25th
ANNUAL
GENERAL
ASSEMBLY
CHENNAI | INDIA

IAMUS | AGA 25

AMET University
Chennai, India

16th - 17th OCTOBER 2025

DISRUPTIVE TECHNOLOGIES AND INNOVATIONS
TOWARDS SUSTAINABLE MARITIME PRACTICES

Proceedings of the International Association of Maritime Universities Student Program (IAMUS)

THE NIPPON FOUNDATION

AMET UNIVERSITY
(Deemed to be University Under Section 3 of UGC Act 1956)

IAMU
International Association of Maritime Universities

The International Association of Maritime Universities (IAMU)

Proceedings of the International Association of Maritime Universities Student Program (IAMUS)

AMET UNIVERSITY

16th - 17th October, 2025

THE NIPPON FOUNDATION

AMET UNIVERSITY

(Deemed to be University Under Section 3 of UGC Act 1956)

IAMU International Association of Maritime Universities

Program Editor

Dr. Deepa Rajesh

Vice-President (Academics)

AMET University, India

Chief Program Editor

Professor Boris Svilicic

Faculty of Maritime Studies

University of Rijeka, Croatia

"A publication of the International Association of Maritime Universities"

For the Publisher

AMET University, India

Table of Contents

Theme

Main Theme

Disruptive Technologies and Innovations towards Sustainable Maritime Practices

Sub-Themes

- ❖ Human Element Leadership & Management
- ❖ Maritime Logistics
- ❖ Maritime Research and Innovation
- ❖ Marine/Maritime Sustainable Development
- ❖ Maritime Women Empowerment

Organizing Committee AGA 25

Dr. J. Ramachandran
Chief Patron, AGA 25
Founder & Chancellor
AMET University, Chennai, India

Dr. Rajesh Ramachandren
Patron of AGA 25
President, AMET University
Chennai, India

Col. Dr. G. Thiruvasagam
President, AGA 25
Provost, AMET University
Chennai, India

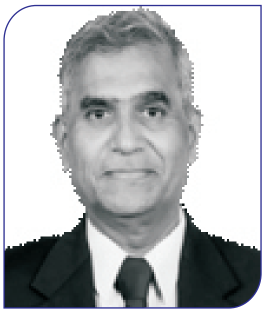
Dr. Deepa Rajesh
Program Editor, AGA 25
Vice President
(Academics)
AMET University
Chennai, India

Dr. V. Rajendran
Vice Chancellor
AMET University
Chennai, India

Dr. V. Sangeetha Albin
Registrar
AMET University
Chennai, India

Capt. K. Karthik
Principal
AMET Institute of
Science and Technology
Chennai, India

Capt. Gopal Srinivas
Principal
AMET University
Chennai, India



Capt. V. Chandrasekhar
Principal
AMET City College
Chennai, India

Local Executive Committee (LEC)

Dr. J. Ramachandran
Lead of LEC

Dr. Rajesh Ramachandren
Lead of LEC

Col. Dr. G. Thiruvasagam
General Chair LEC

Dr. Deepa Rajesh
General Chair LEC

Dr. V. Rajendran
Programme Chair

Dr. T. Sasilatha
Scientific Programme Chair

Capt. K. Karthik
Student Program Chair

Dr. M. Jayaprakashvel
Digital Chair

Dr. V. Sangeetha Albin
Digital Chair

Dr. R. Muthezhilan
Conference
Committee Assistant

Dr. J. Rengamani
Conference
Committee Assistant

Venue

The IAMU Conference takes place in
Radisson Blu Resort, Temple Bay, Mamallapuram, India.

AGA 25 | IAMUS Program Schedule

14th October, 2025 - Tuesday	
Time	**Event and Location**
01:00 PM-04:00 PM	Early Registration Registration Desk in the Lobby at **Radisson Blu Temple Bay Resort, Mamallapuram, Chennai, India**
07:00 PM-09:00 PM	Welcome Reception at Radisson Blu Temple Bay Resort Welcome Remarks **Dr. J Ramachandran** Founder and Chancellor, AMET University, Chief Patron of AGA25 Dinner at Savannah 1 Lawn

15th October, 2025 - Wednesday		
09:00 AM	Registration	
09:30 AM-11:00 AM	**AGA25 Opening Ceremony** at Ballroom (Peninsula + Goldcoast) Video Presentation of Nippon Foundation	
11:00 AM-11:30 AM	Group Photo	Coffee Break
11:30 AM-01:00 PM	Visit to Dakshina Chitra Heritage	01:00 PM-2:30 PM ------- Lunch Break
06:30 PM	Cultural Program	
07:30 PM	Welcome Remarks Dr. Rajesh Ramachandren, President, AMET University, Patron of AGA25	
	Cocktail Dinner at the Radisson Blu Resort Lawn	

16th October, 2025 - Thursday

Hall: ISLE OF WIND

Chair
Capt.K.Karthik
Principal, AMET Knowledge Park, AMET Institute of Science and Technology
Maersk Centre of Excellence, India

TIME	NAME OF THE AUTHOR (S)	INSTITUTION NAME	TITLE OF THE PAPER
09:30 AM - 09:50 AM	Yu-Jin Ha, Ji-Hyeok Yang & Jun-Seong Kim	National Korea Maritime & Ocean University, Republic of Korea	Proposals for Revising STCW for Small Modular Reactors (SMR) Powered Vessels
09:50 AM - 10:10 AM	Wiktoria Dumińska & Jakub Kulbat	Gdynia Maritime University, Poland	The Role of GIS in Oil Pollution Prevention
10:10 AM - 10:30 AM	Fumiya Nohara	Kobe University, Japan	Promoting Sustainability through Hydrogen Infrastructure: Energy Transition
10:30 AM - 11:00 AM	**COFFEE BREAK**		
11:00 AM	Linus Boustedt &	Chalmers University of	Impacts of nearshoring within the

- 11:20 AM	Fatima Ismael	Technology Sweden	textile industry on European liner shipping
11:20 AM - 11:40 PM	Samantha Athena Dsouza & Sankalp Chakravarthy Sreenath	AMET Institute of Science & Technology, India	Nuclear Propulsion in Shipping: A Path Toward Sustainable and Efficient Maritime Operations
11:40 PM - 12:00 PM	Nandana B Panicker	AMET Institute of Science & Technology, India	Marine AI Engineering Assistant for Marine Engineers (MAEA)
12:00 PM - 12:20 PM	Roshini Balaji	AMET Institute of Science & Technology, India	Maritime Sustainable Development
12:20 PM - 12:40 PM	Hrishita Ghosh & Atithi Sur	AMET Institute of Science & Technology, India	Decarbonization by usage of E-Methanol
12:40 PM - 01:00 PM	Rogie Paul G.Apelarta, Kyle Allen C. Caburobias, Ghiesyner V. Escander, Allen Dave P. Gacuma, John Mark M. Gai, Cyran Jehea C. Palomo, Rhoyze Jesus C. Silvederio, Joshua M. Suegay, and Roland John Cyril F. Emague, Andreu Benedict Peñaflor	John B. Lacson Foundation Maritime University (Molo), Inc., Philippines	Maritime Students Coping Mechanism Towards Online Learning
01:00 PM - 02:30 PM	**LUNCH BREAK**		
02:30 PM – 02:50 PM	Keysberg Pereira	International Maritime University of Panama, Panama	Alternative Fuels and Emission Reduction in the Maritime Industry
02:50 PM – 03:10 PM	Ivan Elias Arauz	International Maritime University of Panama, Panama	Blockchain Technology in Maritime Logistics
03:30 PM – 04:00 PM	**COFFEE BREAK**		
07:00 PM	**DINNER**		

17th October, 2025 - Friday	
Time	**Activity**
09:30 AM-10:30 AM	Student Session
10:30 AM-11:00 AM	Coffee Break
11:00 AM-01:00 PM	Student Session
01:00 PM-02:30 PM	Lunch Break
02:30 PM-03:30 PM	Student Session
03:3PM-04:30 PM	Closing Ceremony at Ballroom (Peninsula + Goldcoast)

Technical Tour

Visit to AMET Knowledge Park, AMET Institute of Science and Technology (AMET–IST), Maersk Centre of Excellence

18th October 2025: Exploring Maritime Heritage & Education		
Time	**Activity**	**Details / Location**
08:30 AM	Breakfast	Hotel
09:30 AM	Visit to Mahabalipuram (UNESCO World Heritage Site)	Explore ancient rock-cut temples like Shore Temple, Five Rathas, and Arjuna's Penance. A perfect blend of history, spirituality, and coastal beauty
01:00 PM	Lunch	AMET Knowledge Park, AMET Institute of Science and Technology (AMET–IST), Maersk Centre of Excellence
02:00 PM	AMET Knowledge Park AMET Institute of Science and Technology (AMET–IST) Maersk Centre of Excellence	Tour India's leading maritime university: • Full-mission simulators • AR/VR training labs • Seamanship labs • Engineering & electrical workshops • 150-acre green campus
03:00 PM	Drop at Hotel / Drop at Airport	End of program activities

Program Schedule for Accompanying Persons

16th October 2025: South Indian Culture & Spiritual Heritage		
Time	**Activity**	**Details / Location**
08:30 AM	Breakfast	Hotel
10:30 AM	Visit to Valluvar Kottam	Valluvar Kottam - Honours Tamil poet Thiruvalluvar, showcasing his work in a grand chariot-shaped monument
11:30 AM	Museum	Showcases a rich heritage with ancient artefacts, sculptures, bronze idols, and South Indian cultural history
01:00 PM	**Lunch**	
03:00 PM	Santhome Basilica	Neo-Gothic church built over the tomb of St. Thomas the Apostle. An architectural and spiritual landmark near Marina Beach
04:00 PM	Vivekananda Illam and Marina Beach	Vivekananda Illam showcases Swami Vivekananda's legacy; Marina Beach, India's longest, offers scenic beauty and cultural vibrance
06:00 PM	Return to Hotel	Refresh before Evening Events
07:00 PM	Dinner	Hotel

17th October 2025: Shopping, History & Beach Vibes		
Time	**Activity**	**Details / Location**
08:30 AM	Breakfast	Hotel
10:00 AM	Visit to Jain Navagraha Temple	A peaceful spiritual site dedicated to Jain Tirthankara and Navagrahas; known for its serene environment and intricate architecture
10.30 AM	Visit to Dakshina Chitra Heritage	Cultural village on ECR, showcasing South Indian art, architecture, crafts, and heritage homes
01:00 PM	**Lunch**	
02:00 PM	Phoenix Mall	Phoenix Mall is a premier shopping destination offering top brands, dining, and entertainment under one roof Modern mall featuring global brands, diverse dining, multiplex cinema, and vibrant shopping
06:30 PM	Return to Hotel	Refresh before Evening Events
07:30 PM	Dinner	Hotel

IAMU ANNUAL GENERAL ASSEMBLY (AGA)

The Annual General Assembly (AGA) is a forum to allow the exchange of information, policy approvals, and the development and fostering of good relations and collaboration among IAMU member universities.

The Plenary Session, President's Forum, Project Presentations and IAMU Conference (IAMUC) are the main components of AGA. The IAMU Student Program (IAMUS) may be jointly organized by the host university.

PLENARY SESSION

The Plenary Session provides all staff of member universities with an opportunity to review activities of IAMU and to approve IAMU policies, programs and budget as recommended by the International Executive Board (IEB). The Chair of IAMU and the Executive Director, on behalf of IEB, report to the member universities on the decision of the IEB.

PRESIDENT'S FORUM

The President's Forum is a meeting in which the Presidents of IAMU member universities talk about issues especially on policy, direction, and activity of IAMU considering the academic relationship among member universities as well as the economic and technological developments in the international maritime community. The Local Executive Committee (LEC) of an AGA is responsible for organizing the President's Forum during the AGA.

PROJECT PRESENTATIONS

Each project coordinator/ representative of a research project shall make a project presentation in front of academic staff of member universities during the AGA, which is to improve the quality of the project.

IAMU CONFERENCE

IAMU Conference (IAMUC) provides academic staff of member universities with an opportunity to present the outcomes of their academic/ scientific research to the IAMU community. The LEC together with the International Program Committee (IPC) jointly organizes the IAMU Conference, including the selection of session topics and qualifying papers.

IAMU STUDENT PROGRAM

LEC of an AGA may organize the IAMU Student Program (IAMUS) during the AGA where students of member universities jointly participate in some events related to student's activities.

WELCOME TO AGA25

The Annual General Assembly (AGA) is the annual meeting of the International Association of Maritime Universities (IAMU). The International Association of Maritime Universities Conference (IAMUC), held annually as part of the AGA, brings together experts and official representatives of IAMU member universities from all over the world to discuss recent progress and future trends in Maritime education, training, research, and other matters within the scope of IAMU. AMET University is honored to host the 25th Annual General Assembly, IAMUC and IAMUS 2025.

This event aims to bring together global maritime leaders, academics, industry experts, and policymakers to exchange knowledge, share best practices, and foster international collaboration. The conference seeks to advance maritime education, training, research, and innovation, while strengthening partnerships that address emerging challenges and shape the future of the global maritime sector.

WELCOME TO AMET

The 25th Annual General Assembly will be a landmark event hosted by AMET University, India's first Maritime University, established in 1993. For over three decades, AMET has contributed to the maritime sector by producing skilled professionals, advancing research, and fostering innovations that serve not only India but the global maritime community. Maersk A.P. Moller, Denmark, one of the renowned and leading shipping companies of the world, have established a Centre of Excellence in collaboration with AMET University which is the first model of Centre of Excellence in the world established by a leading shipping company. Likewise, other leading shipping companies like V Ships, PIL, Fleet Management etc., are having Memoranda of Understanding and established their Centre for Training in our Campus.

HISTORICAL BACKGROUND OF THE CITY

Discover India's rich cultural heritage through maritime museums, Centres of Excellence, and industry collaborations. Experience the unique blend of multilingual and multicultural traditions that define India's maritime legacy. Chennai, the Gateway to South India, is a city where tradition and modernity blend seamlessly. From the UNESCO World Heritage Site of Mahabalipuram, known for its ancient rock-cut temples and Dravidian architecture, to the iconic Marina Beach, the world's second-longest beach, the city offers diverse experiences. Heritage landmarks like the Santhome Church and Kapaleeshwarar Temple reflect Chennai's deep spiritual and cultural roots, while the Government Museum showcases India's rich history and art. For cultural immersion, Dakshina Chitra brings alive the traditions and architecture of South India, and for nature lovers, the Arignar Anna Zoological Park offers a glimpse of biodiversity. Adding to its spiritual vibrance, ISKCON Chennai provides a

peaceful retreat of devotion and meditation. Together, these attractions make Chennai a destination of history, culture, spirituality, and coastal beauty.

Program Guidelines

AMET University is hosting the **IAMUS/AGA25**. Presenters are requested to kindly adhere to the following guidelines:

Guidelines for Oral Presentations

1. **Presentation Duration**
   - Each oral presentation slot is allotted **30 minutes**.
   - Session Chairs will strictly enforce time limits to ensure smooth transitions between sessions.
2. **Presentation File Preparation**
   - Use **PowerPoint (.pptx)** format and ensure that **all fonts are embedded**.
   - Bring a **backup PDF version** of your presentation to avoid compatibility issues.
3. **File Submission and Reporting**
   - Save your presentation on a **USB storage device**.
   - Report to your assigned **Session Chair** (as indicated in the IAMUS program) at least **15 minutes before the start** of your session.
   - Confirm that your presentation has been successfully uploaded and is functioning properly before the session begins.

Table of Contents

Proposals for revising STCW for Small Modular Reactors (SMR) powered vessels

Yu-Jin Ha[1], Ji-Hyeok Yang[2] and Jun-Seong Kim[3,*]

[1] *Undergraduate student, Division of Marine System Engineering, National Korea Maritime & Ocean University, Republic of Korea*
[2] *Undergraduate student, Division of Navigation Convergence Studies, National Korea Maritime & Ocean University, Republic of Korea*
[3] *Assistant professor, Division of Marine System Engineering, National Korea Maritime & Ocean University, Republic of Korea*
[*] *Corresponding author: jskim87@kmou.ac.kr; Tel.: +82-51-410-4266.*

Keywords: Small modular reactor (SMR); SMR-powered vessel; education and training program; engineering officers; STCW

1. Introduction

Maritime shipping industry has been making constant efforts for many years to reduce carbon emissions. Meanwhile in new construction, only around 25% of ships are choosing low-carbon alternative fuels, such as LNG, methanol or dual-fuel systems. Despite statements about the necessity for high levels of efficiency and low levels of pollution in shipping, fuel consumption—and therefore carbon emissions is several times higher than that in the industrial and domestic sectors put together. As the Climate Solutions report shows, globally the shipping industry has seen its output of greenhouse gases (GHGs) increase by 20% over the last ten years (2012–2022) (Climate Solutions, 2023). An increase at such a rate will not be acceptable under present rules. Responding to this, the International Maritime Organization (IMO) declared a new goal in July 2023: to achieve zero carbon emissions within shipping industry by 2050.

For them the best hope of commercializing such a ship might be a nuclear-powered freighter, building on proven carbon-zero technology. Today, about 160 ships with around 200 reactors are in operation worldwide. Most are in use as submarines and Naval warships. They have virtually no fuel-tanks, can run for months or even years without refueling, at a time, and are extremely fuel-efficient. Hence the development of the Fourth Generation Small Modular Reactor (SMR) which is safer and easier for workers to operate. Companies such as Terra Power (USA) and New Cleo (UK) are energetically involved in next-generation nuclear propulsion technology development work using SMRs. (Freitas Neto et al., 2021).

With technological advancements underway, the IMO's 11th HTW session is currently discussing provisional training standards for crew on alternative-fuel ships. There is, however, no internationally standardized training regulations for seafarers of these ships. Despite the growing interest among the international community in using gas -powered merchant vessels, and the attentive eye which manufacturing centers around the world are turning towards this form of high energy ship propulsion, we still had no Standard Model for seafarers training on such ships. IAEA report emphasizes that one management system should meet all organizational aims in the nuclear industry. It is suggested that such a unified, standard training model be instituted from the beginning to grow personnel capability in an orderly way (IAEA, 2021).

At the moment, the STCW Convention provides no explicit guidance on training or deployment of crews manning SMR-powered merchant ships. One of the main goals of this study is to present a framework for revising the STCW Convention and to develop specialized training programs for SMR-powered ships. In integrating maritime and SMR technologies, the proposed framework is based on current STCW standards as well as the 2022 U.K. Merchant Shipping (Nuclear Ships) Regulations issued by the Maritime and Coastguard

Agency (MCA). A planned program for training is essential to ensure that SMRs will be safely integrated into the maritime industry and that its purpose is fulfilled.

2. Several Benefits of SMR-Based Ships

Today small modular reactors may be the most noted new nuclear energy technology available. Yet the idea of a small nuclear reactor has a long history. In fact, the first commercial reactors developed and deployed during the late 1950s and 1960s – based on light water reactor (LWR) technology – were to a large extent scaled-up versions of small naval propulsion reactors. Since the same period, a large variety of small reactors have been constructed by governments for security and military purposes. It is not so much their size as the fact that design ideas have made use of this small scale to bring about distinctly new safety features, delivery models and business cases for the present- day small reactors.

Small modular reactors are defined today as nuclear reactors with between 10 Megawatts electronic and 300 MWe power output. All of these units can be transported according to module type and assembled on-site, with a regular construction process leading to timely completion (OECD-NEA, 2021).

2.1 Reduction of Greenhouse Gas Emissions

SMRs do not emit greenhouse gases like carbon dioxide or methane, but fossil fuel-fired power generator: after it burns fuel, it escapes into the air 'schematically speaking'. The average carbon emissions from nuclear power generation is only 15 gCO_2/kWh, a figure much lower than that of coal (820 gCO_2/kWh) and natural gas (490 gCO_2/kWh) (IAEA 2021). The use of SMRs may well contribute to attaining carbon neutrality or even carbon-zero objectives. SMRs are now seen by some people as an environmental positive outcome compared with traditional fossil fuel energy systems.

2.2 Spent Fuel and Radioactive Waste Management

SMRs usually make use of high-burnup fuels, enabling them to reduce the amount of spent nuclear fuel produced. Some SMR designs utilize next-generation reactor technologies such as Sodium-cooled Fast Reactors (SFRs) and Molten Salt Reactors (MSRs), which are intended to reduce the radioactive waste's half-life and improve fuel utilization by means of reprocessing and recycling (IAEA, 2021). This not only increases the efficiency of handling radioactive waste but can also help reduce the long-term environmental impact that nuclear energy systems exert on Earth. The post-nuclear waste dilemma is another issue in which nuclear power, particularly as applied to managing decommissioned submarines and aircraft carriers becomes hazy.

2.3 Passive Decay Heat Removal Systems Safety

Probabilistic safety assessments of small modular reactors show that inherently the decay heat they generate gets less. By gradually reducing reactor output albeit without condensing cooling systems or isolating its coolant features in the cycle, small modular reactors are built for natural coolant circulation. This natural safety feature considerably reduces the likelihood of major incidents such as the Fukushima nuclear crisis, greatly enhancing the safety of small modular reactor-based ships. In addition, small modular reactors are designed to avoid significant risks when primary power failure occurs. However, as noted in a study on the safety and economics of Small Modular Reactors, research continues to confirm and improve the safety qualities of SMR technologies (Freitas Neto et al., 2021). On going research continues to validate and improve the safety characteristics of SMR technologies (Study Team, 2021).

3. Proposed Amendments to the STCW Convention for SMR-Powered Ships

Currently, there are no international regulations for SMR-powered ships. However, there are a few regulations concerning SMR-powered ships, which can be considered the predecessors of SMR-powered vessels. These include:

1. Code of Safety for Nuclear Merchant Ships
2. IAEA regulations
3. Training regulations applied to the crew of the early nuclear-powered ship NS Savannah

4. Training regulations applied to the crew of the early nuclear-powered ship NS Mutsu

5. The United States Naval Nuclear Propulsion Program

Based on the existing regulations for nuclear-powered ships listed above, this paper seeks to explore possible amendments to the STCW Convention to ensure the safe operation of SMR-powered ships.

The redundancy of training brings about an unwieldy system of certification. Its unified training can make workforce management more efficient. The types of vessels involved, as covered above, do not fit the needs of commercial fleets of any scale. Large commercial fleets can also benefit from this kind of training structure however that in any case does not exist currently. In order to ensure safe operation of SMR-powered ships, the existing conventions on nuclear merchant ships are used as a basis for exploring possible amendments to the STCW Convention in this paper. Among the Code's requirements for Nuclear Merchant Ships are qualifications and training requirements not specified according to rank but by function. This coverage ranges from captains and navigation experts to engineers, NSSS operators, radiation emergency rescue personnel and general crew.

Machine certification could pose a problem for these functions under today's rank system within the STCW Convention, although it's inappropriate compared with modern commercial ships which work on a rank-basis too. Another major disadvantage of the Code is that it calls for crew members to be trained separately on each type of reactor, which is unacceptable for large commercial fleets standard modular water reactors powered SMR-powered ships on the other hand are each probably fitted with two or three reactor types at most that have received approval from a classification society or the IMO. Therefore, most merchant vessels will adopt similar reactor systems. A rank-based training system based on the STCW model is suggested in this context.

