along shipping routes. It is by studying bottom organisms that the effect of TBT antifouling has become eminent. The damage due to TBT has been proven as imposex (Suppressing of breeding activity around harbours) in dogwhelk *Nucella lapidus* populations (induction of male characteristics in the female) around harbours and common whelk *Buccinum undatum* in the North sea.

Bio-accumulation:
Bioaccumulation is dependent on the concentration of free biocides in the water, the concentration of organisms and the ability of the organism to accumulate the toxins. Bioaccumulation can be described by a partitioning coefficient called bio-concentration factor (BCF)

$$BCF = \frac{concentration\_in\_the\_aquatic\_organism}{concentration\_in\_seawater}$$

Reference to part of this report which may lead to misinterpretation is not permissible.

The BCF factor will vary dependant on type of organism and where in the food chain the organism is located.

Table 2.6.2-1: Anti-fouling systems history

Anti-fouling systems	**Year**	**Environmental impacts /measures taken**
Resin or pitch used on ship hulls.	**1900**	
Copper-based paints containing mercury oxide, arsenic halogen Compounds	**1960s**	Long-life anti-fouling paints provide protection to hulls for up to 24 months.
Introduction of free association TBT-based anti-fouling paints	**1970s**	Self-polishing anti-fouling paints containing TBT hailed by shipping industry. Anti-fouling toxin is partly released by a reaction with seawater and paint polishes away layer by layer, continuously exposing new layer to seawater. Biocide delivery rate is more or less constant. Ships can now drydock just once every five years.
Introduction of self-polishing co-polymer TBT-based anti-fouling paints.	**1980s**	Worrying side effects of TBT on oysters (deformities) identified in France. TBT-related imposex recorded in English coastal waters. Various countries ban TBT on boats less than 25 metres long.
Introduction of non-stick coating for small vessels. Various tin-free alternatives developed.	**Early 1990s**	Resolution recommends Governments ban TBT on vessels less than 25 metres in length; TBT leaching from paint should be less than 4 micrograms per cm square per day. Japan, New Zealand, Australia ban use of anti-foulants containing TBT Imposex found in dog whelks, attributed to TBT. United States, Canada, Australia, Sweden, the Netherlands impose TBT release rate restrictions.
	1995	IMO creates MEPC working group on harmful effects of anti-fouling paints.
	1997	Japan bans production of TBT-based anti-fouling paints.
	1998	MEPC agrees to draft mandatory regulations to ban organotins used in anti-fouling systems; MEPC approves draft Assembly Resolution setting out time scale to do so.
	1999	IMO 21st Assembly due to adopt Resolution on phasing out organotin compounds acting as biocides in antifouling systems.
	2003	Proposed date for prohibiting application of organotin

		compounds acting as biocide in anti-fouling systems.
	2008	Proposed date for complete prohibition on organotin compounds acting as biocides in anti-fouling systems

2.6.3 Rules & Regulations

Existing Rules & Regulations
There are no current International rules governing environmental maters with regards to antifouling paint systems.

The following national legislation are in effect:

Table 2.6.3-1: Existing legislation

Country	**Legislation**
<u>Canada</u>	- All antifouling applied requires registration - TBT antifouling must not be applied to vessels <25 metres in length. (Aluminium hulls are exempted) - TBT antifouling applied must have a release rate: 1) Less than 4µg TBT/cm^2/day 2) Less than 40µg Copper/cm^2/day - All copper based antifouling applied must have a release rate of less than 40µg Copper/cm^2/day
<u>USA</u>	- All antifouling applied requires registration - TBT antifouling must not be applied to vessels <25 metres in length. (Aluminium hulls are exempted) - TBT antifouling applied must have a release rate of less than 4µg TBT/cm^2/day - TBT antifouling may only be applied by certified applicators - Antifouling applied in major US shipyards must not exceed a maximum of 400 gr. Volatile Organic content (solvent) per litre of paint to comply with air quality legislation. - In certain states washing water and blasting abrasives used to prepare TBT antifouling may be collected and treated as hazardous waste.
<u>European Union (E.U.)</u>	- All antifouling products sold and applied currently require registration in the UK, Sweden, Netherlands, Eire, Belgium and Austria. *Note:* *The EU Biocidal products Derictive (Implementation date March 2000) will require products to be registered in each EU member state. Use of "free association" products containing TBT are banned.* - TBT antifouling must not be applied to vessels <25 metres in length. - In Sweden TBT antifouling must not be applied to vessels operating solely in the Baltic sea. * Antifouling used on vessels operating solely in the Baltic sea and North sea areas must have a copper release rate of less than 55

	µg Copper/cm^2/day. * Pleasure craft antifouling are subject to copper leaching rate restrictions. * All antifouling paints are totally banned on vessels operating solely in fresh water lakes and in the Bay of Bothnia. * TBT Sold must have a release rate of less than 4 µg TBT/cm^2/day - In the UK, TBT antifouling can only be applied or removed in yards registered under Environmental Protection Act. - In the Netherlands TBT products applied must have a release rate of less than 4 µg TBT/cm^2/day. *Note:* *In certain EU countries (eg in the Netherlands, UK and Germany) washing water and blasting abrasives used to prepare TBT antifouling must be collected and treated as hazardous waste.*
Non EU Member states	- All antifouling in Malta and Switzerland require registration. - Most western European states outside the EU (eg Norway) have banned the application of TBT antifouling on vessels <25m in length.
South Africa	- All antifouling require registration. - TBT antifouling must not be applied to vessels <25 metres in length.
Japan	- Antifouling paints applied in Japan do nor require registration, but must contain biocides approved by the government/Industry (JSA/MITI) - The Japanese Ministry of transport, Fisheries Agency and Shipbuilders Association recommend TBT antifouling paints should not be used on any vessel. (This effectively means application of TBT containing antifouling in Japan is not allowed).
Hong Kong	- All antifouling paints applied in Hong Kong must be registered.
Korea	- Proposal to ban TBT antifouling application on vessels< 25m in length is under discussion.
Australia	- All antifouling paints applied in Australia require registration - TBT antifouling must not be applied to vessels < 25 metres in length. - TBT antifouling applied must have a release rate of less than 5µg TBT/cm^2/day
New Zealand	- Application of TBT antifouling is forbidden.

Future Rules & Regulations
The Marine Environmental Protection Committee of IMO (MEPC) have been debating "harmful effects of use of antifouling paints on ships" for several years.

The MEPC meeting held in November 1989 (MEPC 42) approved a draft assembly resolution agreeing that the application of all antifouling containing TBT should be banned throughout the world by 1 January 2003 and that a complete ban on the presence of TBT antifouling on ship hulls be in place by 1 January 2008.

Reference to part of this report which may lead to misinterpretation is not permissible.

It is to be expected that other antifoulings proven to be "damaging to the environment" will be worked into this legislation, and thereby come into effect much quicker at a later stage.

2.6.4 Technology

As TBT antifouling is being banned around the world, alternative antifoulings have been developed.

Different Types Of TBT-Free Antifouling
There are 3 basic types of antifouling technologies developed, Soluble Matrix, Contact leaching and Self-Polishing (SPC) antifouling. Table 2.6.4-1 gives an overview of some of the most known TBT free antifoulings today.

<u>Soluble Matrix Technology</u>
Soluble Matrix antifoulings rely on physical dissolution of the paint film to release biocides, the same way that bathroom soap dissolves in water. The resin used will determine the rate of dissolvement and thereby the lifetime of the paint system.
The main biocides used in these systems are Copper oxides together with organic boosting biocides to provide a broadest possible toxin spectrum.

The life expectancy for Soluble Matrix antifouling is normally not more than 3 years.

<u>Contact Leaching Antifouling</u>
Contact Leaching antifouling are hard, mechanical tough and do not erode over time. They are highly loaded with biocides, which leach through the hard matrix. They have a maximum lifetime of 2 years, as the biocides are relatively quickly.

<u>SPC Antifouling</u>
The Self-Polishing antifouling can be divided in to two main categories; toxin and toxin free coatings.

The toxin free or "Non-Stick" (also known as Low Surface energy absorbing coatings) antifouling is normally a silicon based system and does not use biocides, but has a low friction capability. Although fouling organisms can settle on these coatings in static conditions, they will be washed off as the vessel speed increases. Speeds above 18 knots are needed to wash off all the fouling, consequently these systems are best suited for higher speed vessels.

For lower speed vessels normal TBT-free SPC type antifouling, which contain biocides will be used. Most of these new products use acrylic base polymer, similar to what was used for SPC systems with TBT. The new products mainly use copper oxide together with organic boosting biocides. The new biocides degrade much more rapidly when freed into water. The half-life is down to a few hours compared to a few months with the previously used TBT antifouling. Initially the TBT-free SPC's had a lifetime of about 30-

month, however the newer antifoulings are increasingly promoted by the manufactures to have life times up to 60 month.

Table 2.6.4-1: TBT free alternatives to antifouling paints

Product	Key words
Non-stick paints	
Intersleek 425, International Paint	- used for fast ferries since 1996 - full ship trails conducted on another version which is effective around 15 knots, particularly good for schedule ships which do not stop for long, especially cruise ships - coating will last for 5 years
Hempasil SP-EED, Hempel	- now being tested, promising long term performance - coating is anticipated to be effective for 5-10 years
Sigmaglide, Sigma	- successful application to US naval vessels (aircraft carrier and submarine)
BIOX, Kansai	- applied to water inlets of power stations, too expensive for ships
TBT-free SPC paints	
Intersmooth Ecoflex, International Paint	- self polishing co-polymer (SPC) based on copper acrylate - may be effective up to five years - applied by more than 1200 ships above 4,000 dwt since 1990 - results indicate effectiveness corresponding to TBT-SPC - currently 10 ships with a five year system
Globic SP-ECO 8190, Hempel	- based on fibre composite formulation (hydrolysable zinc carboxylate polymer salt binding technology - tested on a wide range of low to medium speed coastal vessels with medium to long idle periods - a corresponding alternative (8199) is available for medium to high speed deep sea vessels with short idle periods - it has demonstrated a level of fouling control performance higher than conventional tin-free systems
Sea Quantum, Jotun	- SPC tin free alternative based on sophisticated silyl polymer, full five year system - tests by means of sea trails on many types of vessels over the past 4 years with excellent results (86% success rate) - ships in regular traffic in northern waters have highest success rate
Sigmaplane Ecol, Sigma Coatings	- self polishing tin-free antifouling based on copper oxide - commercially in use for six years - one version for high activity vessels with short stationary periods - one version for medium activity vessels with occasional stationary periods of 5 to 20 days - effective life of around three years

Reference to part of this report which may lead to misinterpretation is not permissible.

