ABS

BEYOND THE HORIZON

CARBON NEUTRAL FUEL PATHWAYS *and* TRANSFORMATIONAL TECHNOLOGIES

Executive Summary

Beyond the Horizon: Carbon Neutral Fuel Pathways and Transformational Technologies **is the sixth annual edition of the ABS Sustainability Outlook series.**

This year, we explore transformative technologies that will facilitate the industry's transition toward 2050 by thoroughly assessing carbon-neutral fuel pathways. The industry's efforts have been further complicated by geopolitical events that have generated an environment characterized by increased uncertainty. Given the future fleet expansion, we examined the constraints and opportunities presented by the evolution of global trade and revised and updated our long-term energy forecast in this issue. Our fuel mix forecast was revised and enhanced, and various net-zero scenarios were investigated. The Outlook analyzes the existing fleet and orderbook and addresses the capacity of the maritime ecosystem, including ship repair yard capacity, demand for retrofits, and shipbuilding yard capacity, in addition to engine manufacturing capacity, for the first time.

KEY TAKEAWAYS

Energy Transition Outlook

As with any transition outlook, it is important first to cover the underlying fundamentals which are the trading shifts of the key commodities.

Despite a near-term boost in coal trade due to energy security concerns and high natural gas prices, a long-term decline is expected. Iron ore trade forecasts have been adjusted downwards due to China's expected slower economic growth. However, the growth in minor bulk cargoes, such as bauxite, alumina and fertilizers, is anticipated to become more significant, ultimately comprising over 50 percent of dry bulk cargo trade by 2050. For bulk carriers, there is an increasing interest in alternative propulsion options, with a significant projected transition to methanol and ammonia/hydrogen-based fuels post-2030.

Seaborne crude oil and chemical products trade is projected to increase moderately. The peak in oil product trade will follow the peak in crude oil trade, with shifts in refinery locations affecting global trade flows. Chemical trade forecasts have been revised downward due to less optimistic assumptions made for economic growth. Adoption of alternative fuels, such as liquefied natural gas (LNG), methanol and ammonia is increasing, especially in the very large crude carrier (VLCC) segment.

Container trade has settled into a slower rhythm with modest downgrades in global trade volume forecasts. Shifts toward shorter-haul intra-regional trades, and robust port handling growth in East Asia are noteworthy. There is a notable shift toward methanol dual-fuel propulsion among major liner operators, reflecting broader industry trends toward sustainable shipping practices.

Finally, for the LNG, liquefied petroleum gas (LPG) carriers, e-methane, biomethane, e-ammonia and e-hydrogen are anticipated to gain traction as fuel sources after 2030, despite a conservative start in their adoption.

The revised fuel mix projection maintains the trajectory set in last year's Outlook publication, though recent geopolitical events have caused some recalibration of the forecasting model. These events have disrupted supply chains and increased short-term fuel consumption due to the rerouting of vessels away from the Suez Canal and Red Sea area. In 2023, investments in alternatively fueled vessels continued strongly, with dual-fuel engines being featured in 27 percent of new vessel orders by number of vessels and 49 percent by gross tonnage (gt). The market has seen a dominance of containerships and pure car, truck carrier (PCTC) in these investments, which is gradually shifting to bulk carriers and tankers. The forecasted deliveries up to 2030 and the evolving alternative fuel type usage denotes an active shift toward a more sustainable fleet composition.

This year's projected fuel mix yields several key takeaways. The primary takeaway is a significant and ongoing shift toward cleaner, alternative fuels in the maritime industry, from 2023 to 2050.

1. Decline of Oil-Based Fuel Use

Oil-based fuels dominated the fleet's energy mix in 2023, accounting for 90 percent of the fuel used. However, there's a steady decline projected over the next few decades, reaching down to 15 percent by 2050. This indicates that fossil fuels, even at that low percentage, are projected to still be around. This decline is indicative of the maritime industry's efforts to move away from conventional fossil fuels in response to increasing environmental regulations and pressure to reduce carbon emissions.

