A POCKET GUIDE TO

GREEN MARINE FUELS FOR COMMERCIAL SHIPS

marine insight

"Guide to Green Marine Fuel for Commercial Ships"

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Chapter One

Introduction

The maritime industry has long relied on conventional fossil fuels such as heavy fuel oil (HFO), marine diesel oil (MDO), and marine gas oil (MGO) to power vessels.

While these fuels have been efficient and cost-effective, they contribute significantly to greenhouse gas emissions, air pollution, and climate change.

As global trade expands, the demand for sustainable energy solutions has become more urgent than ever.

Green fuels, also known as alternative or renewable marine fuels, are energy sources derived from sustainable materials that minimize environmental impact.

Unlike fossil fuels, which release large amounts of carbon dioxide (CO_2), sulfur oxides (SO_x), and nitrogen oxides (NO_x), green fuels are designed to produce lower emissions while maintaining or even improving vessel performance.

The adoption of green fuels is not just about regulatory compliance—it represents a transformative shift in how ships are powered. These fuels are key to achieving long-term sustainability, reducing reliance on finite fossil resources, and ensuring a cleaner, more efficient maritime sector.

Defining Green Fuels

Green fuels, also referred to as renewable fuels or alternative marine fuels, are energy sources derived from sustainable resources that produce significantly lower greenhouse gas emissions compared to traditional fossil fuels.

These fuels offer a promising pathway toward reducing the environmental footprint of the shipping industry while ensuring operational efficiency and compliance with evolving global regulations.

Unlike conventional marine fuels, green fuels are designed to minimize carbon emissions, air pollutants, and lifecycle environmental impact.

Their adoption aligns with the industry's broader strategy to transition toward decarbonization, improve fuel efficiency, and future-proof vessels against stricter regulatory frameworks.

The shift toward green fuels is not just a regulatory necessity but also an economic opportunity.

Ports, shipowners, and fuel suppliers investing in cleaner fuel alternatives are positioning themselves at the forefront of the maritime industry's green transition.

The following chapters will explore the various types of green fuels available, their benefits, challenges, and implementation strategies for a sustainable shipping future.