TFA 10, Camrex Chugoku	- self-polishing copper oxide antifouling with gumrosin as the base - has shown a success rate of 80-85% (which is about the limit of this technology) - Seatender is the companies special copper oxide antifouling for specific use (warm water, deep sea, application over old TBT)
Sea Grandprix, Camrex Chugoku	- first used commercially in 1995, now on 500 ships - same controlled polishing rate as TBT copolymer but is copper bound copolymer - linear release, no leached layer, no skeletal layer - foul-free performance of 90-95%
ABC3, Ameron	- contains cuprous oxide and biocides and performs at least as well as tin based paint - cheaper than TBT based paints - used on US Navy vessels since 1983 and on commercial vessels since 1986 - effective life of up to 5 years

Soluble matrix paint	
Exion, Kansai	- zinc acrylate polymer reacting with seawater and working by ionic exchange - the result is a dissolution process that is as even and controlled as that of TBT - product tested on ocean going vessels last three years; container vessel, Mobil and Shell tankers - early days of testing, good results, aiming for 5 year life time

2.6.5 Consequence Of Use Of Different Technologies

When TBT self-polishing antifouling was introduced into the market in 1974 it revolutionised the industry. Large reductions in fuel oil consumption, increased docking intervals, economical savings are some of the features, which resulting in an almost monopolisation of the market in very short time. It is estimated that at least 75% of the world fleet are using TBT containing antifouling today.

The TBT free antifouling was introduced around 1990 in Japan, where the ban first was made effective. During the 10-year time these antifoulings have been on the market, their quality has improved, and the best can be compared with TBT antifoulings. From an environment point of view there is an improvement in removing TBT. However, the TBT is replaced by other biocides that still are toxic. The toxins are less toxic and faster degradable than the TBT.

Biocide free antifouling have been developed but are generally available for higher-speed vessels. This antifouling shows promising features and is based on a hard coating “non-stick" technology, with a very long lifetime (more than 5 years) and very little contamination of surrounding water. However the paint is expensive.

The cost for the different systems composed to a normal TBT antifouling is as follows: (Top quality TBT free products are used in this comparison)

TBT free antifouling ≈ 3 x price of TBT antifouling
Non-Stick antifouling ≈ 10 x price of TBT antifouling

As the TBT antifouling is on its way to be phased out the price ratio above may be taken as:

Non-Stick antifouling ≈ 3 x price of TBT free antifouling

The price difference is actually less as the lifetime of the Non-Stick antifouling is longer than the TBT free antifouling by at least 50%. Even longer life is expected but is not yet proven.

For a large segment of the cruise market and the fast ferry market the "Non-stick" antifouling is absolute an antifouling worth considering. For the slower ferries and passenger vessels the TBT free antifouling will have to be chosen until the non-stick technology or other non-biocide antifoulings can be developed.

3 EMISSION TO AIR

3.1 General

Emissions to air from shipping represent a considerable contribution mainly to the issue of global heating (Green House Gases, GHG) as well as that of acidification.

While landbased emissions of sulphur and nitrogene oxides decreases as results of international agreements (Sulphur/ NO_x protocol, (Convention on Long-Range Transboundary Air Pollution (UNECE))) and GHG are attacked through the Kyoto Protocol, the contribution from shipping as a source, has steadily increased. This is mainly due to no or weak regulation.

In the context of this work, the following emission components are included:

- CO_2, NO_x, SO_x

These are partly interrelated. Consequently, modifications causing the reduction of one component might have unwanted effect on another. This is in particular the case for NO_x and CO_2. However, also when consider relations between other components, such interrelations might occur.

Cruise vessels and ferries will most often have different engine installations to those used in the cargo-carrying segment of merchant shipping. Most often, this segment adopt to the use of multi-unit arrangements of medium speed engines providing a higher degree of flexibility. In some cases, turbine machinery may also be intalled. These arrangements will differ in relation to emission characteristics from the traditional combustion engine weather its of slow speed type or running at medium speeds.

3.2 NO_X Emissions

3.2.1 General

Emissions of NO_x from combustion engines forms mainly as a function of the combustion parameters and is only to a very limited extent dependent upon the characteristics of the fuel. The major amount of NO_x is created at the higher temperature regime of the combustion process. Hence, NO_x emissions from shipboard engines are normally referred to are thermal NO_x.

NO_x-reducing measures are often seen representing three strategies:

- Exhaust gas cleaning
- Fuel treatment
- Engine internal modifications
- Ambient manipulation

The three latter of these both aim at manipulating the actual combustion process aiming at reducing the peak temperature levels.

Emissions from turbine machinery will mirror the type installed. The rear steam turbine installation itself does not emit air emissions at all as a boiler produces the steam required. Consequently, emissions associated to power generation by steam turbine machinery is generated by the process of producing steam and hence allocated to the boiler. Gas turbines utilises fuel most often of a high quality (diesel) whilst a boiler can utilise heavy fuel oils. Mutual for both the turbine alternatives is that they offer lower specific NO_x emission figures than the diesel engine.

3.2.2 Impact On The Environment

Together with the emission of sulphur (SO_x), NO_x is the main source of acidification attacking both watercourses and soil. This effects both water resources as well as vegetation leading to substantial ecological damage as well as to large economical losses. These effects are well documented and monitoring programmes evaluating the effects on forestry and inland fisheries can be used to estimate both the extent of the ecological damage as well as that of the associated economical consequences.

NO_x effect the formation of ground level ozone and might lead to over-fertilisation. The latter causes nutritional imbalance leading to deficiency diseases in vegetation. Acidification have caused the destruction of inland fishing and large forest resources in both central/ eastern Europe as well in the northern areas of the continent.

Due to the formation of ground level ozone, NO_x is also a threat to human health. Asthma, respiratory diseases, changes in membranes and tissues and bronchitis are health concerns related to air pollution in general but to NO_x in particular. Cities and dense populated areas are exposed to these effects and regulations have been enforced on most all activities contributing to the discharge of these emissions (automotive industries, processing industries, etc.)

Acidification is highly corrosive and affect structural objects including buildings. In a historical perspective this is also an element of considerable concern.

3.2.3 Rules & Regulations

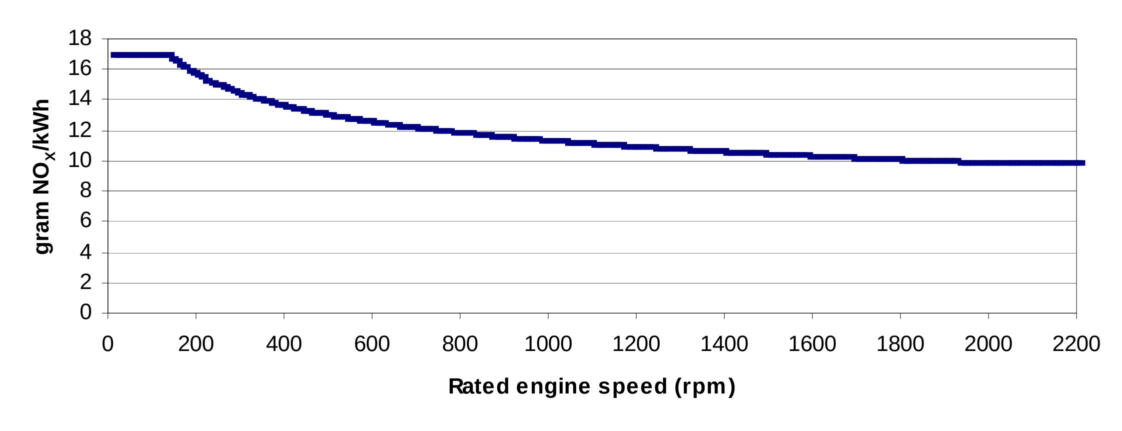
Existing Rules And Regulations

The emissions of NO_x in relation to shipping are regulated internationally through Annex VI to MARPOL. This was amended in 1997 but is at present only ratified by Norway and Sweden. However, the regulation of the Annex covering NO_x has a mechanism giving requirements a retroactive effect. Hence, it is reasonable to assume that the specific NO_x contribution from shipping will stagnate or decrease from year 2000 (new tonnage). It should be noted that the ratification process associated to this Annex has a monitoring mechanism ensuring that the ratification requirements are reconsidered if the process does not proceed satisfactory. The first reassessment of the process is scheduled for year 2003.

There are various non-mandatory initiatives already introduced aiming at promoting shipowners to adopt to NO_x-reducing measures. These are often attached to schemes offering reductions of relevant fees if emission levels are in accordance to specified limits. These limits are most often given with reference to the limits adopted by IMO, see figure Figure 3.2.3-1. To accommodate these schemes, some classification societies have developed voluntary rules establishing necessary provisions. DNV's notation, CLEAN and CLEAN DESIGN make such provisions for a comprehensive range of environmental issues included that of emissions to air.

Reference to part of this report which may lead to misinterpretation is not permissible.

Figure 3.2.3-1, Specific maximum emission levels in accordanve to MARPOL,



Annex VI

Future Rules And Regulations
Some initiatives have been proposed and in fact also initiated on national levels attempting to encourage reductive measures to be implemented. However, these are not of mandatory nature. These initiatives have incurred classification societies to provide services enabling effective emission reducing measures to be introduced and verified.

