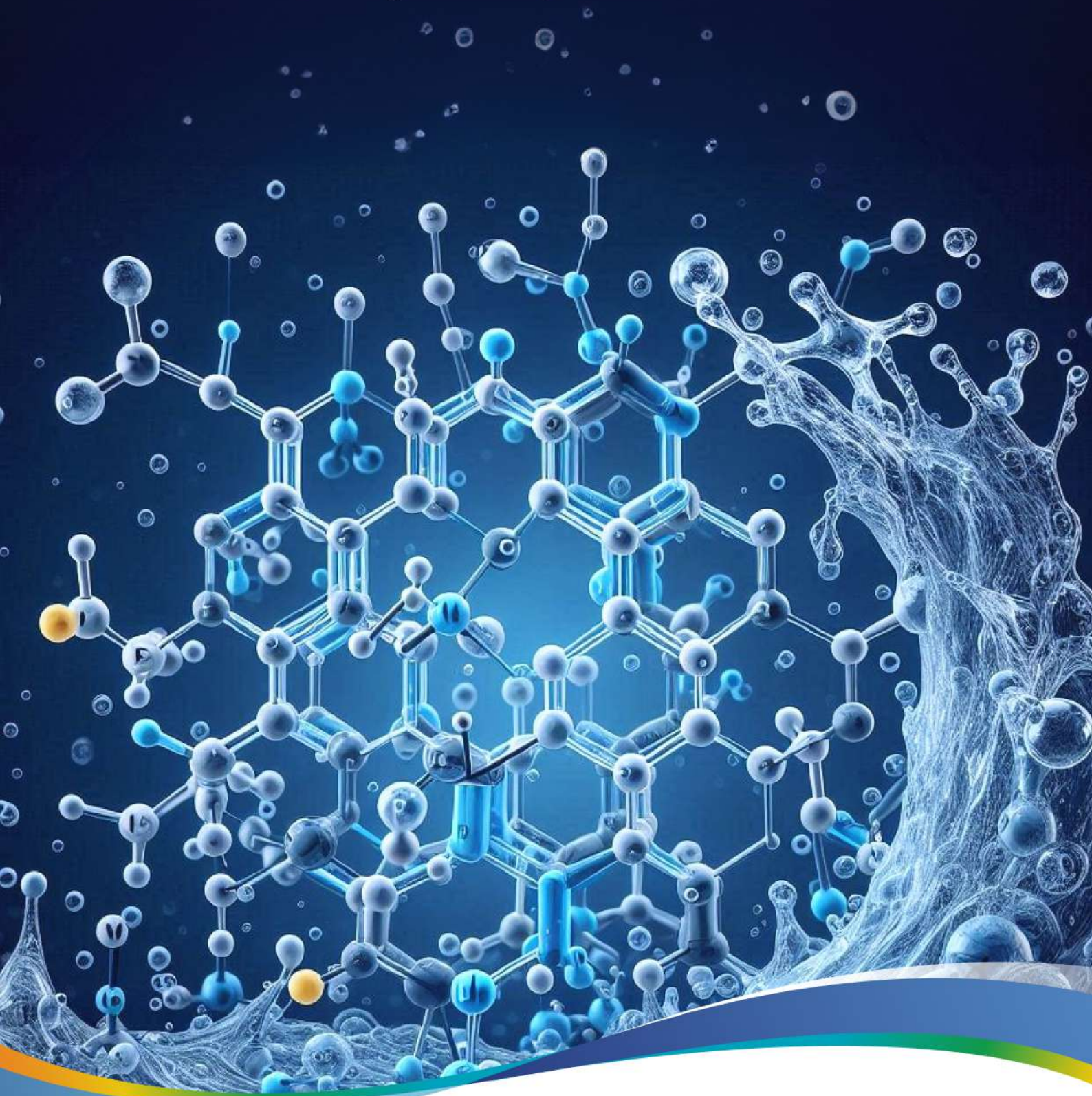
Breathing life into science; creating the next generation of hull coatings using biomimetics

Innovation, inspired by the Ocean



NIPPON PAINT MARINE

Introduction

The shipping industry faces significant challenges as it navigates a path to decarbonisation in 2050. The roadmap to sustainability is highly complex, driven by more stringent global and increasingly fragmented regional regulations, as well as pressures and scrutiny from forces outside of the industry.

While alternative fuels are seen as a crucial element to decarbonisation, the reality is that, currently, there is not the necessary scale or infrastructure to create enough green ammonia, hydrogen, or other future fuel to meet demand. In addition, there is significant competition from other, more advanced industries who are willing to pay more to meet their own renewable fuel needs. This will have the effect of exponentially driving up the costs of new fuels coming into the shipping industry, way beyond the prices currently available within the bunkering supply chain.

Energy efficiency is therefore a constant watchword for good operational performance; enabling the industry to meet current and impending regulations, and also mitigating some of the unavoidable costs of shipping's transition to a hyper-expensive future fuels world.

Within this reality, viable clean technologies are crucial. And hull coatings, as one of the most widely used forms of clean technology today, due to their availability, accessibility, and proven results, will play a fundamental role in delivering the energy efficiency that will be necessary in years to come.

