The Coast Guard Journal of Safety & Security at Sea

Proceedings

Fall 2022

of the Marine Safety & Security Council

Perspectives on Maritime Sustainability

Government ◆ Industry ◆ Technology

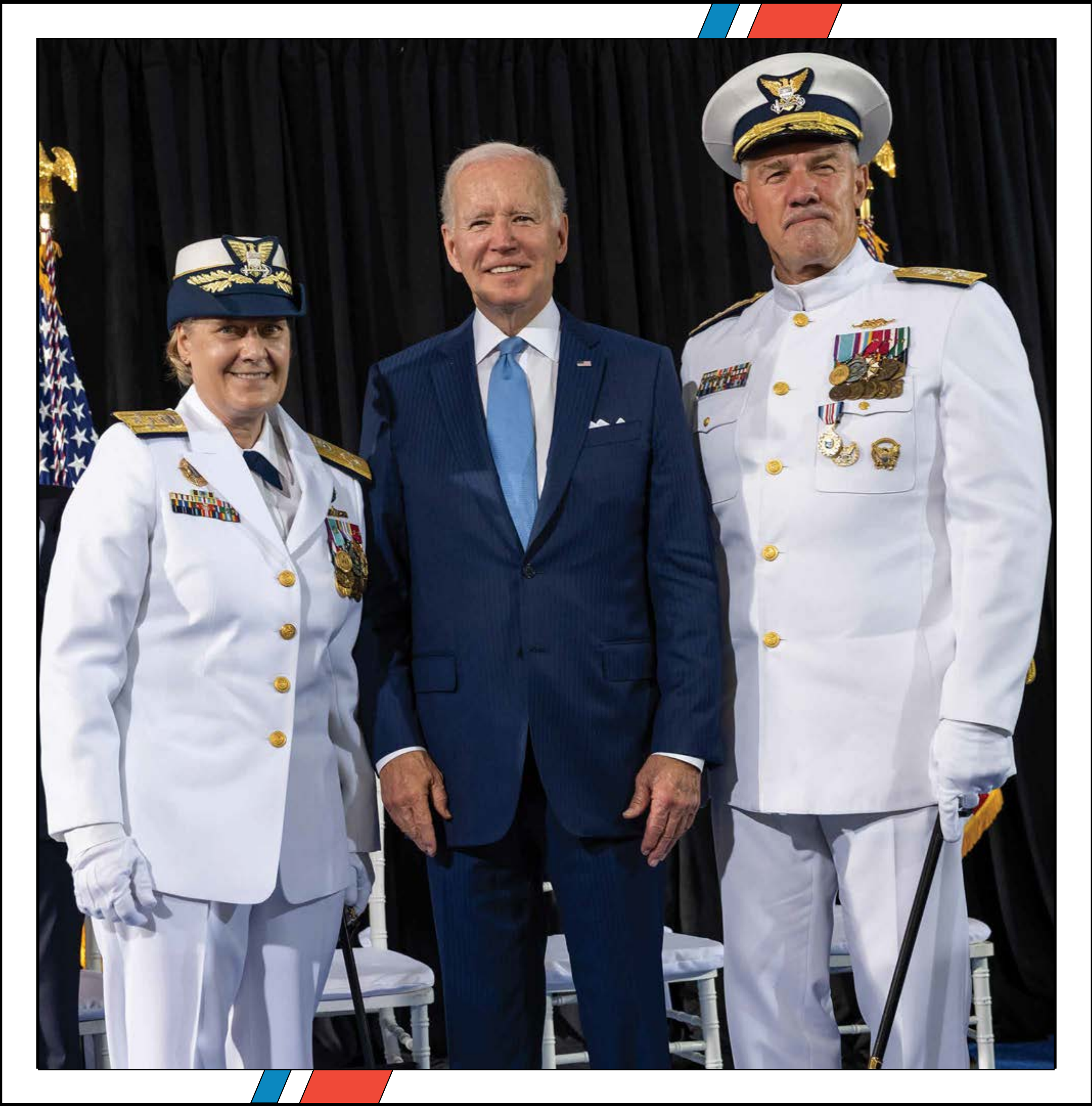
27th Commandant of the Coast

On June 1, 2022, Admiral Linda L. Fagan relieved Admiral Karl Schultz to become the 27th Commandant of the Coast Guard, and the first female military service chief.

Held at Coast Guard Headquarters, President Joseph R. Biden presided over the historic event, which was attended by Department of Homeland Security Secretary Alejandro Mayorkas, as well as family, friends, and colleagues.

Coast Guard photos by Petty Officer 1st Class Travis Magee

Guard, Admiral Linda L. Fagan



PROCEEDINGS

Fall 2022 Vol. 79, Number 2

Environmental Governance

Corporate Social Responsibility

Green Innovations

On Deck

***Governments and regulatory bodies around the world are working to reduce global greenhouse gas emissions from commercial shipping. To meet these emission reduction goals, new technologies are being explored that would reduce and, in some cases, eliminate emissions from commercial shipping. This issue explores many of these technologies. Additionally, the back cover offers students' artistic interpretation of* New Technologies for Greener Shipping.**

Global vegetation map courtesy of NASA

Editorial Team

Samantha L. Quigley
Executive Editor

Antonio E. Balza
Managing Editor

Leslie C. Goodwin
Graphic Designer

Proceedings is published three times a year in the interest of safety at sea under the auspices of the Marine Safety & Security Council. Special permission for republication, either in whole or in part, except for copyrighted material, is not required, provided credit is given to *Proceedings*.

The articles contained in *Proceedings* are submitted by diverse public and private interests in the maritime community as a means to promote maritime safety and security. The views expressed by the authors do not necessarily represent those of the U.S. Coast Guard or the Department of Homeland Security or represent official policy.

Graphics provided by the Coast Guard and its licensors, unless otherwise indicated.

Editorial Contact

Email: HQS-DG-NMCProceedings@uscg.mil

Mail Commandant (CG-5PS)
ATTN: Editor, *Proceedings* Magazine
U.S. Coast Guard Stop 7318
2703 Martin Luther King Jr. Ave. S.E.
Washington, DC 20593-7318

Web: www.dco.uscg.mil/proceedings

Phone: (202) 372-2316

Subscription Requests

Proceedings is free of charge and published in April, August, and December.

Subscriptions:
www.dco.uscg.mil/proceedings

Assistant Commandant's Perspective

by Rear Admiral Wayne R. Arguin
Assistant Commandant for Prevention Policy
U.S. Coast Guard

The marine transportation system (MTS) is the lifeblood of the global economy and critical to our national interests, connecting America's consumers, producers, manufacturers, and farmers to domestic and global markets. Maritime transportation of cargo is the most economical, environmentally friendly, and efficient mode of freight transport, accounting for $5.5 trillion in economic activity each year and the employment of over 30 million Americans. Any significant disruption to the MTS, whether natural or manmade, has the potential to cause cascading and devastating impacts to our domestic and global supply chain. The key to maintaining a viable and healthy MTS lies in stewardship and sustainability, and requires unity of effort from the entire

Champion's Point of View

by Captain Daniel H. Cost
Chief, Office of Design and Engineering Standards
U.S. Coast Guard

"Sustainability is here to stay, or we may not be."
—Niall FitzGerald, international business leader

As we continue to expand the use of the marine transportation system (MTS) to carry more vessels, more cargo, and more people, we must remain ever mindful of our environmental impact. Sustainability is becoming increasingly important and it is critical that we rise to meet the challenge of managing our growing footprint to protect our planet. True success will require contributions and unity of effort from all levels.

Regulators are hard at work to develop and promulgate sustainable strategies and objectives. This is happening globally, as the United Nations maritime community.

The Coast Guard has a long history of environmental stewardship and it is woven into our concept of operations. As part of our mission, we develop standards for the commercial shipping industry, working effectively in coordination with the International Maritime Organization (IMO) and our U.S. interagency partners. We conduct inspections to ensure compliance with these standards, both for our own ships and foreign ships sailing in our waters. We respond when incidents happen and then investigate these incidents as a feedback mechanism to make improvements to our existing standards.

Recently, much attention has been focused on ways to reduce global emissions. At the United Nations Climate Change Conference, 200 countries came together and agreed and stressed the urgency and need for action "in this critical decade" to drive the world toward a more sustainable, low-carbon pathway. The IMO has also been hard at work developing targets and strategies to reduce international shipping industry's emissions, and has set a target goal to halve emissions from shipping by 2050 from 2008 levels. Here in the United States, the administration has also set some ambitious sustainability targets, including a net zero emissions economy by no later than 2050.

Achieving our global sustainability goals will require a joint effort from international, federal, state, local, tribal, and industry stakeholders. Fortunately, there are multiple paths to reach these goals. In the articles that follow, it is clear that maritime stakeholders at all levels are evaluating how they can make a difference. I'd like to thank all those who shared their viewpoints and thoughts on this important topic and I hope you enjoy reading them as much as I did.

and International Maritime Organization set emissions reduction measures. It is happening nationally, as the administration sets ambitious goals and incentives for shifting to greener energy sources. It is happening at the local level as states establish requirements for the transportation infrastructure that moves cargo throughout the ports, railways, and roads.

Businesses, large and small, including international corporations, local companies, classification societies, and even maritime insurers are also taking action. As industries evaluate their business strategies, more and more are looking at how they can leverage environmental, social, and governance principles to transform their business operations and incentivize others to do the same.

Technological advances will also be vital in our sustainability efforts. Whether it's modifying existing systems to run more efficiently, or developing new systems to run on alternative fuels or different power sources, substantial research and development is underway to innovate and find new solutions to reduce our carbon footprint.

This issue of *Proceedings* provides readers with a glimpse into the combined efforts of governments and business, as well as some of the technology being considered, as we come together on our sustainability journey. My sincere thanks go to our authors, who have taken the time to share their ideas and best practices. We hope that you will find this issue to be a valuable resource as you consider how you can contribute to the joint goal of leveraging the MTS for all it has to offer, while also protecting it today so that we can continue to enjoy it tomorrow.

Sustainability Improvements at U.S. Maritime Administration

Infrastructure, investments, and technology innovation

by Peter Simons
Supervisory Transportation Specialist
Office of Port Infrastructure Development
MARAD

Wade Morefield
Transportation Analyst
Office of Ports & Waterways Planning
MARAD

Dan Yuska
Director
Office of Environment and Innovation
MARAD

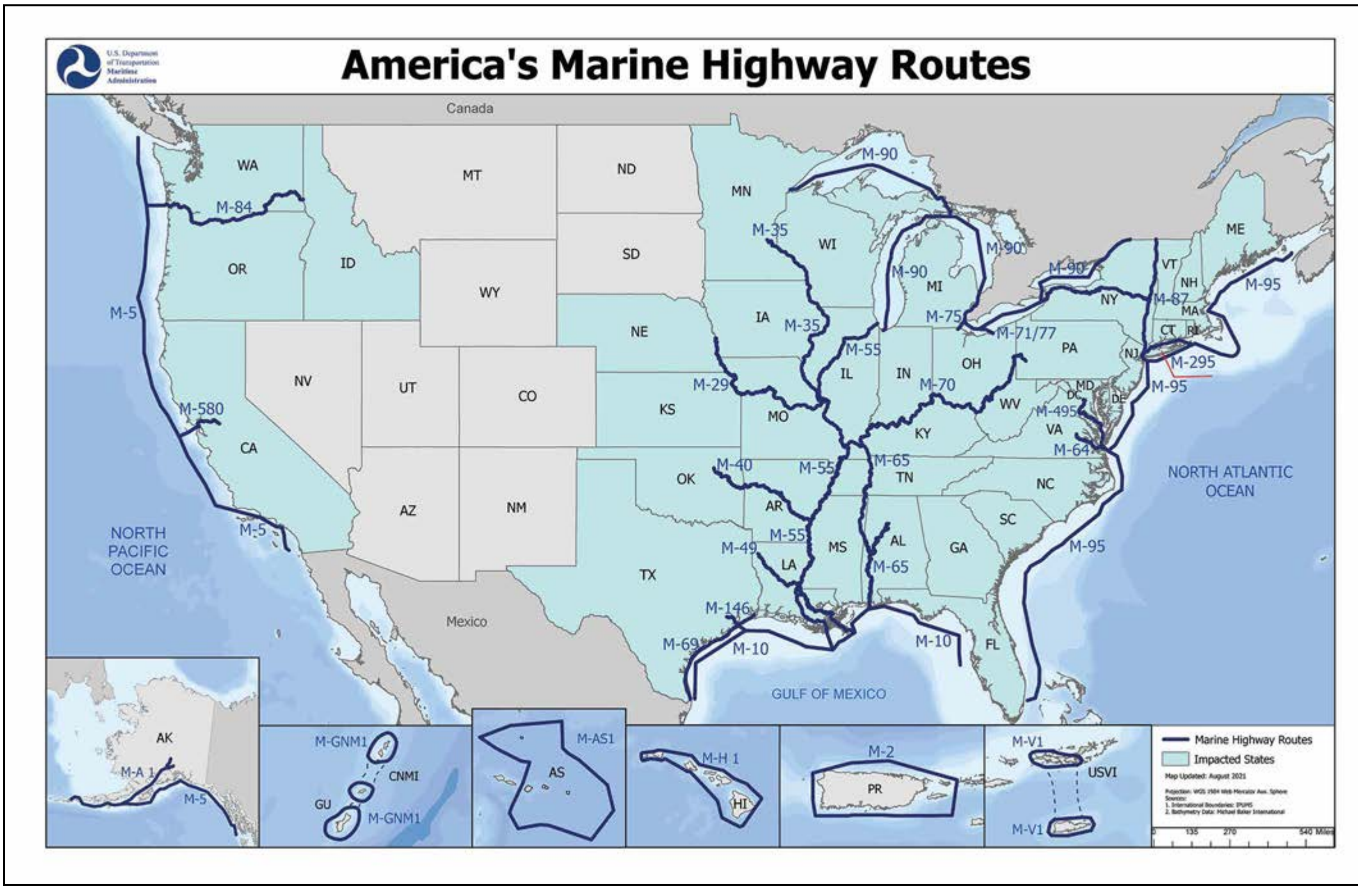
In early November 2021, the White House released the Biden-Harris Action Plan for America's Ports and Waterways.[1] The plan recognizes that American ports are a cornerstone of the U.S. economy, that they support more than 30 million jobs, and represent approximately 26 percent of our nation's gross domestic product (GDP). It goes on to note that "ports face extensive challenges modernizing infrastructure and maintaining essential facilities under threat of sea level rise and other climate changes." In order to address those challenges, the plan commits to a series of federal agency actions, including steps to accelerate investment in our nation's ports, waterways, and freight networks.

The Maritime Administration's (MARAD) major grant programs are a key part of this effort to accelerate investments in waterways, shipyards, and ports. Grants administered by MARAD are discretionary grants, meaning that recipients are selected through a competitive process involving a public solicitation for projects. Applications are then evaluated against criteria established by authorizing legislation, appropriations act language, and related administration policy. In previous years, MARAD-administered grant programs have funded projects that, for the most part, have played an indirect role in helping the maritime community address climate change. That is changing as the grant programs evolve and the purposes for which funding can be used are modified by congressional action.

The Maritime Administration

MARAD is the agency responsible for discharging the U.S. Department of Transportation's (DOT) authorities relating to our nation's waterborne transportation system. At its core, the agency supports the technical aspects of America's maritime transportation infrastructure—ships and shipping, port infrastructure development, reserve fleet operations, national security, environmental stewardship, commerce, and safety. MARAD promotes the use of waterborne transportation and ensures the system's infrastructure integrates seamlessly with other methods of freight transportation. The agency also maintains a fleet of cargo ships in reserve to provide surge sealift capacity during war and national emergencies. Finally, it plays a key role in maintaining the health of the U.S. Merchant Marine. Commercial mariners, vessels, and intermodal facilities are vital commercial and national security links and the agency provides support for current mariners, resources to help educate future mariners, and public awareness about the vital role of maritime operations in Americans' lives.

With those broad responsibilities, MARAD is well positioned to play a key role in helping the maritime sector tackle climate change issues. Although its role in this important effort is multifaceted, it is particularly evident in the agency's major grant programs which support America's marine highway, port infrastructure development, and small shipyards. In addition to these infrastructure-related grant efforts, MARAD manages the Maritime Environmental and Technical Assistance (META) program that focuses on environmental research, demonstration, and technology innovation. In Fiscal Year 21, these grant programs, along with the META, awarded $276.7 million in grants and other incentives to help improve our nation's maritime infrastructure. With the 2021 passage of the Infrastructure Investment and Jobs Act (IIJA), they are poised to play an



America's Marine Highway Program was created by the 2007 Energy Independence and Security Act, with the legislative intent of establishing a short sea transportation program to mitigate landside congestion. Route numbers are based on the designation for nearby highways. Map courtesy of MARAD

even more prominent role in helping to address climate change issues in FY22 and beyond.[2]

A Deeper Dive into MARAD Programs

America's Marine Highway Program

The America's Marine Highway Program (AMHP) is an important component of MARAD's effort to improve the efficiency and environmental performance of the nation's surface transportation system. Created by the 2007 Energy Independence and Security Act, the legislative intent was to establish a short sea transportation program to mitigate landside congestion.[3] The program encourages development and expansion of U.S. documented vessels, shippers' use of marine services, port and landside infrastructure development, and implementation of marine transportation strategies by state and local governments. To date, the AMHP includes 28 designated routes comprising more than 29,000 miles of navigable coastal, inland, and intracoastal waterways. Services between U.S. and Canadian ports on the Great Lakes-St. Lawrence Seaway System, as well as some non-contiguous U.S. ports, are also eligible for assistance under the program.[4]

Since its inception, the AMHP authorization has been updated several times to refine criteria related to route and project designation, as well as eligibility requirements for grants issued through the program. Eligible activities for funding under the program involve the domestic carriage of palletized, unitized, wheeled, or containerized cargo on U.S.-documented vessels along designated AMHP routes. Bulk cargo and passenger services are not currently eligible for assistance under the program.

In December 2021, the DOT awarded $12.6 million in AMHP grants to nine marine highway projects.[5] To date, these grants have funded more than $51.7 million in improvements for 25 projects to develop and expand marine services and facilitate further integration of marine transportation into the nation's surface transportation system. The recently passed IIJA appropriated an additional $25 million to support additional AMHP projects. As outlined in the most recent Notice of Funding Opportunity (NOFO), these new marine highway program grants must be used to "support the development and expansion of documented vessels and landside infrastructure."[6] When permitted under the appropriation, funding may also be made available for specific planning studies relating to eligible vessel or infrastructure projects, but market-related studies are not eligible under this provision. A comprehensive listing of AMHP grant funded projects can be found on the MARAD website.[7]

Grant awards under the AMHP are based on several factors that relate directly to environmental performance and support climate change mitigation. These factors include an estimate of the public benefit that will result from the new or expanded marine service based on reductions in landside freight network congestion; emissions reductions; energy savings; landside transportation infrastructure maintenance savings; economic competitiveness; safety benefits; and freight system resiliency and redundancy.

Applications for AMHP grant funding must also include estimates of cargo volumes that will be shifted to marine service from other freight transportation modes.

An inland terminal, the Port of Virginia's Richmond Marine Terminal, is served by a container-on-barge service from Hampton Roads along M-64, a marine highway route that removes container traffic from local roads and highways. Photo courtesy of The Port of Virginia

Scripps Institution of Oceanography is in the process of replacing the aging R/V *Robert Gordon Sproul* with a new hydrogen hybrid research vessel. The *H_2 Hybrid* SRV will use hydrogen in the form of a fuel cell generator, like the one seen here. Photo courtesy Bruce Appelgate, Scripps Institution of Oceanography

Maritime Environmental and Technical Assistance

The META program is managed by MARAD's Office of Environment, and is designed to foster innovation, research, demonstration, and development of technologies and processes that improve maritime industry performance and competitiveness. To accomplish this, the program partners with federal, state, and local agencies, as well as the maritime industry and academia, on projects that serve to demonstrate, validate, and assess costs and benefits of maritime technology innovation. Initially, most of META's work focused on controlling the spread of aquatic invasive species transported by vessels, and reducing vessel and port air emissions as those two environmental challenges were high priorities domestically and internationally. More recently, the META portfolio has evolved to include underwater noise, safety, energy efficiency, and maritime decarbonization.

Addressing the challenge of maritime sector decarbonization requires greater collaboration among federal agencies and industry stakeholders. Realizing this, over the past few years the META program worked closely with government partners like the Environmental Protection Agency and the Department of Energy, to develop a broad maritime decarbonization strategy. The strategy identifies research, demonstration, and technology (RD&T) needs, and details the need for greater industry incentives to transition to low- and zero-carbon emissions. It also supports U.S. innovation and manufacturing of low-carbon fuels and green technologies.

The RD&T efforts complement other MARAD and interagency grant programs and enhance progress towards sector decarbonization mandates. For example, META has demonstrated maritime applications for next generation biofuels, hydrogen fuel cells, batteries, and hybrid systems. Similarly, the program has supported multimodal modeling tools, lifecycle emissions analyses, and innovative projects that close the carbon loop. These projects have been specifically designed to address data gaps to inform regulatory and policy agencies and provide the industry with necessary information on "what works" for vessel and port operations. Along those lines, these efforts also inform MARAD's port- and shipyard-related grant programs.

Port Infrastructure Development Program

Created by statute in 2009, the Port Infrastructure Development Program (PIDP) was first funded in 2019. Its authorizing statute gives the secretary of transportation authority to make grants to projects that would be used to improve the safety, efficiency, or reliability of:

- the loading and unloading of goods at a port
- the movement of goods into, out of, around, or within a port
- environmental mitigation measures

Grants under PIDP are competitively awarded based on a project's alignment with qualifying and merit criteria described in the NOFO. Generally, an applicant must be a governmental entity, but projects proposed by non-governmental entities are eligible for consideration if the non-governmental entity works with a governmental partner.[8] For example, a private company could team with a governmental entity in the area in which its project is located.

Through the 2021 application and award cycle, eligible projects have been limited to any of six types. These include port gate improvements; road improvements, both connecting to and within a port; rail improvements, both connecting to and within a port; and berth improvements, including docks, wharves, piers, and dredging incidental to the improvement project. Also included are landside improvements in support of cargo operations—silos, container facilities, and other similar facilities. For 2022, eligible projects include operational improvements, like those identified above; projects that improve resiliency; and projects that reduce or eliminate port-related criteria pollutants or greenhouse gas emissions. In general, grants may fund up to 80 percent of the eligible cost of a project.

Since the first grants were awarded in February 2020, the secretary has approved a total of $733.8 million in funding to 58 projects. The funded projects are located in 26 states and two U.S. territories. To date, PIDP grant awards have focused on capital infrastructure investments that enhance the movement of cargoes. For example, of the projects awarded funding, 56 have been for construction activity. This is particularly important considering the recent supply chain resilience challenges. The projects represent mid- to long-term investments in infrastructure that help ports move cargo—exports and imports—and generate the regional and national economic impacts the program is intended to foster.

Like MARAD's other grant programs, PIDP has evolved in purpose and scope since first authorized by Congress. By policy, the solicitation for projects in 2021 included the inclusion of climate change considerations in project selection criteria. Specifically, applicants were

Waves and high water generated by Hurricane Isabel impacted the Port of Baltimore's Dundalk Marine Terminal in September 2003. The storm produced a surge of 6 to 8 feet at the port and flooded downtown Baltimore. Photo courtesy of the Port of Baltimore

After Hurricane Isabel flooded the Port of Baltimore's Dundalk Marine Terminal and downtown Baltimore in September 2003, the Port of Baltimore developed a project to provide flood mitigation improvements at terminal. The project includes a perimeter barrier to prevent overtopping, a box culvert with pump, and a series of backflow preventers in drains. The project is supported by a U.S. Department of Transportation grant and administered by MARAD. Photo courtesy of the Port of Baltimore.

asked to identify whether the project had incorporated climate change in either the planning phase or design components of the project, or both. The IIJA, in addition to providing supplemental PIDP, and AMHP, funding for the next five years, has expanded the types of projects eligible for funding consideration to include projects that improve the resiliency of ports to address climate change-related phenomena like sea-level rise, flooding, extreme weather events, earthquakes, and tsunami inundation. This is in addition to projects that reduce or eliminate port-related criteria pollutant or greenhouse gas emissions like electrification projects, idling reduction infrastructure, electric vehicle charge or hydrogen refueling infrastructure, and installation of anti-idling technologies.

To be clear, projects selected based on these criteria in the future will not represent PIDP's first investment in projects that have a positive impact on the climate or that help ports improve their resiliency. For example, since the program's inception the emissions reduction benefits of a project have been part of the mandatory cost-benefit analysis for DOT's discretionary grant programs.[9] In addition, funding has been provided to several projects that help, or will help, ports improve their resiliency, such as storm water management projects.

Small Shipyard Grant Program

Established in 2008, MARAD's fourth major program is the Small Shipyard Grant Program. Small shipyards are a critical component of U.S. maritime operations and economic security. Employing more than 100,000 Americans, they generate economic activity in communities along and near our nation's ports and waterways, and contribute tens of billions to the GDP.

In its enabling legislation, Congress authorized MARAD to provide assistance to shipyards to support projects that make capital improvements, provide maritime training programs, foster technical skills, and improve operational productivity. Today, its purpose remains largely unchanged. It continues fostering efficiency, competitive operations, and quality ship construction, repair and reconfiguration in small shipyards across the United States while promoting employee skills and enhanced productivity related to shipbuilding, ship repair, and associated industries.

The program's statutory authority provides that only shipyards are eligible applicants, and the shipyard facility for which a grant is sought must be in a single geographic location with no more than 1,200 production employees.[10] The facility must construct, repair, or reconfigure vessels 40 feet in length or greater for commercial or government use, or construct, repair, or reconfigure noncommercial vessels 100 feet in length or greater. By statute, the federal participation in any eligible project cannot exceed 75 percent of its total cost. Eligible projects include capital infrastructure and related improvement and training projects that enhance the purposes of the program. Finally, the program operates under the strictest timeline of any of MARAD's grant programs. A NOFO must be issued by MARAD within 15 days of the date of the program's annual appropriations act, and grants must be awarded no later than 120 days from that date.

To date, the Small Shipyard Grant Program has awarded 299 grants totaling $263 million to shipyards for equipment like cranes, panel lines, welding equipment, and other material handling equipment. Specifically, older cranes and other large equipment from the 1950s were replaced with updated versions featuring modern Tier IV engines capable of running alternate fuels to reduce emissions. Another derivative of the program has been the support of training to qualify welders, fitters, painters, and other skilled tradespeople to help fill the positions that shipyards need to build modern vessels. Recently, the program has funded grants to assist shipyards in reducing their energy consumption through lighting, HVAC, and insulation projects. This is in addition to environmental projects to control storm water runoff, and those that help a shipyard reduce its energy footprint through the installation of electric air compressors and other equipment.

Strategic Link between MARAD Programs

As the previous discussions indicate, MARAD's financial assistance programs are evolving to include a greater emphasis on the reduction of greenhouse gas emissions. The IIJA, for example, added two specific climate-related purposes—climate change resilience and port-related criteria pollutants, or greenhouse gas emissions—to the types of projects eligible for funding under PIDP. Similarly, the president has established climate-related goals for federal agencies, and the programs they implement. These goals include establishing greenhouse gas reduction goals, promoting energy efficiency, incorporating electrification or zero emission vehicle infrastructure, increasing climate resilience, reducing pollution, recycling or redeveloping brownfield sites, and addressing environmental justice concerns.[11]

MARAD's programs are also evolving to reflect synergies with other intra- and inter-agency programs. For example, PIDP and AMHP grants have been awarded to distinct, but complementary, projects. Additionally, the recent statutory inclusion of harbor craft, or related equipment replacements/retrofits, and worker training in the list of PIDP-eligible projects may enable that program to build on the successes of the Small Shipyard Grant Program. The MARAD staff also continues to work closely with other federal agencies to support a broader federal approach to decarbonization of the maritime sector and intermodal components.

About the authors:

Peter Simons is a supervisory transportation specialist in MARAD's Office of Port Infrastructure Development where he manages the engineering and transportation specialist teams He is also MARAD's lead for the Port Infrastructure Development Plan.

Wade Morefield is a transportation analyst in MARAD's Office of Ports & Waterways Planning. His responsibilities include federal funding outreach to ports and maritime stakeholders, freight research and policy development, and support for several federal grant programs. Mr. Morefield has a public administration and transportation planning background with degrees from University of Central Florida and Florida State University.

Daniel Yuska is the director of MARAD's Office of Environment & Innovation. He oversees the Maritime Environmental and Technical Assistance program, as well as domestic and international maritime environmental policy.

Endnotes:

1. The Biden-Harris Action Plan for America's Ports and Waterways. www.whitehouse.gov/briefing-room/statements-releases/2021/11/09/fact-sheet-the-biden-harris-action-plan-for-americas-ports-and-waterways/
2. For example, the Infrastructure Investment and Jobs Act (IIJA) provides funding that supplements the annual appropriations Congress allocates to AMHP and PIDP. IIJA provides an additional $25 million in AMHP funding and, over the next five years, an additional $2.25 billion for PIDP. Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, Div. J, Title VIII, (November 15, 2021)
3. Energy Independence and Security Act, Title XI, Subtitle C – Marine Transportation, P.L. 110-140, December 19, 2007
4. America's Marine Highway Program website: www.maritime.dot.gov/grants/marine-highways/marine-highway
5. Maritime Administration press release, December 10, 2021. www.maritime.dot.gov/newsroom/press-releases/us-transportation-secretary-pete-buttigieg-announces-126-million-grants
6. *Federal Register* 86 FR 27944, May 24, 2021. www.federalregister.gov/documents/2021/05/24/2021-10914/notice-of-funding-opportunity-for-americas-marine-highway-projects
7. Maritime Administration website: https://www.maritime.dot.gov/sites/marad.dot.gov/files/2021-02/AMH%20Project%20Designations%20Jan%202021_0.pdf
8. An eligible applicant can be a port authority, a commission or its subdivision or agent, a state or political subdivision of a state or local government, a Tribal government, a public agency or publicly-chartered authority established by one or more states, a special purpose district with a transportation function, or a multistate or multijurisdictional group of entities. The statute also permits an entity described above to team with a private entity (or group of private entities), including owners or operators of port facilities, on an application. National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, §3504, 134 Stat. 3388, 4399 (2021)
9. Emissions reduction benefits are one of the five categories of benefits discussed in the Department's guidance on how to conduct a project benefit-cost analysis. Benefit-Cost Analysis Guidance for Discretionary Grant Programs, February 2021. www.transportation.gov/sites/dot.gov/files/2021-02/Benefits%20Cost%20Analysis%20Guidance%202021.pdf
10. 46 U.S.C. Sec. 5401 (2021)
11. Exec. Order No. 14008, Tackling the Climate Crisis at Home and Abroad, 8 6 *Fed. Reg.* 7619 (Feb. 1, 2021)

Carbon and Compliance

Trends and tension in the IMO's emerging decarbonization program

by LCDR Benjamin Robinson
Deputy Chief, Environmental Law Division
Office of Maritime and International Law
U.S. Coast Guard

In June 2021, the title of the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, Chapter 4 changed from "Regulations on Energy Efficiency for Ships," to "Regulations on the Carbon Intensity of Ships."[1] The new title is not merely window dressing. The maritime greenhouse gas (GHG) regulations that follow expand on the existing approach and introduce a new, operationally focused approach alongside it.

The existing MARPOL regulations on greenhouse gas emissions date to 2011 when states party to MARPOL first adopted Chapter 4 to be included in Annex VI.[2] This initial gambit established several norms that set the course for developments since. The first is the decision to set energy efficiency goals based on one of 12 vessel types. The next was to begin rating ships' energy efficiency and to require phased improvements in those ratings. This article outlines existing and forthcoming elements of Annex VI's GHG regulations; considers how these embody some paradigmatic shifts in regulatory style; and anticipates areas of the regulation that may require reconsideration as de-carbonization efforts pickup.

MARPOL's Energy Efficiency Regulations

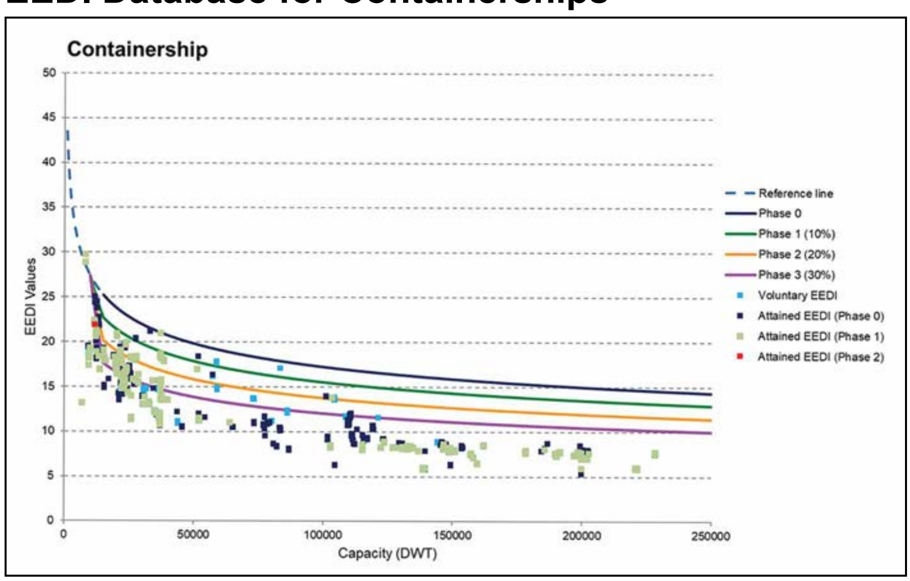
The Carbon Factor

Anomalous as it may be, any coherent discussion of Chapter 4's architecture must begin with an element absent from the language of the regulations themselves—the carbon factor (C_f). This metric is indispensable to tracking and controlling CO_2. C_f, which varies by fuel, is a ratio between a mass of a fuel and the mass of CO_2 emissions produced by its combustion. It thus translates fuel consumption into CO_2 production.[3] As ship owners look to alternative fuels to meet requirements for rating improvements, C_f is a key metric for decision makers and is used in the formulae for both of Chapter 4's rating indexes.

