Green Ship Technology Book

Existing Technology by the Marine Equipment Industry: A Contribution to the Reduction of the Environmental Impact of Shipping
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Disclaimer

This ‘book’ has been written with the aim of showing what the industry can deliver in terms of technology to benefit the environmental impact of ships. EMEC has done its best to ensure that errors factual or otherwise, misquotation, misinterpretation, etc. have been omitted from this ‘book’. The EMEC Working Group for Environment / EMEC have checked the accurateness of the document at the date of printing and decline any responsibility for errors which might still remain herein.

We have appreciated that the compilation of such a document has been a huge task and EMEC would like to thanks all those who have participated with contributions. It must be remembered that this ‘book’ is only a first version and will be subject to regular redrafts. If anybody has any suggestions/ comments/ changes they would wish to make for the following publication please contact the secretariat of the Working Group for Environment and Climate Change:
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A PDF version of this document is also available at http://emec.eu/green

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Shipping is the primary means of transport worldwide. We, in Europe, rely on it for goods and travelling from one corner of our continent to the other. Today’s globalised world trade would not be able to function without ships, after all approximately 70% of the earth’s surface is covered by water.

Considering the staggering percentages of world trade vessels transport (80%), it is remarkable to note that shipping is already the most environmentally friendly mode of transport and that emissions emitted from ships are small (3%). Operational pollution has been reduced to a negligible amount. MARPOL 73/78 is the most important set of international rules dealing with the environment and the mitigation of ships pollution, it has dealt with certain issues. However, there have also been considerable improvements in the efficiency of engines, ship hull designs, propulsion, leading to a decrease of emissions and increase of fuel efficiency.

The environmental footprint of shipping has been significantly improved through inputs from the marine equipment industry, which adopts a holistic approach when looking at the maritime sector. The equipment suppliers are a valued contributor and innovator within the maritime cluster.

The shipbuilding sector encompasses the shipyards and the marine equipment manufacturers including service and knowledge providers. The European marine equipment industry is the global leader in propulsion, cargo handling, communication, automation and environmental systems.

WHAT IS MARINE EQUIPMENT?

The marine equipment sector comprises of all products and services necessary for the operation, building, conversion and maintenance of ships (seagoing and inland waterways). This includes technical services in the field of engineering, installation and commissioning, and lifecycle management of ships. The value of the products, services and systems on board a vessel can exceed 70% (85% for cruise ships) of the value of a ship.

The production ranges from fabrication of steel and other basic materials to the development and supply of engines and propulsion systems, cargo handling systems, general machinery and associated equipment, environmental and safety systems, electronic equipment incorporating sophisticated control systems, advanced telecommunications equipment and IT. Thus the marine equipment industry supports the whole marine value chain and stakeholders: from the port infrastructure and operation to the ship/shore interface, shipbuilding and ship maintenance.

THE MARINE EQUIPMENT INDUSTRIES ENVIRONMENTAL OBJECTIVES

A large part of the improvements in the environmental footprint of shipping is achieved through the efforts of the European marine equipment industry.

A major challenge for the industry today is to ‘transfer technology’ from laboratories to ships, in order to reduce harmful emissions and obtain the benefit to wider society. Investments in upgrading older ships are necessary to make them ‘greener’ and more efficient also in view of setting a benchmark for future new-buildings.

A short term objective for the marine equipment sector is to be able to improve energy efficiency of ships by around 30%. In the medium to long term it has been estimated that a ship’s energy efficiency can be improved by 60%. These ambitious targets can, however, only be achieved by a continuous innovation process and through increased cooperation between the actors within the maritime cluster.

DEVELOPMENT OF GREEN MARINE EQUIPMENT:

Shipping has proved to be an efficient mode of transport throughout history: cutting journey times, building larger vessels to carry more goods, and moving to the combustion engine from the age of steam.

Ship-owners, in particular European ones, in cooperation with European shipbuilders (yards and marine equipment) have opted for efficient and high tech products; this is why the European marine equipment sector is now globally one of the most advanced and innovative, although much more can be achieved. There is already technology existing to help mitigate the environmental impacts from ships. The
equipment manufacturers have to maintain levels of investment for new technologies, especially in the present economic climate.

Future regulation for the ‘greening’ of shipping is likely to be adopted at international level in the very near future. This could provide a benchmark for further innovation and ensures a high level of technical design resulting in better products.

**Green Ship Technology Book**

The aim of this book is to provide the reader with a look at currently existing green technology and the impact it has on the environment from a neutral standpoint. Further developed it could provide a benchmark for the current capabilities of technology and if integrated onboard vessels show what they could achieve above and beyond current regulatory requirements. If this technology could be integrated in today’s ships then they could become 15-20% greener and cleaner. If there is further demonstration of newly researched and developed technology then a 33%+ eco-friendliness could be achieved ultimately leading to the zero emissions ship in the not too distant future.