As the industry adapts to support the global energy transition, continual investment in R&D will be vital, utilising the very latest developments in science, technology and engineering. Critically, it will require inspiration and understanding from a myriad of sources. This paper looks at one such source; the very oceans that are at the heart of the maritime industry and how the principles of biomimetics can drive the next generation of hull coatings.

Age-old natural phenomena, future-first technology

Biofouling – the accumulation and build-up of microorganisms, plants, algae, and animals on the hull of a vessel – has been a significant issue as long as humankind has used the oceans for transport. It can have a huge impact on operational performance, creating drag and reducing speed, manoeuvrability, and levels of efficiency. Indeed, biofouling can lead to decreases of speed by up to 10%, which in turn, can easily require as much as a 40% increase in fuel to counterbalance, and even more in a vessel, which is heavily fouled. This has a significant impact on driving up fuel consumption, associated costs, and emissions, which has further repercussions in a world of more expensive fuels. On top of this, biofouling also acts as a catalyst for the translocation of invasive species, which is currently a cause for debate on its impact.

In the very early days of seafaring, the biological growth on a vessel's hull would be managed by using toxic compounds such as lead, mercury, and even arsenic. Happily, innovation has evolved significantly since those days and regulators, supported by manufacturers, have worked hard to reduce, and subsequently ban, the use of harmful substances in hull coatings; from tributyltin in 2008, to cybutryne in 2023.

Achieving true sustainability in today's market requires unprecedented levels of innovation across all technologies, including the development of hull coatings.

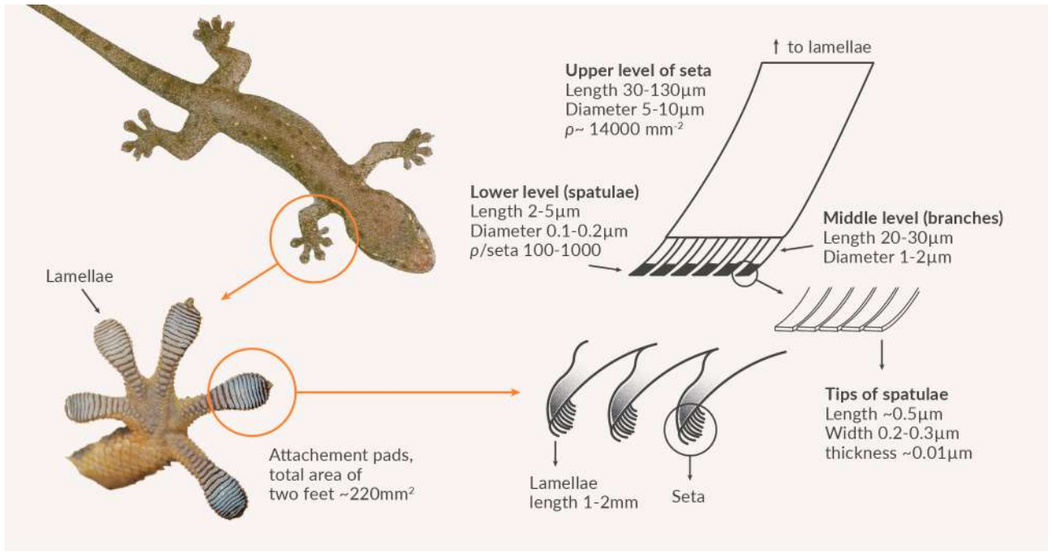
For Nippon Paint Marine, this means taking inspiration from the natural world. Nature has inspired some of the most innovative technologies to solve man-made challenges. And we can continue to look to nature to develop the latest energy efficient hull coatings, harnessing natural phenomena in the development of ever more innovative products that are fit for a future-fuel-powered shipping industry.

A pioneering history of biomimetics

Biomimicry is the concept of taking inspiration from nature-based solutions and designs for efficiency, resilience and – ultimately – survival, which have evolved in the natural world over millions of years. The Biomimicry Institute defines it as "an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies".

Ultimately, thanks to the law of natural selection, what hasn't worked is already a fossil. Species that still exist have principles and 'secrets' to survival that can be unlocked and put into practice within today's world, to solve existing human-based – and human-created – challenges.

The evolution of manmade technology has enabled and equipped global research institutions and scientists to better explore and assess the world around us. It has provided the opportunity to research and develop biomimetic products, technologies, and designs which mimic the form, structure, and function of organisms, or observe a specific trait in nature. Many of these examples are being used for the betterment of society and the environment; from lizards and birds, to whales and fish.



Note. The Tokay Gecko diagram is taken from https://www.researchgate.net/figure/Schematic-structure-of-a-Tokay-gecko-including-the-overall-body-one-foot-a_fig14_24269577

The Tokay Gecko

Scientists discovered that the tiny, microscopic hairs on the pads of the Tokay Gecko helps them 'stick' to surfaces, which led to the development of specialist adhesives, including a way to close wounds without the use of stitches. In 2015, the car manufacturer Ford also stated that it was studying the Tokay Gecko to create an adhesive that would better separate the plethora of plastics and foams left over after a car is stripped of its metal insides. This approach boosted recycling rates and created an opportunity to utilise the different streams for higher-end applications.

