TOWARDS A SUSTAINABLE BLUE ECONOMY: INCORPORATING GREEN NORMS IN INDIA'S SHIPBUILDING AND SHIP REPAIR INDUSTRY

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Acronyms and Abbreviations

AFS	Anti-Fouling Systems
AIRCOAT	Air Induced friction Reducing ship COATing
ARUs	Air Release Units
CII	Carbon Intensity Indicator
CSL	Cochin Shipyard Ltd
DWT	Deadweight
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
GEF	Global Environment Facility
GHG	Greenhouse Gas
GOI	Government of India
GSL	Goa Shipyard Ltd
HSL	Hindustan Shipyard Ltd
IAS	Invasive Aquatic Species
ICCP	Impressed Current Cathodic Protection
IMO	International Maritime Organisation
MDD	Mandovi Drydocks
MEPC	Marine Environment Protection Committee
MIPL	Modest Infrastructure Pvt. Ltd
MoPSW	Ministry of Ports, Shipping and Waterways
NMF	National Maritime Foundation
SEEMP	Ship Energy Efficiency Management Plan
TBT	Tributyltin
UNDP	United Nations Development Programme
WSPL	Waterways Shipyard Pvt. Ltd

Abstract

The synthesis report of the Inter-governmental Panel on Climate Change (sixth assessment report) has unambiguously stated that the earth's climate is changing at an alarming rate, with global surface temperature reaching 1.1 °C above 1850-1900 levels, during the period 2011-2020, principally through anthropogenic greenhouse gas (GHG) emissions that have unequivocally caused global warming. The International Maritime Organisation (IMO) has embarked on a 'mission-mode' to reduce annual greenhouse gas emissions from international shipping by at least half, by 2050, compared to the 2008 emission levels (which are taken as the baseline) and reducing carbon intensity (carbon dioxide emissions per unit transport work) by at least 40 per cent by 2030, while continuing to pursue efforts towards a reduction of 70 per cent by 2050. It is appreciated by the authors that meeting these goals, would require a mix of technical, operational and innovative solutions. This report examines one such solution which is specifically applicable to ships, viz., an underwater-hull protection system (a.k.a. hull biofouling management) that has the potential to reduce GHG gases by approximately 5 to 25 per cent. This report examines the ship's underwater hull protection techniques used in India and latest trends available globally, and makes specific implementable recommendations for the Indian shipbuilding and ship repair sector towards becoming more environmentally sustainable. Since, this report is an outcome of Corporate Social Responsibility (CSR) funds, a deliberate attempt has been made by the authors to educate the lay public about the basics of biofouling on a ship's hull and its prevention.

Acknowledgements

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1 Introduction

Climate change is a rapidly dawning reality upon mankind, resulting in rise in ocean temperature and in the intensity and frequency of extreme weather events.[1] These extreme weather events are amongst the foremost challenges for the world in general and the shipping industry in particular.[2] One of the most important contributors to climate change are the 'greenhouse gases' released by burning of fossil fuels and it is pertinent to mention that maritime transport is overwhelmingly reliant on fossil fuels, with carbon dioxide emissions equivalent to a country of the size of Germany annually.[3] If the shipping sector was a country, it would be the sixth largest polluter in the world.[4] Shipping is critical to global trade as it carries not less than 90 per cent of world commerce, therefore, the onus of reducing carbon footprint to a large extent lies on the sector.[5] Today, an overwhelming majority of the shipping vessels rely on diesel engines to propel, and if action is not taken now to curb emissions from diesel engines, the shipping sector could be responsible for 10-13 per cent of global emissions within a few decades.[6] The United Nations' agency, "*International Maritime Organisation (IMO)*" responsible for regulating shipping, is focused on reducing emissions from oceangoing vessels by fifty percent by 2050 when compared to 2008 emissions levels as the baseline.[7] The IMO has promulgated the *IMO Greenhouse Gas Strategy* for accomplishing the goal of emission reduction with a wide list of short-term, mid-term, and long-term measures candidates.[8] Some of the candidates are, improvement of the '*Energy Efficiency Design Index (EEDI)'* and '*Ship Energy Efficiency Management Plan (SEEMP)*', use of low-carbon and zero-carbon fuels, voyage optimization, innovative emission reduction mechanisms, etc.[9]

The Marine Environment Protection Committee (MEPC)[10] — subsidiary body of the IMO that addresses environmental issues including the control and prevention of ship-source

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[1] Renny Vandewege, "Extreme Weather, Climate Change Driving New IMO Shipping Regulations", Forbes, 01 March 2023 https://www.forbes.com/sites/rennyvandewege/2023/03/01/extreme-weather-climate-change-driving-new-imo-shipping-regulations/?sh=6b17f50548e9.

[2] Ibid.

[3] Simon Bullock, James Mason, Alice Larkin, "The urgent case for stronger climate targets for international shipping", Special section on mitigation in shipping and industry, Climate Policy, Volume 22, 2022 – Issue 3, Taylor & Francis Online, 27 October 2021.

[4] Zoe Schlanger, "If shipping were a country, it would be the world's sixth-biggest greenhouse gas emitter", World Economic Forum, April 18, 2018 https://www.weforum.org/agenda/2018/04/if-shipping-were-a-country-it-would-be-the-world-s-sixth-biggest-greenhouse-gas-emitter.

[5] Anthony King, "Emissions- free sailing is full steam ahead for ocean- going shipping", *Horizon — The EU Research & Innovaytion Magazine*, 06 September 2022 https://ec.europa.eu/research-and-innovation/en/horizon-magazine/emissions-free-sailing-full-steam-ahead-ocean-going shipping#:~:text=Shipping%2C%20while%20essential%20for%20trade,worldwide%20greenhouse%20gases%20(GHG).

[6] Ibid.

[7] "IMO'S work to cut GHG emissions from ships", IMO, accessed on 10 February 2023.

[8] "IMO Action to Reduce Greenhouse Gas Emissions from International Shipping", International Maritime Organisation and Sustainable Development Goals, accessed on 12 April 2023 https://sustainabledevelopment.un.org/content/documents/26620IMO_ACTION_TO_REDUCE_GHG_EMISSIONS_FROM_INTERNATIONAL_SHIPPING.pdf.

[9] Ibid.

[10] Marine Environment Protection Committee (MEPC), IMO, accessed on 15 April 2023

pollution covered by the MARPOL 73/78 convention and protocol, and has laid down rules and regulations for ballast water management, anti-fouling systems, ship recycling, pollution preparedness and response, and identification of special areas and particularly sensitive sea areas — adopted amendments at its 76th session, to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, that all ships will require to calculate their Energy Efficiency Existing Ship Index (EEXI) and establish their Carbon Intensity Indicator (CII) rating. The amendments aim to ensure that ship operators improve their ship's efficiency to reduce the emission levels.[11]

One of the most significant factors adversely impacting the efficiency of ships propulsion is due to the resistance generated by the friction of water on the ship's hull, and this resistance increases with fouling of the hull. Therefore, maintaining a smooth and clean hull, free from biofouling is of paramount importance to optimise the energy efficiency of ships.