3.2.4 Technology

Emissions of NO_x from shipboard dieselengines are thermal NO_x. Technologies for the reduction of this emission component can be categorised:

- Exhaust gas cleaning
- Fuel treatment
- Engine internal modifications
- Ambient manipulation

Exhaust Gas Cleaning
Selective Cathalytic Reduction (SCR) reduces the NO_x in the exhaust gas to nitrogen (N_2) and water by the use of a catalyst and a reducing agent. The method is highly efficient in terms of reduction figures (more than 95%). However, operational efficiency will depend on the specific installation characteristics. SCR systems are relatively large installations and might impose some requirements to the operational parameters of the vessel.

The main parameter determining the efficiency of the catalytic process is the requirement to exhaust gas temperature (minimum requirements in region of 280º – 300ºC). Some engine configurations might not enable to conform to this (at all or not until a specific load point is reached). Low exhaust gas temperatures might cause corrosion problems. An upper limit is normally also given (at 480ºC - 500ºC). High exhaust gas temperatures might in addition to decreased efficiency and operational problems also cause the formation of other undesired gas components. Fuel quality might also effect the SCR's reduction potential as high sulphur fuels will reduce the lifespan and efficiency of the catalyst itself (blockage, deposits).

The catalyst unit decade as a function of time. This is mainly caused by long term thermal loading. Renewal of the catalyst elements are recommended every 20000-25000 operating hours. Some catalyst modules can be "recycled" in the sense that they are returned to the manufacturer and "retreated". This eliminate the problem of disposal.

The reduction agent used in SCR-installations are either Ammonia or Urea. Some classification companies have developed recommendations (Lloyds, DNV) on SCR installations requiring Ammonia to be avoided (from practical reasons as ammonia is highly corrosive). Most recent SCR installations typically uses Urea as reduction agent.

SCR have a large source of reference applications related to general industries (power plants in particular). For marine diesel engine applications, the experience is significantly smaller. However, it is reported that close to 70 SCR systems are under construction or already installed (DNV 1998). Long term operational experience is still somewhat limited. The investment related to SCR operations are considerable (USD 400-600/ kW is sometimes given as a reference figure). Operational costs are largely generated by consumables (reduction agent). However, both these cost elements have decreased significantly over the last few years. SCR is a medium to high NO_x reduction method dependent upon the specifics of the actual scenario.

Fuel Treatment

Most all international marine bunker fuels are Heavy Fuel Oil (HFO) types and this will likely be the case for the future as well. HFOs are mixtures between oil refinery fractions with different properties. Residue oil from atmospheric destillation is becoming more frequent as input for secondary refinery processes. The residues from primary processes will be more rare so that the quality of future fuels must be expected to vary by time and by supplier in one and the same port (Hennie et al., 1998).

Fuel oil properties such as viscosity and density will influence the combustion characteristics. Ignition delay is one such factor influencing thermal NO_x emission production. Viscous fuels with high density might cause ignition delay resulting in cylinder pressure build-up during the initial part of the combustion. Combustion efficiency will be high resulting in high peak temperatures and thereby a high NO_x-level. Equally, varying qualities in other fuel types might effect the combustion process to the extent where it will effect the NO_x emission characteristics. To control these potential sources to increased NOx emission, fuel quality control measures should be considered.

It has been long well known that the adding of water to the fuel producing a fuel/ water emulsion have effects on the combustion process. This measure was previously sometimes adopted in order to reduce soot and deposits in the engine and to reduce

Reference to part of this report which may lead to misinterpretation is not permissible.

particulate in the emission. Later, it has been established that emulsified fuels also reduce the emission of NO_x.

Emulsified fuel causes a micro-vaporisation of the fuel droplets resulting in an improved mixing of fuel and air. This improve the efficiency of the combustion and utilisation of the energy of the fuel. However, water exposed to the heat regime in the engine vaporise and energy is needed for the transformation of water to steam. This process has a "cooling" effect removing the most extreme of temperature peaks resulting in reduced production of NO_x.

Emulsified fuel may be produced by the use of a mechanical homogenizer, ultrasound or steam injection. It can also be produced by pressurising the fuel and water mixture and then choking the flow. When adding water into the fuel, the capacity of the fuel system including the pumps might require altering. This in itself often put a limit to the maximum reduction likely to be achieved from using emulsified fuels.

The NO_x emission level reduces as a function of amount of water present in the fuel (linear relation). Minimum waterlevel is sometimes set to 10 %. Typically, the reduction of 1 % NOx require the addition of 1 % water. This relationship is found to be linear up to approximately 40%. When exceeding this limit, the efficiency of the method is somewhat falling.

Emulsified fuels require a reliable and stable system for the production of a stable emulsion. Provided this requirement can be fulfilled, the method will not impose operational problems. Unstable emulsions might cause excessive wear and operational problems.

The use of emulsified fuel will require provision of water of a certain quality. The cost of using emulsification will beside the plant investments and modifications to the fuels system be linked to this. The use of emulsification is normally considered a medium cost method.

Engine Internal Modifications

The focusing on the slow renewal speed in shipping and hence the recognition of the high number of ageing existing vessels in the world fleet have lead to adjustments and adaptations to existing engine designs for the purpose of reducing NO_x emissions. Such measures include retarded fuel injection, adaptations of the fuel injection rate, change of nozzle specifications, improved fuel atomisation, compression ratio adaptations, turbocharger modifications and improved fuel/air mixing or on ore more of these in a combination.

Retarding fuel injection timing is maybe the most commonly used (historic) measure reducing NO_x. Retarding timing lead to a shortened premixed burning phase and combustion temperature and pressure are reduced. The delayed start of the injection will also lead to a delayed end of the injection process unless the rate of injection is altered. Later stages of the combustion will as a consequence suffer from less optimal conditions.

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This will increase fuel consumption and might cause increased emissions of particulate and smoke. Retarded injection timing is therefore sometimes used in combination with other measures to compensate against this.

Potential of NO_x reductions by retarded timing is limited by a number of factors. Often maximum achievable reductions are set at 5 – 8 %.

Retarded injection combined with a shorter injection period (increased injection rate) allow combustion to take place at a point optimal from an engine efficiency point of view. An increased injection rate allow delay in the initiation of fuel similar to retarded injection timing causing lower peak combustion temperatures and hence reduced NO_x formation. Other measures seen combined with retarded combustion involve increased compression ratio using an extra pilot injection or a combination of both. Improved mixing by charge air movement and combustion chamber geometry are also sometimes seen.

By introducing low NO_x combustion techniques, positive effects can be obtained on efficiency and rate of CO_2 emissions.

Engine internal modifications are associated to low costs. However, comprehensive modifications combining different measures can provide considerable reductions but will also increase the cost. The measures in this category are most often already implemented in present production engines.

Direct injection of water to the combustion chamber is developed from the technology of emulsification /addressed under fuel treatment measures). This offer considerable reductions of up to 50%. However, only very few engine manufacturers offer this solution. Direct combustion simplifies the fuel oil system compared to the implications associated to emulsification. It should be noted that a significant amount of high quality water is required level.

Ambient Manipulation

Methodologies in this category aim at manipulating the operating environment. Methods aim at influencing the quality of the intake air in such a way that it effect the combustion process.

Exhaust Gas Recirculation (EGR) returns a small proportion of the exhaust gas back into the charge air. This will increase the charge air heat capacity and lower the oxygen concentration resulting in lower peak temperatures and thereby a reduction of NO_x emission levels.

Exhaust gas is returned after the turbine outlet, cooled in a heat exchanger and filtered before entering the charge air. The extensive use of residual fuel on ship diesel engines is a practical restriction on the use of EGR as it produce particulate exhaust requiring extensive filtering. Particulate should be avoided in order to avoid influencing turbocharger operation and causing increased smoke emissions (DNV 1998). EGR is best suited for engines using natural gas or a high quality low sulphur fuel type. EGR is not used in marine installations due to the “particulate” problem.

EGR will increase fuel consumption due to poorer combustion properties in the combustion chamber and partly due to increased internal engine power consumption. It will most likely represent a high cost alternative.

The Humid Air Motor (HAM) aim at increasing the specific heat capacity of the charge air simultaneously as oxygen concentration is reduced. The HAM concept is developed by Munters Europa and is in a “pilot development stage”. A few installations have been undertaken and some operational experience is available (Viking Line).

The concept comprises the use of charge air with 100% relative humidity at a higher than normal charge air temperature. As steam has twice the specific heat capacity of dry air, the specific heat capacity of the cylinder charge is increased. At the same time, the steam occupies space that would normally contain oxygen, and the concentration of oxygen in the cylinder charge is reduced.

HAM utilises a humidification tower added to the turbocharged engine replacing the air cooler between the compressor and engine air intake. The tower is fed by preheated water which is brought into contact with compressed air in a counterflow act causing water to evaporate at a sliding temperature. As relative humidity at the air outlet is nearly constant (99.5 %), the absolute humidity will change as function of pressure and the air temperature at the tower outlet. Seawater is proposed used as feed water.

The use of fresh water is most likely not feasible due to high consumption. Further, the HAM concept comprises the addition of voluminous equipment and might not be feasible for implementation onboard existing vessels. For installation onboard new vessels, it is expected that the investment costs will be more or less the same as for a SCR installation. A retrofit on an existing ship is expected to be cheaper than an SCR retrofit. The running expenses in relation to a HAM installation is however far less than for that of a SCR installation.

Full scale testing of the HAM concept have proven it efficient reaching NO_x reduction of up to 70%.

Turbine Machinery And Boilers
These installations differs from the emission characteristics of the traditional combustion process by offering considerably lower emission factors.
Typically, the diesel combustion process will produce some 70 kg NO_x/ ton fuel. Comparable figures for a modern gas turbine is typically 16 kg NO_x/ ton fuel (diesel). A steam turbine will receive steam from a boiler. As the NO_x formation is a thermal process requiring a high regime of temperatures, it is not surprising that the boiler offer even lower NO_x emission figures. A boiler will typically form 2.5-3 kg NO_x/ ton fuel when running on lighter fuel distillates. This will increase to approximately 6 kg NO_x/ ton fuel when using heavy fuel oil.

