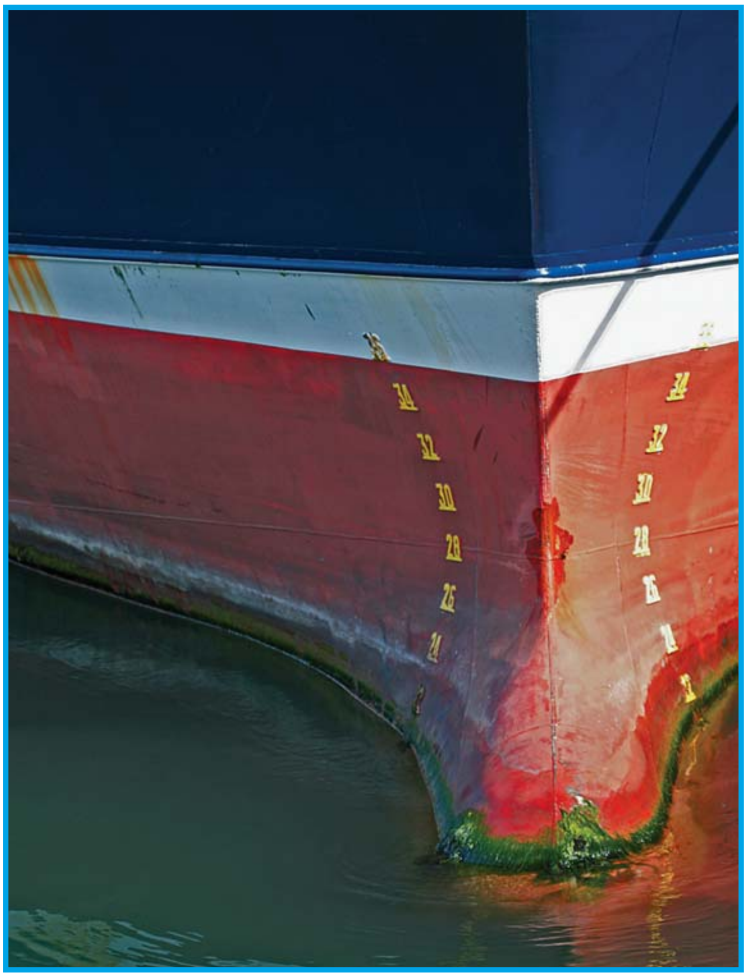
HYDREX WHITE PAPER N°1

WHITE PAPER

Ship Hull Performance in the Post-TBT Era



How to save money while improving hull performance and dramatically reducing environmental impact

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HYDREX

UNDERWATER TECHNOLOGY

Part I. Introduction

The marine fouling problem

Some facts and figures will help put into perspective the substance of this paper on marine fouling and the potential economic and environmental benefits which can be achieved from a correct address to the problem.

- Lloyd's Register–Fairplay put the world fleet at 100, 243 vessels in 2007.
- World fleet fuel consumption (excluding military) estimated at 333 million tonnes.
- Taking the price of bunker fuel at $470 per tonne (at time of writing) shows a total expenditure of $156.51 billion per year on bunker fuel for the non-military world fleet.
- CO_2 (carbon dioxide) emissions estimated at 1,050 million tonnes per year.
- NO_x (nitrous oxides) emissions estimated at 25 million tonnes per year.
- SO_x (sulfur oxides) emissions estimated at 15 million tonnes per year.

(CO_2, NO_x, SO_x are among the key greenhouse gases which international organizations are working hard to reduce.)[1]

The same IMO report has the following explanation of the use of the energy generated by the fuel provided to the ship's engines, taking a well-maintained cargo ship as an example:

> In this case, 43% of the fuel energy is converted into shaft power while the remaining energy is lost in the exhaust or as heat losses. Due to further losses in the propeller and transmission, only 28% of the energy from the fuel that is fed to the main engine generates propulsion thrust in this example. The rest of the energy ends up as heat, as exhaust, and as transmission and propeller losses. The majority of these remaining 28% are spent overcoming hull friction....

You can see from this example that overcoming hull friction takes up a very high percentage of the energy generated by the ship's engines.

Hull friction is a highly variable figure, depending, if one assumes an efficient hull design and construction, on hull smoothness and the degree of marine fouling accumulated on the hull.

Keeping a ship's hull clean of even a small degree of accumulated fouling (slime) and ensuring the coating is in good condition and smooth can save about 20% of fuel consumption. Thus if the entire world fleet were kept clean of slime (assuming well-coated, smooth hulls), the savings in fuel in a year would be 66 million tonnes based on the IMO figures given above. This adds up to a savings of $31.2 billion per year. The reduction in greenhouse gas emissions would be proportional. And that is just with slime. A heavily fouled hull can require as much as 80% more power to propel the vessel at the same speed[2].

These figures are estimates, but they give an idea of the orders of magnitude involved. Marine fouling is a major issue for ships. It has a serious impact on the economics of shipping, and its handling can have major effects on the environment.

Marine fouling has always been a liability for any ship owner or operator since man first

1 Second IMO GHG Study 2009.

2 Michael P. Schultz, "Effects of coating roughness and biofouling on ship resistance and powering," Biofouling, 23-5, 331-341,(2007), DOI: 10.1080/08927010701461974.

...increases in fuel consumption which can be as much as 40%....

took to the sea in ships. The build-up of microorganisms, beginning with light slime and continuing all the way through to heavy barnacles and other hard fouling, adds drag and weight to the hull which then results in increases in fuel consumption which can be as much as 40% according to the US Navy[3]. Especially with today's rising fuel prices, this can mean a major increase in the cost of running a ship or a fleet.

