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WHITE PAPER

Clean Ship Hulls and Ports – Without Compromise

Best approach to safeguarding of the marine environment through correct hull protection and maintenance

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Part I. Introduction

It is fair to say that concern about the impact human activities have on this planet is growing every decade, possibly every year. Damage by shipping to the marine environment, oceans, waterways, ports, shorelines, rivers and lakes is a significant part of this concern, as is the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2) and nitrous oxides (NOx) as well as pollutants such as sulfur oxides (SOx) into the earth's atmosphere by the burning of fossil fuels to drive ships.

While other aspects of ships and shipping play their own part in this environmental concern, a key factor is the underwater ship hull. This is subject to biofouling, as micro-organisms and vegetable and animal matter naturally attach to a ship's hull. If not dealt with effectively, this can lead to three main sources of damage to the environment:

1. **A fouled hull carries with it a fuel penalty. The worse the fouling, the slower the ship will sail at a given RPM. Or, put another way, the more power will be required to keep the ship sailing at a given speed. This means higher fuel consumption. Depending on the degree of fouling, this can be as much as 85% more.[1] Higher fuel consumption results in a greater volume of greenhouse gases and other emissions which pollute the earth's atmosphere.[2]**
2. **The misguided attempt to deal with the fouling by applying to the hull a coating designed to poison the marine life before it can attach itself, or to kill it when it has attached itself, leads to the leaching of very significant concentrations of biocides or poisons into the oceans and waterways. These toxic substances have been shown to harm many varieties of marine life and do not restrict their effects to those species which comprise biofouling. They contaminate the food chain. They have an array of harmful effects on many forms of marine organisms and, through the food chain, on animals and humans.[3]**
3. **If marine biofouling is not dealt with correctly, the accumulated fouling poses a risk of transferring invasive, non-indigenous marine species (NIS or NIMS) around the world with consequent damaging effects to local marine life and a reduction of biodiversity. One of the key means of translocation of NIMS is the badly fouled hulls of ships.[4]**

These three factors are all of grave concern to the environment and to the shipping industry. Shipowners and operators will sooner or later have to act to reduce or remove all three risks, if not out of a sense of responsibility for the environment, then as a result of legislation or regulations, some of which already exist, as well as newly

1 Michael P. Schultz, Effects of coating roughness and biofouling on ship resistance and powering, Biofouling, 23:5, 331-341

2 IMO MEPC 59th session, agenda item 4, Prevention of air pollution from ships, GHG emission from ships (16 July 2009)

3 Stefan Nehring, After the TBT Era: Alternative Anti-fouling Paints and their Ecological Risks

4 IMO BLG 14/INF.4 Sub-committee on bulk liquids and gases, 14th session, Agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships

introduced rules or laws which are likely to become stricter and more far-reaching.

Unfortunately, there is a noticeable tendency to compromise in attempting to deal with these different forms of environmental impact. There seems little point providing a "solution" to one or even two of the three factors mentioned above if this is done at the expense of the other or others, especially as there is an approach which addresses all three successfully without compromise.

For example, coating a ship hull with toxic substances in an effort to keep the hull free of fouling may appear to mitigate the risk of spreading NIS and may reduce the level of fouling and therefore lessen the fuel penalty to some degree, but it involves a huge compromise – the poisoning of the oceans with heavy metals and other harmful chemicals, damaging marine life and contaminating the food chain.

Why take great precautions to protect a port from an invasive, non-indigenous species if this entails widespread pollution of that port through heavy metals and a variety of toxic herbicides and pesticides? It seems odd that researchers and scientists concerned with damage to the environment through the spread of NIS would recommend a solution which will result in increased damage to the environment through heavy metal and harmful biocide accumulations in the ocean. Is one less harmful than the other to the marine environment and the food chain?

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This white paper, *Clean Ship Hulls and Ports – Without Compromise*, examines these factors in detail and presents a new approach which is economically feasible (and in fact very advantageous) and satisfies all three points of environmental impact in the best possible way without, as the title suggests, any compromise. While it is possible that at some future date scientists will develop a completely non-toxic, non-polluting hull coating to which no biofilm or biofouling will adhere, that time has not yet come. The approach outlined in this paper uses existing, tried and tested technology which is currently available and in use. Through this approach, shipowners/operators, port authorities, environmental protection agencies, shipping regulatory bodies and government officials can all benefit in the following ways:

- **Dramatic reduction of fuel consumption and therefore atmospheric pollution,**
- **Reduction to zero of the chemical pollution of the oceans, ports and inland waterways that normally accompanies toxic hull coatings,**
- **Elimination of the risk of spreading invasive, non-indigenous marine species.**

While this approach only concerns the underwater hulls of vessels, the world fleet is large enough today for this alone to be of considerable benefit to the environment.

The white paper includes a detailed case study of a major port and some of the shipowners and operators who are adopting this approach successfully.

The fear exists that any actions taken to reduce environmental impact will be expensive and commercially deleterious to industry. The approach described in this white paper, however, brings with it a major reduction in costs through fuel saving, elimination of unnecessary off-hire time, drydocking, and expensive hull re-coating along with the preparation which that requires.

Part II. The need for change

A number of factors are making it imperative and urgent to change current practices regarding hull protection and maintenance at this time. Before discussing these factors, it is worth summarizing what those current practices generally consist of.

The current norm is for shipowners and operators to apply a biocidal antifouling paint, usually copper-based with added "booster" biocides (a variety of herbicides and pesticides), to a ship's hull when the ship is built, to launch the ship and pay little or no attention to the state of the underwater hull until the vessel is back in drydock, usually somewhere between 2 ½ and 5 years later. In some cases the hull is partially or fully cleaned in the water in the interim. The AF paint gradually leaches its poisonous payload into the oceans, ports and waterways. In-water cleaning of such hulls accelerates the process, causing a pulse release of large quantities of the toxic substances. This approach to antifouling is used on the majority of ships afloat and has been going on ever since the banning of the use of TBT in antifouling paints.

On a much smaller scale, some ships are being launched or relaunched with a foul-release (F-R) paint, usually consisting of some form of silicone-based coating, designed to make it harder for fouling to stick and easier for it to be washed off when the ship is under way. Many of these coatings, although labeled as non-toxic, also release into the water substances which are harmful to marine life.[5] F-R coatings are also somewhat delicate, easily damaged and therefore not generally suitable for in-water cleaning.

As covered in Hydrex White Paper No. 2 *The Slime Factor*,[6] none of these coatings prevent the accumulation of biofouling in the form of biofilm or slime, which accounts for a considerable fuel penalty all on its own.