EEDI and EEXI

At the heart of the 2011 regulations was the Energy Efficiency Design Index (EEDI). The EEDI is a theoretical, technical measurement. It takes into account the power output of propulsion and auxiliary engines, specific fuel consumption—the amount of fuel required to generate a kW-hour—C_f, deadweight tonnage, a reference speed, and several correction factors. Reducing power ratings or using fuels that produce proportionally less CO_2 and higher energy intensity will thus reduce EEDI. For vessels in the design phase, more efficient hull shapes provide another means of reducing EEDI. The formula for

EEDI Database for Containerships



This EEDI database for containerships reflects data for 961 ships: 141 ships for non-mandatory, 373 ships for Phase 0, 446 ships for Phase 1, and 1 ship for Phase 2. Graphic courtesy of the IMO Marine Environment Protection Committee calculating EEDI is not specified by regulation but is instead explained in IMO Guidelines.[4]

Starting in 2013, EEDI was calculated for each new ship and documented on a new certificate, the International Energy Efficiency Certificate. This initial EEDI figure is known as "attained EEDI." Chapter 4 contains a table of reduction factors that are applied—together with a "reference value" based on ship type and deadweight tonnage—to reduce a vessel's required EEDI at set intervals.[5] The reference value for each ship type is based on a regression curve on the data in the IHS Fairplay database for ships built from 1999 to 2008, and is based on capacity, propulsion power, and service speed.

In June 2021, Energy Efficiency Existing Ship Index (EEXI) was added, allowing phased reductions requirements for ships built before the 2013 EEDI rollout.[6] Both EEDI and EEXI are documented in a technical file that shows the basis and method of the EEDI/EEXI calculation. Administrations must collect EEDI, both required and attained, for each vessel and also report them to the IMO for inclusion into its database. As of August 2021, the IMO database contained the EEDI of 7,324 ships.[7]

Ship Energy Efficiency Management Plan

The Ship Energy Efficiency Management Plan (SEEMP) is the ship-level implementation device for Chapter 4. The initial 2013 SEEMP guidelines required shipping companies to develop monitoring, encouraged use of Energy Efficiency Operational Indicator, the predecessor to EEDI/EEXI, and encouraged fuel-efficient operations through improved voyage planning, just in time scheduling, speed optimization, loading optimization, and similar techniques.[8] Although the requirement for a SEEMP is mandatory, guidance, not regulation, sets the content.

The importance of the SEEMP increased in 2016 with the requirement for collecting each ship's fuel consumption.[9] New SEEMP guidelines required a fuel oil consumption data collection plan.[10] This plan establishes a methodology for tracking fuel consumption—either with a flow meter, bunker delivery notes (BDNs), or tank soundings—distance traveled, and hours underway. The 2016 guidelines also recognize direct CO_2 emissions measurement at the stack as an alternative.

Carbon Intensity Indicator

Another major 2021 addition was carbon intensity indicator (CII), a measure of the carbon emissions per unit of work, or deadweight ton-nautical mile. As with EEDI and EEXI, CII is calculated based on formulae in guidelines rather than direct regulation.[11] The IMO's CII calculation guidelines recognize two methods—one based on actual work, or demand-based CII, and the other based on potential work, or supply based CII. However, because demand-based calculations require information on the amount of cargo carried and this information is not presently collected, for now only supply based CII will be used.

In contrast to the technical-theoretical character of EEDI and EEXI, CII is an operational indicator. Reducing fuel consumption while not underway will reduce the overall mass of CO_2 emission, as will using a fuel with a lower C_f. Larger vessels that do not require proportionally greater fuel consumption will also have lower CII.

Starting in 2023, each applicable ship will be required to calculate the CII attained that year for its administration. The administration will, in turn, compare the attained CII to the required CII—calculated using the required schedule of reduction factors—and assign a grade to the ship ranging from A to E. Flag state administrations will require ships with an E rating or three years' worth of D ratings to take corrective actions through the SEEMP.

Shifts in the Regulatory Paradigm

Chapter 4 is novel among IMO regulatory efforts in both the nature of its goal and the regulatory means used to pursue it. The explicitly stated goal is to reduce the carbon intensity of shipping internationally. This goal is distinctive because it reaches beyond the typical scope of IMO regulatory activity—safety of life and property at sea or the local marine environment—to address a problem, planetary in scale, for which shipping is but one of many contributors.[12] Another unique feature of this chapter is that it simultaneously pursues one goal through two methodologies—EEDI/EEXI, or technical carbon intensity, and CII, or operational carbon intensity.[13]

It also stands out for the scope of impact of its regulations. While previous international regulatory efforts have certainly influenced hull and machinery design, fuel chemistry, and vessel navigation practices, no single regulatory effort has reached all of these at once to achieve a single goal.

Chapter 4's methodology is also unique in that most carbon intensity regulations implement an explicitly iterative process. Although there is a long history in marine safety and environmental protection regulations toward ever more robust standards, no IMO regulatory regime so far has made that iterative process a structural component of the regulations themselves. Fuel consumption data reporting is the metric that will drive this process; reduction factors applied to EEDI/EEXI and CII will effectuate the process; and IMO audits and reviews will close the iterative loop with feedback on progress. This dynamic feature of the carbon intensity regulations is explicit in new regulation 20, titled "Goal," which states, "[t]he goal of this chapter is to reduce the carbon intensity of international shipping, working towards the levels of

A reserve marine science technician from Marine Safety Unit Portland, Oregon, monitors the transfer of ethanol from a barge on the Willamette River. Coast Guard photo by Petty Officer 2nd Class Allan Campbell

ambition set out in the *Initial IMO Strategy on reduction of GHG emissions from ships*." As the IMO strategy on GHG emissions evolves, so too will the carbon intensity regulations.

Evolving Company, Flag, and Port State Roles

As in practically all IMO regulatory efforts, flag states will survey ships to determine compliance and issue an International Energy Efficiency (IEE) Certificate. This certificate documents the ship's EEDI/EEXI and its compliance with the requirements. It also documents compliance with the SEEMP and fuel consumption reporting requirements but does not include CII.

The role of port states is currently difficult to discern. Because the goal of the carbon intensity regulations is focused on the aggregate problem of carbon dioxide emissions from ships overall, rather those of a single vessel, the regulations appear less susceptible to typical port state control oversight. One open question for port states is how they will determine that a ship's energy efficiency "substantially corresponds" with the required EEDI/EEXI noted on its certificate. Given the competing interests of meeting schedules, extending vessel life, and managing fuel costs, noncompliance will surely exist.

Annex VI contains a specific regulation on port state control. This regulation explicitly allows port states to check for an IEE Certificate, a statement of compliance with fuel consumption reporting, the SEEMP, and that a vessel has a CII rating. Interestingly, this regulation makes clear that port state inspectors may evaluate whether the SEEMP is "duly implemented." This is noteworthy because the SEEMP regulation states that it may form part of the safety management system (SMS) and under current port state control procedures inspectors do not evaluate SMS implementation in its own right.[14]

The reason for this apparent anomaly may be that current IMO port state control guidance treats overall compliance with other technical and operational requirements as evidence of a properly implemented SMS. Because technical and operational compliance with carbon intensity regulations is difficult or impossible for an inspector to evaluate by visual observation onboard, the inspector must look directly to implementation of the plan itself to gage compliance.

Flag and Port State CII Incentive Regimes

The means of implementing CII is another novel feature of the carbon intensity regulations. Rather than apply a certificate-based mandatory compliance model, the regulations contain an explicit encouragement to flag and port states to reduce CII by providing incentives to ships with CII ratings of A or B. While flag states and port states have long incentivized compliance through inspection targeting systems, incentives have not previously been encouraged by the regulations themselves.

Role of the"Bunkering State"

In the classic "Thames Formulation" of international maritime governance, parties to an IMO convention work together in their capacities as flag states, coastal states, and port states to achieve agreed on safety or environmental protection goals. Annex VI created a new role for parties as fuel regulators. This began with the SO_X regulation, which requires parties to:

- maintain a register of local suppliers of fuel oil
- require those suppliers to provide BDNs, retain copies, and make them available for inspection
- notify flag states of vessel's receiving non-compliant fuel
- take action against fuel oil suppliers that have been found to deliver fuel oil that does not comply with that stated on the BDN [15]

The role of parties as regulators of fuel suppliers is likely to expand apace with required reductions in EEDI/EEXI levels. Once the initial reductions associated with optimizing speed have been exhausted as a means of bringing down EEDI/EEXI, ship owners will look to alternative fuels for further improvements. The IMO, flag states, and port states will, in turn, look to the countries producing fuels for reliable documentation of C_f, and perhaps one day, a lifecycle fuel cost.

> Given the complexity of calculating EEDI/EEXI, class societies, in their capacities as recognized organizations, will play an increasingly larger role in effectuating the carbon intensity regulations. Unenviably, this includes the role of developing corrective action plans for ships with low CII.

The Expanding IMO Role

Where most IMO regimes leave oversight to flag and port states, the carbon intensity regulations are notable for assigning a significant oversight role for the IMO itself. To start, fuel consumption data must be reported to the IMO. The individual EEDI figures for each ship will also be reported to IMO by flag administrations and recognized organizations. Moreover, new Regulation 31 subjects flag states to periodic audits by the IMO to verify compliance with Annex VI and to implementation of corrective action based on the results of those audits.

Less obvious, but equally important, will be the IMO's role in developing safety regulations to address the carriage and use of new fuels like methanol, ammonia, and hydrogen. These coordinated regulatory efforts will be necessary for decarbonization to proceed in a safe manner.

New roles for classification societies

Given the technical complexity of calculating EEDI/EEXI, class societies, in their capacities as recognized organizations, will play an increasingly larger role in effectuating the carbon intensity regulations. This role will also include the unenviable task of developing corrective action plans for ships with low CII ratings.

Emerging Tensions

Chapter 3 vs. Chapter 4

Currently, the fuel oil quality regulations in Chapter 3, which deal with emissions, draw a distinction between traditional marine fuels as "blends of hydrocarbons derived from petroleum refining," and others. [16] Other liquid marine fuels, including biofuels, must be certified to meet SO_X and NO_X standards. Additionally, they must be free of inorganic acid and meet more open-ended criteria, including being safe for the vessel, its machinery, and crew, while not contributing to "overall air pollution." This all-or-nothing dichotomy between petroleum derived fuels and all others does not account for the wide variety of blends of petroleum and biofuels and consequently, the IMO is considering approaches that would put biofuels on equal footing with petroleum fuels. [17]

The extent to which biofuels and bio-blends merit distinct regulatory treatment will, in turn, depend on fuel chemistry and the characteristics of the engine in which it is used. This may require new content in a ship's NO_X technical file and, perhaps, new documentation demonstrating fuel-engine compatibility.

Similarly, the scope of the fuel quality regulations may need to expand as ship operators look to non-conventional fuels. Coal, gaseous, and nuclear fuels are exempt from the current fuel quality regulations. As a result, there is no regulatory requirement for a BDN. As the BDN takes on new functions under Chapter 4's carbon intensity regulations, like documenting C_f, this too may require reconsideration.

The Broadening Horizon Ahead

As significant as these developments are, and as much as they expand the scope of IMO regulatory activity, one stone remains unturned along the path to reducing overall CO_2 contribution from shipping. Developments to date limited their scope to emissions from ship stacks and do not consider the energy required to produce fuels and the CO_2 that results. This broader, well-to-wake view of carbon intensity is assessed in a lifecycle analysis (LCA). Although international LCA standards exist, none have been incorporated into the MARPOL context yet. The IMO's GHG working group is, however, working toward developing guidelines for an IMO standard.[18]

But development of LCA guidelines would just be the first step towards incorporating a well-to-wake approach. Implementing LCA metrics in the IMO's carbon intensity regulatory regime would not just require new calculations for EEDI/EEXI and CII, it would require new documentation and reporting requirements. Just as the C_f for some fuels may become mandatory content for BDNs, so too may the lifecycle carbon intensity of a fuel. And where C_f for a type of fuel is essentially the same for all batches of fuel of a particular grade, lifecycle carbon intensity of a fuel may vary drastically for fuels of the same grade based on the energy sources used to produce it.

Ammonia, for example, produces water, nitrogen, and nitric oxides in combustion and is thus a serious contender for a zero-carbon marine fuel. Since it can be produced by different processes, using energy from a wide variety of sources, merely identifying the fuel as ammonia is insufficient to assess its lifecycle carbon intensity. Any regulatory system that accounts for lifecycle carbon intensity will require a means of ascertaining and verifying it.

Ultimately, the success of a well-to-wake carbon intensity accounting system—both in terms of net GHG reductions and economic viability—will depend on regulators' ability to devise a coherent, practicable approach to a challenge that spans both jurisdictions and disciplinary specialties. This is borne out by the history of other IMO regulatory projects. The IMO's early efforts with safety of life at sea realized their full potential only after flag state administrations' efforts were reinforced by port state control and safety management systems.

The more open ended, iterative, and metric-driven approach of Chapter 4 presents the maritime industry an unprecedented opportunity to meet a regulatory goal through the means of their choosing. Under Chapter 4, ship owners that embrace technological ingenuity and managerial innovation have unprecedented opportunity to set the future course for the industry more broadly. As industry takes up this challenge, regulators will face the accompanying challenge of regulating at the pace of technological change. Because of the unique life-cycle dimension of carbon intensity, regulators must not only assume new roles, but do so in an atmosphere demanding unprecedented levels of coordination.

Despite the modest volume of the new regulations in Chapter 4, their goal is anything but modest. And while the open-ended approach embodied in Chapter 4 provides fewer explicit standards for flag state and ports to enforce, the work of developing the implementing guidance, information collection processes, and iterative reductions are immense. Efforts to bring Chapter 4 into effect will not only change the maritime industry's relationship with fuel, it is likely to spur unprecedented regulatory innovation along the way.

About the author:

LCDR Benjamin Robinson is the deputy chief of the Coast Guard's Environmental Law Division of the Office of Maritime and International Law. He began his Coast Guard career as a marine inspector and has served in both legal and prevention assignments since. He holds a bachelor's degree in marine engineering and shipyard management from the U.S. Merchant Marine Academy and a Juris Doctor from the Seattle University School of Law.

Endnotes:

1. Regulation 20, 2021, Revised MARPOL Annex VI, Resolution MEPC.328(76). Unless specified otherwise, citations to regulations in MARPOL Annex VI are to the amended form adopted by MEPC 76 on June 17, 2021
2. Amendments to MARPOL Annex VI on Regulations for the Prevention of Air Pollution from Ships by Inclusion of New Regulations on Energy Efficiency for Ships Resolution, MEPC.203(62) (July 15, 2011). Initial IMO attempts to address CO_2 emissions from ships date to the 1997 International Conference of Parties to MARPOL 73/78. This effort led to the development of the EEDI precursor, Energy Efficiency Operational Indicator, promulgated in 2009 for adoption on a voluntary basis. Guidelines for voluntary use of the Ship Energy Efficiency Operational Indicator (EEOI), MEPC.1Cir.684 (Aug 17, 2009)
3. The IMO guidelines on calculating EEDI state that the C_f applied should be that of the fuel whose specific fuel consumption was used in the NO_X technical file. A table of standard C_f figures is provided for seven different fuels in the CII guidelines, on the other hand, recognize the possibility of using fuels not listed in the IMO table. For these fuels, the C_f should be obtained from the fuel supplier and "supported by documentary evidence" MEPC.336(76)
4. 2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships
5. Regulation 24
6. Regulation 25
7. IMO Marine Environment Protection Committee, EEDI database—Review of status of technological development MEPC77/INF.3 (20 Aug 2021)
8. 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP), MEPC.213(63) (Mar 2, 2012)
9. Amendments to MARPOL Annex VI (Data collection system for fuel oil consumption of ships), MEPC.278(70) (Oct 28, 2016)
10. 2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP) MEPC.282(70)
11. Because of the limited significance of deadweight tonnage for Ro-Ros and cruise ships, gross tonnage—a volumetric measurement—is substituted in calculating the CII for those vessel types. Regulation 28
12. Shipping was a responsible for 2.89% of the total anthropogenic greenhouse gas emissions in 2018. This proportional share increased from 2.76% in 2012. International Maritime Organization, Fourth IMO Greenhouse Gas Study (2020)
13. Regulation 21
14. Appendix 8, Procedures for Port State Control, A 31/Res.1138 (Jan 6, 2020)
15. Regulation 18.3
16. Ibid
17. Interpretation of regulation 18.3 of MARPOL Annex VI, related to biofuels. Submitted by IACS, MEPC 77/7/7 (Sept. 16, 2021)
18. ISWG-GHG, Further Work to Support the Development of Standalone Lifecycle GHG/Carbon Intensity Assessment Guidelines of Marine Fuels

Standing Tall on the Corner of Prosperity and Stewardship

Low country seaports champion social and environmental sustainability

by CDR Corydon Heard, D.B.A.
Deputy Sector Commander, Sector Charleston
U.S. Coast Guard

LT Nicole Corbett
Enforcement Division Chief, Sector Charleston
U.S. Coast Guard

LCDR Chad Ray
Marine Transportation System Human Capital Planner
U.S. Coast Guard

> *"Every great city has a great river. London has the Thames. New York has the Hudson. Washington has the Potomac. And Charleston… Charleston has two great rivers—the Ashley and the Cooper—and that's where the Atlantic Ocean starts."*
>
> —Sen. Ernest "Fritz" Hollings, South Carolina

Sprawling over the maritime forests dotting the low country's coastal plain, whimsically veiled in wispy Spanish moss, the Southern live oak, or *Quercus Virginiana*, is a hallmark of a region renowned for its natural beauty, rich culture, and deep history. Symbolic of strength and longevity, the live oak is indigenous to both the coastal climate and Southern appeal. Its curved trunk and wayward branches resemble the winding rivers and tidal creeks that feed into the Atlantic Ocean forming the profile of the low country coastline; the geographic region generally accepted as the area between the Charleston Watershed and the Savannah River Basin. Considering the natural grandeur and ambition of the low country, it should come as no surprise that the South Carolina statesman, who dedicated a storied career to ocean policy and conservation, would make such a bold proclamation regarding the origins of the Atlantic.[1]

Over the course of his 38 years in the U.S. Senate, Ernest "Fritz" Hollings garnered an environmental legacy by claiming a seminal role in the formation of the National Oceanic and Atmospheric Administration, enacting several pivotal environmental laws, and establishing the U.S. Commission on Ocean Policy.[2] It is no coincidence that his emphasis on "practical conservationism" would suit a region dependent on both traditional coastal economics as well as modern maritime trade. Indeed, as he prepared to depart the Senate in 2005, the Port of Charleston was embarking on a massive transformation, signaled by the opening

A symbol of strength and longevity, oak trees are plentiful in downtown Charleston, South Carolina's, historic Battery Park. Coast Guard photo by LT Nicole Corbett of the Arthur Ravenel Jr. Bridge. The bridge serves as a gateway for the next generation of cargo vessels that would soon set sail for the nation's Southeast in support of its burgeoning economy.

Fifteen years on and the South is the fastest growing region in the United States with a 10.2 percent population increase over the last decade.[3] The nation's Southeast corridor, in particular, has seen positive trends in every primary economic driver including tourism, technology, manufacturing, and logistics. Of significance, a boom in the automotive and aerospace industries across Charlotte, Nashville, and Atlanta has led to the exponential growth of its seaports, which connect these blossoming cities and the industries they host to the rest of the world. The ports of Charleston and Savannah, Georgia, have both capitalized, making significant investments in waterfront infrastructure and deep draft channels with a clear vision of balancing economic growth with social and environmental impacts through the integration of sustainable technologies, operations, and outreach.[4] Accordingly, each state's Port Authority is making substantial "green" contributions toward safeguarding the natural environment and cultural heritage of the low country with efforts to bring holistic and lasting success to a region known for strength and longevity.

Low Country Initiatives

Over the past 20 years, the South Carolina Ports Authority (SCPA) and Georgia Ports Authority (GPA) have delivered record-breaking numbers in terms of containers, break-bulk, and ro-ro movements, ranking both Charleston and Savannah in the top 10 U.S. container ports. SCPA's capital improvements have undoubtedly reshaped and improved the economic landscape for South Carolina. Similarly, GPA's march toward widespread growth through habitual improvements of the Garden City Terminal—the largest of its kind in North America—and its $973 million harbor expansion project, has boosted Georgia's capability to reach 44 percent of U.S. consumers and manufacturers within two days.

Despite these blockbuster headlines, the fact remains that increased port activities can lead to environmental impacts on air, water, marine life, and land. And port authorities have a vital role to play in mitigating adverse effects to health and the environment. Generally, these impacts can be categorized into three main sources—vessels calling on the port, organic port activities, and transport distribution networks beyond the port. Understanding the wake of these projects and their impacts on the environment is imperative as the SCPA and GPA devote resources to consciously preserve the idyllic landscapes, natural resources, and communities quintessential to the low country way of life.

Air

Dum Spiro Spero. While I Breathe, I Hope.

The Latin phrase adorns the South Carolina state seal and is employed as a motto to symbolize grit and determination. Fortunately, any breath of perseverance taken outdoors in the low country has the likelihood of being clean and fresh. According to the American Lung Association's *State of the Air* report, both Charleston and Savannah are tied for the country's cleanest metropolitan areas for 24-hour particle pollution. Similarly, while Charleston has an above average ranking for low ozone—or smog—days, Savannah is again tied for the cleanest.[5]

However, neither state's Ports Authority rests on a picturesque sea breeze to maintain the area's healthy draw of breath. Instead, through separate initiatives, strategic coalitions with nearby communities and state-run air working groups have been created. These groups ensure constant engagement with their local communities, focusing on the well-being of those that live close to one of the Ports Authority operations and could be impacted by the supply chain transportation logistics system.

In addition, mirroring the shipping line's next-generation fleet of efficient, ultra-large cargo ships that call on low country ports each day, both SCPA and GPA have earned initiatives that will implement a variety of emission-reducing technologies. Through the Diesel Emission Reduction Act, SCPA has earned a $2 million grant to repower 12 rubber-tired gantry cranes with hybrid systems. There is also a $1.3 million grant to repower eight diesel freight haulers with new zero emission, battery electric-powered tractor trucks, reducing harmful emissions from each piece of equipment by 98 percent. SCPA also invested in 25 new hybrid rubber-tired gantry cranes at the Hugh K. Leatherman Terminal. These cranes are 100 percent electric

South Carolina Ports Authority's Capital Investments

- a $500 million investment into the Wando Welch Terminal
- inaugurating the Hugh K. Leatherman Terminal as the first new U.S. container terminal in more than 10 years
- $565 million jointly funded U.S. Army Corps of Engineers Charleston Harbor Deepening Project (aka "Post 45"), which will yield one of the deepest harbors on the East Coast at 52 feet

South Carolina Port Authority's hybrid Rubber-Tired Gantry cranes at the state-of-the-art Hugh K. Leatherman Terminal reduce emissions with each move. South Carolina Ports Authority photo by English Purcell

battery powered, which significantly reduces air emissions and fuel consumption.

Similarly, through the same Act, GPA begins an eighth year in its Drayage Truck Replacement program. Conversationally referred to as "Dray Trucks," this program aims at replacing older, diesel-emitting trucks with newer, eco-friendly models. Owners and motor carriers are now financially encouraged to "go green," an option that previously would have been too expensive. As a result, according to the Environmental Protection Agency's Diesel Emission Quantifier, emissions of nitrogen oxides, particulate matters, hydrocarbon, and carbon monoxide have all been reduced by 10 percent.

GPA's continued engagement towards green initiatives has allowed it to capitalize on a variety of other innovations. The use of electric refrigerated container racks keeps cargo cold, saving 54,000 gallons of diesel each year. Implementing all-electric rubber-tired gantry cranes at the Appalachian Regional Port has reduced the equipment's fuel consumption by 95 percent and virtually eliminated harmful emissions. Finally, refitting the Port of Savannah's ship-to-shore cranes with hybrid capabilities has provided the sky-scraping equipment enough battery power to run each crane for 18 minutes per hour.

Water

As a maritime agency, SCPA depends on a healthy waterway to efficiently handle record-breaking cargo volumes and retail imports, which continue to grow year-over-year. Recognizing the importance of the medium in which they operate, SCPA revels in the opportunity to engage in environmental initiatives that positively impact its clients' mode of transportation. Its role in island and oyster restorations, storm water management, and water monitoring impacts the vital ecosystems, marine species, recreational activities, and local business for the better.

Drum Island, which sits in the center of Charleston Harbor and is the footing for the skyline's Arthur Ravenel Jr. Bridge, is used for dredge spoils from harbor dredge projects. A condition of the 1972 Federal Clean Water Act requires companies that impact national waters and wetland properties to mitigate damage by recreating or preserving new wetland habitats. Twenty-two acres of Drum Island's southern end was revitalized into a thriving salt marsh, changing the public perception of dredge spoils from that of waste to a valuable resource.

Started in 2019, a $3.5 million investment in the Drum Island project allowed for the excavation of approximately 115,000 cubic yards of dirt and the fine grading of the landscape so it was similar to adjacent wetland elevations. It also allowed for the planting of more than 106,000 native marsh plants. Now, this once-eyesore is a highlight for commuters crossing over the Cooper River as various birds, fish, and other marine life can be seen feeding on the island daily. These planted marsh grasses are also now providing some seed stock to South Carolina Department of Natural Resources and its ongoing marsh restoration efforts. Additionally, this has fostered partnerships between the South Carolina Department of Natural Resources, local non-profit groups, and SCPA, creating oyster beds not only on the island, but throughout the harbor, totaling 12 acres of small fish habitat and natural filtration.

A loggerhead hatchling on Georgia's Wassaw Island makes its way to the sea for the first time. Photo courtesy of the Caretta Research Project

Marine Life

As part of their efforts to foster and promote a healthy marine ecosystem, the SCPA and GPA have prioritized conservation of protected indigenous marine species. In Charleston, the SCPA's financial contributions have advanced the maintenance and preservation of the Crab Bank Bird Sanctuary, home to a variety of sea- and shorebirds including threatened species like the Black Skimmer and Least Tern. Additionally, dredged sediment from the Charleston Harbor Deepening Project created approximately 32 acres of new land to serve as a bird-nesting habitat. The partnership with the South Carolina Coastal Bird Conservation Program exemplifies the strong relationships needed to achieve port growth while mitigating environmental impacts.

Similarly, since 2005, GPA has invested thousands in the Caretta Research Project (CRP), a conservation organization named after the predominant low country sea turtle species, the loggerhead, or *Caretta Caretta*. Established in 1973, the CRP studies, supports, tracks, and protects nesting sea turtle mothers and their nests on Georgia's Wassaw Island. While all sea turtles play an essential role in the marine ecosystem, the loggerhead provides multiple benefits including:

- calcium and nutrient recycling for other species through their hatched eggshells
- stimulation of dune grass growth from nesting
- epibiont habitat promotion through settlement on their shells

Other low country varieties, such as the green sea turtle, consume seagrass which contributes to the healthy regrowth of seagrass beds. The large and endangered leatherback sea turtle feeds on jellyfish, an over abundant species that preys upon fish larvae, which helps keep marine food chains balanced.

Every year, the CRP accepts 80 to 90 volunteers that stay overnight for a week alongside wildlife biologists on Wassaw Island's National Wildlife Refuge, an uninhabited, yet critical habitat and location for loggerhead nesting. Volunteers and biologists work from early May through mid-October to monitor nesting females, collect individual biometrics, protect nests, and observe hatchlings along a 6.5-mile-long beach.[6] The CRP also collaborates on a coast-wide genetics project lead by the University of Georgia in which one egg is collected from every nest along the coast, and its mitochondrial DNA is used to identify individual nesting females. In a single reproductive year, female loggerheads lay between four and eight nests with an average of 120 eggs per nest. Over the past 49 years, the CRP has protected and monitored 1,930 individual turtles and 5,440 nests leading to the release of over 373,900 hatchlings, significantly bolstering loggerhead population growth.

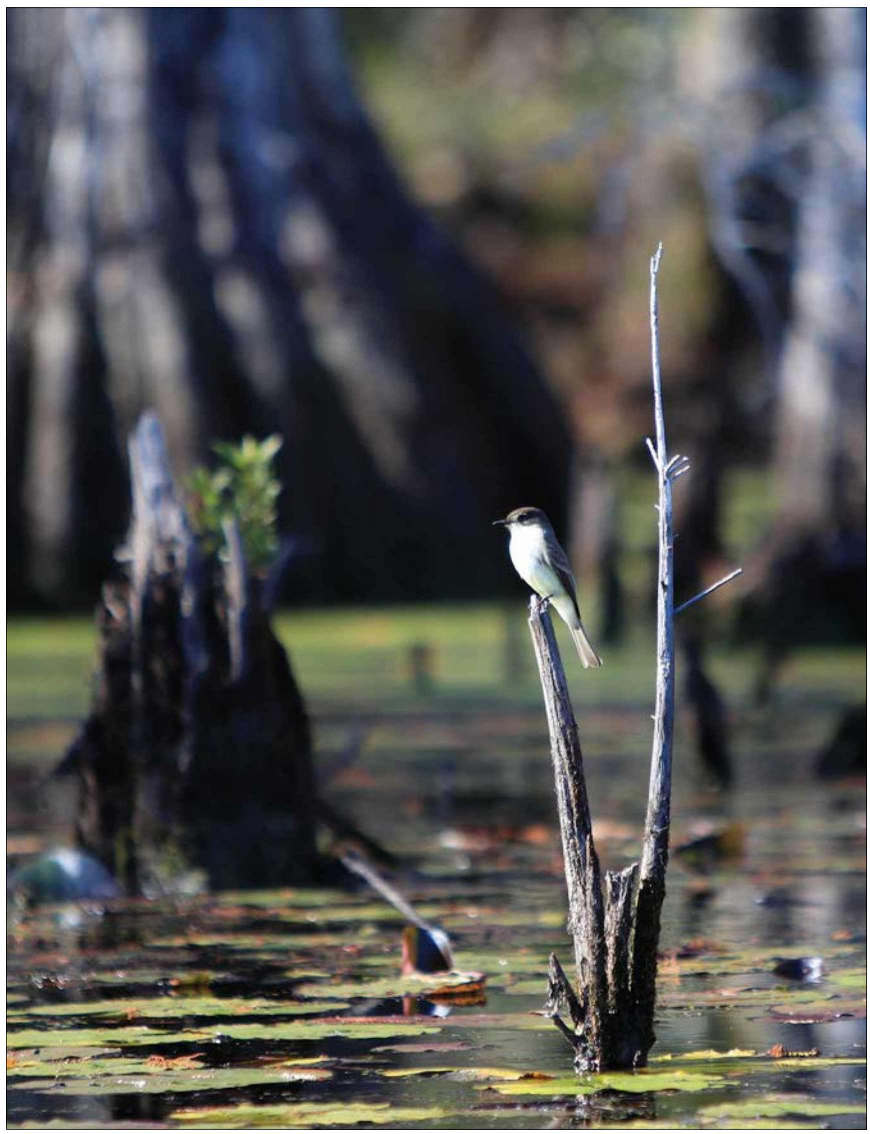
The odds of long-term survival from hatchling to adulthood and sexual maturity—25 to 30 years—is less than 1 percent worldwide for all seven species of sea turtles. In 1978, the loggerhead sea turtle was listed as a threatened species and federally protected under the Endangered Species Act. The first loggerhead conservation efforts consisting of nest protection in Georgia began on Little Cumberland Island in 1969, ahead of the federal listing. Since 1989, biologists have observed a significant increase in nesting activity due to these efforts, which has in turn led to an increase of the number of loggerheads reaching sexual maturity along the low country coast.

Land

Since 2016, SCPA has partnered with environmental groups to preserve and restore nearly 3,000 acres of South Carolina land. The historic Fairlawn Plantation represents 1,142 acres of this preservation initiative and is home to the 170-acre Mayrants Reserve, which serves as an "Important Bird Area" as designated by the Audubon Society. "The preservation of Fairlawn will provide habitat benefits to threatened and endangered species such as the frosted flatwoods salamander, gopher frog, and red cockaded woodpecker, as well as restore longleaf pine forest and provide protection to a variety of native wetland plant," Mark Messersmith, SCPA's permitting manager, said.[7]

Similar initiatives surrounding the greater Charleston Port Complex include, but are not limited to, preservation efforts of the 425-acre Charleston French Quarter and 589-acre Hyde Park Plantation. In addition, the preservation efforts at Timothy Creek and Four Holes Swamp Watershed, a 325-acre area, support SCPA's latest blockbuster strategic collaboration with Walmart and its new 3 million-square-foot distribution center.