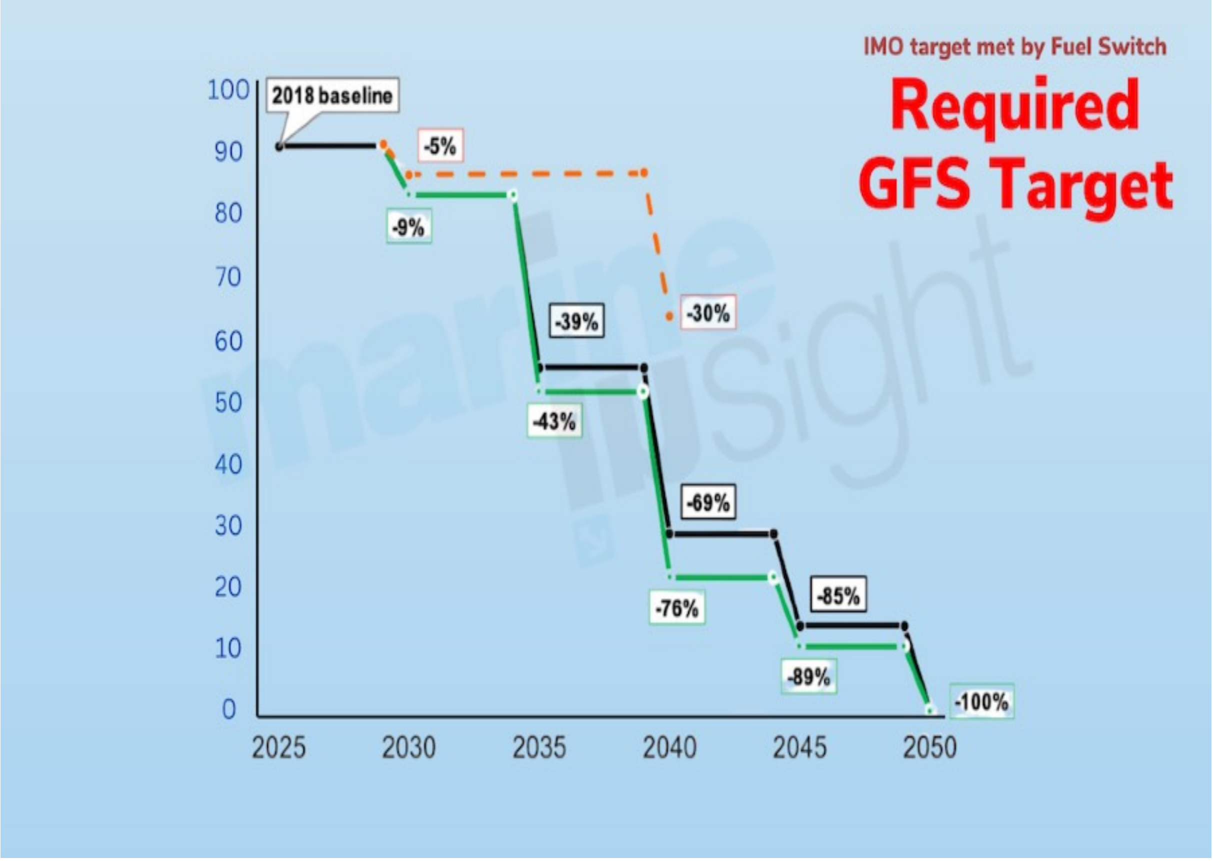
Chapter Two

Need for Green Fuel

The shipping industry plays a crucial role in global trade, transporting nearly 90% of the world's traded goods. However, this vast network of maritime transport is also a significant contributor to climate change, accounting for approximately 3% of global CO_2 emissions.

Recognizing the urgent need to curb these emissions, the International Maritime Organization (IMO) has set ambitious targets to achieve net-zero emissions by 2050.

This objective demands a fundamental shift in fuel consumption and the adoption of sustainable, low-carbon alternatives to traditional marine fuels.



Limitations of Wind Power

While modern vessels can utilize wind power to reduce emissions, its ability to fully replace fuel engines is limited. For example, a British cargo ship recently used sails made from wind turbine material for its maiden voyage.

Propeller systems can only provide up to 30% of the energy vessels need, and even less in poor weather, highlighting the need for alternative green fuels

The Role of Green Fuels in Decarbonizing Shipping

To meet IMO's 2050 decarbonization targets, the industry must transition from fossil fuels to low- and zero-carbon alternatives such as ammonia, hydrogen, and methanol.

These next-generation maritime fuels have the potential to significantly reduce greenhouse gas (GHG) emissions and improve environmental sustainability.

The International Maritime Organization (IMO) has set ambitious targets for the shipping industry to decarbonize by 2050. To achieve these targets, the industry must transition away from traditional fossil fuels and towards low- and zero-carbon alternatives.

These next-generation maritime fuels, such as ammonia, hydrogen, and methanol, hold immense potential for reducing greenhouse gas (GHG) emissions and promoting environmental sustainability within the shipping sector.

Ammonia, for instance, is a carbon-free fuel that can be produced from renewable energy sources. It offers a promising pathway for decarbonization, especially for long-distance shipping. Hydrogen, another zero-emission fuel, can be produced from water using electrolysis powered by renewable energy. It offers high energy density and can be used in fuel cells or internal combustion engines. Methanol, which can be produced from renewable sources like biomass or captured carbon dioxide, is a relatively low-carbon fuel that can be used in existing engines with modifications.

The transition to these green fuels will require significant investments in infrastructure, including production facilities, bunkering infrastructure, and engine retrofits.

Additionally, research and development efforts are needed to optimize the production, storage, and handling of these fuels, as well as to develop efficient and reliable propulsion systems. Collaboration between governments, industry stakeholders, and research institutions will be crucial to accelerate the adoption of green fuels and achieve the IMO's decarbonization goals.