These, then, are the current practices. But what are the concerns?

Increased concern about pollution of ports from in-water cleaning

In many parts of the world, concern over the potential environmental damage which can be caused by current antifouling systems seems to be growing.

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Early in 2010 the Port of San Diego, California, passed a resolution banning the use of copper-based paint on the hulls of recreational boats.[7] "The Port District has committed to developing the policies and programs necessary to reduce copper inputs from recreational and commercial boats," the port said in a statement, adding, "The resolution supports ongoing research to find effective, non-toxic hull paint alternatives to replace the copper anti-fouling paints that leach into the bay." The plan is to reduce the copper levels in advance of regulatory requirements set by the Regional and State Water Quality Control Boards. Regulations call for an incremental copper reduction of 10% by 2012.

5 Monika Nendza, "Hazard assessment of silicone oils (polydimethylsiloxanes, PDMS) used in antifouling-/foul-release-products in the marine environment," Marine Pollution Bulletin 54, no. 8 (August 2007): 1190-1196.

6 Hydrex White Paper No. 2, *The Slime Factor*, http://www.hydrex.be/white_papers.htm

7 Portworld 5 January 2010. http://www.portworld.com/news/i90867/San_Diego_bans_copper_based_anti_fouling_paint (accessed 2 Feb 2011).

The Netherlands,[8] along with France, Germany, UK, Greece, Turkey, UAE, Singapore, Japan, Hong Kong, Brazil, Australia, New Zealand and a long list of others, forbid the in-water cleaning or scrubbing of ship hulls bearing copper-based antifouling paint.

Canada already limits the amount of copper emissions.[9]

The following is a short excerpt from the Proceedings of the 14th Biennial Coastal Zone Conference New Orleans, Louisiana, July 17 to 21, 2005, which summarized general international concerns about copper in antifouling paint:

> **Copper-based bottom paints have been banned for pleasure craft on the east coast of Sweden and are restricted on the west coast of Sweden and in Denmark depending on cuprous oxide leach rates and vessel size. Copper-based antifouling paints have been banned in the Netherlands for recreational boats since 1999. (Swedish Chemicals Inspectorate 2004; Ministry of the Environment Danish Environmental Protection Agency 2003; The Netherlands Ministry of Housing, Spatial Planning and the Environment 2004; College Toelating Bestrijdingsmiddelen 2004).**
>
> **When the dissolved copper level exceeds the standard, it is harmful to marine life such as mussels, oysters, scallops, sea urchins and crustaceans. It also changes the types of phytoplankton that are able to thrive in boat basins. (Calabrese et al.1984; Coglianese & Martin 1981; Gould et al. 1988; Katz 1998; Krett Lane 1980; Krishnakumar et al. 1990; Lee & Xu 1984; Lussier et al.1985; MacDonald 1988; Martin et al. 1981; Redpath 1985; Redpath & Davenport 1988; Stromgren & Nielsen 1991; VanderWeele 1996).[10]**

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It would appear that the writing is on the wall for copper and booster biocide antifouling paint which can be considered only as an interim solution following the ban on TBT, until a non-toxic approach to fouling control could become the accepted treatment of ship hulls.

Increased concern about the spread of NIS

At the same time that copper and booster biocide antifouling paint are coming increasingly under scrutiny, there is a growing concern about the dangers of the spreading of non-indigenous marine species (NIS or NIMS) as a result of hull fouling.

The IMO has tasked the Subcommittee on Bulk Liquids and Gases and a New Zealand Correspondence Group led by Dr. Naomi Parker, Manager Strategic Science

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8 NST Center, http://www.nstcenter.com/writeup.aspx?title=Antifouling%20Coatings&page=TechResourcesAntifoulingCoatings.html, accessed Feb 2011.

9 Ibid.

10 Leigh Taylor Johnson, Jamie Anne Gonzalez, Nontoxic Antifouling? Demonstrating a solution to copper boat bottom paint pollution!, Proceedings of the 14th Biennial Coastal Zone Conference, New Orleans, July 17 - 21, 2005.

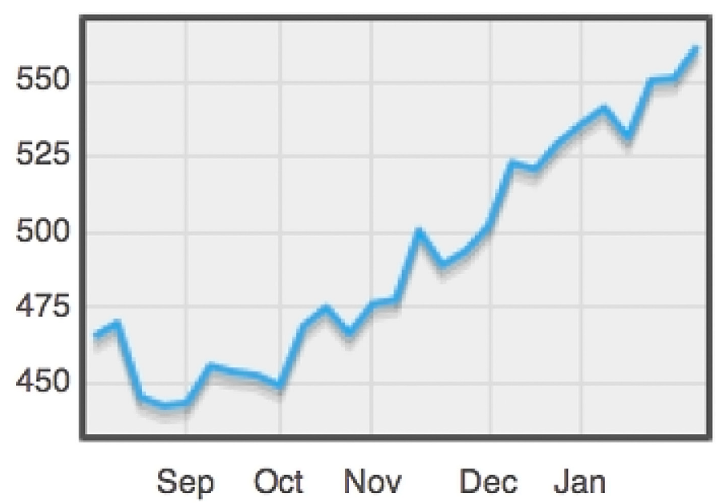
of the New Zealand Ministry of Agriculture and Forestry Biosecurity Department, with determining appropriate measures for the prevention of this perceived threat. The following quote from IMO Bulk Liquids & Gases Subcommittee minutes of 2 December 2009 indicates the increase in the severity of the situation due to the recent economic decline which has placed many cargo ships out of service awaiting hire.

> **The current range of the approved anti-fouling coatings depends on any active ingredients or biocides to be in a copolymer self-polishing matrix. This requires that the ship is predominantly underway so that any fouling organisms are prevented from attachment to the ship's hull. Once the ship is stationary for any length of time, the effectiveness of anti-fouling coatings diminishes with rapid colonization of assemblages of aquatic organisms becoming attached to the hull. Indeed, it is reported in the article mentioned in paragraph 3 that a 200-metre long merchant ship is capable of acquiring 20 tonnes of bio-fouling if stationary for a prolonged period.**[11]

The work of the sub-committee and the correspondence group is moving ahead at time of writing.