3.2.5 Consequence Of Use Of Different Technologies

A practical constraint when considering the implementation of NO_x reducing measures on existing machinery, is the attitude to the engine manufacturer. The shipowner has a requirement associated to reliability of the engine after modifications and will in most cases require some form of statement ensuring such reliability. This is often not easy to achieve. The exemption from this will be the implementation of exhaust gas cleaning (SCR-treatment). Another exemption will be those manufacturers who themselves offer "modification-kits". However, only very few manufacturers offer such kits for older engines.

Furthermore, implementation of measures on existing engines will often alter the general performance in particular that of fuel consumption. This should be carefully considered when evaluating possibilities.

The verification of emission levels for shipboard installations are comprehensive and will incur a considerable cost. This will comply to measures introduced on existing engines. New engine installations will most often carry a compliance certificate and hence, the expense will not incur.

New engines are in compliance with the new regulations. A number of manufacturers offer special low NOx versions adopting engine internal measures or in some cases other measures.

In a case where turbine machinery is installed, emission characteristics will alter dramatically. A modern turbine machinery have from a practical point of view eliminated the NO_x issue. However, as its fuel consumption performance is weaker than that of the diesel combustion process, the contribution of Green House Gases may increase.

Reduction Measure Rating
Dependent upon the ambition in relation to the level of reductions foreseen, different approaches can be adopted. In table 3.2.5-1, the various measures discussed here have been categorised against ambition levels; low, medium and high.

Table 3.2.5-1: NOX reducing measures

Measures π	**Ambitions υ**	**Low**	**Medium**	**High**
Exhaust gas cleaning				SCR
Fuel treatment			Emulsified fuel	
Engine internal modifications		Simple measures (retarded timing, increased	Comprehensive approach combining simple measures with additional modifications	

		injection rate, etc.)	(increased combustion ratio, etc). Direct water injection	
Ambient manipulation				EGR (at present not in use) Humid Air Motor

3.3 SO_X Emissions

3.3.1 General

During combustion, fuel bound sulphur is transformed to SO_x and particularly SO_2. The SO_2 emission component is a function of the sulphur level of the fuel. Hence, the emission of sulphur is a function of the quality of fuel burned and hence, beside consumption rate, fuel quality is essential when considering this emission component.

Approximately 80% of international marine fuel consumption is heavy fuel oil products with sulphur content varying from 2.5% to 4.5%. Lighter fuel oil products contain typically less than 1.5% sulphur. Near coast and short-sea operations are increasingly adapting to the use of these “lighter” products.

The global distribution pattern concerning heavy fuel oil products and those lighter is not necessarily representative for the cruice and ferry segment. A number of companies have adopted a conscious policy of operating on low-sulphur fuels (destilates or diesel products). This is in particular true for coastal and short-sea operators.

3.3.2 Impact On The Environment

The emission of sulphur lead to acidification causing damage to forestry, impacting alkalinity of lakes and affecting agriculture in general. SO_x is corrosive and represent a threat to buildings and constructions in general. Acidification is firstly considered as being a regional pollution problem. It’s effects are similar to those of NO_x (as a contributor to acidification), se previous chapter.

3.3.3 Rules & Regulations

Existing Rules And Regulations
Sulphur is regulated in Annex VI to MARPOL. This Annex is at present not enforced as the ratification process is still ongoing (se previous chapter).
An upper limit for sulphur content in fuel is defined (4.5% m/m). Further, special requirements for special areas are identified. The special areas for SO_x emission control being:

- The Baltic Sea area
- North Sea area (recently designated by IMO (MEPC 44))
- Any other sea areas including port areas designated by IMO in accordance with applicable procedures.

For vessels travelling in such areas, one of the following apply.:

- Sulphur content of the fuel shall not exceed 1.5% m/m.
- An exhaust gas cleaning system approved by or on behalf of the national maritime administration in accordance with guidelines developed by IMO, shall be applied to reduce the total emission of sulphur oxidises from vessels including both auxiliary and main propulsion engines, to 6 g SO_x/kWh or less calculated as total weight emission of sulphur dioxide. Waste streams from the use of such equipment shall not be discharged into enclosed ports or harbours and estuaries unless it can be thoroughly documented that such waste streams have no adverse impact on such ecosystems based upon criteria provided by the port State authorities.
- Any other technological method that is verifiable and enforceable to limit SO_x emissions to a level (described in legislation). These methods shall be approved by the national maritime administration in accordance with IMO guidelines.

The sulphur content of the fuel shall be verifiable. The ship is required to document the delivery of bunker used by a bunker delivery note. This requirement is linked to a regulation putting requirements on the quality of fuel. The following apply:

- Fuel for combustion purposes delivered to and used onboard a vessel shall;
- Be blends of hydrocarbons derived from petroleum refining. This does not preclude the incorporation of small amounts of additives intended to improve some aspects of performance.
- The fuel shall not contain inorganic acids
- The fuel shall not include any added substances or chemical waste
- Details of fuel oil for combustion purposes delivered to and used on board shall be recorded by means of a bunker delivery note, which shall contain detailed data including sulphur content.
- A bunker sample is also required.

Some voluntary limitations or restrictions on SO_x emissions are also introduced in various schemes such as those discussed previously (chapter 3.2.3). These identify requirements to fuel sulphur limits (typically that of 1.5 % m/m) and allow the use of exhaust gas cleaning devices. DNV's voluntary CLEAN and CLEAN DESIGN classification notation provides for provisions also for the topic of SO_x.

Reference to part of this report which may lead to misinterpretation is not permissible.

Future Rules & Regulations
There is no activity on further regulative development internationally on enforcing regulations as such. However, IMO have decided to monitor the average sulphur content of fuels sold as international maritime bunker. This information will be used in order to adjust the maximum allowable sulphur content in future revisions of MARPOL Annex VI.

It should be noted that the current limit is not an ambitious one. In fact, in several areas of the world, it will be difficult to obtain fuel of such a high sulphur content. Present average sulphur content of fuels are at 2.9% (DNV, 1999).

An expansion of restrictions on sulphur emissions will follow the establishment of SO_x emission control areas. (Special Areas for SOx emission control). The criteria's for designating such areas reflect those of ecological, atmospheric, vessel traffic and cost effectiveness. A number of areas are expected to achieve protection by becoming a SO_x emission control area.

3.3.4 Technology

Lean Sulphur Fuels
Significant reductions of SO_x can be achieved by adopting to lighter fuel oil products. Marine bunker fuels with sulphur content as low as 0.01% m/m are available. The use of such fuels does not require the same fuel treatment installations, as is the case when operating on HFO. However, the availability of lighter fuel oil products varies around the world. Hence, a vessel equipped only to run on lighter fuels may need to plan for this.

The lighter fuel oil products are represented by distillate and diesel products. Some residual fuels may also have a relatively low sulphur level.

Sulphur Scrubbing
An alternative to fuel change is that of cleaning the exhaust gas. Processes available for such treatment differ mainly by requirements to the end product. Exhaust gas desuplhurication processes can be used for the production of sulphuric acid. Of obvious reasons, this will not be of interest for the desulphurication requirement for a vessel. Other methods are available also, the most frequently referred to being that of sea water scrubbing (returning wash-water back to the sea).

Desulphurication plants are typically found used onshore in various applications in processing industry and in power plants. Systems for onboard applications arrives from experience in these segments.

A limited number of sea water sulphur scrubbers have been fitted on board vessels with varying results. However, some of these systems claim up to 95% reduction in SO_x levels.

Reference to part of this report which may lead to misinterpretation is not permissible.

Sea water sulphur scrubbers are large expensive units. They are suitable for retrofitting on existing vessels from a practical point of view. However, they do require some reconstruction.

The use of sea water scrubbing will require the shipowner to guarantee (document) that waste streams from such use does not have any adverse impact on the ecosystem. As the use of desulphurication systems only will be an alternative in cases where particular requirement are enforced (special areas), taken into account the documentation requirement, it is unlikely that one will see these systems fitted to any great extent.
The cost of low sulphur fuel is significantly higher than that of HFO. Hence, from a cost point of view, a desulphurication system might be a preferred option.

3.3.5 Consequence Of Use Of Different Technologies

Engines designed for combusting heavy fuel oil can switch to alternative lighter fuels such as destilates or diesel products without any modifications for shorter operations. If the switch is of a permanent nature, some measure may be necessary. However, these will be of limited complexity and most likely restricted to simple adjustments.

Low sulphur fuel will incur an additional cost that might be considerable depending on the ambitions on reduction levels.

3.4 CO_2 Emissions

3.4.1 General

CO_2 emissions are an end product following any combusting process. The consumption of international bunker fuels is a major contributor to global CO_2 emission levels. There are at present no CO_2 cleaning options available.

International shipping as a whole is responsible for some 1.8% of total global CO_2 emissions (IMO, 2000).

3.4.2 Impact On The Environment

Emissions of CO_2 contribute to the "Greenhouse effect" leading to an increase the average temperature on earth. Emissions of CO_2 are a global pollution challenge and has been approached in many industrial segments for many years.

3.4.3 Rules & Regulations

Existing Rules & Regulations
Emissions of CO_2 (or CO_2 equivalents) are regulated in the Kyoto Protocol to the Convention on Climate Change. International transport modes (aviation and shipping) are in effect not regulated. However, respective international bodies (ICAO and IMO) are

Reference to part of this report which may lead to misinterpretation is not permissible.

encouraged to initiate work on the issue of CO_2 reductions. Both these organisations have initiated studies in this field.

This work has not revealed other regulations on regional, national nor local level addressing the CO_2 issue specifically.