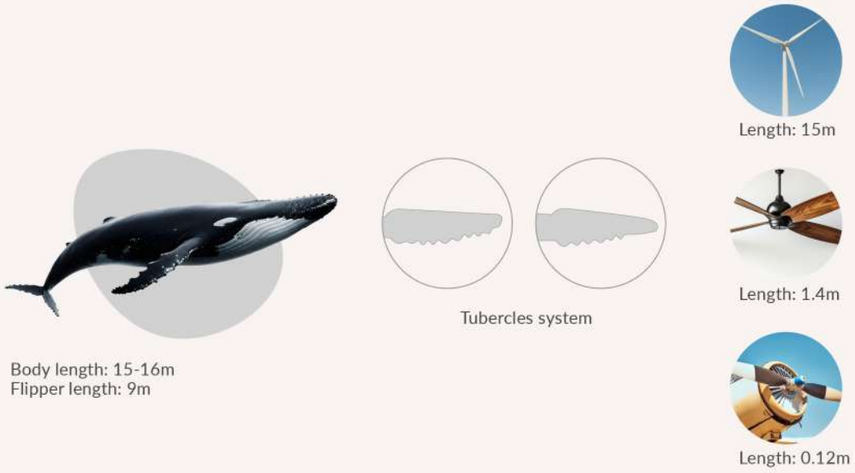
The Kingfisher, The Owl and The Penguin

Japan's Shinkansen bullet train boasted speeds of up to 270kph but had a significant societal and environmental challenge. The train made a loud 'boom' in residential areas as it exited tunnels, due to the pressure build-up as it passed through them. The train's lead designer – an avid bird watcher – developed a solution based on research into the Kingfisher. He observed that the bird had to travel from one dimension (air) to another (water) silently, and at high speed, to catch its prey. He modelled the train design on its beak. He also developed and used connectors based on the silent wings of the Owl and the slippery bellies of the Adélie penguin, which – when combined – made the train 10% faster, reduced power by 15%, and minimised noise disruption.

Biomimicry in maritime

With science suggesting that the beginnings of life were formed in the depths of the oceans, the opportunity for developing biomimetic designs, technologies, and solutions from the sea is exponential. Indeed, the marine environment continues to inspire multiple biomimetic products.

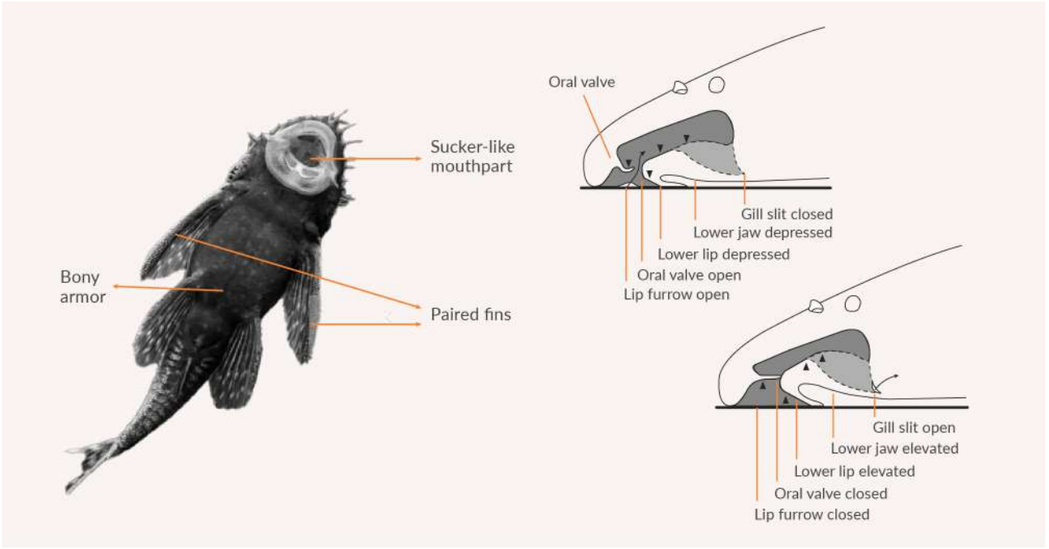
Oceans of Opportunity



Note. The Humpback Whale diagram is taken from https://www.researchgate.net/figure/Biomimetic-scaling-of-the-tubercle-effect-Tubercle-system-of-humpback-whale-fin-provided_fig2_354909240

The Humpback Whale

Scientists at Duke University, West Chester University, and the US Naval Academy discovered that, despite humpback whales having bumps on their fins (called tubercles), which look like they would slow them down, they actually increased lift by 8% and reduced drag by 32%, generating a significant increase in overall efficiency. This understanding has since been applied to wind turbine blades, cooling fans, airplane wings, and propellors.



Note. The suckerfish diagram is taken from https://www.mdpi.com/2313-7673/8/7/534

Suckerfish

Suckerfish are 'hitchhiking' fish that travel the world's oceans clamped to the backs of whales, rays, and sharks, as well as other sea creatures. Researchers followed these fish via a webcam as they hitchhiked alongside a blue whale. The footage showed that the fish hovered slightly above the whale's skin (instead of being attached), forming a low-pressure zone that sucked it in, enabling it to stay effortlessly close to the whale even when the mammal was traveling at full speed. Based on further mathematical modelling, and using computational fluid dynamics analysis, researchers found that the suckerfish were skimming around in a boundary layer cushion of slow-moving water, next to the whale skin. Essentially, they were using the least effort to stay close to the whale and then benefitting from the Venturi Effect, which is the reduction in fluid pressure that results when a fluid flows through a constricted space to move around. This has inspired new technology that can help when attaching sensors and other products to rough surfaces.