There are 7 issues that should be taken into consideration when talking about reducing the environmental impact of vessels:  

1. **Reduction of Gas Emissions (NOx, CO2, SOx, Soot, Smoke and Particulate Matter)**;  
2. **Ship Waste Disposal**;  
3. **Bilge Water Treatment**;  
4. **Black Waste Water Treatment**;  
5. **Grey Waste Water Treatment**;  
6. **Ballast Water Treatment**;  
7. **Underwater Coatings**.

Each topic will be dealt with separately and broken down into subcategories:  

- Legal Basis;  
- Problem Statement;  
- Possible Solutions.

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1 This is a preliminary list of topics dealing with air and water emissions
1. Emissions
1.1 Emissions / SO\textsubscript{X}

1. **Legal Basis**: MARPOL 73/78 Annex VI 
   Directive 2005/33/EC

2. **Problem Statement**: SO\textsubscript{X} emissions can cause acid rain in coastal areas having a detrimental impact on the environment. SO\textsubscript{X} as a product of combusting fuel oil can be reduced by decreasing the sulphur content in the fuel supplied to the vessel. Reduction of SO\textsubscript{X} can be achieved by the after treatment of the exhaust gases from engines and boilers via cleaning. The sulphur content of fuel influences the emissions of particulates. Less sulphur means less particulate matter (PM).

3. **Possible Solutions**: Increased use of fuels with low sulphur content.
   
   Adopting Dual-Fuel-Engines so that a ship could use heavy fuel oil (HFO) on the high seas. In certain coastal areas, entering and/or leaving harbours, the main engines are then driven by Liquified Natural Gas (LNG).

   3. SO\textsubscript{2} – scrubbers can also remove SO\textsubscript{2} from exhaust with or without the help of seawater or in a closed loop system by the addition of chemicals. Scrubbers have been proven to reduce SO\textsubscript{2} emissions by >85%.

   4. Systems which can capture exhaust especially when a ship at berth can also impact the amount of SO\textsubscript{2} emitted, a reduction of >95%.

   5. Waste heat recovery systems can convert energy from ships exhaust gases from propulsion into electrical power for use on-board vessels. These systems can generate significant savings in fuel consumption from the main engine and reduce SO\textsubscript{2} from the main engine’s exhaust being released into the atmosphere.
1.2 Emissions / NO\textsubscript{X}

**1. Legal Basis:** MARPOL 73/78 Annex VI

**2. Problem Statement:** NO\textsubscript{X} emissions contribute to acid rain. A reduction of NO\textsubscript{X} emissions will contribute to better local air quality in coastal areas.

**3. Possible Solutions:** Some measures which could be implemented to reduce these emissions by enhancing the combustion system in ships are:

- Miller Cycle;
- 2-Stage Turbocharging;
- Fuel injection equipment (fuel injection valves and combustion pumps).

There are several technologies that lower the temperature of combustion, e.g. by injection of water that can reduce the emissions of NO\textsubscript{X} from ships resulting in a positive impact on the environment:

- Humid Air Motors;
- Direct Water Injection;
- Exhaust gas recirculation;
- Fuel-Water Emulsification.

Other technologies such as

- Exhaust Gas After Treatment Technologies: These technologies have been proven capable of reducing emissions from engines sufficiently to meet new regulation standards;
- Waste heat recovery systems can also substantially reduce the levels of NO\textsubscript{X};
- Electronically Controlled Camshaft less Engines, Turbochargers, common rail technology, valve control and optimised combustion processes can all achieve positive reductions of NO\textsubscript{X} emissions from ships.
1.3 CO₂

1. **Legal Basis:** At present, there is no any legal obligation to reduce CO₂ in shipping. The MEPC of the IMO is working to ratify the so called ‘Energy Efficient Design Index’² Further measures such as market based instruments are also being discussed in order to provide a basis for the reduction of CO₂ emissions.

2. **Problem Statement:** CO₂ is one of the gases which cause global warming. Reduction of CO₂ emissions is necessary for climate reasons.

3. **Possible Solutions:** CO₂ emissions are a direct result from thermal combustion of fuel. This means that the most substantial effect would be cutting energy consumption, i.e. by reducing speed. Further research and utilising the following processes allow for a further decrease of CO₂ and other emissions to be achieved:

   - **Hybrid Auxiliary Power Generation:** A hybrid auxiliary power system usually consists of a fuel cell, diesel generating set and batteries. The intelligent control system balances the loading of each component for maximum system efficiency. This system can also accept other energy sources such as wind and solar power. If such a system could be introduced a significant reduction of CO₂, NOₓ and particulates could be achieved.

   - **Change of Fuel Type:** Liquefied natural gas.