Additionally, the Savannah River ecosystem has benefitted from GPA's initiatives. Since 2014, more than 100 million gallons of rainwater each year have been rerouted through a 14-acre wetland, eloquently wedged within the heart of GPA's flagship Garden City Terminal. This $3.7 million project leverages microbes living at the roots of regional flora, like sawgrass and rushes, to eat harmful pollutants in rain runoff prior to its entry back into the Savannah River. Aside from providing healthy oxygenated water for the river's marine wildlife, the



Mayrants Reserve, part of nearly 3,000 acres preserved and restored by South Carolina Ports Authority and partners, serves as an Important Bird Area as designated by the Audubon Society. South Carolina Ports Authority photo by English Purcell wetlands have also supported the refuge of local crawfish, brim, egrets, and dragonflies.

GPA has invested thousands to better serve the residential areas in close proximity to the port that are impacted by pollution, noise, and traffic from port industrial sites. Those funds have gone into funding neighborhood community centers, recreational facilities, park beautification, and air monitoring for several communities. GPA's relationship with the Brickyard community, comprised of five small streets between Carver Heights and Bay Street Viaduct at the base of Highway 17, brought attention to an overgrown berm causing excessive noise for residents and resulted in the new construction of a community-gathering pavilion south of GPA's Ocean Terminal facility. Conscious actions by the Port Authorities to nurture forested and urban wetlands resulted in improved water quality and wildlife habitats enabling future generations to enjoy the natural beauty of the low country.

On the Horizon

According to the Smithsonian Institution, the live oak has been a symbol of safety, strength, and resilience for centuries. Like the mighty live oak, a keystone species that serves as the backbone of its ecosystem, the low country's seaports are the economic engine and foundation of the regional economy.[8] Today, the American Southeast is realizing anticipated growth spurred by strategic economic development. In South Carolina, one in 10 jobs are created by the SCPA, and in Georgia the GPA now accounts for 10 percent of total state employment.[9,10] As a result, the low country seaports of Charleston and Savannah are primed for additional throughput as harbor deepening and infrastructure modernizations climax.

Central to this transformation is a vision to improve and minimize any socio-environmental impacts, while partnering with federal and state agencies to bring sustainable success to the region; a revelation foretold more than 20 years ago by Sen. Hollings.

> *In the year 2002, as our population grows, more and more people are moving to the coast to enjoy its beauty and recreational opportunities. As these good folks move to take advantage of coastal living, we have to be careful that we don't destroy the natural resources and quality of life that draw them to our shores. Big changes are coming to all of our coastal counties, and we must make some careful and smart decisions if we want to keep the very resources we depend on.*[11]

According to the International Chamber of Shipping, shipping is the form of commercial transport least damaging to the environment.[12] No doubt, ships can carry vast amounts of cargo in a single trip, reducing road congestion and highway traffic. Nevertheless, with approximately 90 percent of all globally traded goods traveling by sea, it is imperative that ports and shipowners join forces to better understand and implement the meaningful solutions needed to curb any adverse impacts of maritime trade on the environment. Moving forward, continued investment in sociological-environmental programs, technologies, and ingenuity will be integral to responsible global commerce and regional viability.

About the authors:

CDR Corydon Heard is the deputy sector commander at Sector Charleston. He has served in the Office of Budget and Programs as well as the Office of Commercial Vessel Compliance at Coast Guard Headquarters. Prior field assignments include Marine Safety Unit Texas City, Activities Europe, and Sector Baltimore. He is a graduate of the U.S. Merchant Marine Academy, holds an unlimited U.S. Merchant Marine Officer endorsement, and has earned a master's degree, as well as a doctorate in Business Administration.

LCDR Chad Ray is the Marine Transportation System human capital planner in the Office of Waterways and Ocean Policy at Coast Guard Headquarters. Prior field tours include Sector Charleston, Sector New York, Sector San Diego, and USCGC Hamilton *(WHEC-715). He is a graduate of the U.S. Merchant Marine Academy and holds an unlimited U.S. Merchant Marine Officer endorsement.*

LT Nicole Corbett is the Enforcement Division chief at Sector Charleston and is responsible for overseeing the Living Marine Resources program across the low country. Previously, she served as the special assistant to the military advisor to the Secretary of Homeland Security. Prior field tours include Sector Miami and USCGC Morgenthau *(WHEC-722). She is a graduate of the U.S. Coast Guard Academy.*

Endnotes:

1. A native Charlestonian, Citadel alumnus, University of South Carolina graduate, and World War II veteran—Senator Hollings began his political career in the South Carolina House of Representatives (1949–1954); served as both Lieutenant Governor as well as Governor; and went on to represent South Carolina in the U.S. Senate for 38 years, from 1966 to 2005
2. The Coastal Zone Management Act (1972), the Marine Mammal Protection Act (1972), the Oceans Dumping Act (1976), the Sustainable Fisheries Act (1996), and the Oceans Act (2000). /www.noaa.gov/office-education/hollings-scholarship/about-senator-hollings-0
3. *How Did State Populations Change 2010–2020?* Population Reference Bureau. www.prb.org/resources/how-did-state-populations-change-2010-2020/
4. The National Socio-Environmental Synthesis Center defines "Socio-Environmental Systems" as tightly linked social and biophysical subsystems that mutually influence one another and can include; human behaviors, decisions, and policies that influence the status of ecosystems (e.g., water quality), which in turn, influence human beings' quality of life and future decisions. Socio-Environmental Systems. SESYNC. www.sesync.org/socio-environmental-systems
5. www.lung.org/research/sota/city-rankings/msas/charleston-north-charleston-sc#pm24
6. For more information, volunteer opportunities and ways to support the Caretta Research Project and South Carolina Coastal Bird Conservation visit online at: www.carettaresearchproject.org and www.sccoastalbirds.org
7. *SC Ports preserves land*. SCSPA. http://scspa.com/about/our-impact/environmental-initiatives/land/
8. *The Live Oak*. Smithsonian Gardens. https://gardens.si.edu/gardens/nmaahc-landscape/the-live-oak/
9. *South Carolina Ports 2021 Annual Report*. South Carolina Ports Authority (scspa.com). http://scspa.com/about/publications/annual-report/
10. *Georgia Ports FY20 Annual Report* (dcatalog.com), p 28. https://gaports.dcatalog.com/v/FY20-Annual-Report/?1637872957&page=28
11. Sen. Hollings, Congressional Record, June 11, 2002
12. *Environmental Initiatives*. International Chamber of Shipping (ics-shipping.org). www.ics-shipping.org/shipping-fact/environmental-initiatives/

Leveraging Partnerships to Build Climate Change Resiliency in the Arctic

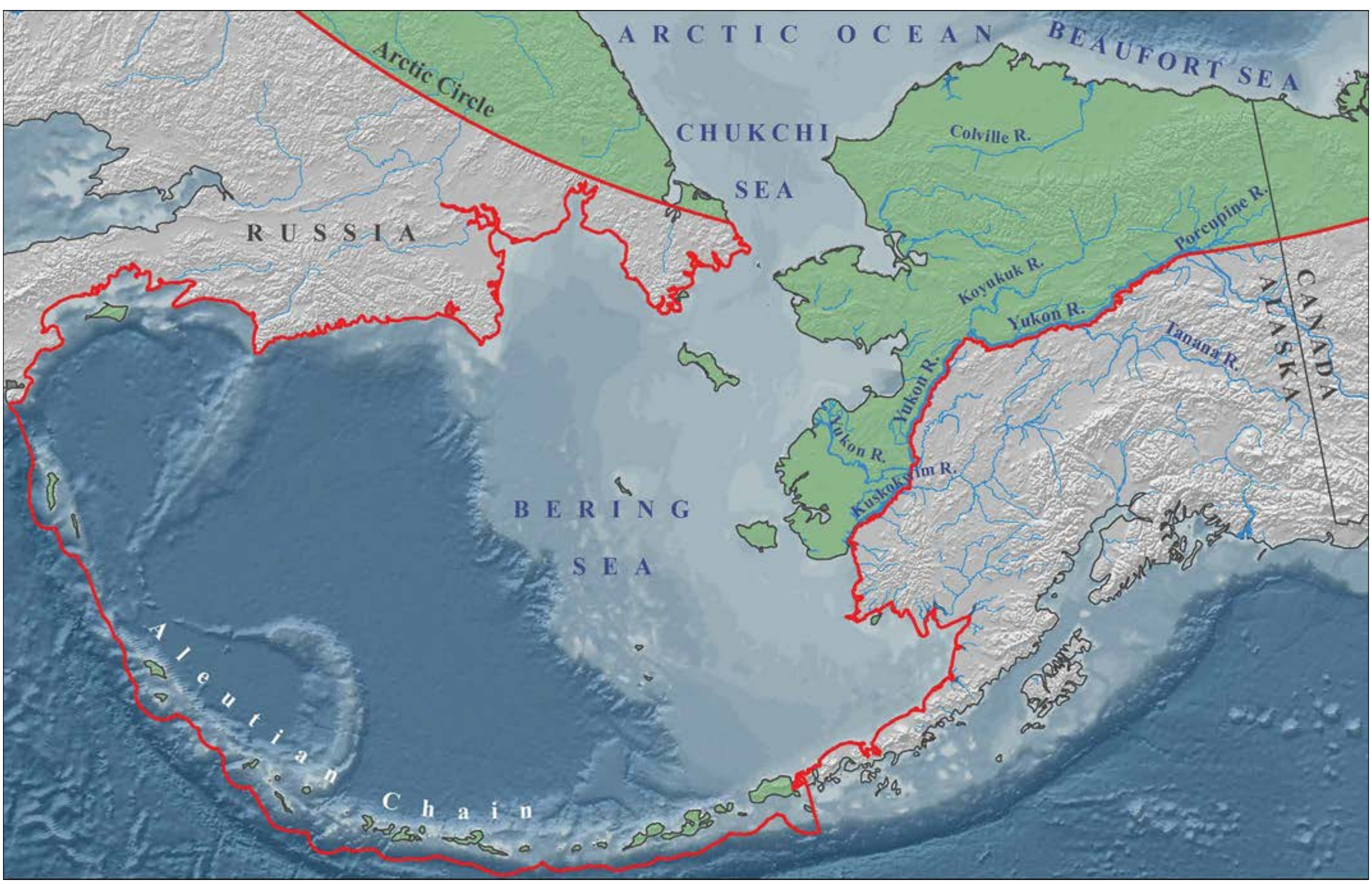
by CDR Jereme Altendorf
Arctic Emergency Management Specialist
U.S. Coast Guard

LCDR Matt Richards
Chief, Emergency Management and Force Readiness Division
U.S. Coast Guard

The rapid pace of climate change in the U.S. Arctic is posing an increased risk for oils spills from vessels traveling Arctic waters, as well as above ground bulk fuel tanks located in every rural Arctic community.

Annual mean surface temperatures in the Arctic have increased by approximately three times the global average over the last 50 years. Specific consequences include, but are not limited to, reduced seasonal sea ice—further opening the Bering Strait to international traffic—significant shoreline erosion, increased permafrost thaw, and more powerful storms, all leading to more severe infrastructure degradation. In some instances, entire Alaskan villages are forced to relocate from the lands their ancestors have called home for thousands of years.

While some areas around the world are planning on how to react to the consequences of climate change, in the U.S. Arctic consequences are being felt now. Region by region, each community must cope with the exposure



The Arctic boundary, as defined by the Arctic Research and Policy Act includes, "all United States and foreign territories north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian Chain." U.S. Arctic Research Commission to different climate change-related shocks, risks, and contingencies to their established way of life. These documented vulnerabilities may be as unique as the communities, families, and individuals affected. This makes building and sustaining resilient geographic communities and villages incredibly difficult.

Therefore, government agencies with relevant statutory or regulatory compliance requirements, to include any of their associated public-private partnerships, have a duty to incorporate adaptive capacity concepts within the bounds of their associated compliance verification program(s). This describes how Coast Guard regulatory program activities changed in conjunction with the changing Arctic environment. Since 2019, Coast Guard Sector Anchorage has acted upon two of the three lines of effort from the Coast Guard's Arctic Strategic Outlook—partnerships and unity of effort. By merging legacy federal environmental law compliance programs with an intentional effort to build dynamic, community-adaptive capacity, the Coast Guard created a blueprint for building and sustaining resiliency within the Arctic.

Life in the U.S. Arctic

The Coast Guard adopted the Arctic Research and Policy Act definition of the Arctic, which includes regulated entities that may impact the Arctic. This area is populated by Alaska Natives, who are part of federally recognized tribes. Their history and identities are directly connected to the land; a connection that is more complex than we could ever fully describe. The ability to obtain a food source year-round that does not have to be shipped in, makes Arctic life possible. Maintaining a traditional-use lifestyle is especially important after U.S. Arctic communities transitioned away from their traditional nomadic culture in the mid-1970s. This lifestyle shift was possible because the U.S. government established school systems and supporting infrastructure, like bulk fuel tank farms fed primarily by annual/biannual tug and barge delivery to power and heat the schools.

Norlisk Oil Spill: A Warning

Thermokarst, erosion from the thawing of ice-rich permafrost, is already being blamed for a significant Arctic oil spill in the Russian Arctic. On May 29, 2020, 4 million gallons of diesel fuel flowed into local rivers when a fuel tank at the Norilisk-Taimyr Energy Thermal Power Plant Number 3 failed. Norilsk Nickel, the Russian company that owns the plant, blamed the incident on instability of the ground underneath the tank due to thawing permafrost, causing one of the tank's pillars to collapse. The Russian government stated it was ordering safety checks on all installations built on permafrost in Russia's Arctic region.

U.S. Arctic Bulk Fuel Tank Infrastructure

Currently, there is no comprehensive evaluation of the status of bulk fuel tanks in the U.S. Arctic. However, better information exists thanks to the collective efforts of the Coast Guard and its partners.

Many of the bulk fuel tank farms in Alaska's rural

Frost heaves and permafrost thawing threatens fuel tanks like these near Newtok, Alaska, shown in October 2018. Coast Guard photo communities are now beyond their designed service life, a problem exacerbated by the high cost of bulk fuel tank maintenance in small, remote, communities not accessible by established roadways. These maintenance tasks and costs are further impacted by an increase in the number and intensity of extreme weather events. Facilities, like those in Newtok, Alaska, are especially susceptible to changes in stability caused by permafrost thaw and ground erosion.

In August 2019, the Lower Kuskokwim School District's fuel storage facility sat just 76 feet from the riverbank's erosion point along Alaska's Kuskokwim River. When the Coast Guard issued an administrative order to the facility's owner, the district, to remove the contents, the tanks held a estimated 36,000 gallons of home heatin oil. Coast Guard photo

Of the 380 regulated bulk fuel facilities in Sector Anchorage's area of responsibility, only 36 are accessible via the Alaskan road system. The other 91 percent of the total regulated facilities are in remote communities and generally owned and operated by Alaska Native tribal governments and/or subsidiary general stores where fuel and goods are purchased. Most villages are only accessible via aircraft, where landing requires small propeller or bush planes landing on, and taking off from, small gravel airstrips. Any consistent commercial service schedules that do exist in villages are not designed to support the needs of regulatory inspectors, examiners, or investigators, making these facilities extremely difficult and expensive to travel to. Given the challenges Sector Anchorage faces maintaining situational awareness of their regulated entities, one can only imagine the challenges facing those charged with the operations and maintenance of each privately owned and managed bulk fuel tank. Without developed roads, airports, and port facilities, which are accessible by car for most Americans, the supply chain for the U.S. Arctic takes significantly longer and is much more expensive than anywhere else. This lack of modern infrastructure also limits communities' ability to undertake even minor projects to safeguard against environmental impacts. For example, when coastal erosion and permafrost thawing destabilizes or threatens to destroy fuel farms, mitigating measures are not easily undertaken locally and require state and federal intervention. These interventions can include federal or state administrative orders to act, compliance assistance, external grant funding, or state and federal regulators taking action to remove the pollution threat or mitigate an active spill.

Regionally Based Solutions are Difficult

Several realities of life in the U.S. Arctic prevent Alaskan communities from "scaling up" oil spill prevention and preparedness programs regionally. Joint response programs and pre-positioned oil spill response equipment are either non-existent or extremely limited in effectiveness due to the vast distance between communities, lack of dedicated professional facility operators and response managers, and absence of commercial oil spill response organizations. The remoteness of these villages also limits the ability for state and federal oversight, assistance, and training. Geographic isolation, as well as limited communications capabilities and connectivity, complicate regional programs and initiatives in a way that is entirely different from the continental United States.

Tribal and municipal governments throughout rural Alaska have limited management capacity that prevent them from developing the strong partnerships necessary to build the adaptive capacity needed to safeguard communities from the impacts of climate change. This resource gap was noted in Article X of the Alaska Constitution, which established the Division of Community and Regional Affairs (DCRA) with the mission of providing support for tribal and municipal governments. While DCRA's staff of local government specialists is key to aiding tribal and municipal governments, state government support is not tailored to address these kinds of challenges. Combined with a lack of organized climate change policy, communities are left vulnerable to the rapidly intensifying impacts of climate change.

U.S. Coast Guard Response

The Coast Guard is closely monitoring the rapidly changing Arctic environment through annual congressionally mandated regulatory on-site inspections with the goal of identifying the consequences of climate change as they impact local communities, the maritime transportation system, and Coast Guard operations. Sector Anchorage's area of responsibility includes all of south central and western Alaska, as well as the North Slope and Aleutian Islands. This includes every tug- and barge-delivered bulk fuel facility and thousands of commercial fishing vessels.

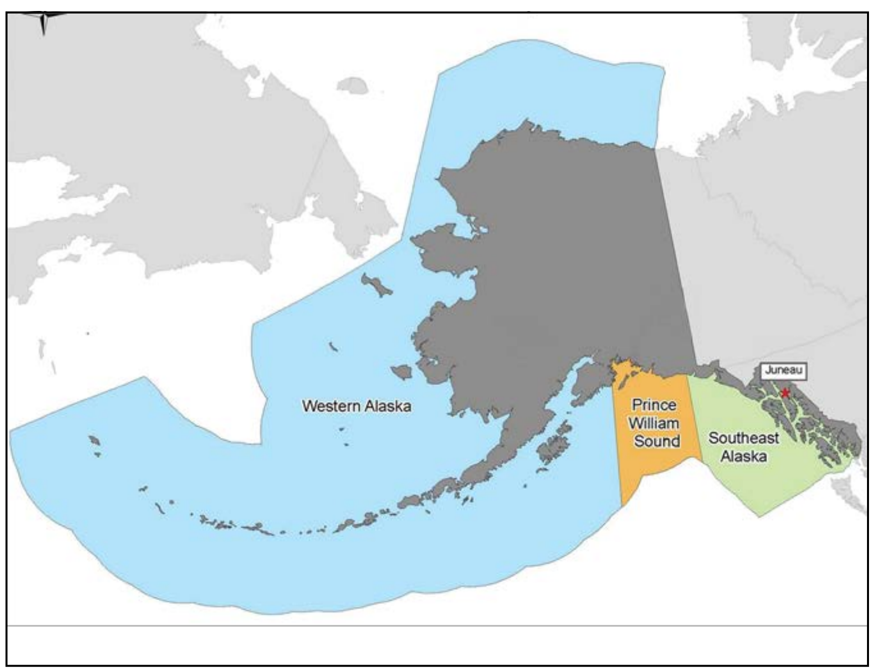
Unlike larger corporate managed facilities found in the contiguous United States, most of the facilities in Alaska are much smaller and operated part time by members of the community instead of professionally trained facility operators. All of these factors, coupled with impacts of climate change, have caused a dramatic increase in spills from these smaller facilities. Even these smaller spills can have severe impacts to the local communities that rely on the environment for subsistence foods.

For years, Sector Anchorage struggled to obtain regulated facility compliance status via on-site inspections consistent with similar Coast Guard operational units in the contiguous United States. Limited funding, personnel, and standardized Coast Guard regulatory processes not appropriate for the U.S. Arctic, lead to a dearth of basic compliance information regarding most of the Sector's regulated community. In fact, Coast Guard Sectors are not constructed or designed to support the collection, processing, and dissemination of our biennial bulk fuel facility inspection data and regulatory outreach operations to external partners. Despite these challenges, Sector Anchorage worked diligently to find unique ways to go beyond regulatory compliance program data collection regarding area preparedness and response planning for spills.

Starting in 2018, funding via the Arctic Shield program, managed by Coast Guard District 17, allowed for additional operational travel funding, providing an unprecedented ability for personnel to conduct compliance inspections in the Arctic and western Alaska. Due to the significant operational planning involved in coordinating regulatory requirements and the complex logistics for traveling Coast Guard inspectors and examiners, Sector Anchorage created the Arctic Coordinating Element, a unique deployment and logistics management group, which manages the multimission Marine Safety Task Force (MSTF). Subsequently, MSTF manages the seasonal deployment of teams to remote areas across the state for the purposes of conducting vessel and facility inspections, providing operator training, improving maritime domain awareness, and conducting outreach for preparedness and safety programs. The direct result of these efforts is a 395 percent increase in physically inspected facilities and an almost 2,000 percent increase in vessel inspections. The task force identifies high risk facilities which are prioritized for additional follow up and support, and these operations directly mitigate pollution and vessel safety risks, while improving maritime domain awareness.

Building Resiliency Through Legacy Regulatory Programs

Sector Anchorage was able to accomplish this by leveraging existing environmental laws and regulations to build an unconventional deployment model able to overcome the challenges of operating in the U.S. Arctic. Many of these laws also have an existing mechanism for building partnerships that include information sharing between government agencies, stakeholders, and the regulated



U.S. Coast Guard District 17's area of responsibility encompasses the entirety of the Alaskan coastline. However, Sector Anchorage is responsible for the area indicated in light blue, including the coastline plus 1,000 yards inland. Coast Guard map community.

Sector Anchorage has successfully relied on its legacy statutory and regulatory authorities, leveraging the partnerships that existed or creating new partnerships to assist communities in building community resiliency through better regulatory compliance. It is important to recognize that regulatory compliance is not one dimensional or binary, but is a desired result of integrated actions that include increased funding to ensure energy security by investing in above ground storage tanks and supporting infrastructure. Regulatory compliance also includes creating two-way information sharing via participation in legacy government committees that were designed to provide communities with assistance to prevent and protect them from internal and external threats.

Spill Location	Spill Amount	Spill Date
Kaktovik	4,200 gallons	January 2017
Scammon Bay	7,000 gallons	April 2018
Gambell	2,700 gallons	June 2018
Newtok	150 gallons	October 2018
Lower Kuskokwim	36,000 gallons (potential)	May 2019
Shuyak	16,000 gallons	August 2020
Wales	1,860 gallons	February 2021
Savoonga	20,000 gallons	March 2021

Spills from USCG regulated facilities that were 150 gallons or greater between January 2017 and November 2021. Coast Guard

Sector Anchorage uses the most applicable legacy laws and regulations, briefly discussed below, to help create opportunities to increase community resiliency.

National Oil and Hazardous Substances Pollution Contingency Plan

The National Oil and Hazardous Substances Pollution Contingency Plan was first developed in 1968, and provides a framework and guidance for oil discharge and hazardous substance release response operations. For facilities in a state of significant disrepair, Sector Anchorage has used 40 CFR 300.322, articulating a "substantial threat to public health or welfare of the United States," to identify a responsible party for a potential or actual oil discharge. Sector Anchorage uses this authority to further compel the responsible party to initiate removal actions, and initiate any necessary mitigation measures and/or clean-up and abatement activities.

The most notable of these cases was the response on Alaska's Lower Kuskokwim River where more than 150 feet of the riverbank had eroded, threatening to destroy the Lower Kuskokwim School District's 36,000-gallon tank farm. Sector Anchorage issued an Oil Pollution Act Administrative Order to the school district and provided oversight of their response actions, which included purchasing new tanks and placing them in a safe location before fuel was transferred.

Port and Waterways Safety Act

One issue frequently reported to the Coast Guard by tribal representatives is the shared use of the marine transportation system and the impacts of increased commercial traffic on traditional use activities. Seasonal whale hunting is an important cultural activity, as well as a major source of food for the year for many coastal tribes.

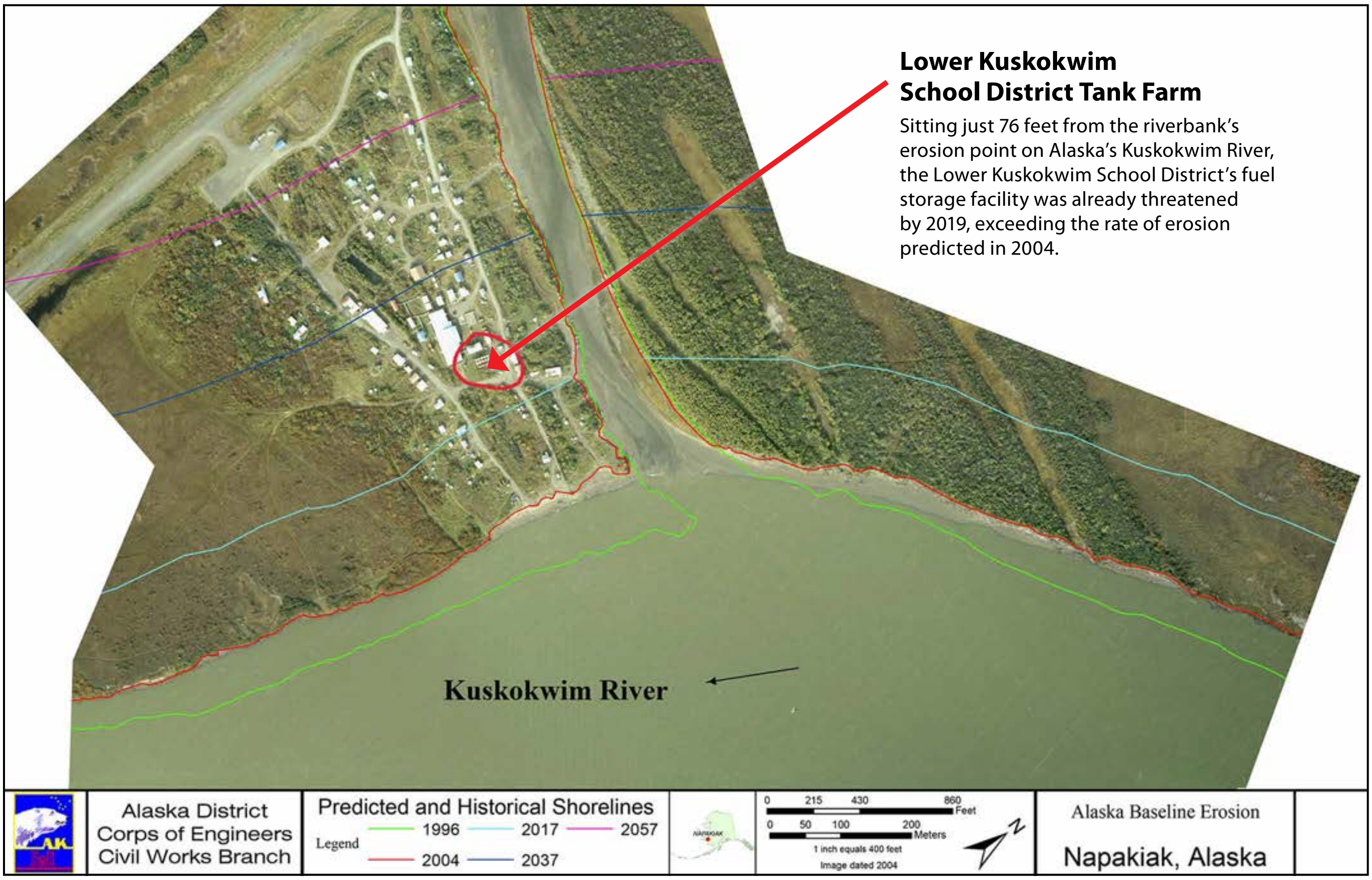
The Coast Guard used authorities granted by the Port and Waterways Safety Act to initiate the Arctic Alaska Port Access Route Study (PARS) to designate routing measures. The goal of PARS is to reduce the risk of marine casualties and increase the efficiency of vessel traffic. This study considers current and potential vessel traffic and density, coastal communities, military operations, wildlife, and tribal concerns. Changes to sea ice patterns and warmer ocean waters have changed the home range of key species and prevented access to traditional harvest areas. These changes have caused new conflicts with shared waterway usage that the Coast Guard hopes to help alleviate with PARS.

Oil Pollution Act of 1990

One of the key provisions of the Oil Pollution Act of 1990 (OPA 90) was the creation of an inspection regime for waterfront facilities via the Code of Federal Regulation (CFR). Specifically, 33 CFR 154.120 allows the "Coast Guard, at any time, to make any examination … to determine compliance."

Many of these facilities change the mode of delivery from barge to air, or vice versa, based on a combination of factors including cost. This makes it even more difficult to track Coast Guard inspection requirements.

Leveraging OPA 90 changes to the Clean Water Act, the Coast Guard uses the Arctic and Western Alaska Area Committee to plan and prepare for an oil discharge or hazardous substance release. This committee is responsible for managing the Arctic and Western Alaska Area Contingency Plan. It is the Clean Water Act requirements, as amended by OPA 90, in which the Coast Guard incorporates tribal input as it relates to oil discharge and hazardous substance release prevention, planning,



Lower Kuskokwim School District Tank Farm
Sitting just 76 feet from the riverbank's erosion point on Alaska's Kuskokwim River, the Lower Kuskokwim School District's fuel storage facility was already threatened by 2019, exceeding the rate of erosion predicted in 2004.

preparedness, response, and enforcement issues.

This input plays a vital role in driving contingency planning efforts and helping to frame the conversation on response tactics. In addition, it is through broad participation in area committees by all involved in preventing and responding to oil and hazardous substance incidents that the Coast Guard can validate climate change impacts to sensitive wildlife species. This includes changes to behavior and migration pattern as well as coastal erosion and other geographical impacts.

Now that the MSTF is in its fourth year of operational planning, Sector Anchorage's partnerships are necessary to the success of the program. As the only federal regulating entity consistently traveling to the Arctic and western Alaska, it is clear that Sector Anchorage has an important role to play in the effort to build more resilient communities. For example, the Sector partnered with DCRA to include basic Coast Guard regulatory information within its statewide bulk fuel facility geographic information system database. Additionally, under the umbrella of the Arctic and Western Alaska Area Committee, the sector partnered with the Denali Commission, the Environmental Protection Agency, Alaska Department of Environmental Conservation, DCRA, and the Alaska Energy Authority to form the Bulk Fuel Facilities Workgroup. This group meets several times annually to discuss each agency's needs regarding bulk fuel tank inspections, infrastructure status, and other related bulk fuel farm operational issues.

These discussions led to the inclusion of Coast Guard compliance status within DCRA's GIS database. Additionally, data compiled by Sector Anchorage is feeding a federally funded risk assessment project seeking to prioritize high-risk facilities to help decision-makers determine which bulk fuel facilities should receive prioritized federal funding for repair, recapitalization, and operator training.

> The Denali Commission is a federal agency created by Congress in 1998 with several missions focused on supporting rural tribes, including rural development and power generation.

Executive Order 13175 and Public Laws 108-199 and 108-477

Signed by President George W. Bush in November 2000, Executive Order 13175 (EO 13175) requires the federal government to establish "regular and meaningful consultation and collaboration with tribal officials in the development of Federal policies that have tribal implications." In 2004, EO 13175 was written into law via Public Laws 108-199 and 108-477. The public law expanded the consultation and coordination requirement with tribal entities and added government-to-government consultation requirements. This is especially important in Alaska where many tribes are organized into for-profit corporations. The Coast Guard has integrated tribal governments into its operational contingency plans and communication strategies in several ways, including through our commitment to engagement via the Arctic and Western Alaska Area Committee, as well as its subcommittees and workgroups. The annual MSTF operations also ensure that Sector Anchorage conducts routine biennial on-site bulk fuel facility inspections.

Conclusion

Climate change is resulting in coastal erosion, changes to the home range of key species, increased commercial traffic, and melting permafrost. These effects all have significant impacts on coastal communities and Coast Guard operations across various mission sets.

In Alaska, oil discharges from rural community bulk fuel farms are happening more frequently each year, and with greater potential impacts. Environmental sensitivity and the historic and cultural importance of the U.S. Arctic to Alaska Natives makes oil discharges a very high-consequence event. The high number of regulated facilities, their remoteness, the logistical challenges in maintaining existing infrastructure and building out new infrastructure, lack of communication options, and redundancy create a substantial challenge for the Coast Guard to effectively manage. The Coast Guard has leveraged legacy regulatory programs to build and/or enhance local partnerships to create a unique and effective collaborative relationship that identifies risk and mitigates the rapidly advancing effects of climate change in the Arctic.

Coast Guard Sector Anchorage has successfully leveraged partnerships with different state and federal agencies, regional stakeholder groups, and tribal entities. These partnerships help improve maritime domain awareness, forecast future impacts, identify at-risk facilities, and recommend prevention and mitigation measures that protect the Arctic environment and the Alaska Native's traditional-use lifestyle. This fact makes it imperative that the regulatory programs the Coast Guard promulgates incorporate the identification of vulnerabilities and ensures all follow-on actions via comprehensive compliance assistance, information exchanges, collaborative workgroups, etc., are designed with adaptive capacity principles in mind. Only consistent, joint, inter-agency regulatory compliance efforts and the creative use of existing environmental laws and regulations will assist rural Alaska communities in their efforts to increase overall community resiliency.

About the Authors:

CDR Jereme M. Altendorf is a United States Coast Guard reserve officer assigned to Sector Anchorage where he is the director, Arctic Coordinating Element which manages the annual operational planning cycle for the Marine Safety Task Force. He has worked in the environmental response field for more than 25 years, is a subject matter expert to the Sector Anchorage Federal On-Scene Coordinator, and manages several special projects for the Arctic and Western Alaska Area Committee.