Increasing cost of fuel and concern about greenhouse gas emissions

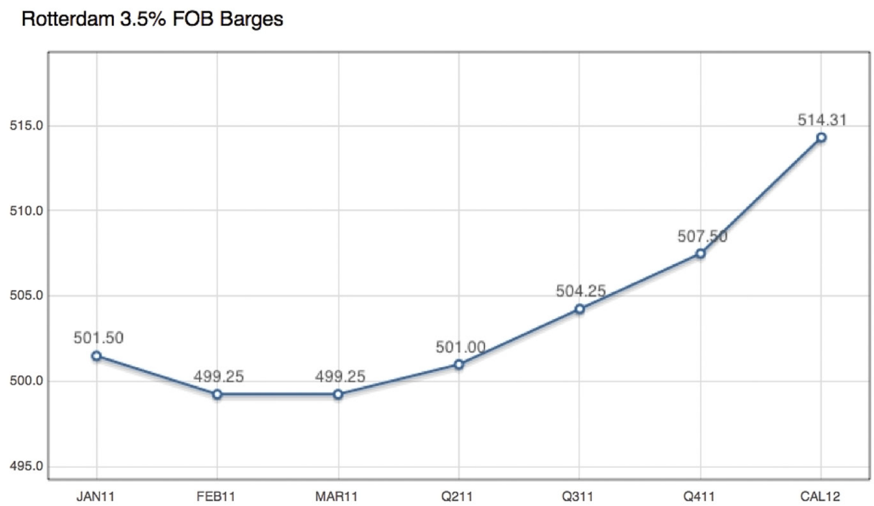
A recent graph of the cost of bunker fuel from late 2010 to early 2011 shows a considerable rise. [12]



11 IMO BLG 14/INF.4 Sub-committee on bulk liquids and gases, 14th session, Agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships

12 Bunkerworld.com accessed Feb 2011.

The future does not look so bright either. The following is a graph of estimated future prices, taking Rotterdam as an example.[13]



Marpol Annex VI entered into force in May 2005, providing comprehensive regulations for the prevention of air pollution from ships.[14] Due to new regulations, the shipping community is faced with new challenges on a large scale, especially those ships that will operate both inside and outside restricted areas, switching over from one fuel to another, in some cases to a distillate fuel.

The long-term average price difference between marine distillate fuels required by new regulations and residual fuels is about double.[15]

In effect, the financial pressure will encourage all shipowners and operators to find ways to reduce fuel costs. Fortunately there is a way to do this which is commercially viable and will save much more than it costs. This will benefit the environment due to a lower carbon footprint and the elimination of ocean pollution caused by toxic antifouling paint at the same time.

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13 Ibid.

14 Wärtsilä Low Sulphur Fuel Guidelines, 23 March 2005.

15 Analysis of the Consequences of Low Sulphur Fuel Requirements, Study commissioned by European Community Shipowners' Association (ECSA), January 2010.

Part III. The real issues involved

1. Pollution of ports and inland waterways by AF and cleaning AF hulls

Traditional, biocidal antifouling paints (AF) leach poisonous substances into the water. That's how they are supposed to work.

Why did the Netherlands introduce a ban on the use of copper-based antifouling paints in inland waters as far back as 1999? Why do Sweden and Denmark, the Port of San Diego and other areas and entities restrict its use? Is this just a case of smoke without fire and a lot of fuss about nothing?

The following extract from the article *After the TBT Era: Alternative Anti-fouling Paints and their Ecological Risks* sheds some light on the effects of copper and the so-called "booster" biocides which are usually part of the copper-based AF paints in general use.

> **The component copper, actually an essential micro-nutrient for plants, animals and humans, holds many dangers.**
>
> **Already some time ago, copper was recognized as a risk in drinking water supplies. Chronic increased copper uptake may cause acute poisoning, especially among babies, and can lead to fatal hepatic cirrhosis. Since 1987, thirteen of such deaths have become known in Germany. It is assumed that copper also has mutagenic and cancerogenic potentials…**
>
> **Already at the beginning of the 1990s, the copper input into the North Sea from shipping related sources was in the order of 10 to 20% of the total inputs. Today the copper concentration in the German coastal waters reaches a level that causes a significant decrease in the photosynthetic efficiency of microalgae in laboratory tests (Rick et al. 1990). Additionally, a shift in the plankton communities from diatoms to small flagellates is very probable. Such modifications can cause, among others, lasting effects on the whole food chain in the aquatic environment.**
>
> **It must be noted here that the available knowledge about its ecotoxicological relevance in the aquatic environment is absolutely insufficient to issue an environmental label for copper as an anti-fouling agent (Ranke & Jastorff 2000). The same applies to synthetic biocides, such as triazines, diuron and dithiocarbamates, which are added to enhance the effect of copper. These highly toxic additives mainly originate from agricultural sources, where they are used to kill pests and fouling biota (Voulvoulis et al. 1999; Ranke & Jastorff 2000). Nevertheless, there is remarkably little information on their toxicity to marine organisms. As the few available data suggest, they are harmful to micro- and macroalgae, to seagrass and to fish (Peters et al. 1994; Scarlett et al. 1999l Ranke & Jastorff 2000). Laboratory and in-situ studies showed that these**

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substances are highly persistent, so that they pose a chronic threat to the marine environment. For example, one alternative, the triazine biocide Irgarol® 1051, has been used in antifoulant paints and already appears to be causing harm (Evans 1999). Irgarol® is a registered trade name of Ciba Specialty Chemicals, Inc….. It has been detected at concentrations approaching acute toxicity thresholds along the coast of England and in the Mediterranean (Readman et al. 1993; Gough et al. 1994; Tolosa et al. 1996; Thomas et al. 2000). Irgarol® also occurs at concentrations high enough to damage microalgal communities off the west coast of Sweden as well as on the German North and Baltic Sea cost (Dahl & Blanck 1996; Biselli et al. 2000).

... booster biocides in TBT alternatives seem to have the same types of unwanted environmental effects as TBT...

Therefore, according to these findings, the use of these compounds is not a genuine alternative to TBT. In fact, the OSPAR Working Group on Diffuse Sources has warned that booster biocides in TBT alternatives seem to have the same types of unwanted environmental effects as TBT (Evans 2000).[16]

Biocidal antifouling paints carry and release harmful substances into the oceans and ports, and do this more than ever when they are cleaned in the water. The following is from the 15th session of the IMO Sub-committee on Bulk Liquids and Gases, Agenda item 9, of November 2010:

7.8 For immersed areas coated with biocidal anti-fouling coatings, cleaning techniques should be used that minimize release of biocide into the environment. Cleaning heavily fouled anti-fouling coating systems can not only generate bio-fouling debris, but prematurely depletes the anti-fouling coating system and may create a pulse of biocide that can harm the local environment and may impact on future applications by the port authority for the disposal of dredge spoil. Depleted anti-fouling coating systems on hulls will rapidly re-foul. In-water cleaning or scrubbing of hulls for the purpose of delaying dry-dockings beyond the specified service life of the coating is therefore not recommended.[17]

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Whether such coatings are cleaned in the water when in port or not, they pollute the ports. Cleaning the AF coatings causes a pulse discharge of the heavy metal and other biocides. But even when they are not cleaned, throughout their stay in a port, ships bearing biocidal AF paint leach toxic chemicals into the water.