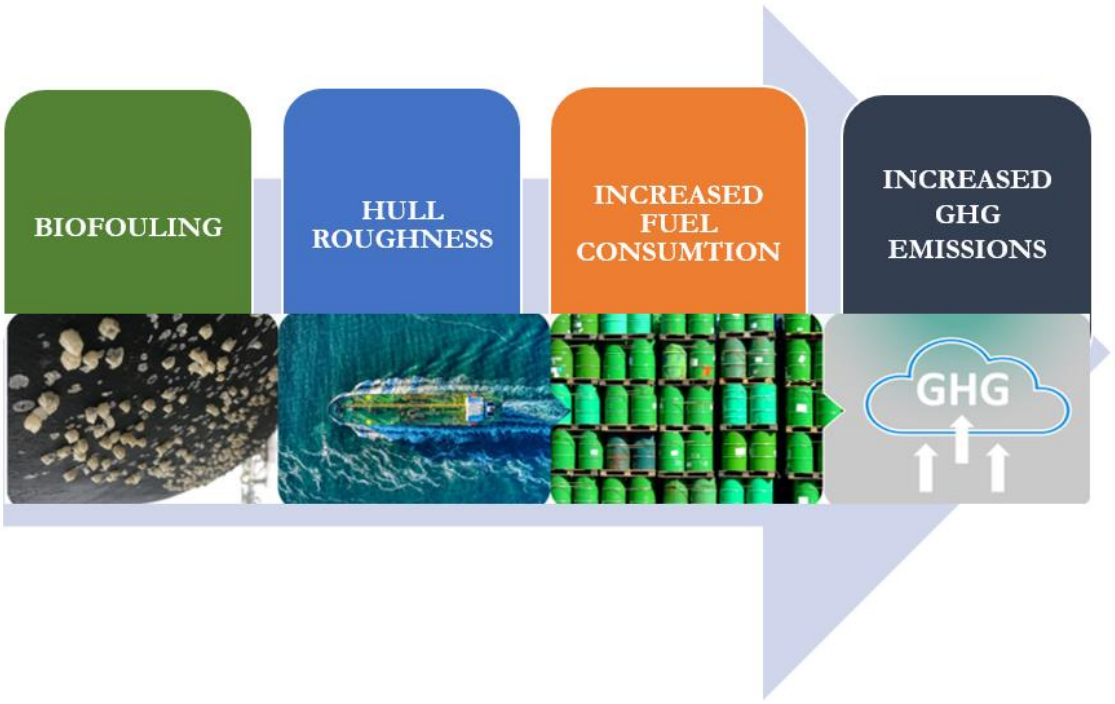

Figure 1: Relation between biofouling and GHG emissions

Source: GEF-UNDP-IMO GloFouling Partnerships Project, 2022[12]

https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-default.aspx.

[11] "Analysing the impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures", *GEF-UNDP-IMO GloFouling Partnerships Project*, 2022 https://www.glofouling.imo.org/_files/ugd/34a7be_02bd986766d44728b85228c3ec9b95ee.pdf

[12] Ibid.

1.1 Biofouling and Its Repercussions

Biofouling is described as the undesirable accumulation of micro-organisms, plants, algae, and animals on the submerged part of a vessel (especially a ship's hull). It is also considered to be one of the main vectors for bio-invasions (transfer of invasive aquatic species from one geographical location to another).[13] Biofouling on the hulls of ships enhances the roughness of the colonized surface, which results in an increased hydrodynamic drag, which consequently leads to higher fuel consumption, and concomitantly, higher GHG emissions, for the same distance traversed or speed attained. Thus, effective management of biofouling of the underwater hull can generate significant gains in terms of reduced fuel consumption and decreased GHG emissions.

The IMO has partnered with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF) under the project named "GloFouling Partnership Project" to protect marine ecosystems from the negative effects of invasive species. The objective of the project is to build capacities in developing countries for implementing IMO Biofouling Guidelines and other relevant recommendations for the management of biofouling and to catalyse the overall reduction of GHG emitted by global shipping.[14] The project analysed the impact of marine biofouling on the energy efficiency of ships and released a report that highlighted the fact that a biofouling layer of slime as thin as 0.5 mm, covering up to 50 per cent of an underwater hull surface, could trigger an increase of GHG emissions in the range of 25 to 30 per cent, depending on the characteristics of the vessel, its speed and other prevailing conditions.[15] There are a number of non-traditional methods such as ultrasonics, electric currents, magnetic fields and optical methods, which are available to control biofouling. However, amongst all traditional and non-traditional methods available, perhaps the most cost-effective method is the use of anti-fouling coatings (paints) and, in particular, biocidal anti-fouling paints.

1.2 Anti-fouling Coatings and Aquatic Invasive Species

Anti-fouling coatings are specialized underwater paints that are applied to the underwater area of the hull, to slow the growth of sub-aquatic organisms which would otherwise adversely affect the performance of the vessel while underway, while also reducing the time period between successive dry-dockings for scheduled maintenance. However, 'anti-fouling' chemicals (also known as 'biocides') are, for the most part, toxic materials and have a deleterious effect upon the

[13] Naida Hakirevic Prevljak, "IMO, Norad embark on new biofouling project", Offshore energy, 16 December 2021.
https://www.offshore-energy.biz/imo-norad-embark-on-new-biofouling-project/
[14] "GloFouling Partnerships", accessed on 28 February 2023.
https://www.glofouling.imo.org/objectives
[15] "Analysing the impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures", *GEF-UNDP-IMO GloFouling Partnerships Project*, 2022.
https://www.glofouling.imo.org/_files/ugd/34a7be_02bd986766d44728b85228c3ec9b95ee.pdf

marine environment.[16] The IMO's Anti-Fouling Systems (AFS) Convention, which prohibits the use of harmful 'organotin' in anti-fouling paints to prevent the potential future use of other harmful substances in anti-fouling systems, has been accepted.[17] While this convention banned the use of 'tributyltin' (TBT) in 2008, several marine scientists and ecologists believe that the current replacement for TBT is only slightly less harmful and is still adversely affecting the marine eco-system.[18] Further, the spread of invasive species has long been recognised as a significant marine environmental threat — one that impacts tourism, aquaculture, fisheries, and results in costly damage to marine infrastructure.[19] It is this realisation that led the Marine Environment Protection Committee (MEPC) of the IMO to promulgate Guideline 207(62) for the control and management of biofouling of ships, thereby minimizing the transfer of invasive aquatic species from one geographical location to another.[20] Invasive Aquatic Species (IAS) may be defined as species that may pose threats to human, animal, and plant life, economic and cultural activities, and the aquatic environment.[21] Thus, it can be appreciated that the impact of biofouling is not limited to the performance of the vessel alone but also adversely impacts the marine eco-systems, directly or indirectly.

Historically, the shipbuilding and the ship-repair industry has underestimated the adverse effect of biofouling.[22] Presently, the use of anti-fouling paints remains the option of choice for preventing biofouling growth. Therefore, there is tremendous potential for research-and-development agencies to develop underwater-hull protection techniques to provide viable alternatives to anti-fouling paint coatings. In 2021, the MEPC adopted an amendment to include controls on the biocide 'cybutryne'. The amendment included a stipulation that with effect from 01 January 2023, ships shall not apply or re-apply anti-fouling systems containing this substance. The amendment also stipulated that ships shall remove any coating of AFS containing this substance at the next scheduled renewal of the anti-fouling system after 01 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne.[23] This circular has brought other non-traditional methods of underwater

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[16] Hyun-Jeong Kim, "Strategic actions for sustainable vessel hull coatings in line with the UN SDGs", Journal of Advanced Marine Engineering and Technology, The Korean Society of Marine Engineering, August 2021. The Korean Society of Marine Engineering (e-jamet.org)

[17] International Maritime Organization (IMO), Accessed 28 February, 2023. https://www.imo.org/en/OurWork/Environment/Pages/Anti-fouling.aspx

[18] Hyun-Jeong Kim, "Strategic actions for sustainable vessel hull coatings in line with the UN SDGs", August 2021. The Korean Society of Marine Engineering (e-jamet.org)

[19] Ibid.

[20] "2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species", Resolution MEPC.207(62), ANNEX 26, International Maritime Organization (IMO), 15 July 2011. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/RESOLUTION%20MEPC.207[62].pdf

[21] International Maritime Organization (IMO), Accessed 28 February, 2023. https://www.imo.org/en/OurWork/Environment/Pages/Biofouling.aspx

[22] "Analysing the impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures", *GEF-UNDP-IMO GloFouling Partnerships Project*, 2022. https://www.glofouling.imo.org/_files/ugd/34a7be_02bd986766d44728b85228c3ec9b95ee.pdf

[23] "Ban on use of Anti-Fouling Systems that contains Cybutryne", Technical Circular No: 019/2022, Indian Register of Shipping (IR CLASS), 2022. IRCLASS- Technical Circular No: 019/2022

hull protection techniques into the limelight for use by the shipbuilding and ship-repair industries.