Chapter Three

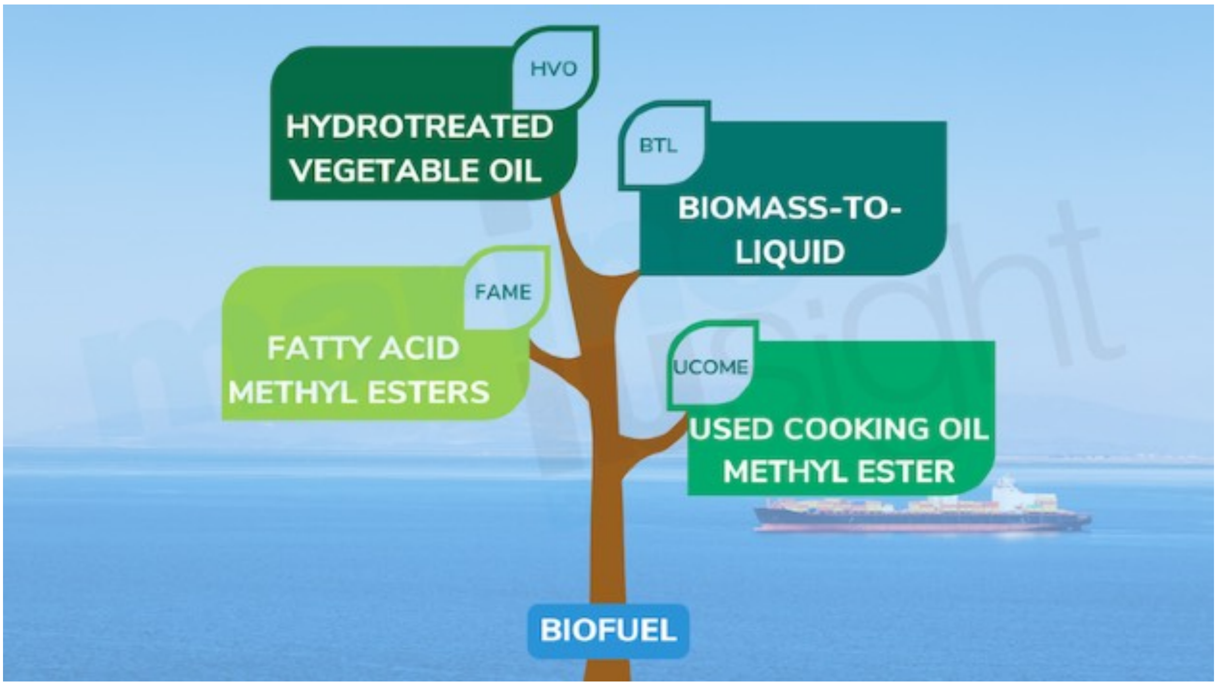
Types of Green Fuel

The maritime industry is actively exploring various green fuels to achieve the International Maritime Organization's (IMO) target of net-zero emissions by 2050. These alternatives to traditional fossil fuels include biofuels, methanol, ammonia, hydrogen, and other emerging options.

Biofuels

Biofuels are produced from organic materials such as forestry and agricultural wastes, non-food energy crops, waste oils, fats, greases, manure, sewage sludge, landfill gas, algae biomass, and municipal solid waste.

They are gaining traction due to their increasing availability across various geographic locations.



A significant advantage of biofuels is their compatibility with existing distribution networks, requiring minimal adaptation for bunkering infrastructure.

Testing has demonstrated their effectiveness in various engine types without needing modifications to onboard fuel refining plants.

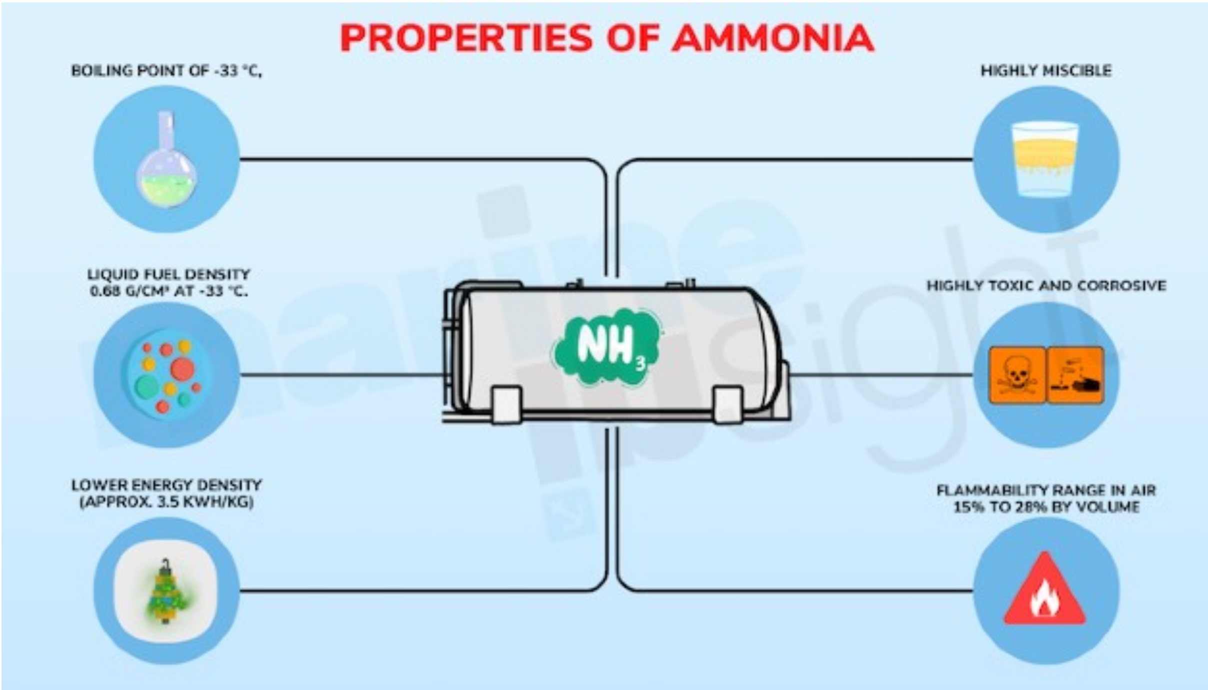
Methanol

Methanol is emerging as a strong contender as a sustainable alternative in the maritime industry. Green methanol can be produced by combining captured carbon dioxide (CO_2) with green hydrogen produced via electrolysis using renewable electricity.