Port authorities and government agencies responsible for the environment are naturally unwilling to have their ports and inland waterways polluted. Their job is to

16 Stefan Nehring, After the TBT Era: Alternative Anti-fouling Paints and their Ecological Risks, Marine Biodiversity Volume 31, Number 2, 341-351, (Jan 2001)

17 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 11

forbid and prevent such pollution.

Dan Rittschof, Associate Professor of Zoology at Duke University Marine Laboratory, sums up the situation with regard to biocides:

> **Existing commercial solutions to fouling are an uncomfortable and increasingly unacceptable compromise between fouling management, corrosion and environmental degradation. Oxidation control measures cause corrosion and have unacceptable environmental impacts. Similarly, broad-spectrum biocides that must be released and diffuse into organisms to kill them have extensive impacts on non-target species and ecosystems. Pressure to find alternative fouling control measures increase as governments become aware of unacceptable environmental impacts [39,40].**[18]

The word "compromise" is key. It is the tendency to compromise that this white paper is addressing.

2. Cleaning of F-R coatings

Modern Foul-Release coatings, either fluoropolymer or silicone-based polymer, make it more difficult for marine fouling (other than biofilm or slime) to adhere; and, when the ship is under way, they tend to release fouling that has adhered, especially when the ship is sailing at higher speeds. Hence the name.

The main problem is that these F-R coatings are well nigh impossible to clean without damaging the surface, which then makes them very prone to fouling.

They do not work on the principle of leaching biocides into the water and, as such, claims have been made that they are non-toxic.

However, silicone F-R coatings release silicone oils into the water. In her paper, *Hazard assessment of silicone oils (polydimethylsiloxanes, PDMS) used in antifouling-/foulrelease-products in the marine environment*, Monika Nendza indicates that these oils can have an adverse impact on marine life:

> **Non-eroding silicone-based coatings can effectively reduce fouling of ship hulls and are an alternative to biocidal and heavy metal-based antifoulings. The products, whose formulations and make up are closely guarded proprietary knowledge, consist of a silicone resin matrix and may contain unbound silicone oils (1-10%). If these oils leach out, they can have impacts on marine environments: PDMS [polydimethylsiloxanes] are persistent, adsorb to suspended particulate matter and may settle into sediment. If oil films build up on sediments, infiltration may inhibit pore water exchange.**
>
> **... At higher exposures, undissolved silicone oil films or droplets can cause physical-mechanic effects with trapping and suffocation of organisms.**

18 Dan Rittschof, "Research on Practical Environmentally Benign Antifouling Coatings," Chapter 27, *Biofouling,* edited by Simone Dürr & Jeremy C. Thomason, Wiley-Blackwell, (November 2010), page 399.

… PDMS make the case that very low water solubility and bioavailability do not necessarily preclude damage to marine environments.[19]

As to their mechanical properties and application, following is a short extract from the book *Biofouling* published in November 2010 by Wiley-Blackwell.

25.4.6 Siloxane–urethane hybrid systems

While silicones appear to be the leading fouling-release coating system to date, silicone elastomer coating systems suffer from several drawbacks.

While silicones appear to be the leading fouling-release coating system to date, silicone elastomer coating systems suffer from several drawbacks. First, silicones are mechanically weak and thus easily damaged by cleaning or docking procedures. Silicone elastomers also have poor adhesion to most substrates and a tie-coat primer is needed to improve the adhesion of the fouling-release coating layer to the anticorrosion primer. This complicates the application of these systems. [20]

Apart from some harmful effects on the marine environment, this points up the problem with many F-R coatings which is that they are not mechanically strong and therefore do not lend themselves to underwater cleaning without damage to the coating.[21]

Once the coating becomes damaged and loses its integrity, fouling attaches much more rapidly. F-R coatings accumulate slime just as readily as any other coating and therefore lose their hydrodynamic advantage rapidly and incur a fuel penalty if not cleaned. Since they do not lend themselves readily to cleaning, this creates a vicious circle.

3. Ships sailing with fouled hulls

The fuel penalty incurred when ships sail with fouled hulls, even if this fouling is limited to slime, has been well documented and is summarized in the paper *The Slime Factor*, the second white paper in this series.[22] The increase in fuel consumption impacts the environment negatively through the extra unnecessary emission of greenhouse gases and atmospheric pollution. The cost of the additional fuel required to overcome the added hull resistance caused by any degree of fouling is far more than the cost of correct hull protection and maintenance, including routine in-water hull cleaning.

Ships sailing with badly fouled hulls also add to the problem of potential translocation of invasive species.

4. The non-indigenous species (NIS) problem

The following short extract from agenda item 9 of the 15th session of the IMO

19 Monika Nendza, "Hazard assessment of silicone oils (polydimethylsiloxanes, PDMS) used in antifouling-/foulrelease-products in the marine environment," Marine Pollution Bulletin 54, no. 8 (August 2007): 1190-1196.

20 Dean C. Webster & Bret J. Chisholm, "New Directions in Antifouling Technology, Chapter 25, *Biofouling,* edited by Simone Dürr & Jeremy C. Thomason, Wiley-Blackwell, (November 2010), page 375.

21 Source: live interviews with underwater hull cleaning divers.

22 Hydrex White Paper No. 2, *The Slime Factor*, January 2011.

Subcommittee on bulk liquids and gases states the problem as it is perceived.

> **In the adoption of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention), Member States of the International Maritime Organization (IMO) made a clear commitment to minimizing the transfer of invasive aquatic species by shipping. Studies have shown that bio-fouling can also be a significant vector for the transfer of invasive aquatic species. Bio-fouling on ships entering the waters of States may result in the establishment of invasive aquatic species which may pose threats to human, animal and plant life, economic and cultural activities and the aquatic environment.**[23]

While it is understandable that port authorities and environmental agencies would not want their waters polluted with additional pulse discharges of heavy metals and other biocides, this risk does not apply to hard, inert coatings such as Surface Treated Composites (STC) which are entirely non-toxic.