2 Biofouling Prevention Methods Used in Indian Shipbuilding and Ship Repair Industry

Ship painting and underwater-hull protection are important for improving the propulsive efficiency of a ship as these measures reduce the roughness of a ship's hull, while protecting and preserving the thickness of the underwater hull plates from corrosion, etc. The increase in hull roughness increases ship's drag and hull friction, both of which directly reduce the ship's speed while increasing the fuel consumption of the main engines. There are two major factors affecting hull roughness — physical and biological. Physical factors include poorly ground weld seams, welding defects, hull plate waviness, plate lapse and corrosion/mechanical damage etc., whereas the biological factors include weed fouling, animal fouling, algae, barnacles, slime, etc. Improper maintenance or malfunctioning of Impressed Current Cathodic Protection (ICCP) systems can also result in an increase of hull roughness.[24]

The Indian shipbuilding industry has 28 shipyards, of which six are under the Central Public Sector, two under State Governments, and the remaining 20 are Private Sector Undertakings.[25] According to the Ministry of Ports, Shipping and Waterways (MoPSW) report of 2021-2022,[26] there are 38 dry-docks in India for ship construction and repair, incorporating both, the public and private sector. In 2021-22, amongst public sector companies, Cochin Shipyard Ltd (CSL), Kochi, had the highest capacity for ship repairs (1,25,000 DWT) followed by Hindustan Shipyard Ltd. (HSL), Visakhapatnam, at 80,000 DWT, and Goa Shipyard Ltd. (GSL), Goa, (4,500 DWT). In the private sector, Waterways Shipyard Pvt. Ltd. (WSPL), Goa, (8,000 DWT) had the highest capacity for ship repair, followed by Modest Infrastructure Pvt. Ltd. (MIPL), Gujarat, (6,000 DWT) and Mandovi Drydocks (MDD), Goa, (5,000 DWT).[27]

As the Indian shipbuilding industry is moving towards modernisation, hull coating as one of the essential elements of shipbuilding and ship repair process needs to be analysed for accelerating the transition.[28] An analysis, which focused on the underwater hull protection techniques used in major shipyards of India, was conducted by National Maritime Foundation (NMF).

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[24] S.N.Batra, *A Guide to Hull Painting of Ships* (Marine Insight, 2014), 106.
[25] Ministry of Ports, Shipping and Waterways, accessed on 1 March 2023. https://shipmin.gov.in/division/shipping
[26] "Statistics of India's shipbuilding and ship repairing industry 2021-22", Transport Research Wing, Ministry of Ports, Shipping and Waterways (MoPSW), Government of India (GOI), New Delhi, February 2023. https://shipmin.gov.in/sites/default/files/SBR%202021-22%20Final.pdf
[27] Ibid.
[28] Bu, H.; Yuan, X.; Niu, J.; Yu, W.; Ji, X.; Lyu, H.; Zhou H., "Ship Painting Process Design Based on IDBSACN-RF", Coatings 2021. https://doi.org/10.3390/coatings11121458

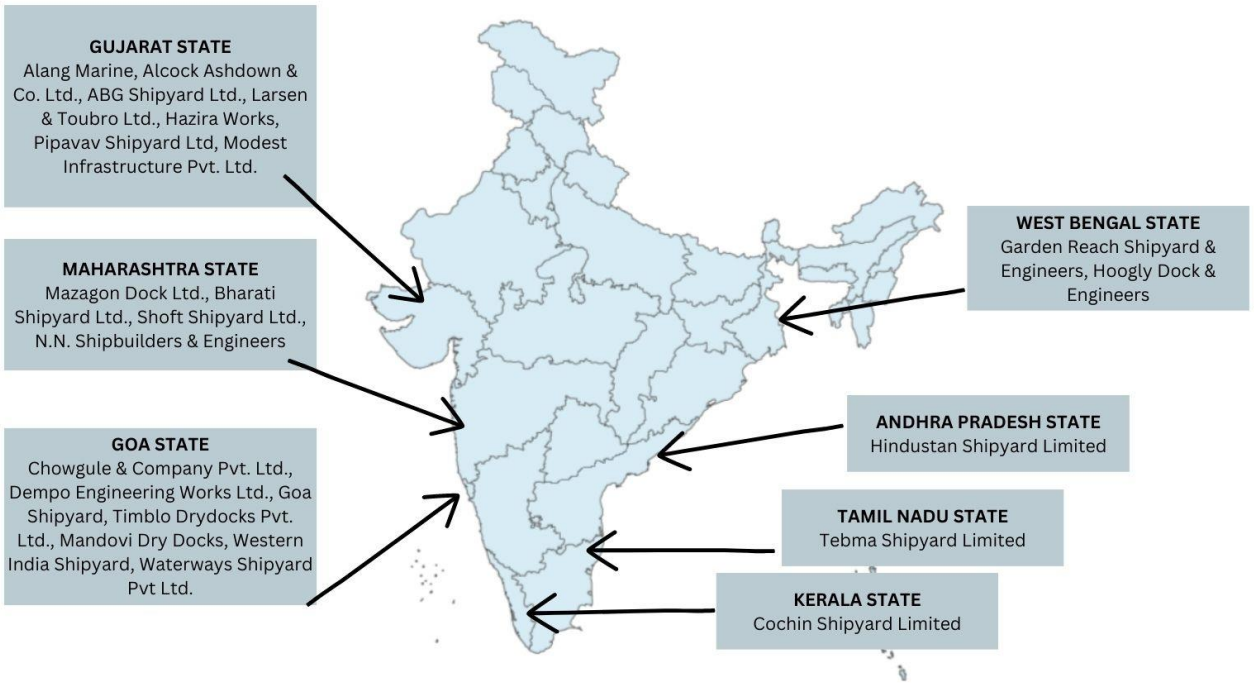
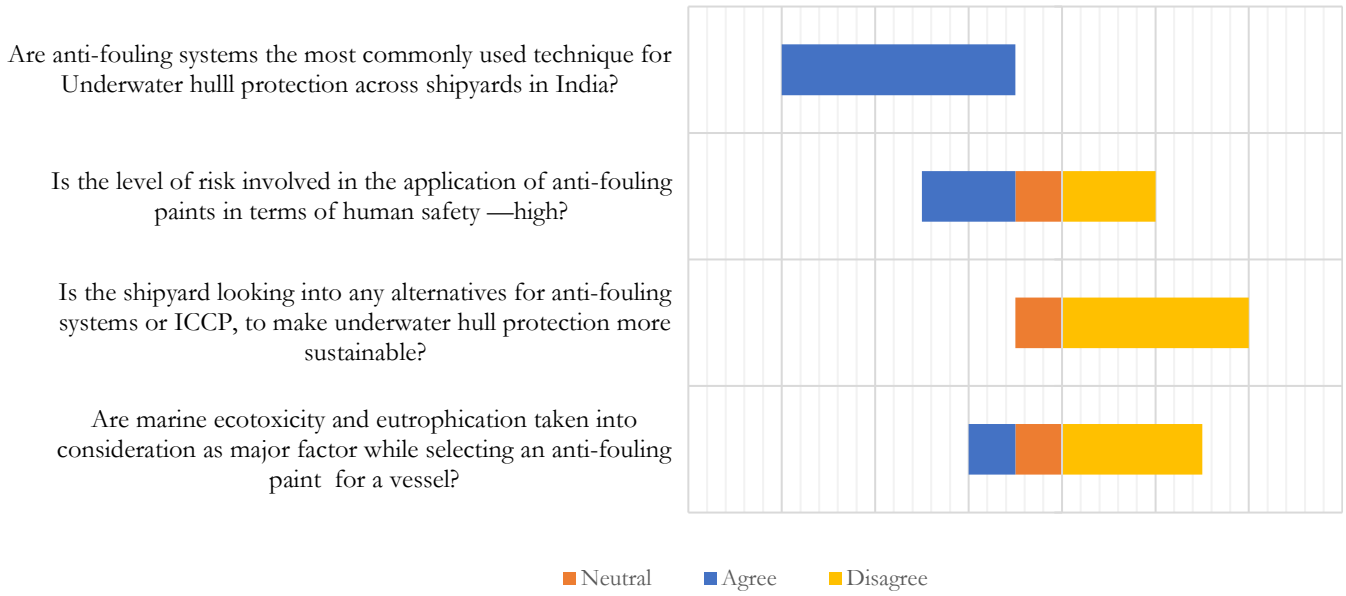


Figure 2: Map highlighting some of the major shipyards of India.
Source: Compiled by Authors (Statistics of India's shipbuilding and ship repairing industry 2021-22),[29] Some shipyards are closed due to financial viability issues.