LCDR Matt Richards is the chief of Emergency Management and Force Readiness at Coast Guard Sector Anchorage, and secretary of the Arctic and Western Alaska Area Committee. He was previously an expert consultant at the International Maritime Organization's Regional Activity Center in Curacao where he was responsible for capacity building activities for 33 Caribbean nations and territories.

References

Arctic Climate Change Update 2021. Arctic Monitoring and Assessment Programme, Arctic Council. www.amapno/documents/download/6759/inline

Arctic Research and Policy Act. (1984). 15 U.S.C. Section 4111. Arctic defined. https://www.law.cornell.edu/uscode/text/15/4111

Cotton, S. (1984). Alaska's "Molly Hootch Case": High Schools and the Village Voice. Retrieved from *Educational Research Quarterly*: www.alaskool.org/native_ed/law/mhootch_erq.html#journal

Hamilton, L. S. (2016, June 23). Climigration? Population and climate change in Arctic Alaska. *Population and Environment*, pp. 115-133. Retrieved from https://link.springer.com/article/10.1007%2Fs11111-016-0259-6

Marino, E. (2012, May). The long history of environmental migration: Assessing vulnerability construction and obstacles to successful relocation in Shishmaref, Alaska. *Global Environmental Change*, 22(2), pp. 374-381. Retrieved from https://doi.org/10.1016/j.gloenvcha.2011.09.016

Nechepurenko, I. (2020, June 4). Retrieved from *New York Times*: www.nytimes.com/2020/06/04/world/europe/russia-oil-spill-arctic.html

Norton-Smith, K. e. (2016, October). Climate Change and Indigenous Peoples: A Synthesis of Current Impacts and Experiences. Unites States Department of Agriculture. Retrieved from https://safe.menlosecurity.com/doc/docview/viewer/docN512A3E5175E54a00ee17524ef9334b8a02a43c0fb1b3b32f6bb50dfd2d692263997653e2bf60

Pacific Environment. (2021). Arctic PARS. Retrieved from www.arcticpars.org

Public Law 107-447. (2004, December 8). Retrieved from www.congress.gov/108/plaws/publ447/PLAW-108publ447.pdf

Public Law 108-199. (2004, January 23). Retrieved from www.congress.gov/108/plaws/publ199/PLAW-108publ199.pdf

Slats, R. e. (2019, November 22). Voices from the Front Lines of a Changing Bering Sea. Retrieved from https://arctic.noaa.gov/Report-Card/Report-Card-2019/ArtMID/7916/ArticleID/850/Voices-from-the-Front-Lines-of-a-Changing-Bering-Sea

Smith, A. (2020, April 1). Tribal nations demand response to climate relocation. *High Country News*

The State of Alaska. (1959, January 3). The Constitution of the State of Alaska. Retrieved from https://ltgov.alaska.gov/information/alaskas-constitution/

Vincent, W. (2010, July 15). Microbial ecosystem responses to rapid climate change in the Arctic. *The ISME Journal: Multidisciplinary Journal of Microbial Ecology*, pp. 1087-1090. Retrieved from https://doi.org/10.1038/ismej.2010.108

Walsh, J. O. (2011). Ongoing Climate Change in the Arctic. *Ambio: A Journal of Environment and Society* (40), pp. 6-16. Retrieved from https://doi.org/10.1007/s13280-011-0211-z

Welch, C. (2019, October 22). Climate Change has finally caught up to this Alaska village. *National Geographic*. Retrieved from www.nationalgeographic.com/science/article/climate-change-finally-caught-up-to-this-alaska-village

White House. (2000). Executive Order 12175 of November 6th. Consultation and Coordination with Indian Tribal Governments. Retrieved from /www.federalregister.gov/documents/2000/11/09/00-29003/consultation-and-coordination-with-indian-tribal-governments

Corporate Social Responsibility

Maritime Sustainability

Regulatory landscape and decarbonization solutions

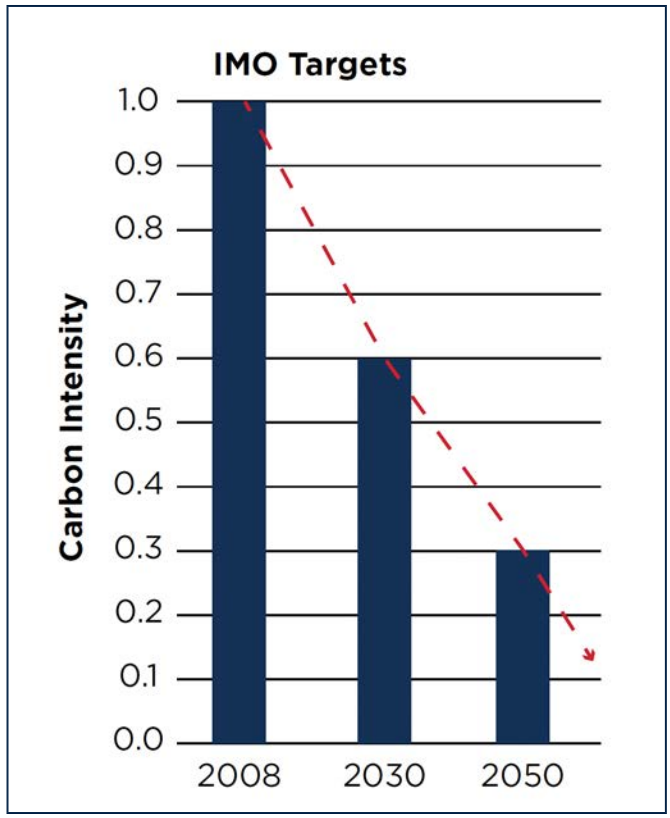
by Matthew Davidson
Vessel Performance Engineer
American Bureau of Shipping

Sarah Bell
Sustainability Engineer
American Bureau of Shipping

International shipping is undergoing a transformation based on global efforts to reduce greenhouse gas (GHG) emissions from shipping, which includes adjusting to the impact of the International Maritime Organization's (IMO) GHG reduction strategy and the relevant regulatory changes. There is, however, consensus that adapting to the new rules and challenges aimed at lowering the industry's collective carbon footprint will be another period defined by the emergence of innovative solutions. There is a range of solutions available to meet the IMO decarbonization goals, as well as other decarbonization drivers, which essentially fall under three categories:

- the use of alternative fuels that have a low- or zero-carbon content
- technology improvements
- operational measures

It is expected that a combination of low- or zero-carbon fuels, technology improvements, and operational measures will provide the solution to meet the decarbonization targets set by IMO and other industry stakeholders.



Graphic courtesy of the American Bureau of Shipping

What is Driving Decarbonization?

The are several key drivers behind the efforts to decarbonize the industry, including:

- existing and future IMO regulations
- societal pressures on companies to operate sustainably in all aspects
- financial institutions supporting the purchase of new ships and retrofits
- corporate governance and shareholders pushing to reduce emissions
- charterers looking for assurance that vessels will be compliant and as efficient as possible
- market-based measures (MBMs) introduced by local and regional authorities

As a result of the IMO's continuous work, part of a global effort to address climate change, the organization adopted the initial GHG strategy in April 2018. The initial strategy has established goals that have caused consideration of potential improvements to vessel design and operational performance, as well as the immediate need to introduce low- and zero-carbon fuels.

The initial goals agreed to by the IMO in 2018 included a reduction of 40 percent in the carbon intensity of shipping by 2030, and 70 percent by 2050. This is in addition to a reduction in absolute GHG emissions of at least 50 percent by 2050, which brings the shipping industry broadly into line with the goals of the U.N.'s Paris Agreement to combat climate change.

Regulatory and Commercial Decarbonization Initiatives

IMO Regulations

The initial GHG strategy introduced a list of candidate short-term, mid-term, and long-term measures to support the IMO's ambition levels. Short-term measures include the evaluation and improvement of vessel energy efficiency through the application of technical measures for existing ships and of operational measures. The basis of the short-term measures lies in the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) regulations, with which all ships over 400 GT and 5000 GT, respectively, will have to comply when they become effective. The regulations are currently under development and will be finalized for implementation at the beginning of 2023 during Marine Environmental Protection Committee 78.

Mid-term and long-term measures include developing an implementation program for alternative low- and zero-carbon fuels, adoption of other possible innovative emission reduction mechanism(s), and MBMs to incentivize GHG emissions reduction. These measures are being considered now with a view to take effect between 2023 and 2030.

Poseidon Principles

This is a global framework for assessing and disclosing the environmental performance of the shipping portfolios held by financial institutions. These principles apply to the lenders, the lessors, and financial guarantors, including export-credit agencies, and are consistent with the policies and ambitions of the IMO. For the global fleet, the Poseidon Principles adopt a decarbonization trajectory similar to the IMO's. Therefore, any vessels that have been financed by the signatories need to demonstrate their carbon-intensity reductions on an annual basis.

Sea Cargo Charter

Charterers are developing their own approach to address the carbon intensity of the vessels they charter. The latest initiative is the Sea Cargo Charter which forms a global framework for assessing and disclosing the environmental performance of chartering activities. Their objective is to set a standard for reporting the emissions associated with chartering activities, thus enhancing transparency and creating a global baseline to support the decarbonization of the global economy.

Market Based Measures

MBMs were included in the initial IMO strategy as a proposed medium-term measure to incentivize the reduction of GHG emissions. Several of these measures have been proposed, but two types seem to have the highest potential for application to shipping—the bunker, or carbon, levy and the global Emissions Trading System (ETS).

The bunker levy concept is based on a global GHG-reduction target. Any emissions above the target would be mostly offset by the purchase of emission-reduction credits. The offsetting activities would be financed by ships' contributions on the purchase of every metric ton of bunker fuel. After these offsetting activities are financed, any remaining funds would be available for adaptation and mitigation activities via the United Nations Framework Convention on Climate Change, as well as for research and development within the IMO framework.

The ETS is a cap-and-trade concept. The cap is set on the total amount of GHG emitted from shipping that would be reduced over time. Within this cap, shipowners and operators can receive or buy emissions credits, which they can trade with other companies, as needed. A limited number of credits—ship emission units—would be released into the market each year so that they have a value.

The European Union established its ETS in 2005, and the marine sector was recently added to this scheme.

Decarbonization Solutions

In the challenging transition to a global, low-carbon fleet by 2050, interim solutions will be crucial. A phased transition focused on retrofitting existing vessels and fuel substitution would offer valuable time for more rapid deployment of decarbonization technologies while allowing supply chains to become commercially viable. The global fleet's path toward meeting the long-term IMO GHG reduction targets will require significant changes to vessel technology and fuels. The adoption of new fuels and technologies will lead to new vessel design and construction, but it will also require significant infrastructure upgrades related to alternative fuel distribution and bunkering at port site facilities.

Alternative Fuels

Alternative fuels will play a dominant role in the decarbonization of the marine sector and are expected to yield the most benefits for reducing GHG emissions. The current regulatory framework is focused on vessel emissions tank-to-wake (TTW) rather than the overall life-cycle emissions of a given fuel, or well-to-wake. However, it is recognized throughout the industry that the life cycle carbon footprint of fuels provides the most complete description of their environmental impact.

Liquefied Natural Gas

Liquefied Natural Gas (LNG) is a relatively mature, low-carbon fuel comprised primarily of methane. It can reduce TTW emissions by about 20 percent compared to fuel oil. This value does not include carbon release from methane slip, which may be an issue in two- or four-stroke engines that operate on LNG in the Otto cycle. Minimizing methane slip is important and the industry is currently developing in-cylinder emissions control

Summary of Characteristics for Fuels Produced from Hydrocarbons

Fuel Type	LHV (kJ/kg)	Density (kg/m³)	Storage Volume Ratio	Vessel Specific GHG Emissions (g/kWh)[1]
VLSFO (ref)	41,600	944	1.0	568 (ref)
LNG	50,000	420	1.9	Diesel Cycle: 424 (-25%) Otto Cycle: 492 (-13%)
LH_2	120,000	71	4.6	0 (-100 %)
LNH_3	18,800	674	3.6	102 (-82%)
LPG	46,000	448	1.9	500 (-12%)
Methanol	19,900	796	2.5	533 (-6%)

This section presents comparative analyses of some of the alternative marine fuels and their life-cycle emissions, with the objective of offering a holistic view of the challenges associated with adopting low- and zero-carbon fuels.

The fuels include:

- Liquefied natural gas (LNG)
- Liquefied petroleum gas (LPG)
- Methanol (CH_3OH)
- Liquefied hydrogen (LH_2)
- Ammonia (NH_3)

The adoption of alternative fuels will require changes to ship designs in order to accommodate storage tanks, as well as fuel-containment and gas-supply systems. The table below offers some key indicators to compare the fuels and to understand some of the design implications. For comparison purposes, very low sulfur fuel oil (VLSFO) is used as the reference.

Graphic courtesy of the American Bureau of Shipping

strategies which could be combined with after treatment systems.

LNG's carbon footprint can be reduced or eliminated if it is produced from renewable sources. These fuels are known as bio-LNG, synthetic natural gas, renewable natural gas, or electro-methane, in which renewable energy is used to produce LNG with the use of electric power.

Liquefied Petroleum Gas

Liquefied Petroleum Gas (LPG) is primarily a mixture of propane and butane, with small fractions of other light hydrocarbon species. It is produced as a byproduct of the processing of natural gas or from oil refining and can be liquefied at low pressures and ambient temperature, which is a major advantage for its transportation compared to other gaseous fuels.

The combustion of LPG results in lower carbon dioxide (CO_2) emissions than diesel fuels due to its lower carbon-to-hydrogen ratio, but higher CO_2 emissions than LNG. This is due to LPG having a higher carbon-to-hydrogen ratio than LNG. However, when considering the life cycle of LPG, its production is less carbon intensive than that of diesel or natural gas. The life cycle GHG emissions of LPG have been reported to be 17 percent lower than that of heavy fuel oil or marine gas oil.

Methanol

Methanol may be used onboard ships as fuel for internal combustion engines or as a fuel source for fuel cell operation. On a commercial scale, it is most commonly produced from natural gas, but can also be produced from renewable sources like biomass or electrolysis using renewable power. Due to its potential to reduce the CO_2 output from marine vessels, methanol's applications are drawing a wide interest from shipowners and operators.

When natural gas is used as feedstock, the GHG well-to-tank (WTT) emissions of methanol are higher than fuel oil, which shows that the source of energy is an important factor impacting the life cycle GHG emissions. Using renewable energy for production greatly reduces the carbon footprint of bio-methanol.

Hydrogen

In recent years, the industry has recognized hydrogen's potential to offer a zero-carbon solution for the future. Hydrogen can be extracted from fossil fuels and biomass, from water, or a combination of the two. The key challenges with hydrogen are the stringent storage requirements and fire hazard mitigation. To become a competitive alternative marine fuel, hydrogen will also face the challenges of availability and high costs to upscale its production and transportation infrastructure.

It has the potential to be a zero-carbon marine fuel when consumed in a fuel cell or a single-fuel internal combustion engine. When consumed in a dual-fuel engine, hydrogen can significantly reduce carbon emissions resulting in very low TTW emissions. However, the lifecycle of hydrogen production must be considered to evaluate the overall carbon footprint of using hydrogen.

Ammonia

Ammonia is the second zero-carbon fuel considered for use in the marine sector, and its production pathway is directly related to hydrogen. It offers ship owners and operators a very low carbon TTW emissions profile, and is typically created by combining nitrogen with hydrogen. Therefore, the emissions from producing hydrogen as feedstock and the emissions arising from the synthesis of ammonia should be considered as part of the life cycle emissions of ammonia. However, if it is produced from fossil sources, such as natural gas, it can have high WTT carbon footprint. Alternatively, it can be produced by electrolysis of water with renewable energy for low carbon footprint (green ammonia).

Biofuels

Biofuels are typically liquid hydrocarbon fuels that are produced from renewable sources such as vegetable and animal oils or agricultural and forestry waste.

The similarity in physical and chemical properties between biofuels and petroleum diesel means that the former can be used as drop-in fuels without any need for equipment modifications or vessel retrofits. One of the key limitations of biofuels is their low availability, and thus high cost, which is expected to change in the following years as more suppliers upscale their production around the globe.

The various types of biofuels have different properties and qualities, resulting in varying emissions reduction benefits. When produced from renewable biomass such as plant fibers and other materials, biofuels have the potential to offset the carbon footprint of a vessel due to the CO_2 absorption of the plant feedstock. However, the total carbon reduction potential of different biofuels heavily depends on their source feedstock, production pathways, and associated emissions.

Technology Improvements

Retrofitting of energy efficiency devices/systems

The adoption of practical energy saving devices, such as pre/post-swirl devices, contra-rotating propellers, low friction coatings, waste heat recovery, and solar power can help the global fleet to increase its design-based efficiency. Many of these devices, however, are not mutually compatible or applicable to all ships. Some of these technologies are also struggling to gain a significant role in our industry because of the high implementation cost and difficult integration of these energy-saving measures in the ship's design and operation. Often, these issues have prevented the use of energy efficiency technologies on ships, particularly when the economic risk of its adoption cannot be readily quantified, as is the case for most new technologies.

Electrification

The efforts to decarbonize shipping are expected to accelerate the electrification of power generation and propulsion systems, which offer the potential for operational flexibility, optimized power consumption, efficiency improvements, and lower emissions from ships.

Novel power generation systems such as hybrid diesel-electric or fuel cells have the potential to offer significant emissions benefits. The first applications of such systems are in specific vessel types, especially those that operate in environmentally sensitive areas such as ports.

Hybrid-electric propulsion systems are currently used in the maritime industry and are increasing in popularity. Their adoption is being led by offshore support vessels and harbor tugs, where the systems readily provide additional energy on demand. Vessels and offshore installations require electric power for a wide range of components, from those that support communications and navigation systems to crew comfort and propulsion systems. These systems have the potential to improve reliability, operational efficiency, fuel consumption rates, environmental footprints, and maintenance costs when compared to traditional electric power systems. A fully integrated hybrid system includes an energy storage system, power generation, and power management systems.

Carbon Capture

Carbon capture and sequestration (CCS) refers to a set of technologies that can be used to remove CO_2 from vessel exhaust gas or the atmosphere and store it for subsequent use. Combustion of zero-carbon fuels, like ammonia and hydrogen, could result in zero CO_2 formation. However, in all other cases of fuels, CO_2 will form as a complete combustion product in proportion to the carbon content of the fuel. Therefore, with all but the zero-carbon fuels, CCS technology could be used on board ships to further reduce their carbon emissions.

Due to their large size and capital cost, these systems are both technically and economically challenging, whether installed on new builds or as vessel retrofits. Despite these technical and economic challenges, carbon capture technology can be an effective way to reduce the GHG emissions of future vessels, especially in combination with low-carbon fuels. Further technical advances are expected to reduce the size, cost, and complexity of CCS systems.

Operational Efficiency

Speed optimization is an operational measure that can have a significant impact on reducing GHG emissions in a relatively short amount of time. It is estimated that 'slow steaming,' as it is known, reduced shipping's overall CO_2 output in 2015 by dropping the carbon intensity of maritime transport by 30 percent compared with 2008 levels. The reduced speeds are having a significant short-term impact before any incremental newbuilding orders are added to the fleet and, even accounting for the increases in tonnage by 2025, overall CO_2 emissions are reduced.

Speed optimization also involves varying the vessel speed to arrive "just in time," thus avoiding idle time outside the terminals and minimizing overall fuel consumption.

Ship type	CO_2 Emissions Reduction	
	1 knot Speed Reduction	2 knot Speed Reduction
Dry Bulk	13%	25%
Oil Tankers	15%	28%
Containerships	6%	11%

Graphic courtesy of the American Bureau of Shipping

The Role of Class Societies in Industry Decarbonization

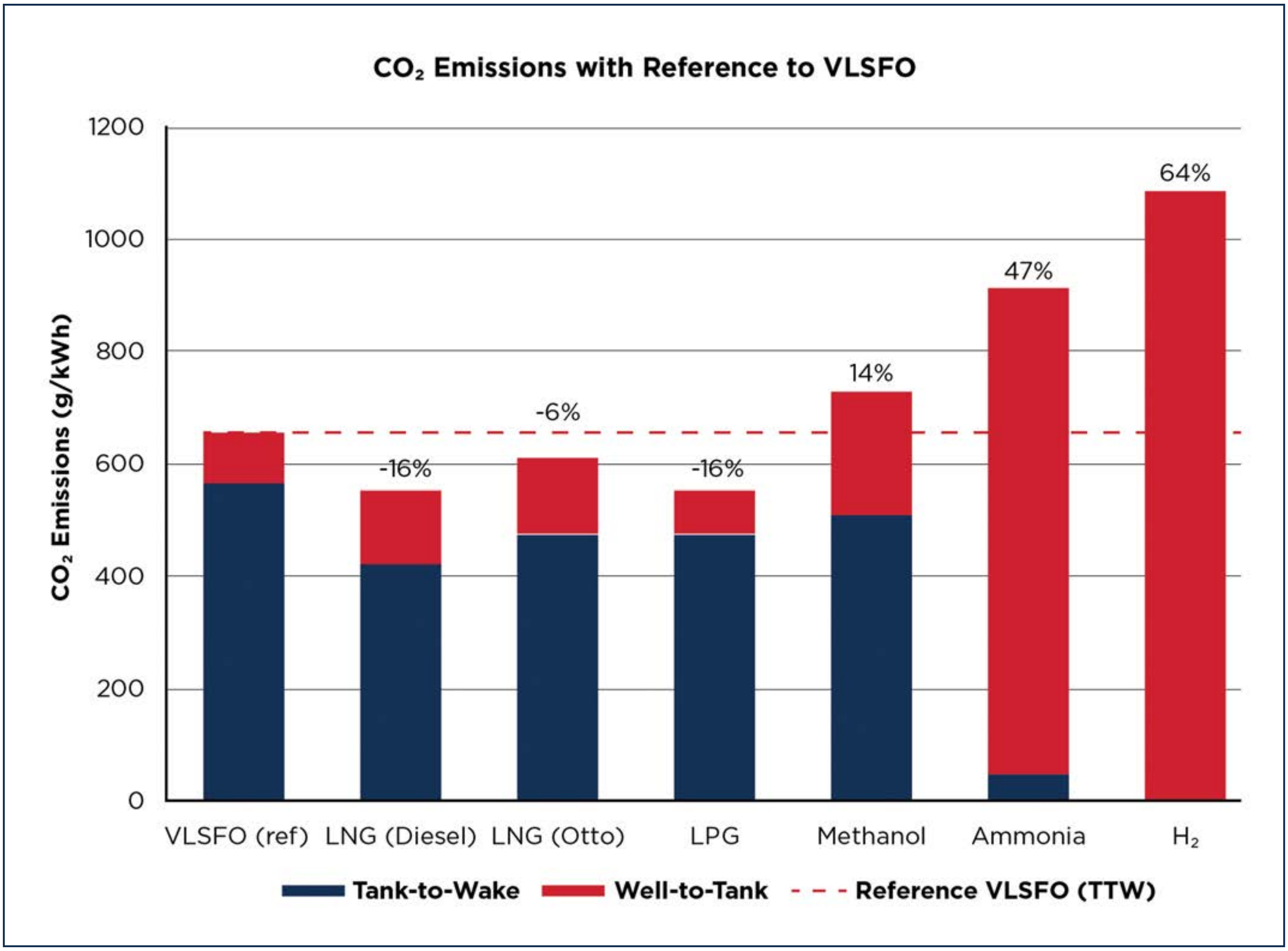
With the IMO having set mid-term targets to reduce shipping's CO_2 and GHG output, owners now face the difficult task of decarbonizing their fleets to meet the 2030 goals. There are so many technology options to consider that selecting a sustainable, fleetwide decarbonization strategy that will align with a company's business goals is increasingly complex. The carbon footprints of each fleet will be different, and each ship will require a bespoke strategy to find the most effective path towards compliance with the new regulations and emissions targets. Class societies are dedicated to helping clients comply with these new regulations and emissions targets.

Reaching the future milestones for decarbonization will require contributions from existing ships. Benchmarking GHG output and investigating ways to reduce that number at the vessel and fleet levels are at the core of this effort. Class societies are committed to supporting the shipping industry by continuing to develop the tools and services that facilitate decision making and help the operator navigate the challenges of decarbonization. They are also focused on working with other industry stakeholders to maintain safety by developing new guidelines and rules as new fuels and technologies are introduced.

Building the decarbonization trajectory for a fleet requires a specific toolbox to address the complexities of decision making. ABS has developed an extensive set of tools and services to help the industry tackle these complex challenges. These services range from developing a sustainability plan through environmental, social, and governance assurance and verification, to benchmarking a fleet's energy efficiency and providing improvement options regarding EEXI and CII. Additionally, evaluation of the life cycle cost of retrofitting or newbuilding for low-carbon fuels is available. Products such as the ABS Environmental Monitor™ help shipowners achieve sustainability goals by benchmarking and monitoring fleet or vessel-specific environmental categories like emissions, garbage, waste, and consumables.

Recognizing that marine operators require support to align with the United Nations Sustainable Development Goals (SDG), ABS has introduced two new sustainability notations—SUSTAIN-1 and SUSTAIN-2, both introduced in 2020. These recognize alignment with the SDGs, and having these notations assigned provides testament to financiers and charterers about the sustainability of the fleet and the company.

ABS has also published a series of guides and sustainability whitepapers to assist shipowners in adapting their vessels for a low-carbon future. These include a *Guide for Sustainability Notations; Guide for Ammonia Fueled Vessels, Biofuels as Marine Fuel Whitepaper;* and *Guide for*



Graphic courtesy of the American Bureau of Shipping

Methanol and Ethanol Fueled Vessels; among others.

Conclusion

The maritime industry is undergoing a significant transformation centered around decarbonization and motivated by IMO regulations; the financial institutions that support new vessel construction and retrofits; the multinational charterers of such vessels; and MBMs emerging from local and regional authorities. The decarbonization solutions the industry has at its disposal center around three areas including alternate fuels and energy sources, as well as technological and operational improvements.

It is expected that the majority of the decarbonization benefits will come from using low- and zero-carbon fuels. Technological and operational improvements, however, can increase the efficiency of vessels and the voyage, respectively, which can be equally effective. It is expected that a combination of the three will provide the desired results and allow the achievement of GHG reduction targets and carbon intensity reduction targets of 2030 and 2050.

About the authors:

Matthew Davidson is a vessel performance engineer in the ABS Global Sustainability Center Houston. His background includes ballast water management, vessel conversions and retrofits, and structural and hydrodynamic analysis of fixed and floating offshore structures. He holds a bachelor's degree in ocean and naval architectural engineering from Memorial University of Newfoundland.

Sarah Bell is a sustainability engineer with ABS Global Sustainability Center Houston. Her background includes ballast water management, damage control systems, vessel shock and vibration certification, and environmental protection systems. She holds a Bachelor of Science degree in offshore and coastal systems engineering from Texas A&M University at Galveston.

References:

ABS *Guide for Gas and Other Low-Flashpoint Fuel Ready Vessels*, July 2020

ABS *Sustainability Low Carbon Shipping Outlook I*, 2019

ABS *Sustainability Low Carbon Shipping Outlook II: Pathways to Sustainable Shipping*, 2020

ABS *Sustainability Low Carbon Shipping Outlook III: View of the Value Chain*, 2021

ABS *Sustainability Whitepaper: Ammonia as Marine Fuel*, October 2020

ABS *Sustainability Whitepaper: Methanol as Marine Fuel*, February 2021

ABS *Sustainability Whitepaper: Hydrogen as Marine Fuel*, June 2021

ABS *Sustainability Whitepaper: Biofuels as Marine Fuel*, May 2021

ABS *Sustainability Whitepaper: LNG as Marine Fuel*, June 2020

Sustainability from a Marine Insurance Perspective

by Trude S. Husebø
Chief Human Resources Officer
Skuld

In response to rapidly intensifying climate change, the United Nations declared a "code red for humanity" in August 2021. That put decarbonization on the minds of everyone in the ocean industries. It is the leading topic on the shipping sector's lengthening environmental, social, and governance (ESG) agenda, and a key area for the marine insurers that help to manage maritime risk.

Skuld is one of a small group of international "Protection & Indemnity" (P&I) clubs. Collectively, these mutual insurers cover more than 90 percent of the global, commercial, ocean-going fleet against third-party claims. Skuld, directly and through its membership, is at the leading edge of action in this planet-critical area.

Decarbonization

New technologies hold many of the keys to how we, as ocean industries, meet the transition to zero-carbon emissions. An important activity for the marine insurance sector is to support the development of next-generation power solutions, such as fuel and battery technologies. For example, some of our members are experimenting with very low-emission alternatives to fossil fuels, including onboard solar generation, hydrogen-powered ships, and even a return to sail. Since new technologies introduce new risks, insurers are an integral part of the common goal of securing and providing tomorrow's zero-carbon shipping solutions.

The insurance industry can play an active role, too. For example, Skuld has recently joined the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping as a mission ambassador. This independent research and development (R&D) center is looking to accelerate the maritime industry's transition to a net-zero future.

Equally, we must remain on the front line of providing the appropriate risk measurements and advisory services to our members and insured customers. We are eager to support high-level R&D initiatives and individual insurance customers' decarbonization projects, but the majority of the efforts shippers are making to decarbonize happens day-to-day. For example, vessel operators are working hard towards adapting to significant new regulatory requirements, not least is the obligation to switch to low-sulphur fuel. On any issue related to risk and process, marine insurers always have a carrot and a stick to deploy. On marine fuel, Skuld refuses to cover fines or penalties assessed against members who fail to meet low-sulphur bunker requirements.

We feel strongly that sustainability impacts will have to be considered more broadly in underwriting decision-making across the marine insurance market. That belief drives our restrictive, but simple and sensible approach to covering fines which arise from any breach of environmental laws and regulations. Less directly, the wider insurance sector, can and do contribute significantly to the zero-carbon transition through loss-prevention initiatives. Skuld also builds internal competencies that support the transition to environmentally friendly shipping.

Insurers must carefully analyze their rules and the terms on which they grant coverage to ensure they are sufficient to cater to these new emissions regimes. They must also maintain a watching brief because several new IMO initiatives and regulations will be launched during the coming years. Underwriting teams must be aware of their impacts and trained appropriately. It is equally important to ensure members and clients are kept aware of the impact of any new rules on the risk profile of vessels and cargoes.

Beyond Emissions

Alongside the effort to reduce the shipping sector's greenhouse gas emissions, environmentally conscious removal of wrecks is another important ESG area for vessel owners and insurers. Green wreck removal is particularly costly, and because specific jurisdictions have different requirements, the process follows no standard approach, which makes generalizations about cost difficult to make.

Other topics have always been important to shipowners and their insurers even before ESG was a hot topic. During these past two pandemic years, crew safety and well-being were high-profile concerns, starkly demonstrating the importance of insurers' work in this area.

For example, COVID-19 highlighted crews' vulnerability to travel restrictions and limited access to medical assistance. We spare no time or expenses to restore the health of stricken crew and passengers during this ongoing crisis.

That said, safety and well-being have been a focus for the P&I sector for decades. It is difficult to overestimate the importance of the area for insurers and their clientele. Skuld has adopted the U.N.'s Sustainability Goal 3—good health and wellbeing—which reflects our hard work to improve health and safety for the crew of any vessel we cover, and also of course, for our own employees. We have also signed the Neptune Declaration on Seafarer Wellbeing and Crew Change, and we actively encourage all our colleagues in the P&I market to do so too.

On a practical level, we are in the process of updating our procedures for the condition surveys we perform on vessels. The new process will include assessment of shipboard working conditions, and general treatment of crews by their employers. We use in-house technical managers to perform surveys that help us get a real impression of what it is like to work on specific ships.

Changing Approaches

Marine insurers have a responsibility to help their customers make transitions and should be engaging their expertise and resources to provide support. One of our strategies is to help traditional shipowners that want to change their industry focus and shift into more climate-friendly sectors. Some may move, for example, from fishing fleets to fish farms, or from tanker ownership to offshore windfarms.

We already see demand from our membership to support them on such journeys, and it will only increase as companies in the shipping sector go green. We are closely involved with some members switching from conventional to green passenger ferries.

Accidents at sea will unfortunately always happen, but our sector is here to ensure that responses to events like wrecks and spills are as rapid and environmentally sensitive as possible. Skuld and other P&I clubs are enormously important in the remediation of pollution incidents, working to guarantee prompt and efficient casualty response services to ensure that all the necessary measures are taken to protect people, property, and the planet, when an emergency occurs.

Ocean pollution is taken very seriously by everyone in the shipping sector. The number of oil spills has dramatically declined during the past half century, with frequency reduced by 90 percent since the 1970s. This is very much thanks to the joint efforts of shipping, marine insurers, and regulators. The insurance market has substantial experience dealing with large pollution incidents and is well aware of its role in ensuring efficient clean up and swift compensation payment to the victims of

Skuld has chosen five Sustainable Development Goals that guide its work on sustainability. Graphic courtesy of Skuld

Sustainability is an essential part of Skuld's strategy, culture, and identity. Photo courtesy of Skuld

such incidents.

Many vital commercial sectors will demand and rely on the transportation of fossil fuels for decades to come. The sudden withdrawal of insurance coverage in some of these sectors could therefore be very damaging. Instead, the insurance community's role must be to help our companies achieve United Nations sustainability goals, and to continue to be part of the protective cordon. As long as hydrocarbons are transported by sea, insurers will be on hand to minimize any potential environmental impacts arising from that process.