Some countries and ports have adopted a policy of entirely banning in-water hull cleaning on all ships. While it is understandable that port authorities and environmental agencies would not want their waters polluted with additional pulse discharges of heavy metals and other biocides, this risk does not apply to hard, inert coatings such as Surface Treated Composites (STC) which are entirely non-toxic. Many ports have recognized this and make a distinction between underwater cleaning of toxic versus non-toxic coatings. An across-the-boards ban appears counterproductive in two major respects. If a vessel arrives in port from another State or port with a badly fouled hull, the NIS which colonize it simply spawn and multiply in the port of arrival, unrestrained, unless the hulls are cleaned upon arrival. NIS are not only translocated by being dislodged in a new environment. That is only half the picture. The other half is the spawning activities of the organisms as they multiply in the invaded port.[24]

There is a second aspect which makes an all-out ban on in-water hull cleaning, even on hulls which will not pollute port waters, counterproductive. If a ship has been in port for some time, the hull will accumulate fouling, especially in warmer waters. If that ship is not allowed to be cleaned before sailing, then it is likely to translocate invasive species from that port to foreign waters where these species are not indigenous, wreaking havoc in the foreign marine ecosystems thus invaded. If the port authorities responsible for regulating the marine environment take the broader view, they will see that in-water hull cleaning of non-toxic hull coatings is in fact the way to prevent both the invasion of home waters by foreign invasive species and the invasion of foreign waters by invasive species emanating from their own waters. Invasive species are, after all a two-way street, both incoming and outgoing.

Not allowing underwater cleaning on non-toxic paints has an adverse effect and promotes the use of toxic AF paint solutions while those toxic AF paints are polluting the ports every day.

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23 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 2

24 John A. Lewis & Ashley D. M. Coutts, "Biofouling Invasions," Chapter 24, *Biofouling,* edited by Simone Dürr & Jeremy C. Thomason, Wiley-Blackwell, (November 2010) pages 348 - 364

5. Frequent drydocking

While frequent drydocking is definitely a way to deal with the situation since high pressure washing in drydock is very effective for removing fouling, it is not practical for a ship to be drydocked frequently. It is too expensive, the facilities do not exist and therefore shipowners will simply avoid it.

Summary

It appears to be somewhat of a "damned if we do and damned if we don't" situation where the current hull coating practices in widespread use are not adequate in themselves to prevent fouling of ship hulls yet are not really suitable routine in-water cleaning. Frequent drydocking is out of the question as it is commercially unviable. And yet ships sailing with fouled hulls, even slime or weed, incur a considerable fuel penalty which results in unnecessarily high GHG emissions and, when the fouling is more advanced, the risk of spreading NIS.

Fortunately there is a way out of this vicious circle.

Part IV. Paving the way to a solution

An answer to ocean pollution

The way to avoid polluting the oceans, ports and inland waterways with toxic chemicals from ship hulls is almost too obvious: only permit coatings on hulls which are proven to be completely non-toxic, non-polluting, not leaching and not harmful in any way to the marine environment. Do not permit ship hulls to be coated with any kind of toxic chemical which leaches into the water. This is cut and dried, black and white. There is no need to compromise and permit substances to be used which are "somewhat less toxic," "poisonous but the poisons are diluted in all those miles of ocean so won't be detrimental to *our* port," or "We don't have adequate proof that these chemicals really are all that harmful." TBT was known to be highly toxic and to be having very destructive effects on the marine environment years before regulations from the IMO finally banned its use. There is a lesson to be learned there.

...today there is at least one class of coating available which does not leach any heavy metals, herbicides, pesticides or harmful oils or any other destructive chemicals into the water.

Perhaps one day, as has been mentioned, scientists will develop the perfect coating which prevents any biofouling, including slime, without being in any way harmful to the marine environment, the aquatic flora and fauna, the food chain or humankind. That would be terrific. It is *not* true of today's crop of biocidal antifouling systems.

However, today there *is* at least one class of coating available which does not leach any heavy metals, herbicides, pesticides or harmful oils or any other destructive chemicals into the water. It is inert. It does not produce any chemical reaction when immersed in sea water or fresh water. This is the class of Surface Treated Composites (STCs). It is not the only inert coating in existence but it is one which provides a workable and viable answer to all the different factors outlined in this paper.

An answer to the fuel penalty and GHG

The way to keep the fuel penalty as low as possible from the point of view of the ship hull is also clear:

1. **Design the hull so that it is hydrodynamically efficient.**
2. **Apply a coating which is smooth, remains smooth and does not add to the hull's resistance.**
3. **Keep the hull free of fouling. Don't sail with even a medium slime. Routine monitoring and in-water cleaning on the right type of hull coating will accomplish this.**
4. **Inspect the ship before sailing and, if the hull is fouled, clean it before leaving port.**

Even if the ship is delayed for half a day before sailing, this time will be made up in the crossing as the clean hull will permit faster sailing with lower fuel consumption. IMO BLG 15/9 Annex 1 pages 9-12 provide detailed recommendations for in-water inspection, cleaning and maintenance which, if followed using trained and experienced personnel to carry out the work, will lead to greatly reduced fuel consumption as well as greatly reducing the NIS risk.[25]

25 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 9-12

An answer to NIS

Ships should be inspected before they sail and cleaned if the hull is fouled. This serves a dual purpose of preventing the spread of NIS and reducing fuel consumption.

Should a ship arrive in port in a heavily fouled state, it should be cleaned as soon as possible, not allowed to remain in port with heavy fouling where the NIS will spawn and the invasive species will spread. Special arrangements can be made to clean such ships so that the debris is collected. This will be expensive, which in itself will discourage shipowners from sailing with heavy fouling. In the end shipowners will save vast amounts of money from sailing with clean hulls.

The greatest economy and benefit is to be gained from routine cleaning. In the case of AF coated hulls, steps must be taken to spread as little of the biocides as possible. Ideally the use of biocidal AF paints will be phased out completely.

In December 2008 a report was written by Marc Geens of Environmental Resources Management entitled *Ecotec-STC Ecospeed: Risk evaluation for the spread of 'alien species' in surface water when using hard coatings on ship hulls.* The entire report is highly relevant to the subject of this white paper and well worth reading. The conclusion is given here:

> **Literature research indicates that a regular removal of a biofilm implies no demonstrable risks for the spread of alien species as long as this happens before mobile spores are formed by the organisms constituting the biofilm. A proper inspection is therefore required.**
>
> **The developing biofilm consists mainly of micro-organisms. Up to now, no studies documenting the introduction of alien species by this kind of biofilm are known. Only for the cholerabacil, is the transportation by ship documented. Probably, this cholerabacil is spread by infected ballast water.**
>
> **A frequent check and cleaning of the coated parts of the ship offers the benefit that the hidden places can be cleaned as well. It seems that these kind of places often carry fully grown biofouling organisms and therefore form a reservoir for colonization of new environments by the present organisms.**
>
> **The literature has not put forward any argument that indicates that viable alien macro-organisms could still be spread to foreign regions if ship hulls are timely cleaned underwater. Moreover, a regular monitoring of the biofouling contains an additional guarantee that no fully-grown alien organisms are present at the coated underwater parts, so the risk for the development of viable migration stages is almost impossible compared to the conventional coatings used until today.**[26]

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26 Marc Geens, "Ecotec-STC: Ecospeed: Risk evaluation for the spread of "alien species" in surface water when using hard coatings on ship hulls," December 2008.