A questionnaire, designed to understand the current scenario in the shipyards and their future plans with respect to underwater hull protection techniques, was circulated to some public and private sector shipyards, and their responses collated. The questionnaire comprised ten questions covering the entire gamut of underwater hull protection techniques with special emphasis on new trends incorporating green technologies. A three-point Likert Survey Scale was developed using the responses received from the different shipyards. *(A Likert scale is a psychometric and unidimensional scale used to assess and understand participant's opinions on a series of statements.[30])* The Likert Scale as shown in Table 1 highlights the opinion of shipyards on four questions related to underwater hull protection techniques. The scale distributes the responses into three anchor points: 'agree', 'disagree', and 'neutral'. There is also a conditional dependence of the answers with respect to the requirement of the shipowners for ship construction or repair. Thus, the neutral point indicates the dependence of building of vessel on the owner's requirement, which may or may not include the sustainable practices over the commonly used commercial methods.

[29] "Statistics of India's shipbuilding and ship repairing industry 2021-22", Ministry of Ports, Shipping and Waterways (MoPSW), New Delhi, February 2023.
[30]Joshi, Ankur & Kale, Saket & Chandel, Satish & Pal, Dinesh, "Likert Scale: Explored and Explained", British Journal of Applied Science & Technology. 7. 396-403. 2015.



Graph 1: Likert Scale generated from the Indian shipyards' responses.

Source: Data collated from shipyards and analysed by the Authors

The Likert Scale derived from the responses only reinforced the anticipated outcomes for the questions asked. The results showed that the most commonly used technique for underwater hull protection in India remains the application of anti-fouling paint, and that marine ecotoxicity and eutrophication are yet to become decision-making factors in the selection/non-selection of anti-fouling paints for the underwater hull of a vessel. In terms of sustainability, the hull coating practices are driven by the shipowner's requirement and is a long way from becoming a norm in the commercial ship building and repair industry. A query relating to the level of risk involved in application of anti-fouling coatings evoked a mixed response, as some shipyards considered it highly risky for the human workers involved, while other shipyards considered this to be much less risky.

The incorporation of sustainable underwater hull protection techniques in shipyards is a viable pathway towards decarbonisation of the shipping sector, as sustainable underwater hull practices are amongst the short-term measures that can be adopted by shipyards for reducing the hydrodynamic drag and thereby reducing GHG emissions from vessels. In January 2022, the Ministry of Ports, Shipping and Waterways (MoPSW), Government of India (GoI) had announced an initiative for 'green' ports and 'green' shipping as part of the Maritime India Vision 2030, so as to reduce the industry's total carbon dioxide emissions.[31] It is clear that India is actively seeking practical solutions and pathways for its transition from a 'Brown' economy to

[31] "Maritime India Vision 2030", Ministry of Ports, Shipping and Waterways (MoPSW), Government of India.

a 'Blue' one. Incorporating 'green' norms to underwater hull protection techniques could be a significant step to achieve the ambitious targets set by the country to reduce its GHG emissions.

3 Global Sustainable Underwater Hull Protection Trends

Underwater-hull protection systems have dual purpose of protecting of the hull from fouling and also reducing the surface roughness. Increasingly stringent environmental regulations and the imperative to lower fuel consumption to not only reduce operating costs but also as one of the practical measures to reduce carbon dioxide emissions have provided an impetus to the development of new anti-fouling technologies.[32] One of the more promising developments includes a hydrophilic anti-fouling coating based on hydrogel technology that comprises a network of advanced polymer chains, which can absorb necessary amounts of water to create water-like boundary and thereby reduce or prevent adherence of marine organisms to ship's hull. The creation of this water-like boundary effectively reduces hydrodynamic drag.[33] In addition, air lubrication systems — both passive and active — also hold out tremendous promise as practical commercial applications for sustainable underwater-hull protection. The authors undertook an extensive review of existing literature to identify various new trends in sustainable underwater-hull protection practices and conducted several interviews with the practitioners in the shipbuilding and ship repair industry to understand the nuances involved in practical commercial adoption of these new technologies. Online interaction and email exchanges with laboratories/ companies were educative and informative. Based on the literature survey and interaction with stakeholders, the authors narrowed down their choice to two technologies/companies that are discussed in the ensuing paragraphs.

3.1 AIRCOAT

The AIRCOAT[34,35] is a Horizon 2020 project that received a total grant of 5.3 million Euros from the European Commission. AIRCOAT is an abbreviation for 'Air Induced friction Reducing ship COATing' and the project aims at developing a biomimetic antifouling coating — a biomimetic antifouling coating is a treatment that prevents the accumulation of marine organisms on a surface. Typical antifouling coatings are not biomimetic but are based on synthetic chemical compounds that can have deleterious effects on the environment. On the other hand, natural materials such as sharkskin continue to provide inspiration for scientists to improve the coatings currently in the market[36] — passive air lubrication technology that avoids

[32] Abdullah Saif Qureshi, Dr. Rajan Ramaswamy, "Evolution of anti-fouling paints", *International Journal of Science and Research (IJSR)*, 2015.
[33] Ibid.
[34] Johannes Oeffnera, Jukka-Pekka Jalkanenb, Stefan Walheimc, Thomas Schimmelc, "From nature to green shipping: Assessing the economic and environmental potential of AIRCOAT on low-draught ships" Proceedings of 8th Transport Research Arena TRA 2020, Helsinki, Finland, April 27-30, 2020.
[35] AIRCOAT, accessed on 26 March 2023. https://aircoat.eu/
[36] J.Busch , W Barthlott, M.Brede, W.Terlau, M. Mail, " Bionics and green technology in maritime shipping: an assessment of the effect of Salvinia air-layer hull coatings for drag and fuel reduction", *The Royal Society Publising* , 9 October 2018.
http://dx.doi.org/10.1098/rsta.2018.026

direct contact of the ship and water, which reduces drag, corrosion and fouling of the hull and may lead to significant fuel savings at global level.