Future Rules & Regulations
IMO have recently initiated a study (1999) responding to the request of the Kyoto Protocol. The purpose of this study is to examine possible greenhouse gas emissions reduction through different technical, operational and market based approaches. The study will include an inventory of CO_2 emissions from ships distributed geographically based upon available statistics. Further, both short and long term measures and their effect will be considered.

The Kyoto Protocol at present addresses the Annex I countries giving identified emission limits. It is assumed likely that the sources of international transport will be regulated prior to those of the Annex II countries. Hence, its should be assumed that the maritime sector will be confronted with regulations involving limits in emission levels.

3.4.4 Technology

Emissions of CO_2 are reduced by reducing specific fuel consumption. However, it is difficult to discuss CO_2 emissions isolated without also reflecting the relationships between CO_2 and NOx. High thermal efficiency is in principle required when optimising fuel consumption. At the same time, a high thermal combustion chamber regime is likely to promote for the formation of NOx. This interrelationship should be considered when evaluating alternative respective measures.

Resistance
Optimising hull shapes has been an issue for many years. The introduction of the bulbous bow, the asymmetric stern among others, have shown great improvements in both general performance as well as for efficiency. Towing tank studies recently undertaken by MARINTEK indicate clearly even further efficiency potentials claiming that power reduction requirements can be reduced in the order of 20 % by relatively minor changes to bow and/or the stern. From, this it should be evident that hull optimisation should be carefully performed early in the design planning stage.

Costs of optimising the hull design is a fixed initial cost largely independent upon the size of the actual vessel. However, the costs of building the actual changes recommended might indulge considerable costs.

Propeller Optimisation
Conventional propeller optimisation focuses on dimensions, revolutions and pitch. The state of the art propeller optimisation procedures focuses on cavitation, noise and pressure pulses. Sometimes, design restrictions may be contradictive with respect to

optimal propeller design (limitations on diameter, cavitation and loading). When focusing on optimising efficiency, reduced power requirement will become a priority propeller design parameter. This might lead to an unconventional propeller arrangement.

A potential reduction level (reflecting required power) caused by propeller optimisation is difficult to determine. However, literature has indicated some general “goal” figures indicating potential reductions for specific scenarios (vessel type/ propeller concept). For container vessels savings potential can be increased to 10%, due to the possibility of using contra-rotating propellers and/or asymmetric sterns. This might also be applicable (to some extent) to passenger vessels.

Efficiency Rating:
Efficiency rating combines a set of measures involving increased compression ratio and fuel injection modifications. The fuel injections rate and characteristics are modified by both a higher fuel nozzles opening pressure and injection pressure. An overall engine optimisation also require some minor modifications and adoptions. This may include alterations to the combustion chamber (increased compression ratio require combustion space to be changed), modifications to the piston/ connection rod and cylinder head (providing higher peak combustion pressure), turbocharger upgrade, charge air cooling upgrade and inlet and exhaust valve lift increase.

State of the art techniques based on the principles of efficiency rating on new medium speed engines and slow speed two stroke engines can offer reduced specific fuel consumption in the range of 10-12 %.

Machinery Plant Configuration
For a new vessel, alternative options for power production should be considered focusing on efficiency. The traditional configuration of a drive train with one ore more main engine(s) connected to a fixed propeller can be challenged by alternatives. The diesel electric propulsion concept is one such offering multi-engine layout providing considerable flexibility allowing (in many cases) optimal fuel consumption at different operational conditions. The diesel electric layout is in essence an electric power plant where onboard load-sharing (both for propulsion and other consumer) is managed focussing on optimising consume and hence minimising fuel consumption. The exact fuel reduction potential depends upon a number of factors and is difficult to estimate. However, considerable fuel saving can be expected on vessels in trades with significant part load operations.

Cruise/ passenger vessels are showing an increased interest in alternative machinery configurations motivated by potential machinery space reduction (more cabins), increased operating flexibility (great deal of auxiliary power needed) and increased fuel economy and environmental friendliness.

3.4.5 Consequence Of Use Of Different Technologies

All known measures aiming at reducing the emission of CO_2 is in effect related to minimising the consume of combustibles. This study has identified 4 categories of measures all representing actions improving fuel efficiency. Some of these may not be practical options for existing vessels whilst some may be introduced more widely. Further, some may introduce limitations impacting vessel functions (i.e. cargo capacity). The reduction of fuel costs represents the saving potential of these measures. The introduction of such measures will generate a cost but will vary as a function of category as well as to the specifics of the actual vessel. For a new design, all categories should be the subject of considerations.

Cruise vessels and ferries are equipped with a considerable number of “domestic” energy consumers in comparison with that of cargo-carrying vessels. Even though propulsive optimisation has a larger potential, one also includes an assessment of these consumers. The assessment of alternative machinery plant configurations should be extended to include this.

3.5 Fire Extinguishing Agents

3.5.1 General

Risk of fire is one of the major hazards in passenger and cruise ships. In addition to the threat to passengers and crew and the economic consequences, shipboard fires may also have negative effects on the environment. The basic fire safety philosophy of passenger ships covered by the SOLAS convention is twofold; to reduce the risk of a fire starting and to minimise consequences of a possible fire.

The required fire safety measures are often divided into active and passive measurements. Passive fire safety includes requirements to combustibility of materials and use of fire resisting divisions and main vertical fire zones. Active fire safety measures include fixed fire fighting systems, water fire mains systems and portable fire extinguishers. Fixed fire fighting systems are discussed in this chapter. Water fire mains systems and portable fire extinguishers in accordance with current international regulations have no negative environmental effects.

3.5.2 Impact On The Environment

Halon and CO_2 are the most commonly used fire extinguishing agents in fixed fire fighting systems of engine rooms and cargo areas in passenger ships operating today.

In the 1970s it was documented that halocarbons, like Clorofluorocarbons (CFC) used in refrigerating systems and Halons used in fire fighting systems, diffuse into the stratosphere and are broken down by photolysis to release chlorine atoms which catalytically destroy the ozone layer.

Halon 1301 has an Ozone Depletion Potential (ODP) of 13, meaning it will destroy 13 times as much ozone as CFC R-11 which is used as basis for comparisons. Based on this knowledge and recognising the results from the Montreal Protocol, IMO banned the use of Halons in ships with keels laid after 1 July 1992.

The other main area of concern is that extinguishing gases like Halon and other halocarbons are classified as greenhouse gases and may add to global warming. CO_2 is used as basis for comparisons and is defined to have a Global Warming Potential (GWP) of 1. Halon 1301 has a GWP of 5800.

The use of CO_2 as extinguishing medium is not considered to contribute to the greenhouse effect. The gas filled in fire extinguishing systems is a by-product of the process industry thereby reducing the CO_2 emissions of this industry. Water based extinguishing systems like sprinklers, water spray and water fog is considered to have no negative effects on the environment, whereas water based systems utilising foam additives have only negligible impact.

Extinguishing agents have no effect on the environment as long as they are safely stored in their respective containers. The agents are only released into the atmosphere in connection with actual fire fighting, incidental leaks or accidental releases of the systems. Limited releases of gas may also occur in connection with testing and maintenance of systems. An effective fire fighting system is important to limit overall environmental consequences of a fire on board a ship.

3.5.3 Rules & Regulations

Existing Rules & Regulations

SOLAS regulations for new passenger ships require sprinkler systems or equivalent systems to be installed in accommodation and service spaces. Car decks are required to be protected by a fixed pressure water-spraying system or equivalent system. Machinery spaces are to be fitted with a fixed total-flooding or global fire extinguishing system. Halon is not accepted used as a fire-extinguishing agent in new passenger vessels.

SOLAS regulations do not specifically state that fire-fighting gases used on ships are to have no Ozone Depletion Potential. However, no fire-fighting agent with positive ODP is being marketed in the shipping industry today and no such agent would be approved by Classification Societies like Det Norske Veritas.

DNV Clean Design class notation requires fire fighting agents to have GWP of less than 1650.

Future Rules & Regulations

A new paragraph has been added to the existing SOLAS regulations for fire fighting in machinery spaces, requiring that a fixed water-based or equivalent local application fire-fighting system is to be fitted in all passenger ships as of 1 July 2002. This system is to provide localised fire suppression in specific fire hazard areas without the necessity of engine shut-down, personnel evacuation, shutting down of forced ventilation fans or sealing of the space. The Norwegian maritime authorities have proposed to implement this requirement for Norwegian passenger ships from 1 October 2000.

Some national maritime authorities, notably Sweden, have taken initiatives in IMO to ban the use of Halon in existing fire fighting system on ships. So far there has been limited support for this internationally. A main argument against this proposal has been the lack of satisfactory facilities for destruction of Halon and a lack of satisfactory controls to avoid deliberate release of Halon to the atmosphere to evade the costs of such destruction. It has been feared that a requirement to replace all existing Halon based fire fighting systems with environmental friendly installations might actually increase harmful releases of the gas.

Apart to restrictions in DNV Clean Design class notation, the study has not revealed any existing requirement to maximum acceptable Global Warming Potential for fire extinguishing agents on ships. There are however concern regarding high GWP values for some of the agents, which are being marketed as replacement gases for Halon. It is not unlikely that future regulations will include such restrictions.

3.5.4 Technology

Carbon Dioxide

CO_2 is the most commonly used fire-extinguishing agent in engine rooms of passenger ship newbuildings today. Similarly to inert gas agents, the most important fire extinguishing mechanism for CO_2 is by reducing the oxygen concentration in the protected space and by raising the heat capacity of the atmosphere supporting the flame. CO_2 is not an inert gas because it is physiologically active and fatal at low concentrations.

CO_2 used as a fire extinguishing agent is not considered to have any negative effects on the environment. Main disadvantages with this gas compared to Halon are the relatively large storage volume and weight, and the fatal danger it implies to any people present in protected spaces. This danger may also prolong the actual release of CO_2 systems and thereby increase the consequences of a fire.

Halocarbon Gases

Halon replacement gases may be classified into two main categories:

1) halocarbon agents
2) inert gases and mixtures.