Table1. A Comparative Analysis of Past Nuclear Ship Regulations and the STCW-Based Training Framework in the SMR Era

Category	Past Nuclear Ship Regulations (Code of Safety for Nuclear Merchant Ships)	Proposed: STCW-Based System for the SMR Era
Standard Framework	Role-based (function-focused)	Rank-based (STCW rank-focused)
Qualification Method	Separate qualifications by role: operator, radiation officer, emergency staff	Integrated management of qualifications by rank: navigator, engineer, crew, etc.
Reactor-Specific Training	Training and separate exams required for each reactor type	Common training possible due to modular SMR design
Operational Efficiency	Redundant training, complex certification structure	Efficient workforce management through unified training
Commercial Ship Applicability	Focused on military or special-purpose vessels; hard to apply to commercial fleets	Training structure applicable even to large-scale commercial fleets

In particular, rather than categorizing qualification requirements into such categories as engineer officer, deck officer, NSSS operator, radiation protection and emergency response crew, the roles are integrated into the three main categories: deck officers, engineer officers and crew in general. Under these integrated roles, tasks should be allocated on SMR ships according to the operational activities relating to each role as follows.

Within the regulatory framework for conventional nuclear-powered ships, the position and qualifications of the crew are established according to their role on the ship. These are including the Master, Shipboard Medical Personnel (doctor with emergency response team), Deck Officers, Reactor or NSSS (Nuclear Steam Supply System) Operators, Engineer Officers, Radiation Protection Officers, Emergency Radiation Responders, and General Crew Members. This role-based approach had led to ad hoc training needs and no overarching standard of training between various reactor types or operating conditions.

The Difference is, that the projected STCW- based framework for the SMR period establishes a rank-based system and merges the above roles into three main workforce groups: Deck Officers, Engineer Officers and General Crew. Special duties such as radiation protection and NSSS operation would be included as component parts of engineer officer training, while emergency response and general safety would become components of general crew training in this model. This reorganization facilitates normalization, improves efficiency and can be applied more generally to commercial fleets due to its modular and standardized nature that is compatible with SMR systems.

Following is to systematize the necessary qualifications for each rank, which has to be educated to use SMR propulsions ships. "As regards safety, the relevant Code of Safety for Nuclear Merchant Ships uses imprecise language “qualified personnel” with no specific for requirements training content, "intended learning outcomes" (ILOs), system of assessment or training duration. Accordingly, in the actual training seamen, such problems as differences of understanding among countries may arise or the quality of training may not be uniform or the mutual recognition of licenses may be difficult.

The SAT model by the IAEA for training of NPP personnel is suggested as a solution to these problems. SAT is a training method introduced by the IAEA that organizes training into the five stages: analysis, design, development, implementation, and evaluation. This method provides transparency about training goals, level of skills, quantifiable results, length of training and criteria of assessment.

Table 2. Comparison Between Traditional IMO-Based Training and the Proposed IAEA + STCW-Based Training Model

Category	Traditional Regulation (IMO Code, 1981)	Proposed Model (IAEA Standards + STCW)
Qualification Terminology	“Qualified personnel,” “Those who have received appropriate training”	Defined by competence (knowledge, skills, attitude)
Training Design	None	SAT-based, structured 5-stage training design
Assessment Methods	Oral exams or “subject to examination”	Outcome-based assessment (written & performance evaluations)
Course Content & Duration	Vague or undefined (e.g., general nuclear physics)	Clear course list with specified topics and training hours
International Recognition	Limited (subject to national interpretation)	High (IAEA & IMO aligned, globally applicable)

Next, by cross referring (comparing) with the relevant training curricula of existing sources, i.e. the IAEA, NS Savannah, NS Mutsu and U.S. Naval Nuclear Propulsion Program, narrowing-down a detailed list of subject requirements for each R&I would be possible. These shared training elements can be described as follows.

Table 3. Comparison of Training Subjects across Nuclear Maritime Programs

Training Subject	IAEA	NS Savannah	NS Mutsu	US Navy
Atomic and Nuclear Physics	✔□	✔□	✔□	✔□
Reactor Physics and Dynamics	✔□	✔□	✔□	✔□
Reactor Engineering	✔□	✔□	✔□	✔□
Radiation Protection and Shielding	✔□	✔□	✔□	✔□
Health Physics	✔□		✔□	✔□
Reactor Chemistry	✔□		✔□	✔□
Materials Science and Metallurgy	✔□			✔□
Mathematical Methods and Numerical Analysis	✔□			
Electrical Power Systems and Instrumentation	✔□	✔□		✔□
Thermodynamics and Power Cycles	✔□	✔□		✔□

Based on the key subjects commonly emphasized across existing programs, an analysis of the subject requirements by rank for newly proposed SMR-powered ships yields the following results.

Table 4. Allocation of SMR Training Subjects by Crew Role

Training Subject	Engineer Officer	Deck Officer	General Crew
Atomic and Nuclear Physics	✔	✔	✔
Reactor Physics and Dynamics	✔	✔	☐
Reactor Engineering	✔	✔	☐
Radiation Protection and Shielding	✔	✔	✔
Health Physics	✔	✔	✔
Reactor Chemistry	✔	✔	✔
Materials Science and Metallurgy	✔	☐	☐
Mathematical Methods and Numerical Analysis	✔	☐	☐
Electrical Power Systems and Instrumentation	✔	✔	☐
Thermodynamics and Power Cycles	✔	✔	☐

4. Conclusion

This study proposed an educational program for SMR-powered merchant ships and advocated for the revision of the STCW Convention. By supplementing traditional nautical training with nuclear-specific education, this curriculum design offers a complete core curriculum in nuclear propulsion that enhances the theory and application of nuclear propulsion. The ultimate goals of this study are as follows

4.1 Enhancing the Safety of Nuclear-Powered Merchant Ships

In order to operate nuclear powered Merchant ships safely, a systematic internationally standardized training is urgently required. Based on the US Navy's nuclear submarine crews and the NS Savannah model, this paper argues for hand-on experiential learning with missions and accountability in the educational process. All undergraduates and seafarers who will serve as officers for SMR-powered vessels have to go through an authorized training course in reactor operation, radiation protection, catastrophe handling. With this kind of education, they grow capable of perceiving crises instantly when they surface in practice, which leads to increased safety and avoidance of accidents on nuclear-powered merchant ships.

4.2 Establishing an Education System Aligned with International Standards

Since nuclear powered ships fall under the supervision of the IMO and national maritime administration, we need a training standard that meets both domestic and international regulations. This paper proposes a new chapter (STCW V) to be added to the existing International Convention and that it should be revised. With a global framework for safety in place, seafarers will be able to receive standardized training and certification to operate SMR vessels.

4.3 Technical Requirements and the Importance of Practical Training

In addition to traditional theory-based instruction, the importance of an integrated theoretical and practical training specifically for the area of SMR powered systems is emphasized in this study. It verifies the significance of providing students with domain knowledge with regard to SMR ship deck and engine operations and nurturing practical ability by dynamic simulation and hands-on practice.

In conclusion, this study was considered also necessary, as it showed that the STCW would need to be updated to deal with ships propelled by SMR and helped to establish the basis for the development of education systems required to allow their safe and efficient operation. It is expected that the proposals here will facilitate the development of global standards in the future.

Acknowledgements

None.

References

Climate Solutions (2023). Establishing Green Shipping Corridor between South Korea, United States and Japan for Zero Carbon Shipping Across the North Pacific Ocean. Climate Solutions, Seoul.

Freitas Neto, L. G., Freire, L. O., dos Santos, A., & de Andrade, D. A. (2021). Potential advantages of molten salt reactor for merchant ship propulsion. Brazilian Journal of Radiation Sciences, 9(2B), 1–18.

International Atomic Energy Agency (IAEA) (2021). Systematic approach to training for nuclear facility personnel. IAEA, Vienna.

Maritime & Coastguard Agency (MCA) (2022). The Merchant Shipping (Nuclear Ships) Regulations 2022. UK Government

OECD Nuclear Energy Agency (NEA) (2021). Small modular reactors: challenges and opportunities (NEA No. 7560). OECD, Paris.

Study Team (2021). Safety and economics of small modular reactors. In: Murakami, T., Anbumozhi, V. (eds.), Global situation of small modular reactor development and deployment. ERIA Research Project Report FY2021 No. 07, pp. 3–11. ERIA, Jakarta.

The 25th IAMUS

Chennai, 16-17 Oct 2025

Proceedings of the International Association of Maritime Universities
Student Program (IAMUS)

Promoting Sustainability through Hydrogen Infrastructure : Addressing Logistical Challenges and Energy Transition

Fumiya Nohara[1*]

[1] *Graduate School of Maritime Sciences, Kobe University, Japan*
[*] *Corresponding author: 245W106W@gsuite.kobe-u.ac.jp; Tel.: +81-90-2197-4627.*

Abstract: The decarbonization of the transportation sector is a critical challenge for Japan's energy policy, and hydrogen energy has emerged as a key solution. As fuel cell vehicles (FCVs) become more commercially viable, the development of hydrogen refueling infrastructure is imperative. In this context, the Japanese government has set a target to increase the number of hydrogen stations to 1000 by 2030. However, the high capital cost of building standalone hydrogen stations, estimated at approximately 500 million yen each, poses a significant barrier to expansion. This study proposes a strategic solution: co-locating hydrogen stations with existing gas stations, which are more widely distributed and significantly less expensive to construct. By leveraging this co-location approach, the study aims to reduce infrastructure costs and accelerate deployment. The research focuses on Hyogo Prefecture, a region with diverse urban and rural areas, and employs a spatial optimization model to determine the optimal locations for co-located hydrogen stations by 2030. Two alternative definitions of municipal centroids are examined: (1) the arithmetic mean of the geographical coordinates of existing gas stations and (2) the population-weighted centroid derived from official census data. Hydrogen demand forecasts are based on projected FCV adoption rates and standardized hydrogen consumption metrics. A greedy algorithm is implemented to assign stations based on proximity and demand magnitude. The results demonstrate that co-location can substantially improve cost efficiency and service coverage, and that the choice of centroid has a notable impact on allocation results. The methodology and findings contribute to a more practical and scalable roadmap for hydrogen infrastructure development in Japan and beyond.

Keywords: hydrogen station optimization; fuel cell vehicle (FCV); spatial planning; centroid analysis; infrastructure co-location

1. Introduction

Hyogo Prefecture offers an ideal case study for examining this approach due to its mix of densely populated urban centers, such as Kobe and Himeji, and less-populated rural areas. This regional diversity allows for the evaluation of hydrogen station placement strategies that balance cost-effectiveness, spatial coverage, and responsiveness to projected demand.

This study develops a spatial optimization model that integrates hydrogen demand forecasting and geographic analysis to identify suitable locations for co-located hydrogen stations within Hyogo Prefecture. It explores the implications of centroid selection methods on allocation outcomes. By comparing the effectiveness of average gas station coordinates versus population-weighted centroids, the study seeks to provide practical insights into infrastructure planning strategies that align with both policy objectives and economic constraints.

The objectives of this study are:

1) Forecast hydrogen demand for 49 municipalities in Hyogo Prefecture in 2030.
2) Allocate hydrogen stations using existing gas stations.
3) Compare centroid calculation methods: gas station average and population weighted.
4) Evaluate the allocation's efficiency using a greedy algorithm.

2. Literature review

Hydrogen station deployment has been widely studied in national policy and infrastructure contexts (Wang et al. 2022). Japan, for instance, aims to install 1000 stations by 2030. However, few studies address practical implementation strategies at the municipal scale. The potential of co-locating hydrogen facilities with existing gas stations has been emphasized (Genovese and Fragiacomo 2023), which aligns with the present study.

Optimization methods have also received attention. Advanced models have been applied to electric or gas station planning (Piedra-de-la-Cuadra and Ortega 2024). However, these approaches often require complex solvers and lack local-level adaptability (Zhu et al. 2024). In contrast, heuristic methods like greedy algorithms offer scalable, low-cost alternatives more suitable for municipal applications.

Centroid-based spatial planning is another key area. It has been demonstrated that site performance depends on how demand centers are defined—by population or infrastructure (Fuse et al. 2021). The importance of spatial equity in public facility siting has also been emphasized (Aljohani and Thompson 2020).

Despite these insights, few studies compare centroid definitions empirically or apply them to real municipal data. This study fills that gap by integrating centroid analysis, demand forecasting, and greedy allocation for hydrogen station planning in Hyogo Prefecture.

3. Methodology

Hydrogen demand in each municipality of Hyogo Prefecture was estimated based on the projected number of fuel cell vehicles (FCVs), their average annual travel distance, and a standardized hydrogen consumption rate of 0.96 kg per 100 kilometers. The demand forecast assumed that FCV adoption correlates with population and vehicle ownership statistics. The resulting output was the total annual hydrogen demand (in kilograms) for each of the 49 cities, wards, and towns under study.

To determine the optimal spatial allocation of hydrogen stations, we applied a centroid-based distance minimization approach, followed by a greedy station assignment algorithm. Two distinct methods were employed to define the geographic centroid of each municipality. Figure 1 outlines the simulation flow in this study.

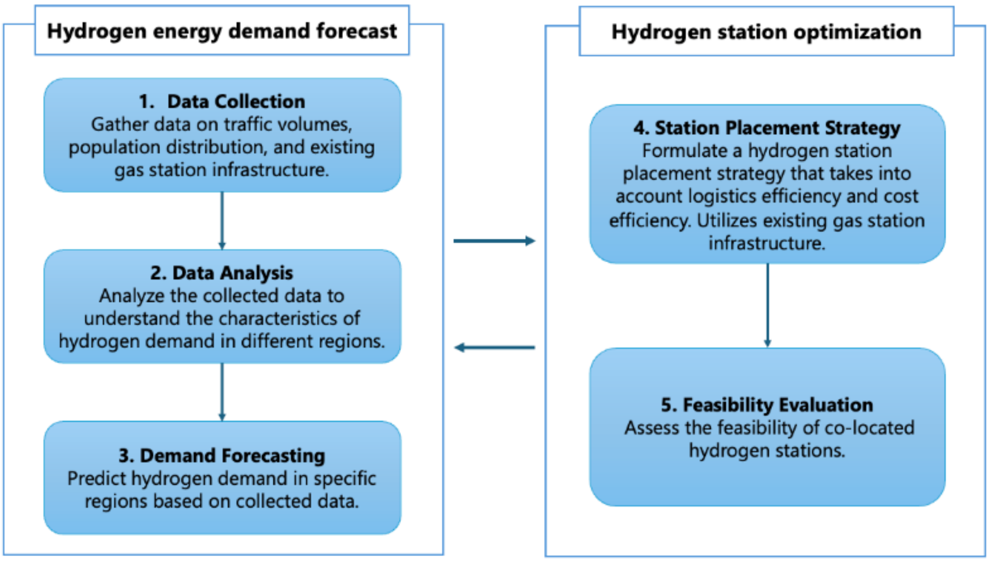


Figure 1. Simulation Flow Chart.

3.1. Hydrogen Demand Forecasting

The first step involves forecasting hydrogen demand across Hyogo Prefecture based on projected fuel cell vehicle (FCV) adoption by 2030. Demand per municipality is estimated using population size, vehicle ownership ratios, and the assumption of uniform adoption rates. Each FCV is expected to consume 0.96 kg of hydrogen per 100 kilometers, and average annual travel distance is incorporated to yield the total annual demand in kilograms. A list of variables is outlined in Table 1.

Table1. Variable definition (Demand forecast)

Variable	Definition
$N_{auto,\,Japan}$	Number of cars nationwide
$N_{auto,\,Japan}$	Number of cars in Hyogo Prefecture
$N_{FCV,\,Hyogo}$	Number of FCVs in Hyogo Prefecture
$N_{auto,\,city}$	Number of cars in the target city
$N_{FCV,\,city}$	Number of FCVs in target cities
$H_{per\ FCV}$	Annual hydrogen consumption per vehicle (kg/year)

a) Number of FCVs in Hyogo Prefecture:

$$N_{FCV,\,Hyogo} = 800{,}000 * (N_{auto,\,Hyogo}/N_{auto,\,Japan}) \tag{1}$$

b) Number of FCVs in the city:

$$N_{FCV,\,city} = N_{FCV,\,Hyogo} * (N_{auto,\,city}/N_{auto,\,Hyogo}) \tag{2}$$

c) Annual hydrogen consumption per FCV:

$$H_{per\ FCV} = 12{,}000km * \left(\frac{0.8kg}{100km}\right) = 96kg \tag{3}$$

d) Annual hydrogen demand (kg):

$$Annual\ Hydrogen\ Demand(kg) = N_{FCV,\,city} * 96kg \tag{4}$$

e) Calculate the number of stations required for each city (demand-based):

$$ANumStaiton_i = \ H_{demand,\,i}/96{,}000 \tag{5}$$

3.2. Centroid Definition

To anchor spatial allocation, two types of municipal centroids are defined. A list of variables is outlined in Table 2.

Table 2. Variable definition (Optimization)

Variable	Definition
$H_{demand,\,i}$	City's annual hydrogen demand (kg)
$D(i,j)$	Straight-line distance between the center of stand and any stand in the city (km)
$NumStaiton_{\,i}$	Number of stations required for each city
$Staiton_{\,j}$	Stand latitude, longitude and address information

3.2.1. Gas Station Average Centroid

This centroid is computed as the arithmetic mean of latitude and longitude values of all existing gas stations within a municipality. It reflects the physical distribution of current fuel infrastructure and generally favors commercial zones. The solution to find the distance from the center of a gas station is defined as follows:

$$D(i,j) = Distance\ between\ City_i\ and\ Station_j \tag{6}$$

3.2.2. Population-Weighted Centroid

Using 1km mesh-based population data from the 2020 national census, the centroid is calculated by assigning weights to each mesh grid. This method captures population density and residential distribution, offering a more demand-centric view.

3.3. Optimization Procedure

A greedy algorithm is employed to assign hydrogen stations to municipalities. After computing straight-line distances from centroids to all potential gas station sites, municipalities are assigned stations based on proximity and required capacity. Each hydrogen station is assumed to handle up to 96,000 kg of hydrogen annually, allowing the number of stations needed per municipality to be derived from demand forecasts.

3.4. Output and Visualization

Results are exported as Excel datasets and mapped using geospatial tools. These outputs provide a basis for comparing how different centroid definitions affect the spatial layout of hydrogen station deployment.

4. Results

4.1. Station Allocation Overview

The optimization algorithm assigned a total of 16 stations across seven municipalities: Kita-Ku and Nishi-Ku (Kobe), Amagasaki, Nishinomiya, Akashi, Kakogawa, and Himeji. These locations were identified as areas with high projected demand in 2030.

4.2. Comparison by Centroid Method

4.2.1 Gas Station Average Centroid

This method favored central commercial areas, resulting in more clustered station placements near existing infrastructure. While logistically convenient, the distribution showed limited reach into peripheral residential zones. The results from this approach are depicted in Figure 2. The numbers in parentheses indicate the optimal number of hydrogen stations.

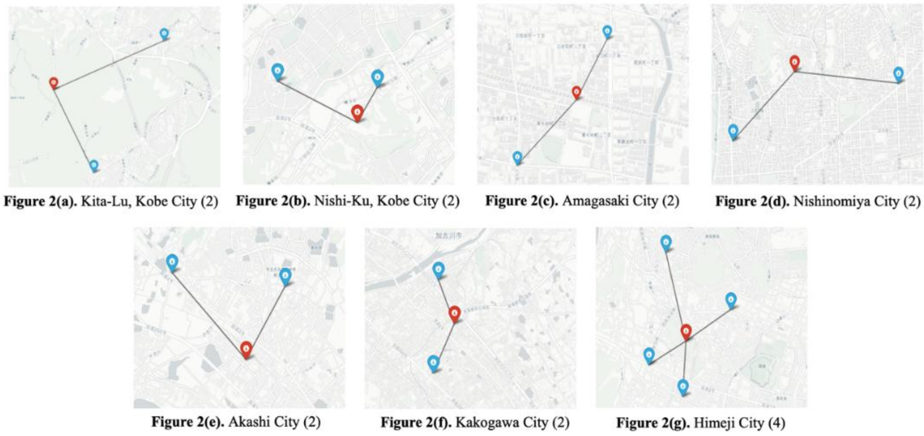


Figure 2(a). Kita-Lu, Kobe City (2) **Figure 2(b).** Nishi-Ku, Kobe City (2) **Figure 2(c).** Amagasaki City (2) **Figure 2(d).** Nishinomiya City (2)

Figure 2(e). Akashi City (2) **Figure 2(f).** Kakogawa City (2) **Figure 2(g).** Himeji City (4)

Figure 2. Gas Station Average Centroid

4.2.2 Population-Weighted Centroid

In contrast, this approach distributed stations more evenly, with a notable emphasis on accessibility for densely populated residential districts. Average distance to demand centers was slightly reduced, and service equity improved. The results from this approach are depicted in Figure 3. The numbers in parentheses indicate the optimal number of hydrogen stations.

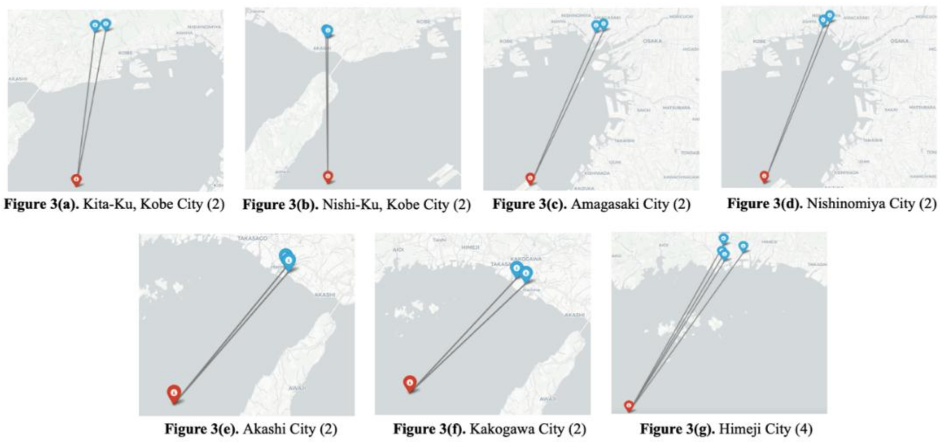


Figure 3(a). Kita-Ku, Kobe City (2) **Figure 3(b).** Nishi-Ku, Kobe City (2) **Figure 3(c).** Amagasaki City (2) **Figure 3(d).** Nishinomiya City (2)

Figure 3(e). Akashi City (2) **Figure 3(f).** Kakogawa City (2) **Figure 3(g).** Himeji City (4)

Figure 3. Population Weighted Centroid

5. Discussion

The findings confirm that the definition of centroid significantly influences which gas stations are selected for co-location with hydrogen facilities. In each of the seven municipalities examined, the two centroid approaches consistently yielded distinct sets of stations with differing geographical, functional, and social characteristics.

In Kita-Ku, Kobe, the stations selected under the gas station average centroid were located along arterial roads, larger in scale, and equipped with multiple refueling lanes, suggesting higher throughput capacity and commercial orientation. In contrast, those chosen via the population-weighted centroid were embedded within residential neighborhoods, closer to schools and supermarkets, and more accessible to daily users.

In Himeji, the average-based sites were adjacent to industrial zones with easy vehicle access, while the population-based stations were closer to densely populated areas and local transportation nodes. Similarly, in Kakogawa and Nishinomiya, population-based stations tended to offer higher accessibility for non-vehicular users such as pedestrians and cyclists, whereas average-based sites prioritized traffic convenience and logistics.

In Amagasaki and Akashi, the gas station average approach selected larger-scale, 24-hour facilities on main roads, while the population-based method led to selection of neighborhood-scaled stations with shorter operating hours and fewer pumps. This trade-off reflects a broader divide between infrastructure-led and demand-led planning.