Maersk is planning to operate methanol-fueled vessels that can transport a large number of containers, which will reduce CO_2 emissions

Ammonia

Another promising alternative to fossil-based maritime fuels is green ammonia. Green ammonia is produced by combining green hydrogen with nitrogen from the air, resulting in a carbon-free fuel.



Ammonia has a higher energy density than conventional fuels, making it attractive for long-distance shipping. However, it requires specialized infrastructure and further development for maritime applications.

Hydrogen

Green hydrogen, produced by splitting water through electrolysis using renewable energy, is a core component for synthesizing other green fuels like ammonia or methanol.

When hydrogen is produced through electrolysis powered by renewable energy, it can be synthesized into green fuels like e-methanol and e-ammonia.

Other Emerging Fuels

The maritime industry is also exploring other emerging fuels to accelerate decarbonization. Green hydrogen and its derivatives, such as e-ethanol and e-ammonia, are emerging as cornerstone solutions for maritime decarbonization.

These fuels align with the IMO’s progress toward a set of binding global regulations for the industry, with a goal of net-zero shipping by or around 2050.

In summary, the transition to green fuels in maritime shipping involves evaluating various options, each with its advantages and challenges. The industry's commitment to innovation and sustainability is driving the development and adoption of these alternative fuels to meet global decarbonization goals.

Chapter Four

Production of Green Fuels

The maritime industry is increasingly focusing on sustainable energy solutions to reduce its environmental footprint. This chapter delves into the production processes of key green fuels—green hydrogen, ammonia, methanol, and synthetic fuels—that are pivotal in driving the sector towards a greener future.

Electrolysis and Green Hydrogen

Green hydrogen is produced through electrolysis, a process that splits water into hydrogen and oxygen using electricity derived from renewable sources such as wind, solar, or hydropower. This method ensures that hydrogen production is carbon-neutral, unlike traditional methods that rely on fossil fuels.

Methanol and Synthetic Fuels

Green methanol can be produced through two primary methods:

- **Biomass Gasification:** Heating plant or organic waste to create a gas that is then converted into bio-methanol.

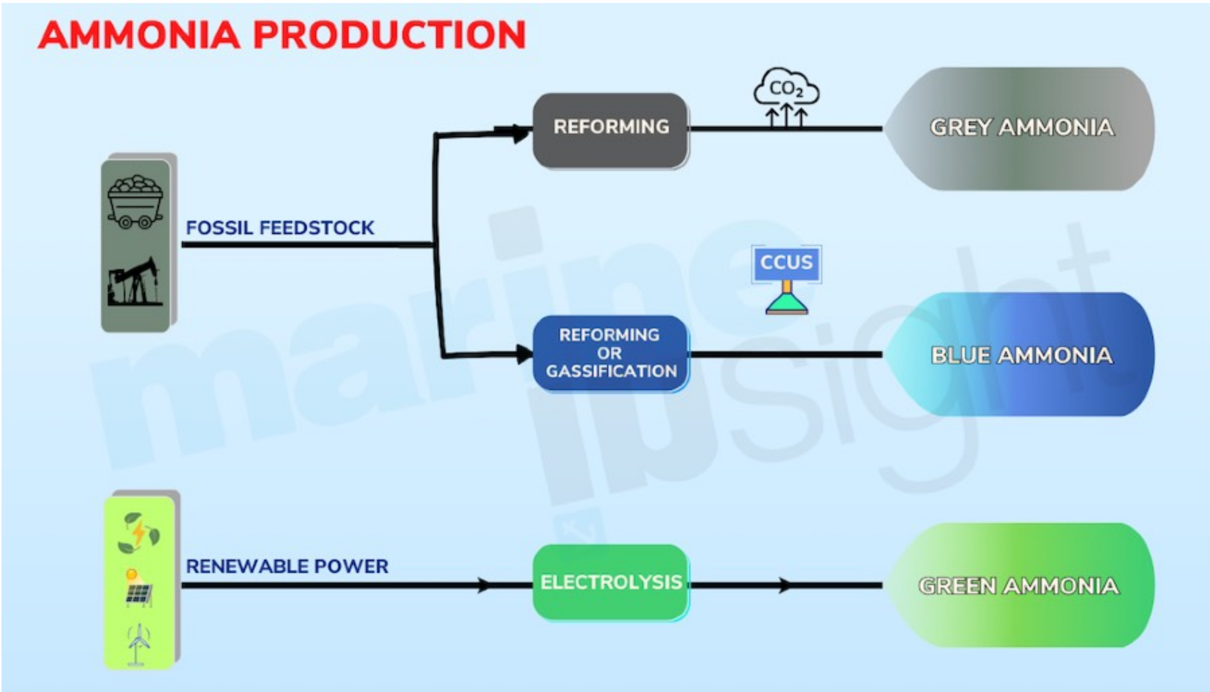
- **CO_2 Capture and Green Hydrogen Combination:** Combining green hydrogen with captured CO_2 to produce e-methanol. Green CO_2 can be extracted from biogas plants or captured directly from the air.