2. Gradual Increase in LNG Use

LNG use is relatively stable, starting at nine percent in 2023 and experiencing an increase to 14 percent by 2028 before stabilizing around 13 percent by 2040. LNG is not entirely carbon-free, but certain LNG pathways (biomethane, e-methane) have the potential to significantly reduce emissions compared to conventional fuels, making it a practical choice for compliance and environmental performance improvements in both the short and long term.

3. Emergence and Growth of Methanol and Ammonia

The most significant growth in alternative fuels, methanol, starts at practically zero percent in 2023, but increases steadily to 42 percent by 2050. Ammonia, similarly, starts from zero percent and grows to 33 percent by 2050. These fuels are likely favored in later years due to their potential to reduce Well-to-Wake (WtW) greenhouse gas (GHG) emissions when produced from renewable sources.

The growth in these fuels is particularly notable from 2030 onward, where methanol jumps from seven percent to 42 percent and ammonia from two percent to 33 percent by 2050, highlighting a strong industry shift toward these more sustainable options.

4. Stable but Minor Role for LPG

LPG has a relatively stable but minor role throughout the forecast period. LPG hovers around one percent throughout, indicating it is not a major player in the fuel transition strategy.

The ongoing decarbonization process incorporates refinements such as the greening of LNG and alignment of WtW emissions calculations with FuelEU Maritime factors. There is a revised upward expectation for oil burning in the second half of this decade due to the slower adoption of dual-fuel engines in the dry bulk and tanker sectors. This adjustment reflects disruptions in major trade routes, notably through Panama and Suez, which have heightened fuel consumption.

Carbon dioxide (CO_2) emissions from shipping are anticipated to peak soon due to fleet growth and ongoing trade disruptions. The subsequent decline in emissions toward 2030 is supported by the implementation of the International Maritime Organization's (IMO) GHG reduction regulations aimed at enhancing fleet efficiency.

Under our base case scenario, the industry aims for a 20 percent reduction in CO_2 emissions by 2030 in comparison to 2008 levels, which is achievable, but reaching a 70 percent reduction by 2040 remains challenging.

ABS Assesses Two Main Net-Zero Scenarios:

1 **The first** scenario assumes a global reduction in emissions through enhanced energy efficiency technologies (EETs), achieving only a 15 percent reduction by 2040.

2 **The second,** more ambitious scenario, hinges on widespread retrofitting and adoption of zero-carbon fuels, such as e-ammonia and e-methanol, aiming to meet the 70 percent reduction target by 2040 through substantial fleet renewal and retrofits.

The maritime industry's transition toward sustainability is underscored by both technological advancements and regulatory pressures. Achieving net-zero emissions by 2050 requires that the economics of using green fuels and carbon capture technologies become favorable well before 2050, through a combination of progressive cost reduction and a carbon price/tax high enough to transition all LNG, ammonia and methanol production to renewable fuels.

The availability and infrastructure for alternative fuels such as LNG, methanol, ammonia and biofuels are developing at different paces.

- **LNG is currently the most developed alternative fuel** in terms of bunkering infrastructure. Major ports worldwide have established LNG bunkering facilities and new projects continue to expand this network. LNG remains a cost-effective option due to its relatively lower price compared to other low-carbon fuels.
- **Methanol is gaining traction** due to its compatibility with existing engine technologies and ease of storage. Several ports have established methanol bunkering facilities, with ongoing projects to develop infrastructure further. Conventional methanol, primarily produced from natural gas, is generally cost-competitive when compared to diesel bunker fuels. The projected cost of methanol can vary but is expected to decrease over time.
- **Ammonia is considered a future zero-carbon fuel**, with significant projects underway to develop its infrastructure. However, ammonia's bunkering network is still in its nascent stages. The toxicity and handling requirements pose challenges that need to be addressed before widespread adoption can occur.
- **Biofuels are also being explored as a viable alternative**. Ports are beginning to integrate biofuels into their bunkering options. Biofuels can be used in existing engines with minimal modifications, but their high cost and limited availability of feedstocks remain significant barriers.

The transition to alternative marine fuels is heavily influenced by the production and availability of renewable electricity, essential for producing green hydrogen, ammonia and methanol. The global capacity for renewable energy is expanding, but the pace and scale of this expansion are crucial for making alternative fuels economically viable and widely available.