In Nishi-Ku, Kobe, both station sets were physically close, but their roles differed: one served a commuter corridor while the other supported a suburban cluster. This indicates that even in similar areas, centroid choice alters service coverage dynamics.

Overall, the comparison reveals a consistent pattern: the gas station average centroid prioritizes infrastructural feasibility and commercial scalability, while the population-weighted centroid enhances accessibility, spatial equity, and alignment with community-level hydrogen demand. These findings align with previous studies that emphasize the importance of spatial fairness and demand-sensitive station siting (Genovese and Fragiacomo 2023). A hybrid strategy that combines infrastructure capacity with localized accessibility may provide the most balanced and context-sensitive deployment plan for hydrogen infrastructure.

6. Conclusion

This study demonstrates that co-locating hydrogen stations with gas stations is both feasible and beneficial in terms of cost and implementation speed. The choice of centroid has a non-negligible effect on spatial outcomes. The Gas Station Average Centroid aligns well with infrastructure realities but may neglect underserved areas. The Population-Weighted Centroid provides a more equitable distribution, aligning with actual residential demand.

From a policy standpoint, the findings highlight a key trade-off: logistical simplicity versus demand coverage. Policymakers may prioritize one over the other depending on whether their goal is rapid deployment or social equity.

Future research could extend this work by incorporating road network distances, land availability constraints, and multi-objective optimization using mathematical solvers such as Gurobi or heuristic search algorithms such as genetic algorithms.

References

Aljohani K, Thompson RG (2020) A multi-criteria spatial evaluation framework to optimise the siting of freight consolidation facilities in inner-city areas. Transp Res Part Policy Pract 138:51–69. https://doi.org/10.1016/j.tra.2020.05.020

Fuse M, Noguchi H, Seya H (2021) Near-term location planning of hydrogen refueling stations in Yokohama City. Int J Hydrog Energy 46:12272–12279. https://doi.org/10.1016/j.ijhydene.2020.09.199

Genovese M, Fragiacomo P (2023) Hydrogen refueling station: Overview of the technological status and research enhancement. J Energy Storage 61:106758. https://doi.org/10.1016/j.est.2023.106758

Piedra-de-la-Cuadra R, Ortega FA (2024) Bilevel optimization for the deployment of refuelling stations for electric vehicles on road networks. Comput Oper Res 162:106460. https://doi.org/10.1016/j.cor.2023.106460

Wang Z, Wang D, Zhao F, et al (2022) Hydrogen Refueling Stations and Carbon Emission Reduction of Coastal Expressways: A Deployment Model and Multi-Scenario Analysis. J Mar Sci Eng 10:992. https://doi.org/10.3390/jmse10070992

Zhu J, Zhu M, Chen L, et al (2024) Multi-Objective Optimization of Urban Gas Station Site Selection Under Territorial Spatial Planning Constraints. ISPRS Int J Geo-Inf 13:375. https://doi.org/10.3390/ijgi13110375

Blockchain Technology in Maritime Logistics

Ivan Elias Arauz[1]

[1] *International Maritime University of Panama, Republic of Panama*
[*] *Corresponding author:* ivan.arauz@umip.ac.pa *; Tel.:* +507 6515-9149

Abstract: The maritime logistics industry is vital to global trade but faces pressure to improve efficiency, transparency, and environmental compliance. Traditional systems rely on paper and disconnected digital tools, causing delays and errors. Blockchain technology offers a secure, decentralized way to store and share data, solving many of these issues.

One major advantage is transparency. Blockchain allows all parties shipping companies, ports, customs, and government agencies to access the same verified information in real time. Smart contracts automate processes, reducing human error and delays.

Traceability is also improved. Every transaction is permanently recorded, enabling companies to track goods from origin to destination. This prevents cargo theft, supports product recalls, and ensures legal and ethical sourcing.

Security is strengthened through blockchain's tamper proof structure, which reduces fraud and document forgery. Replacing paper documents with digital versions speeds up customs and inspections.

Blockchain also supports environmental goals. Ships can send real-time emissions data to the blockchain, helping companies comply with international regulations and prove their sustainability.

Storing official certificates digitally improves efficiency and document integrity. Combined with AI, blockchain can optimize fuel use and reduce emissions.

Projects like TradeLens and GSBN demonstrate blockchain's real-world potential *(IBM & Maersk, 2018; GSBN, 2021)*. Overall, it offers a powerful path toward a more transparent, secure, and sustainable maritime logistics system.

Keywords: Blockchain technology; Maritime logistics; Supply chain transparency; Smart contract; Sustainable shipping.

1. Introduction

The global economy relies heavily on maritime logistics, with over 80% of world trade by volume carried by sea. However, the systems that support this critical sector often lag behind modern standards. Traditional maritime logistics still depend on physical documents, isolated databases, and slow communication. These outdated practices lead to delays, errors, fraud, and inefficiencies.

Blockchain technology offers a powerful tool to address these problems. Originally developed for cryptocurrencies, blockchain has since found use in many industries, including supply chain management. In the context of maritime logistics, blockchain offers new ways to streamline operations, improve trust, ensure transparency, and reduce environmental impacts.

This paper explains how blockchain works, its benefits for maritime logistics, real-world examples, and the challenges that must be overcome for its full implementation.

2. Understanding Blockchain Technology

Blockchain, a digital ledger technology, operates differently from traditional centralized databases. Instead of storing data in a single location, blockchain records information across a network of interconnected computers. Each entry, or "block," is securely linked to the preceding one, forming an immutable chain. Once data is added to the blockchain, it becomes virtually impossible to alter it without altering every subsequent block, ensuring its high level of security.

One of the key advantages of blockchain is its decentralized nature, which means no single entity or entity has control over the data. Consequently, all participants on the network have access to the same verified and reliable information in real time. Additionally, blockchain supports “smart contracts,” which are self-executing programs that automatically perform actions when specific conditions are met.

These features make blockchain an ideal solution for industries that prioritize transparency, trust, and accuracy, such as shipping.

3. Enhancing Transparency in the Supply Chain

Blockchain offers several significant advantages in maritime logistics, particularly in enhancing transparency. In contrast to traditional supply chains, where each participant maintains their own records, which can be inconsistent or even deliberately altered, blockchain provides a shared version of the truth. This transparency fosters trust, reduces the risk of fraud, and simplifies dispute resolution.

Furthermore, smart contracts automate various steps within the supply chain. For instance, when a ship arrives at port and unloads cargo, a smart contract can automatically trigger payment or notify customs. This automation streamlines processes, reduces paperwork, and expedites operations.

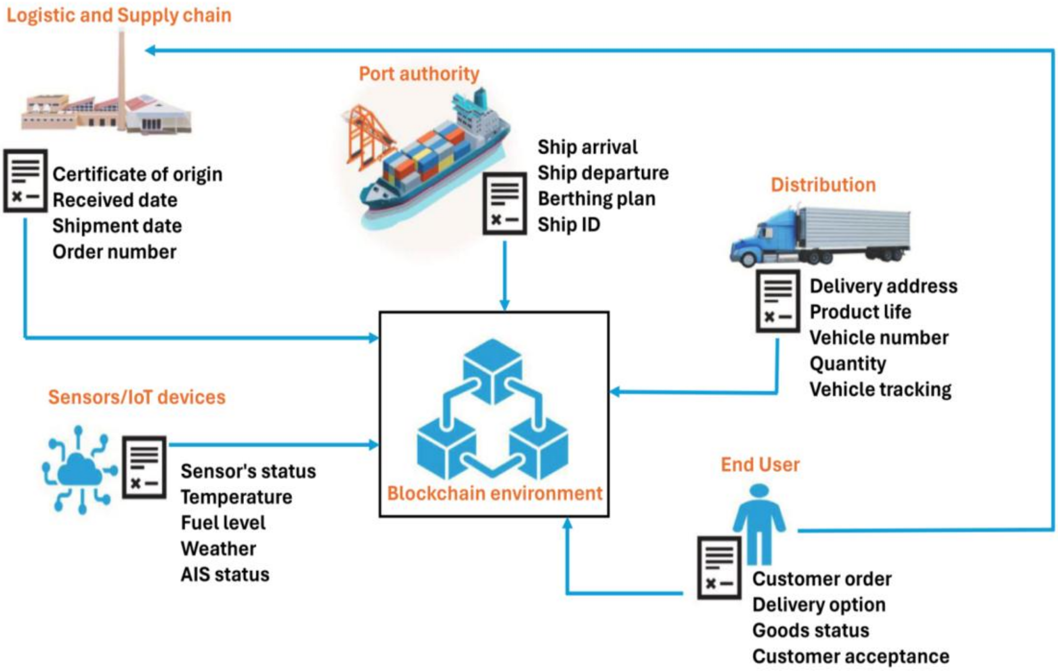


Figure 1. Maritime Blockchain

4. Improved Traceability and Security

Traceability is crucial in various industries, particularly for high-value goods, food, and pharmaceuticals. Blockchain meticulously records every step of a shipment’s journey, from its origin to its final destination. In case of any issues, such as contamination, damage, or theft, companies can pinpoint the exact moment the problem occurred.

This traceability also plays a vital role in enforcing regulations, particularly those requiring companies to demonstrate the ethical sourcing of their products. Blockchain empowers the fight against illegal shipping practices and forced labor by providing irrefutable proof of origin and transport history.

Security is another significant advantage. Since blockchain is decentralized and tamper-resistant, it poses an extremely high barrier to hacking. Unlike centralized systems that can be targeted by a single cyberattack, blockchain distributes the risk across the entire network.

Furthermore, digitizing essential documents like bills of lading and customs declarations reduces the risk of document fraud and simplifies the verification of authenticity during inspections.

5. Supporting Environmental Sustainability

The shipping industry is one of the largest contributors to global greenhouse gas emissions. New international regulations, such as those from the International Maritime Organization (IMO), require companies to reduce their environmental impact. Blockchain can help with this challenge.

Sensors on ships can record data on emissions, fuel use, and engine performance. This data can be automatically uploaded to a blockchain, creating a reliable and unchangeable environmental record. Authorities and stakeholders can then use this data to verify compliance with laws and encourage cleaner practices. Moreover, when combined with artificial intelligence and analytics, blockchain data can help identify ways to reduce emissions, cut fuel costs, and improve route planning.

Table 1. Before and after blockchain in Maritime industry.

Key features	Before Blockchain	After Blockchain
Visibility	• Transactions are time-consuming and slow. • Documents are paper-based, fail to provide real-time visibility.	• Automating all transactions. • Providing a digital platform for information sharing.
Traceability	• Documents fail to ensure real-time traceability.	• Tracking and tracing information. • Providing real-time shipping information. • Ensuring information sharing among different parties.
Immutability	• Any part of the maritime network can modify transaction information. • With a centralized database, high risk of fraud.	• Transactions are timestamped. • Providing a single source of data, an immutable database.
Smart contracts	• Postponement between delivery times and payment terms when dealing with multiple parties.	• Automatically adjusting marine insurance.

6. Handling Documents and Certifications

Maritime logistics involve many certificates and legal documents such as certificates of origin, inspection reports, and safety approvals. These documents are often paper-based, which makes them easy to lose or forge, and they slow down the shipping process.

Blockchain provides a digital solution. Documents stored on a blockchain are secure, verifiable, and easy to access. During inspections or customs checks, officials can instantly verify the documents' authenticity, reducing wait times and improving efficiency.

By cutting out paper and reducing manual processing, blockchain not only speeds up operations but also helps reduce environmental waste.

7. Real-World Applications

Several blockchain projects have already been tested or implemented in maritime logistics:

TradeLens, developed by IBM and Maersk *(2018)*, is one of the most well-known. It allows different players in the supply chain to track containers, exchange documents, and verify records on a single blockchain platform.

Global Shipping Business Network (GSBN) is a consortium aiming to create industry-wide blockchain standards and improve data exchange.

Blockchain in Transport Alliance (BiTA) is working to promote adoption of blockchain across logistics and supply chains by developing common frameworks.

These projects show the potential of blockchain to solve long-standing problems in shipping. They also highlight the need for collaboration across companies and countries to make blockchain systems work smoothly on a global scale.

8. Conclusion

Blockchain technology holds transformative potential for the maritime logistics industry. Its ability to provide secure, transparent, and automated solutions addresses many of the sector's biggest pain points from documentation errors and customs delays to cargo theft and emissions compliance.

Although challenges remain in terms of integration, regulation, and scalability, the progress of initiatives like TradeLens and GSBN shows that blockchain is already reshaping how global shipping operates.

As the maritime sector continues to evolve in response to digital transformation and environmental pressures, blockchain emerges not just as a technical upgrade but as a strategic enabler for a smarter, safer, and more sustainable future.

Acknowledgments

No external funding was received for this study.

References

Carson, B., Romanelli, G., Walsh, P., & Zhumaev, A. (2018). Blockchain beyond the hype: What is the strategic business value? McKinsey & Company. Retrieved from https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/blockchain-beyond-the-hype

Global Shipping Business Network (GSBN). (2021). A new era of global trade: Digitalizing maritime logistics. Retrieved from https://gsbn.trade/

Hackius, N., & Petersen, M. (2017). Blockchain in logistics and supply chain: Trick or treat? In *Proceedings of the Hamburg International Conference of Logistics (HICL)* (Vol. 23, pp. 3–18). https://doi.org/10.15480/882.1444

IBM & Maersk. (2018). TradeLens: How blockchain is transforming the shipping industry. Retrieved from https://www.ibm.com/blogs/blockchain/2018/08/tradelens-how-blockchain-is-transforming-the-shipping-industry/

International Maritime Organization (IMO). (2020). IMO strategy on reduction of GHG emissions from ships. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

World Economic Forum. (2020). Redesigning trust: Blockchain deployment toolkit. Retrieved from https://www.weforum.org/whitepapers/redesigning-trust-blockchain-deployment-toolkit

Zhang, Y., Kasahara, S., Shen, Y., Jiang, X., & Wan, J. (2019). Smart contract-based access control for the internet of things. *IEEE Internet of Things Journal*, 6(2), 1594–1605. https://doi.org/10.1109/JIOT.2018.2847705

Nuclear Propulsion in Shipping: A Path Toward Sustainable and Efficient Maritime Operations

Samantha Athena Dsouza[1,*], Sankalp Chakravarthy Sreenath[2]

[1,2]*Academy of Maritime Education and Training, Chennai, India*

[*]*Corresponding author: samathena13@gmail.com; Tel.: +91-8277216277*

Abstract

This paper examines the feasibility and economic viability of using nuclear fuel as a propulsion method in the commercial shipping industry, focusing on Small Modular Reactors (SMRs) and Molten Salt Reactors (MSRs). These advanced reactor technologies offer major advantages, including high energy density, extended operational range, minimal refueling requirements, and near-zero greenhouse gas emissions. Nuclear propulsion enables longer bunker periods, reduces dependence on fossil fuels, and presents no significant fuel leakage risks, making it a safer and more reliable alternative.

The study evaluates lifecycle costs and operational performance compared to traditional propulsion systems, demonstrating that despite higher initial investment, nuclear-powered vessels offer long-term savings and environmental benefits. Key challenges such as regulatory barriers, waste management, public perception, and safety concerns must be addressed. With advancing reactor technologies, robust safety protocols, and coordinated global policy efforts, nuclear propulsion stands as a practical, secure, and sustainable solution for the future of maritime transport, contributing to both decarbonization and energy security.

Keywords: Nuclear propulsion, small modular reactors (SMRs), molten salt reactors (MSRs), nuclear-powered vessel economics, maritime decarbonization

1. Introduction

The maritime industry is undergoing a significant transformation in its approach to propulsion fuels, driven by increasing environmental concerns and the need to comply with international standards such as the International Maritime Organization's (IMO) net-zero emission goals (International Maritime Organization, 2023). To meet these ambitious targets, the industry is actively exploring viable, sustainable, and economically feasible alternatives to conventional fuels. One promising solution is nuclear propulsion, particularly through the use of Molten Salt Reactors (MSRs) and Small Modular Reactors (SMRs) (Core Power, 2021). These advanced technologies offer several advantages, including extended bunkering intervals, minimal risk of weaponization, and robust shielding to prevent radiation leakage, thereby addressing both safety and environmental concerns (International Atomic Energy Agency, 2022).

Importantly, the design of these reactors ensures they pose no threat to the marine ecosystem, which helps alleviate international apprehensions regarding their use and reduces the likelihood of sanctions. Although the implementation of nuclear propulsion involves high initial investment and requires specialized training for crew members, the overall lifecycle cost of such vessels can prove to be economically advantageous.

2. Research Methodology

This research adopts a multi-step methodology to analyze the feasibility, safety, and regulatory landscape for the integration of nuclear propulsion in maritime operations. The methodology is divided into three key stages:

2.1. *Literature & Policy Review*

Objective: To examine existing international conventions and regulatory frameworks that govern maritime fuels and safety, particularly to understand their applicability or gaps in the context of nuclear propulsion.

2.2. *Comparative Analysis*

Objective: To compare traditional marine fuels (e.g., HFO, FO, DO, VLSFO) and their handling frameworks with advanced nuclear fuel technologies such as Small Modular Reactors (SMRs) and molten salt reactors.

Approach: Develop comparative matrices across four focus areas:

1. Production & Supply
2. Shore-side Handling
3. Shipboard Handling
4. Training, Certification & Regulation

2.3. *Stakeholder & Expert Consultation*

Objective: To collect expert insights from regulators, nuclear engineers, maritime operators, and training institutions regarding feasibility, safety, and implementation challenges.

Approach:

1. Conduct structured interviews.
2. Gather operational feedback and readiness assessments from:

   (i) Shipbuilders, (ii) Reactor designers and (iii) Port authorities

3. Traditional Marine Fuels and Their Limitations

Conventional marine fuels—primarily heavy fuel oil (HFO) and distillate fuels such as marine diesel oil (MDO) and marine gas oil (MGO)—continue to dominate global merchant shipping. As of 2021, HFO accounted for an estimated 50–60% of total bunker fuel consumption, with lighter distillate fuels like MDO and MGO comprising most of the remainder (ClassNK, n.d.).

These traditional fuels are characterized by high carbon intensity. For example, the combustion of ISO 8217-grade HFO emits approximately 3.11 grams of CO_2 per gram of fuel, or around 77 grams of CO_2 per megajoule (MJ) of energy produced. Distillate fuels like MDO and MGO generate slightly higher emissions per unit mass—about 3.21 g CO_2 /g—but are slightly less carbon-intensive by energy content, at around 75 g CO_2 /MJ (International Maritime Organization, 2014; International Maritime Organization, 2020). When upstream emissions—such as extraction, refining, and transport—are factored in, the life-cycle emissions of these fuels rise to roughly 90–95 g CO_2 /MJ (U.S. Department of Transportation, Maritime Administration, n.d.). Even low-sulfur variants like very low sulfur fuel oil (VLSFO) offer limited improvement, with carbon emission factors close to 3.19 g CO_2 /g (The International Council on Clean Transportation, n.d.). These figures align closely with the industry average of 91.2 g CO_2 /MJ reported for marine fuels used in 2020 (European Commission, Directorate-General for Mobility and Transport, 2020).

The fundamental drawback of these fuels is their substantial greenhouse gas (GHG) emissions, which contribute significantly to climate change. In addition to carbon dioxide, their combustion also produces high levels of sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter—pollutants with serious environmental and health implications. These concerns have prompted regulatory bodies like the International Maritime Organization (IMO) and regional authorities to implement stricter emissions standards. Notable examples include the IMO 2020 global sulfur cap and the EU's FuelEU Maritime initiative, both of which are pushing the maritime sector toward cleaner alternatives.

In light of these challenges, it is increasingly clear that the industry must transition away from fossil-based marine fuels. The environmental limitations of HFO, MDO, and MGO underscore the need for cleaner, more sustainable energy solutions. Emerging low-carbon or zero-carbon alternatives—such as ammonia, hydrogen, biofuels, and even nuclear propulsion—offer promising pathways for dramatically reducing the maritime sector's environmental footprint. Among these, nuclear fuel stands out for its near-zero operational emissions, positioning it as a particularly attractive option for achieving long-term climate goals.

4. Molten Salt Reactors for Nuclear Propulsion in Commercial Shipping

Our research focuses on the application of Molten Salt Reactors (MSRs) as a means of nuclear propulsion for commercial shipping. This interest is driven by the numerous advantages MSRs offer over conventional nuclear reactors, particularly in terms of safety, efficiency, and sustainability.

4.1. Introduction to Molten Salt Reactors (MSRs)

Molten Salt Reactors represent a class of advanced nuclear reactors in which the nuclear fuel is dissolved in molten salt, rather than being used in solid form as in traditional light-water reactors. MSRs fall under the broader category of Generation IV nuclear technologies, which are being developed to provide safer, more efficient, and more environmentally sustainable nuclear power.

In MSRs, molten salts serve a dual role—they act both as the carrier of nuclear fuel and as the primary coolant. Unlike Pressurized Water Reactors (PWRs), which require water under high pressure (around 150 atmospheres) to remain liquid at operating temperatures of approximately 315°C, MSRs operate at atmospheric pressure, with coolant temperatures ranging from 500°C to 1400°C. This fundamental difference leads to substantial reductions in mechanical stress on reactor components and improves thermal efficiency.

Common molten salts used in these reactors include lithium-beryllium fluoride and lithium fluoride, which possess excellent heat transfer properties, low vapor pressure, and high capacity for thermal energy storage, making them particularly suitable for marine propulsion systems.

Table 1. Comparison of Propulsion Types

Parameter	HFO Systems	MSRs
Emissions	High	Zero (CO_2, SOx)
Refueling Frequency	10–20 days	1–3 years
Operating Pressure	High	Low
Waste Management	Moderate	Complex
Energy Density	Low	Very High

4.2. Working Mechanism of MSRs

MSRs typically utilize thorium (Th-232) as the base fertile material. Thorium itself is not fissile but can absorb a neutron to become uranium-233 (U-233), which is fissile and capable of sustaining a nuclear chain reaction (Serp et al., 2014).

The reactor operates with molten salt fuel circulating through graphite core channels, generating an epithermal neutron spectrum (LeBlanc, 2010). Heat produced from fission is transferred through a three-stage heat exchange system: from the primary salt loop to a secondary coolant, and finally to the power conversion system—typically a turbine generator (Leblanc & Weaver, 2015). In a reference MSR design, the system produces power levels up to 1,000 MWe, with coolant inlet and outlet temperatures of 565°C and 700°C, respectively. For co-generation applications, such as hydrogen production, the outlet temperature may reach as high as 850°C.

The thermal efficiency of MSRs ranges from 45% to 50%, significantly higher than that of conventional reactors. Remarkably, MSRs can produce up to 200 times more energy from the same amount of fuel compared to traditional uranium-based reactors (Touran et al., 2020).

4.3. Advantages of Using Thorium

Thorium offers multiple benefits over uranium as a nuclear fuel:

1. **Abundance:** Thorium is approximately three to five times more abundant than uranium in the Earth's crust. The International Atomic Energy Agency (IAEA) estimates global thorium reserves at about 6.2 million metric tons.

2. **Safety and Mining:** It is easier and safer to mine and handle than uranium, with lower radiotoxicity and minimal enrichment requirements.

3. **Waste Reduction:** Thorium-based reactors produce significantly less long-lived radioactive waste—up to two orders of magnitude lower than current reactors. The radiotoxicity of this waste decreases to safer levels within a few hundred years.