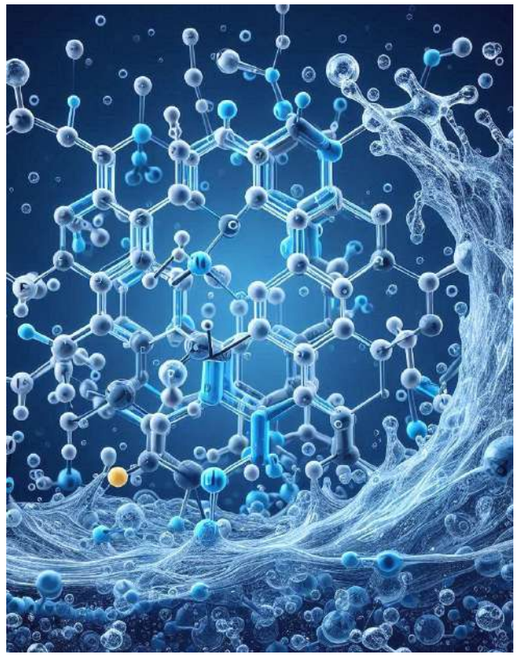
These types of innovations comprise a growing collective of biomimetic technologies and products that have been developed from the ocean. However, we are only scratching the surface of what is possible, as just 5% of the ocean has currently been fully explored.

Biomimetics therefore represents a significant opportunity for the development of marine coatings and it is an area where Nippon Paint Marine has, and will continue to make, a pioneering impact.

Nippon Paint Marine – A history of biomimetic breakthrough

For over 140 years, Nippon Paint Marine has been at the forefront of innovation within the maritime industry, inspired by customers' and the market's evolving needs and challenges. Its entire Research and Development (R&D) programme is focused on providing solutions for the industry which enable ship owners to accelerate their pathway to decarbonisation, that protect the marine environment and ocean ecology, and which enrich the living world through the power of science and imagination.

Nippon Paint Marine's belief in, and approach to biomimetics, which began in 2001, and the use of 'hydrogel' technology in pioneering antifouling coatings, is an example of this. A hydrogel is a material which consists of a polymer network that contains water, and many marine organisms are known to have such hydrogels on their body surfaces. It has been argued that their hydrogels can lower the frictional resistance and contribute to their unexplained fast swimming speed. Used within coatings, hydrogel technology smooths the waterflow around the hull, reducing the hull-to-water friction and therefore drag, which in turn reduces fuel consumption and emissions significantly.



> *"We fundamentally believed that by understanding the mechanisms of important coating film performance based on actual real world and natural phenomena and reproducing them in coating design using a scientific approach, we could create innovative 'water trapping' technologies that would differentiate our products and speed up development. At the time, the entire group was committed and focused on the theory of biomimetics.*

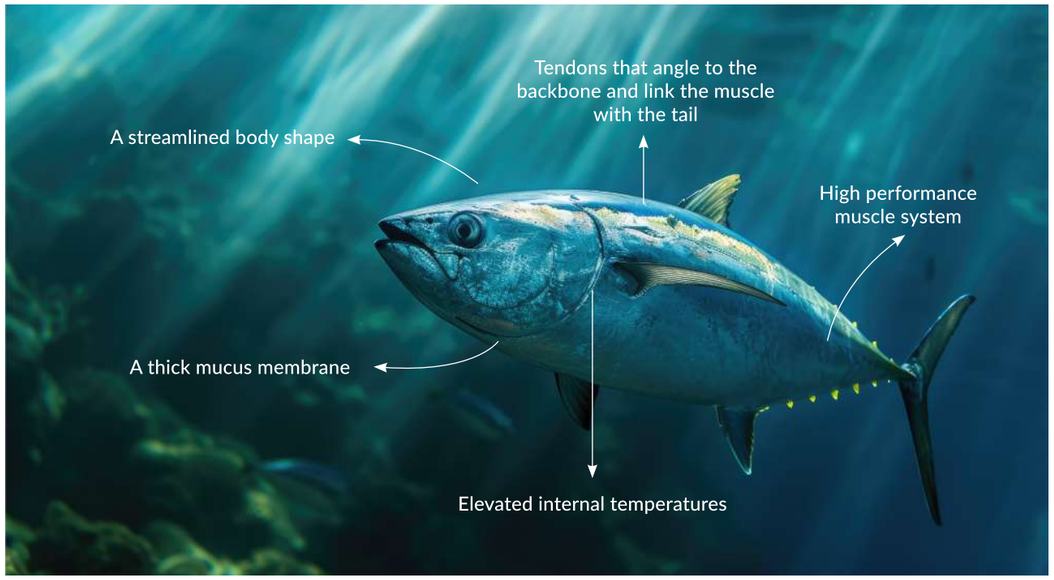
Kazuaki. MASUDA,
Technology Division Director

The Nippon Paint Marine team that was established to focus on researching and developing the biomimetic concept consisted of several members with specific, complimentary skill sets that were grouped together to deliver the best results; polymer and biochemistry experts, as well as fluid dynamics and marine science specialists who could provide knowledge and insight on the real-world practical application of an innovation.