While the industry adjusts to these new realities, the path to achieving significant emissions reductions will require concerted efforts across technology adoption, regulatory compliance, and operational shifts. The outlined data and forecasts serve as a critical guide for stakeholders in navigating these changes.

Market Outlook and Ecosystem Capacity

As of April 2024, the global shipping fleet comprises over 109,000 vessels, accounting for approximately 1.6 billion gt. Despite fluctuations due to the global financial crisis and subsequent economic conditions, recent trends show a significant rebound in newbuilding contracting. By the end of 2023, the global orderbook for ships over 5,000 gt increased to 208 million (m gt), representing 14.3 percent of the world fleet. This marks the highest level since 2011 and a 71 percent increase from the end of 2021.

As far as the current orderbook is concerned, the demand for gas carriers and liner vessels, particularly containerships and car carriers, remains robust. In contrast, the orderbooks for crude and product tankers, as well as dry bulk carriers, are comparatively modest. Notable contractions in the orderbook for cruise ships reflect the sector's challenges during the global pandemic. Moving forward, the orderbook is expected to shrink as newly ordered ships are delivered and contracting activity remains subdued due to various economic and market pressures. By 2026, the orderbook is forecasted to decrease to around 170m gt.

The adoption of alternative fuels and EETs is critical under an increasingly stringent regulatory landscape. The FuelEU Maritime requirements and similar requirements expected from the IMO introduce new complexities and will require stakeholders to consider how they can pool credits for compliance. Regarding the adoption of alternative fuels, looking at the orderbook, the following can be highlighted:

- **Methanol shows a remarkable increase** to 203 vessels from just 30, with significant uptake in containerships and a new introduction to bulkers and tankers. This reflects growing confidence in methanol as a viable alternative fuel.
- **Ammonia usage sees an increase** and the e-ammonia pathway has the potential to reach carbon net zero as a long-term decarbonization option.
- **Sustainable biofuels are deemed as short- and mid-term options** for the existing fleet, the challenge is how closely the supply of biofuels can meet the demand.
- **LNG usage is set to increase significantly** in the orderbook with 837 new vessels. There is a substantial increase in containerships adopting LNG, likely due to lower emissions compared to traditional fuels.
- **LPG, ethane and hydrogen show moderate increases**. LPG sees a slight decrease, while ethane remains specialized. Hydrogen sees a small uptick, reflecting its potential future growth as technology and infrastructure mature.
- **Battery-powered vessels remain consistent**, indicating steady but not explosive growth. This may reflect ongoing developments in battery technology, which might not yet be ready for mainstream large-scale adoption.

The shift from LNG in the existing fleet to a more diversified set of fuels in the orderbook, particularly green methanol and green ammonia, suggests a trend toward exploring multiple viable options for reducing GHG emissions. The growth in methanol usage is particularly notable and may indicate a shift toward its adoption due to advancements in technology and fuel availability. Battery technology adoption does not increase significantly, which may suggest that while it is viable for certain types of vessels or operational profiles, it may not yet be suited for the main types of large commercial vessels. The consistent introduction of hydrogen and ammonia highlights ongoing interest in these fuels as long-term solutions to decarbonization challenges, despite current hurdles in their widespread adoption.

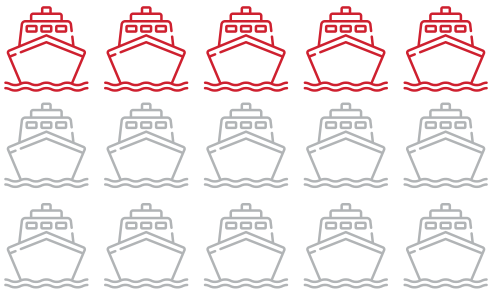
The current fleet shows modest EET adoption, but projections for newbuilds are more promising, with a notable increase in ships designed to use alternative fuels such as LNG, methanol and ammonia. The total EET adoption rate in the global fleet orderbook jumped from 28 percent last year to 37.4 percent this year, highlighting a shift toward more sustainable shipping practices.