4. **Proliferation Resistance:** Thorium's by-products, primarily U-233 and a small amount of plutonium, are not easily weaponizable, making thorium fuel cycles inherently resistant to nuclear proliferation.

5. **Waste Utilization:** Thorium reactors can also be used to consume existing plutonium stockpiles, helping to mitigate current nuclear waste challenges.

4.4. *Thermal Efficiency of Molten Salt Reactors*

Thermal efficiency (η) measures how effectively a heat engine converts thermal energy into work. For Molten Salt Reactors (MSRs), operating at a high temperature range enhances efficiency. The formula uses the absolute temperatures (in Kelvin) of the hot and cold reservoirs. With $T_{hot}=973\ K$ *and* $T_{cold}=573\ K$, the efficiency is ***approximately 0.41 or 41%***

$$\eta = \frac{(T_{hot} - T_{cold})}{T_{hot}}$$

Equation 1: Thermal Efficiency

4.5. *Safety Aspects of MSRs*

One of the most compelling arguments for MSRs in commercial shipping is their superior safety profile:

1. **Meltdown Immunity**: Unlike traditional reactors, MSRs cannot suffer from a meltdown, reducing the risk of catastrophic accidents like those at Chernobyl, Fukushima, and Three Mile Island (Thompson, 2023).

2. **Atmospheric Operation**: Operating at atmospheric pressure, MSRs eliminate the risk of explosive pressure failures, negating the need for bulky containment domes (Yamada, 2024).

3. **Passive Safety Mechanisms**: In the event of overheating, MSRs employ freeze plugs—actively cooled solid salt barriers that melt at high temperatures. This allows the fuel to drain into subcritical containment tanks, automatically halting the reaction (Thompson, 2023).

4. **Solidification on Leak**: In the case of a rupture or leak, the molten salt will cool and solidify, containing radioactive materials and preventing environmental contamination (Yamada, 2024).

5. **Intrinsic Stability**: As the temperature rises, the expansion of the molten salt leads to a natural decrease in reactivity, further stabilizing the system without external intervention (Patel, 2022).

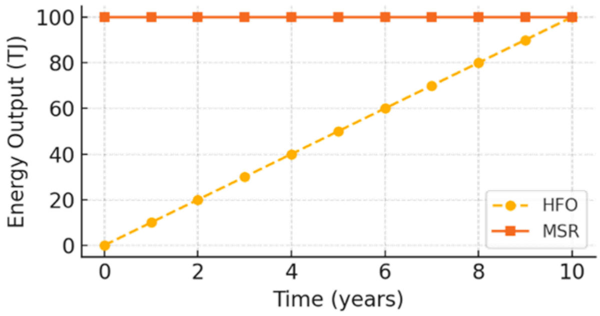


Figure 1: Fuel Cycle Duration vs Energy Output

This graph illustrates the correlation between the duration of the nuclear fuel cycle and the cumulative energy output of different propulsion systems. MSRs demonstrate significantly extended fuel cycles and higher energy outputs compared to conventional fuel and pressurized water reactors, highlighting their efficiency and sustainability in maritime applications.

4.6. *Future Scope*

The deployment of thorium-fueled Molten Salt Reactors (MSRs) and Small Modular Reactors (SMRs) in maritime propulsion presents a transformative pathway for the shipping industry. With abundant thorium reserves and inherent reactor safety features, future maritime reactors could achieve ultra-long operational cycles with minimal refueling requirements (Serp et al., 2014). The scalability of SMRs makes them ideal for integration into different vessel classes. As regulatory frameworks adapt, commercial nuclear-powered shipping lanes may become a reality, especially for transoceanic freight routes (Dutta, 2023). Advances in compact shielding and containment will facilitate safer onboard operations and crew proximity. Ongoing research in advanced materials and corrosion resistance will further improve reactor longevity in marine environments (LeBlanc, 2010). With rising fuel costs and stricter emission regulations, thorium-based nuclear propulsion offers a compelling solution for achieving IMO 2050 decarbonization targets.

5. Conclusion

Molten Salt Reactors offer a promising pathway for the decarbonization and modernization of commercial maritime shipping. With their high thermal efficiency, intrinsic safety features, and the ability to utilize abundant thorium fuel, MSRs present a transformative solution to current limitations in marine propulsion technology. Addressing the material and chemical challenges will be critical to unlocking their full potential and making nuclear- powered shipping a viable and sustainable reality for the future.

References

ClassNK (n.d.) Fuel oil. Available at: https://classnk.or.jp

Core Power (2021) Nuclear propulsion: A solution for decarbonizing shipping. Available at: https://corepower.energy

Dutta, S. (2023) Regulatory harmonization for nuclear marine vessels. IMO Policy Journal 18: 62–70.

European Commission, Directorate-General for Mobility and Transport (2020) EU MRV data and reporting: Summary for the year 2020. Available at: https://transport.ec.europa.eu

International Atomic Energy Agency (IAEA) (2022) Nuclear technology for shipping. Available at: https://www.iaea.org

International Maritime Organization (IMO) (2014) Third IMO GHG study 2014. Available at: https://wwwcdn.imo.org

International Maritime Organization (IMO) (2020) Fourth IMO GHG study 2020. Available at: https://wwwcdn.imo.org

International Maritime Organization (IMO) (2023) IMO strategy on reduction of GHG emissions from ships. Available at: https://wwwcdn.imo.org

LeBlanc, J. (2010) Molten salt reactors: A new beginning for an old idea. Nuclear Engineering and Design 240(6): 1644–1656.

Leblanc, D. & Weaver, J.K. (2015) Improved fuel utilization in thorium-fueled MSRs. Annals of Nuclear Energy 85: 1011–1020.

Patel, K. (2022) Marine environmental impact of nuclear fuel cycles. OE and Energy Journal 22(3): 33–41.

Serp, J., Allibert, M., Beneš, O., Delpech, S., Feynberg, O., Ghetta, V., Heuer, D., Holcomb, D., Ignatiev, V., Kloosterman, J.L., Luzzi, L. & Merle-Lucotte, E. (2014) The molten salt reactor (MSR) in generation IV: Overview and perspectives. Progress in Nuclear Energy 77: 308–319. https://doi.org/10.1016/j.pnucene.2014.02.014

Thompson, R. (2023) MSR safety systems and marine applications. Nuclear Engineering International 53: 67–74.

Touran, N., et al. (2020) Technical and economic viability of MSRs for ship propulsion. Nuclear Technology 206(6): 813–830.

U.S. Department of Transportation, Maritime Administration (MARAD) (n.d.) The Maritime Administration vision for marine renewable energy. Available at: https://maritime.dot.gov

The International Council on Clean Transportation (ICCT) (n.d.) Well-to-wake greenhouse gas emissions of marine fuels: Report. Available at: https://theicct.org

Yamada, T. (2024) MSR thermal analysis. Journal of Nuclear Science and Technology 60(1): 12–20.

The 25th IAMUS

Chennai, 16-17 Oct 2025

Proceedings of the International Association of Maritime Universities Student Program (IAMUS)

The Role of GIS (Geographic Information System) in Oil Pollution Prevention

Wiktoria Dumińska [1], Jakub Kulbat [1,*]

[1]Gdynia Maritime University, Poland

*Corresponding author: j.b.kulbat@gmail.com; Tel.: +48 452-511-188.

Abstract: Crude oil is the foundation of modern civilization, serving as the primary energy resource for sea, air and road transport. Since 1964, the sea transport of this resource has been associated with dozens of minor and major accidents. Oil spills, resulting from accidental or intentional releases of petroleum substances into sea environment, pose a threat to humans but, more significantly, an ecological hazard, including biodiversity loss and water contamination. Despite the global increase in oil transport, the number of tanker accidents has been declining. However, it has not reached zero, necessitating continuous efforts to develop innovative solutions capable of monitoring, preventing, and mitigating the consequences of oil spills.

The aim of the research was to verify and discuss the role of geographic information systems in the development of solutions and methods for monitoring and preventing oil spills. This study employed methods such as statistical analysis, environmental interviews, and a literature review, with a particular focus on the role of Geographic Information Systems (GIS). The research compares historical oil spill management methods to contemporary techniques. Data on oil spills and GIS applications were analyzed to assess trends and improvements in spill management. The findings indicate that GIS technologies, combined with advanced simulation tools, have significantly reduced the response time required to effectively reduce the impacts of oil spills and have diminished their environmental consequences. They have also contributed to improving the safety of marine ecosystems. Initially, oil spill management relied on manual mapping and estimations of the disaster's area, which resulted in delays and inaccuracies. Today, GIS enables precise tracking and modeling of spill trajectories through the use of satellite imagery, synthetic aperture radar (SAR), and real-time environmental data, such as radio reports from ships or aircraft. The advancement of GIS technology is essential for effectively addressing future environmental challenges.

Further research should focus on simulating spill scenarios and developing new pathways for spatial data analysis software, such as ArcGIS, QGIS, or open-source programs like GNOME. These tools can support rapid decision-making, enhance the efficiency of response operations, and optimize the allocation of rescue resources. This is particularly important considering the number of pollution incidents detected each year – over 7,000 such cases have been reported in European waters.

Keywords: shipboard oil; Geographic Information System; marine environmental; safety; tankship.

1. Introduction

This study examines oil spills deriving from tankship operations, one of the principal environmental challenges associated with maritime petroleum transportation. In the early 20th century, during the petroleum expansion, vast quantities of oil were transported to fuel industrial expansion and military endeavors while environmental concerns were largely disregarded. However, as tanker traffic proliferated, major incidents — such as the 1967 Torrey Canyon disaster off the coast of Cornwall — precipitated international scrutiny of the ecological impacts of oil spills. As can be seen in Figure 1, the Torrey Canyon disaster occurred before full, accurate statistics were kept. Moreover - between March 28 and 30 the ship was bombed by British Naval and Air Forces in order to open the remaining tanks and release the rest of the oil into the sea (Cooper 1968).

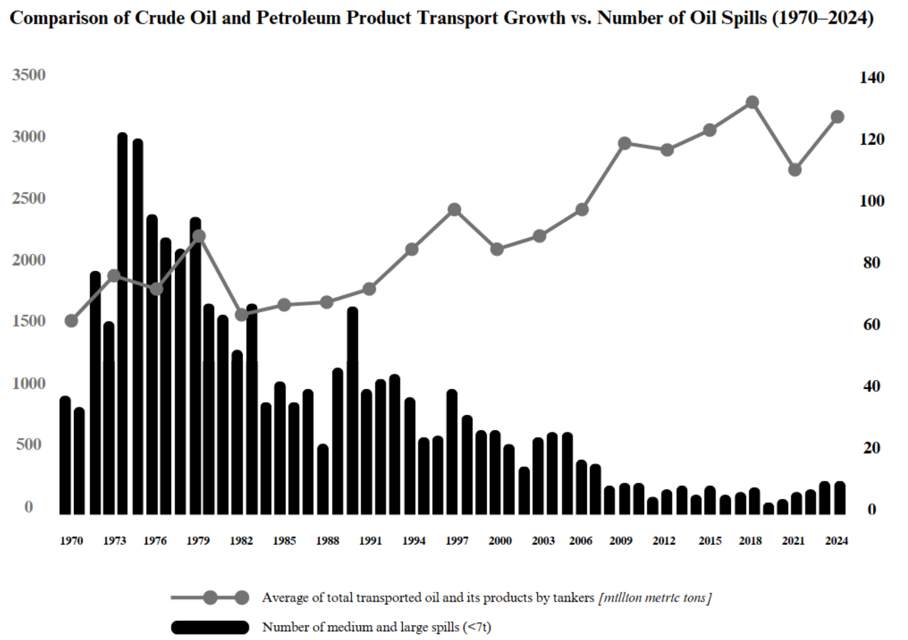


Figure 1. Comparison of Crude Oil and Petroleum Product Transport Growth vs. Number of Oil Spills (1970–2024).
Source: Authors' analysis of UNCTADStat Statistics.

Regardless of the growing shipboard oil market and the steadily increasing number of tankers, the number of spills exceeding 7 tons has been consistently decreasing year by year (Figure 1)(Table 1). This trend is attributed not only to technological advancements in hull construction but to regulatory changes, specialized training for ship crews, and increased attention to tankships navigation safety. Finally, detecting and tracking every oil spill. The results of the authors' research indicate that both the size of spills and their number are also decreasing.

Year	Name of Tank Carrier	Location	Amount of Spilled Oil *[tons]*	Total Number of Spills Larger than 7 tons in every 10 years
1967	Torrey Canyon	Cornwall and Isles of Scilly	117 000	N/A
1968	World Glory	South Africa	50 000	
1978	Amoco Cadiz	Brittany	223 000	788
1979	Aegean Captain, Atlantic Empress	Trinidad and Tobago	287 000	
1983	Castillo de Bellver	South Africa	170 000	454
1988	Exxon Valdez	P.W. Sound, Alaska	40 000	
1992	Aegean Sea	A Coruña	74 000	352
1996	Sea Empress	Wales	72 000	
2002	Prestige	Galicia	63 000	181
2007	Hebei Spirit	South Korea	11 000	
2010	Eagle Otomer	USA	1 300	63
2018	Sanchi	East China Sea	113 000	

Table 1. Comparison of the 2 largest oil tanker disasters and total number of spills >7t in each decade (1964-2024).
Source: Authors' analysis of various statistics and spill incident cases.

Early detection methods were rudimentary, relying on visual observations from aircraft or from the side of vessels, techniques that, despite their simplicity, still underpin modern surveillance efforts now enhanced by satellite imagery and remote sensing. In this paper, authors analyze the evolution of response times and mitigation strategies over the past six decades while also evaluating contemporary monitoring techniques. By integrating historical perspectives with modern technological advances, this study offers critical insights into how rapid response mechanisms and improved forecasting have transformed oil spill management.

2. Spill tracking methods

Historically, oil spill detection relied on human observation and rudimentary techniques that varied with proximity to the shoreline. Near coastlines, onshore observers visually identified slicks while vessel crews monitored for signs of oil at sea. To expand these early efforts, aerial surveillance using patrol aircraft and military planes extended observation over remote and expansive regions. Helicopters further enhanced detection with their agile, low-altitude capabilities, offering detailed assessments in complex coastal areas.

Despite their value, these traditional, optical methods were limited by weather conditions, visibility issues, and the sheer vastness of the ocean. With advancing technology, remote sensing techniques such as satellite imagery, unmanned aerial or underwater vehicles (drones), and AIS oil-tracking buoys have emerged. These modern methodologies now play a critical role in providing real-time, accurate, and efficient monitoring of oil spills (National Academies of Sciences, Engineering, and Medicine 2022).

2.1. Remote sensing

Since Synthetic Aperture Radar (SAR) technology was invented, it has formed the basis for the remote sensing of oil spills. SAR operates by emitting microwave signals and analyzing the returned echoes to synthesize high-resolution images, regardless of ambient conditions. Its fundamental principle is based on the fact that oil dampens capillary waves, creating smoother surfaces that reflect radar signals differently than clean water. This contrast produces distinctive dark signatures on SAR images that accurately indicate the presence of oil. Because SAR penetrates cloud cover and functions independently of sunlight, it remains effective in adverse weather and night-time conditions (Moreira 2013). Additionally, SAR provides detailed information on the location, extent, movement, and texture of spills through precise geographical coordinates and fine spatial resolution. However its capability to rapidly scan vast oceanic areas enables near real-time monitoring of dynamic spill events – multiple satellites would be required to provide daily coverage of the oil spill’s extent (Caruso 2013).

By integrating SAR data with other remote sensing information, researchers can reliably discriminate between true oil spills and look-alike phenomena. This integration enhances our understanding of oil fate and transport while significantly improving spill response strategies. As remote sensing technologies continue to evolve, SAR remains indispensable for environmental monitoring and the effective mitigation of oil spills.

2.2. Predictive modelling

Predictive modeling in oil spill tracking integrates multiple remote sensing platforms to simulate the evolution and dispersion of spilled oil over time. One key advancement is the deployment of the Visible Infrared Imaging Radiometer Suite (VIIRS), which captures data across optical, thermal, and infrared bands. In contrast to VIIRS, Synthetic Aperture Radar (SAR) relies on microwave signals to detect variations in sea surface roughness, producing distinctive signatures when oil dampens capillary waves. The multispectral capability of VIIRS enables the discrimination of oil based on its unique spectral signature and even assists in assessing spill thickness. Data from that, along with additional thermal imaging and multispectral sensors, are integrated with real-time atmospheric and oceanographic inputs to define the boundary conditions for oil dispersion (Sun 2018).

Advanced Geographic Information Systems (GIS) organize these diverse datasets into spatial grids, facilitating mapping of dynamic spill trajectories. This integration allows predictive models to account for wind, ocean currents, and weather variables, thereby simulating spill evolution more precisely. The resulting synergy not only enhances the accuracy of spill detection but also improves situational awareness, enabling more efficient resource allocation during emergency response. By providing actionable insights, these comprehensive models help identify areas at heightened environmental risk while supporting effective mitigation measures. As remote sensing technologies continue to evolve, such predictive modeling remains indispensable for both immediate spill response and long-term environmental protection.

3. Use of GIS in creating trajectory models

The use of Geographic Information Systems (GIS) has become an indispensable element in the detection, monitoring and management of marine oil spills. By integrating remotely sensed data — particularly from satellites — GIS enables precise mapping of oil slicks and supports real-time monitoring. This technology assists in determining the extent of contamination, assessing oil layer thickness, and estimating surface coverage, all of which are critical factors for planning an effective response. GIS also plays a key role in building spill trajectory models, helping authorities confirm predictions and adjust strategies accordingly. These systems support decision-making by identifying areas suitable for mechanical recovery or the application of dispersants, as well as by locating valuable nearby resources such as sea wildlife habitats and zones of economic or cultural assets.

Predictive models embedded within GIS frameworks simulate oil movement based on environmental parameters such as ocean currents, wind speed, wave movement, and water and air temperatures. Although modeling the behavior of individual oil particles remains challenging — especially due to subtle, small-scale variations — GIS improves forecast accuracy by integrating both static and dynamic data into layered vector maps. These models are continuously updated with remote sensing data obtained via satellites, drones, and patrol aircraft, ensuring timely and verified inputs. Despite technological advancements, traditional aerial and maritime observations remain vital for verifying model outputs and refining real-time predictions. Overall, the use of GIS in trajectory modeling enhances coordination among response agencies and increases the effectiveness of strategies aimed at minimizing environmental damage.

Over the years, numerous models have been developed to simulate oil spill movement with growing precision. Each model is designed with specific objectives and must operate within certain limitations, often defined by the resolution and capabilities of the simulation equipment used. Even when detailed environmental data — such as cloud cover, wind velocity, ocean currents, wave height, and temperatures of water and air — are collected directly from the spill area, accurately modeling oil particle behavior remains a major challenge. Minor differences in particle properties can result in divergent movement paths, making position forecasting inherently complex. Furthermore, in recent years, specialized monitoring agencies have emerged, capable of detecting and archiving satellite imagery of even the smallest leaks, slicks, and surface sheens. These institutions are playing an increasingly important role in global spill surveillance, although their presence is still relatively recent.

In Table 2, the authors aimed to highlight that reports from past oil spills indicate that, despite the availability of satellite data, response teams frequently relied on traditional aerial or maritime observations and, when feasible, land-based monitoring. The choice of observation method often depended on the distance between the spill's center and the nearest land—satellite imaging was more commonly used in remote, offshore locations. Moreover, the time needed to control or eliminate the primary source of a spill varied significantly. In many cases, rapid containment was achieved when the vessel had already sunk or been intentionally submerged, often concentrating the remaining oil near the wreck, which limited its spread on the water's surface.

Name Of Tankship	Date Of Incident	Approximate Time Of Essential Mitigation	Tracking Method	Approx. Distance To Nearest Land
SS Torrey Canyon	18th of March 1967	~ 12 days	[1]VO (Visual Observation)	16 NM
World Glory	13th of June 1968	~ 20 days	VO	65 NM
Amoco Cadiz	16th of March 1978	~ 50 days	VO	1 NM
Aegean Captain & Atlantic Empress	19th of July 1979	~ 20 days	VO and Landsat Satellite	10 NM
Castillo de Bellver	6th of August 1983	~ 6 days	VO	70 NM
Exxon Valdez	24th of March 1989	~ 30 days	VO	<1 NM
Aegean Sea	3rd of December 1992	~ 5 days	VO	<1 NM
Sea Empress	15th of February 1996	~ 6 days	VO	<1 NM
Prestige	13th of November 2002	~ 45 days	VO, [2]RS (Remote Sensing), [3]MOTHY	130 NM

Hebei Spirit	7th of December 2007	~ 20 days	VO, RS	6 NM
Eagle Otome	23rd of January 2010	~ 18 days	VO	<1 NM
Sanchi	6th of January 2018	~ 8 days	VO, RS, VIIRS	160 NM

Table 2. Comparison of approximate time of essential mitigation, tracking methods and distances to the nearest land for large tanker incidents (1964-2024).
Source: Authors' analysis of various statistics and spill incident cases.

[1]VO – Visual Observations from land, vessels or aerial vehicles or devices.
[2]RS – Remote sensing
[3]MOTHY – MOTHY Operational Oil Spill Prediction System is a pollutant drift model, developed and operated by Météo-France.
It includes hydrodynamic coastal ocean modelling and real time atmospheric forcing from a global meteorological model (Daniel 2003).

3.1. European Spill Data

In Europe, the European Maritime Safety Agency (EMSA) operates with one of its mandates being the detection and monitoring of oil spills in the waters of European states. Its CleanSeaNet Service has been effectively collecting data on concerning leaks since 2007. The collected reports undergo a thorough verification process and are subsequently forwarded to the respective national authorities, which then re-assess the presence of a spill. At that stage, the country implements appropriate measures to either prevent further leakage or mitigate its effects.

Satellite	2007	2008	2009	2010	2020	2021	2022	2023
Number of detections	1590	3311	2106	1766	7672	6205	4918	7513
Average number per image	1.22	1.38	1.00	0.75	0.08	0.07	0.08	0.07

Table 3. Number of Annual Satellite Detections in selected years in CleanSeaNet Service covering European Waters.
Source: Authors' Analysis of various reports from EMSA CleanSeaNet Service.

The authors analyzed and filtered reports from the first four years of CleanSeaNet Service operation and the most recent four years, thereby obtaining insights into the differences between the early stages of SAR imagery use in marine environment monitoring, and present practices (Table 3).

The observed global trend indicates a reduction in the number of potential spills identified per image. The mean number per image during the study period 2007–2010 was 1.08. In contrast, although a considerably higher number of potential spills is currently detected, the actual average number of confirmed spills in the study period 2020–2023 is 0.08, representing a 93% decrease.

4. Conclusion

In conclusion, the integration of predictive models within GIS frameworks has markedly enhanced our ability to simulate and forecast the movement of oil spills. These models synthesize dynamic environmental parameters, including ocean currents, wind speed, wave dynamics, and temperature differentials, to build a detailed picture of spill dispersion. Continuous updates with remote sensing data from satellites, drones, and patrol aircraft ensure that predictions remain both timely and verifiable. Despite these advancements, traditional methods such as aerial and maritime observations continue to play a critical role in validating model outputs and refining real-time forecasts. The layered vector maps combining static and dynamic data have significantly improved forecast accuracy and operational readiness. This evolution is exemplified by the European Maritime Safety Agency's CleanSeaNet Service, which, through rigorous verification processes, has maintained lower confirmed spill rates even amidst a high volume of potential detections. The enhanced integration of technologies has also improved coordination among response agencies, ultimately increasing the overall effectiveness of spill mitigation strategies. Nevertheless, the inherent challenges in modeling individual oil particle behavior underscore the need for further innovation and refinement. Overall, the fusion of modern GIS technologies with conventional monitoring approaches establishes a robust framework for both predicting and managing oil spill incidents. Future developments in spatial data analysis and simulation techniques promise to further augment the precision and efficacy of environmental protection efforts.