Looking internally, sustainable investment is an ESG issue for all insurers. Skuld is identifying and assessing a range of investment opportunities that would improve our overall ESG-risk profile, encouraging our external asset managers to develop investment vehicles that combine sustainability with our other investment criteria, and preparing to make climate-related, non-financial disclosures. This is happening across the insurance and financial sectors.

These internal efforts are important, as are others, such as careful care for the well-being of the insurance workforce and a concerted effort to reduce the environmental impact of our operations. However, the greatest ESG impact we can make as insurers is to act as a trusted partner of our insurance-buying members and clients. We need to talk to them about the risks that threaten them, how those risks may be changing, what they can do to minimise such risks, and how we can help.

We have made sustainability an essential part of Skuld's strategy, culture, and identity. We are committed to continuing our work as an important way to meet our aim of preventing injury to people, property, and the environment. We encourage everyone across the ocean industries to do the same.

About the author:
Trude Husebø has been part of Skuld's executive management team for 14 years, leading human resources, communication, and sustainability. She works with the sustainability programme of the International Group of P&I Clubs, chairs its One Industry Voice subcommittee, and has helped to facilitate sustainability programmes in other organisations. Holding a master's degree in management, she has been in charge of HR and communications for shipowners, law firms, and gas industry companies for more than 30 years.

Hybrid Tugs

Improving system efficiencies as a viable decarbonization pathway

by John Buchanan
President
Harbor Docking and Towing

The maritime industry, especially towing, is experiencing smaller margins and increased pressure to accelerate decarbonization. Understanding our customers' needs to reduce their carbon footprints across operations in order to meet decarbonization goals, Harbor Docking and Towing (HDT) faces a challenge: offering technical solutions that work today while remaining competitive. Considering a tug's 40-year lifespan, it becomes increasingly apparent that any single measure would not result in meeting our targets, so HDT is embarking on a course to deploy innovative technologies and explore new pathways for decarbonizing generally hard-to-abate maritime applications. Going green impacts our bottom line, but in a positive way by cutting our fuel consumptions and reducing maintenance cost, which has reduced our carbon footprint.

This article explores HDT's decarbonization options through the design of two of its newest tugs.

Goal Setting

The shipping community is setting ambitious goals for decarbonization based on the International Maritime Organization's goal of achieving a 40 percent carbon intensity reduction by 2030. By 2050, the goal increases to a 70 percent carbon intensity reduction, as well as a 50 percent total emissions reduction based on 2008 levels.

Currently, these decarbonization targets are intended for much larger cargo vessels like tankers serviced by HDT. However, as these larger vessel companies commit to sustainability improvements, their strategies not only include the vessels they operate, but more often they are also looking at the entire supply chain. For example, Amazon, one of the largest companies in the world, recently committed to a goal of net zero carbon across all operations by 2040. This means that in order to remain competitive, servicing companies like ours also need to start considering their own sustainability goals, especially when building newer vessels.

> Carbon output and fuel consumption have a linear relationship of 10.5 kg/gallon

Operational Efficiency

There are multiple decarbonization options that vessel owners can consider. The first involves improving operational efficiencies. By using less energy, a vessel consumes less fuel, and thus emits less carbon dioxide.

Service tugs typically have a short waterline length and the high power density needed for towing that allows them to reach speeds of 12–13 knots. However, the power, and thus fuel, necessary to reach these speeds is extremely inefficient. For a conventional 100-foot tug, the difference in power required to sail at 10 knots is more than 200 percent of the power needed to sail at 8 knots. The economic incentive for cutting fuel costs is clear and owners and operators have implemented a range of policies, technologies, and measures to incentivize crews and dispatch to reduce vessel cruising speeds, improve vessel efficiencies, and ultimately lower costs and carbon output.

Drop-In Fuels

A second option for reducing carbon impact involves synthetic and renewable diesel fuels like gas-to-liquid; hydrotreated vegetable oil; biodiesel-diesel blends like B50; and fatty acid methyl esters. These "drop-in" fuels have similar qualities to diesel, but with a much lower carbon footprint. Additionally, most diesel engines can operate with drop-in fuels or traditional and drop-in fuel mixtures.

The decarbonization impact of using drop-in fuels is heavily dependent on the availability of biomass feedstock. While drop-in fuels produced from biomass feedstock are technically possible today, they're lack of availability at U.S. ports make them commercially infeasible at this time. However, as decarbonization demand continues to grow and regulators set carbon intensity values for biomass feedstocks, as well as consider implementing carbon taxing, it will be interesting to watch for potential growth of biomass fuels.

For owners, the ability to mix and match the percentage of drop-ins with existing diesel fuels could be a viable option for achieving company decarbonization goals with their existing vessels.

Vessel Design-Based Measures

The third option to reduce carbon impact is to improve vessel design-based measures. A range of advances in tug and drivetrain designs have been developed in the past decade to optimize performance output. In general, bollard pull for ship handling is the primary performance requirement with dynamic escort towing, with steering and braking forces, coming in a close second. As a result, a traditional harbor tug operational profile is characterized by a highly skewed power curve, as it was designed for maximum bollard pull capability and fuel efficiency at bollard pull conditions.

This single design point approach created very powerful tugs with the assumption that if energy efficiency was high at the single design point—bollard pull—it would also be good at the working points in between. This assumption is now being challenged by studying the working points where tugs actually use the most energy.

The multiple design-point approach optimizes total system efficiency over multiple design points, improving system efficiencies for those conditions where the tug uses the most energy. This creates better system efficiency and results in lower fuel consumption and emissions. In other words, modern tug design is shifting towards an availability of power philosophy rather than a philosophy of full, continuous power at all times.

In a multi-design point, the goal is to have higher efficiencies at established design points based on the most common operating profile of the vessel, while accepting lower efficiencies at maximum power due to lower operational use. The result of this type of multi-point approach supports the use of a hybrid diesel-electric propulsion system. While a traditional tug's main engines run at an inefficient idle condition more than 32 percent of the time, a diesel-electric system could allow the operator to secure the diesel engine when not needed. This would significantly improve fuel consumption and reduce vessel emissions.

> As described in a 2014 IEA Bioenergy report: "Drop-in" biofuels are defined as liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and fully compatible with existing petroleum infrastructure.

Caterpillar, a pioneer in hybrid system design, initially designed them for use in offshore industry applications. Now, the same patented control algorithms are being used in hybrid tug power plant applications. The hybrid design provides tug owner/operators with the ability to improve fuel savings, lower emissions, and extend engine maintenance intervals.

When HDT contracted to build two new harbor tugs to add to its fleet, it took into consideration all of the options above, including the inclusion of a hybrid diesel-electric plant. The goal for these new vessels was to reduce emissions, while also providing the capability needed to handle today's larger ships.

In 2019–2020, *Ralph* and *CAPT Robb*, HDT's newest tugs were built at Washburn & Doughty Associates Inc. in Boothbay, Maine. At 93 feet long, 38 feet wide, and

Harbor Docking and Towing's goal for its newest tugs, *Ralph*, pictured here, and *CAPT Robb*, was to reduce emissions, while also providing the capability needed to handle today's larger ships. The powerful, environmentally friendly tugs present no downside, according to the company's president, John Buchanan. Photo courtesy of Harbor Docking and Towing

CAPT Robb, pictured here, and *Ralph*, are two of Harbor Docking and Towing's newest hybrid diesel-electric tugs. Built by Washburn & Doughty Associates Inc., they are 93 feet long, 38 feet wide, and boast 91 short tons of bollard pull. Each tug is powered by two 2,550 HP main engines, two 565 KW generators, and a 200 KW generator. Photo courtesy of Harbor Docking and Towing

with 91 short tons of bollard pull, these vessels are powered by two 2,550 HP main engines, two 565 KW generators, and a 200 KW generator. This all drives two azimuthing thruster units powering 2,800 mm propellers in high efficiency nozzles.

For towing operations, each vessel is fitted with a Markey DEPCF-52-75HP electric-driven hawser winch. The electric-driven winch provides more energy efficiency when compared to hydraulic-driven winches. In total, 475 feet of 10-inch circumference Samson AmSteel-Blue hawser line is fitted in a single drum arrangement. Samson AmSteel-Blue Dyneema fiber rope materials are lighter and stronger than traditional steel wire rope.

For push-pull docking-assisted vessels, the tugs are fitted with two upper rows of 24-inch cylindrical fender, a middle 16-inch soft loop fender, and a lower laminated fender. Twelve-inch black rubber "D" fenders are fitted at the main deck on the sides and around the stern. Between the D fender and the middle bow fender there is a double row of soft loop fender, with the aft end of the soft loop fender tapered to approximately the depth of the D fender. The softer cylindrical fenders provide a "soft" landing, while the laminated fenders distribute tug power over a wider area. The working equipment is completed by an EBI TC10 telescopic boom crane with a maximum 30-foot reach and 4,000 pounds at maximum reach lifting capacity.

Both vessels are also fitted with an ABS class-approved fire-fighting I system driven by the starboard main engines on the power take off (PTO) side. During fire-fighting, maneuverability and propulsion power is maintained through the vessels' hybrid drive systems and/or the port-side main engine.

Propulsion Plant Design

The two main engines power the main thrusters via a straight composite shaft line. Between each main engine and thruster there is a main clutch mounted in a bell housing attached to the engine. The single skid arrangement, in combination with the bell-house mounted clutch and straight-line composite shaft, provides modern tug designs with an elegant solution to misalignment issues of days past.

Each of the Caterpillar 3512E engines generates 2,550 HP @ 1800 RPM.

An electric 560 KW electric motor-generator is mounted juxtaposed to the mechanical input drive of the azimuthing thruster upper gearbox. This allows the motor-generator to work in a hybrid power take in/PTO arrangement. In PTO mode, electricity can be provided to the vessel from the main engines. In power take in (PTI) mode, the motor-generator can work as part of the propulsion system. To take advantage of the PTI/PTO capabilities, the azimuthing thrusters use a pinion straddle mounted upper gearbox arrangement. This prevents the need for customized in-line motor-generator units, increasing flexibility for selection of off-the-shelf drive system components. The electric motor-generator, in combination with the bell-house mounted clutch on the main engines, provides a range of operational modes, as well as performance benefits with increased load response.

The hybrid system design also provides owners and operators with the type of performance required for high power demands when it is needed. When operated in parallel, the electric motor acts as a torque-enhancer, improving load response characteristics. At top rpm ranges, the hybrid E-motor provides an extra boost to the tug's main engines. The boost, or turbo, feature provides more power at the top range, even allowing for the *Ralph* and *CAPT Robb* to be fitted with smaller engines. Other tugs of similar high bollard are generally fitted with 16-cylinder engines instead of the 12-cylinder CAT 3512E.

While this is a nice feature on diesel-driven engines, it is an invaluable feature on future alternative fuel and blend-driven engines. Regardless of whether the future of marine fuels will be some form of natural gas, diesel blends, or methanol, the energy densities of these fuels are lower compared to diesel. Hybrid systems are a must to provide customers with the diesel-like performance needed for their operations.

A More Efficient Tug Design

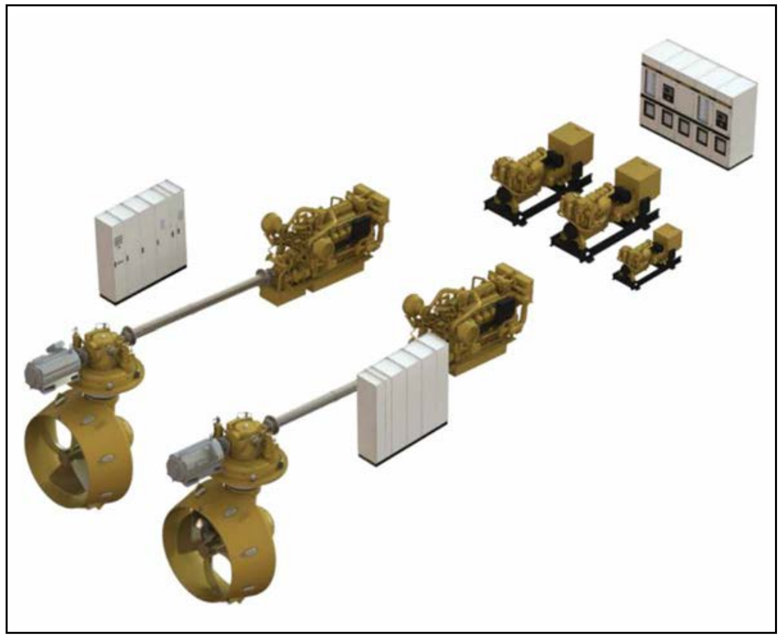
The most efficient engine is the one you don't need to run. These are also the engines that emit fewest particles. On a traditional tug, the main engines are always running. Slower transit speeds of around 6 knots can be achieved by engaging and disengaging the clutch. Below those speeds, when maneuvering near assisted vessels, or just standing by, these tugs turn the thrust vectors of their azimuthing Z-drives into each other, wasting energy by creating juxtaposed propeller washes. Again, slow speed and standby modes account for approximately 32 percent of a tug's operational time.

Ralph and *CAPT Robb* can operate up to 10.5 knots in a diesel-electric configuration with both C18 generator sets running. However, in its more common operating mode, it can run at 8 knots with a single C18 running. Further, when the tug is just standing by, both engines can be secured, and *Ralph* and *CAPT Robb* can just use the motor generator. By securing the engines on *Ralph* and *CAPT Robb* when not needed, this hybrid system can save more than 8 gallons per hour, leading to a 46 percent reduction in fuel consumption.

Moving Forward

Ralph and *CAPT Robb* are the biggest and most modern tugs in HDT's fleet. As such it is difficult to make a direct comparison between our newest vessels and older EPA Tier I and II tugs. We do see fuel savings with our hybrid tugs compared to the other vessels. These fuel savings directly translate to a 70 percent carbon intensity reduction for our fleet. Pound-for-pound, these are the best tugs in our fleet.

Hybrid Drivetrain Arrangement for *Ralph* and *CAPT Robb*



Courtesy of Harbor Docking and Towing

Further integration and electrification of tug systems seems inevitable. Bringing a hybrid automotive user experience to the marine environment will be key. Whether that means battery-electric tugs like Crowley's E-wolf and the Canadian Haisea ElektRA tugs, or parallel hybrids like *Ralph* and *CAPT Robb*, remains to be seen.

In the meantime, HDT is moving forward with our own new build program. Our goal is to use the newest technology combined with the lessons learned from *Ralph* and *CAPT Robb* to ensure that HDT can be a real contributor on the path toward decarbonization without compromising the power needed to safely handle today's larger ships.

About the Author:

John Buchanan, president of Harbor Docking and Towing (HDT), brought 30 years of U.S. Coast Guard experience to the company when he started in 2016 as the director of safety responsible for the Subchapter M transition. Coast Guard Master Chief Buchanan served as officer-in-charge aboard coastal patrol boats; led national-level standardization teams; conducted ready for operations inspections; was instrumental in the post-Hurricane Katrina disaster response; and served as lead federal agent for all waterborne security activities for high profile events.

Chevron Shipping's Path to Lower Emissions

by Matt Turns
General Manager, Strategy & Business Performance
Chevron Shipping Company

Energy is essential to achieving a more prosperous and sustainable world, enabling modern life, and the conveniences that come with it. Affordable, reliable energy will continue to be essential for growing a global economy and lifting billions out of poverty.

The future of energy is lower carbon. To achieve this lower carbon future, the carbon intensity of oil and gas operations must be reduced and solutions for lower carbon energy must be provided. The maritime industry has been on its own decarbonization path. In 2018, the International Maritime Organization (IMO) set goals for international shipping to reduce its total annual greenhouse gas emissions by at least 50 percent of 2008 levels by 2050, while reducing carbon intensity by 70 percent over the same period.

Chevron's View

Chevron Shipping aligns with our parent company, Chevron Corporation, in delivering our goal of lower carbon. To achieve this, we are accelerating progress toward a lower carbon future by continuing to lower the carbon intensity of our operations and making investments to develop lower carbon energy solutions for the future. We are investing more than $10 billion between now and 2028, with $2 billion earmarked to lower the carbon intensity of our operations.

Innovation will be critical to achieving IMO targets. Breakthroughs will be needed, and technologies must adapt and be developed. Additionally, global energy challenges must be solved on a massive scale. Chevron and the energy sector—including maritime—can play a major role in addressing this challenge.

We view liquefied natural gas as the short-term lower emission fuel and see promising alternative fuels, like ammonia, as integral in meeting the IMO 2050 target. Regarding propulsion technology, we see the internal combustion engine as most likely dominant through 2050. Chevron is fostering hydrogen demand growth through original equipment manufacturer alliances with Toyota, Cummins, and Caterpillar, and we believe that investing in bio feedstocks is critical to securing our lower-carbon fuels value chain—including sustainable aviation fuels. Through a memorandum of understanding between Chevron Products Company, Delta Air Lines, and Google, we have agreed to track sustainable aviation fuel test batch emissions data using cloud-based technology.

A Changing Industry

There is a desire to continue the decarbonization of the maritime industry. Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, Poseidon Principles, Global Centre for Maritime Decarbonization, and Sea Cargo Charter are just a few organizations aiming to advance

While the *Apollo Voyager* most often supports ship-to-ship operations at the request of Chevron's Richmond Refinery, it also makes frequent voyages to Panama. The vessel has reduced its emissions by improving business processes and communications, adjusting voyage speeds, and implementing a main engine low-load initiative. Photo courtesy of Chevron Shipping Company global decarbonization and/or lower carbon initiatives. Chevron recently joined Sea Cargo Charter's benchmark initiative for responsible shipping activities, transparent greenhouse gas (GHG) reporting, and improved decision-making in line with U.N. decarbonization targets. Additionally, regional initiatives are also enacting measures that aim to advance this goal.

The European Union's "Fit for 55" package includes the FuelEU Maritime proposal which seeks to increase the use of sustainable alternative fuels at EU ports, as well as establish limits on GHG intensity of energy used on board vessels. "Fit for 55" also includes an expanded emissions trading system (ETS). Both FuelEU Maritime and the ETS are expected to include international shipping beginning in 2023.

Chevron supports well-designed climate policies such as a price on carbon to enable scalable decarbonization of the energy system. Chevron believes this is one of the most efficient ways to harness market forces to reduce emissions. For the maritime sector, these market-based mechanisms should be as broad as possible to maintain a level playing field and reduce trade distortions.

> "The FuelEU Maritime initiative proposes a common EU regulatory framework to increase the share of renewable and low-carbon fuels in the fuel mix of international maritime transport without creating barriers to the single market," as proposed by the EU Commission.

Chevron Shipping has been on its own decarbonization journey, beginning two years ago with a review of our environmental strategy. We found that while we were very strong in the traditional areas of environmental stewardship, including preventing releases and reducing waste, lowering carbon required additional focus. As we looked across the segments of our organization, we recognized that there were many lower-carbon activities happening, but they could be better organized, centralized, and coordinated by a single group.

This more centralized approach allowed us to prioritize and focus our efforts. Chevron Shipping not only owns and operates ships, we are also one of the world's largest charterers of tankers, and have looked for opportunities to reduce our carbon intensity in both of these areas.

Sea Cargo Charter

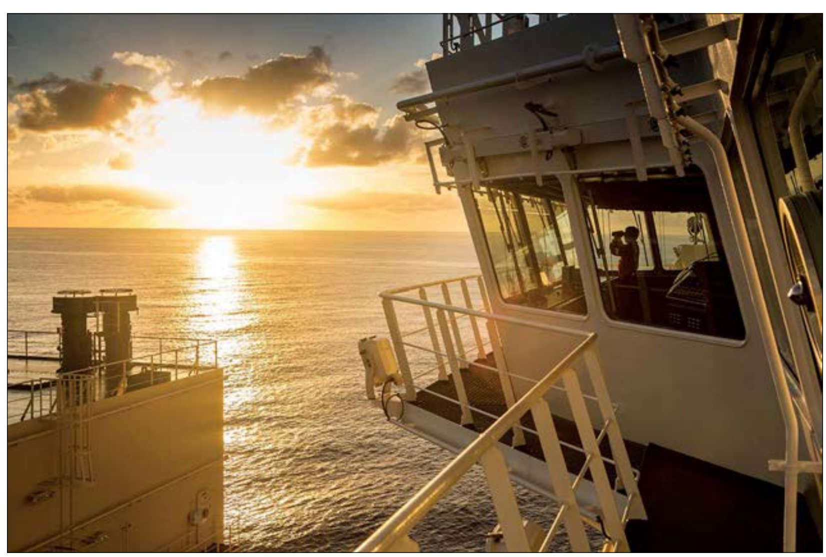
While we have been tracking the GHG emissions of our operated fleet, we have had much less visibility into the emissions of the third-party chartered ships. Our continued focus on tracking and lowering emissions from within our owned and operated fleet, in addition to our third-party fleets, piqued our interest in learning more about the Sea Cargo Charter.

Sea Cargo Charter establishes a common baseline to quantitatively assess and disclose whether shipping activities are aligned with adopted climate goals. Their charter is consistent with the policies and ambitions adopted by the IMO and the anticipated future regulatory framework. By joining Sea Cargo Charter, Chevron joins other maritime leaders in committing to even greater transparency in measuring and reporting GHG emissions.

With the help of Sea Cargo Charter, we will start tracking its chartered ship emissions against a common baseline as a way to monitor how business decisions impact emissions. Our efforts to make the information visible required close coordination between Information Technology, Operations, and Fleet Technical organizations.

Additional Opportunities

In addition to joining the Sea Cargo Charter, Chevron Shipping is exploring and executing on multiple solutions to achieve our lower carbon goals within our operated fleet. The initial focus was on information transparency so we could find the opportunities and measure our progress.



The *Asia Excellence* is one of Chevron's new, technologically advanced LNG ships supporting the company's growing global LNG leadership position. Each of Chevron's LNG ships can hold approximately 160,000 cubic meters of LNG at the necessary -260 F while in transit. Photo courtesy of Chevron Shipping Company

Chevron's *Pegasus Voyager*, left, and *Polaris Voyager*, not pictured, are specifically designed for ship-to-ship operations (e.g., lightering), with controllable pitch propellers and bow thrusters providing extra maneuverability. In addition to being safe, modern vessels, these sister ships have achieved significant emission reductions. In 2021, they reduced CO_2 emissions by more than 104,000 metric tons compared to 2019 consumption values. This was achieved by making operational adjustments and improving business processes and communications across functions and assets.

Armed with better information on fuel consumption, and therefore emissions, we could quantify the benefits of optimized routing, speeds, and energy usage within our operated fleet. Reviewed daily, our new 'dashboard' system brings visibility to the ships deviating from expectations and also enables an immediate dialogue for ways to increase vessel efficiency.

Scheduling was another area of improvement. One of the benefits of being an integrated oil company is that we can work with the refineries and adjust arrival dates to reduce demurrage and maximize efficiency. This data transparency allows us to make high-quality, value-based decisions across the supply chain, in addition to operational improvements. In 2021, these improvements reduced CO_2 emissions by more than 104,000 metric tons, compared to 2019 levels.

What's Next?

Longer-term, Chevron Shipping is continuing to explore new technologies, energy-saving devices, and future fuels. We are also looking to partner with other industry organizations to create cutting-edge solutions. The advances in technology are moving at a rapid pace. Even vessels that we acquired over the past 2–3 years are significantly more fuel-efficient than ships acquired 5–10 years ago.

For more information

For more information on Sea Cargo Charter, visit www.seacargocharter.org/about/governance

"We believe the path to meet our 2050 goals will be a mix of many incremental improvements and industry-wide transformation. We are prepared and dedicated to the journey," David Moore, senior manager, Chevron Shipping Operational Excellence (OE) Health, Environment and Safety, said. This path will require establishing new fuel alternatives and associated infrastructure and supply in order for the industry to meet the IMO 2050 goals.

Working Together

In our industry, members from across the maritime sector will need to work together. Reaching our carbon reduction goals will take creating and testing many different solutions from different parts of the industry. It will also require industry and governments to align on policies and infrastructure development, as well as cooperative action amongst charterers, owners, operators, ports, and regulators, including ship class societies to ensure that solutions are not only efficient but also safe.

About the author:

Matt Turns is the general manager of Chevron Shipping Company's Strategy & Business Performance. He holds a B.S. in naval architecture from Webb Institute and an MBA from Arizona State University's W.P. School of Business.

Green Innovations

Hydrogen Vessel Feasibility Studies at Sandia National Laboratories

by Leonard E. Klebanoff, Ph.D.
Lead, Maritime Applications for Hydrogen Fuel Cells
Sandia National Laboratories

In its IMO *Action to Reduce Greenhouse Gas Emissions from International Shipping* document, the International Maritime Organization recently called for a reduction of total annual greenhouse gas (GHG) emissions from international shipping by at least 50 percent of 2008 levels by 2050.[1] In order to achieve this reduction, a shift in ship propulsion fuel away from traditional fossil-derived fuels to fuels that, from "well-to-waves," reduce or eliminate GHG emissions will be needed. Reductions in the criteria pollutant emissions like the oxides of nitrogen (NO_X), hydrocarbons (HC) and particulate matter (PM) are also important, as these adversely affect human health in the short term.[2] Broad surveys of possible alternative fuels have been published,[3,4,5] as well as studies of specific candidate fuels such as dimethyl ether,[6] methanol,[7] ammonia,[8] liquid natural gas,[9] and biodiesel.[10] Among the candidate fuels for replacing marine hydrocarbon fuels is hydrogen. The safety-related properties of hydrogen as a fuel[11] and a description of hydrogen fuel cells[12] have been published previously.

Even before the announced IMO strategy, the use of hydrogen technology in maritime applications has been considered for the past two decades, with increasing interest in the use of hydrogen fuel cell technology on ships. Early studies examined the first approaches toward an integrated use of hydrogen, both in fuel cells and internal combustion engines (ICE), for the entire maritime scope of shore power, prime vessel power, and vessel auxiliary power.[13,14] In 2016, L. van Biert and coworkers[15] reviewed the status of the different types of fuel cells that could be used on a ship, as well as the various approaches to hydrogen storage or on-board hydrogen generation—for example, the reforming of other fuels. Others performed analysis using hydrogen in ICEs as a replacement for burning heavy fuel oils on transoceanic vessels.[16]

A number of recent studies have been published with a focus on lifecycle emissions,[17,18] maritime fuel cell thermodynamics,[19] safety,[20] and comparative reports of the varying types of fuel cells and hydrogen storage approaches available to future low-emission shipping.[21,22,23]

The original idea for Sandia to examine the feasibility of hydrogen fuel cell vessels came in 2015 from Mr. Tom Escher of the Red & White Fleet in San Francisco. He suggested we initially examine the feasibility of a hydrogen fuel-cell ferry. Funding for this first study came from the U.S. Department of Transportation's Maritime Administration (MARAD), and involved a collaboration between Sandia; the naval architect Elliott Bay Design Group; and the class society American Bureau of Shipping (ABS). The result of this study is the San Francisco Bay Area Renewable Energy Electric Vessel with Zero Emissions, or more concisely, the *SF-BREEZE*, a conceptual high-speed hydrogen fuel-cell ferry designed for commercial use in San Francisco Bay.

The *SF-BREEZE*

In order to satisfy the requirements of ferry operation, the *SF-BREEZE* design combines renewable liquid hydrogen (LH_2), proton exchange membrane (PEM) fuel cell technology, and a catamaran hull design to provide high-speed ferry service for 150 passengers at 35-knot top speed. A full account of the vessel design, as well as the technical and economic feasibilities are reported elsewhere.[24]

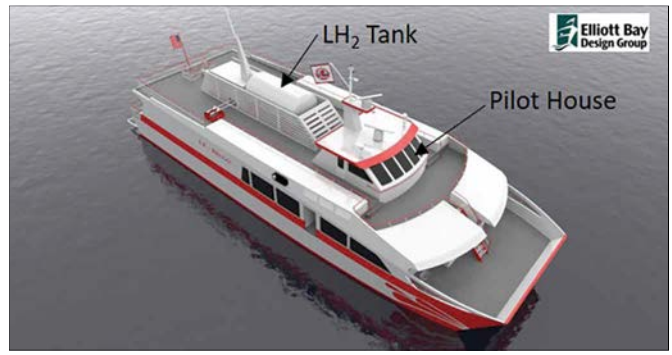
As indicated by the *SF-BREEZE* engineering drawings, the top deck holds a cylindrical 1200 kg capacity LH_2 tank with enough hydrogen for 4 hours of continuous operation. The tank size is driven by the desire to refuel only a couple of times per day during operations. The high-speed—35 knots—requirements of the design necessitate the lightest and most compact method of storing 1200 kg of hydrogen, namely LH_2 storage in a traditional cryogenic tank. The PEM fuel cells, a total installed fuel cell power equal to 4.9 MW, were selected for their fast turn on, minimal weight, commercial availability, established track record, and ability to run on pure hydrogen.

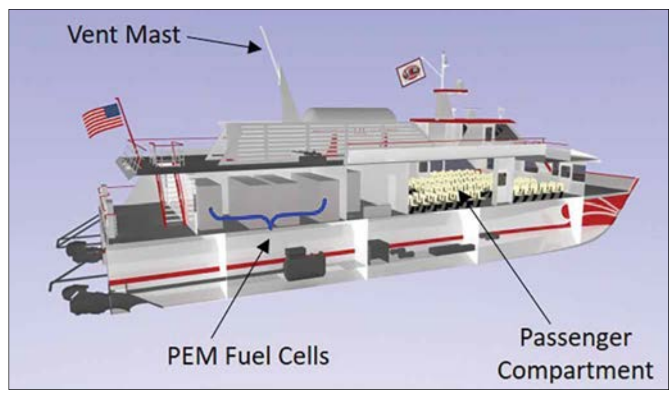
The vessel was generally designed to be compliant with the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code),[25] which was written with natural gas in mind. The IGF Code is a good starting point for compliant design of hydrogen vessels because of the similarities of the safety-related combustion properties of hydrogen and natural gas.[26] The *SF-BREEZE*'s Vent Mast, a safety requirement for hydrogen vessel designs, allows for safe venting and dispersion of boil-off gas from the LH_2 tanks during periods of vessel inactivity, as well as exhaust from fuel cell room ventilation. During the *SF-BREEZE* project, Sandia held monthly meetings with the United States Coast Guard to provide hydrogen technology "tech transfer," and to help develop science-based hydrogen regulations in the maritime space.

During the final stages of work on the *SF-BREEZE*, Sandia briefed the Scripps Institution of Oceanography (SIO) on H_2 vessel technology. The SIO staff was thinking about a new nonpolluting coastal research vessel to replace fossil-fuel vessels that were recently retired or near retirement. For a research vessel, the advantages of using hydrogen fuel cells are considerable:[27]

- Zero-emissions hydrogen technology allows the collection of air samples with no interference from vessel engine emissions.
- Hydrogen is readily used in arctic oceanographic exploration because it is not susceptible to the waxing/freezing problems of petroleum-based fuels.
- The complete elimination of vessel particulate emissions in arctic research missions avoids the formation of "black ice" which is a major concern for increased solar absorbance leading to increased rates of ice melt.
- Fuel cells are low-noise power systems, meaning an H_2 fuel-cell research vessel would radiate substantially less underwater noise, enabling better scientific acoustic surveys with reduced noise impacts on marine wildlife.
- Being electrical devices, PEM fuel cells offer faster power response than conventional diesel engine propulsion technology, which is an advantage in vessel handling and positioning.
- Fuel cells generate pure deionized water which is needed for laboratory use and can also be treated to use as the ship's source of potable water.
- Having no fossil fuels onboard means no risk of a polluting fuel spill, which allows oceanographers to work in sensitive habitats without fear of polluting them.

These potential benefits motivated a detailed exploration of the technical, regulatory, and economic feasibility of designing, building, and operating a practical, commercial, zero- emission coastal research vessel. This led to a MARAD-funded project consisting of a collaboration between Sandia, the naval architect Glosten and SIO, the results of which have been published.[28]

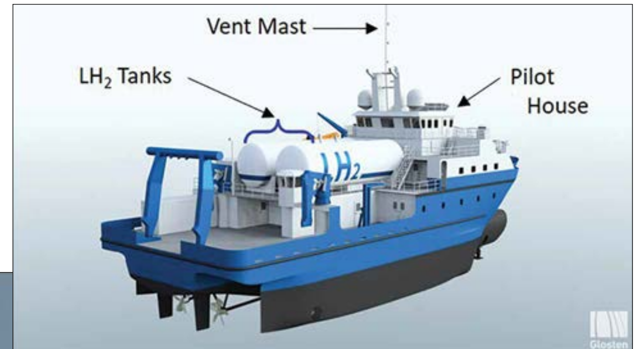


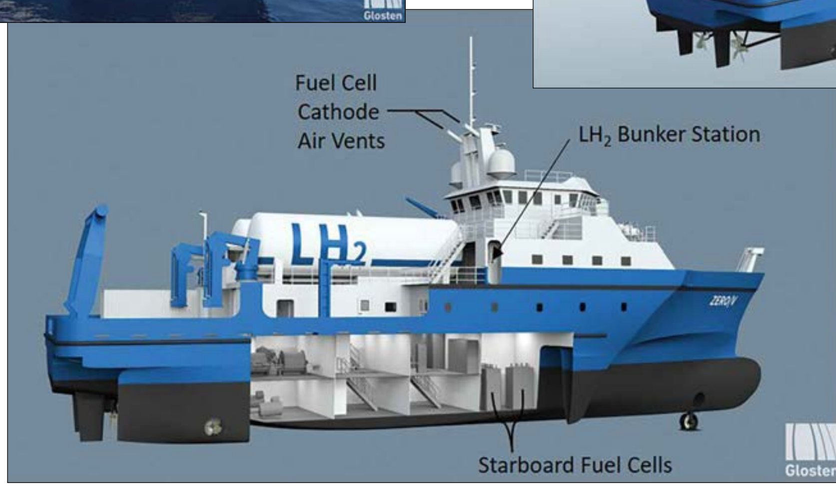


Engineering models provide views of the *SF-BREEZE*, including a cutaway version, to show the PEM fuel cell power racks on the main deck. The top deck holds the LH_2 storage tank, the associated Vent Mast, evaporation equipment, and the pilot house. Image courtesy of Elliot Bay Design Group

The *Zero-V*

The hydrogen-powered coastal research vessel *Zero-V* engineering models show the placement of PEM fuel cells (1800 kW) and the cryogenic LH_2 tanks. The *Zero-V* requires two large LH_2 tanks—10,900 kg total consumable capacity—because of the considerable distance of 2,400 nautical miles that the research vessel must travel before refueling. The *Zero-V* design follows the IGF Code[29] and is based on a trimaran hull type, which was





Engineering models of the *Zero-V*, including a cut-away view (bottom), show parts of the vessel, including some of the hydrogen technology components. Image courtesy of Glosten

selected because it enabled the vessel to meet all space, volume, and stability requirements. More specifically, the design has a wide deck allowing for a large deckhouse and superstructure which affords ample accommodations, laboratory, and service spaces, in addition to excellent stability characteristics.