Decarbonizing existing fleets through retrofitting to use alternative fuels is a key strategy for the industry. As of March 2024, only a small fraction of the fleet has been retrofitted, with methanol dual-fuel retrofits emerging as a popular choice, particularly in the containership sector. The future potential for retrofitting is linked to the advancement of technology and regulatory pressures, with a significant portion of the fleet identified as candidates for such upgrades.

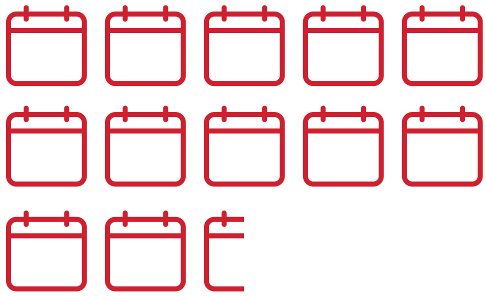
Over the last decade, there have been substantial fluctuations in the global shipyard capacity. In the 2010s, industry capacity decreased significantly, predominantly as a result of consolidation, particularly in Asia. In recent years, renewed demand for newbuilds and retrofits leading to the reactivation of defunct facilities, and productivity improvements at active yards have all contributed to a modest increase in capacity. Clarksons Research estimates that the overall utilization of shipyards for newbuildings will continue to be exceptionally high in the coming years, with a potential increase to 95 percent by the end of the decade.

Notwithstanding this incremental growth in potential capability, the pool of repair shipyards equipped to perform fuel retrofits continues to be considerably limited. This constraint restricts retrofitting operations as spare capacity at the shipyard is limited. Shipyards located in non-traditional shipbuilding nations are therefore presented with the prospect of leveraging this void by enhancing their capacity to manage retrofits.

1/3 of fleet capacity is older than 15 years



The average global fleet age is **12.5 years**



A third of the fleet capacity is currently older than 15 years, and the elderly global fleet, which has an average age of 12.5 years, emphasizes the critical need for substantial fleet renewal. A substantial replacement cycle is required for this older tonnage, which is anticipated to gain momentum through the 2030s. The transition to alternative fuels and environmental regulations within the industry also contribute to this process of renewal.

Alternative Fuel Pathways and Timelines

Compared to the well-recognized Tank-to-Wake (TtW) GHG emission factors, Well-to-Tank (WtT) emission factors are more sensitive to operating locations and fuel production technologies.

The most viable fuel pathways to reach short-term decarbonization goals are identified as blue ammonia, blue hydrogen, e-methane, e-methanol, e-ammonia, e-hydrogen, e-diesel, biodiesel, biomethane and biomethanol. Considering WtW GHG emission savings, the carbon neutral pathways to 2050 are identified as e-methane, e-diesel, e-methanol, e-ammonia, e-hydrogen, biodiesel, biomethanol and biomethane.

In terms of cost-effectiveness, ABS developed the GHG Abatement Cost (GAC) index to statistically assess the trade-offs between cost and GHG emission savings, specifically focusing on the WtW approach.

Based on the GAC analysis of the three developed scenarios (e-fuels high uptake, bio-fuels high uptake and blue fuels high uptake), a projected ranking of the different fuel pathways' cost effectiveness at 2050 was calculated. According to ABS' GAC methodology and current fuel prices, biofuels and blue fuels will have a lower carbon abatement cost compared to others.