   - **Alternative propulsion:** A kite on the bow of a ship can use wind energy to give the ship and added means of propulsion. The average tanker could save approximately up to 20% of fuel depending on route and wind conditions. Kite technology, as a result of its compact size could easily be retrofitted onboard existing ships. It has also been argued that kites could be used alongside conventional means of thrust contributing to hybrid propulsion. By having such high fuel efficiency ships would need to burn less resulting in a reduction of CO₂ and other harmful emissions.

² For the position of EMEC please refer to its EEDI position paper.
Applying a so called Waste Heat recovery / Booster system into the ship could provide a significant extension to the traditional operation profile of conventional ship propulsion. This allows for up to 12% savings on primary energy (fuel) and hence CO₂. This solution would require a different approach to conceptual design and operation.

‘Cold Ironing’ (ship-to-shore power): When ships are in port they are able to connect to shore-side electrical power after the engines have been switched off. This enables ship systems to operate from clean power supplies to eliminate airborne emissions in harbor.

**Waste heat recovery:**

**Hydrogen (Fuel Cell) Systems:** Equipment manufacturers and academic institutes are well under way with research and demonstrations of hydrogen fuel cells as an alternative means for powering ships. It has been suggested that hydrogen systems could be up to 50% more efficient than existing engines, also mitigating certain emissions (NOₓ, SOₓ and particulate matter). This would also lead to a certain reduction of CO₂ emissions.

**High Efficient Marine Systems:** Marine systems such as rudders can generate about 5% of the ships overall resistance. Rudders exist which are manufactured using state of the art technologies and materials reducing their resistance through water giving the average fuel saving of 2-5%, thereby reducing emissions.
1.4 Soot, smoke and particulate matter

1. **Legal Basis:** MARPOL 73/78 Annex VI – Particulate matter is part of the legislation. Soot and smoke is not covered.

2. **Problem Statement:** The composition and properties of particulates varies greatly and is therefore difficult to define. At present, a quantitative relationship between the smoke opacity and the particulate emission has not been proven.

3. **Possible Solutions:** The most effective method of reducing particulate emissions is to use lighter distillate fuels. Additional reductions in particulate emissions can be achieved by increasing the fuel injection pressure, by using cyclone separators or electrostatic precipitators. Wherever technology is implemented to reduce Sulphur will have a direct impact on the reduction of particulate matter. This is because particulate matter reduction is a side process of sulphur removal or exhaust gas scrubbing.
1.5 Current Emission Legislation

<table>
<thead>
<tr>
<th>Air Pollutants</th>
<th>Technology to reduce emissions</th>
<th>Legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse gases</td>
<td>CO₂, CH₄, N₂O, NOₓ, CO, SF₆</td>
<td>Amended regulation 12 to the MARPOL Annex VI of the MEPC of the IMO, 57th session, 2008</td>
</tr>
<tr>
<td>Particulates</td>
<td>PM₁₀</td>
<td>Amended regulation 14 to the MARPOL Annex VI of the MEPC of the IMO, 57th session, 2008</td>
</tr>
<tr>
<td>Ozone precursors</td>
<td>NOₓ</td>
<td><strong>UNECE 2007</strong> loose international regulation on maritime engines and fuels <strong>Amended regulation 13 to the MARPOL Annex VI of the MEPC of the IMO, 57th session, 2008</strong> NOₓ regulations for new engines - MEPC agreed amendments for the three-tier structure for new engines (final approval expected in October 2008)</td>
</tr>
<tr>
<td>VOCs</td>
<td>Oxidation catalysts</td>
<td><strong>Regulation 15 to the MARPOL Annex VI</strong> - Draft guidelines for the development of a VOC management plan were approved, with a view to adoption at MEPC 58th. The purpose of the VOC Management Plan is to ensure that the operation of a tanker, to which regulation 15 of Annex VI applies, prevents or minimizes VOC emissions to the extent possible. <strong>NOₓ Technical Code</strong> The MEPC approved draft amendments to the NOₓ Technical Code, to give a revised NOₓ Technical Code 2008. The draft amended NOₓ Technical Code, includes a new Chapter 7 based on the agreed approach for NOₓ regulation of existing (pre-2000) engines established in the draft amended MARPOL Annex VI. The draft amended NOₓ Code includes provisions for direct measurement and monitoring methods, a certification procedure for existing engines, and test cycles to be applied to Tier II and Tier III engines.</td>
</tr>
</tbody>
</table>
2. Ship Waste Treatment

1. **Legal Basis:** MARPOL 73/78.- Annex V
   
   Directive 2000/59/EC

   The definition of garbage is as follows:

   **Garbage includes all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of the vessel and liable to be disposed of continuously or periodically.**

   The annex totally prohibits the disposal of plastics anywhere in the sea, and severely restricts discharge of other garbage from ships into coastal waters.