Over the centuries there have been a number of solutions to this problem of fouling, most of which have simply become new problems. For a while, in the latter part of the 20th century, the marine industry thought the problem was solved with an antifouling paint which contained tin compounds such as tributyl-tin (TBT). While this was effective in preventing fouling, it was found to be extremely toxic and harmful to the marine environment, and tin was banned, and finally ceased to be used in antifouling paints in 2008. In general, the worst solutions attempted have been those which apparently provided the benefits of keeping a ship hull free of fouling but did so at the expense of pollution and poisoning of the inland waters, ports, oceans and the food chain.

The "post-TBT" era is a somewhat confusing one. The most common replacement for the TBT-based antifoulants has been antifouling paint which leaches copper and other biocides into the water to kill the marine life which fouls the hull. This solution has proved to be less effective than the TBT-based predecessor while still continuing the pollution of the oceans and waterways with a combination of poisons, perhaps less harmful than TBT but toxic nonetheless. These antifoulants (AF), also known as Self-Polishing Copolymers (SPC) do not last long, requiring frequent replacement in drydock, and cannot be cleaned in the water without causing even heavier pollution and reducing the life of the paint on the hull.

Estimates place the amount of copper leached into the oceans and waterways by ships using copper-based antifouling paint at over 1 million tonnes annually.[4]

Other solutions in the post-TBT era include "foul-release" silicone hull coatings but these have proved to be easily damaged, not very lasting and not suitable for regular in-water hull cleaning. They also pose an environmental hazard of their own.[5]

Recently the problem has been compounded by research into the transfer of invasive, non-indigenous ("alien") marine species which may attach themselves to the ship hull and be displaced in foreign ports and waters, posing a potential hazard to the local marine environment thus "invaded." Research has shown that existing heavy metal based antifoulings have the potential of worsening rather than preventing the problem of invasive, non-indigenous aquatic species.[6]

The real solution

Common sense dictates that a solution to the problem of marine fouling would meet the following criteria:

- Provide maximum protection against corrosion and cavitation for the lifetime of the vessel without the need of repainting.
- Be cost efficient, not only in terms of being economical to apply and maintain, but also in terms of saving fuel costs, reducing out-of-operation or off-hire time for the vessel, requiring minimal drydocking time and not needing to be

3 Daniel Kane, Hull and Propeller Performance Monitoring: Fuel Conversion and Emissions Reduction, in Climate Change and Ships: Increasing Energy Efficiency, Proceedings, SNAME, February 16-17, 2010.

4 JunLian Wang et. al., "A survey analysis of heavy metals bio-accumulation in internal organs of sea shell animals affected by the sustainable pollution of antifouling paints used for ships anchored at some domestic maritime spaces," Chinese Science Bulletin (2008).

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 Richard F. Piola, Katherine A. Dafforn, and Emma L. Johnston, "The influence of antifouling practices on marine invasions," Biofouling, 25, no. 7, (2009): 633 - 644.

replaced during the lifetime of the ship.

- Not harm the marine environment in any way. This includes not leaching any bio-cides or harmful substances, and also acting to prevent the spread of non-indigenous species. The solution must be non-toxic, contain no bio-cides, not harm the marine environment or the food chain.
- Result in improved performance, thus increasing hull efficiency and significantly reducing fuel consumption over time.
- Allowing fast, easy, preventative in-water ship hull cleaning in a environ-mentally safe way.
- Be easy to apply and to maintain.
- Reduce time in drydock and frequency of drydocking.

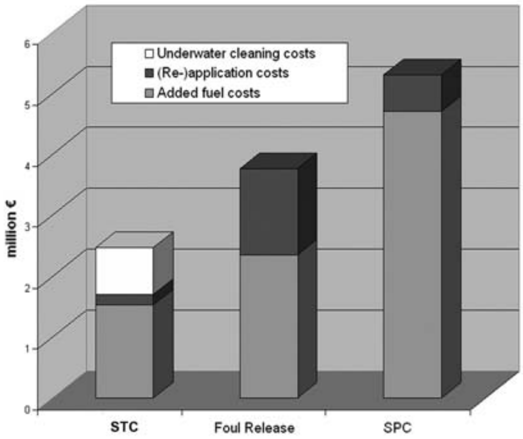
The real solution rules out paints which have a leaching function of any kind....

The real solution rules out paints which have a leaching function of any kind into the water; we have already seen what happened with TBT. Copper oxides and various herbicides are all pollutants.

It also precludes coatings which need frequent replacement or which cannot stand up to routine in-water cleaning. Frequent drydock cleaning has proved to be economically unviable, whereas regular inspections and preventative in-water cleaning based on monitoring result in great financial savings and become a completely viable approach if performed efficiently and well.

Paints which have an active ingredient, by their very nature, are unsuitable for the purpose of protecting a ship hull. By contrast, a hard coating which contains no active ingredients but is as inert and long lasting as possible, provides excellent hull protection and is easy to keep clean of fouling. The ideal coating would actually improve in smoothness and performance over time.

Solving this problem may seem daunting. However, there is a solution which combines a hard, durable non-toxic hull coating, with advanced in-water hull cleaning technology. This solution, known as Surface Treated Composite (STC), answers all aspects of the problem when fully implemented, is entirely environmentally safe, and can save ship owners and operators millions of dollars annually in operational costs.[7]



(Fig. 1) This chart compares the estimated economical impact (in million €) over 25 years for a 1000-TEU container vessel using three different underwater hull coatings. In the chart, STC (Surface Treated Composite) refers to a combination of a hard coating with regular underwater cleaning. Foul Release is a current generation silicone foul release coating. SPC (self-polishing copolymer) is a typical copper-oxide and booster biocide leaching hull paint of the type in common use. The chart shows the savings possible for a single vessel. Other costs such as off-hire time have not been considered in this chart, but these add considerably to the overall picture when the frequent drydockings needed to replace the Foul Release and SPC are borne in mind, since the STC in this case lasts the lifetime of the ship and needs no replacing. (ibid)

Use of such a hard coating with advanced in-water hull cleaning technology results in zero emission of toxic substances into the water, yields substantial savings on fuel consumption thus reducing CO_2 emissions, has been proven to be extremely corrosion and cavitation resistant, lasts the lifetime

7 "ECOTEC-STC: Evaluation of a biocide-free hull protection and antifouling system with environmental and economical benefits," EU LIFE Project ECOTEC-STC LIFE06 ENV/B/000362 (2006).

of the ship, and eliminates the need for drydocking solely due to deterioration of hull coating. If the cleaning is carried out regularly before fouling is allowed to build up beyond the light stage, it also helps curtail the spread of invasive, non-indigenous species. This approach (STC) to antifouling has been in use for nearly a decade and has passed every test. It is no longer experimental.