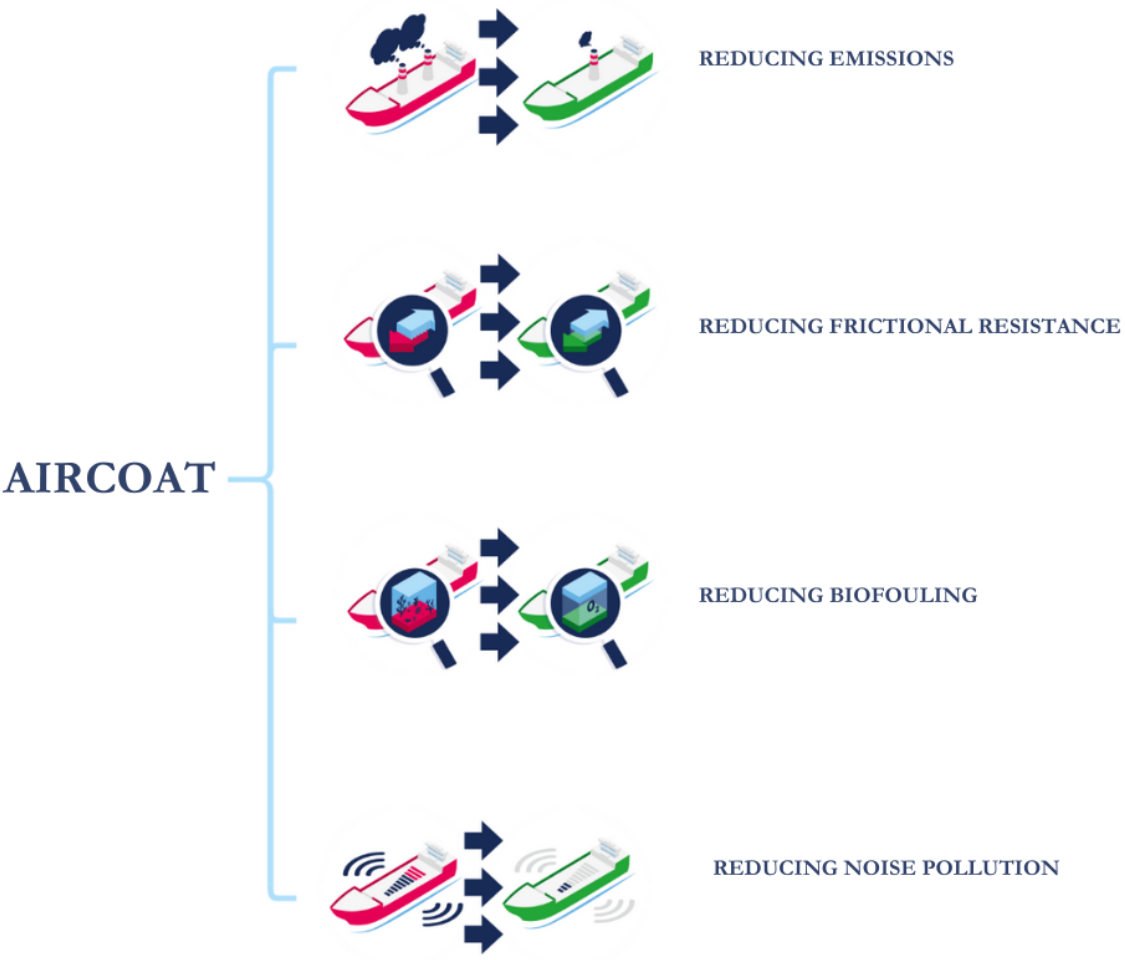


Figure 3: AIRCOAT air layer: positive environmental impacts
Source: Authors, AIRCOAT[37]

This passive air lubrication technology is based on a biomimetic ship hull coating that introduces a permanent layer of air on a surface under water, inspired by the 'Salvinia effect'. The Salvinia effect uses a hierarchically structured surface with specialised micro- and nano-structures, in combination with hydrophilic and hydrophobic areas. The structure mimics the biochemical processes of the Salvinia plant, which allow long-term air retention and prevent air-loss even in turbulent flow conditions.[38] The effect enables the trapping of air through this structured surface. This technology can be implemented by using a self-adhesive foil system. Although this product is not yet commercially available, it has the potential to revolutionise the

[37] AIRCOAT, accessed on 26 March 2023, https://aircoat.eu/
[38]J.Busch , W Barthlott, M.Brede, W.Terlau, M. Mail, " Bionics and green technology in maritime shipping: an assessment of the effect of Salvinia air-layer hull coatings for drag and fuel reduction", *The Royal Society Publising* , 9 October 2018.
http://dx.doi.org/10.1098/rsta.2018.026

entire hull-coating process. The layer of air created in ship's hull area that lies 'between wind and water' serves as a slip agent, increasing the velocity at the phase boundary layer. This, in turn, leads to reduced shear stress and, ultimately, reduced skin-friction. A friction coefficient reduction between 2 and 20 per cent has been observed in different experimental scenarios conducted by the AIRCOAT team, as reported in email exchanges/online interaction between the authors and the team.

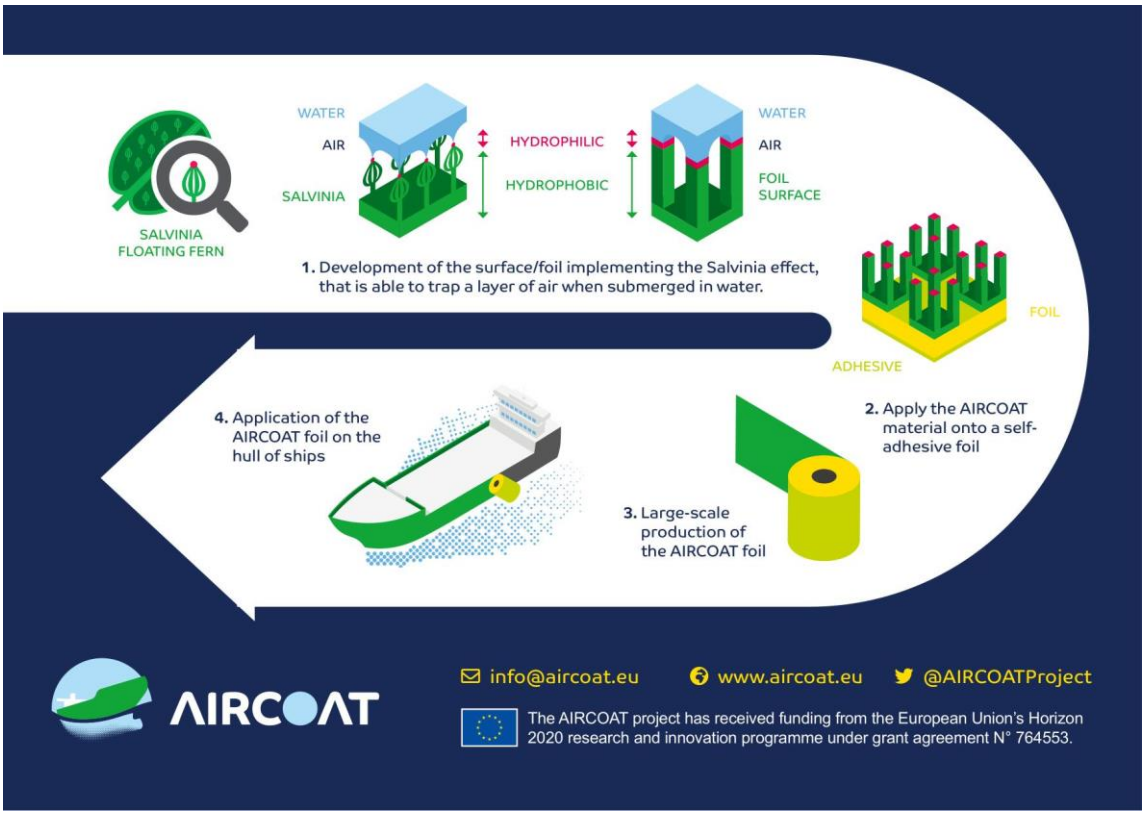


Figure 4: AIRCOAT development and its application
Source: AIRCOAT[39]

3.1.1 Malta Field Test of AIRCOAT

The AIRCOAT team did a field test on a boat in June 2021 in Malta. The foil was applied on the port side of the vessel while the starboard side was coated with a control foil. The boat was in Mediterranean Sea for 120 days. Samples were then studied for fouling diversity and for cleanability.[40] The field test gave following results (refer Table 1) —

[39] AIRCOAT, accessed on 26 March 2023, https://aircoat.eu/
[40] "Matla Field Test and Biofouling Results", AIRCOAT, accessed on 14 April 2023. https://aircoat.eu/malta-field-test-and-biofouling-results/

Sno.	Parameters	Results
1	Performance under real world conditions	a. A full air layer was observed upon contact with water. b. Air layer was intact after navigating for 30 mins at 3 knots. c. Fouling was observed after air layer loss on the boat during long-term experiments in the field.
2	Air Layer Durability	a. Tests confirmed observation that smaller structures hold a more stable air layer, and thus longer air layer retention capabilities. b. In lab experiment, increased rotational speed reduced the durability of the air layer, though the cause of air loss remains unclear.
3	Fouling Growth Inhibition and Attachment Strength	a. Successful prevention of microfouling by the underwater air layer was demonstrated. b. Fouling release properties were achieved and demonstrated

Table 1: Results of Malta Field Test of AIRCOAT
Source: Authors, AIRCOAT[41]

Figure 5: Silvery air layer visible on hull (during the Malta field test if AIRCOAT)
Source: AIRCOAT[42]

[41] Ibid.
[42] Ibid.

