Eco-Design of Research Vessels

by Andre Cattrijsse, Roland Rogers, Harrold van Vliet, and Pieter Huyskens

Introduction

To improve the aging European marine research fleet on green ship operations, the EUROFLEETS project drafted guidelines for eco-responsibility of existing and eco-design for new build research vessels. This essay summarizes these guidelines but considers only those technologies that improve a ship's environmental impact beyond the legal requisites as "*green*."

The fashionable "green ship" does not exist and the environmental impact free vessel is a theoretical concept. The term "greener" or "cleaner" ship is better wording. Reducing the environmental footprint of ships and their operations involves too many aspects for a straightforward meaning of the "green ship" concept. The continuous development of technologies and conventions gradually narrows the perception of "*green*." A flashy green ship today will likely be a pitch black one tomorrow. A clear definition of the green ship concept and its auditing would be beneficial for the entire shipping industry. A mature green status necessitates full consideration of the cradle-to-cradle approach.

Pollution by Oil

Ship operational oil pollution remains an important environmental issue. Oils and oily residuals continuously enter the environment either through direct release or from deck run wash. The yearly amount of oily substances that enters the marine environment through simple ship operations is larger than those caused by incidents or accidents and estimated to amount annually to over 80 million litres. MARPOL allows discharge of bilge water at concentrations below 15 parts per million under strict circumstances. [MARPOL is the International Convention for the Prevention of Pollution from Ships; MARPOL is short for 'marine pollution.']

High speed centrifuges or membrane microfiltration technologies clean bilge water to much lower concentrations. Even better, operators should choose not to discharge under any circumstance and dispose of oil at shore. Many research vessel operators have indicated that they will adopt this approach.

The use of biodegradable oils and lubes in the maritime sector is growing. Biodegradable

The RV *Oceania* is owned by the Polish Academy of Sciences; this sail-powered vessel has been in operation since 1985.

oils degrade three to four times faster than conventional oils but are still considered pollution as they leave a sheen on the water surface and have similar negative effects on biota.

Since 2006, the United States National Oceanic and Atmospheric Administration (NOAA) operates three smaller research vessels on the Great Lakes that run totally petroleum free. It took NOAA five years from effective start to accomplish petroleum free operations.

Bacterial growth in tanks holding biofuels or low sulphur fuels which are blended with biofuels may cause problems with filters and quality of the fuel.

A water lubed stern tube is not novel and recent technological improvement of bearings for water lubricated shafts offers the opportunity of almost total elimination of operational oil loss. Some operators reported that biofouling in such systems can be problematic.

Pollution by Sewage

Ships may discharge sewage at an appropriate distance to shore. To ensure less impact, sewage treatment systems can be installed. When the ship carries an approved treatment plant or a comminuting [pulverizing] and disinfecting system, discharge may occur closer to shore.

Although capacity is an issue, holding tanks are the best option as delivery to shore will prevent direct impact on the marine environment. While most regional research vessels will often operate beyond the minimum distances to shore dictated by MARPOL, operators can still choose to install membrane bioreactors to clean their discharge and thus minimize impact. Bioreactors cannot cope with large changes in salinity and the remaining sludge needs to be disposed of in harbours. Flushing toilets with seawater compromises the biological treatment of sewage waters.

It is anticipated that future MARPOL IV amendments will further strengthen the conditions under which sewage can be discharged at sea, even up to no discharge if no treatment installation is present. Vacuum toilets are an elegant way to reduce the amount of black water, making storage on board easier.

Pollution by Garbage

Recently the Marine Environment Protection Committee amended MARPOL Annex V. All wastes, except food, can no longer be discarded at sea. European research vessel operators have expressed their preference for stowing garbage regardless of involved smell and hygiene issues. Operators can reduce or exclude discharge at sea by installing waste compressors or certified incinerators. Garbage should be compressed carefully as disposal costs on land will increase if the different types of waste cannot be separated. Heat produced by incinerators should be recycled and used for electric power production.

Air Pollution

The easiest, cheapest, and most important way to cut back emissions of carbon dioxide (CO_2), nitrogen oxide (NO_x), sulfur oxide (SO_x), and soot is reducing speed, thereby reducing operational costs at a similar pace. This slow steaming includes a prudent operational “style” (i.e., smooth accelerations and decelerations).