Goal of this paper

The purpose of this white paper is to discuss the economic and environmental aspects of this advanced underwater hull protection (STC) and maintenance technology and present the facts so that ship owners, operators and all those interested in effectively addressing the marine fouling issue can see that there is a solution which is cost-effective, which will result in huge savings compared to the technology and approaches currently in widespread use, and which is entirely non-toxic and safe for the environment.

Part II. Trends in antifouling

Antifouling solutions are tending more and more to move away from harmful, biocide-leaching antifouling paints towards the use of new-technology solutions which do not harm the marine environment and food chain. Forward-thinking ship owners and operators are recognizing the sense in refusing to pour poisons into the oceans in the name of antifouling and at the same time are saving very large sums of money by using permanent hard coatings and regular in-water cleaning which keeps ship hull performance at optimum without risking the spread of invasive non-indigenous aquatic species.

This trend has been clear since as early as the beginning of the 21st century.

Environmental concerns

In October 2001, the IMO International Conference on the Control of Harmful Anti-Fouling Systems for Ships, in Agenda item 8, included the following points:

> RECOGNIZING the importance of protecting the marine environment and human health from adverse effects of anti-fouling systems,
>
> RECOGNIZING ALSO that the use of anti-fouling systems to prevent the build-up of organisms on the surface of ships is of critical importance to efficient commerce, shipping and impeding the spread of harmful aquatic organisms and pathogens,
>
> RECOGNIZING FURTHER the need to continue to develop anti-fouling systems which are effective and environmentally safe and to promote the substitution of harmful systems by less harmful systems or preferably harmless systems,

and agreed to the following:

> ...
>
> The Parties undertake to encourage the continued development of anti-fouling systems that are effective and environmentally safe.[8]

It was well known at the time of that conference that tributyl-tin (TBT) biocide leaching antifoulants were extremely harmful to the environment. However, it wasn't until seven years later that the use of TBT as an antifoulant was completely ended.

Copper Oxide and Other Biocides

A less potent biocide leaching type of paint became the main replacement for TBT-bearing antifoulants (AF), using the key active ingredient of copper oxide but also leaching "booster biocides." This paint has a relatively short lifespan which means frequent drydocking so that the hull can be repainted since the active ingredient, leached continually into the water in ports, waterways and the oceans, must by its nature "wear out." While they do not contain TBT, the fact remains that these copper-based antifouling paints leach poisonous substances into the oceans and can hardly be termed "environ-

8 IMO, International Conference on the Control of Harmful Anti-fouling Systems for Ships, Agenda item 8 AFS/CONF/26 (18 October 2001): 1-3.

mentally safe." They perhaps meet the IMO's hopes for a "less harmful system" than TBT but certainly not that of a "harmless system."

Hulls painted with copper-based antifouling paint cannot be cleaned in the water without causing a sudden, heavy discharge of copper and other biocides. Mark Ingle of Naval Sea Systems Command (NAVSEA) reported to attendants at the National Paint & Coatings Association International Marine & Offshore Coatings Expo in June 2007 that a single hull cleaning can remove 30 - 51% of one entire coat of antifouling paint.[9]

... a single hull cleaning can remove 30 - 51% of one entire coat of antifouling paint.

This has contributed to a number of ports and regions banning in-water hull cleaning completely for fear of pollution. Other port authorities who have conducted extensive tests, permit in-water cleaning of non-toxic coatings while forbidding in-water cleaning on hulls coated with copper- and other biocide-based paints.[10] This type of coating also deteriorates with each cleaning, increasing skin drag and defeating the purpose of having a smooth hull. Partial repainting of the hull without entirely removing the previous coat results in roughness and impaired hydrodynamics.

An article entitled "Challenges for the Development of New Non-Toxic Antifouling Solutions" appeared in the International Journal of Molecular Sciences in October 2009 outlining the dangers of Post TBT AF paints. An excerpt follows:

> During the 60s the chemical industry developed efficient AF paints using organotin compounds: tributyltin (TBT) and triphenyltin (TPT). These chemicals were highly toxic for many aquatic organisms and have been proven to contaminate the food chain and to be persistent in the environment. Since the ban of TBT-based paints (September 2008, AFS Treaty [2]), new formulation[s] have been developed containing high levels of copper and herbicides such as Irgarol 1051, diuron, chlorothalonil, dichlorofuanid and zineb. However, even if these paints claimed to be environmentally friendly when first put on the market, there are now evidences of a wide spread of these compounds in many countries (Europe, North America and Japan) with significant concentrations in marinas and harbours [8]. In addition, it has been stated that bacteria which are in contact with AF paints can develop rapidly resistance to biocides, especially in estuaries [9,10], where most of the boats and aquaculture structures are moored. An important factor contributing to resistance is the shift of resistant bacteria to new areas due to their presence as fouling organisms in ballast waters or on ship's hulls.[11]

At the June 2002 National Paint and Coatings Association meeting, Senior Engineer, Coatings, Naval Sea Systems Command (NAVSEA), Mr. Mark Ingle, discussed in detail the US Navy's stance on antifoulants.[12] This presentation included the facts that emissions from antifouling coatings are an identified discharge under the Uniform National Discharge Standards (UNDS) program, that Canada had placed limits on copper emissions from antifouling paints, that the Netherlands had forbidden in-water cleaning of ships with copper-leaching coatings and other indicators that copper-based antifoulants were on the way out, following in the footsteps of their TBT-leaching predecessors.