2. **Problem Statement:**

   The main problem is that the disposal of garbage occurs to a large extent out of the public eye.

   70% of ships garbage immediately sinks to the bottom of the ocean. Rather often, rubbish such as bottles and receptacles with openings, can lead to the death of fish and other marine organisms. 15% of garbage is washed up on the shore.

   The remaining 15% floats on or just under the surface of the sea. Often this rubbish comes together and forms large ‘garbage islands’. These ‘islands’ can grow uncontrollably as a result of the sea currents picking up more rubbish. They are also used by countless animal species as a means of transport. Sensitive ecosystems, for example, in the Polar Regions, can be put at risk as result of these floating ‘islands’ and the alien organisms being carried by them.
Waste discharge into the sea is allowed by MARPOL under certain conditions. The discharged waste has to be noted down, in a waste disposal log stating the following information:

- The type of discharged waste;
- The amount of discharged waste;
- The time and position of discharge.

<table>
<thead>
<tr>
<th>TYPE OF WASTE</th>
<th>DISCHARGED OUTSIDE THE SPECIAL MARITIME AREAS</th>
<th>DISCHARGED INTO THE SPECIAL MARITIME AREAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic materials such as rigging, netting, plastic bags, etc:</td>
<td>FORBIDDEN</td>
<td>FORBIDDEN</td>
</tr>
<tr>
<td>Floating materials such as cork, foam, packaging, etc:</td>
<td>Allowed with an offshore distance of ( \geq 25 \text{ nm} )</td>
<td>FORBIDDEN</td>
</tr>
<tr>
<td>Metal, paper/card, Stoneware, Glass, etc:</td>
<td>Allowed with an offshore distance of ( \geq 12 \text{ nm} )</td>
<td>FORBIDDEN</td>
</tr>
<tr>
<td>Other waste: incl. Metal, paper/card box, stoneware, Glass, etc: broken or crushed with a thickness (&lt; 25 \text{ mm} )</td>
<td>Allowed with an offshore distance of ( \geq 3 \text{ nm} )</td>
<td>FORBIDDEN</td>
</tr>
<tr>
<td>Food remains, not broken down:</td>
<td>Allowed with an offshore distance of ( \geq 12 \text{ nm} )</td>
<td>Allowed with an offshore distance of ( \geq 12 \text{ nm} )</td>
</tr>
<tr>
<td>Food remains, broken down:</td>
<td>Allowed with an offshore distance of ( \geq 3 \text{ nm} )</td>
<td>Allowed with an offshore distance of ( \geq 12 \text{ nm} )</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>In the case of mixed waste stricter regulations apply.</td>
<td>In the case of mixed waste stricter regulations apply.</td>
</tr>
</tbody>
</table>

Table: Discharge figures for waste from MARPOL Annex V

3. **Possible Solutions:**

There are currently technological solutions that could be implemented and further developed to ensure that waste is no longer discharged at sea. Due to limited space onboard ships, the equipment manufacturers have developed various methods of waste treatment.

**Waste Compressors:** They reduce the volume of rubbish so that it can be stored onboard before being offloaded to shore based facilities. This can be done by simply squeezing and breaking down waste followed by the process of compression. This might it difficult to be recycled further. Compressing and storage of waste is an effective technical solution to dealing with the rubbish being thrown overboard.

**Plasma Technology:** Plasma technology used in conjunction with other onboard systems is another example of effective garbage disposal.

Plasma, which can reach temperatures of up to 6 thousand degrees centigrade, can reduce waste into a non toxic sludge. The complex compounds which make up plastic, etc. can be reduced into hydrogen and carbon dioxide.
3. Bilge Water Treatment Systems

1. **LEGAL BASIS:** MARPOL 73/78, Annex I

Oil has a detrimental impact on the environment especially at sea. This does not just mean that catastrophic tanker disasters are the only source of oil that is damaging but also legally discharged oily based effluent from ships.

2. **PROBLEM STATEMENT:** The amount of resources required for high viscosity (heavy) fuel oil treatment, with its deteriorating quality, is of concern because of its environmental impact, manpower and engine lifetime. At times expensive measures are used to improve fuel handling, combustion characteristics and emissions that negate the low cost of heavy fuel oil.

The quality of fuel is a problem. When ships use the lowest grade of fuel in existence and therefore it needs a lot of treatment before it can be used in the engines. This is problematic because fuel has a certain amount of water in it and some very heavy fuel molecules. This is separated via ‘separators’ and the two components are removed. After this process a mixture of water and oil remains, called sludge. This ‘sludge’ cannot be used for anything and depending on fuel quality an average ship can produce from a few litres up to several tons of the stuff a day. This ‘sludge’ can also not be burned in an incinerator. Due to the fact that ship-owners have to pay to discharge this ‘sludge’ at shore-based facilities, they usually try to reduce it to a minimum. One way of doing this is to put it in a settling tank and pump out the water which settles under the layer of oil. This water can then be pumped overboard via the 15 ppm bilge water treatment system. This is where the process could go wrong and that part of the oil is pumped overboard also, via this bilge water treatment system.