The IMO is certainly taking the view that in-water cleaning is an integral part of dealing with the NIS threat as the following quotes from the Bulk Liquids and Gases Sub-committee reports show:

> **….Member States may wish to require mandatory hull cleaning to have been undertaken prior to ships crossing their 200 miles Exclusive Economic Zone or prior to the ship leaving its laying up anchorage. The Sub-Committee may wish to direct the Bio-fouling Working Group to consider the matter and recommend appropriate action.**[27]
>
> …
>
> **4.4 A ship following this guidance and [maintaining a microfouling layer] [without any macrofouling] would [be considered a clean ship and would] have a very low potential for transferring invasive aquatic species.**[28]

An answer for ports, Port Authorities and States

Ports would do well to permit and encourage in-water cleaning of hulls coated with non-toxic coatings before ships sail.

1. Many ports already differentiate between hulls coated with toxic coatings, where in-water cleaning can be especially damaging to the port environment, and those coated with non-toxic, non-polluting coatings where cleaning presents no threat. All ports should consider this distinction.
2. Ports would do well to permit and encourage in-water cleaning of hulls coated with non-toxic coatings before ships sail.
3. Ports would also be wise to permit and encourage in-water cleaning of inbound ships, as long as these are coated with non-toxic coatings and the fouling falls within the slime/weed stage.
4. Special provision should be made by ports for the cleaning of ships coated with non-toxic coatings that arrive heavily fouled. They must be cleaned immediately because every day in port the NIS they carry may be spawning. They must be cleaned, preferably at anchor, and the debris collected. This will be expensive but may encourage shipowners to clean before sailing to a foreign port.
5. Ports could consider instituting penalties for ships arriving with a toxic coated and/or badly fouled hull by increasing port fees, and reward ships sailing with a non-toxic, clean hull by reducing their port fees.
6. Until ships generally convert to hard, non-toxic underwater hull coatings, light cleaning on slime or light weed even on traditionally coated hulls or F-R coatings is probably preferable to no cleaning at all, but each port would need to assess the risks in its unique situation and circumstances. This approach is recommended by the IMO:

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27 IMO BLG 14/INF.4 Sub-committee on bulk liquids and gases, 14th session, Agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships

28 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9 Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 4

> **7.5 In-water cleaning can be an important part of bio-fouling management. In-water cleaning can also introduce different degrees of environmental risk, depending on the nature of bio-fouling (i.e. microfouling versus macrofouling), the amount of anti-fouling coating system residue released and the biocidal content of the anti-fouling coating system. Relative to macrofouling, microfouling can be removed with gentler techniques that minimize degradation of the anti-fouling coating system and/or biocide release. Microfouling removal may enhance a ship's hull efficiency, reducing fuel consumption and greenhouse gas emissions. It is therefore recommended that the ship's hull is cleaned when practicable by soft methods if significant microfouling occurs. In-water cleaning can also reduce the risk of spreading invasive aquatic species by preventing macrofouling accumulation.**[29]

Benefits for all

Who benefits from this approach? Just about everyone involved.

Shipowners and operators save huge amounts of money by reducing fuel consumption. They also have the satisfaction of knowing that their ships are playing their part as "good citizens" in terms of eliminating ocean pollution caused by biocidal hull coatings, reducing GHG as far as possible and preventing the spread of NIS.

Port authorities and government officials responsible for the environment benefit by eliminating the pollution of their ports and the spread of NIS.

Again, the IMO states it very clearly.

Port authorities and government officials responsible for the environment benefit by eliminating the pollution of their ports and the spread of NIS.

> **Implementing practices to control and manage bio-fouling can greatly assist in reducing the risk of the transfer of invasive aquatic species. Such management practices can also improve a ship's hydrodynamic performance and can be effective tools in enhancing energy efficiency and reducing air emissions from ships. This concept has been identified by the IMO in the "Guidance for the development of a ship energy efficiency management plan (SEEMP)" (MEPC.1/Circ.683).**[30]

What exactly is the new, best practice approach?

A hard STC is applied which lasts the lifetime of the ship. The hull is thoroughly prepared so that the coating adheres perfectly. This will guarantee its lasting the lifetime of the ship.

If a ship currently has an AF or F-R coating, this should be replaced at the first opportunity with a hard STC coating which is entirely non-toxic and which can be cleaned repeatedly in the water without suffering any damage and, in fact, with

29 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9, Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 10

30 IMO Subcommittee on bulk liquids and gases, 15th session, agenda item 9, Development of international measures for minimizing the transfer of invasive aquatic species through bio-fouling of ships (12 Nov 2010), Annex 1, page 2

improvement after each cleaning.

If a ship has lain idle for some time at a port so that the hull has become fouled to any degree, the hull should be cleaned in the water before the vessel sails. The hull would be inspected after the cleaning, ideally by a classification society, and given a clean bill of health.

The ship thus sails at optimum performance, resulting in minimal fuel consumption and therefore minimal GHG emissions.

Arriving at a foreign port, the ship presents a certificate from a classification society or some other qualified body showing that

1. **the hull coating is non-toxic, non-polluting**
2. **the hull was 100% clean on sailing and therefore on arrival** (ships generally pick up no fouling when sailing).

Applied consistently by all ports, this approach will eventually bring about a very desirable result: the ports will remain clean, ships will sail with unfouled hulls, fuel consumption will drop, GHG will be reduced, NIS will not be spread.

The port of arrival rewards such a ship with reduced port fees. The opposite also applies. If a ship arrives with a biocidal antifouling system and in a heavily fouled state, the Port Authority imposes a penalty and requires that it be cleaned immediately, with precautions taken to reduce pollution and prevent the spread of NIS.

If the ship remains any significant length of time in the port of arrival so that fouling builds up, it is again cleaned in the water in port (preferably at anchor, not quayside) and a certificate is again issued before she sails.