Synthetic fuels, also known as electrofuels (e-fuels), are created using renewable energy sources. Green LNG (Liquefied Natural

Gas) is produced from green SNG (Synthetic Natural Gas), with the green CO_2 extracted from biogas plants or air capture.

Ammonia Production

Green ammonia is synthesized by combining nitrogen from the air with green hydrogen via the Haber-Bosch process. The hydrogen used in this process must be produced from renewable sources to be considered green ammonia.



When assessing the environmental impact of green fuels, it's crucial to consider emissions from the entire lifecycle, including extraction, production, transportation, and storage, not just combustion.

The adoption of these green fuels in maritime operations holds the promise of significantly reducing greenhouse gas emissions, contributing to a more sustainable and environmentally friendly shipping industry.

Chapter Five

Well to Wake Analysis of Fuels

In the pursuit of sustainable maritime operations, it's essential to evaluate the environmental impact of fuels comprehensively. This is where the concept of Well-to-Wake (WtW) analysis becomes pivotal.

What is Well-to-Wake Analysis?

Well-to-Wake analysis is a holistic assessment method that examines the total greenhouse gas (GHG) emissions associated with a fuel throughout its entire lifecycle.

For maritime fuels, this encompasses every phase from the initial extraction of raw materials (the "well") to the final utilization of the fuel for propulsion (the "wake"). This approach is akin to the well-to-wheel analysis used in the automotive industry.

Why is Well-to-Wake Analysis Important?

Understanding the full spectrum of emissions is crucial for several reasons:

1. **Comprehensive Environmental Impact:** By evaluating each stage of a fuel's lifecycle, stakeholders can identify and mitigate emissions that might be overlooked if only the combustion phase were considered.

2. **Informed Decision-Making:** A WtW perspective ensures that the selection of alternative fuels is based on their true environmental benefits, preventing scenarios where a fuel appears sustainable during combustion but has high upstream emissions.

3. **Policy Development:** Regulatory bodies can formulate more effective environmental policies by considering WtW emissions, and promoting fuels and technologies that offer genuine GHG reductions.

4. **Avoiding Unintended Consequences:** Without a WtW approach, there's a risk of adopting fuels that, while reducing emissions during vessel operation, may cause significant environmental harm during production or distribution phases.

Incorporating Well-to-Wake analysis into the evaluation of maritime fuels ensures a thorough understanding of their environmental impacts, guiding the industry toward truly sustainable solutions.

Chapter Six

Challenges in Adopting Green Fuels

The maritime industry is under increasing pressure to adopt sustainable practices and reduce emissions. Green fuels offer a promising path toward a more sustainable maritime future, but their adoption faces several challenges.

This chapter will explore the key hurdles in transitioning to green fuels, focusing on infrastructure and distribution, retrofitting existing ships, safety regulations, and economic factors.

Infrastructure and Distribution

One of the primary challenges in adopting green fuels is the need for significant changes to the maritime industry's infrastructure.

This includes developing new fuel storage facilities and bunkering stations that can handle the unique characteristics of each type of green fuel. For example, hydrogen requires entirely new fueling infrastructure because it must be stored at high pressures or cryogenic temperatures. Similarly, LNG demands specific storage solutions to maintain its low temperature.

Ports within green shipping corridors need the required infrastructure to facilitate the green fuel transition, which means supporting green fuel storage and bunkering (truck-to-ship, and ship-to-ship), and/or charging facilities.

Although there has been technological progress, with the Port of Rotterdam marking the first successful bunkering of green methanol-powered container vessels in September 2023, and

Scandinavia introduced the world's first carbon-free ammonia fuel bunker network in 2022, a widespread, global transformation that requires coordinated efforts across various industries and stakeholders.

The availability of green fuels at ports worldwide is also a challenge. Only about 120 ports are capable of storing and delivering methanol, and not enough green methanol.

Where this fuel is available, it's often secured by private arrangements between a few large shipowners and methanol producers.