References

Cooper, Leslie H N (1968) Scientific Consequences of the Wreck of the "Torrey Canyon. Helgoländer Wissenschaftliche Meeresuntersuchungen, vol. 17, no. 1-4, 40–355, https://doi.org/10.1007/bf01611235

National Academies of Sciences, Engineering, and Medicine (2022) Oil in the Sea IV: Inputs, Fates, and Effects. Washington, DC: The National Academies Press. 111-159 https://doi.org/10.17226/26410

Moreira, Alberto, et al (2013) A Tutorial on Synthetic Aperture Radar. IEEE Geoscience and Remote Sensing Magazine, vol. 1, no. 1, 6–43, www.geog.ucl.ac.uk/~mdisney/teaching/PPRS/PPRS_7/esa_sar_tutorial.pdf, https://doi.org/10.1109/mgrs.2013.2248301

Caruso, Michael, et al (2013) Oil Spills and Slicks Imaged by Synthetic Aperture Radar. Oceanography, vol. 26, no. 2, https://doi.org/10.5670/oceanog.2013.34

Sun, Shaojie, et al (2018) Tracking an Oil Tanker Collision and Spilled Oils in the East China Sea Using Multisensor Day and Night Satellite Imagery. Geophysical Research Letters, vol. 45, no. 7, 3212–3220, https://doi.org/10.1002/2018gl077433

Boufadel, Michel, et al (2015) Exxon Valdez Oil Spill Restoration Project Final Report Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William Sound, Alaska Restoration Project 15150121, https://www.arlis.org/docs/vol1/EVOS/2015/RP15150121.pdf

Kurtz, Rick S (1995) Cultural Resources Protection and Oil Spill Mitigation after the Exxon Valdez Disaster. Vol. 12

Daniel, Pierre, et al (2001) Forecasting the Erika Oil Spills. International Oil Spill Conference Proceedings, vol. 2001, no. 1, 649–655, https://doi.org/10.7901/2169-3358-2001-1-649

Daniel, Pierre, et al (2003) Improvement of Drift Calculation in Mothy Operational Oil Spill Prediction System. International Oil Spill Conference Proceedings, vol. 2003, no. 1, 1067–1072, https://doi.org/10.7901/2169-3358-2003-1-1067

Stuart A, et al (1981) THEATLANTIC EMPRESSSINKING — a LARGE SPILL without ENVIRONMENTAL DISASTER. International Oil Spill Conference Proceedings, vol. 1981, no. 1, 429–435, https://doi.org/10.7901/2169-3358-1981-1-429

Moldan, A G S, et al (1985) Some Aspects of the Castillo de Bellver Oil spill. Marine Pollution Bulletin, vol. 16, no. 3, 97–102, https://doi.org/10.1016/0025-326x(85)90530-2

NTSB (2010) Collision of Tankship Eagle Otome with Cargo Vessel Gull Arrow and Subsequent Collision with the Dixie Vengeance Tow Sabine-Neches Canal, National Transportation Safety Board. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAR1104.pdf

European Maritime Safety Agency 2010 CleanSeaNet First Generation Report. https://www.emsa.europa.eu/csn-menu/csn-service/download/1516/1309/23.html

Assilzadeh H , Gao Y (2008) Oil Spill Emergency Response Mapping for Coastal Area Using SAR Imagery and GIS. OCEANS, Canada, https://ieeexplore.ieee.org/abstract/document/5151820, https://doi.org/10.1109/oceans.2008.5151820

Camliyurt G, et al (2024) Enhancing shipboard oil pollution prevention: Machine learning innovations in oil discharge monitoring equipment. ELSEVIER, online, https://doi.org/10.2139/ssrn.4888923

Chiu C, et al (2023) Utilizing Numerical Models and GIS to Enhance Information Management for Oil Spill Emergency Response and Resource Allocation in the Taiwan Waters. Journal of Marine Science and Engineering, online, https://doi.org/10.3390/jmse11112094

Pyrchla J, et al (2014) Sieciocentryczny system informacji geograficznej zatoki gdańskiej wspomagania działań operacyjnych morskich służb państwowych. I-NET.PL, Gdańsk

Wiewióra A, et al (1999) Ropa naftowa w transporcie morskim. Trademar, Gdynia

C. Cao, et al (2014) Early On-Orbit Performance of the Visible Infrared Imaging Radiometer Suite Onboard the Suomi National Polar-Orbiting Partnership (S-NPP) Satellite. IEEE Transactions on Geoscience and Remote Sensing, vol. 52, no. 2, pp. 1142-1156, https://doi.org/10.1109/TGRS.2013.2247768

Xudong Huang, et al (2022) A novel deep learning method for marine oil spill detection from satellite synthetic aperture radar imagery. Marine Pollution Bulletin, Volume 179, https://doi.org/10.1016/j.marpolbul.2022.113666

Marghany, M (2019) Synthetic aperture radar imaging mechanism for oil spills. Gulf Professional Publishing. ISBN: 978-0-12-818111-9

Ivanov, A Yu, Zatyagalova, V V (2008) A GIS approach to mapping oil spills in a marine environment, International Journal of Remote Sensing, 29(21), pp. 6297–6313. https://doi.org/10.1080/01431160802175587

Cedre https://wwz.cedre.fr/en Accessed 24 January 2025

European Maritime Safety Agency https://www.emsa.europa.eu/ Accessed 24 January 2025

International Tanker Owners Pollution Federation https://www.itopf.org/ Accessed 24 January 2025

The 25th IAMUS

Proceedings of the International Association of Maritime Universities Student Program (IAMUS)

Chennai, 16-17 Oct 2025

Marine AI Engineering Assistant for Marine Engineers (MAEA)

Nandana B Panicker[1,*]

[1]*AMET Institute of Science and Technology, Chennai, India*
[*] *Corresponding author: nandanapanicker12@gmail.com, Tel.:* +91 98950779480.

Abstract: The Marine AI Engineering Assistant (MAEA) is an advanced AI-powered system designed to support marine engineers by improving efficiency, safety, and sustainability in the maritime Industry. Unlike automation systems that replace human roles, MAEA works alongside engineers, helping them with predictive maintenance, fuel optimization, and cybersecurity. By using real time sensor data and machine learning, it can detect potential machinery failures early, allowing engineers to prevent costly breakdowns. Additionally, its intelligent fuel optimization system analyzes factors like weather, cargo weight, and engine performance to suggest efficient fuel usage, reducing costs and ensuring compliance with environmental regulations. MAEA also enhances cybersecurity by using AI–driven defense mechanisms to protect ships from digital threats. It acts as a decision-support tool, offering real-time troubleshooting assistance through voice commands or a digital interface, helping engineers solve technical issues more effectively. Another key feature is its augmented Reality (AR) integration, which provides virtual training and guidance for repairs and emergency procedures. By combining AI with practical engineering needs, MAEA Empowers marine engineers, making ship operations more reliable, secure, and technologically advanced.

Keywords: Human AI collaboration, AI as a tool not a replacement, Decision support System, Maritime safety, Supporting Marine engineers

1. Introduction

The maritime industry is evolving rapidly with the growing influence of technology, and Artificial Intelligence (AI) is becoming a key part of that change. From navigation to maintenance, AI is being used to make ship operations more efficient, safer, and smarter. Among these advancements, the concept of a Marine AI Assistant is gaining attention—an intelligent tool designed specifically to support marine engineers in their daily tasks onboard.

Marine engineers often work under challenging conditions, where quick thinking and accurate decisions are crucial. A marine AI assistant can help by analyzing data, predicting faults, and offering real-time suggestions, making the job more manageable and reducing the chances of human error. This paper looks into how AI assistants can support marine engineers, the benefits they offer, the current challenges, and what the future might hold as this technology continues to grow.

2. The Evolving role of Marine Engineers in the Digital Era.

Marine engineers have always played a crucial role in ensuring the functionality, safety, and efficiency of a vessel's systems. Traditionally, their responsibilities included manual inspection of engines, routine maintenance, troubleshooting electrical systems, and managing fuel and power systems. However, as vessels become more complex and technologically integrated, the expectations placed on marine engineers have expanded significantly.

Modern ships now rely heavily on digital systems, real-time data monitoring, and automated control platforms. This transformation requires marine engineers not only to have mechanical and electrical expertise but also to interpret digital signals, manage software-based controls, and react quickly to system alerts. As a result, the marine engineer's role has evolved from primarily hands on mechanical work to a hybrid of technical oversight, analytical reasoning, and quick decision making under pressure.

AI is now emerging as a key tool to support this evolution. It helps engineers make faster, data driven decisions while reducing fatigue and the risk of human error. Marine AI assistants are designed to complement engineers not replace them by acting as a second brain: constantly monitoring ship systems, predicting issues, and guiding appropriate responses. In this digital era, marine engineers are not being replaced by AI; instead, they are becoming more empowered through it.

Table 1: Comparison between Traditional Monitoring Systems and AI-Based Monitoring Systems in Marine Engineering

Criteria	Traditional Monitoring System	AI-Based Monitoring System
Response Time	Slower, depends on human intervention	Real-time response with automated alerts
Accuracy	Prone to human error and manual misinterpretation	High accuracy due to data driven algorithms
Maintenance	Reactive approach; issues identified after occurrence	Predictive maintenance; detects anomalies beforehand
Data Handling	Limited data collection and manual logging	Continuous real-time data processing and logging
Human Involvement	Requires constant supervision	Minimal intervention; AI handles most tasks autonomously
Decision -Making	Subjective and experience based	Objective and analytics-based decision-making

3. Marine AI Assistants – A Support System for Engineers

The Marine AI Engineering Assistant (MAEA) is designed not as a replacement for marine engineers, but as a tool to enhance their capabilities. In today’s demanding shipboard environments, engineers are often expected to manage complex mechanical, electrical, and digital systems simultaneously. This multitasking, especially under pressure or during emergencies, increases the risk of human error. MAEA addresses this challenge by acting as a digital co-pilot— monitoring systems in real time, predicting issues before they escalate, and providing engineers with immediate insights and decision support.

One of MAEA’s core strengths is its ability to analyze sensor data from machinery and detect early signs of wear, overheating, or mechanical stress. By alerting the engineer before a fault occurs, it enables timely maintenance and avoids costly breakdowns or unsafe conditions. Additionally, AI– driven diagnostics reduce the time spent manually inspecting systems or interpreting technical logs, allowing engineers to focus on action rather than analysis.

Another key function is fuel optimization. Engineers traditionally rely on experience and standard practices to manage fuel usage. MAEA enhances this process by considering live variables such as cargo load, sea state, engine condition, and weather forecasts to suggest more efficient engine settings and routing strategies. This not only improves fuel efficiency but also helps ships meet international environmental regulations.

MAEA also plays a role in supporting less experienced engineers or cadets. Through voice commands, a touchscreen interface, or even augmented reality overlays, it can provide real-time instructions during equipment operation, repairs, or safety drills. This built-in guidance system supports training onboard, allowing cadets to learn through hands-on interaction with intelligent support. Ultimately, the Marine AI Assistant is not just a software tool—it’s a responsive, evolving support system built around the needs of the engineer. Whether in a calm engine room or under high-stress emergency conditions, it serves as a reliable, always-alert partner that amplifies human judgment with the power of data and technology.

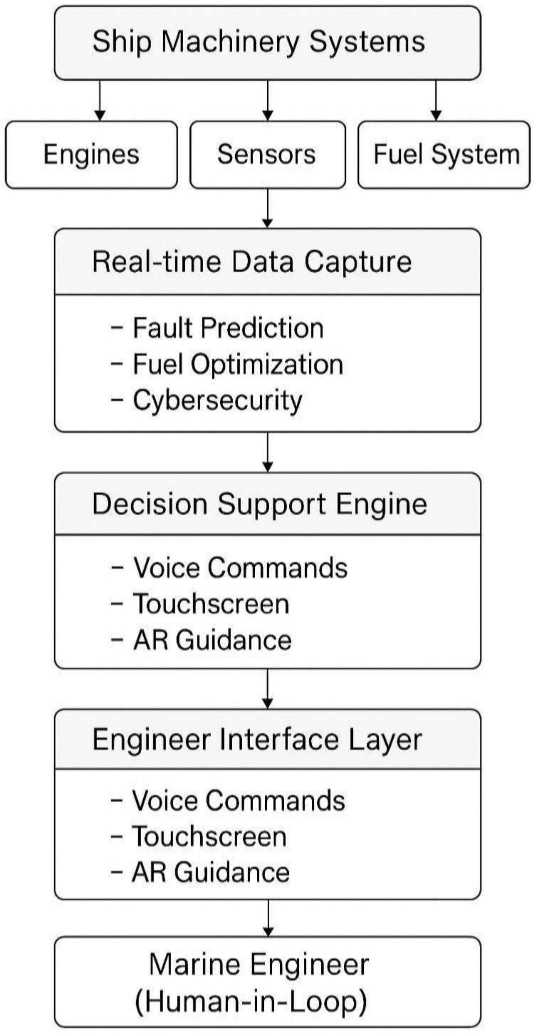


Figure 1. System Architecture of the Marine AI Engineering Assistant

4. Future Scope: Hybrid Systems and Human-AI Collaboration

As Artificial Intelligence continues to evolve in the maritime sector, there is growing interest in developing systems that not only process data and provide decision-making support, but also interact with the physical environment. One promising direction is the integration of Marine AI Assistants with robotic systems—creating hybrid solutions that combine intelligent software with physical mobility and precision. These systems could prove highly useful in scenarios where human access is limited, such as confined engine spaces, areas exposed to extreme temperatures, or during emergency situations like fire or flooding (Man et al., 2020).

Rather than replacing the role of marine engineers, these hybrid systems are intended to complement and support their work. For example, a robotic unit could perform routine inspections, detect signs of corrosion, or capture thermal imagery of machinery components, while the AI assistant analyzes the data and advises the human engineer. This setup could significantly reduce workload, improve safety, and enable faster decision-making, especially in high-pressure conditions (Fang et al., 2021).

However, it is important to recognize the challenges in implementing such systems. Building robots that can withstand the harsh and variable conditions of a marine environment—such as high humidity, vibrations, and saltwater exposure requires durable design and significant investment. For many commercial vessels, this may not yet be a cost-effective option. That said, in the long term, especially for specialized ships or offshore platforms, hybrid AI-robot systems could become a valuable asset (IACS, 2021).

Importantly, the introduction of such systems should not be viewed as a step toward reducing crew size, but rather as a move toward making marine engineering tasks safer, more efficient, and more sustainable. The human engineer remains central to operations, with AI and robotics serving as tools to enhance their capabilities. As technology advances, future research can explore practical ways to integrate these systems without disrupting the essential human element of marine engineering (Schröder & Wrede, 2020).

5. Challenges Faced by Marine Engineers and how AI helps

Marine engineers often operate under high-pressure conditions where even minor oversights can lead to major risks. Long working hours, unpredictable machinery behavior, and the responsibility to maintain critical systems—all while at sea—can make their roles both physically and mentally demanding. Many vessels still rely on manual logging, routine-based maintenance schedules, and engineer intuition to identify and respond system failures. This traditional approach is not only time-consuming but also prone to human error and delayed reactions.

One major challenge is the early detection of machinery faults. Without real-time analytics, engineers may only identify problems when performance drops or failures occur. AI helps by constantly analyzing engine and machinery data to detect patterns that humans might overlook. It not only flags issues early but also prioritize alerts based on severity, allowing engineers to act quickly and efficiently.

Another challenge is optimizing fuel use under varying sea conditions. Without digital assistance, engineers must rely on historical data and best guesses. AI assistants use live environmental data and machine learning models to suggest optimal fuel consumption settings, helping ships operate more sustainably and within international emissions standards.

Engineers also face challenges in emergency decision-making, especially when dealing with multiple alarms or unexpected events. AI support systems can provide ranked action suggestions and predictive scenario outcomes to help engineers act fast and confidently. Furthermore, by automating routine monitoring and reporting, AI allows engineers to focus on more technical and safety-critical operations.

By addressing these core challenges, Marine AI Assistants become an indispensable ally— elevating the safety, efficiency, and well-being of engineers on board.

6. Conclusion

Marine engineers are the backbone of a ship's operational stability and safety. As vessels grow more advanced and data-driven, the need for intelligent tools to support these professionals becomes more urgent. The Marine AI Engineering Assistant (MAEA) is not a replacement for human skill, but an enhancement—designed to empower engineers with real-time insights, predictive alerts, and intelligent automation.

By reducing routine workload, supporting diagnostics, and providing decision-making aid during emergencies, MAEA strengthens the role of marine engineers in a digitally evolving maritime landscape. Its long-term potential extends beyond software, possibly merging with robotics to assist physically in hazardous conditions—without threatening the human presence onboard. As the maritime industry progresses, embracing human-AI collaboration will be key to safer, more efficient, and more sustainable ship operations. MAEA represents this future—where marine engineers are not replaced by machines but are elevated by them.

References

Smith J., Chen L (2020). Artificial intelligence in marine engineering: Applications and challenges. Ocean Engineering Journal,178,106936. https://doi.org/10.1016/j.oceaneng.2020.106396.

Kumar A., Jose S. (2021). Smart ships: Leveraging AI for engine monitoring and maintenance. Journal of Marine Science and Technology, 25(4), 785-798. https://doi.org/10.1007/s00773-021-00811-4.

D. Nguyen, et al. (2021). Fuel efficiency optimization using AI in marine transportation. IEEE Access, 9, 150321-150332. https://doi.org/10.4031/MTSJ.55.1.5.

Rudan I. (2021). Decision Support Systems in Maritime Operations Using AI. Marine Technology Society Journal, 55(1),38-44. https;//doi.org/10.4031/MTSJ.55.1.5.

P. Fernandez and K. Tanaka. (2020). AI-based monitoring and diagnostics in marine subsystems. Artificial intelligence in Engineering, 34,27 – 36. https://doi.org/10.1016/j.engappai.2020.103580.

Maritime Students’ Coping Mechanism Towards Online Learning

Rogie Paul G.Apelarta[1], Kyle Allen C. Caburobias[2], Ghiesyner V. Escander[3], Allen Dave P. Gacuma[4], John Mark M. Gai[5], Cyran Jehea C. Palomo[6], Rhoyze Jesus C. Silvederio[7], Joshua M. Suegay[8], and Roland John Cyril F. Emague[9]*

[1-9] *John B. Lacson Foundation Maritime University (Molo), Inc., Philippines*
* *Corresponding author: xyrhille.flores@gmail.com; (33) 336-54-49*

Abstract: This study aimed to identify the maritime students' level of coping mechanism towards online learning. The data were gathered from 181 respondents enrolled in the Bachelor of Science in Marine Engineering (BSMARE) program of John B. Lacson Foundation Maritime University, Molo, Inc (JBLFMU-Molo, Inc.). They were grouped according to students' classification, place of origin, and socio-economic status. This study used an Adapted-Modified Research Instrument. The statistical tools used were mean, standard deviation, t-Test, and one-way ANOVA. The study concluded that the students enrolled in online learning show high coping levels in terms of coping mechanisms regardless of students’ classification, place of origin, and socio- economic status. Furthermore, the study revealed that there is no significant difference in levels of coping mechanism of students enrolled in online learning when grouped according to students' classification, place of origin, and socio-economic status.

Keywords: maritime students; level of coping mechanism; online learning

1. Introduction

The rise of online learning has significantly changed educational practices around the world, especially in Marine Engineering education. In response to the COVID-19 pandemic, many maritime institutions, including the John B. Lacson Foundation Maritime University-Molo (JBLFMU-Molo), quickly adopted online learning to maintain instruction. This study examines how students cope with online learning, highlighting their adaptability and the challenges they encounter during this transition.

Online learning, also known as e-learning or online education, involves the separation of teachers and students and uses technology to facilitate communication (Simonson & Berg, 2023). The COVID-19 outbreak in December 2019 has greatly impacted various sectors, particularly education. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), about 800 million learners globally have been affected. One in five learners cannot attend school, and one in four lacks access to higher education. Over 102 countries have imposed nationwide school closures, while 11 have localized closures. This ongoing crisis has hindered millions from attending classes, worsening educational inequalities and increasing the risk of illiteracy (Global Campaign for Education, 2020).

To address these challenges, the JBLFMU-Molo community has developed strategies to adapt to the new educational landscape, emphasizing the importance of distance learning. This study aims to assess the coping mechanisms and strategies employed by maritime students enrolled in online courses, providing insights into their experiences and adaptability in this new learning environment.

2. Theoretical and Conceptual Framework

This study is grounded in Dweck’s Socio-Cognitive Theory, which posits that the Social Cognitive model of motivation encompasses helpless and mastery-oriented responses that affect students’ achievement goals, subsequently influencing their beliefs and behaviors. In the current educational climate, students have faced challenges in acquiring new knowledge due to the absence of face-to-face learning, particularly in programs like BSMARE that require practical laboratory activities for comprehensive understanding. Research on enhancing the interactivity of online learning indicates that students exhibit creativity in developing problem-solving techniques and coping strategies within their online courses; those with superior problem-solving abilities are better equipped to navigate the difficulties of online learning environments (Sundberg et al., 2004).

As the objective of this research is to determine the level of coping mechanism of the students participating in online learning, the researchers have created a research paradigm with regards to the students' classification, socio-economic status, and place of origin.

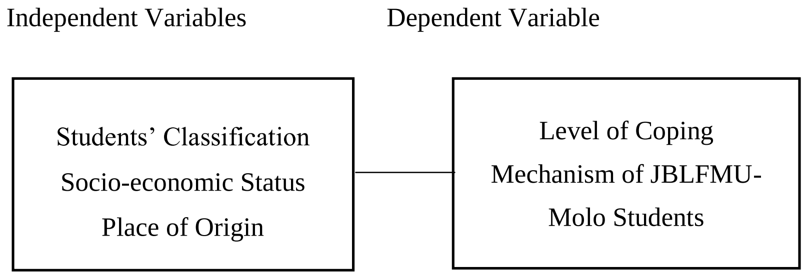


Figure 1. Research Paradigm Showing the Relationships of Variables Used in this Study

3. Statement of the Problem

This study aimed to evaluate the level of coping mechanism of JBLFMU-Molo Maritime College Students in the context of online learning, specifically addressing the following questions:

1. What is the level of coping mechanism of JBLFMU-Molo students in online learning when taken as a group?
2. What is the level of coping mechanisms of JBLFMU-Molo students taking online learning when grouped according to students' classification, socio-economic status, and place of origin?
3. Is there a significant difference in the level of coping mechanism of JBLFMU-Molo students taking online learning when grouped according to students' classification, socio-economic status, and place of origin?

4. Methodology

The study utilized a quantitative, descriptive research design to investigate the level of coping strategies of second-year Bachelor of Science in Marine Engineering (BSMARE) students at John B. Lacson Foundation Maritime University - Molo during the first semester of the Academic Year 2021-2022. A total of 181 students were randomly selected as respondents. Data were collected through an Adapted-Modified Research Instrument that assessed several key variables, including students' classification, socio-economic status, and place of origin, and their strategies for coping with online learning. The analysis incorporated both descriptive and inferential statistics to evaluate the levels of coping mechanisms and identify any significant differences across the various demographic variables.