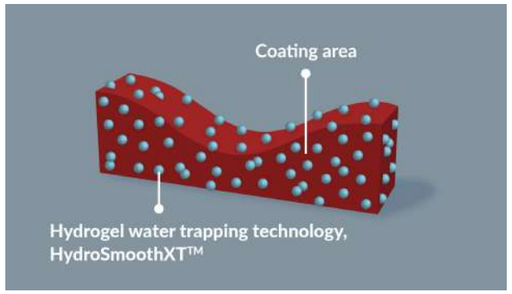
Extensive consultations and collaborations were also conducted with educational institutions such as Osaka University and the National Institute of Advanced Industrial Science and Technology. Corporate and commercial companies and organisations were also consulted within the shipping and shipbuilding sector. As well as this, the R&D team also obtained support from an aqualife park to try and measure the surface properties of living aquatic animals (including the surface roughness and rubber hardness of dolphins which can also swim at extraordinary speeds). This helped in the development and selection of their approach, identified where further investment in research was required, and where patents needed to be obtained.

As part of the biomimetic R&D programme, the team members examined the studies on the high-speed swimming capabilities of tuna, which can reach speeds of up to 100 km/h. To achieve such velocity in seawater requires special physiological and hydrodynamic mechanisms and capabilities. This includes a streamlined body shape, elevated internal temperatures, as well as a high-performance muscle system, located in the central part of the body, and tendons that angle to the backbone and link the muscle with the tail.

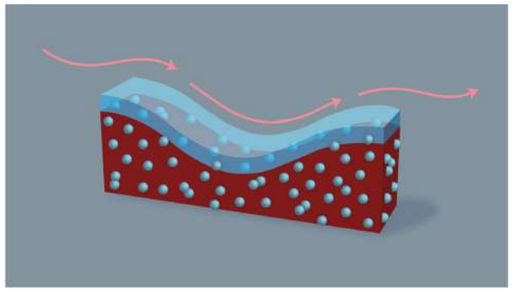
However, it also requires special conditioning and substances on the body surface to reduce friction and resistance to drag. Specifically, the R&D team knew that there are solutions to which certain polymers or surfactants can be added to reduce the resistance of fluids (the Toms Effect). This phenomenon was observed not only in synthetic polymers, but also mucus. Many fish including tuna have a thick mucous membrane, which secretes mucus from the body surface of the fish. Such mucus-like substances comprise of viscous sugar or protein complexes, with a high affinity for water, which are often argued to support the reduction of frictional resistance.

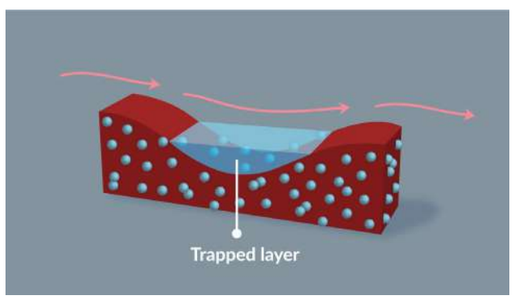


Hydrogel ‘water trapping’ technology – an age-old concept solving modern-day challenges



The Nippon Paint Marine team focused on replicating this natural phenomenon and developing specifically designed hydrogels for paints; the scientific theory being that a hull coating could be created that ‘traps’ a layer of seawater into the surface boundary membrane, which in turn, increases the more controlled turbulence generation of a vessel’s hull, reducing friction.





In antifouling systems, a network of hydrophilic polymer material with three-dimensional crosslinking works within a superefficient metal-/silyl-acrylate copolymer paint to trap a microscopic layer of water on the coating’s surface, as the ship moves through the water. In essence, the technology smooths the water flow around the hull, creating a slippery surface not dissimilar to how the thick mucous membrane of tuna skin may work to help the fish speedily glide through the ocean. On a vessel, this ‘tuna skin cladding’ reduces hull-to-water friction to such an extent that fuel consumption and emissions can be reduced dramatically.

Over the course of a five-year R&D programme, and in collaboration with Osaka University, the team worked through many stages of practical application. This included better understanding the relationship of surface roughness and fluid dynamics, and the chemical properties of hydrogel materials, designing paint formulations based on the insights generated, as well as confirming the reproducibility of the paint film surface conditions and properties.

Finally, the team succeeded in the industrialisation of the technology so that the hydrogel material and its water trapping function harmonised well with other coating materials and their performance. The reduced friction was not only confirmed in laboratory fluid dynamics tests but also validated and proven using Kobe University’s training vessel in live sea trials. As part of the research at Kobe University, the vessel’s speed and fuel consumption were continuously monitored over the same route and under other key operating conditions with the same vessel over a one-year period. This test proved that the fuel consumption was improved in practice compared to the conventional paint without hydrogel.

HydroSmoothXT™ - the world’s first hydrogel-containing antifouling technology

Following years of research and testing, in 2006, Nippon Paint Marine was the first company to patent its unique ‘Water Trapping Technology’ and the use of hydrogel in self-polishing antifouling paints; a technology called HydroSmoothXT™. And in 2008, the company launched the first product in the range, LF-Sea (‘LF’ meaning ‘low friction’), the world’s first biomimetic low-friction antifouling coating, which incorporated a specially formulated and unique hydrogel into Nippon’s ultra-efficient copper silyl acrylate self-polishing antifouling paint; the technology was proven to reduce fuel consumption and associated emissions by up to 4% compared to the conventional silyl-type paint without hydrogel. This was achieved through a combination of lower friction - derived from lower friction coefficient by the HydroSmoothXT™ technology - as well as the superior fouling prevention performance inherited from conventional products.