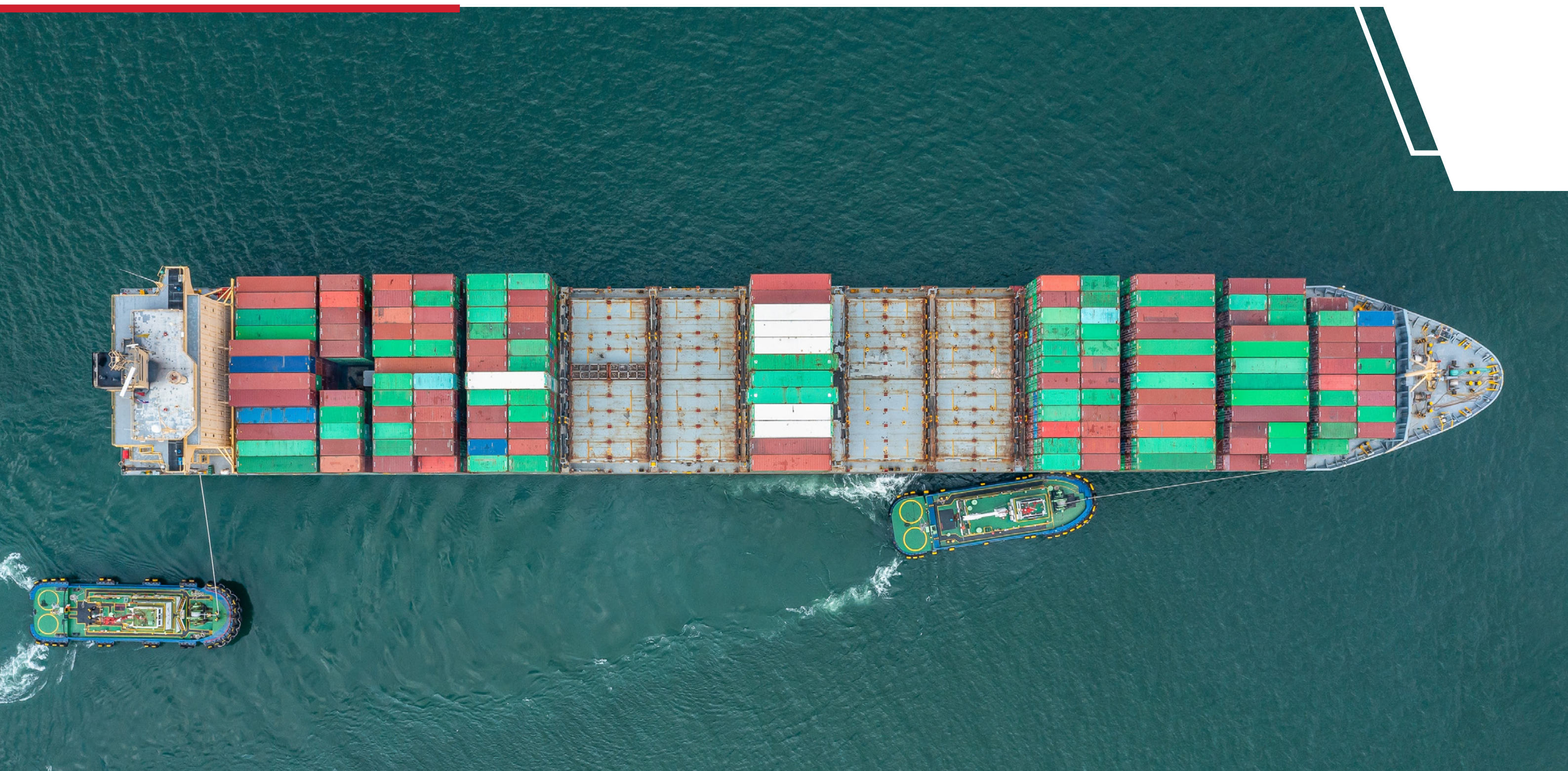
The majority of the e-fuel production paths are currently moving from the demonstration stage to system commissioning, with full commercial operation expected in the mid-2030s.

Biofuel pathways are ahead of e-fuels in terms of technology readiness level (TRL), and they are projected to reach full commercial operation stage in the early 2030s.

Blue fuel pathways are expected to reach fully commercial TRL before e-fuels. Blue fuel pathways depend on the maturity level of the carbon value chain. While land-based carbon capture and storage technologies have been commercialized, their cost for large-scale blue hydrogen and ammonia production are challenging for full maturity development.

Key Transformational Technologies

The shipping industry is also exploring various technologies to meet net-zero targets, focusing on improving energy efficiency, utilizing alternative fuels and considering innovative, non-traditional solutions, such as onboard carbon capture and storage (OCCS). These efforts are critical in navigating the decarbonization pathway effectively.