Applied consistently by all ports, this approach will eventually bring about a very desirable result: the ports will remain clean, ships will sail with unfouled hulls, fuel consumption will drop, GHG will be reduced, NIS will not be spread.

Part V. Case studies

The Netherlands

The Dutch government has shown that it is, quite rightly, very concerned about the pollution of its waterways and ports. Prior to 1960 it was safe to swim in the Rhine, and the city of Rotterdam used the river water from the Meuse as drinking water. All this changed in the 60s and strict measures had to be introduced in the December 1970 Surface Water Pollution Act which have done much to rectify the pollution which then became widespread.

The Netherlands was one of the first countries to ban in-water cleaning of ship hulls so as to avoid the pulse release of TBT. In the late 1990s, the Dutch government announced that no Dutch government vessel would use TBT after 2000, long before the international ban. In 2003 it was the Dutch government which proposed a ban on copper-based antifouling paint.

Today the Netherlands bans, and has banned for many years, underwater cleaning in Dutch waters of hulls coated with copper-based antifouling paint.

...on February 15th, 2010, the State Secretary of Transport and Water Management granted a special permit, an exception to its ban on underwater cleaning in Dutch ports. This special permit allowed in-water cleaning of ships coated with a Surface Treated Composite (STC), specifically Ecospeed.

It is therefore quite significant that on February 15th, 2010, the State Secretary of Transport and Water Management granted a special permit, an exception to its ban on underwater cleaning in Dutch ports. This special permit allowed in-water cleaning of ships coated with a Surface Treated Composite (STC), specifically Ecospeed. This is a specific exception to the long-standing Netherlands ban on all underwater hull cleaning in Dutch ports.

It was in 2005 that Hydrex reapplied for a permit to perform underwater maintenance and cleaning on hulls coated with Ecospeed. Extensive testing was done by the Dutch government which culminated in the Ordinance of 15 Feb 2010 which permitted underwater hull cleaning on hulls coated with Ecospeed.

The entire Ordinance of 15 Feb 2010, RWS/DZL-2010/869, *Ordinance of underwater polishing and cleaning of ships which are provided with the Ecospeed type coating*,[31] is well worth reading as it clearly states the background, the extensive prior testing that was carried out and the reasoning behind this unusual exception to the ban on underwater hull cleaning in the Netherlands. It is a model which all ports could emulate.

The decision expressed by the Ordinance was to grant Hydrex NV a permit for the in-water cleaning in a number of Dutch ports of ship hulls coated with Ecospeed. Certain conditions were stipulated. The fouling has to be no more severe than slime, weed or algae. The type of cleaning equipment and brushes used was specified. The Ordinance required a report ahead of time showing that the hull to be cleaned was coated with Ecospeed, along with an inspection report indicating the level of fouling on the hull.

The extensive testing carried out by the Dutch government prior to issuing this special permit showed conclusively that there was no adverse environmental effect

31 Dutch State Secretary of Transport and Water Management Ordinance of underwater polishing and cleaning of ships which are provided with the Ecospeed type coating, 15 Feb 2010.

from any aspect of in-water cleaning of Ecospeed coated hulls:

Tested in test containers

Toxicity and estrogenic testing on trial plates coated with Ecospeed in test containers showed no noticeable effects of any consequence. The situation in the test containers can be regarded as a 'worst case scenario' situation, because in practice a significant dilution takes place in the surface water during the underwater curing. Considering the research results, no adverse effects are expected from the cured Ecospeed coating underwater.

The extensive testing carried out by the Dutch government prior to issuing this special permit showed conclusively that there was no adverse environmental effect from any aspect of in-water cleaning of Ecospeed coated hulls

Emissions during polishing

During polishing, floating particles are expected to be released, depending on the duration of curing before polishing – a small amount of styrene which has no toxic effects. Furthermore, a small amount of harder component, diisobutyl phthalate (DIBP)) will be released. The research results submitted by the company showed that ... under worst case scenarios no adverse effects were present from the release of these substances.

Emissions during cleaning

The cleaning of the ships shall periodically take place to remove organisms from the ship. An additional advantage of this method of work performance is that it gets done while ships can be loaded/unloaded.

When cleaning, where the coating is fully cured, the surface structure of the coating Ecospeed becomes slightly smoothed and can release negligible quantities of chemicals. However when cleaning, more suspended solids will be released, largely consisting of loose pieces of fouling. Because this fouling is of organic nature, the company expects no adverse effects for the surface water.

...

4.4.2 Review the best available techniques (BAT)

In general, BAT with respect to treatment of ships' hulls has been to protect them with antifouling coatings. The application and removal of these coatings has so far normally been carried out in drydock. Within the drydock environment many measures are taken to prevent pollution of the water by material removed during this activity. This is considered BAT.

The technique of treatment covered by this ordinance is different, namely the underwater cleaning and polishing of ships whose hulls are coated with Ecospeed. Ecospeed is a type of synthetic material without antifouling/biocide which is very hard and is polished very smooth.

This method of preserving ships' hulls is new and so is the request for its treatment. In view of the earlier mentioned researches this method of treatment is considered as more environmentally friendly than the traditional method of preservation and handling of ships' hulls. Indeed, there are no toxic substances used.

….

At this time of writing, according to Mr. Thijs Poortvliet of the Netherlands Ministry of Public Works and Waterways, Ecospeed STC is the only underwater hull coating which may be cleaned in Dutch ports. Various entities such as shipyards in the Netherlands tried to appeal the Ordinance and have it rescinded and each such appeal was reviewed but none prevailed, and the decision outlined in the 15th Feb 2010 Ordinance was upheld by the Dutch authorities.

The Ordinance specifically granted permission for in-water cleaning of ship hulls at the following ports, as long as those hulls were coated with Ecospeed:

Province Zuid-Holland:
- Rotterdam
- Schiedam
- Vlaardingen
- Scheveningen
- Moerdijk
- Dordrecht
- Papendrecht
- Zwijndrecht

Province Zeeland:
- Vlissingen
- Zierikzee
- Yerseke
- Terneuzen
- Breskens

Province Groningen:
- Eemshaven
- Delfzijl

Province Friesland:
- Harlingen

Many shipowners and operators have taken and are taking advantage of this special permit to have their Ecospeed coated ships cleaned in Dutch ports.

The situation with other ports around the world

The rules and regulations for in-water cleaning of ship hulls varies from country to country and from port to port.

The following ports normally do not permit in-water hull cleaning but have made an exception for hulls coated with Ecospeed:

Port of Antwerp
The Port of Antwerp has authorized the in-water cleaning of ships coated with Ecospeed.