Halocarbon agents include compounds containing carbon, hydrogen, bromine, chlorine, fluorine and iodine. These agents extinguish fires by a combination of chemical and physical mechanisms.

Halocarbons can be stored and discharged from typical Halon 1301 hardware, but are less efficient with respect to storage volume and weight, produce more decomposition products and are presently more expensive than Halon 1301.

Main advantages of the halocarbon gases is that they are not normally not dangerous for people present in the protected space, and the fact that required volume and weight of these agents is much smaller than for CO_2 and inert gases.

A number of halocarbons (e.g. FM200 and Halotron) are now being marketed as replacement gases for Halon. These gases have zero ODP, bur typically fairly high GWP (e.g. FM200 has a GWP value of 2050) and lifetime. Several of these gases are type approved by Classification Societies and National Maritime Authorities. However, their high GWP values have lead to discussions regarding their environmental acceptability in the future. With respect to environmental aspects they are not the optimal fire extinguishing agents.

Inert Gas Agents
Inert gas alternatives include nitrogen and argon, and blends of these. The blend Inergen also contains a small fraction of CO_2. The CO_2 content in Inergen is carefully calculated to stimulate respiration in case of people been present in the protected space. This makes it possible for people to survive in spaces with lower concentrations of oxygen than what is possible for pure nitrogen/ argon blends.

Inert gas agents are stored as pressurised gases and therefore require substantially greater storage volume than Halon and other halocarbons. Inert gas agents are not considered to have any negative effects on the environment.

Water Based Systems
Water drencher systems are acceptable as a global fire fighting system in engine rooms according to SOLAS. However, such systems are not considered to be effective in extinguishing typical engine room fires and new installations are therefore not accepted by most mayor classification societies and National maritime authorities.

Water fog systems as a global fire fighting system in engine rooms have been approved by a number of classification societies and maritime authorities. Such systems appear to be an effective and environmentally friendly alternative for engine rooms of limited size. Cost effectiveness and possibility to obtaining satisfactory fire fighting abilities have proven much more difficult in larger spaces.

Water based systems like sprinklers or water fog systems may be used for refrigerated spaces provided satisfactory measures are taken to avoid freezing. Such measures may include anti-freezing additives or air pressurised dry-pipe sections.

Reference to part of this report which may lead to misinterpretation is not permissible.

3.5.5 Consequence Of Use Of Different Technologies

Comparisons of required weight and volume equivalents for different fire fighting agents:

Table 3.5.5-1: Fire fighting agents.

Agent	**ODP**	**GWP**	**MSIC**	**GVEq**	**WEq**	**SVEq**	**Comments**
HALON 1301	13	5800	7	1	1	1	Condensed
HALOTRON 2	0	?	12	1.6	1.2	1.5	Condensed
FM-200	0	2050	12	1.6	1.8	2.1	Condensed
CO_2	0	1	30	4.3	1.3	2.7	Condensed
NITROGEN	0	0	45	6.4	1.2	8.0	Compressed to 200 bar
INERGEN	0	0	50	7.1	1.6	44.6 (8.9)	Compressed to 40 bar (Compressed to 200 bar)
ARGON	0	0	55	7.8	2.1	9.82	Compressed to 200 bar

* INERGEN compressed to 200 bar => SVEq=8.9

ODP - Ozone Depleting Potential
GWP - Global Warming Potential(relative to CO_2 over a 100 years timespan)
MSIC - Minimum Safe Inerting Concentration (r reference c comound)
GVEq - Gas Volume Equivalent (GVEq = MSICc/ MSICr)
WEq - Weight Equivalent (WEq = GVEq x (MWc/MWr))
SVEq - Storage Volume Equivalent

3.6 Refrigeration Systems

3.6.1 General

The predominant refrigerants in use today are members of the halocarbon family of chemical compounds. Their most essential characteristic is their chemical stability, ensuring that the fluids do not decompose or react to form something else when used as refrigerants. Other traditional prime aspects relate to health and safety. Safety codes require the use of non-flammable refrigerants with low toxicity in residential and most commercial applications.

In addition to the traditional criteria, environmental considerations are today of major importance. Before the introduction of halocarbons, ammonia (NH_3) and CO_2 were commonly used natural refrigerants. These natural refrigerants almost completely disappeared from new refrigeration systems in the 1960s, as they were considered inferior to halocarbons with respect to health, safety and efficiency.

3.6.2 Impact On The Environment

Similar to Halons used in fire fighting systems, it has been documented that traditional halocarbons used as refrigerators like CFCs diffuse into the stratosphere and catalytically destroy the ozone layer. The widely used R-11 and R-12 are used as basis for comparisons of Ozone Depletion Potential and have been assign an ODP of 1.

Halocarbons are also classified as greenhouse gases and may add to global warming. CO_2 over a time horizon of a 100 years, is used as basis for comparisons and has been assigned a Global Warming Potential (GWP) of 1. R-12 has a GWP of 8500.

Refrigerants have no direct effect on the environment as long as they are contained within the cooling system. However, leaks may occur, as well a limited releases of gas in connection with testing, maintenance and scrapping of systems.

Ammonia and CO_2 used as refrigerants are considered to have none or only neglectable negative impacts on the environment.

The following table shows environmental properties for some refrigerants:

Table 3.6.2-1: Environmental properties for some refrigerants

	ODP	GWP
Natural Refrigerants		
NH_3	0	0
Propane	0	7
$C0_2$	0	1
CFCs (Chlorofluorocarbons)		
R-11	1	4000
R-12	1	8500
HCFCs (Hydrochlorofluorocarbons)		
R-22	0.055	1600
R-401 A	0.03	1025
R-402 A	0.02	2650
HFC (Hydrofluorocarbons)		
R-134 a	0	1200
R-410 A	0	2020
R-404 A	0	3520
R-407 C	0	1600

(The above figures are taken from several sources and should be understood as approximate values.)

The table above illustrates that even though HFC have no ODP they still have relatively high values for GWP.

Reference to part of this report which may lead to misinterpretation is not permissible.

3.6.3 Rules & Regulations

Existing Rules & Regulations
At a international conference in Montreal in 1987, an adaptation of a CFC protocol to the Vienna Convention culminated in the "Montreal Protocol on Substance which Deplete the Ozone Layer", which came into force in 1989 after being ratified by a sufficient number of countries. Today more than 160 countries have ratified the protocol and it has been amended several times. As a result, CFCs and Halons are being phased out in developed countries since 1996, and HCFCs will be gradually phased out by 2020.

The European Union has curtailed the phase out period further. Individual countries have even stricter requirements and have already banned HCFC in new equipment and accelerated phase out in existing systems.

Future Rules & Regulations
USA have banned the production of R-22 for the use in new installations from 2010 and completely banned it from 2020.

3.6.4 Technology

New and alternative refrigerants are being introduced to substitute the refrigerants that are being phased out.

The main groups of halocarbons are as follows:

CFCs:
Chlorofluorocarbons have chlorine content, which presents a high risk to the ozone layer. Common types include RA 1, R-12, R-500 and R-502. CFCs are being phased out completely.

HCFCs:
Hydrochlorofluorocarbons have low chlorine content and present a much lower risk to the ozone layer. Types include R-22, R-401A and R-402A. These are service refrigerants used in existing systems. These refrigerants are likely to be phased out in the future.

HFC:
Hydrofluorocarbons are chlorine free and have no Ozone Depletion Potential. Types include R-134a, R-404A, R-407C and R-410 A.

Natural refrigerants such as NH_3, Propane and CO_2 are considered the most environmental friendly refrigerants. These refrigerants are relatively low cost and are available world-wide.

3.6.5 Consequence Of Use Of Different Technologies

The drive from the refrigerant manufactures seem to be toward replacement chemical refrigerants, rather than toward the use of natural refrigerants such as ammonia and carbon dioxide. The reason for this is unclear. In the short run it will be cheaper to find alternative refrigerants that can be used with existing technology in stead of retrofitting refrigeration plants. However, these alternative refrigerants are generally much more expensive in themselves than the natural options.

Reference to part of this report which may lead to misinterpretation is not permissible.

4 DELIVERY TO SHORE

4.1 Garbage Handling

4.1.1 General

According to IMO, it has been estimated that on a cruise ship, each person generates more than 2.5 kilograms of garbage per day. On a ship carrying 3,000 passengers and crew, more than seven tonnes of garbage may be generated on a daily basis, including three tonnes of combustible waste, three tonnes of glass and one tonne of wet/food waste.

Garbage may be discharged to the sea, delivered to shore or incinerated onboard. Incineration is creating emissions to air. As such it falls into all three main pollution categories as defined in this report. For simplicity it will be viewed as one in the following.

A zero discharge to sea policy is often adopted for environmental image benefits.

4.1.2 Impact On The Environment

Floating garbage is polluting the world's oceans and beaches and is possibly the most visible effect of ship generated pollution.

Marine mammals and seabirds are strangled by fishing lines, plastic ropes and drink-can straps. Fishermen have to discard their catches when trawls are filled with all kinds of garbage. Beaches and bays are made ugly and unsafe when filled with garbage, including sewage waste and sanitary items such as used syringes. Local communities have to spend resources every year to keep beaches clean and safe in order not to lose regional incomes and jobs from tourism and recreation. Farmers cannot allow cattle to graze on shore meadows, as the animals risk getting harmed by plastic, glass or metal objects washed ashore.

Marine litter gives rise to a wide range of negative ecological impacts on the beaches, on the open sea and on the sea bottom. These effects include entanglement, ingestion, smothering, and transport of invasive species, poisoning by breakdown products and risks to human health.
Despite years of national and international efforts, legislation, beach clean-up activities and public awareness campaigns, ugly and dangerous litter is still found in large quantities on beaches, in archipelagos, on the open sea and on the seabed.

Emissions of importance from incinerators include dioxins and toxic metals. The emissions of nitrogen and sulphur oxides will be small and will be exceeded by orders of magnitude by the emissions from the engines powering the ship. Incineration carries the inherent advantage that discharges to sea are being avoided.