Onboard Carbon Capture and Storage (OCCS) Systems

OCCS is gaining traction as a viable solution for reducing emissions from ships. This technology, still in its early stages, captures CO_2 produced by ships' engines, either before or after combustion. Methods include pre-combustion, post-combustion and oxy-combustion, each with specific technologies and storage techniques, such as liquefaction and mineralization.

- Achieving carbon capture percentages of 80 percent and higher is possible, making OCCS a compelling choice for a long-term decarbonization strategy. However, there may be a need for a higher amount of energy and equipment, which could make it less appealing for achieving high carbon capturing rates.
- Post-combustion-based OCCS has proven to be more feasible compared to pre-combustion and oxy-combustion systems. Several pilot studies on chemical absorption and calcium looping-based, post-combustion OCCS have demonstrated promising carbon capture rates.
- The additional energy consumption for carbon reduction by OCCS was found to differ depending on the type of fuel used, rather than the type of vessel. In terms of emission and cost savings, OCCS on LNG-fueled vessels proves to be more effective compared to OCCS on methanol-fueled vessels and diesel-fueled vessels.

Wind Assisted Propulsion

Wind Assisted Propulsion Systems (WAPS) are evolving technologies that harness wind power to aid traditional ship engines, providing economic and environmental benefits. The main types include rotor sails, wing sails, suction sails, and kite sails. Rotor sails use the Magnus effect to create thrust, while wing sails function like aircraft wings to maximize lift. Suction sails utilize an egg-shaped profile with a suction mechanism to generate lift without rotation, and kite sails use large kites flown ahead of the vessel for propulsion, particularly effective in open ocean conditions. These systems are being increasingly adopted, with a notable number of vessels already in service or awaiting installation.

WAPS technologies offer benefits under both European Union Emission Trading System (EU ETS) and FuelEU Maritime regulations. For EU ETS, WAPS can assist in reducing onboard fuel consumption, which in the context of EU ETS has a direct effect on the compliance cost, as less fuel consumed results in less taxed emissions. An additional benefit, under the FuelEU Maritime, is the potential five percent reduction on the GHG intensity calculation of energy used on board for those vessels where wind assisted propulsion accounts for 15 percent or more of the energy used for propulsion.

For ship operators, accurately predicting fuel savings is crucial and can vary from low to high confidence levels. Low confidence predictions are general estimates, while medium and high confidence predictions involve detailed analysis and specific data. Integration of WAPS into vessels requires careful planning, addressing structural and operational aspects. Continuous in-service monitoring and third-party performance evaluations ensure optimal operation and safety. WAPS represents a significant opportunity to enhance fuel efficiency and reduce emissions in support of the industries decarbonization efforts.

Beyond the Engine

Advancements in alternative energy sources, such as fuel cells, hybrid systems and nuclear power, are crucial. Fuel cells offer a cleaner alternative by converting chemical energy directly into electrical energy, producing only water vapor as a byproduct. Hybrid systems combine conventional engines with electric motors and batteries, enhancing fuel efficiency and reducing emissions.

- The application of fuel cells depends on factors, such as efficiency, operating temperature, fuel availability and vessel specifications.
- Proton exchange membranes, molten carbonate and solid oxide fuel cells (SOFCs) are considered to be the most promising solutions for marine applications.
- Battery and hybrid ship propulsion systems have already been utilized to power smaller vessels and port handling equipment, and the shift toward larger ships is currently in progress.
- Battery and hybrid systems are considered clean for TtW, although they may not be as favorable when it comes to WtT emissions accounting. This makes them a less appealing option for decarbonization in the current state of TRL.

Nuclear power is highlighted as a significant enabler for decarbonization, providing a high-density, long-term power supply. It supports the creation of carbon-free fuels and can be integrated into ships for propulsion or installed on floating offshore platforms, contributing to the global push for zero emissions.

- Advanced nuclear reactors have many possible implementations within the maritime value chain due to their potential flexibility, offering various arrangements of size and power output, long fueling cycles, the possibility of factory fabrication and small carbon footprints.
- The main barriers limiting nuclear adoption are the regulatory gaps regarding mobile and non-traditional reactors, as most regulatory bodies address only traditional reactors.
- Port electrification through clean nuclear energy would assist in the push toward decarbonization, as it would facilitate the electrification of port equipment as well as provide an onshore power supply to visiting vessels.
- Ammonia and hydrogen from nuclear reactors can be used as carbon-free pink fuels for vessels.