Ahead of MARPOL, European Commission (EC) regulations have made low sulphur distillate marine fuels generally available in Europe. New editions of two International Organization for Standardization (ISO) standards on marine fuels have been developed to meet higher international requirements for air quality, ship safety, engine performance, and crew health.

For most regional research vessels, shore power supply is not a difficult issue. In many cases smaller ships are even lying cold while in the harbour and will not add to air pollution in port areas. A vessel equipped with a dual fuel generator can run on liquefied natural gas (LNG) from a storage tank onshore to minimize air pollution.

Incorporating an optimum hull design is a straightforward process and standard approach for new builds. Improved hull designs significantly add up to fuel efficiency and thus reduced emissions. They also help in improving sea keeping behaviour and optimization of the entire operational profile.

Innovative hulls like trimaran [multi-hulled] or SWATH [small waterplane area twin hull] forms can further reduce drag while maintaining stability. Other innovative hull designs that increase efficiency and improve sea keeping behaviour include prolonged bow types.

The Monterey Bay Aquarium Research Institute in California, United States of America, commissioned a design study to develop a low environmental impact research vessel for the replacement of the *Western Flyer*. The study concluded that against trimaran or SWATH designs, a monohull offered the best option to produce a ship that reaches the best environmental performance while maintaining a high standard for research capability.

Improved hull design may reduce or even eliminate the need for ballast water. This not only 'releases' considerable amounts of energy required to transport the ballast water but also stops the transfer of invasive species.

Choosing the proper propeller/rudder system improves propulsive efficiency. The retrofit of a better propeller design can greatly aid in fuel consumption decrease. Reblading propellers has been reported to reduce fuel consumption on average by about 10%. Novel propeller designs like the contracted loaded tip (CLT) and counter rotating propellers or boss cap fins have documented important power savings.

The RV *Princess Royal* is a coastal research catamaran owned by Newcastle University (United Kingdom) and is more power efficient than conventional designs. The hull, rudder and propellers have been fully optimized to keep fuel consumption and thus engine exhausts low while enhancing sea keeping and speed potential.

The government of Norway has a new ice-class research vessel under construction for the Norwegian Polar Institute in Tromsø. When completed, the research vessel will be 100 metres long, 21 metres wide, and will be operated by the Institute of Marine Research in Bergen. The above image is one of the artist impressions of the new research vessel.

Several commercially available software tools allow for reducing fuel consumption. Based on individual ship data, benchmarking and reference information, such techniques also improve maintenance schemes of the main engines and auxiliary systems.

The energy stored in the main engine exhaust can be recuperated and provide savings in primary energy consumption and hence result in a reduction of emissions. The new breed of heat recovery systems allows for generating electricity to supplement propulsion or heating. Heat can be recuperated from cooling water and exhaust. The latter will need larger installations and may compromise exhaust cleaning systems.

The first LNG powered vessel, a ferry, was placed into operation in Norway in 2000 and since then a continuously growing number of vessels sail on LNG. Legislation and certification has evolved such that international voyages are now possible. The new Norwegian Arctic research vessel will be equipped to run on LNG for limited periods. Designs for implementing LNG on smaller vessels are being developed.

LNG not only provides SO_x free and significantly reduced NO_x and CO_2 emissions, but also provides an economically interesting fuel at today's oil prices. The major drawbacks for using LNG are found in the need for space for the holding tanks (the LNG capacity needed is approximately three to four times the tank capacity required for diesel) and a supply chain that is not always fully and/or region wide operational, but strong international efforts are being made to solve that.

LNG should be a very interesting fuel for relatively small vessels with a limited number of days of operation between port calls, which enables bunkering at regular intervals.

Regional research vessels could be equipped with dual fuel engines and a combination of diesel and LNG tanks in order to run on LNG to the extent possible.

NO_x can be reduced through lowering combustion temperatures but will conflict with heat recuperation. Slow steaming, humid air motors, direct water injection, exhaust gas recirculation and fuel-water emulsification reduce combustion temperatures. Except for slow steaming, these options would lead to greater fuel consumption. Modifications to a fuel system probably need ad hoc evaluation for retrofitting.