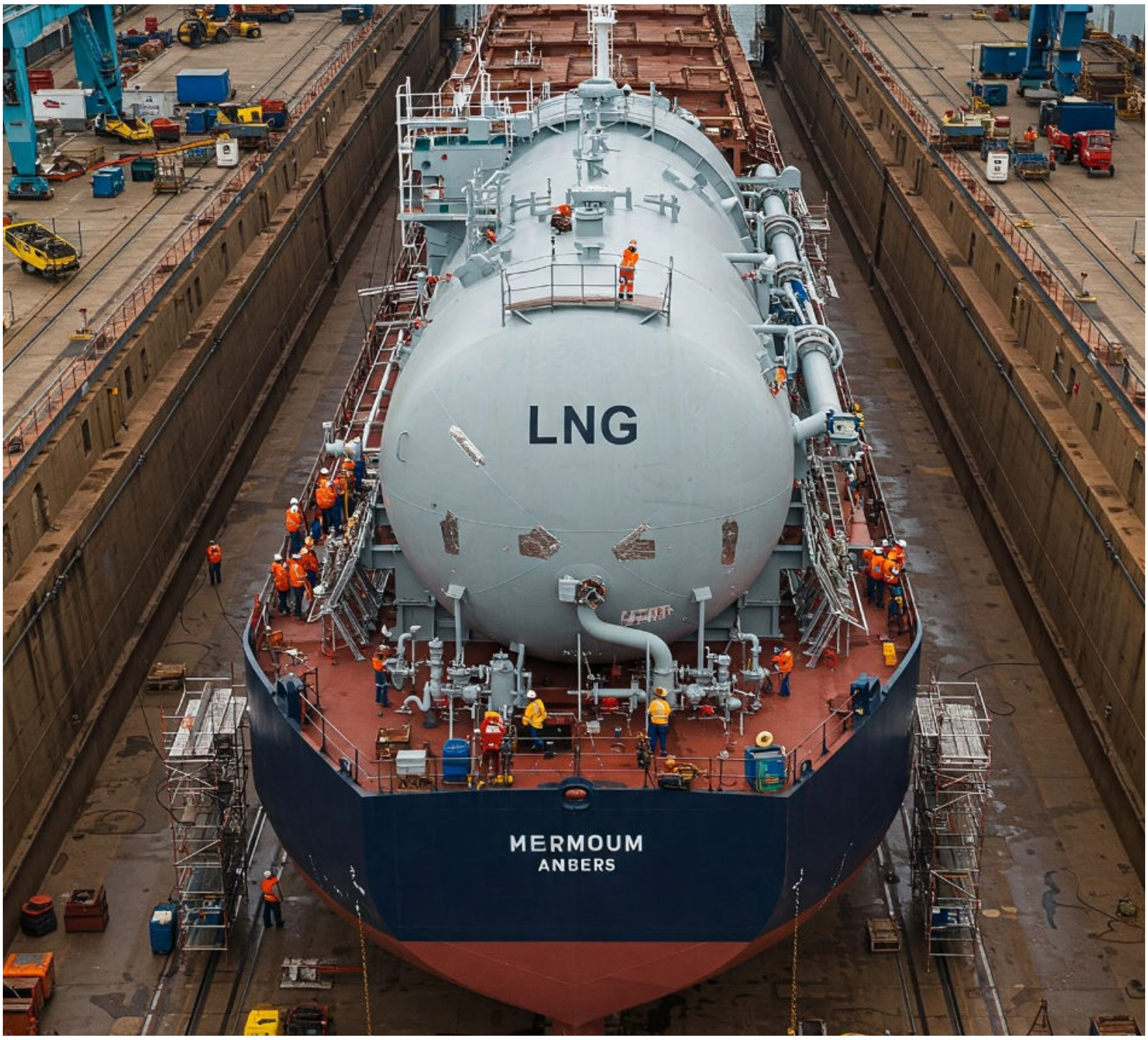
Key stakeholders for any given port along a green corridor include port authorities, vessel owners and operators, government and regulators, fuel producers, customer/cargo owners, and financial institutions.

Involving all stakeholders, who are likely dispersed across vast geographical areas, is crucial and depends on trust and decision-making processes with clear goals.

Retrofitting Existing Ships

The world's fleet of around 61,000 ships will need to be upgraded or replaced before 2050 because vessels that run on oil and diesel cannot simply switch to burning green fuels.

Retrofitting can allow existing vessels to run on methanol and ammonia, but it costs between US$5 million and US$15 million a ship, depending on the fuel.



Older vessels are likely to reach the end of their service before this investment is paid off, and the cost is the same even for smaller ships.

Safety Regulations

A lack of safety regulations is partly responsible for the slow uptake of alternative fuels. The IMO has issued safety regulations for methanol as fuel, but not for ammonia and hydrogen, which has cast doubt on their future among shipowners.

For every alternative fuel, it is necessary to adapt safety solutions to ensure that the vessels operate safely, protecting both the crew and the environment.

Economic Factors

The cost of the green shipping transition is another challenge. Sceptics question the widespread adoption of green shipping corridors because the necessary changes come with a large price tag to construct new infrastructure and upgrade fleets, not to mention the increased expense of alternative green fuels compared to their fossil fuel counterparts.