The discharge of oil can be broken down as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Annual Discharge</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilge Oil and fuel</td>
<td>252,000 tons</td>
<td>45%</td>
</tr>
<tr>
<td>Ship repairs</td>
<td>4,000 tons</td>
<td>1%</td>
</tr>
<tr>
<td>Tanker accidents</td>
<td>121,000 tons</td>
<td>22%</td>
</tr>
<tr>
<td>Damages (without tanker)</td>
<td>20,000 tons</td>
<td>4%</td>
</tr>
<tr>
<td>Tanker, normal exploitation</td>
<td>158,000 tons</td>
<td>28%</td>
</tr>
</tbody>
</table>

Table: amount of discharged oil
Bilge water can be pumped through a piping system into a bilge water holding tank or directly into the sea through a bilge water de-oiling installation. Over the years the composition of bilge water has changed, due to the fact that different oils and fuels are being used. Bilge water is a mixture of different substances and has constantly changing concentrations.

The following substances can be found in bilge water:

- Leaked condensed and coolant water;
- Oil from various sources: Lubrication, gear oils, hydro system liquids, etc;
- All kinds of fuel: diesel, fuel oil, heavy with different viscosity;
- Dirt and paint particles;
- Corrosion protection agents.

### 3. Possible Solutions:

One possible solution to treat bilge water effectively is by starting at the source. Cleaner fuel would result in less sludge and therefore less oil pollution. Clean fuel would mean less air pollution and less oil pollution, having a positive impact on the environment on more than one level.

There is very effective technology currently available on the market to clean bilge water before it is discharged into the sea:

#### High Speed Centrifuges:

They are capable of effectively separating emulsions and removing suspended particles found in bilge water. Once separation of water and oily constituents has been achieved by centrifugal force, the water can be discharged into the sea and the oily remains fed into a tank to be treated at a later stage.

Technologies using the process of microfiltration are already in existence to clean bilge water. Membranes are used, where the water passes through, and acts as a barrier capable of removing solids and/or other materials. This filtered water can then be discharged in to the sea.

#### Cascade Tanks:

Bilge water can be fed into the top of a tank and then by gravitational force passes through sponges which can catch the oily substances and allow the cleansed water be collected at the bottom. This only works for certain viscosities of oil, the smaller the oil droplets the less effective this method is.

Through the application of various technologies it is possible to clean bilge water almost entirely of oily particles. The use of this equipment ensures the mitigation of bilge water discharge pollution.
4/5. Black Water and Gray Water

**Definition:**
Black Water: is a term used to describe wastewater containing faecal matter and urine (water from toilets).

Grey Water: is a term generally used to describe water generated from domestic activities such as dishwashing, laundry and bathing.

**1. Legal Basis:** Annex IV of MARPOL 73/78.

Grey water is not regulated by MARPOL or any other international regulations.

**2. Problem Statement:**
Discharged waste water can lead to hygienic problems like the dangerous germs being released in coastal regions. In addition to this, waste water released in sheltered coastal areas could contain harmful nutrients, disinfectants as well as detergents that can have a largely detrimental impact to marine environments.

The design, building and operation of a ship’s waste water purification system is regulated by a set of general conditions, and largely differs from land-based waste water treatment systems.

The problem of waste water is the variety of pollutants it contains some of which are soluble and others in solid forms. Non biodegradable elements such as plastic, grain, hair, fibres and different kinds of fat must be removed from the water by periodic de-silting or by extraction through a suitable filtration system. The amount of black water onboard ships depends on the technology installed to sanitise it.

**3. Possible Solutions:**
Black and grey water treatment systems could be installed on vessels in order to purify the water discharged into the sea. A number of cruise ships have had their sewage treatment systems retrofitted in order to ensure they have less of an environmental impact as a result of their black and grey water effluent.

**Membrane bioreactors:** Membrane Bioreactors can effectively cleanse black and grey wastewater. The water is first fed into the bioreactor where biomass breaks down the organic matter. This is then processed through a filter and into a second bioreactor. The solution is put through membrane modules to make sure it is scoured and properly cleaned. What is left after the cleaning stage can then be directly discharged into the sea.

**Vacuum toilets:** Vacuum toilets can reduce the amount of black water discharged black water by 1/3. This technology can be combined with a sludge reactor with membrane filtration, collecting grey water. The grey water following treatment in the reactor can be used for the flushing of toilets therefore reducing its volume by 75%.