Manufacturers of combustion catalysts claim to reduce NO_x formation during the combustion process up to 75% with a minimum of investment. Selective catalytic reduction (SCR) passes exhaust fumes over a catalyst bed where urea or ammonia is injected to reduce the nitrogen oxides to atmospheric nitrogen. These installations need maintenance and supply of the catalyst substance but are becoming more compact and cheaper. As most modern trucks have SCRs installed, they can offer a viable solution for smaller vessels with an efficiency of up to 85% for marine applications.

Distillate fuels produce much less particulate matter than residual fuels. Particulate filters (cyclone separators, wall flow filters, or electrostatic precipitators) or increased fuel injection pressure will further remove particulate matter. The cheapest method is keeping the engines in good condition. Diesel particle filter technologies, which are almost standard in the automobile industry, have been successfully applied on board smaller vessels. Often particle matter filters are housed together with SCR and diesel oxidation catalyst technology in one unit to clean diesel engine exhausts from the total spectrum of pollutants.

Installations to remove SO_x from the exhaust are being installed on ships to comply with MARPOL regulations. Scrubbers can reduce SO_x above 80%. Installing such systems on existing vessels is an engineering challenge as the demand for space and the weight of the installations limit options. A typical regional research vessel will run on low sulphur distillate fuel to comply with EC regulations. Larger ocean going vessels likely do not consume enough distillate fuel to benefit from the installation of a scrubber.

Hybrid propulsion systems take advantage of the best of both mechanical and electric power generation. Fuel cells or battery systems offer the possibility of providing propulsion power under limited conditions for restricted periods of time. Energy can also be stored in batteries to aid both propulsion and hotel loads. The Damen hybrid tug and green tug designs prove that batteries can be installed for propulsion of smaller vessels. When these batteries are charged with shore power, total environmental efficiency needs to be evaluated. Surplus ship generated energy should be supplied to such batteries.

A number of pilot projects exist where solar panels provide auxiliary power to small ferries and on large merchant vessels. Like fuel cells, solar panels can currently only aid in reducing energy consumption by providing power for hotel loads or auxiliary systems. In general, solar power generation is not cost effective yet and the potential depends on future developments in efficiency. Most research vessels lack deck space to generate much power.

Several other pilot projects exist where merchant vessels are equipped with sails or kites or Flettner rotors to sustain propulsion during transit. Using sailing vessels as research platforms is not utopic. A few cases clearly demonstrate that the capacity of a sailing research ship does not need to be limited to one or two science tasks.

The Polish *Oceania* has demonstrated its sailing capacity for more than two decades. The French *Tara* supports various research tasks around the world and the United States *Derek M. Baylis* performs different research activities including ROV work and acoustic surveying. The operational costs of *Derek M. Baylis* were found to be three times cheaper than a conventional coastal research vessel. The success of this vessel has resulted in the design of an ocean class research ship.

The RV *Simon Stevin* is the new build coastal multi-purpose research ship of the Flanders Marine Institute, Belgium. The ship carries an active anti-fouling system and a silicone based hull paint, uses waste heat recuperation, has a low noise profile, burns low sulphur fuel, and carries the ISO14001 accreditation.

The concept of pumping air under a hull to reduce drag is implemented on a small number of large merchant ships. Results from existing projects demonstrate its potential and designers claim a maximum of 15% reduction in fuel consumption. As air bubbles block signals of acoustic equipment, the application of such technology on board research vessels can be limited during transit. The technology also is only effective on longer ships, thereby excluding usage on smaller research vessels.

Anti-Fouling Systems

Clean biofoul-free hulls reduce drag and aid substantially in controlling fuel consumption. Periodic cleaning of the hull should be standard practice as this will indirectly help in reducing exhaust pollutants.

Epoxy resin coatings last longer than conventional paints and, due to their low friction with water, help in reducing resistance. These coatings still release toxic compounds. Only biocide-free anti-fouling mechanisms are environmentally friendly. The technology of applying natural biocides is still under development.