Introducing zero-emission fuels will raise operational costs initially, so it’s imperative to share the burden and risk across the green corridor to bridge the total cost of ownership (TCO) gap between fossil-fuel-powered vessels vs those powered by green fuels.

Government intervention is essential to mitigate investment risks for fuel producers and vessel/fleet operators and could include implementing contracts based on cost-for-difference and providing tax incentives and direct subsidies.

In conclusion, while the transition to green fuels in the maritime industry is essential for a sustainable future, it is fraught with challenges.

Addressing these hurdles requires coordinated efforts among stakeholders, substantial investments in infrastructure, clear safety regulations, and supportive economic policies.

Chapter Seven

The Future of Green Fuels

The maritime industry is under increasing pressure to adopt sustainable practices and reduce its environmental impact. Traditional marine fuels, such as heavy fuel oil, contribute significantly to air pollution and global warming.

To mitigate these effects, the industry is exploring alternative energy sources, including hydrogen, biofuels, liquefied natural gas (LNG), and ammonia. International regulations and industry innovations are driving the transition to these green fuels.

The International Maritime Organization (IMO) has set ambitious targets to reduce greenhouse gas (GHG) emissions from ships, aiming for at least a 50% reduction by 2050 compared to 2008 levels, with efforts to phase them out entirely within the century.

IMO Regulations

The IMO has established new GHG emissions reduction goals for the shipping industry, necessitating a shift from conventional fuels to zero or near-zero GHG fuels by 2050. Current IMO regulations address onboard tank-to-propeller CO_2 emissions from fossil fuels.

Additionally, the IMO is developing guidelines to determine lifecycle CO_2 and GHG emission factors for all types of fuels, including biofuels and electrofuels.

These regulations and guidelines are crucial for driving the adoption of green fuels and achieving sustainable maritime operations. The IMO's efforts include technical analysis and providing access to information on zero- and near-zero marine fuels and technologies.

EU and International Policies

The shift to green fuels is influenced by environmental consciousness and advancements in technology.

Various shipping companies are experimenting with green fuels to assess their viability and integrate them into their operations.

Green hydrogen and its derivatives, such as e-ethanol and e-ammonia, are emerging as solutions for maritime decarbonization and align with the IMO's goals for net-zero shipping by 2050.

When produced through electrolysis powered by renewable energy, hydrogen can be synthesized into green fuels like e-methanol and e-ammonia.

Industry Investments and Innovations

The maritime industry's move towards green fuels requires ongoing innovation in fuel technologies, propulsion systems, and operational strategies.

Companies are scaling up the production of green fuels; for example, Copenhagen Infrastructure Partners is building a renewable energy project in Western Australia to produce green ammonia.

This plant could reduce annual CO_2 emissions by 4.4 million tonnes. Other companies, such as Phelan Green Energy in South Africa and Hyphen Hydrogen Energy in Namibia, are developing facilities to produce e-ammonia at scale. Hyphen's plant represents a significant investment and will offset millions of tonnes of carbon dioxide emissions each year.

Challenges and Future Outlook

Despite the progress, the transition to green fuels in maritime operations faces several challenges. The production and distribution infrastructure for alternative fuels like green hydrogen and ammonia are still in development, and the costs associated with these fuels remain high.

Additionally, there are technical challenges related to the storage and handling of these fuels on vessels. However, with continued investment, innovation, and supportive policies, the maritime industry is poised to make significant strides towards a sustainable and environmentally friendly future.

Chapter Eight

Comparing Different Green Fuels

As the maritime industry strives to mitigate its environmental footprint, several alternative fuels are under consideration to replace traditional fossil fuels.

This chapter provides a comparative analysis of four prominent green fuels—Hydrogen, Ammonia, Methanol, and Liquefied Natural Gas (LNG)—focusing on their energy density, cost and scalability, and environmental impact.

Energy Density

Hydrogen: Hydrogen can be utilized in fuel cells, blended with conventional fuels, or used as a complete substitute in combustion engines.

However, it has a low volumetric energy density, approximately 8.5 MJ/L, necessitating larger storage volumes or high-pressure tanks, which can pose challenges for maritime applications.

Ammonia: Ammonia offers a higher energy density than hydrogen, around 11.5 MJ/L, making it more suitable for maritime storage and usage. It can be utilized in existing engines and bunkering facilities with appropriate modifications.

Methanol: Methanol has an energy density of approximately 15.8 MJ/L, which is higher than hydrogen and ammonia but lower than LNG.

It can be integrated into dual-fuel propulsion systems, allowing for retrofitting of existing vessels to burn both methanol and diesel.

LNG: Liquefied Natural Gas boasts a relatively high energy density of about 22.2 MJ/L, making it an efficient alternative fuel in terms of storage and range.

Cost and Scalability

Achieving net-zero emissions by 2050 will require substantial adoption of alternative fuels. For instance, approximately 59.5 million tons of hydrogen will be needed annually for direct use and clean fuel production.