**How a Membrane Bioreactor (MBR) works (simplified drawing)**
6. Ballast Water

1. **LEGAL BASIS:** International Convention for the Control and Management of Ships’ Ballast Water and Sediments

2. **PROBLEM STATEMENT:** Ballast water is essential for ship stability e.g. when it is carrying an unevenly distributed load. A ship fills up between 10 and 50% of its whole tonnage with ballast water in coastal regions and discharges it when the load is changed. (A tanker when empty fills up with 60,000 tons of ballast water when it has a carrying capacity of 200,000 tons. A container ship fills up 10-20% of their carrying capacity when empty.) Therefore per year up to 10-12 billion tons of salt water is displaced.

Figure: the circulation of the ballast water during the ship’s voyage
Aquatic organisms (plants as well as animals) are displaced as a result of the changing of ballast water. (~3,000 – 4,500 types) Invasive organisms can bring about changes to the marine flora and fauna and cause damage to marine industries such as fishing.

<table>
<thead>
<tr>
<th>NAME</th>
<th>NATIVE TO</th>
<th>INTRODUCED TO</th>
<th>IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholera</td>
<td>Various strains with broad</td>
<td>South America, Gulf of Mexico and</td>
<td>Some cholera epidemics appear to be directly associated with ballast</td>
</tr>
<tr>
<td>Vibrio Cholerae (various</td>
<td>ranges</td>
<td>other areas</td>
<td>water</td>
</tr>
<tr>
<td>strains)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladoceran Water Flea</td>
<td>Black and Caspian Seas</td>
<td>Baltic Sea</td>
<td>Reproduces to form very large populations that dominate the zoo-</td>
</tr>
<tr>
<td>Cercopagis Pengoi</td>
<td></td>
<td></td>
<td>plankton community and clog fishing nets and trawls, with associated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>economic impacts</td>
</tr>
<tr>
<td>Mitten Crab</td>
<td>Northern Asia</td>
<td>Western Europe, Baltic Sea and</td>
<td>Undergoes mass migrations for reproductive purposes. Burrows into</td>
</tr>
<tr>
<td>Eiocheir Sinensis</td>
<td></td>
<td>West Coast North America</td>
<td>river banks and dykes causing erosion and siltation. Preys on native</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>fish and invertebrate species, causing local extinctions during</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>population outbreaks. Interferes with fishing activities</td>
</tr>
<tr>
<td>Toxic Algae</td>
<td>Various species with</td>
<td>Several species have been</td>
<td>May form Harmful Algae Blooms. Depending on the species, can cause</td>
</tr>
<tr>
<td>(Red/Brown/Green Tides)</td>
<td>broad ranges</td>
<td>transferred to new areas in ships'</td>
<td>massive kills of marine life through oxygen depletion, release of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ballast water</td>
<td>toxins and/or mucus. Can foul beaches and impact on tourism and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>recreation. Some species may contaminate filter-feeding shellfish and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cause fisheries to be closed. Consumption of contaminated shellfish</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>by humans may cause severe illness and death</td>
</tr>
<tr>
<td>Round Goby</td>
<td>Black, Asov and Caspian Seas</td>
<td>Baltic Sea and North America</td>
<td>Highly adaptable and invasive. Increases in numbers and spreads</td>
</tr>
<tr>
<td>Neogobius Melanostomus</td>
<td></td>
<td></td>
<td>quickly. Competes for food and habitat with native fishes including</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>commercially important species, and preys on their eggs and young.</td>
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<td></td>
<td></td>
<td>Spawns multiple times per season and survives in poor water quality</td>
</tr>
<tr>
<td>North American Comb Jelly</td>
<td>Eastern Seaboard of the</td>
<td>Black, Azov and Caspian Seas</td>
<td>Reproduces rapidly (self fertilising hermaphrodite) under favourable</td>
</tr>
<tr>
<td>Mnemiopsis Leidy</td>
<td>Americas</td>
<td></td>
<td>conditions. Feeds excessively on zooplankton. Depletes zooplankton</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>stocks; altering food web and ecosystem function. Contributed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>significantly to collapse of Black and Azov Sea fisheries in 1990s,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with massive economic and social impact. Now threatens similar impact</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in Caspian Sea.</td>
</tr>
<tr>
<td>North Pacific Seastar</td>
<td>Northern Pacific</td>
<td>Southern Australia</td>
<td>Reproduces in large numbers, reaching ‘plague’ proportions rapidly</td>
</tr>
<tr>
<td>Asterias Amurensis</td>
<td></td>
<td></td>
<td>in invaded environments. Feeds on shellfish, including commercially</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>valuable scallop, oyster and clam species</td>
</tr>
<tr>
<td>Zebra Mussel</td>
<td>Eastern Europe (Black Sea)</td>
<td>Western and northern Europe,</td>
<td>Fouls all available hard surfaces in mass numbers. Displaces native</td>
</tr>
<tr>
<td>Dreissena Polyomorpha</td>
<td></td>
<td>including Ireland and Baltic Sea;</td>
<td>aquatic life. Alters habitat, ecosystem and food web. Causes severe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>eastern half of North America</td>
<td>fouling problems on infrastructure and vessels. Blocks water intake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>pipes, sluices and irrigation ditches. Economic costs to USA alone of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>around US$750 million to $1 billion between 1989 and 2000</td>
</tr>
<tr>
<td>Asian Kelp</td>
<td>Northern Asia</td>
<td>Southern Australia, New Zealand,</td>
<td>Grows and spreads rapidly, both vegetatively and through dispersal</td>
</tr>
<tr>
<td>Undaria Pinnatifida</td>
<td></td>
<td>West Coast of the United States,</td>
<td>of spores. Displaces native algae and marine life. Alters habitat,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Europe and Argentina</td>
<td>ecosystem and food web. May affect commercial shellfish stocks through</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>space competition and alteration of habitat</td>
</tr>
</tbody>
</table>