Garbage delivered ashore contributes negatively by adding to the garbage disposal impacts for land based disposal, but positively in a resource perspective if the garbage may be recycled.

4.1.3 Rules & Regulations

Existing Rules & Regulations
The handling of garbage is regulated internationally by MARPOL Annex V.

The discharge overboard of plastic is prohibited in all areas, whereas the discharge of other types of garbage is allowed depending on the distance from shore.

Discharge of garbage other than food waste is prohibited in special areas. The special areas are the Mediterranean Sea area, the Baltic Sea area, the Black Sea area, the Red Sea, the wider Caribbean region, the North sea area, the Arabian Gulf area and the Antarctic area. It should be noted that the Baltic Convention prohibits the use of incinerators in the Baltic Sea area.

The regulations are summarised below:

Table 4.1.3-1: Waste disposal requirements.

Waste Type	Outside Special Areas	In Special Areas
Plastics - including synthetic ropes, fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited
Dunnage, lining and packing materials	> 25 miles offshore	Disposal prohibited
Paper, rags, glass, metal, bottles, crockery and similar refuse	> 12 miles offshore	Disposal prohibited
Paper, rags, glass, etc. Comminuted or ground	> 3 miles offshore	Disposal prohibited
Food waste, not comminuted or ground	> 12 miles offshore	> 12 miles offshore
Food waste	> 3 miles offshore	> 12 miles offshore

In the US the USPH and USDA regulations apply.

MARPOL Annex V, regulation 9, requires that all garbage discharges are being registered in a Garbage Record Book. The date, time, position of ship, description of the garbage and the estimated amount incinerated or discharged must be logged and signed. The books must be kept for a period of two years after the date of the last entry.
From 1 July 1998, all ships of 400 gross tonnage and above and every ship certified to carry 15 persons or more must carry a Garbage Management Plan, to include written procedures for collecting, storing, processing and disposing of garbage, including the use of equipment on board. The Garbage Management Plan should designate the person responsible for carrying out the plan and should be in the working language of the crew.

Exhaust gas emissions from incineration are covered by MARPOL Annex VI. The requirements given here are not very restrictive at this time. The following specifications must be met:

(1) CO levels must be lower than 200 g/m3
(2) the smoke number must be below Bacharach 3
(3) Carbon in the ash must be below 10 percent.

These regulations should be met without difficulty by any modern, well-operated incinerator.

Future IMO regulations can be expected to be much more restrictive.
The Annex also prohibits the incineration on board ship of certain products, such as contaminated packaging materials and polychlorinated biphenyl's (PCBs)

According to the Helsinki Commission - Baltic Marine Environment Protection Commission - also known as HELCOM, any incineration of ship-generated wastes on board ships, irrespective of their nationality, operating in the Baltic Sea, is prohibited. (HELCOM Recommendation 14/8, Regulation 9)

Future Rules & Regulations
New areas may be included among the special areas. Local regulations exist in a number of areas like Alaska and California, and this development may well accelerate in the future.

Amendments to MARPOL have been proposed, including the statement:

"*Subject to the provisions of paragraph 5 of this regulation, incineration shall not take place*
(a) within the Antarctic area as defined in regulation 10(g) of Annex I, of the present convention,
(b) inside ports, harbours, and estuaries."

4.1.4 Technology

Integrated Garbage Management Systems
Modern waste plants onboard cruise vessels and ferries should be designed according to an integrated approach, addressing all garbage disposal needs onboard in order to obtain a balanced and efficient handling of all waste. Areas to consider are sorting, transport, pre-processing, storing, recycling and incineration.

The plant should have full redundancy, and be designed for peak loads.

Reference to part of this report which may lead to misinterpretation is not permissible.

Sorting And Re-Cycling
Sorting into garbage categories may be according to company policy or the categories that may be handled by the reception facilities ashore. Categories may be:

- Glass
  - Transparent
  - Brown
  - Green
- Metal
  - Aluminium
  - Steel
- Paper
- Special waste (Batteries, dry-clean, photo lab & other chemicals etc.)
- Plastic
- Food
- Other burnable waste

In order to minimise storage space for waste products the following may apply:

Heavy-duty vibration crushers may process glass into big bags or boxes. Glass may be separated in colours. The number of separations should be in accordance with reception facilities a shore.

Clean cardboard boxes and paper should be compacted by a heavy-duty compactor. The pressure should not be less than 15 tons. The compacted material should be strapped by the machine and ready for transportation by the ship forklift to the storage room and from there to the ship shell door.

Aluminium cans and tins should be processed by a densifier to cubicle blocks.
The pressure should not be less than 30 tons.

A procedure for rinsing out contaminated cans should be done before being densified.

Clean plastics should be processed to a roller or in a melting machine.

A substantial part of the garbage of the various categories may be contaminated by food. Contaminated garbage must be cleaned prior to re-cycling and/or stored in a refrigerated odour-proof room prior to delivery to shore.

Incineration
The waste to be incinerated consists mainly of paper, plastic, wood, clothes, oily rag, sludge oil, food waste, hospital waste and swipe from public areas and cabins. Solids dried from the sewage plant may be included as well (section 2.1).

Paper and cardboard are also in increasing amounts being compacted and recycled for reasons of resource savings. Contaminated paper, cardboard and plastic should be incinerated. Hospital waste must be handled as infectious waste and be disposed of without mixing with other general waste.

The incinerator should be of the high temperature type and provided with access door for manual disposal of such waste directly into the primary combustion chamber.

The incinerator should be equipped with separate sludge oil burner. The sludge oil has to be heated up to 70-80 ^{o}C and homogenised before burning.

The incinerator can have an automatic feeding and ash discharge system, which enables the incinerator to operate continuously with full load 24 hours/day if needed.

For clean handling, ash can be transported directly into sealed one way bags for storing and later on for disposal onshore. When only burnable materials are fed into the incinerator, the reduction in volume will be as much as 95% given that resident time in the incinerator is be long enough to assure that all organic waste are burned out to less than 3% by weight (unburned components). The ash is normally classified as toxic and should be disinfected and compacted.

Flue Gas Cleaning
All parameters for O2 - CO - CO_2 - temperatures and number of soot particles in flue gas can be monitored.

Proven technology for flue gas cleaning is available, and has been used for onshore plants as well as in the cruise industry. This advanced technology is particularly effective in removing acid-forming gases such as HCL, SO_2 and HF with a cleaning capacity exceeding 99% and it limits noxious flue gas and fly ash.

The US EPA Clean Air Act and the European standards 17th BImSchV as well as the IMO Annex VI are available standards. The latter is considerably less strict than the two former.

U.S. Environmental Protection Agency (EPA) guidelines (U.S. EPA, 1994) place limits on the following materials: particulates, cadmium, lead, mercury, sulphur dioxide, hydrogen chloride, and ash as given below:

Table 4.1.4-1: EPA Guidelines for Air Emissions from Incinerators

Emission	Existing Plants	New Plants
Particulates	69 mg/dcsm	15 mg/dcsm
Opacity	10%	10%
Cadmium	0.1 mg/dcsm	0.01 mg/dcsm
Lead	1.6 mg/dcsm	0.10 mg/dcsm
Mercury	0.08 mg/dcsm	
Sulfur dioxide	80 ppmv	30 ppmv or 80% reduction
Hydrogen chloride	250 ppmv or 50% reduction	30 ppmv or 95% reduction
Fly ash/bottom ash	No visible emissions from buildings, ash transfer points, or ash-handling areas	

The allowable organic emissions (measured as dioxin/furan) is 60 ng/dscm total mass or 1.0 ng/dscm dioxin/furan toxic equivalent.

Table 4.1.4-2: Waste pre-treatment & Incineration

Type of Waste	Pre-treatment	Destruction
Food waste	Dewatering	Incineration
Black water[1]	Biological treatment/ Dewatering	Incineration of sludge
Grey water[2]	Dewatering	Incineration of residue
Bilge water	Oil separation	Incineration of oil
Oily rags	–	Incineration
Medical waste	–	Incineration
Paper	–	Incineration
Plastic	–	Incineration

[1] Black water is human waste from latrines and urinals.
[2] Grey water is the effluent from showers, sinks, laundry, dishwashers, the galley, the scullery, and so on.

Food Waste Treatment
The amounts of food waste onboard a cruise vessel makes treatment onboard necessary. Treatment equipment may include pulpers, disposers, water extractors and pulper water treatment.

Pulper water is biologically treated due to odour and build up of grease of pipelines.
The processing water for extractors is collected in an economising tank for re-circulation. The drain from the economising tank is connected to a grease trap and from grease trap to grey water or black water tank.
Food waste can be injected to the incinerator by a pump.

Operational Aspects

Purchasing
Environmental aspects needs to be considered during the purchasing of goods, food, etc. in order to avoid excessive packaging and waste accumulation. As an example the use of butter in plastic portion packaged generates indefinitely more garbage than the use of butter in bulk.

Excessive packaging material may also be removed ashore before boarding the ship in the first place.

Routines
Efficient routines need to be implemented in order to streamline the operation. These should be documented in a Garbage Management Plan which should include written procedures for collecting , storing, processing and disposing of garbage, including the use of equipment on board

4.1.5 Technologies For The Future

It is clear that a number of candidate techniques are available for the destruction of waste. Products of the various methods are similar. Control of noxious compounds can be handled in each method. Present models do not appear to be competitive with incineration in the area of shipboard waste disposal, but further development and demonstration projects are under way that could change the picture.