These attributes, combined with the light weight of the LH_2 fuel, allows the fuel storage tanks to be placed in an elevated position on the 01 deck without adversely affecting the vessel's stability.

The *H_2 Hybrid*

The *SF-BREEZE* and *Zero-V* feasibility studies examined the use of hydrogen PEM fuel cells to provide all required propulsion power for the vessel. However, early uses of hydrogen technology on ships may be more limited, with the hydrogen fuel-cell power acting as a hybrid power component supplementing a primarily diesel-based powertrain. A natural question arose: How useful is hydrogen fuel-cell technology as a hybrid power system component? For this feasibility study,[30] we examined hydrogen fuel cells as hybrid power systems supplementing primary diesel power. We targeted a different kind of vessel, namely an H_2 hybrid cost-constrained coastal/local research vessel intended as a replacement for the smaller SIO R/V *Robert Gordon Sproul*, which is approaching the end of its service life. This MARAD-funded project continued the collaboration between Sandia, Glosten, and SIO.

A trimaran hull was used for the *Zero-V*[31] since the previous *Zero-V* project determined a monohull vessel would not provide sufficient stability for an all-hydrogen powered vessel of that size. However, due to the limited introduction of hydrogen technology, a monohull was the only hull design pursued for the *H_2 Hybrid* Sproul Replacement Vessel (SRV).[32] In addition, since this vessel is cost-limited, a monohull of conventional proportions would be the most cost-effective design.

Once the LH_2 tank size was chosen—733 kg consumable LH_2—the *H_2 Hybrid* SRV was designed. Since the *H_2 Hybrid* SRV is not completely reliant on hydrogen power for propulsion, there is no need to have redundancy in the hydrogen system—LH_2 tanks, evaporators, manifolding, fuel cells. This means that just a single LH_2 tank needs to be accommodated. As required by the IGF Code,[33] the LH_2 tank needs to be located no closer than 20 percent of the vessel beam to the side of the vessel.

The *H_2 Hybrid* has a total of 800 kW of installed hydrogen fuel-cell power. This hydrogen fuel-cell system is in addition to the 1185 kW diesel generator plant. It was found that the *H_2 Hybrid* provided much superior performance—better zero-emissions range and emissions benefits—than a Li-ion battery hybrid vessel due to the higher volumetric energy storage density of the LH_2/fuel cell combination.[34]

Based on this study, SIO sought, and was granted, funding from the state of California for the *H2 Hybrid* vessel. The organization announced on July 23, 2021, that California would provide $35 million towards the design, construction, and commissioning of the vessel as a replacement for the R/V *Robert Gordon Sproul*.[35] The project began in Spring 2022.

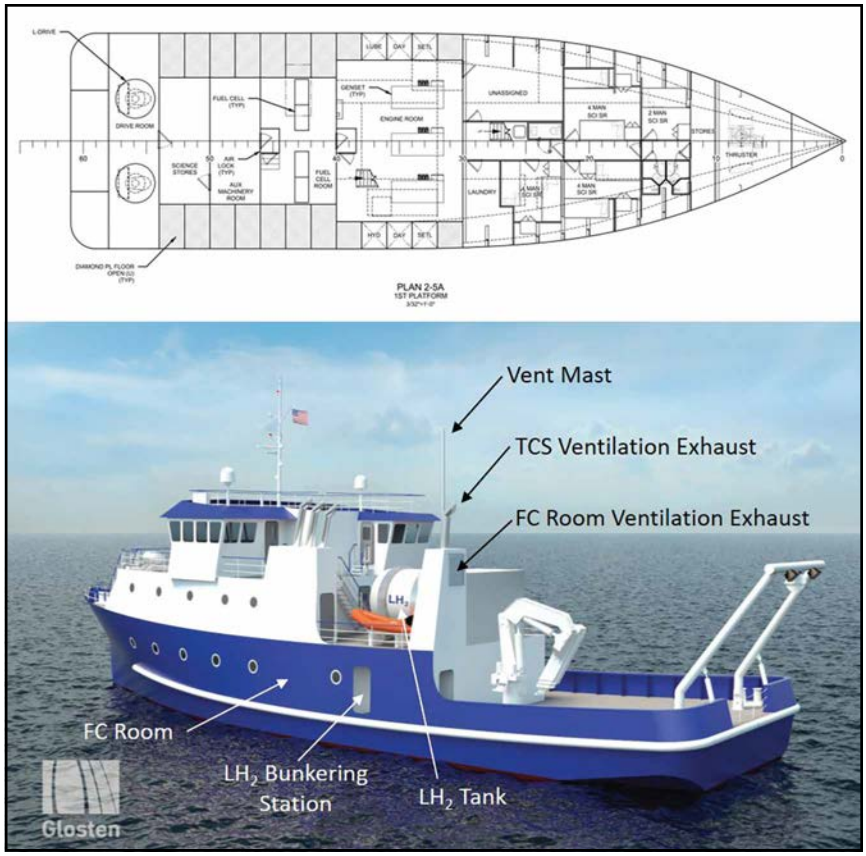
Air Emissions

Fuel cells are zero emission at the point of use. However, there are emissions associated with the production and delivery of hydrogen to the vessel, or the so-called "fuel pathway" emissions. A full analysis of the GHG and criteria pollutant—NO_X, HC, and PM—emissions—for the *SF-BREEZE* has been published[36] and shown in Figure 1. Presented are the production and delivery GHG emissions, the so-called "well-to-tank" (WTT) emissions, for a variety of different ways of making hydrogen.[37]

The current commercial method of making LH_2, namely fossil-derived natural gas (NG) reforming to hydrogen, followed by hydrogen liquefaction, releases significant CO_2 (eq.) per megajoule of LH_2 (126.3). The formulation CO_2 (eq.) considers that there are other gases that contribute to global warming besides CO_2 itself.[38] Water electrolysis using conventional grid power produces even more CO_2 (eq.) emissions—235.9 grams CO_2 (eq.)/MJ_{fuel}—because water electrolysis is very energy intensive, and the current electrical grid used to perform the electrolysis is based on fossil fuels. Fortunately, when renewable sources of hydrogen are available that do not involve fossil fuel, the fuel pathway GHG emissions are dramatically reduced. Renewable methods include wood gasification, and electrolysis of water using low-carbon electricity sources such as nuclear power or wind.

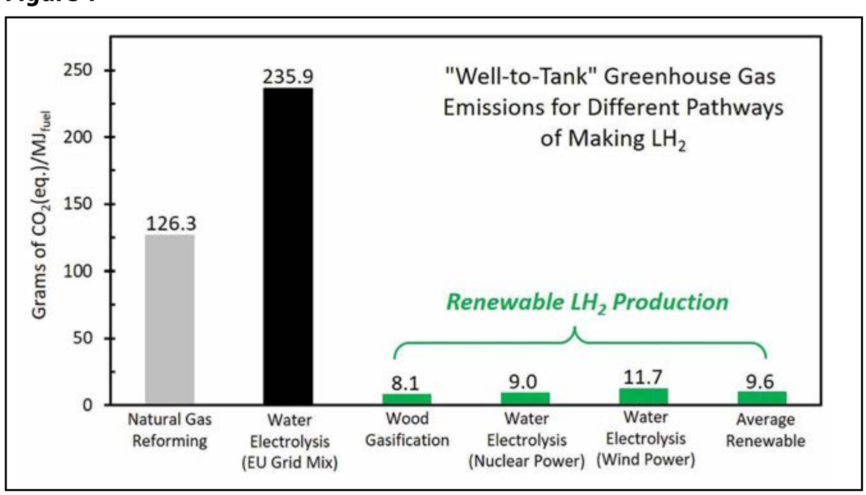
Since PEM fuel cells produce no pollutant emissions at the point of use, these WTT LH_2 production numbers also provide the well-to-waves, or well-to-wake, (WTW) emissions, which includes emissions from the vessel operation, if any. For a hydrogen fuel-cell vessel, the WTT emissions equals the WTW emissions.

Using non-renewable fossil-derived LH_2 leads to undesirable GHG emissions for the *Zero-V*, even greater than for the equivalent diesel-fueled vessel.[39] However, the situation is dramatically improved



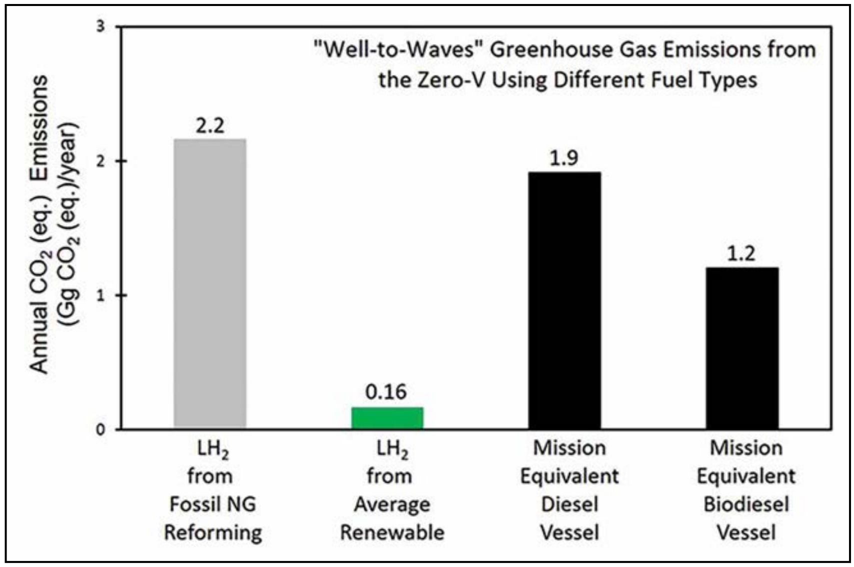
Renderings of the *H_2 Hybrid* SRV present the layout of the vessel, including its first platform (below the main deck) arrangement showing the fuel cell and diesel engine rooms. The second image shows the locations of the LH_2 tank and other hydrogen fuel cell technology features, including the exhaust vent for the fuel cell (FC) room ventilation, and a tank connection space exhaust. Image courtesy of Glosten

Figure 1



Represented above is the greenhouse gas emissions associated with producing one megajoule of finished hydrogen fuel on a lower-heating value basis, or MJ_{fuel}. It also shows production and delivery GHG emissions—the so-called "well-to-tank" emissions—for a variety of different methods of making hydrogen.[18] Graph courtesy of Leonard E. Klebanoff, Ph.D.

using renewable LH_2. Taking the average value of the renewable production pathways shown, the annual WTW GHG emissions from the *Zero-V* using renewable LH_2 becomes 0.16 Gg CO_2 (eq.)/year. This is 91.6 percent less than the WTW GHG emissions from the equivalent diesel vessel running on conventional diesel fuel (1.9), a level of GHG emissions reduction needed to survive growth in the fleet.[40,41,42] It is clear that the real potential in hydrogen technology to reduce maritime GHG emissions lies not in the use of hydrogen derived from fossil natural gas (NG), but rather in using renewable hydrogen. On the other hand, the criteria pollutant emissions—NO_X, HC, PM—from a hydrogen vessel are much lower than for equivalent diesel-fueled vessels regardless of whether the hydrogen is renewable.[43,44,45]



The chart shows the greenhouse gas (GHG) emission results for the *Zero-V*, comparing the annual GHG well-to-waves emissions for the vessel running on either fossil natural gas LH_2 or renewable LH_2, along with the GHG emissions from mission-equivalent vessels powered with either diesel fuel or biodiesel fuel. Graph courtesy of Leonard E. Klebanoff, Ph.D.

Conclusions

The Sandia hydrogen vessel feasibility studies affirmatively answered many feasibility questions including whether hydrogen vessels were up to the task in the areas of speed, range, passenger capacity, and feasibility in fueling sites and provision. Additionally, the studies explored whether these vessels would provide the required GHG reductions and whether they would satisfy Coast Guard requirements and be supported by port authorities.

It's worth noting that all of these questions were inherently "show-stopping" if they were found to be infeasible. However, the only item for which feasibility was not demonstrated, and not examined in the studies, concerned the commercial attractiveness of a hydrogen vessel. That is ultimately for the future marine marketplace, with all its complexity, to determine. While the Coast Guard review has found no "show-stopping" problems thus far, the approval of any given vessel, either by the Coast guard or other national regulatory authority for another country, will depend on the particular design of the vessel under review.

The full final reports for the *SF-BREEZE*, *Zero-V*, and *H_2 Hybrid* projects are available for download at the Sandia

Questions Addressed in Sandia's Hydrogen Vessel Feasibility Studies

The list below indicates the questions that arose and were answered, with a check mark signifying that feasibility was indeed found and the question answered affirmatively.

- ✓ Will H_2 vessels float?
- ✓ Can they go fast enough, up to 35 knots, depending on the application?
- ✓ Can they carry a decent number of people (~150) as needed for a ferry service?
- ✓ Do they have sufficient range before needing refueling?
- ✓ Can the hydrogen suppliers (e.g., Air Products, Linde) provide the needed LH_2 per day?
- ✓ Can the hydrogen suppliers provide renewable LH_2?
- ✓ Can viable H_2 ferries be refueled fast enough with LH_2 for commuter service?
- ✓ Would using new and unfamiliar hydrogen technology be supported by Port Authorities?
- ✓ Are deep cuts in WTW GHG emissions possible with H_2 vessels?
- ✓ Are deep cuts in WTW criteria pollutant emissions possible with H_2 vessels?
- ✓ Could H_2 fuel-cell maritime vessels satisfy the U.S. Coast Guard (USCG) without presenting any "show stopping" issues?
- ✓ Can they satisfy USCG regulatory requirements to gain an Approval in Principal?
- ✓ Can suitable hydrogen refueling sites be found for these vessels?
- ✓ Would there be support from local government (City Hall, others) for this new maritime technology?

Commercial attractiveness was not assessed as it is a consideration for the marine marketplace to determine.

Hydrogen Program Maritime website: www.maritime.sandia.gov. This website also allows download of other hydrogen maritime studies at Sandia not covered here.

About the author:

Leonard "Lennie" Klebanoff, Ph.D., earned his Bachelor of Science and Master of Science degrees, both in chemistry, from Bucknell University, and his Ph.D. in physical chemistry from the University of California-Berkeley. He is the Sandia Maritime Hydrogen Program lead and has authored more than 120 scientific papers, edited one book, and holds patents, both filed and issued.

Acknowledgements:

These Sandia hydrogen vessel feasibility studies received help, support, and guidance from hundreds of people, all of whom are identified in the Final Reports for these studies.

The author would like to thank the following for their contributions to each project:

SF-BREEZE *Study—Curt Leffers and Kelly Sonerholm, both formerly of Elliot Bay Design Group.*

Zero-V *Study—Sean Caughlan, Robin Madsen, Tim Leach, and Cody Conard from Glosten; Bruce Appelgate Jr., and Zoltan Kelety from the Scripps Institution of Oceanography; and Gerd Petra Haugom, Hans-Christian Wintervoll, and Anthony Teo of DNV-GL.*

H_2 Hybrid *Study—The Scripps Institution of Oceanography and Glosten participants, as well as the Scripps Marine Operations Committee, who helped develop the science mission requirements for the R/V Sproul replacement.*

Finally, the author acknowledges Dr. Joe Pratt for initiating the hydrogen maritime program at Sandia National Laboratories.

Sandia National Laboratories is a multi-mission laboratory managed by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Endnotes:

1. The IMO recommendations can be found at: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/IMO%20ACTION%20TO%20REDUCE%20GHG%20EMISSIONS%20FROM%20INTERNATIONAL%20SHIPPING.pdf
2. A. Sydbom, A. Blomberg, S. Parnia, N. Stenfors, T. Sandström and S.E. Dahlen, *European Respiratory Journal*, 17(4), 733 (2001)
3. C. Deniz and B. Zincir, J. *Cleaner Production* 113 (2016) 438–449
4. M. Percic, N. Vladimir and A. Fan, *Applied Energy* 279 (2020) 115848 1–18
5. J. Hansson, S. Mansson, S. Brynolf and M. Grahn, *Biomass and Bioenergy* 126 (2019) 159–173
6. J. Park, I. Choi, J. Oh and C. Lee, J. *Mar. Sci. Eng.* 8 (2020) 322 1–19
7. M. Svanberg, J. Ellis, J. Lundgren and I. Landälv, *Renewable and Sustainable Energy Reviews* 94 (2018) 1217–1228
8. J. Hansson, S. Brynolf, E. Fridell and M. Lehtveer, *Sustainability* 12 (2020) 3265 1-20
9. O. Schinas and M. Butler, *Ocean Engineering* 122 (2016) 84–96
10. C.W. Mohd Noor, M.M. Noor and R. Mamat, *Renewable and Sustainable Energy Reviews* 94 (2018) 127–142
11. L.E. Klebanoff, J.W. Pratt and C.B. LaFleur, *Int. J. Hydrogen Energy* 42, 757 (2017)
12. L.E. Klebanoff, J.O. Keller, M.H. Fronk and P. Scott, "Hydrogen Conversion Technologies and Automotive Applications," Chapter 2 in *Hydrogen Storage Technology, Materials and Applications*, Ed. L.E. Klebanoff, (Taylor and Francis, Boca Raton, 2012) p. 31
13. R.W. Foster, *Proceedings of the 2000 Hydrogen Program Review*, NREL/CP-570-28890, pages 1–8
14. M. Kickulies, *Fuel Cells Bulletin*, September 2005
15. L. van Biert, M. Godjevac, K. Visser and P.V. Aravind, *J. Power Sources* 327 (2016) 345–364
16. Y. Bicer and I. Dincer, *Int. J. Hydrogen Energy* 43 (2018) 4583–4596
17. J.C.G. Trillos, D. Wilken, U. Brand, T. Vogt (2021) *Life Cycle Assessment of a Hydrogen and Fuel Cell RoPax Ferry Prototype*. In: S. Albrecht, M. Fischer, P. Leistner and L. Schebek (eds) Progress in Life Cycle Assessment 2019. Sustainable Production, Life Cycle Engineering and Management. Springer, Cham. https://doi.org/10.1007/978-3-030-50519-6_2
18. L.E. Klebanoff , J.W. Pratt, C.M. Leffers, K.T. Sonerholm, T. Escher, J. Burgard, and S. Ghosh, *Transportation Research* D 54, (2017) 250–268
19. R.A. Evrin and I. Dincer, *Int. J. Hydrogen Energy* 44 (2019) 6519–6928
20. F.G. Aarskog, O.R. Hansen, T. Stromgren and O. Ulleberg, *Int. J. Hydrogen Energy* 45 (2020) 1359–1372
21. O.B. Inal and C. Deniz, *J. of Cleaner Production* 265 (2020) 121734 1–10
22. L. Van Hoecke, L. Laffineur, R. Campe, P. Perreault, S.W. Verbruggen and S. Lenaerts, *Energy Environ. Sci.* 14 (2021) 815–843
23. H. Xing, C. Stuart, S. Spence and H. Chen, *Sustainability* 13 (2021) 1213 1–34.
24. J.W. Pratt and L.E. Klebanoff, Sandia National Laboratories Report #: SAND2016-9719, September 2016
25. *International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IFG Code)*, as amended by Resolution MSC.391 (95), International Maritime Organization
26. L.E. Klebanoff, J.W. Pratt and C.B. LaFleur, *Int. J. Hydrogen Energy* 42, 757 (2017)
27. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energy* 45 (2020) 25328–25343
28. Ibid.
29. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energy* 45 (2020) 25328–25343
30. L.E. Klebanoff, S.A.M. Caughlan, R.T. Madsen, C.J. Conard, T.S. Leach and T.B. Appelgate, Jr., *Int. J. Hydrogen Energy* 46 (2021) 38051–38072
31. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energy* 45 (2020) 25328–25343
32. L.E. Klebanoff, S.A.M. Caughlan, R.T. Madsen, C.J. Conard, T.S. Leach and T.B. Appelgate, Jr., *Int. J. Hydrogen Energy* 46 (2021) 38051–38072
33. *International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IFG Code)*, as amended by Resolution MSC.391 (95), International Maritime Organization
34. L.E. Klebanoff, S.A.M. Caughlan, R.T. Madsen, C.J. Conard, T.S. Leach and T.B. Appelgate, Jr., *Int. J. Hydrogen Energy* 46 (2021) 38051–38072
35. The Scripps Institution of Oceanography announced on July 23, 2021 the granting of a $35M proposal by the State of California for the creation of the Hydrogen Hybrid. The announcement can be found at: https://scripps.ucsd.edu/news/uc-san-diego-receives-35-million-state-funding-new-california-coastal-research-vessel
36. L.E. Klebanoff , J.W. Pratt, C.M. Leffers, K.T. Sonerholm, T. Escher, J. Burgard, and S. Ghosh, *Transportation Research* D 54, (2017) 250–268
37. Ibid
38. Ibid
39. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energ*y 45 (2020) 25328–25343
40. L.E. Klebanoff , J.W. Pratt, C.M. Leffers, K.T. Sonerholm, T. Escher, J. Burgard, and S. Ghosh, *Transportation Research* D 54, (2017) 250–268
41. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energy* 45 (2020) 25328–25343
42. L.E. Klebanoff, S.A.M. Caughlan, R.T. Madsen, C.J. Conard, T.S. Leach and T.B. Appelgate, Jr., *Int. J. Hydrogen Energy* 46 (2021) 38051–38072
43. L.E. Klebanoff , J.W. Pratt, C.M. Leffers, K.T. Sonerholm, T. Escher, J. Burgard, and S. Ghosh, *Transportation Research* D 54, (2017) 250–268
44. R.T. Madsen, L.E. Klebanoff, S.A.M. Caughlan, J.W. Pratt, T.S. Leach, T.B. Appelgate Jr., S.Z. Kelety, H.-C. Wintervoll, G.P. Haugom, A.T.Y. Teo and S. Ghosh, *Int. J. of Hydrogen Energy* 45 (2020) 25328–25343
45. L.E. Klebanoff, S.A.M. Caughlan, R.T. Madsen, C.J. Conard, T.S. Leach and T.B. Appelgate, Jr., *Int. J. Hydrogen Energy* 46 (2021) 38051–38072

Alternative Diesel

A viable bridge to reduce emissions

by LCDR Daniel Velez
Office of Design and Engineering Standards
U.S. Coast Guard

LT Joseph Kolb
Office of Design and Engineering Standards
U.S. Coast Guard

Alison Drapeau
Biomedical Engineering
Worcester Polytechnic Institute

Michaela Kelly
Mechanical Engineering
Worcester Polytechnic Institute

Molly MacAllister
Mechanical Engineering
Worcester Polytechnic Institute

On a tonnage basis, most of the world's goods move over water. Indeed, compared with other modes, the maritime industry remains the most efficient means of transporting goods.

Maritime shipping emits considerably less carbon per ton of cargo shipped compared to air or land transport.[1] However, maritime shipping still represents a significant portion of total worldwide carbon emissions, accounting for approximately 3 percent of the total output.[2] As with other transport sectors, there are many technological and regulatory opportunities for lessening maritime shipping's climate change impacts.

Climate change represents a critical challenge to the commercial interests, environmental welfare, and national security interests of the United States.[3] Nevertheless, with a plethora of emerging technologies, alternative fuels, and possible regulatory schemes, it is critical that new technologies and regulatory proposals are adopted with care, systematically examining the range of possible impacts. By not examining the effects of new technologies on a truly end-to-end, or complete lifecycle basis, the best intended approaches may, in fact, have more severe climate impacts while simultaneously upending the fight against climate change.

Summer 2021 marked the occasion of United Nations 26th Climate Change Conference (COP26), during which the United States reaffirmed commitments to reduce carbon intensity of transportation systems, including maritime shipping, under the Paris Agreement.[4] Even before the conclusion of COP26, there had been worldwide initiatives to reduce the carbon impact of maritime shipping.

Over the last decade, the International Maritime Organization (IMO) has been responding to the call of climate change action by steadily developing regulatory frameworks to assess and mitigate maritime emissions. The initial IMO Green House Gas (GHG) strategy seeks "to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40 percent by 2030, pursuing efforts towards 70 percent by 2050, compared to 2008." The strategy continues, stating the total annual GHG emissions from international shipping should be reduced by at least 50 percent by 2050 compared to 2008.[5]

In support of the GHG strategy, and as the initial framework to measure and control maritime emissions, the IMO has developed energy efficiency indices mandatory for both new ships and existing ships, and the Ship Energy Efficiency Management Plan. These schemes attempt to quantify and manage the carbon impact of shipping as measured by the amount of carbon produced at the stack of the ship. In light of this strategy, the excitement surrounding the push for zero-emission fuels, such as ammonia, is understandable, as they have a zero-carbon impact when burned. Limiting carbon reduction strategy to stack emissions alone, however, does not account for the true total carbon impact of these fuels. The IMO's GHG strategy does not currently take into consideration the creation, transportation, and storage of any fuel burned in its net scoring of carbon intensity mitigation. Additionally, the carbon intensity of replacing (i.e., scrapping and building) ships in the maritime fleet that burn these fuels in order to meet stated carbon reduction goals has not been considered.

There have been many studies that gauge the relative climate change impacts of using different alternative fuels, most of which are focused on automobiles.[6] Most of these studies analyze carbon impact on a well-to-tailpipe basis, an analysis that properly accounts for the carbon intensity of creating any fuel before it is burned.

Unfortunately, there are very few, if any, peer-reviewed studies that analyze the climate change impacts of alternative fuels used in maritime shipping, especially those offering a well-to-wake analysis. Indeed, this represents a gap in critical knowledge of total carbon impact on relative climate change and illustrates the need to expand further upon the accounting of stack emissions alone. There exists an apparent need to close this gap in order to meet the actual intent of IMO's GHG strategy.

A cradle-to-grave analysis provides tremendous insight into how to fully account for carbon impact. The use of ammonia as an alternative fuel is a revealing example of how a narrower view can show misleading results. When used in a combustion process, ammonia leads to water vapor and other nitrogen byproducts, like nitrogen oxide (NO_X), but no direct greenhouse gas emissions.[7] Focused on consumption emissions alone, the "stack" or "wake" carbon emissions here would be essentially zero. Nearly all the world's ammonia is currently produced via the Haber process, which requires a hydrogen gas feedstock. Hydrogen is primarily produced via steam reformation of fossil fuels, which is a process that is extremely carbon intensive.[8]

While hydrogen can be produced from water through electrolysis, which could conceivably be powered by renewable resources—wind, solar, or hydroelectric—there is currently no infrastructure to produce hydrogen at-scale through this approach. Further complicating ammonia as a fuel is its toxicity to human life and the environmentally harmful effects of non-GHG NO_X emissions resulting from ammonia combustion in propulsion plants.

In light of this identified information gap, the Coast Guard Office of Design and Engineering Standards hosted three engineering student interns from the Worcester Polytechnic Institute (WPI) during fall 2021 to assist in a well-to-wake analysis.[9] This comprehensive seven-week project aimed at assessing various alternative fuels for use in maritime shipping through development of a modeling system to calculate the total emissions of carbon throughout the fuels' lifecycles, from raw material extraction to fuel consumption.

The objective of the analysis was to understand the true carbon impact of various fuels beyond just stack emissions, with the end goal being to weigh these findings against the standard heavy fuel oil (HFO) currently burned in maritime shipping. Liquefied natural gas (LNG), methanol, ammonia, biodiesel, and Fischer-Tropsch diesel, all of which exhibit realistic potentials for widespread use in the near future, were chosen as the target alternative fuels.

A Closer Look at Alternative Diesels

Fischer-Tropsch diesel was one of the more interesting alternative fuels considered during the Coast Guard-WPI study. The Fischer-Tropsch process was developed in 1925 by German chemists Franz Fischer and Hans Tropsch. It remains the most critical step in the production of a category of synthetic fuels known as electrofuels, or e-fuels.[10] Through a series of chemical reactions, liquid hydrocarbons are synthesized from a mixture of carbon monoxide and hydrogen, known as water gas. Included in these liquid hydrocarbons are the potentially usable e-fuels, notably here, diesel.[11]

The overall reaction that produces the useful alkanes, in which n=12 would constitute average diesel fuel, is:

$$(2n + 1)\ H_2 + n\ CO \rightarrow C_nH_{2n+2} + n\ H_2O$$

This reaction is extremely unfavorable and occurs at high temperatures and pressures in the presence of

Considering only the carbon emissions from a ship's stack does not account for its true carbon impact. A cradle-to-grave, or well-to-wake, analysis provides a much fuller picture. liveslow | istock / Getty Images Plus catalysts to promote the reaction. The process is therefore very energy intensive when not conducted using renewable energy sources, leading to a significant "well" carbon intensity. This is indicated in the results of Figure 1, which assumed non-renewable energy source use, as Fischer-Tropsch diesel showed slightly greater carbon emissions as compared to HFO. However, there are potentially other carbon-generating offsets that are not included in this description which will be addressed later.

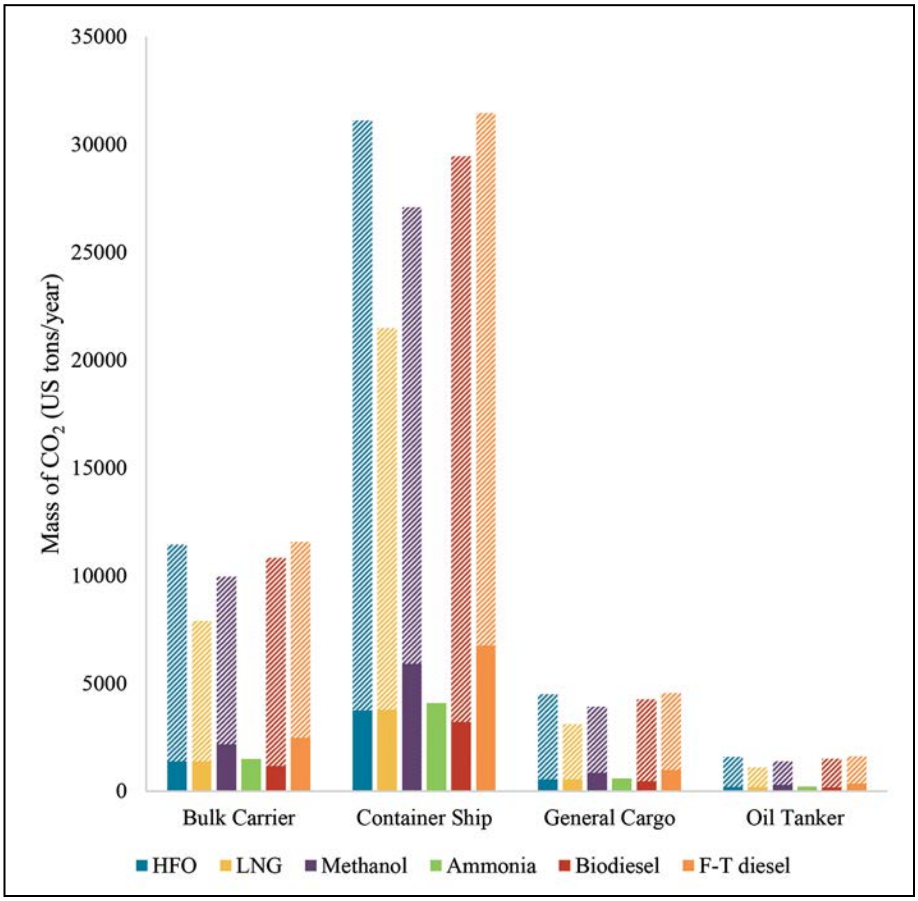


Figure 1. Comparison of annual well-to-wake carbon emissions of various marine fuels against an HFO baseline for four ship types. The shaded bars represent the tank-to-wake portion of emissions, while the solid bars represent the well-to-tank portion, while the entire bar represents well-to-wake.

