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TOWARDS A SUSTAINABLE BLUE ECONOMY: INCORPORATING GREEN NORMS IN SHIPS' UNDERWATER HULL PROTECTION PRACTICES IN INDIA

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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.[1] *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.*[2] *It is appreciated by the authors that meeting these goals, would require a mix of technical, operational and innovative solutions. This paper 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.*[3] *This paper 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 research article 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.*

Keywords: Biofouling, Anti-fouling paints, Sustainability, Green technology, Maritime, Underwater Hull Protection Practices, Air lubrication systems, AIRCOAT, Silverstream technology, Indian Shipbuilding and Repair Industry

Biofouling and its Repercussions

Biofouling is described as the undesirable accumulation of microorganisms, plants, algae, and animals on the submerged part of a vessel (especially a ship's hull). It is also considered to be

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[1] Hoesung Lee et al, "Synthesis Report of The IPCC Sixth Assessment Report (Ar6)", Intergovernmental Panel on Climate Change (IPCC), 2023.
https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf

[2] "IMO'S work to cut GHG emissions from ships", International Maritime Organisation (IMO), accessed on 10 February 2023
https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

[3] Ibid.

one of the main vectors for bio-invasions (transfer of invasive aquatic species from one geographical location to another).[4] Biofouling on the hulls of ships enhances the roughness of the colonized surface, which results in an increase of 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.[5] 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.[6] 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.

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 marine environment.[7] 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.[8] While this convention banned

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[4] 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/

[5] "GloFouling Partnerships", accessed on 28 February 2023 https://www.glofouling.imo.org/objectives

[6] "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

[7] 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)

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

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.[9] 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.[10] 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.[11] 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.[12] 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.[13] 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.[14] This circular has brought other non-traditional methods of underwater hull protection techniques into the limelight for use by the shipbuilding and ship-repair industries.

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[9] 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)

[10] Ibid

[11] "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

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

[13] "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

[14] "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

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.[15]

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.[16] According to the Ministry of Ports, Shipping and Waterways (MoPSW) report of 2021-2022,[17] 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).[18]

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.[19] An analysis, which focused on the underwater hull protection techniques used in major shipyards of India, was conducted by National Maritime Foundation (NMF). 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*

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[15] S.N.Batra, *A Guide to Hull Painting of Ships* (Marine Insight, 2014), 106
[16] Ministry of Ports, Shipping and Waterways, accessed on 1 March 2023
https://shipmin.gov.in/division/shipping
[17] "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
[18] Ibid
[19] 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

statements.[20]*)* The Likert Scale below 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.

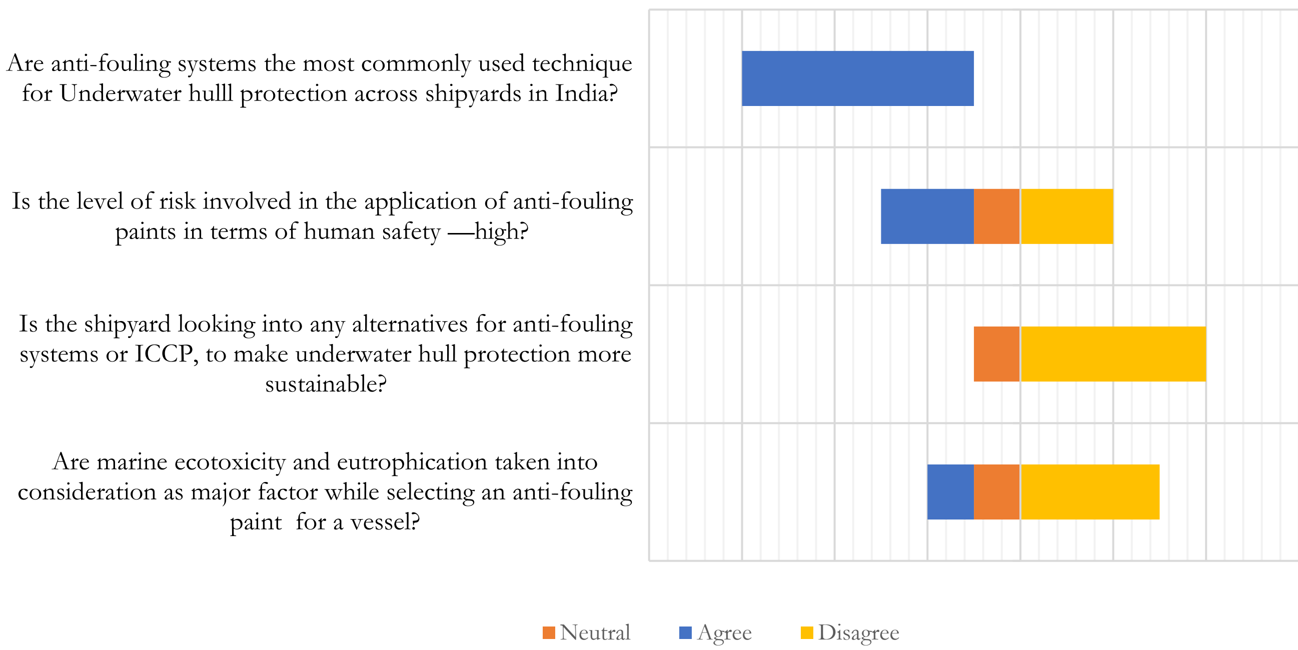


Table 1: Likert Scale generated from the Indian shipyards' responses

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

[20]Joshi, Ankur & Kale, Saket & Chandel, Satish & Pal, Dinesh, "Likert Scale: Explored and Explained", British Journal of Applied Science & Technology. 7. 396-403. 2015

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.[21] It is clear that India is actively seeking practical solutions and pathways for its transition from a 'Brown' economy to 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.