Finally, the role of digitalization is enhancing operational efficiency and supporting decarbonization efforts. Technologies, such as artificial intelligence (AI) and digital twins, optimize ship operations, reduce emissions and improve safety.

Offshore Industry Insights

The offshore industry is at an important stage, trying to balance traditional energy sources with emergent energy sources and decarbonization technologies in the evolving energy evolution. The traditional offshore oil and gas sector, which is currently accounting for 16 percent of the global energy mix, is going to continue to be a critical energy source for the foreseeable future as alternative energies alone will not be able to make up the difference in growing energy demand. Meanwhile, offshore wind power is gaining traction, with large-scale wind farm capacities projected to grow significantly by 2030, especially under rapid decarbonization scenarios. Offshore hydrogen production is also emerging as a viable energy solution, although high costs remain a challenge as technology advances.

The market for offshore drilling units and support vessels reflects the industry's current and future supply and demand levels. The orderbook for mobile offshore drilling units (MODUs) is limited, with high costs and long lead times discouraging new orders. However, electrification and digital emission-monitoring solutions are being adopted to improve efficiency and reduce emissions. Offshore support vessels (OSVs) are transitioning toward hybrid propulsion and dual low-carbon fuels, though uncertainty about future fuel types and short-term contracts pose challenges. Decarbonization efforts include fleet digitalization, operational efficiencies, advanced engine technology, waste heat recovery, and energy storage systems.

There is societal and industry emphasis on the integration of renewable energy sources like offshore wind and hydrogen production. Offshore wind capacity is expected to quadruple by 2030 despite supply chain challenges, driven by private and public investments. Innovations such as high-voltage direct current technology and integrated wind-to-hydrogen systems are key to enhancing energy transmission. Biodiversity considerations are becoming ever more critical, with industry practices increasingly aligning with international frameworks to minimize environmental impacts. The offshore industry is evolving to meet decarbonization targets while ensuring marine ecosystem protection and sustainability.

CONCLUSION

This year's publication provides an insightful overview of the maritime industry's ongoing transformation toward decarbonization by 2050.

This transformation is highlighted by a shift from traditional fossil fuels to alternative, less carbon-intensive fuels such as LNG, methanol, ammonia and various forms of e-fuels and biofuels. This transformation is also highlighted by the significant changes in global trade dynamics, technological advancements and the regulatory landscape that are steering the industry toward these new fuel paradigms. The energy transition, which involves a mix of methanol, ammonia and LNG, suggests a strategic pivot that not only aligns with global carbon reduction goals but also adapts to evolving market demands and geopolitical influences.

The global energy transition efforts give rise to the need for the transportation of new energy carriers. Maritime routes link regions with a high demand for clean energy sources, such as ammonia and hydrogen, to production centers of alternative fuels. A prime example is the construction of Very Large Ammonia Carriers (VLAC) to transport ammonia from Australia, a significant producer of green ammonia, to Japan, which is dedicated to attaining carbon neutrality.

In conclusion, as the maritime sector navigates the complexities of the 21st century, stakeholders from all facets of the industry – ranging from shipbuilders to operators – must embrace a proactive approach to innovation and regulatory compliance. The outlined transition to cleaner fuel alternatives represents a pivotal opportunity for the industry to lead in global environmental stewardship while ensuring economic viability and competitiveness in the global marketplace. The collaborative efforts required to retrofit existing fleets and to enhance the capacity of shipyards for new, greener vessels will be critical. As we look to the future, the industry's commitment to a sustainable transformation is clear, but achieving these ambitious goals will require continued diligence, innovation and global cooperation to effectively overcome the technical and economic challenges highlighted in this report.

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CONTACT US

Global Sustainability Center

1701 City Plaza Drive | Spring, Texas 77389, USA

+1-281-877-6000 | sustainability@eagle.org

www.eagle.org/sustainability

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