9 Mark Ingle, Presentation to National Paint & Coatings Association International Marine & Offshore Coatings Expo (June 2007): 35.
10 Ordinance of 15 February 2010 from the State Secretary of Transport and Water Management of the Netherlands: "Ordinance of underwater polishing and cleaning of ships which are provided with the Ecospeed type coating."
11 Jean-Phillipe Maréchal, Claire Hellio, "Challenges for the Development of New Non-Toxic Antifouling Solutions," International Journal of Molecular Science 10 (2009): 4623-4637; doi:10.3390/ijms10114623.
12 Mark Ingle, "Naval Sea Systems Command Antifouling Program" (presentation at National Paints & Coatings Association meeting June 2002.

As early as September 2000, a brief article in the US Navy magazine *All Hands* stated the Navy's position on ocean pollution with regard to biocides in antifoulants.

> The Naval Sea Systems Command Materials Engineering Directorate (NAVSEA 05M) is developing new underwater-hull coatings to improve the coastal marine environment by reducing or eliminating the amount of copper released from the anti-fouling paint on U.S. Navy ships.
>
> Today, the Navy and many commercial ship owners use specialized, copper-oxide-bearing paints on underwater portions of a ship's hull to prevent the growth of marine organisms such as barnacles, tubeworms and sea grasses. A fouled hull can reduce a ship's speed by 5 percent and increase fuel consumption by 40 percent. The downside is that copper is a biocide that can kill marine life even after the metal is deposited in sediments.
>
> To prevent pollution, NAVSEA initiated a program this year to develop new underwater-hull coating technologies that prevent fouling without releasing copper or other pollutants into the water.
>
> ...
>
> "Copper-free, anti-fouling coatings are the right answer for everyone," said Ingle. "I'm proud that the Navy is leading the way."[13]

A fouled hull can reduce a ship's speed by 5 percent and increase fuel consumption by 40 percent.

Unfortunately, ten years later, the US Navy is still using heavy copper and biocide laden paints on the majority of its ships and combining this with underwater cleaning which causes heavy discharges of the pollutants. And the Navy is not alone in this practice. Close to 100% of the vessels afloat today are using antiquated, environmentally-unfriendly antifouling paints which pour tons of copper and other biocides into the oceans every year, with apparent disregard for the consequences to the marine environment. This is all the harder to understand since the dangers are known and alternative technology exists which has been proven safe to the environment and which, if implemented correctly, is extremely cost-effective and can save shipowners and operators very significant amounts of money.

Silicone-based foul-release coatings

Another approach to fouling which has been developed is based on silicone coatings for ships. Unfortunately these "foul-release" or "non-stick" coatings are not very robust, tend to damage easily, are not suitable for needed routine cleaning (as the surface is easily damaged) and can also pose an environmental hazard of their own:

> 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

13 "INNOVATORS - improved hull coatings from NAVSEA - Brief Article," All Hands, Official magazine of the US Navy, (September 2000).

> 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.
>
> ... PDMS make the case that very low water solubility and bioavailability do not necessarily preclude damage to marine environments.[14]

For both these reasons, their fragility and the fact that they are not environmentally friendly, silicone coatings have not proved to be a satisfactory long-term solution for underwater hull protection and antifouling.

Hull performance and fuel savings

Studies have shown that biofouling begins within hours of a vessel being launched after cleaning or repainting of the hull, whether or not the heavy metal based antifouling paint or a foul-release coating is used. A light build-up of slime is enough to significantly increase fuel consumption within a relatively short time of cleaning or painting. Figures vary but the following is a quote from one such study.

> An effective coating is critical to the sea-going performance of ships, as inadequate coatings can result in increased drag, leading to either increased propulsive power to maintain a given speed or to reduced speed at a given input power compared with a hydraulic smooth and unfouled hull. The skin friction on some ship hull types can account for as much as 90 per cent of the total drag even when the hull is free of fouling (Schultz 2007). For mid-sized merchant and naval vessels, such as frigates and destroyers that are typically 150 m in length, at cruising speed (7.7 m s–1 or 15 knots) or near maximum (15.4 m s–1 or 30 knots), an 8–18% penalty in propulsive power has been attributed to a mature slime (bacteria and diatom film) and up to 80 per cent for heavy calcareous deposits. This is in good agreement with a recent paper on full-scale ship resistance and powering predictions, based on laboratory drag measurements and boundary layer similarity law analysis (Schultz 2007).[15]

A video produced by the Office of Naval Research states:

> High-performance U.S. Naval warships and submarines rely on critical design factors such as top speed, acceleration and hydroacoustic stealth to achieve their mission. The build-up of marine crustaceans, namely barnacles on ships' hulls, adds weight and increases drag, reducing a vessel's fuel efficiency, especially for Navy ships as they move throughout the world's oceans. In fact, colonized barnacles and biofilms settled on the hull of a Navy ship translates into roughly $1 billion annually in extra fuel costs and maintenance efforts.[16]

Fuel prices are rising. And changes in IMO regulation for sulfur content promise to cause even higher increases in fuel costs over the coming years.

At the same time, the global economy has been declining for several years and ship

14 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.
15 Maria Salta et al., "Designing biomimetic antifouling surfaces," Philosophical Transactions of the Royal Society (October 28, 2010) 368: 4729-4754.
16 Office of Naval Research Hull Bug video transcript, accessed November 2010, http://www.onr.navy.mil/Media-Center/Video-Gallery/Transcripts/Marine-Biofouling-Hull-BUG-2009.aspx.

owners and operators, cruise lines, merchant shipping, navies and others are running on tighter budgets and margins. The cost of hull protection and maintenance must be carefully balanced against savings in fuel consumption. The numbers tell the story quite clearly. Keeping hulls clean of fouling, even light slime, through regular in-water cleaning can result in massive savings, dwarfing the cost of paint application and in-water hull maintenance.