Following its launch, LF-Sea was applied to over 1,400 vessels, ranging from fishing boats to VLCC tankers. In 2020, the technology won the Japanese Government Award for Global Warming Prevention Activity in recognition of the significant contribution the coating has had, and continues to have, on reducing emissions and the shipping industry’s impact on the environment, and in pioneering innovation in hull coatings development.

LF-Sea

Launched
2008
Key innovation
World’s first biomimetic antifouling utilising hydrogel technology and the first in Nippon Paint Marine’s HydroSmoothXT™ range.
Efficiency gains
4%

Number of vessels coated
Over 1,400 vessels
Vessel types
VLCCs, Tankers, BC/Cargo, PCC, Containers
Key customers
Niovis Shipping, Mitsui O.S.K. Lines, Ltd (MOL), Polaris Shipping, Jiangsu Ocean Shipping Co (JOSCO)

Success story

Example of analyses on actual vessels
In over 1,400 paint applications, analysis results also revealed many instances of efficiency gains of 5% or more. A conservative case within typical range, rather than an extreme example, is presented here:

Vessel type and Tonnage
12,825 DWT Chemical Tanker
Applied vessel area
Flat Bottom and Vertical Bottom
Date of application
12th November 2012
Efficiency gain (%)
3.9 % compared to a conventional self-polishing hull coating

Fuel tonne and cost reduction (tonnes/$)
231.0 tonnes and 138,600 USD* per year
Emission reduction (CO2 tonnes)
716 tonnes per year

**Calculated at USD600 per tonne*

Continued innovation of the hydrogel range of coatings

Following the success of LF-Sea, Nippon Paint Marine developed a more advanced, ultra-low-friction technology within its HydroSmoothXT™ range, launching A-LF-Sea (meaning 'Advanced Low friction') to market in 2013. Developed in conjunction with the Japanese government, as well as ship owners ClassNK and MOL, A-LF-Sea uses the patented water trapping function to lower the hydrodynamic footprint of a vessel's hull. The system also incorporates an anticorrosive and tie coat that were developed by incorporating Nippon's rheological control technique, a special technology related to the flow of coatings, which the company had used to make car paint flow more smoothly and evenly over the surface.

By using both the new rheologically-controlled anticorrosive scheme, NOA Rheo system, onto a fully blasted or newbuild hull and applying the new antifouling with the enhanced performance hydrogel, Nippon's R&D team developed a solution that generated fuel and emissions savings of up to 10% compared to conventional anticorrosives without this rheology control and conventional silyl-type antifouling without hydrogel.

In conjunction with this, for owners whose hull is in good condition, or are struggling with budget or finding the dry dock time in their schedules to remove their existing bottom coating completely, the new ultra-low-friction antifouling of A-LF-Sea can be applied to a ship directly by overcoating most existing regular antifoulings.

A-LF-Sea

Launched
2013
Key innovation
Combines Nippon's rheological technique with hydrogel
Efficiency gains
8% / 10% (NOA Rheo system)

Number of vessels coated
Over 3000 vessels
Vessel types
VLCCs, Tankers, BC/Cargo, PCC, Containers
Key customers
Carnival Corporation, Norwegian Cruise Line, Cenk Group, Gaslog Evergreen, Danaos Shipping, Berge Bulk Maritime

Success story

Example of analyses on actual vessels
In over 3,000 paint applications, there are many instances of efficiency gains exceeding 10% even without NOA Rheo system. A conservative case within a typical range is presented here:

Vessel type and Tonnage
89,900 DWT Container
Applied vessel area
Flat Bottom and Vertical Bottom
Date of application
19th March 2019
Efficiency gain (%)
7.2 % (without NOA Rheo system) compared to a conventional self-polishing hull coating

Fuel tonne and cost reduction (tonnes/$)
8,694 tonnes and 5,216,677 USD* per year
Emission reduction (CO2 tonnes)
26,951 tonnes per year

**Calculated at USD600 per tonne*

Embracing a new dawn of antifoulings with nanotechnology

Following 15 years of testing, as well as amassing and analysing a multitude of data from vessels operating with its unique HydroSmoothXT™ range of water-trapping coatings, the Nippon Paint Marine R&D team turned to nanotechnology as inspiration for the next innovative iteration of its hydrogel range of antifoulings.

Nanotechnology is the science and engineering that is devoted to the design, production, and use of structures, devices, and systems from the manipulation of atoms and molecules at nanoscale. Relatively recent real-world successes include the production of more durable adhesives using nanotubes, cancer-treating drugs equipped with nanoparticles, or solar panels that are more efficient and light weight.

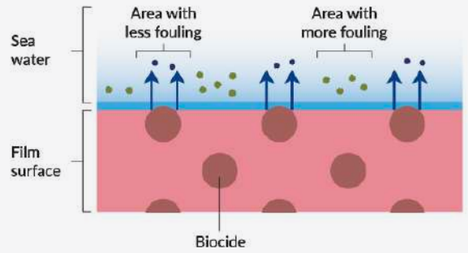
Following shipping's increased focus on decarbonisation, tightening environmental regulations, and the continual rise of sea water temperatures due to global warming, and the varying changes of shipping operations, Nippon Paint Marine developed another 'world first' for its HydroSmoothXT™ antifouling technology to support the continuous efficient operation of commercial vessels.