5. Results

The findings indicated that the overall level of coping mechanisms among students was classified as "High Coping," with a mean score of 3.88 (SD = 0.593). Analysis based on student classification (Polaris and Regular classes), socio-economic status, and place of origin revealed that all groups exhibited similar coping levels, also categorized as "High Coping."

Table 1. Level of Coping Mechanism of JBFLMU-Molo Maritime Students Towards Online Learning when Taken as a Whole and Grouped According to Student Classification, Socio-economic Status, and Place of Origin

Category	n	Mean	SD	Description
Student Classification				
Polaris Class	40	3.90	0.744	High Coping
Regular Class	142	3.87	0.546	High Coping
Socio-economic Status				
Low Income	75	3.85	0.651	High Coping
Middle Income	86	3.91	0.523	High Coping
High Income	20	3.85	0.671	High Coping
Place of Origin				
Rural	97	3.92	0.534	High Coping
Urban	84	3.83	0.656	High Coping
TOTAL	181	3.88	0.593	High Coping

Notably, there were no significant differences among the variables of student classification, place of origin, and socio-economic status suggesting that all students demonstrated strong coping capabilities irrespective of these factors.

Table 2. t-test for Significant Difference in the Level of Coping Mechanism of JBFLMU Molo Maritime Students towards Online Learning when Grouped according to Students' Classification and Place of Origin

Category	t	df	Sig
Student Classification			
Polaris Class			
	0.260	179	0.795
Regular Class			
Place of Origin			
Rural			
	0.938	160	0.350
Urban			

Significant at 0.05, 95% confidence level

Table 3. One-Way ANOVA for Significant Difference in the Level of Coping Mechanism of JBFLMU Molo Maritime Students towards Online Learning when Grouped according to Socio-economic Status

Source of Variation	Sum of Square	df	Mean Square	F	Sig.
Socio-economic Status					
Between Groups	0.133	2	0.067		
				0.188	0.829
Within Groups	63.192	178	0.355		

Significant at 0.05, 95% confidence level

The results indicate that JBLFMU Maritime students are effectively managing the transition to online learning, showcasing resilience and adaptability regardless of their socio-economic background or geographical location. The lack of significant differences among groups suggests that the coping strategies employed are universally effective across diverse student demographics.

6. Conclusions

The research emphasizes the impressive ability of students at JBLFMU-Molo to adapt to online learning, exhibiting their resilience in the face of new challenges. To continue fostering this positive momentum, it's essential for educators to embrace innovative teaching strategies, while institutions work to overcome ongoing issues related to technology access and student engagement. The adaptability of these students is truly commendable and points to the need for consistent support systems in online education. Moreover, the study emphasizes the importance of refining online teaching methods to enhance student engagement and academic performance, ensuring that all learners have the best opportunities to succeed in this evolving educational landscape.

Recommendations

To ensure ongoing success in online learning, it is essential to encourage students to develop effective strategies for adaptation. Additionally, further research should be conducted to include other maritime programs and institutions, validating the findings and exploring differences across various educational contexts. Educators must also prioritize the enhancement of online education by focusing on improving the quality of online instruction and engagement methods to effectively support student learning.

References

Baloran, E. (2020). Knowledge, attitudes, anxiety, and coping strategies of students during COVID-19 pandemic. *Research Gate*. https://doi.org/10.1080/15325024.2020.1769300

Barrot, J., Llenares, I., & del Rosario, L. (2021). Students' online learning challenges during the pandemic and how they cope with them: The case of the Philippines. *Education and Information*, Springer Link. https://doi.org/10.1007/s10639-021-10589-x

Busaba, S., Budsaba, W., Chavant, S., Jadsada, K., & Pataraporn, Y. (2022). Prevalence of perceived stress and coping strategies among healthcare workers during the COVID-19 outbreak at Bangkok metropolitan, Thailand. PLoS ONE. Retrieved May 26, 2023, from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0270924

Doron, J., Stephan, Y., Boiché, J., & Scanff, C. L. (2009). Coping with examinations: Exploring relationships between students' coping strategies, implicit theories of ability, and perceived control. *British Journal of Educational Psychology*, 79(3), 515–528. https://doi.org/10.1348/978185409X402580

Global Campaign for Education. (2020). #CoronaVirus: Don't let our children down! *Global Campaign for Education*. Retrieved May 24, 2023, from https://campaignforeducation.org/en/press-centre/coronavirus-dont-let-our-children-down

Simonson, M., & Berg, G. (2023). Distance learning | education. *Britannica*. Retrieved May 24, 2023, from https://www.britannica.com/topic/distance-learning

Sundberg, C. W., Odell, M., Sunal, D., Mays, A., & Ruchti, P. (2004). Team teaching in an online environment: Effects on instructors and students. *Northwest Journal of Teacher Education*, 3(1), 189. https://doi.org/10.15760/nwjte.2004.3.1.5

The 25th IAMUS

Chennai, 16-17 Oct 2025

Proceedings of the International Association of Maritime Universities
Student Program (IAMUS)

Decarbonization by Usage of E Methanol

Hrishita Ghosh[1,*], Atithi Sur[2]

[1]*Academy of Maritime Education and Training, Chennai, India*

Abstract: Reducing carbon dioxide emissions plays a vital role in sustainable maritime practices, and a key indicator of progress in the industry is the advancement of green shipping. Among the emerging alternative fuels, e-methanol a type of green methanol shows significant promise, although it currently receives less attention. E-methanol is produced by combining renewable carbon dioxide (recycled CO_2) with hydrogen, which is separated from water (H_2O) through electrolysis. Compared to traditional methanol, e-methanol offers a lower carbon footprint and can be stored and transported using existing infrastructure. Despite these advantages, e-methanol faces challenges such as lower energy density and the need for larger storage tanks. Additionally, the limited availability of feedstock raises concerns about its scalability. However, its cost competitiveness improves significantly in solar-rich regions. Studies suggest that by 2050, Germany could benefit from e-methanol imports from Morocco and Chile, with production costs projected to be 4–14% and 15–22% lower, respectively. Similarly, Finland could see cost reductions of up to 26% by 2030 and 37% by 2050 through imports. This study explores the scalability and cost-reduction potential of e-methanol, emphasizing its role in supporting sustainable development within the maritime sector.

Keywords: e-methanol, decarbonization, maritime industry, sustainable development.

1. Introduction

Shipping has been central to global trade, driving the exchange of goods and ideas worldwide while advancing globalization and technology. Even today, about 90% of world trade relies on maritime transport.

Historically, shipping has evolved from wooden ships to steam and diesel engines, becoming highly efficient but at a significant environmental cost. The industry emits around 1,000 Mt of CO_2 annually, accounting for about 3% of global emissions, and this figure is projected to rise by up to 50% by mid-century without strict interventions. Ships primarily use heavy fuel oil (HFO), which releases harmful greenhouse gases such as CO_2, CH_4, and N_2O, contributing to global warming, rising sea levels, and other climate-related impacts.

Emissions vary based on vessel type, size, fuel, and distance travelled. For example, cargo ships emit about 16.14 grams of CO_2 per kilometre per ton of cargo, while container ships and bulk carriers emit approximately 140 and 440 million metric tons of CO_2 annually, respectively.

In response, the International Maritime Organization (IMO) adopted an Initial Strategy in 2018 to reduce and eventually eliminate greenhouse gas (GHG) emissions from shipping, supporting the UN Sustainable Development Goal 13. This has spurred the exploration of low-carbon alternative fuels such as ammonia, hydrogen, and methanol. Among these, e-methanol stands out for its low emissions and scalability, which this paper will explore in detail.

2. Why E Methanol?

2.1 Green Methanol: A Clean Fuel for Shipping Green methanol is a cleaner alternative to the traditional heavy fuel oil used in ships. As the shipping industry aims for net-zero carbon emissions by 2050, it is turning to alternative fuels like green methanol to reduce greenhouse gas (GHG) emissions.

Green methanol is a liquid fuel that is easy to store and handle. It is compatible with existing ship engines (both two-stroke and four-stroke) and storage tanks. It is produced in two main forms:

1. E-methanol – produced using renewable energy (solar, wind) to generate hydrogen, which is then combined with captured CO_2 from the air.

E-methanol has a lower carbon footprint than bio-methanol, as it recycles CO_2 rather than introducing new carbon into the atmosphere. While bio-methanol can still involve fossil fuel use in its production, e-methanol offers a more sustainable path for decarbonizing shipping and other industries.

3. Advantages of E Methanol

E-methanol presents a compelling array of benefits, including significant greenhouse gas (GHG) mitigation. It reduces NO_x emissions by 13% and SO_x emissions by 12% compared to heavy fuel oil. Its ease of handling is notable, with straightforward storage, transportation, and distribution. E-methanol blends seamlessly with traditional fuels, and its liquid state at ambient temperatures facilitates simple and safe handling.

Additionally, it boasts lower emissions, offering a near-zero carbon footprint. As an efficient hydrogen carrier, e-methanol can be readily converted into hydrogen. Its compatibility with existing infrastructure eliminates the need for significant additional investment, making it an attractive option for industry adoption. With applications spanning the marine, aviation, and chemical sectors, e-methanol emerges as a promising solution for reducing GHG emissions across multiple industries.

4. Conventions and Regulations related to GHG Emissions

1. SDG Goal 13: Calls for urgent action to combat climate change and its impacts. The International Maritime Organization (IMO) supports this goal by aiming to reduce greenhouse gas (GHG) emissions from the shipping sector.
2. IMO Strategy (2023): This strategy outlines a vision to reduce CO_2 emissions from international shipping by at least 40% by 2030. It also promotes the adoption of zero- or near-zero emission technologies, aiming for these sources to supply 5–10% of the energy used in international shipping by 2030.
3. Paris Agreement – Article 2: Aims to keep the rise in global temperatures well below 2°C, while pursuing efforts to limit it to 1.5°C.
4. IGF Code: The International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) sets mandatory safety requirements for vessels powered by gas or low-flashpoint fuels .It ensures safe vessel design and operation, minimizing risks to human life, property, and the environment.
5. Energy Policy Act (1992): U.S. legislation aimed at promoting energy efficiency, the use of alternative fuels, clean coal technology, electric vehicles, and renewable energy development.
6. COP26 Outcomes: Key outcomes from the 2021 United Nations Climate Change Conference (COP26) include strengthened national climate commitments (NDCs), a focus on phasing down coal, increased climate finance for developing countries, and finalizing the Paris Rulebook to ensure transparency and accountability in emissions reporting**.**
    - Acknowledgement of the climate emergency
    - Accelerated global climate action
    - Commitments to phase out fossil fuels
    - Increased climate finance and adaptation support
    - Finalization of the Paris Agreement rulebook
    - Recognition and initial steps to address loss and damage in vulnerable countries

7. European Environment Agency
   Under the European Climate Law, the European Union aims to achieve climate neutrality by 2050. It also targets a 55% reduction in greenhouse gas (GHG) emissions by 2030, compared to 1990 levels.

5. Engine Mechanism: **Retrofitting Existing Vessels for E-Methanol Use**

Retrofitting existing vessels to use e-methanol is a cost-effective strategy that allows ship-owners to reduce emissions without the need to build new ships. This process involves several key considerations, including the installation of separate fuel storage tanks to prevent contamination, engine upgrades to ensure safe fuel handling and combustion, and exhaust system modifications to comply with international regulations. Major engine manufacturers now offer dual-fuel engines capable of operating on e-methanol. These systems typically fall into two categories:

- Low-pressure systems, which involve fuel injection at approximately 10 bar and temperatures between 25–50°C

- High-pressure systems, which require injection at around 400 bar and often incorporate water mixing to help reduce emissions

E-methanol offers significant environmental benefits, including substantial reductions in sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter. However, to comply with IMO Tier III standards for NOx emissions, additional measures such as water injection may still be necessary. It is also important to note that dual-fuel engines may involve higher maintenance costs compared to conventional systems.

Despite these challenges, the outlook for e-methanol is promising. Production is expected to rise substantially, with bio-methanol and e-methanol projected to account for 80% of total methanol production by 2050. In response, many companies are developing methanol-ready engines and fuel supply systems. Several vessels already in operation or on order, reflecting the growing adoption of this environmentally friendly fuel in the maritime sector.

7. Methodology

Currently most hydrogen is produced from fossil fuel according to study of irena 2018 , hydrogen Is produced from fossil fuel about 40% , 30% and 18% only 4% is hydrogen is producing from renewable energies .there are various methods to produce e methanol which are described below

7.1 *By catalytic methanol synthesis:* Hydrogen is obtained from water through electrolysis in a single step using a catalyst, followed by the reaction with CO_2 to produce e-methanol. This is considered a practical method for producing e-methanol. Countries like Iceland, Norway, Australia, Belgium, and the Netherlands, which produce e-methanol at a high rate (more than 1000 tons per year), use this mature production method. The balanced chemical equation is given below in steps :
   1. $2H_2O$ (l)Electrolysis$2H_2$ (g)+O_2 (g)
   2. CO_2 (g)+$3H_2$ (g)→CH_3OH (l)+H_2O (l)
   3. CO_2 (g)+$2H_2O$ (l)ElectricityCH_3OH (l)+$1.5O_2$ (g)

   Renewable electricity -electrolysers – methanol production -e methanol
   H2O- [2 h2o – 2h2 +o2] -co2 -h2o- e methanol

7.2. *By syngas :* Syngas is a mixture of hydrogen and carbon monoxide or carbon dioxide gases, which acts as a catalyst during the process of electrolysis followed by reaction with CO_2 to produce e-methanol. This method can achieve higher conversion efficiency
   1. By water Electrolysis : $2H2O \rightarrow ELECTRICITY \rightarrow 2H2 + O2$
   2. Co2 Reduction to CO: $2CO2 \rightarrow 2CO + O2$
   3. Syngas Formation: Mixture of H_2 and CO (Syngas)
   4. Methanol Synthesis: $2CO+4H_2 \rightarrow 2CH_3OH$

   Renewable electricity -electrolyser – co2 -e methanol production [h2o] – emethanol
   H2o & co2 [2h2o-2h2 +o2] & [2co2 -2co + o2]-syngas [h2/co] -h2o – e methanol

7.3. *Direct electrocatalytic synthesis:* This method usually involves the direct electrocatalytic synthesis of methanol from water and CO_2 .
   However, this approach has limited efficiency. The overall process can be summarized as:

Renewable electricity → electrolyser → e-methanol
H20 –[ch3oh – co2 + h2o] – e methanol .
$2H2O(l) \rightarrow 2H2(g) + O2 \rightarrow \text{METHANOL} \rightarrow H2O$
By Catalytic methanol synthesis
$$2CO2 \rightarrow 2CO + O2 \xrightarrow[H2/CO]{O2} EMETHANOL \rightarrow H2O$$
$RENEWABLE\ ELECTRICITY \rightarrow ELECTROLYSER \rightarrow E\ METHANOl$

Each CO molecule requires 3 molecules of hydrogen, which produces 1 molecule of water for each molecule of methanol. For 1 tonne of methanol, it requires 1.38 tonnes of CO and 0.19 tonnes of hydrogen. Additionally, producing 1 tonne of methanol requires 10–11 MWh of energy. According to the study, a large-scale e-methanol plant producing 1,000 tonnes per day would require an electrolyser capacity of at least 420 megawatts. Therefore, to produce a large amount of methanol, electrolysers with gigawatt-scale capacity are needed, and production capacity at this scale still needs to be developed. This process can be carried out at temperatures of 200–300 degrees Celsius and under pressure.

8. Scalability

The cost and production rate are inversely proportional in the case of renewable methanol. Currently, the cost of methanol production is high, and the production rate is low. With the adoption of appropriate policies, renewable methanol can become cost-competitive by 2050.Currently, the production of e-methanol depends on the availability of hydrogen and carbon dioxide. The cost of e-methanol is fundamentally driven by the prices of its two key inputs: carbon dioxide and hydrogen.

The required carbon dioxide can be acquired from industrial flue gases, biogenic resources, or through direct air capture (DAC). Note: DAC is a modern technology that removes carbon dioxide molecules from the air through physical or chemical processes to produce e-methanol, CO can be obtained using the e fuel method. Industrial processes typically emit a high amount of carbon dioxide about 36 gigatonnes (Gt) annually. By combining this CO with hydrogen, we can produce e-methanol. This technique effectively reuses CO, helping to achieve net-zero carbon emissions in the atmosphere. The CO sources can vary, either coming from carbon capture and storage (CCS) systems or from direct air capture (DAC). Using CO from industrial sources for the production of e-methanol can also help reduce emissions from heavy industries.

According to IRENA's estimates, renewable methanol production could reach 250 million tonnes per year by 2050, which would require approximately 48 million tonnes of renewable hydrogen. Solar and wind power are currently the most practical renewable energy technologies; however, they are not available at all times. For example, solar energy can only be utilized when the sun is shining, and wind energy is only available when the wind blows.

Methanol produced from biomass and waste products is an economical way of generating methanol. Although the raw materials for its production are widely available, they are still not sufficient to meet global energy demands on their own.

The most efficient method for producing methanol is through the hydrogenation of CO. Natural gas-based plants offer some cost advantages, particularly at larger scales, which help reduce the cost per tonne of methanol production. Additionally, the electrochemical process of water electrolysis can be effective—especially if innovations lead to larger module sizes and improvements in stack manufacturing—making the process more cost-efficient.

According to IRENA's estimates, renewable methanol production could reach 250 million tonnes per year by 2050, requiring approximately 48 million tonnes of renewable hydrogen.

A review conducted in 2007 found that the cost of CO production ranged between USD 550 and USD 670 per tonne. In a more recent IRENA report, the cost of capturing CO from flue gases or directly from the atmosphere was estimated at approximately USD 570 to 1,000 per tonne (EUR 510–900 per tonne).

For plants with capacities ranging from 4,000 tonnes to 1.8 million tonnes per year, the overall cost of producing e-methanol is estimated to be between USD 300 and USD 1,000 per tonne. Reports with lower cost estimates often assume very low electricity prices or offset methanol production costs by accounting for the sale of oxygen co-produced during electrolysis—valued between USD 45 and USD 180 per tonne of oxygen .For every tonne of methanol produced, approximately 1.5 tonnes of oxygen are generated as a by-product of water electrolysis. As e-fuel production scales up, the availability of oxygen will increase significantly, likely exceeding demand and thereby reducing its market value. Consequently, the overall cost of producing e-methanol typically ranges between USD 400 and USD 1,000 per tonne, with electricity cost being the most significant factor. Additionally, most studies assume the cost of CO_2 to range between USD 0 and USD 55 per tonne. However, in the case of Direct Air Capture (DAC), the cost of CO_2 is substantially higher.

9. Drawbacks

E-Methanol as a fuel in shipping*, although a great alternative, has several drawbacks as well.The first, for instance, is the energy density of the fuel. E-Methanol has a lower energy density than other fuels, thus requiring larger storage tanks or occupying more space onboard. Currently, the cost of producing renewable methanol is high, while production volumes remain low.

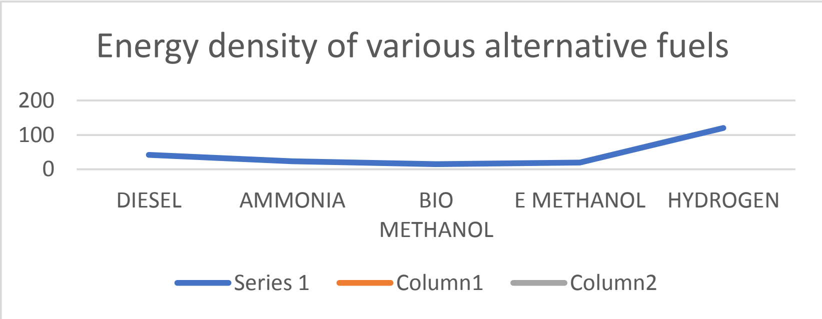


Figure 1. Comparison of Energy Density of Fuels

References

IRENA (2021), International Renewable Energy Agency. (2021). *Innovation Outlook: Renewable Methanol*. Abu Dhabi: IRENA. ISBN: 978-92-9260-320-5. Available at: https://www.irena.org/publications/2021/Jan/Renewable-Methanol

Maersk Mc- Kinney Møller Center for Zero Carbon Shipping (2021), Maersk Mc-Kinney Møller Center for Zero Carbon Shipping. (2021). *E-methanol: A game changer for decarbonising heavy transport and industry*. Available at: https://www.weforum.org/stories/2025/02/emethanol-a-game-changer-for-decarbonizing-shipping/

Methanol Institute (2023), Methanol Institute. (2023). *Renewable Methanol: Advantages, engine mechanisms, and adoption pathways*. Methanol Institute. Available at: https://methanol.org/renewable-methanol

Methanol Institute (2023),Methanol Institute. (2023, March 9). *Alternative fuel use - regulatory status mapped*. Available at: https://www.methanol.org

UNFCCC (2015), United Nations Framework Convention on Climate Change (UNFCCC). (2015). *Adoption of the Paris Agreement*. Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

United Nations (n.d.), United Nations. (n.d.). *Sustainable Development Goal 13: Climate Action*. Available at: https://sdgs.un.org/goals/goal13

International Maritime Organization (IMO) (n.d.), International Maritime Organization. (n.d.). *International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code)*. Available at: https://www.imo.org/en/OurWork/Safety/Pages/IGF-Code.aspx

The 25th IAMUS

Proceedings of the International Association of Maritime Universities
Student Program (IAMUS)

Chennai, 16-17 Oct 2025

Maritime Sustainable Development

Roshini Balaji[1]

[1]*Academy of Maritime Education and Training, Chennai, India*

riroshini707@gmail.com, Tel.:+91 8939199296

Abstract: Maritime transportation, vital for global trade, poses significant threats to oceans, essential ecosystems that regulate climate and support 37% of the global population. Sustainable Development Goal 14 (Life below Water) addresses these threats, yet current efforts remain inadequate. This paper examines key maritime environmental challenges: scrubber discharge, ballast water pollution, and antifouling paints. These practices release harmful substances, disrupt ecosystems, and introduce invasive species. Our findings highlight the importance of enhanced international cooperation, investment in ocean science, and ecosystem-based management, guided by treaties like the 2023 Biodiversity beyond National Jurisdiction. Sustainable maritime practices are crucial for ocean health and future resilience.

Keywords: Globalization, Environmental Sustainability, Maritime Transportation, Ocean Resources, Sustainable Development, Marine Pollution, Climate Change

1. Introduction

Sustainable Development Goal 14 focuses on conserving the oceans, covering more than 75% of the Earth's surface and containing 97% of its water. Oceans are fundamental to sustaining life and maintaining planetary health. Oceans provide food, medicine, and coastal protection, but are under threat from pollution, acidification, and overuse. Marine pollution hit 17 million metric tons in 2021 and may triple by 2040 Ocean acidification, driven by CO_2 absorption, disrupts marine life and food security.

Despite absorbing 23% of CO_2 and 90% of excess heat, rising ocean temperatures and pollution are degrading ecosystems. Plastic waste, mainly single-use items, causes $13 billion in damages annually. The shipping industry responsible for 90% of global trade exacerbates this crisis through scrubber discharge, invasive species via ballast water, and toxic antifouling paints. These practices, along with plastic waste and climate change, are accelerating marine biodiversity loss.

Urgent global collaboration is needed to enforce regulations, invest in clean technologies, and adopt eco-friendly alternatives. Sustainable ocean management is vital not just for environmental reasons but for global economic stability, food security, and future resilience.