The current trend is to avoid frequent drydocking and extend drydocking intervals as much as possible. Classification requirements have pegged the drydocking interval at 2½ or 5 years for most vessels and in some exceptional cases up to 7½ years. Docking is expensive, difficult to schedule and disrupts the vessel's operations for a protracted period of time. Currently, frequent drydocking occurs primarily due to the lack of effectiveness of the antifouling paints to keep the hull free from fouling and the loss of corrosion protection as a result of damage to the coating system. It suits any shipowner or operator not to have to drydock the vessel any more than is absolutely required to keep it in class.

Currently, frequent drydocking occurs primarily due to the lack of effectiveness of the antifouling paints to keep the hull free from fouling...

The following excerpt from the IMO Marine Environment Protection Committee 59th Session Agenda item 4 (MEPC 59/WP.8 16 July 2009), gives an idea of where the industry is headed as far as hull coating, protection and maintenance.

Hull maintenance

4.21 Docking intervals should be integrated with ship operator's ongoing assessment of ship performance. Hull resistance can be optimized by new-technology coating systems, possibly in combination with cleaning intervals. Regular in-water inspection of the condition of the hull is recommended.

4.22 Propeller cleaning and polishing or even appropriate coating may significantly increase fuel efficiency. The need for ships to maintain efficiency through in-water hull cleaning should be recognized and facilitated by port States.

4.23 Consideration may be given to the possibility of timely full removal and replacement of underwater paint systems to avoid the increased hull roughness caused by repeated spot blasting and repairs over multiple dockings.

4.24 Generally, the smoother the hull, the better the fuel efficiency.[17]

Note the reference to "new-technology coating systems." It should also be noted with regard to point 4.23 that the Surface Treated Composite (STC) hull protection system only requires that the hull be coated once for the lifetime of the vessel. It then improves in smoothness with in-water cleaning and at the most would require minor touch-ups when the ship is in drydock as a result of class requirements. This avoids the issue mentioned in 4.23 completely. It also fulfills the 4.24 condition.

The following table illustrates the problem on a grand scale, applying to all ships afloat. But what applies on a global level, is equally relevant to a single fleet or a single ship.

17 IMO Marine Environment Protection Committee 59th Session Agenda item 4 (MEPC 59/WP.8 16 July 2009).

[Hull condition]	Additional shaft power (%)	Additional fuel in 2020 (million tonnes)	CO_2 emissions (million tonnes)	Additional fuel cost (billion $)
Freshly applied coating	0	0	0	0
Deteriorated coating or thin slime	9	44	134	22
Heavy slime	19	92	279	46
Small calcareous fouling or macroalgae	33	160	486	80
Medium calcareous fouling	52	253	768	127
Heavy calcareous fouling	84	408	1,238	204

(Fig. 2) Estimated effect of effective fouling control on annual fuel consumption and CO_2 emissions [for all shipping]. All figures are projected to 2020 and are com-pared to a fouling free hull. (The increased shaft power as a function of the fouling degree is obtained from Schultz (2007) and is based on his calculations for an Oliver Hazard Perry class frigate sailing at 15 knots.)[18]

Summary

The marine industry is looking for hull (and propeller and other underwater equipment) solutions which, with proper in-water clea-ning and no or minimal drydocking, will reduce fuel consumption, while not polluting the oceans or harming the environment. Fortunately such a solution exists and it is highly cost-effective.

18 "The environmental importance of using effective antifouling coatings in relation to GHG emissions," IPPIC report (April 2009).

Part III. Examining the problems of hull protection and performance

1. A rough or fouled hull can drastically impair ship performance

Any vessel submerged in water for even a relatively short time is subject to the effects of corrosion and erosion. Water is a powerful corrosive agent. Thus ship hulls need to be protected.

The smoothness of the hull has a great deal to do with friction in the water. A rough hull creates greater skin friction and increases the propulsive power needed to move the vessel through the water at a given speed, all other factors being equal. This directly affects the amount of fuel needed to propel a vessel of the same displacement and hull form at a given speed. The smoothness of the hull, and therefore the minimization of skin friction or drag, depends on the surface itself, the coating used, and on the presence or absence of biofouling. Biofouling affects the hull of any ship within a very short time of its being submerged and builds up over time. The rate of this build-up depends on a number of factors including where the vessel is operating, whether or not it is moving at speed or is stationary and the effectiveness of the coating system applied to the hull. Partial replacement of hull coatings can result in a very rough surface and therefore increased skin drag regardless of the presence or absence of biofouling.

These problems with hull protection and skin drag, if not properly addressed, can add up to enormous expense in the simple operation of a ship and make the running of a vessel far more expensive than needed. Failure to address the problem could lead to fuel consumption penalties as high as 80% or beyond. With the high and rising cost of fuel, this can be a make-break point for a commercial shipping activity. There are also performance issues for non-commercial vessels such as navy or government ships if these problems are not addressed, seriously reducing their speed and hindering them in the execution of their duties.

Failure to address the problem could lead to fuel consumption penalties as high as 80%.

Not using the best hull coating, and neglecting routine underwater hull cleaning in an effort to cut costs is false economy on a grand scale and results in huge increases in operating costs.