Table: Examples of aquatic bio-invasions causing major environmental impact.

3. **POSSIBLE SOLUTIONS:** All ships now have to be fitted with ballast water treatment systems. There are various technologies currently available employing different methods such as, chemical treatment, heating, filtration, ultraviolet light, etc.

The International Convention for the Control and Management of Ships’ Ballast Water and Sediments also allows for the adoption of prototype technologies in certain ships if agreed upon by the IMO.

There are effective technologies already in existence with the scope for further innovation and research. Removing organisms from ballast water goes a long way to ensuring that alien species do not invade fragile marine ecosystems.

3 for more information and examples, see http://globallast.imo.org/poster4_english.pdf
7. Underwater Coatings


2. **Problem Statement:** Many ships and underwater structures are protected from attachment of undesired organisms by being coated with antifouling paints. Often the build up of organisms on the immersed areas of a ship can have a negative impact on its safety and performance and increase its fuel requirements. Biofouling can be found on unprotected surfaces and materials immersed in water.

Fouled ships also play a role in the spreading of invasive species around the world.

Both ships and other marine structures become more prone to corrosion since adhering organisms can damage the corrosion protection system.

Fuel burned by ships represents a significant share of global CO₂ emissions. Therefore, well performing antifouling paints play an important role in protecting the environment from excessive emissions of greenhouse gases.

Some antifouling coatings contain hazardous chemicals which can be harmful to marine organisms. Annex 1 of the IMO AFS Convention lists harmful antifouling systems to which control measures apply.

3. **Possible Solutions:** The use of modern biocides with short life expectancy and consequently low risk on environmental accumulation. Also biocides that lead to a low risk on biological accumulation can be acceptable.

*Modern biocide release systems* These limit the amount of biocide that is emitted into the marine environment by providing a controlled and stable release of the active compound(s).

*Biocide-free fouling control paints* These coatings are suitable for use on vessels which meet certain operational requirements (e.g. speed and frequency of idle periods).

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1 This chapter was developed and produced with the help of the European Council of producers and importers of paints, printing inks and artists' colours.
The aforementioned issues all have solutions which exist today and can positively influence the impact a ship has on the environment. However, there are always areas where innovation could still be promoted and further research into more efficient, innovative and eco-friendly products could be undertaken.

**Further Research:** Expensive measures are currently required to improve fuel handling, combustion characteristics and emissions that negate the low cost of heavy fuel oil. Fuel processing, supply and storage of alternative fuels such as RME, LNG, Methanol and LPG, must be researched for cost reduction and environmental benefits, especially for coastal and short sea shipping. Improved treatment of fuel by the fuel supply chain would bring better utilisation of vessel design for cargo space, reduced onboard workload, reduced environmental impacts and improved engine life.

Research may lead to the reformation of diesel fuel for future marine fuel cell applications. Expansion of electric power options with increased efficiency and environmental benefit will be achieved by the adoption of high power fuel cells. Fuel cell technology derived from land based power and heavy-duty land transport applications needs to be demonstrated in a marine application.

Ship propulsion systems will continue to be dominated by petroleum based fuels. If and when gas infrastructures become available then gas could be a credible alternative fuel to be more widely used. It is predicted that sources of biofuel will not become readily available to shipping and should not be counted upon as a sustainable solution to petroleum. Other methods of propulsion such as wind technology, and solar power are not yet a viable alternative to internal combustion, but do go a long way to contribute to a reduction in emissions alongside traditional engines.