Some techniques use physical instability as a growth inhibitor. Surface treated coatings do not release toxins but involve frequent hull cleaning. Silicon based paints slowly grind off under friction during sailing, inhibiting the settlement of biota. Both the cleaning and slow grinding release polymer microparticles. Scientists have recently drawn attention to the presence and possible negative effects of microplastics in the environment.

Non-stick coatings provide a very smooth surface preventing settlement of organisms and allow for easier cleaning. Such coatings are only suitable for vessels that operate above 30 knots and repairing damaged surfaces is difficult.

Photoactive paints that release hydrogen peroxide under light have proven to be effective. Another innovative technology consists of slime producing coatings that continuously slough off of the hull and help in reducing drag. Active anti-biofouling systems that create an electric potential difference between the hull and water to prevent biofouling are regularly and successfully installed on both large and small vessels.

Ballast Water and Sediments

Exchanging ballast water is not a very common operational procedure for smaller research vessels where cargo loads are relatively stable. In most cases regional research vessels will not often cross significant biological 'provinces' where other fauna/flora occur. Releasing ballast water may therefore not affect the local fauna and flora as no major differences will exist in the aquatic communities of the different places visited by the regional vessel. [Editor's note: The exceptions here are active aquaculture areas where "bay management areas" are widely used to limit the transport of diseases by local vessels.]

The International Maritime Organization Convention on ballast water that will come into force applies to all ships, so smaller research vessels will need to carry ballast water treatment systems. Designing a zero ballast ship is, however, possible and future research vessels should be designed as such.

Underwater Radiated Noise

There are two main reasons for reducing underwater radiated noise: reducing the impact on marine life and improving the signal-to-noise ratio during acoustic surveys. Diesel-electric propulsion with resilient mounted generator sets and fixed pitch propeller are proven to allow for quiet operations. Contracted Loaded Tip (CLT) propellers are known to reduce underwater noise.

Most new build research vessels are designed to operate in 'silent' mode. The main reason to use low noise engine installations is science and not environmental concern. Yet, as the goal exceeds required conventions, silent research vessels are considered green in this aspect.

Depending on a case by case scenario, and if the operational profile allows, an all-electric propulsion system can aid in maintaining a cleaner engine exhaust and lowering fuel consumption. This can be challenged as the efficiency of electric motors seriously drops under low loads.

Maintaining low noise levels is an ongoing process. Without proper maintenance, systems will deteriorate and vessels will no longer meet their noise goals.

Conduct and Administrative Tools

Simply applying whatever sweep of green technologies on board a vessel does not suffice. Creating environmental awareness among shore staff and crew by continued training and follow-up is paramount to achieving a greener ship.

Sails are a viable option for research vessels without compromising the research capacity and performance while dramatically reducing environmental impact and operational costs. Shown here is the French-owned RV *Tara*.

The RV *Ramòn Margalef* is the new research vessel of the Spanish Institute of Oceanography. The vessel uses biocide-free silicon hull paints, ozone treatment of ballast water, and bio-hydraulic oils; sails in a silent mode; houses a power management system; and carries a clean ship notation.

The major classification bureaus issue Green Class notations. International standards such as ISO9001, the ISO14001 and the International Safety Management Code include environmental management systems for use on board vessels. Other "environmental awareness labels" (e.g., *Der Blaue Engel* [Blue Angel]) may also be applied to vessels and/or operators and help in maintaining a high level of environmentally friendly operations.

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) established a code of conduct for responsible marine research in the OSPAR maritime area. Additionally, the United Nations Convention on the Law of the Sea also stipulates that marine scientific research shall be conducted in compliance with all relevant regulations including those for the protection and preservation of the marine environment. The implementation of such guidelines should be assured through the research vessel environmental management plans. The international and European research ship operator networks – International Research Ship Operators and European Research Vessel Operators – have established similar guidelines for marine science operations.

Examples of Greener Research Vessels

Newcastle University in the United Kingdom claims that its new *Princess Royal* is far more power efficient than conventional designs. The hull, rudder and propellers of this coastal catamaran research vessel have been fully optimized to keep fuel consumption and thus engine exhausts low while enhancing sea keeping and speed potential. A power management system was installed to keep track of its performance. The vessel systems have been optimized for reduced environmental impact. A high-tech inverter battery system minimizes generator running time; solar panels are integrated into the electrical system to maintain the batteries in a carbon-free manner; the hydraulic system is optimized for minimum energy usage; and the use of biofuels and other environmental systems are being explored.