In January 2021, the company launched a new antifouling technology that enhanced antifouling performance to a level and consistency never seen before within the market; FASTAR XI and XII, which can deliver operational efficiency savings of up to 8% compared to conventional paint without hydrogel technology. When compared to the market average, market introduction results show that an average speed loss of 1.2% over a 60-month period, provides up to 14.1% fuel savings compared to the market average speed loss of 5.9% over the same period, assuming the same speed is maintained.

FASTAR is a low-friction, self-polishing antifouling coating which uses a unique hydrophilic and hydrophobic nanodomain resin structure in the coating film. This unique breakthrough brought a new dimension of resin/paint design which allows more precise polishing control and the enhanced activity of antifouling components by their diffusion through the nanodomain structure. The new dimension also allows a part of the character of hydrogel technology to be incorporated into the structure and can also be used in conjunction with the original hydrogel to maximise fuel savings. This provides excellent antifouling performance by uniformly and efficiently releasing antifouling components from the surface of the coating film, minimising the effect that seawater temperatures, vessel speeds, and other external factors have on a coating – and therefore vessel – performance. The resin's nano-domain structure derives from the micro-domain structure used in another Nippon Paint Marine product, AQUATERRAS – the world's first and currently only biocide free self-polishing coating with a proven and verified track record. The coating uses the science and materials derived from medical anti-thrombogenic polymer technology, which allows its components to be accurately delivered and released in a precise, controlled, and effective way.

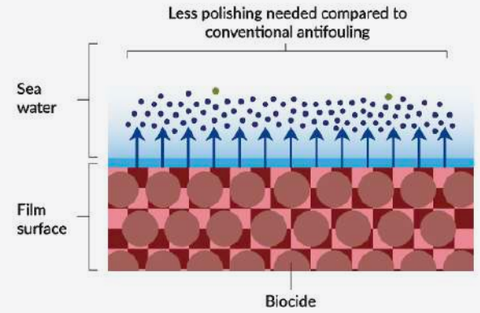
Nanotechnology also substantially improves the time and the film thickness required for application, compared to other hull coatings. This means that ship owners applying the product can benefit from reduced in-dock application and faster drying times, which provides further cost savings and efficiencies. For example, the total minimum drying time at drydock for a large container vessel is reduced by a maximum of 37%, compared to the length of time needed for other typical coating systems, depending on the actual ambient temperature, during application.

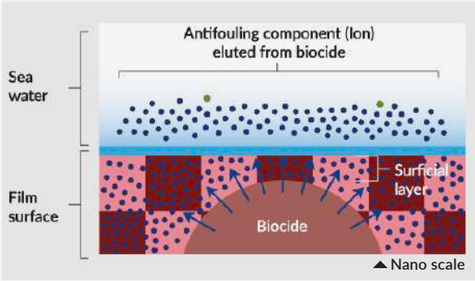
Conventional antifouling in operation



- Non-domain binders limited to control biocide release
- Uncontrolled seawater polishing results in hydrophilic surface only
- It requires more polishing to ensure better performance
- Biocides deplete resulting in increased fouling
- Increased dry film thickness or remedial coatings are required

FASTAR antifouling in operation





- Unique hydrophobic and hydrophilic nanodomain structured binder provides polishing precision
- Controlled biocide release across the entire coated surface
- Lower dry film thickness than existing self-polishing copolymer coatings
- Hydrogel water trapping technology, HydroSmoothXT™ included as an option for greater fuel savings

Hydrophilic domain

Hydrophobic domain

FASTAR® XI / XII

Launched
2021
Key innovation
Combines Nippon Paint Marine's HydroSmoothXT™ water-trapping technology with nanotechnology
Efficiency gains
8%, plus shorter drydocking times

Number of vessels coated
Over 1,000 vessels
Vessel types
VLCCs, Tankers, BC/Cargo, PCC, Container
Key customers
KC Maritime, The Sanko Steamship Co. Ltd, M. Pallonji Logistics Singapore Pte Ltd, Polaris Shipping, COSCO, KSS Line

Success story

Example of analyses on actual vessels
As the rate of adoption accelerates and surpasses 1,000 vessels, many instances revealed further efficiency gains compared to A-LF-SEA. Based on close analysis of results, a typical case is presented here:

Vessel type and Tonnage
180,020 DWT Bulk Carrier
Applied vessel area
Flat Bottom, Vertical Bottom and Lower Boot-top
Date of application
26th November 2021
Efficiency gain (%)
11.6 % compared to a conventional self-polishing hull coating

Fuel tonne and cost reduction (tonnes/$)
1,167 tonnes and 700,200 USD* per year
Emission reduction (CO2 tonnes)
3,618 tonnes per year

**Calculated at USD600 per tonne*

The success of Nippon Paint Marine's HydroSmoothXT™ low friction antifouling coatings can be further measured by their significant uptake across the global commercial fleet; since its inception in 2008, over 5,000 vessels have been coated with the technology.