2. Key challenges

2.1 Scrubber discharge: threat to marine life

To meet sulphur limits, many ships use scrubbers to continue using cheaper high-sulphur heavy fuel oil (HFO). While reducing sulphur dioxide emissions, scrubbers discharge toxic wash water containing PAHs, heavy metals, and acidic compounds into the ocean, especially in ecologically sensitive areas. Despite compliance with IMO guidelines, this contributes to marine degradation. Studies show scrubber-equipped ships emit more CO_2, particulate matter, and black carbon than vessels using low-sulphur marine gas oil (MGO). All scrubber types contribute to ocean acidification and reduced water quality.

The International Council on Clean Transportation (ICCT) calls for regulatory reform, including national bans on scrubber discharges, IMO harmonization of global discharge standards, and a phased ban on scrubbers in new and existing ships. True environmental compliance requires a shift to cleaner fuels.

2.1.1 Analysis of data

Ships use scrubbers as a way to comply with regional and global fuel sulfur standards by removing sulfur dioxide (SO2) from the exhaust rather than using lower sulfur fuels. In the North American Emission Control Area (ECA), the maximum allowable fuel sulfur content is 0.10% by mass. The ECA extends 200 nautical miles from the U.S. and Canadian coasts and includes all Canadian waters south of 60°N latitude. The ECA does not cover the American and Canadian Arctic regions. Outside ECAs, marine fuel's maximum allowable sulfur content is 0.50% as of January 1, 2020. Before 2020, the maximum allowable sulfur content was 3.50%. This tightening of the global fuel sulfur cap drove dramatic increases in scrubber installations, and the rapid uptake of scrubber installations and orders in the lead-up to 2020

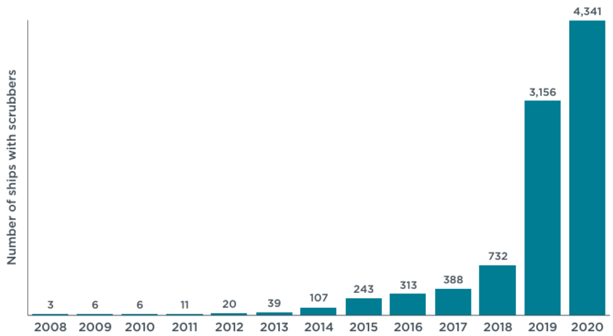


Figure 1. Number of ships with scrubbers by year. Source: DNV GL (2020)

While scrubbers reduce SO_2 emissions, they often generate higher levels of CO_2, black carbon, and particulate matter compared to cleaner fuels like marine gas oil (MGO). Their wash water discharges—from open-loop, closed-loop, or hybrid systems—are acidic, turbid, and contaminated with nitrates, PAHs, and heavy metals, exacerbating ocean acidification and ecological toxicity. Despite technical compliance, IMO guidelines lack binding enforcement and omit key pollutants, leaving scrubber discharges largely unregulated. This is particularly alarming in sensitive regions such as Canada's Great Lakes and the St. Lawrence Estuary, where species like belugas and killer whales face heightened exposure to chemical pollutants. Notably, closed-loop systems can release more heavy metals than open-loop ones, underscoring the urgent need for stricter regulatory frameworks and comprehensive monitoring.

2.1.2 IMO Scrubber Regulations: The Compliance Gap

Scrubber discharges, while technically compliant with IMO guidelines, raise concerns about their environmental impact. The IMO's guidelines, introduced in 2005, lack sufficient numeric discharge criteria and have not been strengthened despite growing concerns. The increase in scrubber-equipped ships has amplified environmental risks, especially in sensitive areas like the Great Lakes and St. Lawrence Estuary, where species such as the Southern Resident killer whale and belugas are already threatened.

2.2 Anti fouling paints:

Innovative ship hull coatings play a critical role in improving fuel efficiency, reducing air emissions, cutting noise pollution, and preventing the spread of invasive species. Merchant vessels, with lifespans of 20-25 years, Innovative hull coatings improve fuel efficiency, cut emissions, reduce noise pollution, and help prevent the spread of invasive species. Over their 20–25 year lifespan, merchant ships travel through various ecosystems and face biofouling, which increases drag and fuel use. Fouled hulls also carry harmful species like barnacles and zebra mussels. Advanced coatings address these issues, supporting cleaner and more efficient maritime operations.

2.2.1 Effects on the marine environment:

Biofouling the accumulation of organisms like barnacles and mussels on hulls and propellers—poses both ecological and operational risks. It facilitates the spread of invasive species, increases hull roughness, and can raise fuel consumption by up to 40%, leading to elevated emissions and underwater noise. This noise disrupts marine life, particularly species like whales. Although hull cleaning offers temporary relief, it is costly and may exacerbate species transfer. Anti-fouling coatings provide a more sustainable and effective solution, preserving ship efficiency while minimizing environmental harm.

2.2.2 Antifouling: Sustainable solution

Anti-fouling coatings are applied to ship hulls to prevent the attachment of marine organisms such as barnacles, zebra mussels, and algae, thereby reducing drag, improving fuel efficiency, and limiting the spread of invasive species. Historically, copper was widely used for this purpose, but its toxicity and corrosive properties prompted the development of modern anti-fouling paints. Although effective, traditional biocidal paints containing copper and arsenic leach into marine environments, posing ecological risks. While tributyltin (TBT) has been banned since 2008, copper-based coatings remain prevalent. Teflon-based alternatives prevent attachment without killing organisms, yet contribute to plastic pollution through flaking. Recent innovations—particularly from Canadian companies offer eco-friendly, non-toxic coatings that enhance vessel performance while minimizing environmental impact.

2.2.3 Regulations on antifouling:

In 2001, the International Convention on the Control of Harmful Anti-fouling Systems on Ships prohibited the use of harmful substances like tributyltin (TBT) in anti-fouling paints. This was further amended in 2021 to restrict the chemical cybutryne. In line with these efforts, the IMO has set guidelines to reduce biofouling and invasive species transfer, encouraging measures like hull inspections and cleaning. In Canada, vessels over 400 gross tonnes are required to carry an International Anti-Fouling System certificate, ensuring compliance with the Convention's anti-fouling standards. Vessels under 400 gross tonnes must also confirm their anti-fouling treatments meet these requirements, with ongoing evaluation of biofouling's role in invasive species transfer shaping future regulations.

2.3 Ballast water management

2.3.1 The Control of Harmful Invasive Species

Ballast water, used by ships for stability, often contains aquatic organisms like microbes, plants, and animals. When released untreated at a destination, it can introduce invasive species, leading to ecological and economic damage. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention), adopted in 2004, established global regulations to control this transfer. Ballast water can carry a range of marine life, including bacteria, larvae, and small invertebrates.

These species may establish populations in new environments, outcompeting native species and causing biodiversity loss. Invasive species are a major threat to ecosystems, public health, and coastal industries. Environmental impacts include species extinction, harm to public health, and disruption to local industries and biodiversity. Invasive species can cause significant economic damage. For example, the introduction of invasive mollusks in the U.S. costs approximately $6 billion annually. In Scandinavia, the round goby has disrupted aquatic ecosystems, while the Chinese mitten crab has invaded much of the Baltic sea, leading to a decline in native species such as crayfish.

.

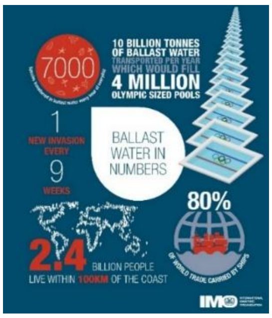


Figure 2. Published by IMO, International Maritime Organization, "Ballast water in numbers,"

2.3.2 Global response:

Preventing the transfer of invasive species requires global cooperation. The UN Convention on the Law of the Sea (Article 196) provides a framework for controlling marine pollution, including invasive species. The

IMO adopted resolutions A.774(18) in 1993 and A.868(20) in 1997 to develop guidelines and work towards a legally binding treaty. The BWM Convention mandates ships to implement a Ballast Water Management Plan, maintain a Ballast Water Record Book, and follow prescribed procedures.

2.3.4 Implementation of the IMO Convention

The BWM Convention sets two standards for discharged ballast water: D-1 for ballast water exchange and D-2 for ballast water treatment. D-1 became mandatory on 8 September 2018. Starting with the first IOPP renewal survey after 8 September 2019, vessels must meet the D-2 standard by installing an approved Ballast Water Management System (BWMS). New ships are required to have a treatment system installed at delivery.

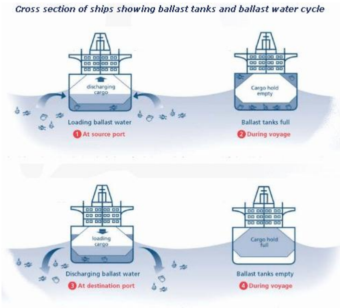


Figure 3. Published by IMO, International Maritime Organization, "Ballast water cycle diagram,"

2.3.5 Treatments of ballast water

Effective implementation and treatments includes UV disinfection to eliminate harmful organisms and pH monitoring to assess treatment conditions, ensuring compliance with regulations and protection of marine ecosystems**.**

3. Conclusion

The world's oceans are facing critical challenges due to pollution, climate change, and harmful maritime practices. In 2021, over 17 million metric tons of waste entered the ocean, with projections showing a significant rise in the coming years. The ocean is rapidly losing its ability to support marine biodiversity and regulate the climate.

This study highlights key threats such as scrubber discharges harming marine ecosystems, ineffective enforcement of IMO ballast water treatment regulations, and toxic anti-fouling paints jeopardizing marine life. These issues underscore the urgent need for stricter regulations, sustainable alternatives, and global cooperation. To achieve SDG 14, swift and decisive action is required, including stricter enforcement of maritime regulations, increased investment in sustainable shipping technologies, and global collaboration. Nations must prioritize ocean science, phase out harmful practices, and hold industries accountable for their environmental impact. Without immediate intervention, the health of the oceans will continue to deteriorate, threatening biodiversity, livelihoods, and the planet's climate stability.

References

International Maritime Organization. "BWM Technologies". https://www.imo.org/en/OurWork/Environment/Pages/BWMTechnologies.asp
International Maritime Organization. "Ballast Water Management**"**https://www.imo.org/en/OurWork/Environment/Pages/BallastWaterManagement.aspx
International Maritime Organization **"**International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM)" https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx
Sensorex December 2019 "How Does Ballast Water Affect the Environment?" https://sensorex.com/how-does-ballast-water-affect-environment/?srsltid=AfmBOoqi1zM2zR-qGkZYMPopucO816n3aYDEU-qtOb4ZzKW-2pJ33UP8
Clear seas Article **"**Ballast water management: stopping the spread of invasive species by ships"https://clearseas.org/insights/ballast-water-management-stopping-the-spread-of-invasive-species-by-ships/
Fisheries and Oceans Canada. (2018). A Canadian Action Plan to Address the Threat of Aquatic Invasive Species(opens in a new tab).
Canadian Science Advisory Secretariat. (2014). National Risk Assessment for Introduction of Aquatic Nonindigenous Species to Canada by Ballast Water.(opens PDF)(opens in a new tab) Fisheries and Oceans Canada for Transport Canada.

Government of Canada. (2021). European Green Crab(opens in a new tab).
International Maritime Organization. (2019). Ballast water management – the control of harmful invasive species(opens in a new tab).
International Maritime Organization. (2019). Implementing the Ballast Water Management Convention – What are the ballast water management standards? (opens in a new tab)
Regulation D-2 Ballast Water Performance Standard Government of Canada. (2019). Canada Gazette, Part II, Volume 155, Number 13: Ballast Water Regulations (opens in a new tab).
Government of Canada. (2019). Canada Gazette, Part II, Volume 155, Number 13: Ballast Water Regulations (opens in a new tab).
DNV Maritime Impact. (2019). Type-Approved, USCG-Compliant Ballast Water Treatment Systems Now Widely Available(opens in a new tab).
DNV "Ballast water management (BWM) and biofouling**"** https://www.dnv.com/maritime/ballast-water-management/
International Maritime Organization "Ballast water management - the control of harmful invasive species"https://www.imo.org/en/MediaCentre/HotTopics/Pages/BWM-default.aspx
Bryan Comer, PhD, Elise Georgeff, and Liudmila Osipova, PhD "Air emissions and water pollution discharges from ships with scrubbers" November 2020
Clear Seas "Article Anti-fouling paints: What are they and what effects do they have on the environment?" https://clearseas.org/insights/anti-fouling-paints-what-are-they-and-what-effects-do-they-have-on-the-environment/
United Nations "Goal 14: Conserve and sustainably use the oceans, seas and marine resources" https://www.un.org/sustainabledevelopment/oceans/
The Global Goals "conserve and sustainably use the oceans, seas and marine resources for sustainable development." https://www.globalgoals.org/goals/14-life-below-water/
United Nations "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" https://www.unep.org/topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-14

The 25th IAMUS

Proceedings of the International Association of Maritime Universities
Student Program (IAMUS)

Chennai, 16-17 Oct 2025

Impacts of Nearshoring within the Textile Industry on European Liner Shipping

Linus Boustedt[1,*], Fatima Ismael[2]

[1] *Chalmers university of technology, Sweden*
[2] *Chalmers university of technology, Sweden*
[*] *Corresponding author: linus.boustedt4@gmail.com; Tel.:* +46-73-521-07-56

Abstract: This thesis explores the possibilities on how nearshoring in the European textile industry might affect shipping networks. Nearshoring, which in short is relocating production closer to consumer markets, is gaining attention due to global supply chain disruptions (e.g., COVID-19, geopolitical instability) and sustainability concerns. The study analyzes sustainability and financial reports from textile companies MANGO, Lindex, IKEA, Didriksons, Ellos Group and interviews with three shipping companies along with one interview with a director of a maritime newspaper. Findings show some movement toward nearshoring, citing benefits like shorter lead times, reduced emissions, and improved responsiveness. However, widespread implementation remains limited; many firms continue relying on offshore production in Asia due to established networks and cost advantages. Shipping companies report minimal impact so far but are monitoring shifts and exploring short-sea shipping as a competitive option. The report concludes that while nearshoring is increasingly discussed, its real impact on European shipping networks is still emerging.

Keywords: Nearshoring, Network planning, Offshoring, Outsourcing

1. Introduction

The COVID-19 pandemic has disrupted global trade flows, exposing vulnerabilities in current supply chain configurations. Container shortages, congested ports, and delayed shipments emphasized the risks inherent in relying heavily on distant manufacturing hubs, particularly in Asia. At the same time, the Suez Canal block and the ongoing war in Ukraine intensified conversations around geopolitical risk and logistics resilience (Notteboom et al., 2024). The textile industry, which is characterized by short product cycles and high demand sensitivity, found itself impacted more than other commodities. Therefore, many companies began considering nearshoring and bringing production closer to European markets as a means to create shorter lead times, reduce transport costs, and increase flexibility (Van Hassel et al., 2022). This paper explores whether such nearshoring movements are influencing European liner shipping networks and whether current trends signal a long-term shift of maritime logistics. The aim of the paper is to investigate the connection between supply chain strategy and shipping network evolution in the context of global instability.

In particular, the textile industry highlights these vulnerabilities. The textile supply chains are some of the most globally dispersed and sensitive to disruption due to the industry's large mass production and seasonal variability (García-Alaminos et al., 2024). Nearshoring is seen not only as a response to logistical inefficiencies but also as a mindful strategy to align with evolving consumer expectations around sustainability and responsiveness (McKinsey & Company, 2021). Customers are increasingly prioritizing faster deliveries and greater transparency, prompting brands to reevaluate their offshoring strategies. The shift is also supported by technological advancements in automation and digitization, which reduce labor cost disadvantages in nearshore regions. The question is no longer whether change is needed, but how quickly and effectively organizations can reconfigure their networks to build greater resilience (Di Stefano et al., 2024). This thesis responds to this strategic uncertainty by investigating how such trends are reflected in European maritime transport and container shipping networks.

To fulfill the aim of the study the following questions were constructed

- What indications are there that nearshoring is being implemented by textile manufacturing companies?

- What are the main reasons nearshoring is looked upon as an option when setting up supply chains?
- How does the shift from offshoring to nearshoring impact liner shipping companies in the context of network planning?

2. Frame of Reference

This study draws on theoretical perspectives from international logistics, supply chain resilience, and maritime network design. In particular, it incorporates definitions and distinctions among outsourcing, offshoring, nearshoring, and backshoring (Merino et al., 2020). Outsourcing broadly refers to transferring business functions to external entities, while offshoring involves relocating production to distant regions, typically for cost savings. Nearshoring, by contrast, moves production closer to home markets to reduce transit time, enhance flexibility, and mitigate geopolitical and logistical risks (Gadde & Jonsson, 2019).

COVID-19 exposed major weaknesses in global supply chains, especially in the textile sector, where lead time and seasonal cycles are critical. Multiple studies show that transport delays, container shortages, and trade route disruptions, as mentioned in the introduction (e.g., Red Sea conflict, Suez blockage) has led companies to explore nearshoring (UNCTAD, 2022; Notteboom et al., 2024). Nearshoring also offers sustainability benefits by cutting emissions from long-haul shipping (Van Hassel et al., 2022), although it raises challenges such as infrastructure capacity and supplier capacity in nearshore regions (García-Alaminos et al., 2024).

Liner shipping network design theory is how shipping lines adapt to cargo flows by optimizing routes, port locations, and modal integration (Bergmann et al., 2023). The emergence of nearshoring as a trend might push carriers to develop short-sea routes and improve port efficiency. The reconfiguration involves cost trade-offs, service frequency adjustments, and the integration of rail and road modes (Suárez-Alemán et al., 2015). These concepts underpin this papers analysis of how textile nearshoring may reshape liner shipping logistics across Europe.

3. Methods

This paper applied a qualitative, multi-method approach to capture evolving industry dynamics. Building on Denscombe's (2010) methodological framework, the combination of literature analysis, sustainability report reviews, and semi-structured interviews to widen our reach for our findings were used. Sustainability and financial reports of the European textile firms MANGO, Lindex, IKEA, Ellos Group and Didriksons were analyzed to detect shifts in supplier geography and supply chain strategy.

We also conducted semi-structured interviews with logistics professionals from liner shipping companies and a maritime industry journalist. Interviewees provided insights into how shipping companies perceive nearshoring trends and whether they are adjusting their network design. To ensure validity, a standardized interview guide was used, and anonymity was guaranteed to encourage candid responses.

Secondary data were retrieved from academic databases and trade associations (e.g., EURATEX, UNCTAD), and search terms included "nearshoring," "textile imports," "short sea shipping," and "logistics resilience." Data triangulation strengthened the robustness of interpretations by comparing qualitative interviews with statistical data on EU textile imports (Euratex, 2024). Overall, the chosen methods align with the study's aim to understand qualitative shifts in strategy and network adaptation in the face of ongoing disruptions.

4. Results

The results of this study indicate a shift in sourcing behavior among European textile companies, with nearshoring explored as a complement to offshore production in response to global disruptions and sustainability pressures. This transition is evident in company-level sourcing decisions and partially reflected in EU trade trends. According to Euratex (2024), China's share of EU textile imports declined from 38% in 2020 to 28% in 2023, while Turkey and Bangladesh gained share. Although the report does not provide an exact percentage increase for proximity markets overall, it suggests a modest but consistent rebalancing in favor of regional suppliers, in line with growing environmental and logistical concerns (Euratex, 2024).

The company Lindex demonstrated a visible increase in sourcing from European and nearby regions between 2022 and 2023. The number of factories in Italy rose from 10 to 13, while the number in Turkey remained stable at 11. At the same time, Lindex reduced its supplier base in China from 30 to 26 factories and in Bangladesh from 27 to 23 (Lindex, 2023). These changes reflect a strategic focus on flexibility, transport reliability, and emissions reduction, consistent with Lindex's goal of achieving climate neutrality by 2040. The company emphasized that nearshore sourcing supports shorter lead times, reduces freight exposure, and enhances transparency in the supply chain (Lindex, 2023).

MANGO also increased its reliance on proximity markets between 2022 and 2023. The number of factories in Spain rose from 169 to 197, and in Portugal from 67 to 77. Additional new suppliers appeared in Poland (2), Switzerland (1), Bosnia (1), and Ukraine (2). While the number of factories in Morocco decreased slightly (from 87 to 82), the overall factory footprint in Europe and surrounding countries expanded (MANGO, 2023). MANGO attributed these shifts to the need for faster product turnaround, greater agility in inventory management, and resilience against disruptions affecting long-haul transport routes (MANGO, 2023).

Ellos Group, a digital fashion and home retailer, continues to rely heavily on offshore sourcing, with 57.4% of its suppliers based in China as of 2023. Contrary to nearshoring trends observed in other brands, Ellos Group has reduced its supplier presence in the EU, Eastern Europe, and Turkey between 2021 and 2023. This decline is attributed to challenges such as inflation in Turkey, the war in Ukraine, and increased minimum order requirements from regional suppliers (Ellos Group, 2023). Despite this, Ellos Group maintains a focus on improving supply chain transparency through initiatives like its Code of Conduct and aims for 100% supply chain traceability by 2030. These efforts suggest that while nearshoring is not currently a strategic focus, the company is aligning with industry-wide expectations around ethical sourcing and compliance (Ellos Group, 2023).

Didriksons, known for its functional outerwear, continues to rely primarily on Asian suppliers, particularly in China and Bangladesh. In 2022, the company had 11 suppliers in China and 2 in Bangladesh; in 2023, this changed only slightly to 10 and 2, respectively. Didriksons also retained one supplier in Sweden (Didriksons, 2023), indicating that nearshoring is not currently a strategic priority. Instead, the company focuses on long- term supplier relationships and improving transport efficiency. Sustainability efforts are centered on reducing the environmental footprint of logistics, such as consolidating sea shipments and minimizing unnecessary handling rather than relocating production (Didriksons, 2023).

IKEA, as a major global home furnishing retailer, continues to source a large portion of its products from within Europe, especially wood-based items. The company's five largest manufacturing countries include Poland, Germany, Sweden, Italy, and China. While the company has recently opened a 35,000-square-meter production facility in Slovakia, this move is not indicative of a broad nearshoring shift but rather an effort to optimize production efficiency for specific product categories (IKEA, 2024). IKEA's regional sourcing strategy appears to be stable rather than expanding, with the company prioritizing logistical efficiency and carbon footprint reduction within its existing European and Asian manufacturing networks (IKEA, 2024).

From a macro perspective, the EU textile trade landscape shows that countries like Turkey and Tunisia are expanding their roles as nearshore suppliers. Turkey alone now exports over €10 billion annually in textiles to the EU, benefitting from its customs union agreement and advanced manufacturing base (Euratex, 2024). Morocco and Tunisia remain among the EU's top ten textile suppliers and are frequently referenced as proximity sourcing countries in the nearshoring discussion. While MANGO continues to work with a significant number of suppliers in Morocco 87 in 2022 and 82 in 2023 the data indicates relative stability rather than growth (MANGO, 2023). Although Turkey and other nearby countries have seen increases in export share, specific trends for Morocco and Tunisia are less clearly defined (Euratex, 2024)

Despite this growth, nearshoring is not without challenges. Several companies point to capacity constraints in regional ports and inconsistent customs procedures as barriers to efficient up scaling (Lindex, 2023; IKEA, 2024). Moreover, nearshoring is typically reserved for high-margin or time sensitive products, while basic garments continue to be sourced from Asia, for instance like Didriksons, (2023), who chose to remain in Asia where production remains cost efficient and highly scalable. This reflects the dual model approach most companies are adopting, leveraging nearshore advantages without fully displacing their offshore base (MANGO, 2023)

The environmental dimension further supports the business case for nearshoring. Companies like IKEA and Lindex specifically noted that shorter transport distances contribute to their emission reduction targets, provided that transport routes are well-planned and intermodal systems are optimized (IKEA, 2024; Lindex, 2023). However, several of the interviews acknowledged that poorly utilized short-sea shipping networks or fragmented logistics planning could undermine these environmental benefits. Consequently, successful nearshoring depends on more than geography it is also dependent on coordinated infrastructure and digital integration (Suárez-Alemán et al., 2015).