The test demonstrated successful adhesion of the foil and air layer stability on the boat over 120 days under practical conditions — though the test parameters need to be analysed in greater detail before extrapolating them to meaningful conclusions — in the Mediterranean Sea. No fouling was observed as long as the air layer was intact. This demonstration of air-retaining foil — AIRCOAT indicates potential for future non-toxic fouling prevention.[43]

3.2 Silverstream Technology

Silverstream Technology[44,45] is a market leader in air lubrication systems for the shipping industry. They have patented an air-lubrication system called the '*Silverstream® System*', which essentially involves the release of pressurized air from Air Release Units (ARUs) in the hull to create a uniform carpet of microbubbles that coats the entire length of the vessel's keel and decreases frictional resistance between the vessel's hull and the water, thereby reducing both, fuel consumption and GHG emissions. The system harnesses the power of both, compressed air and the ocean, to deliver between five and ten percent fuel and emissions savings. Since the firm undertakes the complete process from the design stage to fitment, trials and system handover, the system is suitable for both, new construction vessels, as also for retrofitting onboard vessels that are already in service. In the case of a retro-fitment, all structural integration work can be completed during the normal dry-docking period.

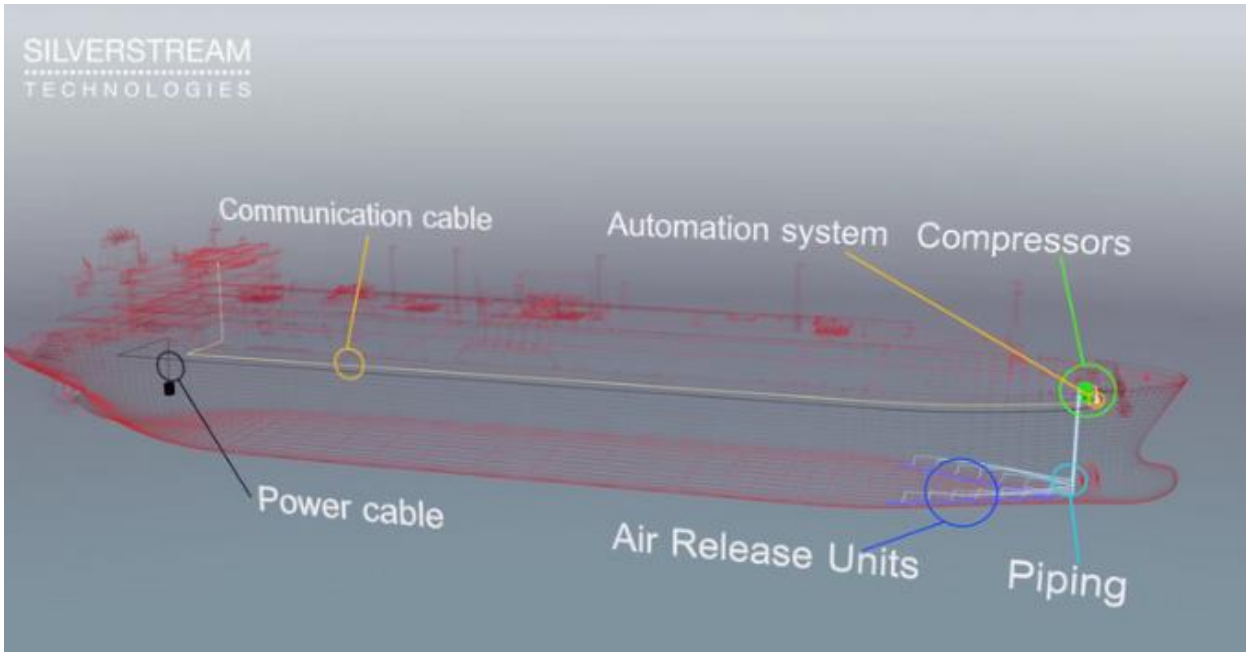


Figure 6: Silverstream System on a vessel
Source: Silverstream technology[46]

[43] Ibid.
[44] N Silberschmidt, T Pappas, D Connolly and L De Freitas, "Full Scale Performance Measurement and Analysis of the Silverstream Air Lubrication System", *The Royal Institution of Naval Architects*, October 2018, London, UK.
[45] SilverStream Technologies, accessed on 26 March 2023. https://www.silverstream-tech.com/
[46] Ibid.

In compliance with IMO's Energy Efficiency Existing Ship Index (EEXI) for newly constructed vessels and the Energy Efficiency Design Index (EEDI) for existing vessels, the air lubrication technology is advocated as a clean technology that significantly improves the aforementioned efficiency ratings.[47] The Silverstream® System is also well-suited to IMO's operational Carbon Intensity Indicator (CII) regulation, which mandates that ships of 5,000 gross tonnage and above must ensure a continuous improvement of the vessel's operational emissions output.[48] The Silverstream technology is fuel-agnostic and additionally reduces underwater fouling and radiated noise. The system is claimed to last the full lifecycle of the vessel and deliver efficiency gains by net fuel and emission savings, depending on the vessel type as shown in Table 2.

Ship Type	System Operational Speed (KTS)	Typical Operational Draught (M)	Flat Bottom as a percent of total wetted surface area	Net Savings Silverstream system performance
Cruise Ship	10-20	8-9	30-35 %	5-7 %
New Generation RoRo	10-22	7-8	26-32 %	5-7 %
Containership (>9,000 TEU)	10-23	14-16	25-30 %	5-6.5 %
Gas Carriers (LNGC, VLECs and VLGCs)	10-19	9-12	35-40 %	6-9 %
Large Wet & Dry Bulk Carrier (> 100k DWT)	10-15	13-20	25-45 %	6-11 %

Table 2: Net Savings using Silverstream system for different types of vessels at specific operational speed and draught.
Source: Silverstream Technology [49]

During interaction with the authors, the Silverstream team claimed that beneficial effects with respect to environmental impacts could be accrued through reduction in emissions, fouling, noise, underwater radiated noise and increase in speed by using Silverstream systems[50], as shown in figure 7.

[47] N Silberschmidt, T Pappas et at, *The Royal Institution of Naval Architects*, October 2018, London, UK.
[48] SilverStream Technologies, accessed on 26 March 2023. https://www.silverstream-tech.com/
[49] Ibid.
[50] Ibid.

Figure 7: Silverstream System: positive environmental impacts
Source: Presentation given by Silverstream technology team during interaction

3.3 AIRCOAT, Silverstream® System and Anti-fouling paints — A Comparison

The authors divided the project into two phases. In the first phase, they undertook a comprehensive literature review and desk-based research. The second phase included interviews and interactions with a variety of stakeholders in the field of improving hull coatings. A substantial amount of data was collected by means of questionnaires, to understand the underwater hull protection technology market and its development with respect to time. The authors have tabulated below in Table 3, their appreciation of critical parameters relevant to the three potential applications discussed in this report, and their appreciation is based on interactions with major Indian shipyards and companies working towards sustainability in the maritime sector, including inputs provided by the AIRCOAT and the Silverstream teams.