When combined with renewable energy sources, Fischer-Tropsch diesel shows promise as a means of reducing total carbon impact on a well-to-wake basis. The Coast Guard-WPI study indicated a reduction of "wake" carbon intensity for this fuel as compared to HFO. Reducing the "well" carbon intensity through use of renewable energy sources would result in further reduction of overall carbon intensity, more in line with the IMO strategy. In addition to carbon emission savings, the Fischer–Tropsch process has also received attention as providing a source of low-sulfur diesel fuel and as a means to address issues related to dwindling supply or increasing cost of petroleum-derived hydrocarbons.

In the same vein as Fischer-Tropsch diesel, biodiesel is another interesting example from the alternative fuels analyzed. Biodiesel is a renewable fuel produced from agricultural resources, typically vegetable oils and animal fats, which are transformed into long-chain fatty acid esters through a process known as transesterification.[12] During the process of transesterification, the organic group R″ of an ester is exchanged with the organic group R′ of an alcohol. The organic group R″ represents the long-chain alkyl group of the vegetable oil or animal fat and low molecular weight alcohols—ethanol and methanol—are used resulting in the overall reaction: R′OH + R″OOR → R″OH + R′OOR.

Though this reaction does occur in the presence of catalysts, the lower temperatures and pressures required make this reaction far less energy intensive as compared to the Fischer-Tropsch process. This is indicated in the results of Figure 1, such that biodiesel showed slightly less carbon emissions as compared to HFO. Indeed, the report showed this carbon intensity reduction was seen at both the "well" and the "wake" ends of the fuel's lifetime.

Though biodiesel offers obvious carbon impact savings over HFO, the alternative fuel is still not without its drawbacks in regards to upscaling production necessary to fuel maritime shipping. Most notably, because the feedstock is derived from agricultural resources, there are concerns with regard to biodiesel production taxing food chain supplies, as current production of the feedstock is not sufficient to replace traditional HFO. Additionally, there are concerns with regard to yield efficiency per unit area of the feedstock when upscaling production to necessary industrial levels. Despite these shortcomings, there are additional benefits to the use of biodiesel beyond carbon impact reduction as, like Fischer-Tropsch diesel, biodiesel is an excellent source of ultra-low-sulfur diesel fuel. There are potentially other carbon offsets involving the early retirement of vessels, and related carbon impact.

A Well-to-Wake Study

Data collection for the Coast Guard-WPI study on well-to-wake carbon emissions was based on peer-reviewed sources of data and analyses. These included the *IMO's Fourth Greenhouse Gas Study 2020* and the widely accepted Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) database sponsored by the Argonne National Laboratory.[13] From there, a novel approach was taken to model the usage of alternative fuels against HFO and thus calculate the total carbon impact of the alternate fuels from well to wake.

Ship Type	Average Remaining Life in 2021 (years)	Ship Displacement (tons)	Emission Factor for Steel per Ship (tons CO_2)	Yearly Cost per Ship (ton CO_2/year)	Lifespan Savings per Ship (tons CO_2)
Bulk carriers	19.4	15,000	24,000	800	15,520
Container ships	17.3	17,000	27,200	907	15,685
General cargo	3.7	15,000	24,000	800	2,960
Oil tankers	11	25,947	41,515	1,384	15,222

Table 1: Carbon costs associated with construction of a new ship and compared to the average age of the existing maritime shipping fleet.

Briefly, from published values of carbon emission data for HFO, the mass of HFO used on an annual basis to move a ship was determined. Assuming that the energy requirement to move cargo by each type of alternative fuel is approximately the same, the above calculations were then reversed to extrapolate total carbon emissions for each alternative fuel. This methodology provides a useful, simplified insight into how the push for cleaner burning fuels may affect overall total carbon impact.

Although the final report of the Coast Guard-WPI study has not been academically peer-reviewed, many preliminary key takeaways can be observed. Figure 1 shows the study's well-to-wake results for the carbon intensity of the various marine fuels. The shaded portion of the column represents the tank-to-wake portion of emissions, while the solid portion represents well-to-tank. Note that the carbon impact is assessed by average mass of each type of ship, as well as average distance each type of ship travels in a given year. In this sense a lighter ship, which travels a greater distance, could conceivably create the same carbon impact as a heavier ship traveling, on average, a shorter distance. This also means that well-to-tank emissions will not categorically be the same across all ship types for the same fuel, because different ships will require different amounts of sourced fuel per year.

The initial observation is that all fuel types, except Fischer-Tropsch diesel, showed lower total carbon emissions as compared to the HFO baseline. This result is expected, as LNG, methanol, and ammonia are recognized as lower-emission fuels and remain prominent options in meeting the IMO's GHG strategy for zero-carbon emissions. More strikingly, however, is how poorly each alternative fuel scored against HFO when including well-to-tank, and how ammonia, a zero-carbon fuel when burned, showed a non-zero total carbon emission. This result is a bit less expected, but it represents the foundational takeaway from the report, which lies in the inability of stack emissions alone to capture the total carbon impact of alternative fuels.

Indeed, all of the alternative fuels studied, except biodiesel, showed greater carbon emissions well-to-tank as compared to the HFO baseline. These emission values are the result of the existing maritime fueling infrastructure being geared toward diesel fuel usage and do not account for use of "clean energy" in fuel production. This highlights existing obstacles—clean production, transportation, and storage—still to be overcome in the push towards using these alternative fuels. Such observations are not trivial and serve to illustrate the risks associated with failing to account for carbon emissions in a truly cradle-to-grave approach.

Beyond Stack Emissions

As has been shown in the Coast Guard-WPI report and presented in this paper, the IMO's GHG reduction strategy targets currently consider only stack emissions from maritime shipping and do not account for the carbon impact from a total well-to-wake basis. Indeed, it can be reasonably assumed that the IMO's intent is for the use of alternative fuel sources that have zero carbon impact when burned, such as ammonia, which would eliminate stack emissions altogether. An unintended consequence of this change, certainly one that must properly be accounted for, is the need to retrofit or even replace the existing maritime shipping fleet in order to burn the new fuels. Indeed, the carbon impact of this endeavor is non-zero, but rather can accumulate significantly, as expanded upon below.

In order to help determine what the carbon impact of replacing the existing fleet would look like, an informal analysis is presented here to estimate the carbon emissions associated with construction of a new ship. Several assumptions were made to simplify calculations. These include assuming that the displacement tonnage of a ship is roughly equal to the mass of the ship; that the mass of a ship is almost entirely steel; and that the average age of the fleet will remain constant through 2030. Additionally, only the carbon used to create a new ship was accounted for, not the carbon already spent building the existing fleet. By determining the average displacement tonnages for different ship types, and with a published emission factor of 1.6 tons of carbon per ton of steel, total carbon emissions required to construct a new ship were calculated. Table 1 gives the results of these calculations per year by remaining ship service-life basis.

Assuming the average lifespan of a ship to be 30 years, the annual carbon cost to construct a new ship is not zero, most notably for oil tankers due to their generally larger displacement. The carbon impact of replacing the fleet becomes even more noticeable after factoring in the average age of the ships, with the younger ship types all displaying significant carbon costs should they be pulled from the fleet early.

Figure 2 displays the well-to-wake results for the carbon intensity of the various marine fuels, but with the annual ship replacement carbon costs for biodiesel and Fischer-Tropsch diesel discounted, marked by the red bars. These results may still seem insignificant in comparison to HFO, but several key takeaways exist. First, it should be noted that not only has Fischer-Tropsch diesel become less carbon intensive than HFO for container ships, but biodiesel and Fischer-Tropsch diesel are both more in line with the more traditional greener fuels like LNG and methanol. More notably, overall carbon emissions for both biodiesel and Fischer-Tropsch diesel are now less than that of LNG and methanol for oil tankers.

Figure 3 shows a closer comparison of Fischer-Tropsch diesel and biodiesel versus ammonia, indicating that carbon emissions for these diesels are now even less than that of ammonia, a strict zero-carbon emission fuel. This remarkable observation indicates the possibility of Fischer-Tropsch diesel and biodiesel being the optimal fuel choice for oil tankers, should they remain in service and age out naturally versus being pulled early to accommodate new fuel types. Figure 3 also demonstrates that inclusion of carbon credits for ship replacement leads to results that are comparable or less than methanol emissions. The results shown in Table 1 and Figure 2 may be preliminary in nature, but they open the door for expanded conversation regarding the use of alternative fuels in maritime shipping and their effects on overall carbon output.

A Fleet in Transition

Given the noticeable carbon impact of rebuilding the maritime shipping fleet discussed above, there is an opportunity for a potential carbon-generating offset. The significance of using Fischer-Tropsch diesel and biodiesel in the short term with the existing maritime shipping fleet should not be overlooked. It is fully acknowledged in this preliminary work that the existing fleet cannot meet the stack reduction goals set by the IMO, even with a switch to greener diesel sources. To meet these goals would require either complete replacement of the fleet or complete overhaul of the fleet's propulsion systems. With the average lifespan of a ship close to 30 years, early retirement could mean losing upwards of 20 years of a ship's service life by the first IMO target goal in 2030. This total loss of useable machinery, especially when accounting for total replacement costs, could lead to a significant net carbon impact, as shown in the final column of Table 1.

In light of this, the opportunity for potential carbon savings becomes apparent. Instead of quick replacement of the existing maritime fleet, Fischer-Tropsch diesel and biodiesel may have the potential to support fleet transition to newer ships that support low- and zero-carbon emission fuels over time. Other technologies such as wind sails could possibly also extend the efficiency of

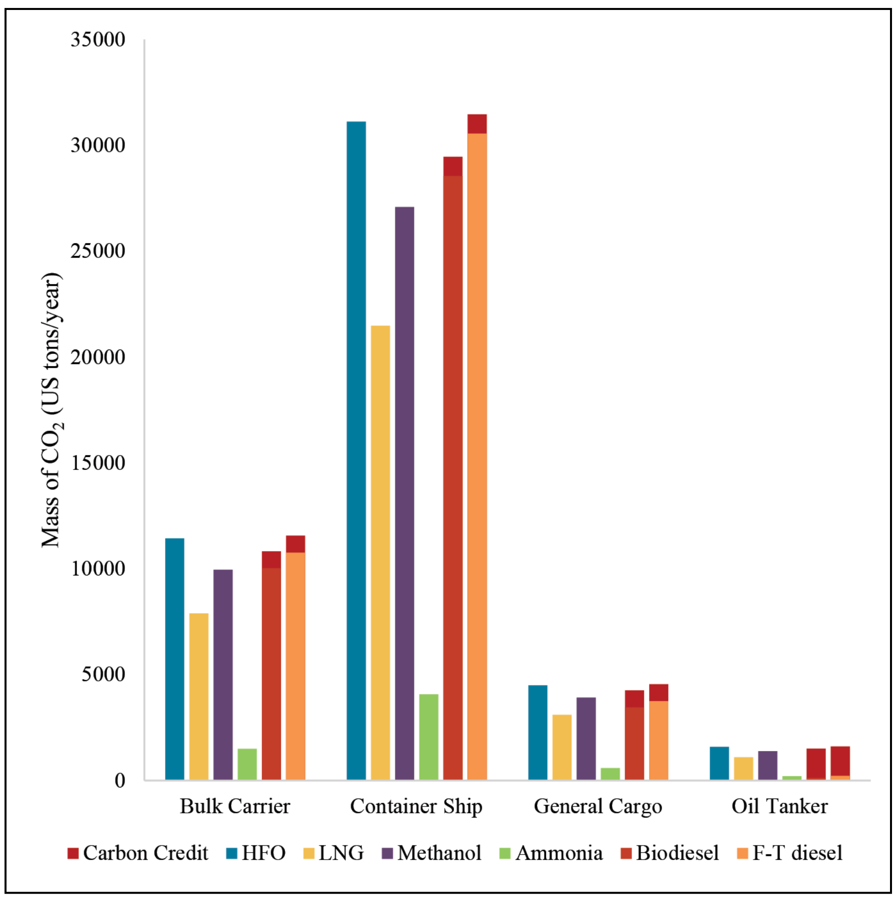


Figure 2. Comparison of annual well-to-wake carbon emissions of various marine fuels with Fischer-Tropsch diesel and biodiesel adjusted for yearly carbon costs per ship.

existing diesel-powered ships.

This allows for existing ships to age out naturally, taking advantage of the potential carbon reductions, and for greener fuel technology to develop further, overcoming their carbon impacts on the "well" end. Fischer-Tropsch diesel and biodiesel can be burned in existing fleet prime movers with little-to-no ship modification required. And, as the Coast Guard-WPI research demonstrated, even when not produced with clean energy, they offer overall net reductions in carbon emissions on a well-to-wake basis.

Development and use of clean energy and more advanced industrial practices only compound this net reduction. Indeed, the notion of gradual fuel transition in the fleet quickly becomes significant and directly supports the intent of the IMO's GHG strategy. Thus, the point of emphasis is that existing vessels should be allowed to operate in the cleanest fulfillment of their lifespan, while facilitating the transition to alternative fuels in parallel.

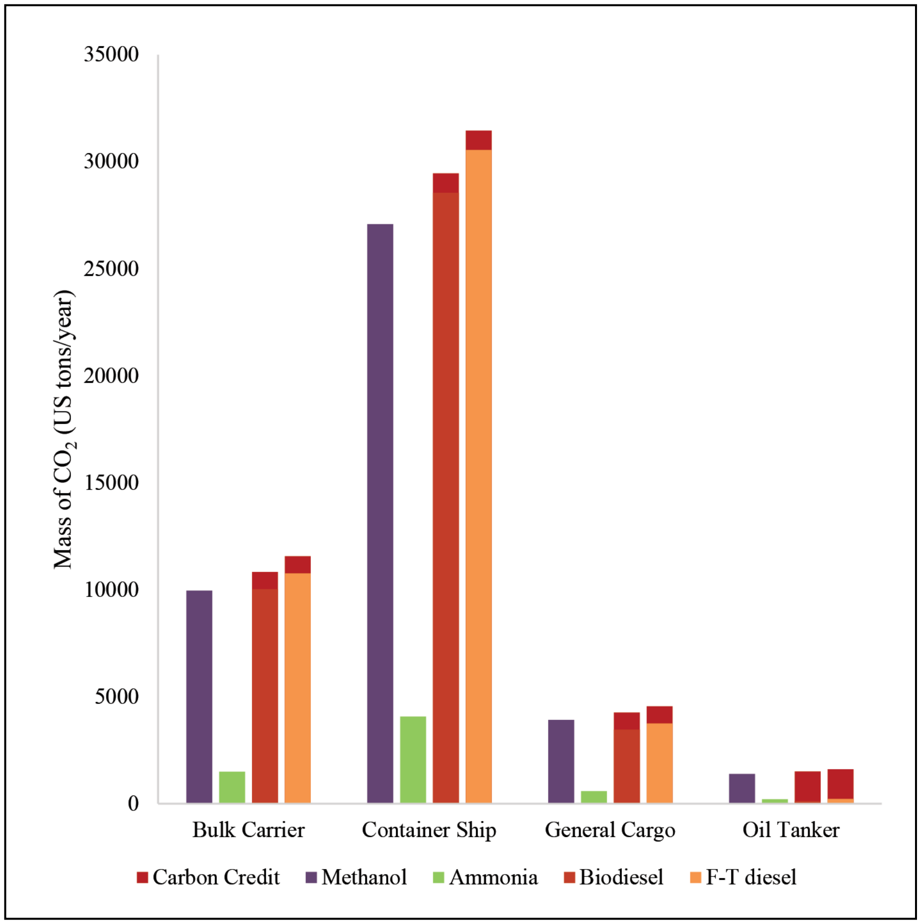


Figure 3. A closer comparison of biodiesel and Fischer-Tropsch diesel, with yearly carbon cost adjustment, to ammonia.

About the authors:

LCDR Dan Velez is the chief of the Coast Guard's Hazardous Materials Division, Office of Design and Engineering Standards. He received his B.S. in chemical engineering from Caltech, an M.S. in environmental engineering from Georgia Tech, an M.S. in mechanical engineering from Carnegie Mellon, and a J.D. from William and Mary.

LT Joseph Kolb works in the Coast Guard's Hazardous Materials Division, Office of Design and Engineering Standards. He received a B.S. in chemistry from University of Virginia, an M.S. in chemical engineering from The Ohio State University, and was commissioned through Officer Candidate School.

Ms. Alison Drapeau, biomedical engineering; Ms. Michaela Kelly, mechanical engineering; and Ms. Molly MacAllister, mechanical engineering; are currently juniors working towards Bachelor of Science degrees at Worcester Polytechnic Institute. MacAllister is also a midshipman with Holy Cross Naval ROTC.

Endnotes:

1. International Maritime Organization. (2009). Second IMO GHG Study 2009. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/SecondIMOGHGStudy2009.pdf
2. International Maritime Organization. (2021). Fourth IMO GHG Study 2020. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf
3. Department of Defense, Office of the Undersecretary of Defense (Acquisition and Sustainment). 2021. Department of Defense Draft Climate Adaptation Plan. Report Submitted to National Climate Task Force and Federal Chief Sustainability Officer. 1 September 2021. https://media.defense.gov/2021/Oct/07/2002869699/-1/-1/0/DEPARTMENT-OF-DEFENSE-CLIMATE-ADAPTATION-PLAN-2.PDF
4. United Nations Framework Convention on Climate Change, 2021 United Nations Climate Change Conference. (2021). COP26: The Glasgow Climate Pact. https://ukcop26.org/cop26-presidency-outcomes-the-climate-pact/
5. International Maritime Organization. (2018). Adoption of the Initial IMO Strategy on Reduction of GHG Emissions from Ships and Existing IMO Activity Related to Reducing GHG Emissions in the Shipping Sector. 13 April 2018. https://unfccc.int/sites/default/files/resource/250_IMO%20submission_Talanoa%20Dialogue_April%202018.pdf
6. Van Mierlo, J., et al, *Proceedings of the Institution of Mechanical Engineers* 217 Part D, 583–593 (2003). https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.879.9517&rep=rep1&type=pdf
7. Kobayashi, H., et al, *Proceedings of the Combustion Institute* 37, 109–133 (2019). https://doi.org/10.1016/j.proci.2018.09.029
8. Rapier, R. (2020). Life Cycle Emissions of Hydrogen. https://4thgeneration.energy/life-cycles-emissions-of-hydrogen/
9. Drapeau, A., Kelly, M., & MacAllister, M. (2021). Green fuels for maritime vessels and their carbon impacts [Undergraduate interactive qualifying project, Worcester Polytechnic Institute].
10. Van Kranenburg, K., et al. (2020). E-fuels: Towards a More Sustainable Future for Truck Transport, Shipping and Aviation. http://publications.tno.nl/publication/34636875/KDhcac/vankranenburg-2020-efuels.pdf
11. Brynolf, S., et al, *Renewable and Sustainable Energy Reviews* 81 Part 2, 1887–1905 (2018). https://doi.org/10.1016/j.rser.2017.05.288
12. Department of Energy, Alternative Fuels Data Center. Biodiesel Production and Distribution. https://afdc.energy.gov/fuels/biodiesel_production.html
13. Argonne National Laboratory, GREET Model. (2021). https://greet.es.anl.gov/

A Fuel in Transition

Liquefied natural gas

by LCDR William J. Hickey
Detachment Chief
Liquefied Gas Carrier National Center of Expertise
U.S. Coast Guard

Aditya Aggarwal
General Manager
SEA-LNG Limited

Sjaak Klap
Principal Environmental Advisor
Society of Gas as a Marine Fuel

Today, the use of natural gas as a marine fuel plays a critical role in reducing airborne emissions of sulfur and nitrogen oxides in the marine environment, improving the world's air quality while meeting current International Maritime Organization (IMO) emission standards. As the world's liquefied natural gas (LNG) marine fuel value chain continues to bourgeon, so does its endurance, attractiveness, and reliability. The IMO set strategic initiatives to reduce global emissions of greenhouse gases (GHG) with milestones set for 2030 and 2050. These actions provide an opportunity for the LNG industry to demonstrate its ability to advance over the next three decades and lead the world marine industry to a lower carbon economy.

This article will discuss a few of the ongoing advancements in natural gas technology and how we might expect natural gas to meet emission-reduction targets by these critical dates.

Key Driver for LNG Today

Emission Standards Drive Growth for Natural Gas as a Fuel

The primary international regulatory mechanism for controlling air pollution from ships is IMO's International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, Regulations for the Prevention of Air Pollution from Ships. It was further implemented in the United States through the Act to Prevent Pollution from Ships (APPS) in accordance with 33 United States Code of Federal Regulations. The current regulations within Annex VI are one of several factors that has driven the industry to adopt new technologies, including the use of low sulfur fuels, remedial devices like exhaust scrubbers, or non-oil based fuels,[1] like LNG.

Through APPS, the Coast Guard has the authority and responsibility to enforce MARPOL Annex VI requirements for vessels operating within a U.S. emission control area (ECA). As a party to Annex VI, the Coast Guard is also bound to verify compliance with fuel standards for a vessel operating beyond U.S. waters.

The sulfur limits are 0.10 percent m/m when a vessel is operating within the ECA and 0.50 percent m/m when operating outside control area. In addition to the ECA and global sulfur caps, the control of nitrogen oxides (NOx) is provided through the survey and certification standards for the issuance of the Engine International Air Pollution Prevention Certificate, also a MARPOL Annex VI requirement.[2]

Fossil LNG emits virtually no sulfur oxides (SO_X) or particulate matter and is compliant with the IMO's SO_X emissions limits inside and outside of the ECAs. NO_X emissions can be up to 95 percent lower compared with marine residual and distillate oil fuels.[3] The environmental performance of natural gas as a marine fuel is one of several factors that has promoted its growth throughout the marine transportation system.

Maritime Governance, Fleet, and Infrastructure Growth

Liquefied Natural Gas Carriers Paved the Way

The safe and effective use of natural gas as marine fuel

Total Weighted Cycle Emission Limits

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	$45 \cdot n^{(-0.2)}$ e.g., 720 rpm – 12.1	9.8
II	1 January 2011	14.4	$44 \cdot n^{(-0.23)}$ e.g., 720 rpm – 9.7	7.7
III	1 January 2016	3.4	$9 \cdot n^{(-0.2)}$ e.g., 720 rpm – 2.4	2.0

Courtesy of the International Maritime Organization was demonstrated years ago onboard LNG carriers (LNGC) that consume boil-off gas (BOG) for power and propulsion. BOG is evaporated LNG vapor that causes the pressure inside the cargo tank to rise during storage and transportation. BOG supplied to gas consumers within the engine room is one method for the crew to safely manage the tank pressure and temperature.

Prescriptive safety standards that govern the use of natural gas as fuel on liquefied gas carriers is provided in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.[4] Coast Guard foreign gas carrier examiners (FGCE) are advanced vessel examiners trained to verify compliance with the LNGC Certificate of Compliance. The FGCE competency establishes specialized knowledge within the workforce to help develop future low-flashpoint fuel.

Today, LNG meets world energy security needs and strategic environmental and sustainability initiatives. Liquefied gas carriers provide the critical link in the value chain between liquefaction terminals and regasification terminals, often on different continents. At of the end of 2020, there were 642 LNGCs operating worldwide and another 161 carriers on order.[5] The majority of LNGCs are around 170,000 cubic meters capacity with the largest, the Q-Max, having a capacity of 266,000 cubic meters.

The first LNG carrier in the world, *Methane Pioneer,* began her maiden voyage in 1959, departing from Louisiana en route to England's Canvey Island. With the Sabine Pass Liquefaction Terminal Train 6 and Venture Global Calcasieu Pass Liquefaction Terminal bringing the total number of operating LNG export terminals in the United States to eight, the nation is on pace to become the world's largest LNG exporter.[6,7]

International Regulatory Framework

IMO addressed the safety challenges presented by natural gas-fueled ships by adopting the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code), which came into force January 1, 2017. The IGF Code is applicable to any ship subject to The International Convention for the Safety of Life at Sea and which uses a low-flashpoint fuel, other than liquefied gas carriers that are subjected to the ICG. The code provides goal-based requirements for the design, construction, and operation of ships and installations of systems using gas or other low-flashpoint fuels, as well as prescriptive requirements for ships using natural gas as a fuel.[8]

Foreign-flagged vessels operating within U.S. navigable waters are subject to the Coast Guard Port State Control program, including vessel examinations. Those using low-flashpoint fuels are examined for compliance with the IGF Code as part of the vessels' routine Port State Control exams. In September 2021, several Coast Guard units developed and led training for the first wave of low-flashpoint fuel examiners to help ensure the organization continues advancing technical proficiency while maintaining pace with this growing industry.

Coast Guard marine inspectors conduct examination of a cargo tank relief valve during a Liquefied Gas Carrier Accelerated Program course. Coast Guard photo

The Coast Guard's Liquefied Gas Carrier National Center of Expertise, the Office of Design and Engineering Standards, the Office of Commercial Vessel Compliance, and Training Center Yorktown collaborated with Sector Jacksonville to develop and lead training for the first wave of low-flashpoint fuel examiners.

National Policy

On March 6, 2019, Coast Guard Rear Admiral John P. Nadeau testified before the Committee on Transportation and Infrastructure's Subcommittee on the Coast Guard and Maritime Transportation.

Two ships load liquefied natural gas (LNG) at Cameron LNG's liquefaction facility, where the first two liquefaction trains produce LNG for customers around the world. Photo courtesy of Cameron LNG.

We have worked with industry to use provisions in our regulations, because right now regulations would not cover LNG as fuel. But we do have provisions and regulations to allow us to do equivalencies, and that is what we have done, where we have worked in partnership with industry as well as the IMO and others around the globe to … develop a set of standards that are uniform. And we have done that, both for the ships as well as some of the infrastructure. And we have worked with them, as well, on the actual procedures and the handling and the bunkering."

As RADM Nadeau mentioned, the Coast Guard has worked in partnership with the IMO to develop standards for ships. A critical national policy that has helped promote the use of LNG as a marine fuel on U.S.-flagged vessels includes the Coast Guard's Office of Design and Engineering Standards policy letter CG-ENG 01-12 Change 1, which provides design criteria for natural gas fuel systems. The policy provides a level of safety at least equivalent to that provided for traditional fuel systems, as required by existing regulations, while recognizing the IGF code as the baseline standard.[9] This national policy continues to provide industry with an avenue to obtain administration approval. Another avenue is via a concept review and design basis approval from the Coast Guard.

In addition to system design standards, several national policies were developed to facilitate LNG infrastructure growth. These policies served to provide appropriate maritime governance across the maritime transportation system including LNG bunkering facilities, LNG bunker barges, LNG bunkering operations, crew training, and simultaneous operations.

Fleet and Infrastructure Growth

In the first quarter of 2022, there were 226 vessels in operation using natural gas as a fuel and another 434 on order worldwide. These numbers indicate that the natural gas-fueled fleet will nearly triple in the immediate future. Most orders are for large vessels operating in worldwide deep-sea trades. The high energy demand for these vessels will greatly increase natural gas consumption and drives the need for additional and more geographically diverse LNG bunkering assets.

Under the United States' national policy framework there are nine U.S.-flagged natural gas-fueled vessels in operation with five under construction. In addition, there are three U.S.-flagged LNG bunker barges in operation and two more in early stages of construction. Finally, there are four LNG bunkering facilities currently operating in the United States.

Future Maritime Emissions

Since the introduction of the global sulphur cap in 2020, the environmental focus has shifted to carbon dioxide (CO_2) and other GHG. LNG provides the industry with a low-carbon fuel comprised primarily of methane. IMO's initial strategy is aimed at GHG emission reduction, however it only refers to CO_2. Though methane and nitrous oxides are currently outside the strategy's scope, IMO is discussing including them in its strategy.

The IMO's initial strategy on the reduction of GHG emissions from shipping sets key ambitions, but the main goals are:

- Cutting annual GHG emissions from international shipping by 50 percent of the 2008 totals by 2050, and working toward phasing out GHG emissions from shipping entirely as soon as possible in this century.
- Reducing the carbon intensity of international shipping, as an average across international shipping, at least 40 percent by 2030, pursuing efforts towards 70 percent by 2050, as compared to 2008 levels.

IMO's Marine Environment Protection Committee is developing short-, mid-, and long-term measures to realize these goals. The IMO and member states are under increasing pressure to reduce GHG emissions further and faster to bring the industry's emissions in line with the COP-21 Paris climate agreement and IMO is planning a revision of its Initial Strategy in 2023.

The lifecycle of fuel classifications include well-to-tank, tank-to-wake, and well-to-wake bases. A well-to-wake basis refers to the full lifecycle assessment of GHG from production through downstream emissions. LNG can provide a 23 percent reduction in GHG emissions on a well-to-wake basis right now.[10]

The IMO regulates on a tank-to-wake basis which considers GHG emissions from the ship's fuel tank to its exhaust, or the downstream emissions, but does not take into consideration emissions from the production and transportation of the fuel, or the upstream emissions. Upstream GHG emissions from production and transportation, including bunkering to the ship's fuel tank, are considered as well-to-tank. The Society of Gas as a Marine Fuel has proposed to the IMO that it regulate GHG emissions on a well-to-wake basis to account for the entire emission lifecycle.

Optimization

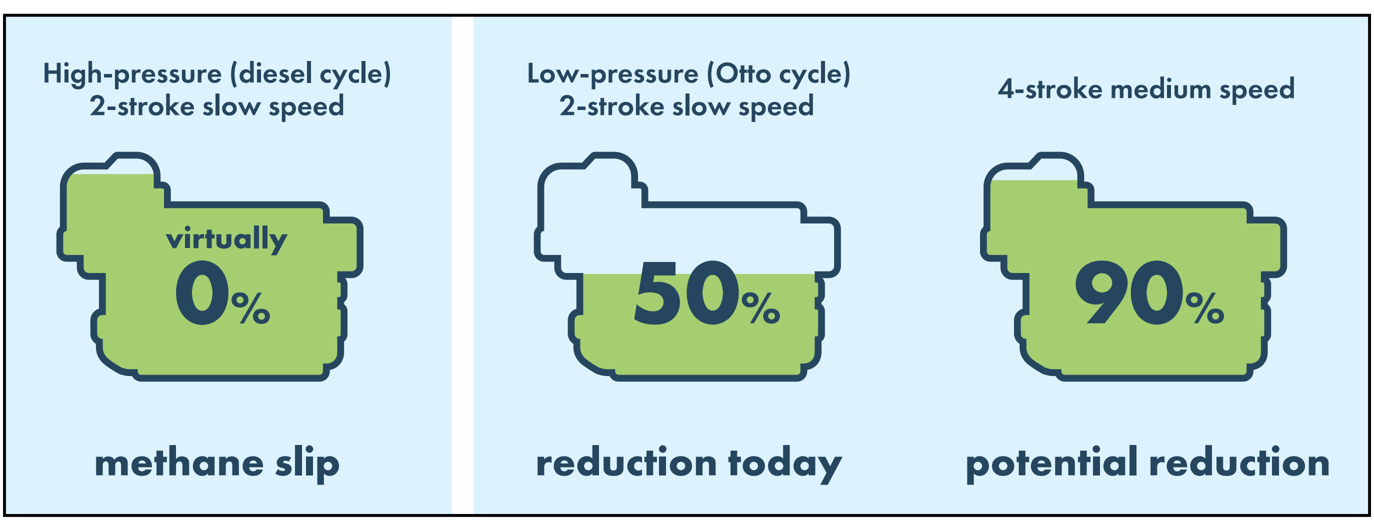
Methane Slip

Methane slip is a phenomenon associated with LNG as a marine fuel and describes what happens when part of the fuel injected into an engine's cylinders is not combusted and leaves the stack as methane. Although methane slip is currently an unregulated gaseous emission, methane is such a strong GHG, it may be introduced as part of the IMOs GHG reduction strategy.