Port of Ghent
The Port of Ghent has also authorized the in-water cleaning of ships coated with Ecospeed.

Port of Oslo
In February 2010, the Port of Oslo approved the in-port underwater cleaning of the Disney *Magic's* hull (coated with Ecospeed).

> **Based on our evaluation of the supporting documentation in your request, we find that since the hull coating does not harm the environment we are positive of your request. Port of Oslo is therefore pleased to inform you that Disney *Magic's* request for hull cleaning while at berth in Port of Oslo in 2010 is approved.**[32]

Port of Helsinki
In-water cleaning of vessels coated with Ecospeed is permitted in the Port of Helsinki.

This is an expanding list and it is expected that many more ports will permit in-water cleaning of ship hulls as long as the guidelines in this white paper are followed.

32 Anne Sigrid Hamran, Port Director, Port of Oslo, Norway, letter of 23 Feb 2010.

Part VI. Ecospeed STC

While there are a number of hard coatings (epoxy based and others) for underwater hull coatings on the market today, the only one known to us at time of writing which lasts the lifetime of the ship, comes with a 10-year guarantee and is extremely hard, corrosion and cavitation resistant, while remaining flexible, is Ecospeed, a product of Hydrex NV.

Not just a coating, the STC Ecospeed is a system which combines an extremely hard, durable coating consisting of relatively large glass platelets in a vinyl ester resin base, with routine in-water cleaning. Hydrex has developed a line of underwater cleaning equipment and has a team of trained divers who are expert in its use and experienced in cleaning Ecospeed coated hulls as well as hulls in general. The Hydrex group also offers hull monitoring and inspection services in addition to carrying out all levels of underwater repairs to ships.

The Ecospeed system has been in use since 2003 on many and varied ship hulls. So far in the intervening years no hull has needed to be recoated, and only minor touch-ups have been carried out in drydock.

The coating improves with each hull cleaning, becoming more hydrodynamically smooth and less prone to fouling under the combined action of the in-water cleaning brushes with the hydraulic action of the water.

Ships using Ecospeed per specifications have noted speed increases from 16 knots to 20 knots when the old coating was removed and Ecospeed was applied and conditioned.

Ships using Ecospeed per specifications have noted speed increases from 16 knots to 20 knots when the old coating was removed and Ecospeed was applied and conditioned. In fact, the results of ships using Ecospeed have exceeded the initial sea speed trials, since the coating is smoother and offers less friction than a typical unfouled AF coated hull.

A full description of the Ecospeed system can be found in the EU LIFE Project ECOTEC-STC LIFE06 ENV/B/000362 *ECOTEC-STC: Evaluation of a biocide-free hull protection and antifouling system with environmental and economical benefits, Layman's Report.* This report is available on request and can be downloaded at www.hydrex.be/sources/pdf/Laymans_Report.pdf [33]

A number of other reports on the subject can be found at the following web page: www.hydrex.be/life_reports.htm

The Hydrex Group

The Hydrex Group, an international underwater hull performance, protection, monitoring, maintenance and repair organization, is one of several suppliers capable of delivering high quality in-water ship hull cleaning on a global basis.

Not only has Hydrex developed Ecospeed as the ideal underwater hull coating, but has also invented and engineered a full line of advanced hydraulic underwater hull cleaning equipment designed specially to condition and clean Ecospeed-coated hulls, which is also usable on any other hull coating. It has developed methods of

33 EU LIFE Project ECOTEC-STC LIFE06 ENV/B/000362 ECOTEC-STC: Evaluation of a biocide-free hull protection and antifouling system with environmental and economical benefits, Layman's Report

containing heavy fouling debris cleaned off badly fouled hulls.

Hydrex has also recruited and trained a team of underwater hull cleaning and repair experts to deliver standard cleaning and repair of a very high quality. In addition to setting up satellite offices in strategic locations, the company has built up a network of local suppliers of underwater hull inspection, cleaning and repair as well as propeller polishing and related underwater hull services. In this way Hydrex guarantees its underwater hull maintenance and repair services around the world. Ecospeed itself is guaranteed to last intact on the hull for a full 10 years and that is a conservative guarantee which the company is currently considering extending.

Hydrex has been developing its own underwater hull protection and maintenance system for several decades, based on an equal concern for the avoidance of pollution of the oceans and air and for the economic benefits to be derived from keeping ship hulls free of fouling, thus reducing fuel consumption and emissions. All these factors have been taken into account and the best possible approach to the problem of hull protection and fouling has been developed.

Inquiries and information

We invite inquiries. We stand by to answer questions, provide references, disseminate information and help you with your specific vessel or fleet situations.

Free initial consultation for your vessel of fleet

We offer a free initial consultation to any shipowner, operator, charterer, navy representative, government official or officer, academic institution and anyone else who can benefit from the most advanced approach we know to the problems of underwater ship hull performance.

Future white papers and journal

We will be writing and distributing a series of white papers, each of which will go into one or more aspects of underwater ship hull performance in more depth and detail. This is the third white paper in the series. White papers No 1 & 2 are available for download at http://www.hydrex.be/white_papers.htm and printed copies can be requested free of charge. Much of the information in these white papers has already been researched and written up but this is often in highly technical papers of specialized distribution not necessarily easy for shipowners and operators to digest.

In early 2011 Hydrex launched a quarterly *Journal of Ship Hull Performance* featuring these white papers as well as related articles, news and information of interest to shipowners, operators and other decision makers in the marine industry.

If you would like to receive these white papers and/or the journal on an ongoing basis, please sign up on line at http://eepurl.com/ck9Tb or write to us, email us or phone us with your request. Let us know if you prefer electronic or printed copies of the white papers and journals. These are all provided to you free of charge and without obligation.

Vessel or fleet operational costs assessment

Find out if your operational costs for your vessel(s) or your fleet could be drastically reduced by changing your approach to underwater hull protection and maintenance.

To obtain a free initial consultation on ship hull performance for your vessel(s) or fleet simply send an email to the following email address with "Free Consultancy" in the subject line and information about your vessel or fleet and an expert will get back to you promptly:

performance@hydrex.be

To find out more about Ecospeed and Hydrex, visit the following websites:

www.hydrex.be

www.hydrex.us

www.ecospeed.be

If you would like to be added to the mailing list for future white papers on ship hull performance and related subjects and/or copies of the quarterly journal *Ship Hull Performance* please send us your request at the following email address:

publications@hydrex.us

For comments, input, information about the content of this white paper or any communication relating to it, please send an email to the above email address and we will respond.

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