Unfortunately, many of the attempted solutions for the hull performance problems which have been developed over time have themselves turned out to be destructive or ineffective. This includes the use of metallic and other biocides in the paint used to coat the hulls. These biocide or "active ingredient" paints, such as those containing tributyl-tin (TBT) or copper oxide and/or a variety of pesticides and herbicides, have been found to contaminate the marine environment and the food chain, including the human food chain, which clearly makes them an unacceptable solution. These biocide-based antifoulants (AF) were an attempt to bypass the need to clean ship hulls by releasing poisons to kill the marine life which otherwise attaches to the vessels. However, it is obvious that poisons which kill marine life are going to be dangerous to the aquatic environment and the food chain and should not be tolerated. Killing off marine life and contaminating the food chain in the name of trade, commerce, defense and so on, is clearly wrong-headed.

If one wants a smooth, clean ship hull (and one does, for very good hydrodynamic and economic reasons) then one must be prepared to clean the hull. If you want a clean car, then you must clean the car. This is not accomplished by spraying it with a paint that oozes some dirt dissolving magic potion. You simply make sure your car is painted with a hard, shiny, long-lasting paint that will not be damaged with regular, normal, cleaning and then you clean the dirt off the car when it starts to get dirty. An almost unimaginable ideal would be a car whose surface improves with every cleaning, making it look shinier than when it first rolled off the factory floor, and lowering fuel consumption. Yet this is a fair comparison with STCs on ship hulls.

In the case of ship hulls, the need to clean the underwater hull has been evident since ships were invented. If cleaning is done routinely when needed on the right type of coating, while the vessel is still in the water and often without interrupting normal ship activities, this is not a difficult or costly activity and is one which pays for itself many times over through increased fuel performance of ships so cleaned.

If cleaning is done routinely when needed on the right type of coating, ... this is not a difficult or costly activity and is one which pays for itself many times over through increased fuel performance ....

Some coatings, such as those based on biocides or silicone, cannot be cleaned without damaging the surface over time. Since it is economically inefficient to allow a build-up of biofouling, these coatings have limited usefulness as solutions for hull performance problems.

2. Frequent drydocking– a shipowner's bane

Any shipowner or operator knows that short drydocking intervals raise costs, since drydocking is expensive and causes loss of revenues through non-operation/off-hire of ships. This is just as serious a consideration for commercial vessels not able to earn their keep while they are out of action as it is for naval or government or other non-commercial ships which are out of service for weeks or months and thus not available for duty.

Apart from classification requirements or absolute disasters, the most usual reason for a ship having to go to drydock can be summed up in the single phrase: **underwater hull coating**. The current crop of copper-based AFs in widespread use have a limited lifespan (between 2 and 3 years) before they "wear out" and need to be replaced. In order to remain in class, most vessels must now be drydocked at least once every 2 ½ or 5 years (7 ½ years test cases ongoing). The need to paint due to the short lifespan of AF paints often results in more frequent drydockings than is needed to meet class or flag state requirements. Repainting and surface preparation requirements are nowadays a determining factor in deciding where to drydock, which can cause a vessel to have to be in the wrong place at the wrong time and undergo the expense of drydocking so that painting (and other needed maintenance) can be carried out. Not having to paint, in combination with the available underwater technologies for maintenance and repair, may well extend the drydocking interval and thus save a great deal of expense and loss of business/off-hire for the ship owner or operator.[19]

19 "Doing without drydocks," BIMCO Sea_View, accessed November 2010, https://www.bimco.org/en/Corporate/Education/Seascapes/Sea_View/Doing_without_drydocks.aspx.

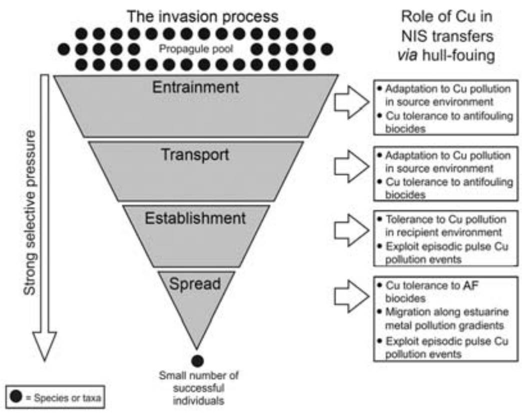
There is also the expense of frequent repainting. In some cases five coats of paint are required. Replacing paint on the hull is not a cheap affair and can interfere with the mechanical work which needs to be done when the ship is in drydock.

3. Invasive non-indigenous aquatic species

There is another problem related to ship hulls and biofouling which has come to the fore in recent years as research has shown that there may be a danger of transporting potentially invasive aquatic species from one marine environment to another where they do not occur naturally, known as non-indigenous species (NIS) or "alien species." The danger is that if biofouling is allowed to build up beyond the slime, weed or light algae stage to the more advanced stages of barnacles, tube worms and other heavier "hard" fouling, then these invasive species can be displaced in distant ports where they threaten to upset the natural marine environment. It should be noted that this problem ceases to exist, at least as far as ship hulls are concerned, if the hull is kept clean on a regular basis and not allowed to foul beyond the stage of slime, weed and light algae. These forms of fouling are universal and do not pose the invasion threat.[20]

Research has shown that traditional heavy metal AF paints such as copper oxide based antifouling can increase the threat of environmentally harmful transfer of invasive species via ship hull fouling, as explained in the following article abstract.

> **Vessel hull-fouling is increasingly recognised as one of the major vectors for the transfer of marine non-indigenous species. For hundreds of years, copper (Cu) has been used as a primary biocide to prevent the establishment of fouling assemblages on ships' hulls. Some non-indigenous fouling taxa continue to be transferred via hull-fouling despite the presence of Cu antifouling biocides. In addition, several of these species appear to enjoy a competitive advantage over similar native taxa within metal-polluted environments. This metal tolerance may further assist their establishment and spread in new habitats. This review synthesises existing research on the links between Cu and the invasion of fouling species, and shows that, with respect to the vector of hull-fouling, tolerance to Cu has the potential to play a role in the transfer of non-indigenous fouling organisms. Also highlighted are the future directions for research into this important nexus between industry, ecology and environmental management.[21]**



(Fig. 3) Diagram depicting the four stages involved in the invasion process and the influence that Cu may play in facilitating a successful species transfer via the common marine transport vector of hull-fouling. (ibid.)