Insights from the interviews conducted with representatives of liner shipping companies and a maritime journalist underscore a growing industry recognition of nearshoring as a practical layer within broader sourcing strategies. One logistics director noted that interest in proximity sourcing surged during the COVID-19 pandemic and has remained elevated due to ongoing geopolitical instability and freight market volatility. According to the interviewees, many European textile brands are looking to reduce their dependence on Asian suppliers by diversifying into regions closer to their home market such as Turkey, Morocco, and Eastern Europe. However, they emphasized that this does not represent a replacement of offshore models but rather an additional sourcing strategy. One respondent described this approach as "building optionality," highlighting the importance of flexibility and the ability to respond to market shifts without abandoning global networks entirely. This hybridization of supply chains is now influencing how carriers structure their routes, with a noticeable uptick in demand for short-sea services within the Mediterranean and Black Sea regions.

Interviewees also discussed the operational implications for shipping companies and logistics infrastructure. All shipping representatives reported increased activity in regional feeder networks, particularly those linking the Eastern Mediterranean with Northern Europe. However, several pointed to structural challenges such as underdeveloped port infrastructure, capacity constraints, and regulatory inconsistencies in emerging nearshore regions. These issues hinder seamless cargo movement and limit the scalability of regional sourcing. Environmental concerns were also raised, with interviewees agreeing that while nearshoring can reduce emissions through shorter transport distances, this benefit is conditional on efficient loading and well-coordinated intermodal connections. Without those, nearshoring could paradoxically lead to higher per-unit emissions due to fragmented routes and smaller, more frequent shipments. One carrier representative called for targeted EU policy support, especially in the form of investments in port capacity and green corridor development, to ensure nearshoring is economically and environmentally sustainable.

5. Analysis and Discussion

The results confirm a growing trend toward nearshoring in the European textile industry, driven by a need for supply chain resilience, speed, and risk mitigation (Di Stefano et al., 2024). However, the extent of this shift is moderated by infrastructure limitations and cost structures. Shipping companies are challenged to adapt their networks to serve a more fragmented and dynamic customer base. In particular, the need to synchronize feeder services, optimize port rotations, and invest in regional capacity is more pronounced (Santos et al., 2022).

Another important dimension is policy. European transport and trade policies that promote modal shift, digital infrastructure, and emission reduction could further facilitate nearshoring (UNCTAD, 2022). A respondent noted that the EU needs a coordinated logistics vision that includes both maritime and inland corridors. This vision needs to support multimodal integration and minimize administrative friction. Without coordination, the benefits of nearshoring may be diluted by inefficiencies in the last mile.

The paper also identifies contrast between economic and environmental objectives. While nearshoring can theoretically reduce emissions by minimizing long distance sea transport, in reality it introduces new challenges. Fragmented networks may lead to inefficiencies unless digital platforms are adapted, and cooperative logistics systems are incorporated. There is a need for integration between sea and inland transport systems to fully realize the potential of nearshoring.

Interviewees emphasized that dynamic route adjustment, smaller vessels, and increased port calls are now part of routine planning. These shifts are demanding more operational agility and higher accuracy. Port authorities and terminal operators need to adapt to these changes by investing in faster turnaround capabilities, automated handling systems, and inland integration (World Shipping Council, 2023). The geopolitical landscape also weighs heavily in decision making as trade tensions, sanctions, and regulatory shifts have made firms more cautious about overreliance on one particular sourcing area. Interviews suggested that nearshoring offers not just logistical benefits but political benefits this strategic move further complicates network planning for shipping lines (Notteboom et al., 2024).

6. Conclusion

This paper confirms an adequate but noticeable shift towards nearshoring in the European textile industry. The analysis of companies' data and stakeholder interviews indicates that while offshoring remains the most common strategy, firms are increasingly exploring nearshore locations like Turkey, Portugal, and Eastern Europe to enhance resilience, create shorter lead times, all whilst meeting sustainability goals (Magnus et al., 2024). Notably, brands like MANGO and Lindex show clear signs of reallocating part of their production closer to Europe, supported by financial gains and environmental commitments (Lindex, 2023; MANGO, 2023).

Liner shipping companies are responding cautiously. While some reports increased short-sea volumes, global trade lanes still dominate capacity and profitability. Interviews highlighted constraints such as limited infrastructure in secondary ports, policy gaps, and fragmented regional networks that hamper full-scale nearshoring adoption (Notteboom et al., 2024). Nonetheless, some carriers are reconsidering routes and exploring feeder services between emerging production hubs and key European markets. While some carriers are sticking to their global network and relying on offshoring production.

Future research should further quantify the cost, carbon, and service-level impacts of nearshoring and evaluate how digitalization, automation, and EU policy frameworks could facilitate a smoother transition. The shift toward hybrid sourcing models suggests that supply chains and shipping networks must become more agile, diversified, and environmentally aligned. Nearshoring, while not a full substitute for globalization, is reshaping operational strategies and demanding adaptive capacity from maritime logistics stakeholders.

References

Bergmann, M., Msakni, M. K., Hemmati, A., & Fagerholt, K. (2023). An adaptive heuristic for feeder network design with optional transshipment. *Transportation Research Part E: Logistics and Transportation Review, 176*, 103153. https://doi.org/10.1016/j.tre.2023.103153

Denscombe, M. (2010). *The good research guide: For small-scale social research projects* (4th ed.). Open University Press.

Di Stefano, C., Fratocchi, L., Martínez-Mora, C., & Merino, F. (2024). Manufacturing reshoring and sustainable development goals: A home versus host country perspective. *Sustainable Development, 32*(1), 863–875. https://doi.org/10.1002/sd.2710

Euratex. (2024). *Facts & key figures 2024 of the European textile and clothing industry*. https://euratex.eu/wp-content/uploads/EURATEX-Facts-Key-Figures-2024.pdf

Gadde, L.-E., & Jonsson, P. (2019). Future changes in sourcing patterns: 2025 outlook for the Swedish textile industry. *Journal of Purchasing and Supply Management, 25*(3), 100526. https://doi.org/10.1016/j.pursup.2018.12.004

García-Alaminos, A., Zafrilla, J., & Monsalve, F. (2024). Forced labour in the fashion industry: A hypothetical EU-driven reorganisation of textile value chains. *Economic Systems Research, 36*(3), 451–476. https://doi.org/10.1080/09535314.2024.2345096

IKEA. (2024). *Sustainability report 2023–2024*. https://www.ikea.com

Lindex. (2023). *Sustainability report 2023*. https://about.lindex.com

Magnus, K.-H., Ibáñez, P., Scalco, A., & Hügl, J. (2024). Reimagining the apparel value chain amid volatility. *McKinsey & Company*. https://www.mckinsey.com/industries/retail/our-insights/reimagining-the- apparel-value-chain-amid-volatility

MANGO. (2023). *Sustainability report 2023*. https://www.mangofashiongroup.com

Merino, F., Di Stefano, C., & Fratocchi, L. (2020). Back-shoring vs. near-shoring: A comparative study. *Advances in Transdisciplinary Engineering, 13*, 622–633. https://doi.org/10.3233/ATDE200201 Notteboom, T., Haralambides, H., & Cullinane, K. (2024). The Red Sea crisis: Ramifications for vessel operations, shipping networks, and maritime supply chains. *Maritime Economics & Logistics, 26*(1), 1–20. https://doi.org/10.1057/s41278-024-00287-z

Suárez-Alemán, A., Trujillo, L., & Cullinane, K. (2015). Short sea shipping in Europe and its implications for intermodal freight transport. *Transport Reviews, 35*(4), 441–458. https://doi.org/10.1080/01441647.2015.1034763

UNCTAD. (2022). *Impact of the COVID-19 pandemic on trade and development: Lessons learned*. https://unctad.org/system/files/official-document/osg2022d1_en.pdf

Van Hassel, E., Vanelslander, T., & Notteboom, T. (2022). Revisiting nearshoring: Impacts on logistics networks in a volatile world. *Journal of Transport Geography, 98*, 103243. https://doi.org/10.1016/j.jtrangeo.2021.103243

Alternative Fuels and Emission Reduction in the Maritime Industry

Keysberg Pereira[1]

[1] *International Maritime University of Panama, Republic of Panama*
[*] *Corresponding author: keysberg.pereira@umip.ac.pa ; Tel.: (+507) 6199-2738*

Abstract: The maritime industry, which facilitates over 80% of global trade by volume, is a fundamental pillar of the international economy. However, it is also responsible for approximately 3% of total greenhouse gas (GHG) emissions worldwide, primarily due to the use of heavy fuel oil in ship engines. In response to global climate challenges and increasing regulatory pressure, especially under the leadership of the International Maritime Organization (IMO), the shipping sector is transitioning toward cleaner, low and zero carbon fuels.

Among the most promising alternative fuels are green ammonia, green hydrogen, and bio-LNG (biologically liquefied natural gas). Green ammonia, produced from renewable energy sources and nitrogen, offers zero CO_2 emissions at the point of use. Hydrogen, especially in its green form generated through electrolysis using renewable power, is another clean option with high energy potential. Bio-LNG, derived from organic waste, reduces lifecycle GHG emissions and can be distributed using the existing LNG infrastructure, making it particularly attractive in the short to medium term.

Despite their environmental benefits, the adoption of these fuels presents considerable challenges. These include technological development for onboard fuel systems, regulatory standardization, safety management, fuel availability, and the need for specialized port infrastructure. Achieving a successful transition will require a collaborative approach involving national governments, port authorities, shipowners, classification societies, fuel suppliers, and research institutions.

Keywords: Alternative Fuels; Emission reduction; LNG.

1. Introduction

The maritime industry covers over 80% of global trade but accounts for around 3% of global greenhouse gas emissions. In response to climate goals, the International Maritime Organization (IMO) is guiding the sector toward low and zero-carbon fuels, with green ammonia, hydrogen, and bio-LNG emerging as key options. However, adoption involves challenges in safety, infrastructure, and regulation. Panama, through its strategic location and the work of MTCC-Latin America, supports regional decarbonization and innovation in clean maritime fuels. This paper examines the benefits and challenges of alternative fuels in the shipping sector and highlights the importance of collaboration to achieve emission reduction goals.

2. MTCC-Latin America: Regional Leadership in Maritime Decarbonization

Panama's leadership in green shipping is further strengthened by the presence of the Maritime Technology Cooperation Centre for Latin America (MTCC-Latin America). Based in Panama City, this institution is part of the IMO's Global MTCC Network (GMN), co-funded by the European Union. It plays a vital role in building technical capacity, supporting regulatory alignment, and promoting innovation across the region.

MTCC-Latin America conducts pilot projects to test and validate low-carbon maritime technologies in real-world settings. It also delivers training workshops and technical support to regional governments and maritime stakeholders, enhancing energy efficiency standards and emission monitoring systems. In addition, it assists with the creation of national strategies and regulatory frameworks that are aligned with IMO objectives.

By fostering collaboration between governments, port authorities, and academic institutions, MTCC-Latin America helps ensure that the transition to alternative fuels in Latin America is both technically feasible and economically sustainable. Its work complements and reinforces the efforts of the Panama Canal, establishing Panama as a true center of excellence in maritime sustainability.

3. Strategic Priorities

To guide the decarbonization of maritime transport, the following priorities have emerged:

Regulatory frameworks must evolve in line with IMO targets, ensuring safe and standardized adoption of new fuels.

Investment in infrastructure such as bunkering facilities for alternative fuels, safety systems, and training programs is essential.

The Panama Canal's environmental incentives and its role in green shipping corridors can influence global fleet behavior.

MTCC-Latin America contributes critical research, technical support, and regional coordination for low-carbon transitions.

The development of green shipping corridors between key global ports offers scalable and coordinated pathways to reduce emissions.

Public-private collaboration and international partnerships will be necessary to fund, test, and implement fuel transition strategies.

The transition to alternative fuels in shipping is not only an environmental imperative but also a transformative opportunity. As the maritime sector aligns with global decarbonization goals, the use of clean fuels like green ammonia, hydrogen, and bio-LNG becomes increasingly vital. These fuels can drastically cut emissions while also driving innovation and modernizing the global fleet.

Panama, through the leadership of the Panama Canal and the contributions of MTCC-Latin America, is in a unique position to support and guide this transition across Latin America and beyond. With its geographic advantage, established maritime infrastructure, and proactive environmental policies, Panama can serve as a model for the implementation of sustainable shipping practices.

By embracing cleaner energy, investing in infrastructure, and fostering regional and international collaboration, the maritime industry can meet climate goals while securing a more resilient and competitive future.

4. Transitioning to Alternative Fuels: Benefits and Challenges

The shift toward alternative fuels such as LNG, green ammonia, and hydrogen in maritime shipping brings significant environmental benefits but also introduces new safety challenges. Several incidents over the past years have highlighted risks, leading to industry-wide improvements and ongoing efforts to enhance safety.

4.1 Notable LNG Incidents and Responses

While LNG has been used safely for decades, a few incidents during bunkering and operations have occurred. For example, in 2006, a notable incident involved an LNG bunkering leak on a vessel in Europe, which, although contained without casualties, underscored the potential risks of gas leaks and ignition. In 2015, the LNG carrier Al Ghariya experienced a minor gas leak due to equipment failure, leading to improvements in maintenance protocols.

In response, the International Maritime Organization (IMO) adopted the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) in 2017, establishing stringent guidelines for LNG fuel systems, including tank design, gas detection, ventilation, and crew training. LNG bunkering procedures have been standardized globally, with strict safety zones and communication protocols during fuel transfer. Advances in gas detection technology and automatic shut-off valves have reduced the risk of undetected leaks and explosions.

Looking forward, future goals include enhancing LNG tank insulation and containment to prevent cryogenic burns and boil-off gas, developing real time leak detection systems, and expanding crew training focused on LNG emergency response and firefighting.

4.2 Emerging Concerns with Ammonia and Hydrogen

Although maritime use of ammonia fuel is still emerging, industrial accidents involving ammonia mostly in chemical plants and refrigeration provide important lessons. Ammonia leaks have caused serious toxic exposures and explosions, emphasizing the necessity for robust containment, ventilation, and emergency protocols on ships.

Hydrogen presents additional challenges due to its low ignition energy and wide flammability range. Industrial hydrogen explosions worldwide highlight these risks, compounded by the difficulty of detecting leaks since hydrogen is colorless, odorless, and disperses rapidly, often escaping detection until ignition.

To address these challenges, specialized storage tanks with advanced materials resistant to hydrogen embrittlement are being designed. Sensitive hydrogen sensors and continuous monitoring systems are being installed on vessels. International regulations and standards specifically addressing ammonia and hydrogen handling onboard are under development, with the IMO expected to update codes as these fuels gain wider adoption. Remote-controlled and automated fuel handling systems are also being implemented to minimize human exposure.

5. Advances in Crew Training and Infrastructure

The safe integration of alternative fuels into maritime operations relies heavily on the human element. Beyond the fundamental training on fuel handling and safety procedures, recent advances emphasize competency development in risk management and hazard identification specific to these fuels. Training now includes modules on understanding the chemical properties, such as ammonia’s toxicity and hydrogen’s explosive limits, which differ significantly from traditional marine fuels. This nuanced understanding is critical to preventing accidents and managing emergencies effectively.

6. Visual References on Alternative Fuels and Maritime Decarbonization

Figure 1

IMO and EU regulatory framework for GHG emissions reduction from international shipping

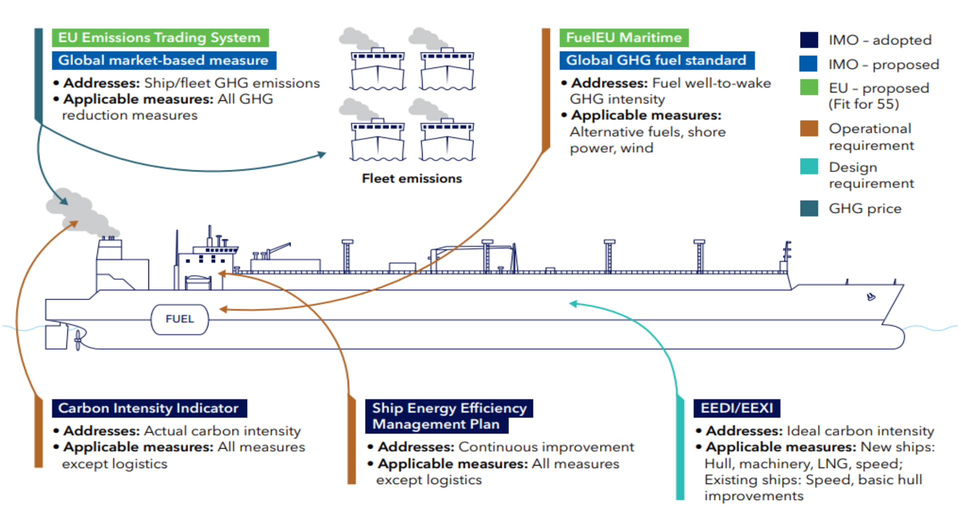


Figure 1. Regulatory Framework by IMO and EU for Maritime Greenhouse Gas Emissions Reduction

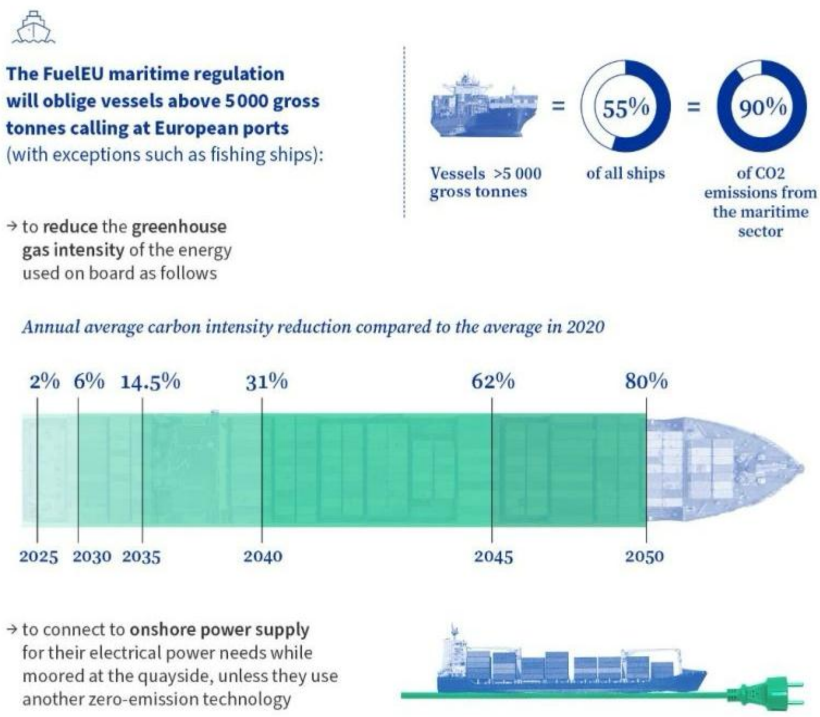


Figure 2. FuelEU Maritime Regulation Carbon Intensity Reduction Pathway and Onshore Power Supply Requirements

7. Conclusion

The maritime industry stands at a decisive point in its evolution, where environmental responsibility, regulatory pressure, and technological innovation converge to redefine the future of global shipping. As climate change accelerates and sustainability becomes a core expectation, the sector must transition away from traditional fossil fuels toward low- and zero-carbon alternatives.

Alternative fuels such as green ammonia, hydrogen, and bio-LNG represent some of the most promising solutions for reducing greenhouse gas emissions in the maritime sector. Their adoption, however, introduces a range of technical, logistical, and operational challenges. These include the development of new fuel handling systems, safe storage technologies, port infrastructure upgrades, and the re-training of crews. The shift is not only a matter of changing fuels—it requires a holistic transformation of the entire maritime value chain.

At the same time, onboard carbon capture systems are gaining attention as a practical option to reduce emissions from existing vessels that are not yet ready to transition to alternative fuels. This technology provides a bridge between the present and the decarbonized future, helping the industry meet intermediate emission reduction targets while long-term solutions mature and become more widely available.

Safety remains a critical concern as new fuels are integrated into commercial shipping. Incidents involving LNG, hydrogen, and ammonia have demonstrated the need for robust safety management systems, advanced detection and monitoring technologies, and standardized international guidelines. Lessons learned from these experiences have already led to improvements in regulations and crew training, but ongoing research and investment are essential to stay ahead of emerging risks.

In addition to technological and regulatory innovation, education and workforce development are essential to ensure a safe and effective transition. Maritime professionals must be equipped with the knowledge and skills to manage new fuels and systems, respond to emergencies, and operate within evolving safety and environmental standards.

Global collaboration will be the cornerstone of this transformation. Public-private partnerships, cross-sector innovation, and harmonized international policies are necessary to fund, test, and implement sustainable shipping solutions. The creation of green corridors, the standardization of bunkering systems, and the integration of smart port technologies are all key components of a resilient and forward-looking maritime industry.

In conclusion, the decarbonization of maritime transport is a complex but achievable goal. It demands a coordinated effort that embraces alternative fuels, carbon mitigation strategies, and the modernization of infrastructure and human capital. With a collective commitment to innovation, safety, and sustainability, the shipping industry can evolve into a cleaner, more efficient, and more responsible pillar of global trade.

Acknowledgements

I would like to thank my university for providing the opportunity and support to participate in the IAMU event. This work was prepared independently and without external sponsorship.

References

Consilium Safety (2024) Alternative fuels. Available at: https://www.consiliumsafety.com/en/about/alternative-fuels/ (Accessed: 8 July 2025)

Lim, Y. (2025) Alternative fuels for environmentally-friendly ships: Hydrogen, ammonia, bio-fuels and e-fuels. Springer Briefs in Applied Sciences and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-85082-0

Maritime Technology Cooperation Center – Latin America (2019) Pilot project 2: Fuel oil consumption data collection and reporting. Technical study. International Maritime University of Panama. Available at: https://www.mtcclatinamerica.com/downloads/pp2.pdf (Accessed: 8 July 2025)

SAFETY4SEA (n.d.) Decarbonization in shipping and the adoption of alternative fuels. Available at: https://safety4sea.com/cm-decarbonization-in-shipping-and-the-adoption-of-alternative-fuels/ (Accessed: 8 July 2025).

AMET UNIVERSITY
(Deemed to be University Under Section 3 of UGC Act 1956)
CHENNAI | TAMILNADU | INDIA

25th ANNUAL GENERAL ASSEMBLY
14th-18th OCTOBER, 2025

Further details

Academy of Maritime Education and Training (AMET)
135, East Coast Road, Kanathur - 603112 | Chennai | India

+91 94447 52994 | aga25@ametuniv.ac.in

President, AGA25

Dr. G. Thiruvasagam | Phone: +91 95661 12211

Program Editor, AGA25

Dr. Deepa Rajesh | Phone: +91 80563 81238

Gallery

https://aga25.ametuniv.ac.in/gallery/

For photos, please refer

https://aga25.ametuniv.ac.in/gallery/