By 2030, zero-carbon fuels must constitute about 10% of the maritime fuel mix, equating to roughly 70 million tons of e-ammonia. This volume is significantly higher than the current global trade volumes of ammonia and methanol, indicating substantial scaling efforts are necessary.

Currently, LNG is the most widely available alternative fuel, with an established distribution infrastructure and sufficient supply to meet industry demands. However, its environmental benefits are moderate compared to other green fuels.

Environmental Impact

Hydrogen: Green hydrogen, produced via renewable energy-driven water electrolysis, offers a zero-emission fuel option. However, its production is currently more expensive than conventional (grey) hydrogen, posing economic challenges.

Ammonia: When produced from green hydrogen, green ammonia can achieve a greenhouse gas footprint up to 90% lower than conventional marine fuels. However, ammonia is toxic, and its use requires careful handling and safety measures.

Methanol: Transitioning from heavy fuel oil to methanol can lead to significant emission reductions: up to 99% for SOx, 95% for particulate matter, 60% for NOx, and 25% for CO2. When produced from renewable sources, methanol can be nearly carbon-neutral.

LNG: LNG combustion results in lower CO2 emissions compared to traditional marine fuels and virtually eliminates SOx emissions. However, methane slip—unburned methane released during combustion—is a concern, as methane is a potent greenhouse gas. Advanced engine technologies and exhaust treatments can mitigate this issue.

Fuel	Energy Density (MJ/L)	Cost and Scalability	Environmental Impact
Hydrogen	8.5	Requires significant scaling; current production is limited and costly.	Zero emissions when produced from renewable sources; production cost is higher compared to grey hydrogen.
Ammonia	11.5	Needs substantial scaling; current global trade volumes are lower than required for widespread adoption.	Potential for up to 90% lower GHG footprint compared to conventional fuels; toxicity necessitates stringent safety protocols.
Methanol	15.8	Requires scaling; current production levels are insufficient for large-scale maritime use.	Significant reductions in SOx, PM, NOx, and CO2 emissions; can be nearly carbon-neutral when produced from renewable sources.
LNG	22.2	Widely available with established infrastructure; considered a transitional fuel.	Lower CO2 and negligible SOx emissions compared to traditional fuels; methane slip is a concern but can be mitigated with advanced technologies.

Conclusion

This exploration of green fuels in the maritime industry highlights the shift from traditional fossil fuels to sustainable alternatives, emphasizing this transition as crucial for the future of global shipping.

Hydrogen, Ammonia, Methanol, and LNG are potential green fuels for maritime operations. Hydrogen is clean but has low energy density. Ammonia has a higher energy density but is toxic. Methanol can be nearly carbon-neutral and is good for retrofitting existing vessels. LNG is a transitional fuel with moderate environmental benefits.

Scaling up green fuels is essential to reach net zero by 2050. This requires significant investment and collaboration across industries and governments.

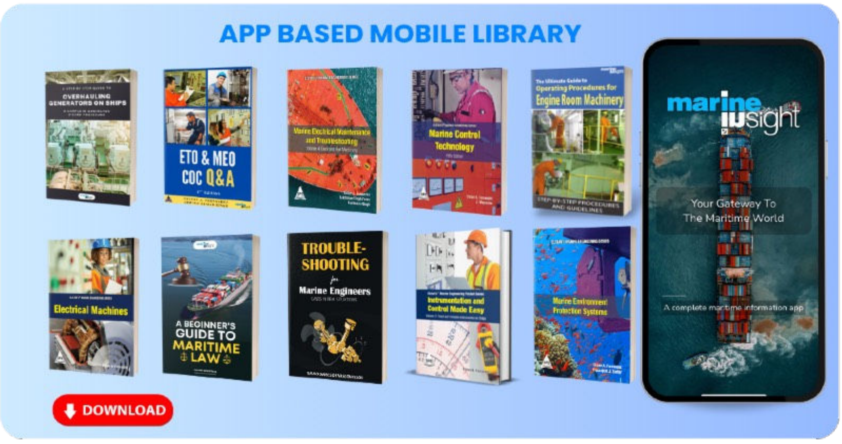
The maritime industry's shift to green fuels requires careful consideration of environmental impacts. Lifecycle analyses and safety protocols are essential to ensure genuine benefits. Collaboration and sustainable practices will enable the industry to overcome challenges and achieve a greener future.

The maritime industry is shifting from fossil fuels to greener options like Hydrogen, Ammonia, Methanol, and LNG to achieve net-zero emissions by 2050. Each fuel has benefits and drawbacks, requiring investment, collaboration, and environmental assessment.

The maritime industry can achieve a greener future by embracing innovation, collaboration, and sustainable practices to shift towards green fuels.

Additional Resource for Seafarers:

eBooks : learn.marineinsight.com



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