The IMO and a number of other organizations have recognized the problem of invasive aquatic species and their transfer

20 Marc Geens, "Ecotec-STC: Ecospeed: Risk evaluation for the spread of 'alien species' in surface water when using hard coatings on ship hulls." Project - 0058713, December 2008.

21 Richard F. Piola, Katherine A. Dafforn, and Emma L. Johnston, "The influence of antifouling practices on marine invasions," Biofouling, 25, no. 7, (2009): 633 - 644.

via biofouling, and are taking steps to address it. Following is an excerpt from SUB-COMMITTEE ON BULK LIQUIDS AND GASES 15th session Agenda item 9 LG 15/9/#12 November 2010:

> **DEVELOPMENT OF INTERNATIONAL MEASURES FOR MINIMIZING THE TRANSFER OF INVASIVE AQUATIC SPECIES THROUGH BIOFOULING OF SHIPS**
>
> 1.3 The potential for invasive aquatic species transferred through biofouling to cause harm has been recognized by the IMO, the Convention on Biological Diversity (CBD), several UNEP [United Nations Environmental Programme] Regional Seas Conventions (e.g., Barcelona Convention for the Protection of the Mediterranean Sea Against Pollution), the Asia Pacific Economic Cooperation forum (APEC), and the Secretariat of the Pacific Region Environmental Program (SPREP).
>
> 1.4 All ships have some degree of biofouling, even those which may have been recently cleaned or had a new application of an anti-fouling coating system. Studies have shown that the biofouling process begins within the first few hours of a ship's immersion in water.
>
> ...
>
> 1.5 Implementing practices to control and manage biofouling 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 C.1/Circ.683'.[22]

Since keeping a hull clean is an economically sound practice anyway, the NIS problem is best solved through a hard coating and regular cleaning, not allowing fouling to develop to any serious degree. This makes sense economically and environmentally.

4. Rising cost of fuel

This is a problem which is increasing as legislation tightens up on CO_2 emissions around the world.[23] How to compensate for higher fuel prices (with the potential of additional levies on bunker fuel) squeezing margins? It is a problem every shipowner or operator has to consider. And part of the answer definitely lies in improving ship hull performance and efficiency.

If regular hull cleaning can reduce the fuel consumption penalty of fouling by 40%, then advanced mathematics is not required in order to see that there is a way to save a great deal of expense in the fuel department. In-water hull cleaning is proportionately far cheaper than spending the extra money on fuel trying to overcome the additional hull friction caused by the build-up of slime and other fouling.

22 IMO, SUB-COMMITTEE ON BULK LIQUIDS AND GASES 15th session Agenda item 9 LG 15/9/#12 November 2010.
23 Mark F. Lewis, "Bunker Fuels – Is The End in Sight For Oil's 'Sulfur-Sink'?" Middle East Economic Survey, 58, no. 25 (20 June 2005).

Part IV. The solution to ship hull performance in the post-TBT era

The theoretical ideal solution would perhaps be a substance which could be applied to the hull of a ship which protected the hull completely against corrosion, erosion and cavitation, which lasted the life of the ship without replacement or repair, which resulted in a perfectly smooth hull, and to which no marine life could ever adhere, not even the thinnest of slime layers, which therefore never required any cleaning, and which was completely friendly to the environment.

Unfortunately, no one has come up with such a substance. It has remained a dream for centuries and not all the powers of modern science have brought it into being. Even when the marine industry imagined that such a solution had been found (TBT), it turned out to be severely destructive to the marine environment, causing mutation amongst oysters, contaminating the food chain and generally wreaking havoc under water–a psychotic solution.

The best approach/best available technology, therefore, would be the closest one could come to that, without the destructive side effects–a coating which :

- has a high mechanical strength which provides a durable protection to the underwater vessel
- protects the hull against corrosion, erosion and cavitation, even in extremely harsh conditions
- lasts the lifetime of the hull without replacement, requiring only minor touch-ups
- is completely non-toxic and has no ill-effects of any kind on the marine environment
- is cost-effective
- is easy to apply
- is easy to clean
- improves over time when in service
- allows preventative underwater maintenance in between drydockings in an environmentally safe way
- comes as a technology which can be implemented worldwide without adversely interrupting normal ship operations
- is cost-effective in relation to money saved by improved performance
- can, in combination with simple monitoring, prevent a build-up of even light slime, thus resulting in enormous savings in fuel consumption and improved hull performance so that the cost of underwater cleanings is dwarfed by the savings in fuel.

That approach does exist.

The coating (Surface Treated Composite–STC) is a paint containing relatively large glass platelets (not micronized), which is applied once in two coats to the hull (for extremely harsh conditions, a stronger version with larger glass platelets and more than two coats can be applied). After the vessel is launched, the coating is conditioned by divers using underwater mechanical brush equipment, and is, as needed, cleaned in the water without adversely affecting the marine environment. Service life is equal to that of the ship hull, and the coating improves with repeated underwater hull cleaning, i.e. after say 20 years the coating is in better condition than it was when it was first applied. It becomes smoother and consequently provides even less friction and is less prone to biofouling.

This approach has many benefits:

- It is applied once and lasts for the lifetime of the hull, offering full protection against corrosion, erosion and cavitation in the harshest of conditions, requiring only minor touch-ups (typically less than 1% of the underwater surface per drydocking).

- Initial cost of coating is comparable to other coatings and actually less than convenational AF coatings when all factors are taken into consideration (only two coats required, two-hour drying time, 95% solid, and other factors).

- It includes keeping the underwater hull free from slime through monitoring in combination with preventative underwater hull cleaning. This results in great cost benefits as well as the environmental benefit of significantly reduced CO_2 emissions.