Factors	**Anti-fouling paints**	**AIRCOAT**	**Silverstream® System**
Applicability	Applicable on all hull forms	Applicable on all hull forms	Applicable for flat bottom hull forms only

Application process and ease of application	A paint scheme is applied on the hull with specific film thickness and inter-coat drying intervals. Standard Operating Procedures (SOPs) exist for application of paint scheme.	A foil is stuck on the hull. Difficult to implement because presently the procedure is manual and there are limitations of adhesiveness, environmental conditions like humidity etc. and size of foils.	Air Release Units (ARUs) are installed in the vessel that uses air compressors and air outlet in the hull to release air bubbles constantly. Can be fitted without much difficulty.
Extra cargo space and energy required	No	No	Yes, it requires extra energy for compressed air supply and occupies some cargo space
Noise pollution	Does not contribute to underwater noise reduction	Reduces underwater noise from vessel	Reduces underwater noise from vessel
Anti-fouling property	Chemicals present in the paint have anti-fouling property	Formation of a passive air layer prevents fouling.	Formation of active air bubble layer at wetted surface area prevents fouling.
Marine ecotoxicity and eutrophication	The chemicals from the paint adversely affect the marine ecosystem	Eco-friendly	Eco-friendly
Initial Cost	Lower than AIRCOAT and Silverstream® System	Higher than anti-fouling paints	Higher than anti-fouling paints
Overall Effectiveness	Lower performance	Better performance but maintaining the passive air layer constantly is difficult	Better performance than normally painted hull vessel
Commercial availability	Yes, readily available	No, still in laboratory phase	Yes

Table 3: Compares the three systems that can be used for underwater hull protection.
Source: Collated and analysed by Authors

4 Discussion and Recommendations

AIRCOAT is a 'passive' air-lubrication system whereas Silverstream® System is an 'active' one. Unlike active air lubrication technologies, AIRCOAT has no limit with respect to hull forms whereas the Silverstream® System is preferred for flat bottoms. The latter consumes energy to ensure the supply of compressed air and modifications are undertaken during maintenance periods to provide air outlets in the hull and the fitment of air compressors and associated auxiliaries, air reservoirs and piping, thereby consuming some cargo space. However, the energy and space penalties are negligible compared with the overall savings that accrue. During their interaction with the authors, the AIRCOAT team stated that based upon the several experiments undertaken to analyse the performance of the AIRCOAT system in a marine environment, they had deduced a 10 per cent reduction in friction and were able to validate the entire experiment by numerical simulation. Currently, the AIRCOAT system is yet to mature commercially and still has some challenges to overcome. The Silverstream® System, on the other hand, is already available commercially and has also demonstrated its efficiency in actual field settings, with a saving of 5-10 per cent in terms of fuel and GHG emissions. Both, AIRCOAT and the Silverstream® System are environmentally friendly and have negligible adverse effects on the marine ecosystem when compared with anti-fouling paints. They also have the additional advantage of reducing fuel consumption and GHG emissions. However, the application of AIRCOAT or the Silverstream® System is capital-intensive and costlier than the application of anti-fouling paints.

4.1 Recommendations for the Indian Shipbuilding and Ship Repair Industry

In accordance with Maritime India Vision 2030[51], the authors recommend the following:

- Active Air Lubrication Technology, which is commercially available, may be considered as an immediate step towards decarbonisation.
- Implement a gradual phasing-out of biocidal anti-fouling paints.
- Intensify research and development efforts in Indian academia and laboratories to find better alternatives for sustainable Underwater Hull Protection Practices.

[51] Maritime India Vision 2030, Ministry of Ports, Shipping and Waterways (MoPSW), 2021 https://sagarmala.gov.in/sites/default/files/MIV%202030%20Report.pdf.

5 Conclusion

The clock is ticking fast for the maritime industry to meet the stringent emission regulations. Maximising vessel efficiency, irrespective of fuel choice, is a crucial factor to reduce operating costs and ensure profitability. Thus, the authors feel that analysing different sustainable practices for underwater hull protection is an important step towards decarbonisation. The potential of sustainable underwater hull protection practices needs more study and research with respect to Indian shipbuilding and ship-repair practices.

Appendix

The research is focused on increasing the awareness in the Indian Shipbuilding and Ship Repair Industry and the associated ecosystem about the technical advancements done globally in sustainable underwater hull protection practices, to reduce the emissions and make the underwater hull protection eco-friendly. This awareness would in turn lead to adaptation and implementation of environmentally sustainable practices in the Indian shipbuilding and ship repair industry. The authors collected their data from literature review, virtual interactions, responses from questionnaire, and field visit.

The questionnaire was designed to understand the Indian shipyards and methods used by them for underwater hull protection. The questions sought to understand how ship owner's requirement affect the decision-making process of choosing a particular hull protection system from the many options available, how widespread is the use of anti-fouling paints in the industry, and what future plans do shipyards have for making underwater hull protection environmentally sustainable.

The responses received from different shipyards have not been edited and they provide an insight about the present practices prevalent in the Indian Shipyards and their future plans with respect to underwater hull protection.

Questions used for the research are enumerated below:

1. In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?
2. What are the top three anti-fouling paints used at the shipyard to reduce biofouling?
3. What are the three most important factors for the selection of anti-fouling paints for a vessel?
    a. Paint and application cost
    b. Marine ecotoxicity and eutrophication
    c. Physical properties of the vessel & sea route
    d. Life span of the paint
    e. Effect on human health
    f. Anti-fouling properties
4. What is the level of risk involved in the application of anti-fouling paints in terms of human safety?
    a. Low
    b. Medium
    c. High
5. What are the conditions and pre-treatment required before the application of anti-fouling paint?
6. What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)
7. What is the drydock interval for a medium-sized ferry?
8. Is any active or passive lubrication method currently being used for reducing drag?

9. In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?
10. Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection?
    a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms.
    b. Enzyme-based coating systems
    c. New biocide free, two-component, fouling release coating.
    d. Copper-Free Antifouling coating
    e. Self-adhesive /fouling-release coatings.
    f. Nano antifouling coating

Responses received from different Indian Shipyards:

The responses were received through google forms and emails. Shipyards A, B and C submitted responses through google forms while others were received through email. The responses are tabulated below:

Shipyard A

S No.	Questions	Answers
1	In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?	Yes
2	What are the top three anti-fouling paints used at the shipyard to reduce biofouling?	polymer based paints by jotun, elzo noble, etc
3	What are the three most important factors for the selection of anti-fouling paints for a vessel? a) Paint and application cost b) Marine ecotoxicity and eutrophication c) Physical properties of the vessel & sea route d) Life span of the paint e) Effect on human health f) Anti-fouling properties	Paint and application cost, Lifespan of the paint, Anti-fouling properties
4	What is the level of risk involved in the application of anti-fouling paints in terms of human safety? a. Low b. Medium c. High	Low
5	What are the conditions and pre-treatment required before the application of anti-fouling paint?	Blasting and painting

6	What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)	3 months
7	What is the drydock interval for a medium-sized ferry?	5 months
8	Is any active or passive lubrication method currently being used for reducing drag?	No
9	In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?	Not present in the paints in use
10	Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection? a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms. b. Enzyme-based coating systems c. new biocide free, two-component, fouling release coating. d. Copper-Free Antifouling coating e. Self-adhesive /fouling-release coatings. f. Nano antifouling coating	None of the above