Table 4.1.5-1: Future Waste Disposal Technologies:

Attribute	Supercritical Water Oxidation	Molten Metal Technology	Plasma Arc Thermal Conversion Technology	Vitrification	Molten Salt Oxidation
Status of technology	One commercial plant operating ashore.	Commercial plant construction has begun for chemical and nuclear wastes	Technology being marketed for commercial applications to waste disposal	Mature technology Pending municipal waste stream demo with industry Application development required.	Small-scale use since 1950s Large R&D program in 1990s DOD and DOE mixed waste
Process versatility	Solids pumpable as slurry Organics destruction Inorganics	All shipboard solid waste can be processed Concentration of liquid waste	All shipboard solid waste can be processed Concentration of liquid waste	Concentration of liquid waste streams required Shred solids Large	Combustible solids Organic liquids

	decontamination and concentration	streams required Shred solids	streams required Shred solids	capacity possible	
Process density	0.5 to 1.4 lb/h/ft^2	Not known	0.5 to 1 lb/h/ft^2	100 to 300 lb/h/ft^2 organics 15 to 30 lb/h/ft^2 inorganics	Not known
Ship system demands	Cooling water Electric power Discharge pump (brine) Ventilation Fresh water feed	Cooling water Electric power Ventilation Stack gas treatment	Cooling water Need inert gas Ventilation Stack gas treatment Electric power	Cooling water Ventilation Need stack gas treatment Electric power	Salt resupply Low-pressure air or oxygen Cooling water Ventilation Stack treatment Fuel/electricity for start-up
Ship motion effects	Manageable	Need design development to minimise effects of ship motion on molten pool	Need design development to minimise effects of ship motion on molten pool	Need design development to minimise effects of ship motion on molten pool	Need to minimise effects on molten salt pool
Process sensitivity	Streams that result in salt formation require additional in-reactor technology	Must be maintained molten, or long start-up required Unknown	High temperature must be established but can be accomplished quickly Unknown	Must be maintained molten, or long start-up	Keep molten salt or extended start-up Salt disposal
End products	CO_2 H_2O N_2 Solid salts possible Metal ions	Combustible gas (fuel gas) HCl Slag Volatile metals	Slag Stack gas Combustible pyrolysis gas	Vitrified solid (glass) Stack gas Must burn off combustible gas (fuel gas) Combustible pyrolysis gas	CO_2, H_2O, N_2, O_2 Salt particulates Spent salts
Process safety	High pressure water/steam May require injection of caustic High pressure O_2	Very high temperatures Handling of hot slag Flammable product gases	Very high temperature High voltage Molten slag Flammable product gas	Very high temperature Handling of molten glass product Flammable product gas	Hot molten salt Possible superheated vapor explosion Spent salts
Projected reliability	High pressure slurry feed	Unknown	Unknown	Few moving parts High	Unknown

	pump Reactor materials (corrosion) Vessel cleaning of scale/salts			temperature risks	
Projected maintainability	Mechanically able to service anticipated equipment Vessel life from corrosion standpoint unknown	Unknown	Unknown	Unknown	Unknown
Projected controllability	Auto control can be applied Control temperature pressure and effluents	Unknown	Development needed Shutdown not a problem	Not complicated	Unknown

4.1.6 Consequence Of Use Of Different Technologies

Costs
A zero discharge to sea policy does involve additional costs, as additional processing of some sort is required. Flue gas cleaning to the highest standard carries additional costs.

Gains
The direct environmental gains are obvious in a sense that pollution of the sea with garbage is avoided altogether. From an image point of view this is probably very important as the dumping of garbage overboard is generally considered by the public and hence customers as highly undesirable.
The heat produced by incineration may be used onboard.

Breach of dumping regulations may carry heavy fines and massive negative publicity, as experienced in a recent case in the US.

5 PREVENTIVE DESIGN

5.1 General

Safe shipping has up to now been considered as a question of avoiding situations where personal injury or damage to property is a consequence of critical situations.

Whilst this of course is still the case focus has increased also on avoiding damages to the environment. When introducing the term “Preventive Design” the intent is to identify further measures to:

- Reduce the likelihood of accidents
- Reduce the consequences should an accident occur

Typically the following incidents/accidents lead to pollution having an impact on the environment:

- Operational accidental spills
  Bunkering may be a critical operation with local impact should an accident occur. In addition the publicity will often be substantial since the spill will take place within the harbour limits, even if the amount of oil and consequently the overall environmental impact is limited.

- Stranding and collision
  The typical maritime accident is stranding or collision with another ship, pier, or similar. Such accidents will very often lead to rupturing the ship’s hull resulting in spillage of fuel oil, and where relevant to spillage of cargo, whether this is oil or dry-cargo. Dependent on the situation such accidents may also result in fires.

  The typical oil spillage has major local impact in the time following immediately after the accident. The oil spill will first of all cause damages to sea birds and coastline vegetation. Further will both the oil on the water and future contamination of fish may cause problems and be damaging for the local fisheries.

- Other accidents
  Ships can be prone to accidents similar to those found in land-based industry, e.g. fire and explosion caused by welding or other hot work, electrical failures, etc. Fires and release of gases may have a dramatic local impact, but generally with limited duration until the fire is extinguished. Such accidents are not subject for detailed evaluation in this report.

Reference to part of this report which may lead to misinterpretation is not permissible.

5.2 Accident Prevention

Accidents will happen as a consequence of a situation developing beyond the control of the responsible persons, or as stated in Webster's Dictionary:

"An unfortunate event resulting especially from carelessness or ignorance".

In the maritime industry it is generally anticipated that the professional, well-educated, operators will take due care of the vessel and the operations in a responsible manner. The education is regulated by national and international legislation and certificate requirements. Even with the best education the work environment and available tools is important for the operators to have best possible control, and hence reduce possibilities of misjudgement and accidents. It is, however, not within the scope of this report to extend the human element further.

Should an unwanted event develop despite actions to improve the work environment it will be beneficiary to build in second barriers for avoiding a negative development of the event, or for reducing the consequences.

5.2.1 Rules & Regulations

When excluding statutory rules having regard to taxation purposes, rules and regulations in the maritime industry have historically aimed at increasing the overall safety.

Existing Rules & Regulations

International Regulations
United Nations through their International Maritime Organisation, IMO, administers the main international regulations for the maritime industry. The rules cover both technical issues built into the ship and knowledge and education requirements for the maritime personnel.

National Regulations
In addition to the international legislation some countries have introduced their own, national, legislation. The national legislation may be interpretations of the IMO regulations, or additional requirements for the local areas.

Classification Societies
Classification societies have developed rules both for the design, construction and operation of ships. The rules give basic requirements to ensure that operation of the ships can be carried out with a defined minimum level of safety, both with regard to personnel, the ship with cargo and the environment.

In addition to the basic rules classification societies have additional, voluntary, class notations enhancing focus on special services carried out by the vessel in question, or to enhance focus on special subjects. Det Norske Veritas has for instance introduced Environmental Class including two separate class notations, CLEAN and CLEAN DESIGN, suited to enhance measures for environmental protection.

Future Rules & Regulations
There has not been flagged any new, coming, international rules or regulations for passenger vessels within the IMO/MARPOL frame of rules related to external accident prevention.

SOLAS Amendments May 1994 specify that in order to prevent ignition of fires onboard ships constructed before 01.07.98 stricter requirements for protection of oil fuel lines (jacketed piping for high-pressure pipes, insulation of surfaces with temp. above 220 ^{o}C, screening).

5.2.2 Technology

There is a continued development of technology used to reduce accident probability, and parts of the shipping industry has already implemented several solutions such as:

- Improved process control of machinery systems, incorporating both propulsion and power generation systems
- Use of diesel electric propulsion systems giving increased flexibility also in respect of redundancy in critical situations
- Improved navigational aids, including satellite navigation, electronic charts, better radars with collision warning systems, etc.
- Technology and knowledge applied on human factors through increased awareness of the importance of man-machine communication and working environment. This is in particular important for control tasks like navigation, manoeuvring and external communication in critical situations.

5.3 Machinery Systems

On ferries and cruise vessels machinery systems applied in the later years have through a development enhancing both the flexibility to run the machinery in an efficient manner, and to improve reliability.

Some vessels are designed and built with fully independent machinery and propulsion plants, giving a redundant machinery system. Other vessels are arranged with a less sophisticated systems, but still such that a minimum of power is available at all times.

The following, whether alone or in combination, are often seen implemented on modern ferries or cruise vessels:

- Fuel system:
  Separate, and independent, fuel storage systems with procedures to use one system at a time to avoid problems caused by possible contamination of the fuel.

Reference to part of this report which may lead to misinterpretation is not permissible.

- Electric Power Management:
  With recent installations power failures, "black out", is steadily less likely.
- Propulsion lines:
  On modern ferries or cruise vessels dual propulsion systems is often seen, whether direct coupled to multi engine systems through a gear box, or electrically driven.
  In some vessels omnidirectional thrusters are used instead of the traditional tunnel thrusters for manoeuvring purposes. In emergencies these thrusters can even give sufficient power to at least keep the ship up against the weather and propagate at low speed, a so-called "take me home device".

5.4 Bridge, Navigation And Manoeuvring Equipment And Arrangement

Modern technology has improved the possibilities to control the ship's operations, in particular with respect to position finding, course setting, etc., through satellite navigation systems. In addition these new systems have often implemented new technology for man-machine communication.

By careful arrangement of the bridge control will be improved through efficient communication, improved field of vision, etc.

Manoeuvring possibilities of ferries and cruise vessels is often found far better than on other ships through implementation of efficient propulsion systems and thruster types.

5.5 Hull/Arrangement

5.5.1 General

Ferries and cruise vessels will, in case of an accident, constitute a smaller pollution hazard than many other ships, at least in the context of total volume. Since ferries and cruise vessels often trafficate narrow waters an accident may have significant local effect. Several ferries and cruise vessels are therefore seen with fuel oil tanks in a protected location away from the side shell.

5.5.2 Consequence Of Protected Location For Oil Tanks

With oil tanks arranged in a protected location it will be avoided that low energy collisions or stranding result in oil spills of any significance.

It should, however, be noted that also in case of a stranding where no oil spill has been observed initially the inner hull may be damaged from wave action and ship motion if the ship is not salvaged in due course.

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