- The smooth, hard coating resists fouling. But if fouled, even the toughest and hardest calcareous fouling will not damage the paint and it can easily be cleaned back to better than its original post-drydock conditioned, pristine surface.

- The combination of a hard coating and routine in-water cleaning keeps the hull at optimum performance, greatly reducing fuel consumption. The hull performance improves with each cleaning so that the hull will perform even better after 20 years of routine maintenance than when the coating is first applied.

The combination of a hard coating and routine in-water cleaning keeps the hull at optimum performance, greatly reducing fuel consumption. The hull performance improves with each cleaning so that the hull will perform ever better after 20 years of routine maintenance than when the coating is first applied.

- Repainting is not required, thus drydocking intervals for hull maintenance can be the maximum permitted by other class and flag state requirements (currently 2 ½ or 5 years). After the initial coating, the ship will not need to go through any repainting of the underwater hull. Underwater hull painting will therefore not be a reason to drydock the ship. The (resale) value of the vessel is improved by long term protection of the hull.

- The solution is entirely environmentally safe. It results in no pollution of the marine environment or the air, either when the coating is applied or when it is in use for the lifetime of the ship. By improving hull performance it also greatly reduces the carbon

By improving hull performance it also greatly reduces the carbon footprint of the vessel in direct proportion to the fuel savings achieved.

footprint of the vessel in direct proportion to the fuel savings achieved.

- Hard coating combined with routine in-water cleaning substantially reduces the risk of spreading non-indigenous aquatic species via biofouling.

The only possible perceived drawback is the need for routine in-water hull cleaning. However, this turns out not to be a drawback at all. Routine cleaning is a fact of life. If one wants a clean hull, then one has to be prepared to clean it. Naturally the easier the surface is to clean and the more it improves with cleaning, the better.

Eight key points to look for in an underwater hull coating

When considering the best solution for underwater hull coating on a ship or a fleet, whether it be a cruise line, navy or government vessels, an offshore platform, semisubmersible or other vessel, an ice breaker, a tanker or VLCC, ro-ro, container ship, cargo vessel, or any other type of ship, some points to look for and questions to ask would include:

1. Does the paint have an active antifouling biocide or other ingredient which will spread pollution (such as copper oxide, herbicides or silicone oils) and therefore preclude eligibility for a Green Ship certification by class? Or is it a hard, inert coating which will not harm the marine environment?
2. Does the coating provide full protection of the hull against corrosion, erosion and cavitation for the lifetime of the ship without needing to be replaced? Is it guaranteed for at least ten years?
3. Does the coating contain relatively large glass platelets in a resin base so that it will provide full protection and improve with routine in-water cleaning, becoming smoother and performing better over time?
4. Is the paint able to withstand the heaviest fouling and yet still easily be cleaned in the water to its original or an improved condition without any damage?
5. Can the paint be cleaned regularly with the ship in the water without suffering any deterioration in performance (wearing away, scratching, chipping, etc.) but in fact improving in performance with such cleaning?
6. Does the paint supplier provide monitoring tools and underwater maintenance programs to back the product up?
7. Do the paint suppliers have experience with underwater cleanings and do they take responsibility for the underwater cleanings performed on their paint?
8. Any non-toxic paint will require underwater cleaning in between drydockings: does the paint supplier provide a solution for this?

Part V. A Model STC: Ecospeed® from Hydrex

Ecospeed® is a patented system of underwater hull protection which combines a glass platelet, vinyl ester resin based coating and regular in-water cleaning to keep any ship hull operating at maximum performance. Ecospeed coating classifies as a Surface Treated Composite (STC) and is available from Hydrex, an international company specializing in underwater ship protection and maintenance and repair.

The coating is applied once, either on a new-build or in dry-dock when a ship's hull needs repainting, and lasts the lifetime of the vessel with only minor touch-ups (typically less than 1% of the whole surface per drydocking).

The coating is applied once, either on a new-build or in drydock when a ship's hull needs repainting, and lasts the lifetime of the vessel with only minor touch-ups (typically less than 1% of the whole surface per drydocking). It is guaranteed for 10 years.

Initial application is comparable in cost to any other underwater hull paint but it is easier than others to apply in that it requires only two coats on bare metal with a two hour drying time in between coats and extended maximum overspray time. It is initially conditioned by underwater brushing, resulting in a smooth, fouling resistant surface.

Through regular inspection of the ship hull and in-water cleaning of slime build-up, the ship is kept at optimum performance. In fact the coating improves with regular cleaning, skin friction reducing with each cleaning. Cleaning of the largest vessels can be accomplished in 6 - 12 hours and can usually be carried out without adversely interrupting the ship's normal operations.

Ecospeed has been tested by European authorities and certified completely non-toxic and not harmful to the environment in any way.[24] [25]

Ships that use Ecospeed on their hulls sail with the security of knowing that they are not spreading any pollution through their hull coating. And because they are easily maintained at optimum performance, they save very significant fuel costs, while reducing CO_2 emissions.

After decades of research beginning in the 1970s, Ecospeed was developed by Hydrex as the best specific approach to underwater hull protection, an approach that does not harm the environment and yet comes as close as possible to the ideal solution in terms of ship hull performance and fuel efficiency. It combines care for the environment with greatly reduced operating costs and a significant reduction in total ownership cost for ship and fleet owners and operators.

24 A. Wijga et al., "Biocide free 'antifouling' for ships. Emissions from the underwater coating 'Ecospeed'," EU Life Project, Accessed November 2010, http://www.hydrex.be/sources/pdf/Laboratory_report_Ecospeed.pdf

25 ECOTEC-STC - Demonstration of a 100% non-toxic hull protection and anti-fouling system contribution to zero emissions to the aquatic environment and saving 3-8 % heavy fuels, accessed November 2010, http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3087

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