Hydrogel water trapping technology, HydroSmoothXT™ included as an option for ultra-low friction

Lower VOC and CO^2 emissions

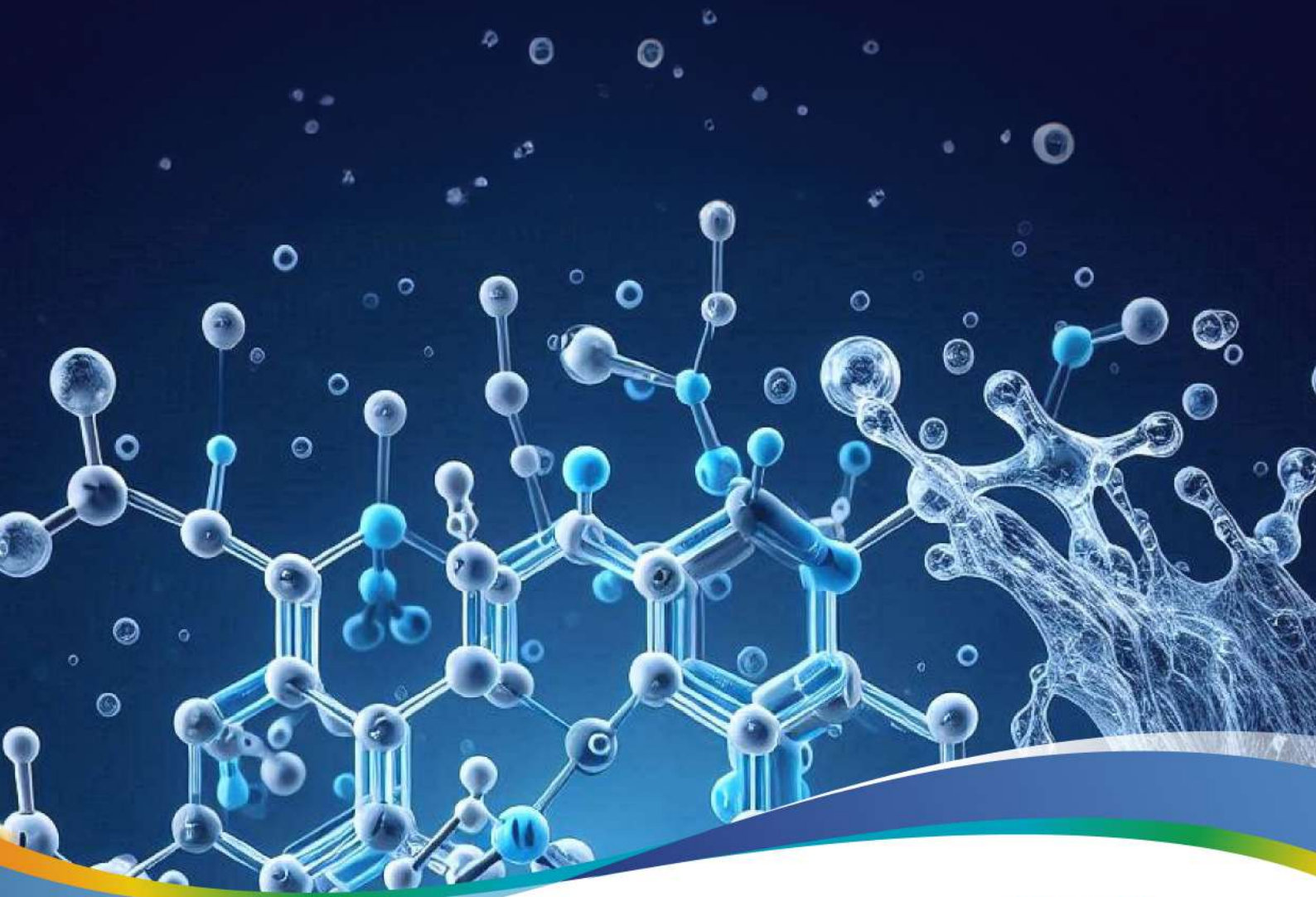
Environmentally friendly by associating with UN's Sustainable Development Goals*

Looking to the future; Developing solutions that drive performance…Inspired by you

We are now at a tipping point where breaking down new barriers, embracing radical thinking, and committing to the unrelenting pursuit of innovation are essential to surmounting the seismic challenges that the global shipping industry faces. Regulations will increase and become more stringent, and a future fuels world presents potential safety, ecological, and financial challenges. All of which is set against a backdrop where global shipping faces its ultimate responsibility as a key player in safeguarding the sustainability of our planet. It is a time for leadership and collaboration in supporting the industry to meet its targets and ambitions, something Nippon Paint Marine, as a pioneer in marine coatings, is committed to, and takes very seriously.

Inspired by our customers' challenges, as well as our team's experience, knowledge, and innovation capabilities, Nippon Paint Marine will continue to evolve and develop technology and solutions that match the level of complexity and performance that the shipping industry, and the planet, now demands.

For Nippon Paint Marine, this means that future innovations – due to launch to the market in 2024 and beyond – will not just include on-going product adaptations and evolution, but also the development of the next generation of hydrogel-based HydroSmoothXT solutions. In doing this, Nippon Paint Marine will create and deliver even more pioneering technology, driven by our world-leading teams of experts, and inspired by the engineering brilliance of the natural world around us.



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Basic & New

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