A holistic approach to energy and waste management needs to be developed. We must explore how one system’s waste can be used as an input to another. Flue gas cleaning systems need to recover waste heat and waste water might be used in diesel engine injection systems. New approaches are required for the management of ballast water. We need to develop new materials and treatments; to improve ease of recycling and reduce anti fouling contamination. Additionally the use of renewable materials and re-cycling needs to be investigated.
Energy efficient power management and propulsion monitoring system designs are required for multiple engine/drive installations. System modelling tools are required to analyse the performance of a range of propulsion options for different ship designs, operating characteristics and whole product cycle environmental impact and cost in order to optimise the design at system level.

The range of ship types and their applications is constantly expanding, and operators require machinery systems with higher power density, efficiency and greater flexibility in design and operation. Whilst improvements to existing technologies will meet some of these requirements, radical changes in the powering and propulsion plants will be necessary to meet the current and future environmental legislation. This is because some development results are inversely proportional to each other e.g. an increase in plant efficiency results in increased specific NOx levels but lower CO2 levels. Hence, there is a need to minimise energy consumption as well as primary emission levels of all pollutants.

New cost effective ship designs, optimised for European (coastal) routes, are required to provide alternatives to road transport to reduce pollution and congestion. These designs require Propulsion System Design and Integration Optimisation through whole ship and operating cycle power management.

Expansion of electric propulsion options or hybrids (conventional plus electric) with increased efficiency and environmental benefit may be achieved by the adoption of high power fuel cells. Alternative energy sources may be developed through photovoltaic and wind/wave energy conversion technology for hybrid electricity generation on board.

The European marine equipment industry is constantly focusing on developing parts, materials and services which can perform outstandingly today and in the future for both transport and the environment.
Life cycle of a ship

1. **Materials**

Steel is still the main material for shipbuilding. However, the European marine equipment manufacturers are investigating where feasible, the use of materials that further optimise the environmental footprint.

2. **Enhanced Shipbuilding Process**

Environmental issues concerning the building of ships fall within the competence of the shipyards. Many assembly and installation operations are, however, carried out by their suppliers. The European equipment manufacturers contribute towards improving the logistics between the complex network of suppliers and shipyards leading to more effective management and allowing the assembly process of manufactured goods to be conducted as efficiently as possible.

The introduction of electronic communication tools further increases the performance of the supply chain, resulting in a reduction of negative externalities for the environment.

3. **Manufacture of equipment**

European equipment manufacturers are already complying with strict environmental standards. They promote the extension of international standards of environmental protection to global shipping.

The knowledge and problem solving experience of the equipment sector is crucial for inputs at the design phase when it comes to creating environmentally friendly and sustainable vessels. European solutions can make environmentally efficient ships competitive.

Approximately 70% (85% for cruise ships) of a ship’s value is marine equipment. Therefore it has to be ensured at the equipment manufacturing stage that ships can live up to environmental and safety standards, which will ultimately have a positive effect on marine environment.
4. **Energy Efficient Ship Systems**

The European marine equipment sector is very diverse and it has substantial know-how about components and systems. Therefore it has a unique advantage to remain the maritime technological pacemaker by keeping their ability to integrate various different systems improving the energy efficiency of maritime transport to a sustainable level.

It is the objective of the marine equipment sector to improve energy efficiency of ships by up to 30% in the short term. In the medium to long term it has been estimated that a ship's energy efficiency can be improved by 60%. These ambitious targets can, however, only be achieved by a continuous innovation process (keeping the cutting-edge-technology position).

5. **Safety at Sea**

Thanks to centuries of experience, the shipbuilding industry is producing vessels which are increasingly safer for crews, passengers and the environment. However, the eventuality of an accident in the harsh maritime environment can never be completely ruled out. The maintenance and the operation of a ship, as well as external factors, such as critical weather conditions, have to be taken into account when considering the safety of shipping. Still, the marine equipment industry plays a fundamental role in the prevention of accidents and in the reduction of their consequences for the environment.

This can be done, for example, through high level ship automation which can support the human factor, preventing the malfunctioning of equipment. Automation takes care of equipment operation and thereby minimizes the scope of human error. Furthermore it also ensures that accidental pollution can be prevented.

6. **Operation at Sea**

Efficient ship operation is essential for cleaner voyages at sea and in port. Ships should be well maintained/modernised to guarantee maximum efficiency and to keep up-to-date with International and European legislation with regard to the environment. The European marine equipment industry supports the value oriented retrofitting of hulls in good condition and state of the art design with the most efficient and highest standard of modern equipment. This will not only make ships greener and cleaner but also maintain the overall value of a ship.

7. **Decommissioning**

The end of the life-cycle of a vessel is naturally relevant to the environment. While recycling normally takes place far from the influence of the equipment manufacturer, the choice of materials and the design of marine equipment and ships can help minimize the impact of decommissioning.

Much of the equipment on board a ship can survive the ship itself, and remain useful after the vessel itself has been scrapped. It must be remembered that up to 98% of a ship can be recycled in comparison to less than 60% of an airplane.