Shipyard B

S No.	Questions	Answers
1	In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?	Yes
2	What are the top three anti-fouling paints used at the shipyard to reduce biofouling?	Silyl Acrylate antifouling paint, Self-polishing antifouling system incorporating Copper Acrylate SPC, Anti fouling paint having tin free biocides
3	What are the three most important factors for the selection of anti-fouling paints for a vessel? g) Paint and application cost	Paint and application cost, Lifespan of the paint, Anti-fouling properties

	h) Marine ecotoxicity and eutrophication i) Physical properties of the vessel & sea route j) Life span of the paint k) Effect on human health l) Anti-fouling properties	
4	What is the level of risk involved in the application of anti-fouling paints in terms of human safety? d. Low e. Medium f. High	Low
5	What are the conditions and pre-treatment required before the application of anti-fouling paint?	Depends if it is a complete paint renewal wherein SA2.5 is achieved prior system coating. However, if it is overcoating on existing paint scheme, surface abrasion is undertaken
6	What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)	14 to 21 Days
7	What is the drydock interval for a medium-sized ferry?	2 to 5 years
8	Is any active or passive lubrication method currently being used for reducing drag?	Maybe
9	In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?	The paints for commercial ships are sourced by the customer. The Yard will ensure that the paints supplied are in compliance with the MEPC amendments. The paints for Naval vessels are cleared by the Ministry of Defence and the same would be used.
10	Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection? a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms. b. Enzyme-based coating systems c. new biocide free, two-component, fouling release coating. d. Copper-Free Antifouling coating e. Self-adhesive /fouling-release coatings. f. Nano antifouling coating	None of the above

Shipyard C

S No.	Questions	Answers
1	In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?	Yes
2	What are the top three anti-fouling paints used at the shipyard to reduce biofouling?	Ablative type - Cuprous oxide, Self Polishing Copolymers - Silyl Acrylate based, Biocide free Silicone elastomer
3	What are the three most important factors for the selection of anti-fouling paints for a vessel? a) Paint and application cost b) Marine ecotoxicity and eutrophication c) Physical properties of the vessel & sea route d) Life span of the paint e) Effect on human health f) Anti-fouling properties	Paint and application cost, Lifespan of the paint, Anti-fouling properties
4	What is the level of risk involved in the application of anti-fouling paints in terms of human safety? a. Low b. Medium c. High	Low
5	What are the conditions and pre-treatment required before the application of anti-fouling paint?	Depends if it is a complete paint renewal wherein SA2.5 is achieved prior system coating. However, if it is overcoating on existing paint scheme, surface abrasion is undertaken
6	What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)	14 to 21 Days
7	What is the drydock interval for a medium-sized ferry?	2 to 5 years
8	Is any active or passive lubrication method currently being used for reducing drag?	Maybe

9	In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?	The paints for commercial ships are sourced by the customer. The Yard will ensure that the paints supplied are in compliance with the MEPC amendments. The paints for Naval vessels are cleared by the Ministry of Defence and the same would be used.
10	Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection? a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms. b. Enzyme-based coating systems c. new biocide free, two-component, fouling release coating. d. Copper-Free Antifouling coating e. Self-adhesive /fouling-release coatings. f. Nano antifouling coating	None of the above

Shipyard D

S No.	Questions	Answers
1	In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?	Yes
2	What are the top three anti-fouling paints used at the shipyard to reduce biofouling?	Primer 1 coat 50 DFT, Anti-corrosive (Aluminium 1 coat 150 DFT + Bronze 1 coat 150 DFT), Tie Coat- 1 coat 125 DFT, Anti Fouling (Red 1 coat 150 DFT + Brown 1 coat 150 DFT) Red: Pattern No. N8010-P009602 Brown: Pattern No. N8010-P009603 Paints are sourced by OEMs: M/s Akzo Nobel,

		M/s Jotun, M/s PPG coatings
3	What are the three most important factors for the selection of anti-fouling paints for a vessel? g) Paint and application cost h) Marine ecotoxicity and eutrophication i) Physical properties of the vessel & sea route j) Life span of the paint k) Effect on human health l) Anti-fouling properties	A. First, prior floating the tender for procuring paints, the technical parameters gets frozen. Next, the delivery schedule, shelf life and location affect the cost. B. Whether the paint is river based or sea-water based paint.
4	What is the level of risk involved in the application of anti-fouling paints in terms of human safety? d. Low e. Medium f. High	Low
5	What are the conditions and pre-treatment required before the application of anti-fouling paint?	Surface preparation (SA 2,1/2 of Swedish standard) and entire painting is to be undertaken under documented supervision of paint OEM. The minimum drying time, primer to finish coat, maximum overcoat are as recommended by paint OEM.
6	What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)	Approx.: 38 hrs after pre-treatment
7	What is the drydock interval for a medium-sized ferry?	Nil response
8	Is any active or passive lubrication method currently being used for reducing drag?	No lubrication method is used for reducing drag. Passive methods such as ICCP are used for a longer life of underwater Hull.
9	In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-	Paints supplied by OEMs are Compliant with IMO Antifouling System Convention AFS/CONF/26.

	fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?	
10	Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection? a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms. b. Enzyme-based coating systems c. new biocide free, two-component, fouling release coating. d. Copper-Free Antifouling coating e. Self-adhesive /fouling-release coatings. f. Nano antifouling coating	Nil response

Shipyard E

S No.	Questions	Answers
1	In your opinion, are anti-fouling systems the most commonly used technique for underwater hull protection across shipyards in India?	Yes
2	What are the top three anti-fouling paints used at the shipyard to reduce biofouling?	TBT free SPCs/FRC
3	What are the three most important factors for the selection of anti-fouling paints for a vessel? m) Paint and application cost n) Marine ecotoxicity and eutrophication o) Physical properties of the vessel & sea route p) Life span of the paint q) Effect on human health r) Anti-fouling properties	This is dependent upon vessel movement and weight of water current flow and friction of the ship. It is released when it comes in contact with water.
4	What is the level of risk involved in the application of anti-fouling paints in terms of human safety? g. Low h. Medium i. High	High
5	What are the conditions and pre-treatment required before the application of anti-fouling paint?	Nil response

6	What is the overall duration of hull coating for a medium-sized ferry? (Including pre-treatment)	Dependent upon product data sheet of paint such as Primer to Anticorrosive - 14 days, Anticorrosive to Antifouling - 7 days
7	What is the drydock interval for a medium-sized ferry?	Nil response
8	Is any active or passive lubrication method currently being used for reducing drag?	No
9	In 2021, the MEPC adopted amendments to include controls on the biocide cybutryne. The amendments enter into force on 1 January 2023. Ships shall not apply or re-apply anti-fouling systems containing this substance from 1 January 2023. Ships shall remove or apply a coating to AFS with this substance at the next scheduled renewal of the anti-fouling system after 1 January 2023, but no later than 60 months following the last application to the ship of an anti-fouling system containing cybutryne. What is the shipyard's plan for underwater hull protection from 2023 to incorporate this?	The Shipyard is working on a new technology system of the self-polishing copolymer (SPC) anti-fouling paint. Every manufacture supplier TPT free Antifouling for outer hull area.
10	Is the shipyard looking into any of the alternatives mentioned below for underwater hull protection? a. Low energy, hydrophobic foul-release coatings facilitate an easy release of marine organisms. b. Enzyme-based coating systems c. new biocide free, two-component, fouling release coating. d. Copper-Free Antifouling coating e. Self-adhesive /fouling-release coatings. f. Nano antifouling coating	Yes, we are following the multicoat system for outer hull area since it is exposed, there are more possibilities to gauge surface contamination so surface cleaning is mandatory before further system coat application.

Shipyard F (Exchanged via emails in statement format)

The following measures have been undertaken by Shipyard F with respect to environmentally sustainable activities in shipbuilding and ship repairs:

- Application of anti-fouling paints in the underwater area of a naval vessel, diving support vessels and floating dock to meet AFS convention, IMO Resolution MEPC 331(76) applicable from 1st Jan 2023, which prohibits application of cybutryne (CAS no. 28159-98-0).
- provision to ballast treatment plant in a naval vessel and diving support vessels meeting Annexure I of MARPOL 73/78 regulations.

- provision of incinerator in a naval vessel and diving support vessels and floating dock meeting Annexure V of MARPOL 73/78 regulations.

Additional measures under consideration at design phase:

- provision of enthalpy wheel between incoming fresh air and exhaust air ducts to precondition the incoming fresh air.