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.[22] 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.[23] 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.

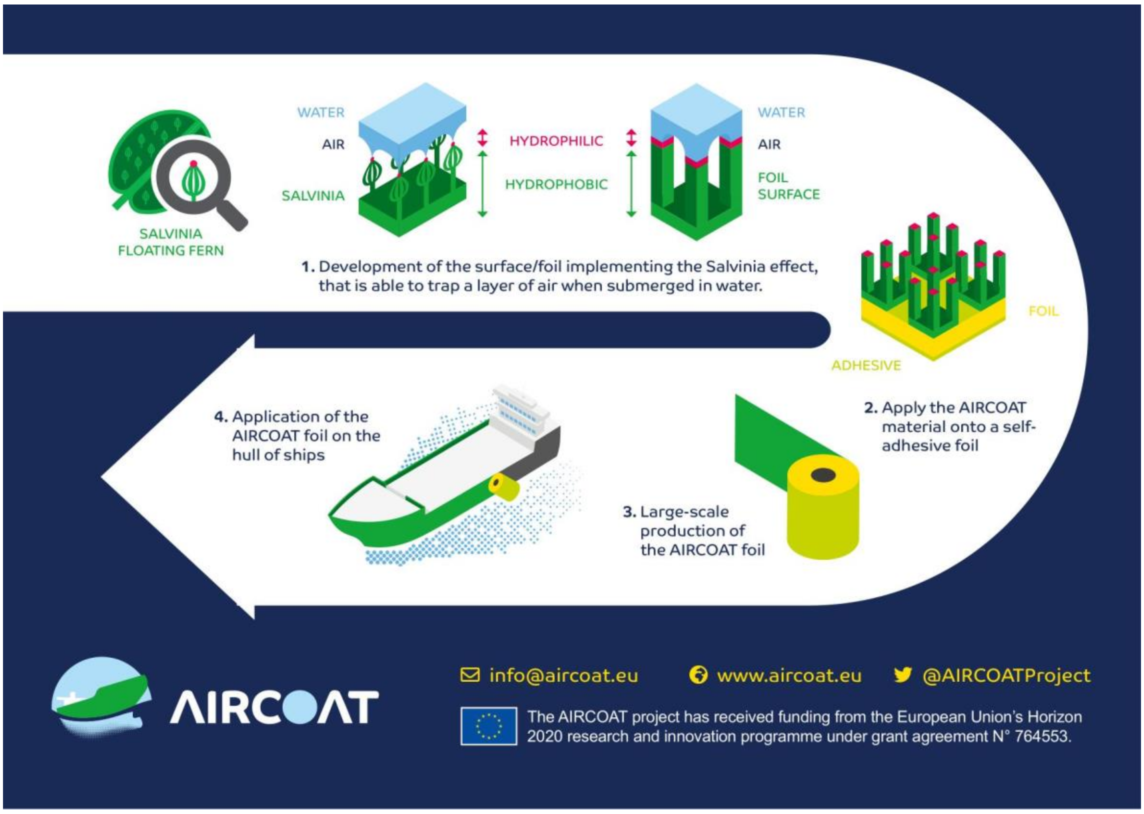
AIRCOAT. The AIRCOAT[24,25] is a Horizon 2020 project that received a total grant of 5.3 million Euros from the European Commission. AIRCOAT is an abbreviation for 'Air Induced friction Reducing ship COATing' and the project aims at developing a biomimetic antifouling

[21] "Maritime India Vision 2030", Ministry of Ports, Shipping and Waterways (MoPSW), Government of India
[22] Abdullah Saif Qureshi, Dr. Rajan Ramaswamy, "Evolution of anti-fouling paints", *International Journal of Science and Research (IJSR)*, 2015
[23] Ibid
[24] 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
[25] AIRCOAT, accessed on 26 March 2023, https://aircoat.eu/

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[26] — passive air lubrication technology that avoids 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. The 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.[27] 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 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.

[26] 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

[27] Ibid.



Source: AIRCOAT[28]

Silverstream Technology. Silverstream Technology[29,30] 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 5 and10 per cent 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 retrofitment, all structural integration work can be completed during the normal dry-docking period. 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.[31] 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.[32] The

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[28] AIRCOAT, accessed on 26 March 2023, https://aircoat.eu/
[29] 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
[30] SilverStream Technologies, accessed on 26 March 2023. https://www.silverstream-tech.com/
[31] N Silberschmidt, T Pappas et at, *The Royal Institution of Naval Architects*, October 2018, London, UK
[32] SilverStream Technologies, accessed on 26 March 2023. https://www.silverstream-tech.com/

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.

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 by the use of Silverstream system for different types of vessels at specific operational speed and draught.
Source: Silverstream Technology [33]

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 their appreciation of critical parameters relevant to the three potential applications discussed in this paper, 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

[33] Ibid.

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

Discussion

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.

Recommendations for the Indian Shipbuilding and Ship Repair Industry

In accordance with Maritime India Vision 2030[34], 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.

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

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

sustainable underwater hull protection practices needs more study and research with respect to Indian shipbuilding and ship-repair practices.

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