Two other traditional ship designs demonstrate that new vessels are often equipped with a number of green technologies that have become almost standard. The *Simon Stevin*, a 2012 new build for Belgium, was equipped with waste heat recovery, vacuum toilets, and silicone based hull painting to reduce drag and active anti-fouling. The vessel runs on low sulphur fuel, is silent and ISO14001 accredited. The Spanish *Ramòn Margalef* uses biocide-free silicon hull paints, ozone treatment of ballast water, and bio-hydraulic oils; sails in a silent mode; houses a power management system; and carries a clean ship notation.

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The *Tara Oceans* and the *Derek M. Baylis* demonstrate the possibilities. The sailing ocean class research ship *Rachel Carson* was designed for Oregon State University to accommodate containers and is capable of performing all possible research tasks. Some operations require diesel engines but all other research can be performed under sail, doubtlessly decreasing the operational costs and the environmental impact.

Conclusions

The aging European, and likely the global, research vessel fleet can improve substantially on environmental friendliness. Commercial fleets often find customer driven incentives to green vessels and operations. The driver for research ships is weaker than for commercial fleets and is not directly and totally financial; the progress is clearly slower. Research ships with a green design are rare but needed. The mission of research ships is ultimately to help care for the environment. The research community should demand that vessel operators adopt state of the art greening technologies for research ships as they function as ambassadors for the ocean environment. The technologies are available and can be evaluated on an ad hoc basis without too much effort for retrofitting on existing or installing on new build research vessels.

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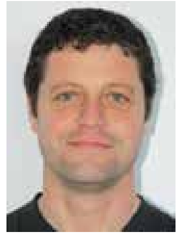
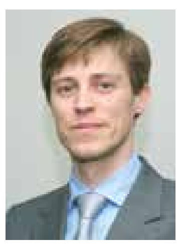


Andre Cattrijsse is Head of the Research Facilities Department of the Flanders Marine Institute in Oostende, Belgium. In 1995 he obtained a PhD in marine ecology and continued working as a marine biologist at the University of Ghent until 2000. Dr. Cattrijsse has 13 years of experience as a research vessel manager and is an active member in several European networks on marine research infrastructure.

Roland J. Rogers retired as the Naval Liaison Officer at the Defence Evaluation and Research Agency in Winfrith, United Kingdom, in June 2002 after a long career as a specialist Oceanographic and Meteorological Officer in the British Royal Navy. He joined QinetiQ in June 2002 to continue working in the area of military marine environmental impact assessment as the domain expert on the relevant law and policy. In May 2008 Mr. Rogers joined the National Marine Facilities (NMF) Department of the National Oceanography Centre in Southampton where he managed the National Marine Equipment Pool. He is now the Advisor on Marine Law and Policy at the NMF Sea Systems Department where he also undertakes commissioned research and consultancy in marine law and policy specializing in the areas of marine scientific research, marine autonomous systems, underwater noise, and the geo politics of polar regions.

Harrold van Vliet graduated in 2003 with a degree in shipbuilding and began his career as a shipbuilding engineer for the Offshore and Transport Department of the Damen Shipyard Group in Gorinchem, The Netherlands. Mr. van Vliet currently holds the position of Design and Proposal Engineer with Damen.



Pieter Huyskens graduated magna cum laude and was awarded the degree of Master of Science in Automotive Engineering in 2006. He was offered a position at the Karel de Grote University College in Antwerp, Belgium, where he became a part-time lecturer and part-time research engineer. After two years of teaching at bachelor and master levels, Mr. Huyskens also accepted a research position at the University of Ghent. His academic work was mainly focused on alternative fuels such as hydrogen, (m)ethanol, and pure plant oils; combustion optimization; and reducing the environmental impact in general. In 2011 he took up the position as Program Manager Sustainability at the Research Department of the Damen Shipyard Group in Gorinchem, The Netherlands, where he coordinates projects and activities aimed at reducing the environmental impact of Damen vessels.