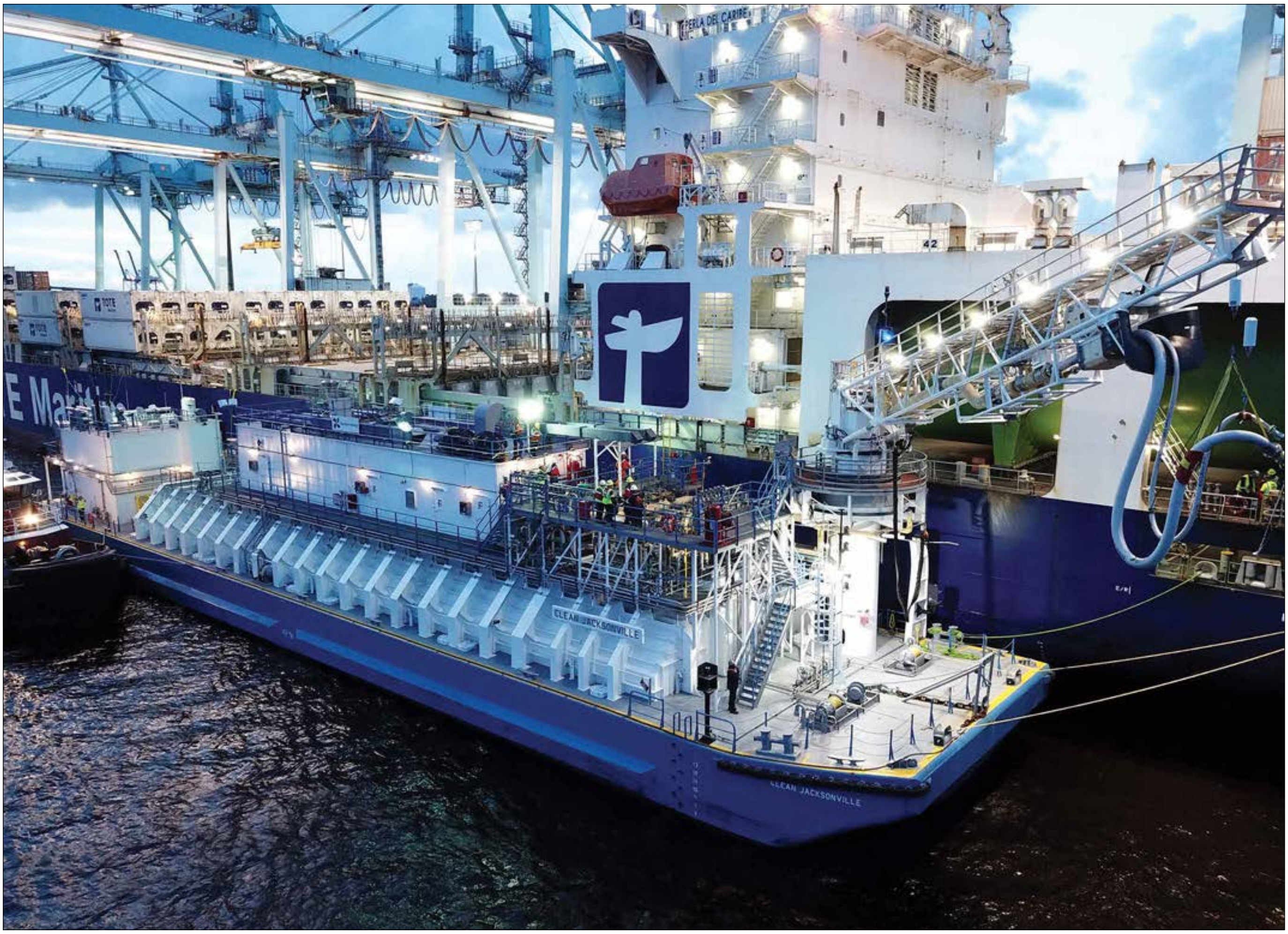
Supply chain methane emissions on a well-to-wake basis is around 6 percent of total GHG emissions.[11] Currently, significant effort is being made to reduce methane slip levels. As such, engine manufacturers have been able to reduce methane slip considerably in recent years through significant improvements in engine designs. Two-stroke vs. 4-stroke cycle and the type of fuel injection equipment result in various levels of methane slip.

Additionally, LNG suppliers continue to make significant progress in reducing methane slip. Current technologies in research and development, such as combustion

Methane Slip



Graphic courtesy of SEA-LNG



Clean Jacksonville, America's first LNG bunkering vessel, completes fueling with a blend of liquefied natural gas and renewable liquefied natural gas at JAX LNG, in Jacksonville, Florida, in September 2021. The vessel was loaded with the blend in preparation for refueling TOTE Maritime Puerto Rico's *Isla Bella*, the world's first LNG-powered container ship. Photo courtesy of JAX-LNG

enhancing and exhaust gas after-treatment will also play a part. By 2030 engine manufacturers expect LNG-fueled engine technologies to have minimal levels of methane slip.[12]

Human Element

Though the conversation surrounding the path to a zero-carbon future tends to revolve around fuel performance and assets, we must also consider human element issues. Mariners, management, and regulators continue to grow their knowledge and experience with the increased use of natural gas as a fuel. Many lessons learned during system design, construction, operations, infrastructure, and governance continue to shape and improve safety management systems, procedures, and industry guidance which promotes a positive safety culture. Experience from the liquefied natural gas carrier industry was leveraged among regulators, classification societies, and industry to help facilitate the initial use of natural gas as a fuel. These human element issues may pose a significant challenge when considering other alternative fuels which may lack that same level of experience from top to bottom as compared to LNG.

Growing Infrastructure

LNG bunkering infrastructure in the United States will continue to grow outside the ports of Jacksonville, Canaveral, and Fourchon. The Coast Guard's Office of Design and Engineering Standards has recently conducted concept reviews and design basis approvals for three LNG bunker barges which will begin construction or retrofit this year. This is in addition to the *Clean Jacksonville*, *Q-4000*, and *Clean Canaveral*, which are already operating in the United States.

Outside of the four LNG bunker facilities, which include, Eagle LNG, Harvey Gulf, Puget LNG, and JAX LNG—which can only load LNG barges—multiple mobile bunkering facility operations have been proposed for U.S. ports on the east, west, and gulf coasts. Globally, there are nearly 100 ports currently supplying

LNG as a marine fuel. By leveraging this existing and growing infrastructure, a "drop-in" alternative could be used for LNG future fuels.

Future Fuels

Marine fuels offer the most powerful tool in addressing the emission challenge for the shipping industry and there is little doubt that the maritime energy transition requires more than one solution. However, in the absence of compatibility and interoperability of multi-fuel solutions, the industry would be subjected to risks arising from accessibility, affordability, and availability of marine bunkers. While sustainably produced ammonia, methanol, and hydrogen may offer future emission benefits, significant environmental benefits are available today through the use of LNG which offers operators a 23 percent reduction in GHG emissions. The LNG pathway offers a viable route towards a zero-carbon future for the maritime sector through its BioLNG and renewable synthetic LNG variants. The U.S. Environmental Protection Agency refers to liquefied biomethane (LBM), or BioLNG, as renewable natural gas (RNG), and liquefied synthetic methane (LSM) as renewable synthetic LNG, or e-LNG.

Liquefied BioMethane

LBM is a non-fossil, renewable green energy which may be derived from a variety of sources, including landfills, digesters at waste treatment plants, agricultural and forestry residues, and organic waste management operations.[13] There are two main ways of producing biomethane from biomass, namely anaerobic digestion and gasification. Anaerobic digestion of biomass produces biogas which is then treated to remove moisture, particulates, contaminants, and other non-methane gases which increases methane content and overall quality for injection into the pipeline.[14] Gasification is a process in which biomass feedstocks are reacted with oxygen and/or steam at high temperatures to produce syngas which is then fed into a methanation process. The biomethane produced from anaerobic digestion or gasification must then be liquefied to become LBM.

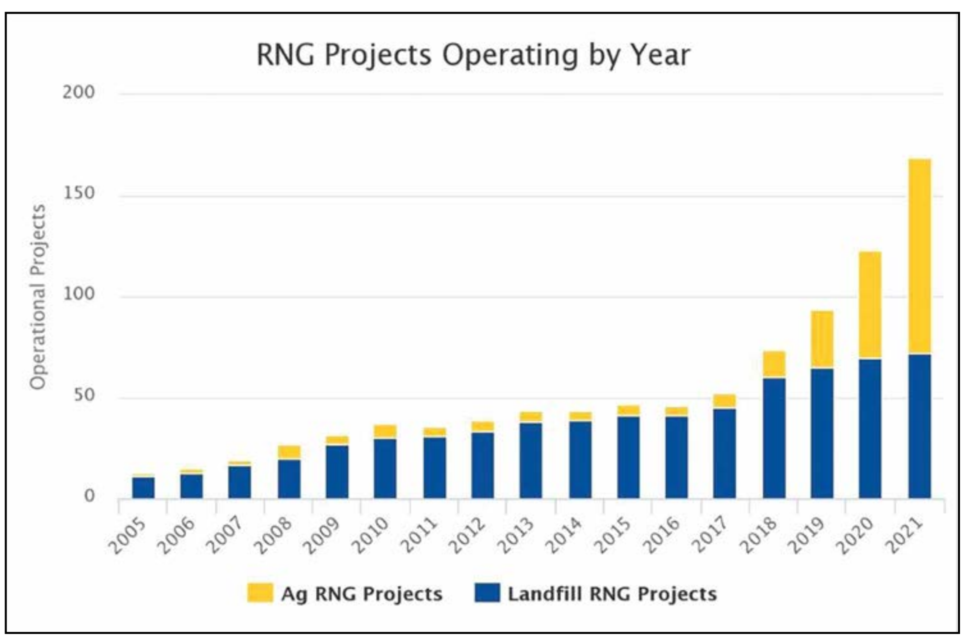
The use of LBM, or RNG, as a marine fuel offers net-zero carbon potential since it significantly reduces emissions that would have otherwise been released into the atmosphere and displaces fossil fuels in the combustion cycle. Farm-based RNG production sourced from dairy or swine manure has the potential to offer negative GHG emissions on a full lifecycle basis due to capturing methane emissions that would otherwise be released into the atmosphere.

> Different than renewable synthetic methane, which uses renewables to create synthetic gas, syngas is a mixture of hydrogen and carbon oxides that can be made from biomass.

The United States is seeing growth in LBM projects with more than 150 agriculture and landfill projects currently in operation. The use of LBM can provide benefits toward fuel security, economic revenues, local air quality, and greenhouse gas emission reductions.[15] Furthermore, policy development has allowed incentives for some transportation sectors, with the exception of marine, under the Federal Renewable Fuel Standard (RFS) program. Future amendments to the RFS program that include the marine transportation sector would benefit the industry, as well as producers of LBM.

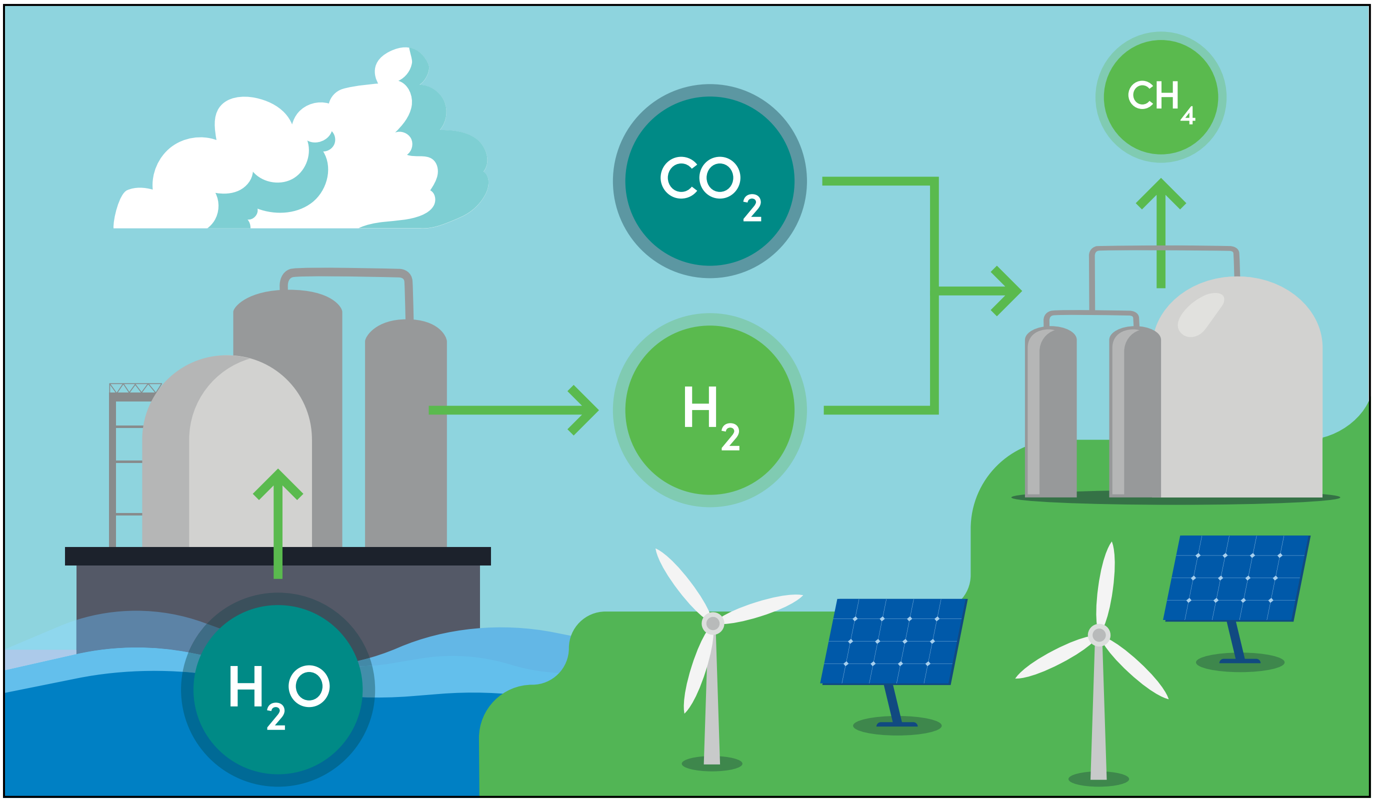
CMA CGM has announced their commitment to the energy transition through the use of LBM. They indicate a 67 percent reduction in GHG emissions on a

Renewable Natural Gas Projects in the U.S., 2005–2021



U.S. Environmental Protection Agency graphic

Synthetic Liquefied Natural Gas Production



Graphic courtesy of SEA-LNG

well-to-wake basis and an 88 percent reduction in GHG emissions on a tank-to-wake basis can be achieved by using LBM combined with their dual-fuel gas technology, paving their path towards achieving carbon neutrality.[16] In December 2021, CMA CGM in partnership with Shell performed the first LBM bunkering in the port of Rotterdam. The container ship *Aurora* received a 10 percent blend of LBM.[17] In September 2021, the first LBM bunkering in the U.S. was delivered by JAX LNG to the M/V *Isla Bella* demonstrating the ability to capitalize on LBM's environmental benefits today in the United States.[18]

Liquefied Synthetic Methane

LSM, or renewable synthetic methane, is methane derived from synthesis of CO_2 and hydrogen produced by the electrolysis of water using renewable energy. Similar to LMB, LSM offers a carbon-free drop-in fuel that could be used interchangeably with existing natural gas infrastructure.[19,20]

The production process for LSM is also known as power-to-gas. MAN Energy Solutions developed a pilot facility in Werlte, Germany, that uses carbon neutral renewable energy to operate an electrolysis plant which serves to separate the hydrogen and oxygen in water. Carbon dioxide obtained as a waste gas from anaerobic digestion is then added to the hydrogen in a methanation reactor resulting in synthetic methane. After a final cleaning process the gas can be injected into existing natural gas infrastructure and distributed for liquefaction to create LSM. Two main factors exist when considering LSM's GHG impact; the feedstock used to create synthetic gas, and the fuel replaced by the gas in its final application.

Under ideal circumstances, replacing heavy fuel oils with LSM from a power-to-gas reactor, which uses biogenic CO_2 or captures it directly from the atmosphere using Direct Air Capture, may cut emissions completely along the value chain.[21] The use of LSM puts carbon neutrality by 2050 within reach, however several factors would need to be addressed which include renewable electricity capacity, technology readiness, and costs.[22]

Conclusion

During the American Bureau of Shipping's North America Regional Committee Meeting, Assistant Commandant of Prevention Policy Rear Admiral John W. Mauger discussed the triple challenge facing the Coast Guard's prevention program.

"We really see three major challenges driving our business and affecting how we do our work. The first challenge is really a drive to get more capacity out of the maritime transportation system. In addition, there's really a desire to reduce the environmental footprint," he said. "And the only way that you can grow capacity while reducing the footprint is by making things much more complex in terms of increased automation, optimization of designs, and operational modes."

The industry has accepted that the IMO GHG emission reduction targets for 2050 cannot be met with only the fuels currently available and that new low or zero-carbon "green" fuels will have to be developed. The candidate fuels have diverse production pathways resulting in different overall environmental impacts. As a result, the GHG intensity of all new fuels will need to be assessed on a well-to-wake basis. Work is already underway at IMO to develop lifecycle GHG/carbon intensity guidelines, also known as LCA guidelines, that can be used for assessing the overall climate impact of the new fuels.

In light of ongoing technological developments combined with the growing infrastructure to support LNG, public and private stakeholder familiarity, and increased mariner competence, LNG remains a viable fuel to meet the maritime global emission targets. The shipping industry needs to focus on the most practical solution that can be safely used aboard ships today while putting us on track to achieve the sustainability goals of the future. We cannot dismiss LNG as a transition fuel, leading the journey to a cleaner and safer future for the maritime industry.

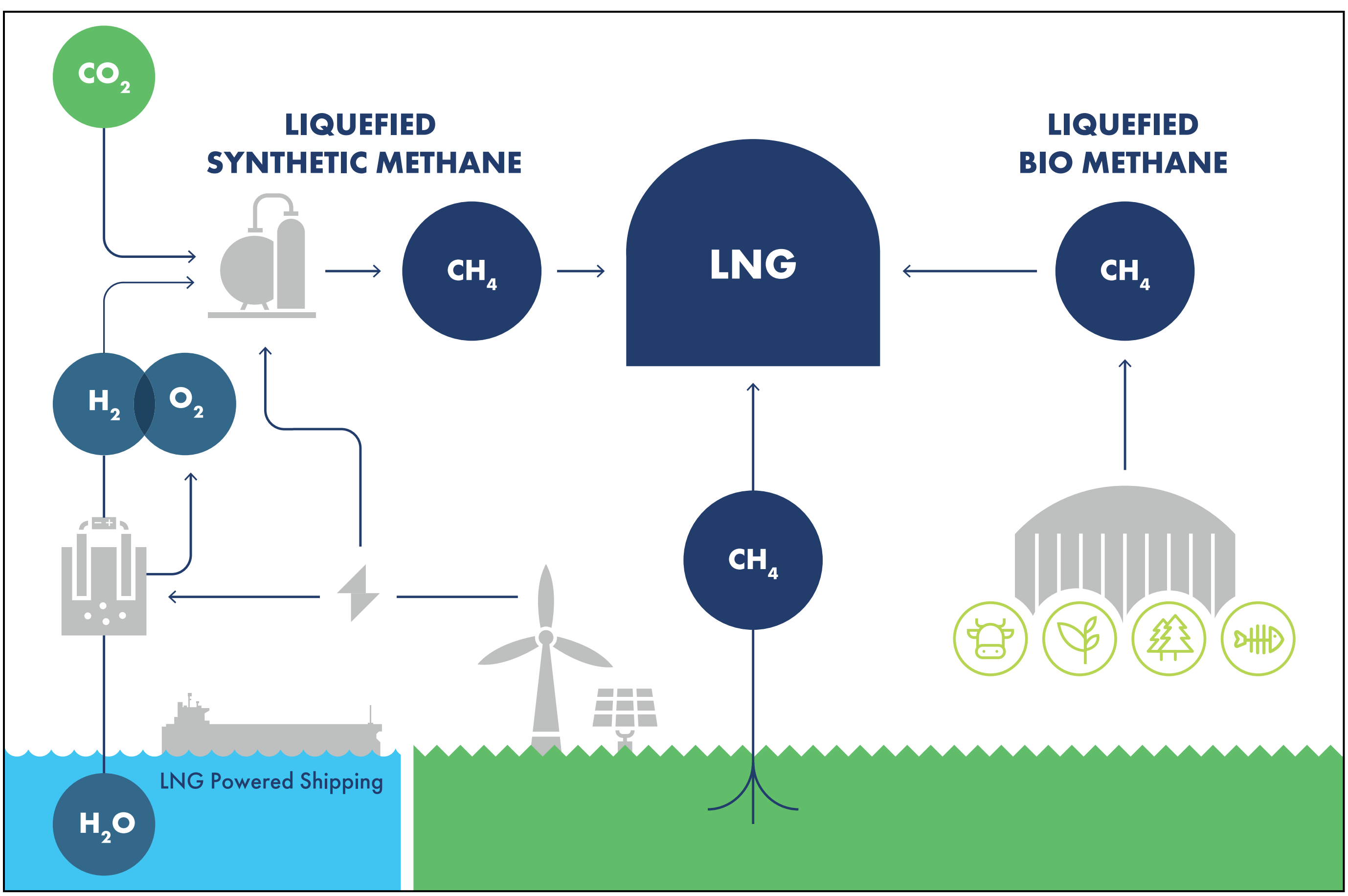
About the authors:

LCDR William Hickey serves as the detachment chief for the Coast Guard's Liquefied Gas Carrier National Center of Expertise. Prior to this assignment, he was the head of Marine Safety Unit Lake Charles' prevention department. He earned a Bachelor of Engineering in mechanical engineering from the State University of New York Maritime.

Mr Sjaak Klap is a principal environmental advisor at the Society for Gas as a Marine Fuel, a non-government organisation founded in 2013 with the key aim of promoting safety and industry best practice for gas as an alternative, cleaner, and sustainable shipping fuel. Beginning his career in shipping, he ventured into other industrial sectors before returning to the shipping industry as vice president business development for Spliethoff, an Amsterdam-based shipping company, before taking his present position at SGMF. He studied marine engineering, business administration, and logistics.

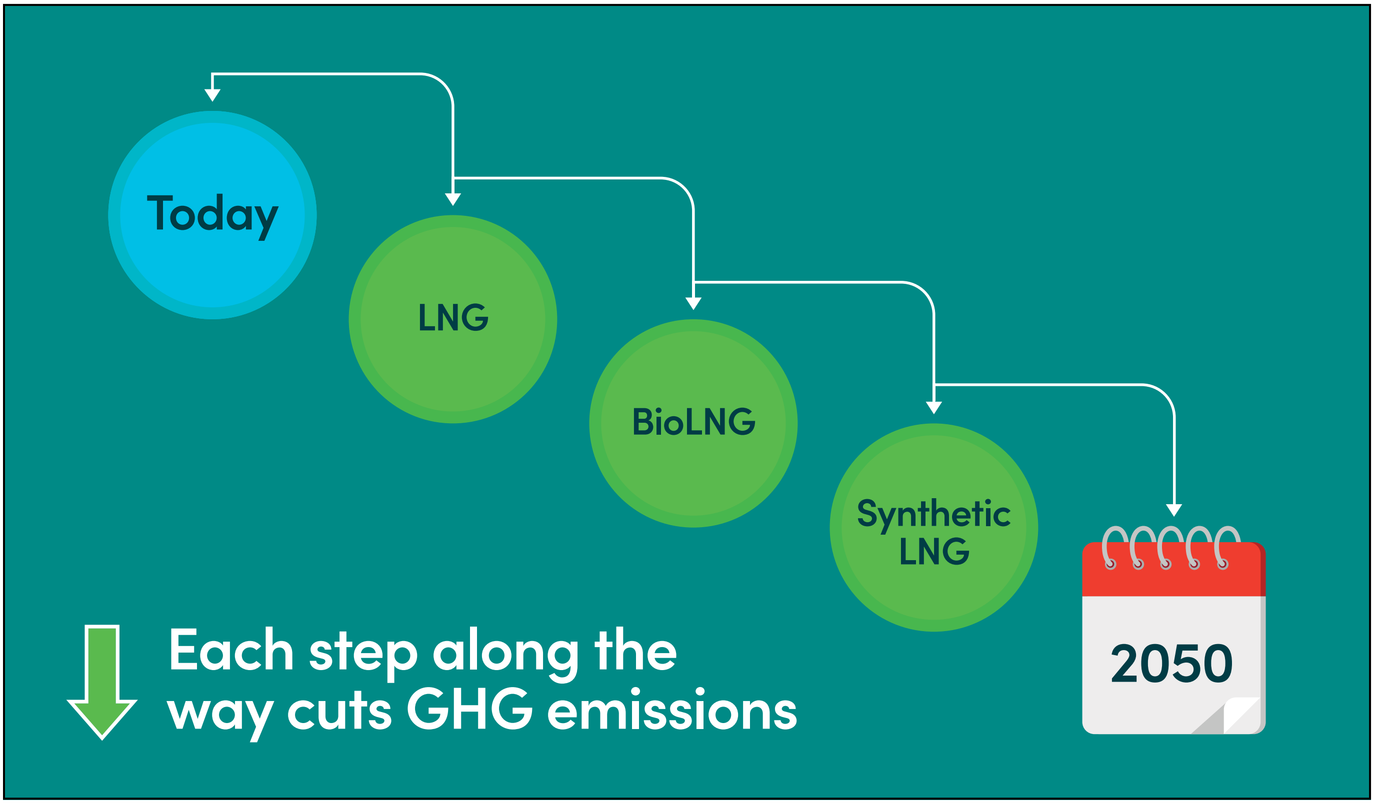
Mr. Aditya Aggarwal, a registered professional engineer, is the general manager of SEA-LNG, a multisector industry coalition focusing on LNG as marine fuel. He has more than two decades of diverse global

GHG Reduction Using LSM and LBM as Alternative Methane Sources



Graphic courtesy of SEA-LNG

Liquefied Natural Gas Pathway to 2050



Graphic courtesy of SEA-LNG

experience in the marine, offshore, and subsea industries. Mr. Aggarwal earned a diploma in marine engineering from Singapore Polytechnic, a bachelor's and master's in naval architecture and marine engineering from the University of New Orleans, and an MBA from Texas A&M University's Mays Business School.

References:

U.S. EIA "U.S. liquefied natural gas export capacity will be worlds largest by end of 2022": December 9, 2021 online: www.eia.gov/todayinenergy/detail.php?id=50598

Federal Energy Regulatory Commission, "North American LNG Export Terminals – Existing, Approved not Yet Built, and Proposed": November 17, 2021. https://cms.ferc.gov/media/north-american-lng-export-terminals-existing-approved-not-yet-built-and-proposed-2.

The Society of Gas as a Marine Fuel, December 2021: www.sgmf.info/

Endnotes:

1. William J. Cotta P.E. (M), William Alex Haugh, Lee Franklin P.E. "Liquefied Natural Gas as Fuel Design Considerations." U.S. Coast Guard, 2017
2. CG-CVC, "Implementation of Compliance/Enforcement Policy for MARPOL Annex VI Regulation 14, including IMO 2020 Sulfur Cap." U.S. Coast Guard Commercial Vessel Compliance, January 13, 2020: www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/CG-CVC/CVC_MMS/CVC-WI-022_signed.pdf
3. Sphera, "Definitive Study on Lifecycle Analysis for LNG as a Marine Fuel" and "Sphera 2nd Lifecycle GHG Emission Study on the use of LNG as a Marine Fuel." April 2021
4. The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
5. SIGTTO 2020 Annual Report and Accounts (2020) www.sigtto.org/media/3454/2020-annual-report.pdf
6. U.S. liquefied natural gas export capacity will be world's largest by end of 2022: December 9, 2021 EIA Report: www.eia.gov/todayinenergy/detail.php?id=50598
7. North American LNG Export Terminals—Existing, Approved not Yet Built, and Proposed: November 17, 2021. https://cms.ferc.gov/media/north-american-lng-export-terminals-existing-approved-not-yet-built-and-proposed-2
8. International Code of Safety for Ships using Gases or other Low-flashpoint Fuels, 2016 Edition.
9. CG-ENG, "Equivalency Determination- Design Criteria For Natural Gas Fuel Systems (Change-1)," U.S. Coast Guard, 2017
10. Sphera, "Definitive Study on Lifecycle Analysis for LNG as a Marine Fuel" and "Sphera 2nd Lifecycle GHG Emission Study on the use of LNG as a Marine Fuel." April 2021
11. ABS. Sustainability Whitepaper. "LNG as a Marine Fuel." June 2020
12. Ibid
13. U.S. EPA "An Overview of Renewable Natural Gas from Biogas." July 2020. Available online: www.epa.gov/lmop/renewable-natural-gas
14. Outlook for biogas and biomethane, IEA 2020
15. Ibid
16. CMA CGM, "A concrete commitment to energy transition in shipping." July 05, 202120 CE DELFT, "Availability and costs of liquefied bio-and synthetic methane." March 2020
17. Surabhi Sahu, "CMA CGM, Shell perform first Bio-LNG bunkering in Rotterdam." December 02, 2021 online: www.spglobal.com/platts/en/market-insights/latest-news/energy-transition/120221-cma-cgm-shell-perform-first-bio-lng-bunkering-in-rotterdam
18. Sarah Smith, "Renewable LNG bunkering completed in US." *LNG Industry.* September 24, 2021
19. Sphera, "Definitive Study on Lifecycle Analysis for LNG as a Marine Fuel" and "Sphera 2nd Lifecycle GHG Emission Study on the use of LNG as a Marine Fuel." April 2021
20. CE DELFT, "Availability and costs of liquefied bio-and synthetic methane." March 2020
21. MAN Energy Solutions. "Power-to-X Solutions." December 2021. Available online: www.man-es.com/energy-storage/solutions/power-to-x
22. CE DELFT, "Availability and costs of liquefied bio-and synthetic methane." March 2020

Hydrogen and Fuel Cell Technology is Poised to Transform the U.S. Maritime Industry

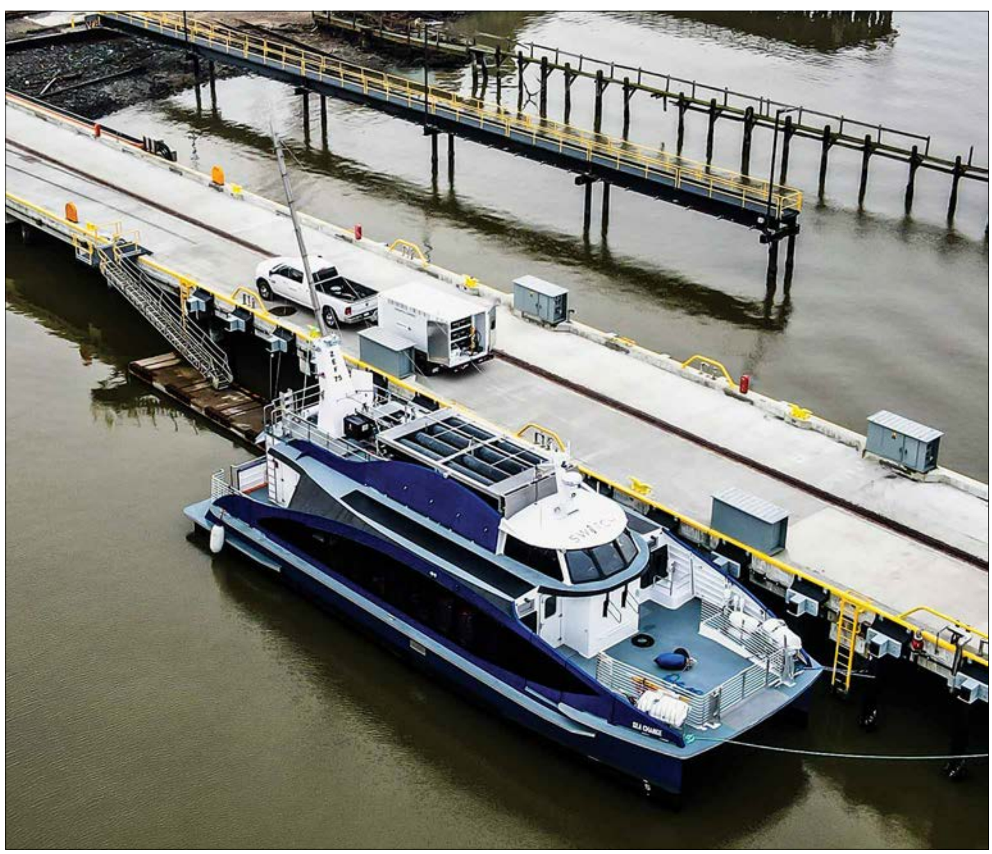
by Joseph Pratt, Ph.D.
CEO and CTO
Zero Emission Industries

Sea Change, the first hydrogen fuel cell vessel in the United States, and the first hydrogen fuel cell commercial ferry in the world, made history when it launched August 12, 2021, at All American Marine shipyard in Bellingham, Washington. The vessel is the result of an effort that began in 2013 at the U.S. Department of Energy's Sandia National Laboratories. Two years later a study called the "SF-BREEZE" was released showing how a 150-passenger hydrogen fuel cell ferry could be built, certificated, operated, and fueled.[1]

In 2018, Golden Gate Zero Emission Marine, now Zero Emission Industries (ZEI), was founded to provide zero emission power solutions to vessel operators around the world. Shortly after, the California Air Resources Board awarded a $3 million grant to a team led by the company to build the *Sea Change*, then called the *Water-Go-Round*. The grant allowed the team to show, not tell, how the marine industry could transition away from diesel fuel and to zero-emission hydrogen.

Sea Change is a 72-foot, 7-inch-long aluminum catamaran, with a capacity of 80 passengers and crew. It can reach a top speed of 22 knots and is powered by twin 300 kW electric motors. Hydrogen fuel cells provide 360 kW of power to the motor, and for high-speed sprints, lithium-ion (Li-ion) batteries provide 100 kWh of power. The fuel, compressed hydrogen, is stored in tanks on the top deck at 3,600 psi, and can be fueled by a truck.

It is not an exaggeration to say that the *Sea Change* and the effort that led up to it have already revolutionized



A compressed hydrogen trailer refuels the *Sea Change* through the onboard bunkering system. Zero Emission Industries has developed a low-cost, portable fueling interface box capable of fueling any vessel with compressed hydrogen, eliminating a significant barrier to hydrogen-powered vessel adoption. Photo courtesy of All American Marine how the world views the transition to a decarbonized marine sector. Numerous vessels around the world are now following its lead. This article describes why by explaining how the technology works and the implications for hydrogen fuel cells as a power source in the marine sector.

Introduction to Fuel Cells

A fuel cell is a solid-state electrochemical power source and like a battery in many ways. This means it has no moving parts and generates electricity directly from a chemical reaction without combustion. Batteries and fuel cells require different chemicals to produce electricity, but when these chemicals react inside the fuel cell or battery they turn into electricity.

By contrast, combustion engines generate electricity through a longer process, first converting chemicals to heat, then to mechanical energy, then to electricity. The ability of batteries and fuel cells to shortcut this process gives them a much higher energy efficiency than combustion engines.

The net chemical reaction inside a fuel cell is:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O + \text{electricity} + \text{heat}.$$

That is, hydrogen and oxygen react to generate water, electricity, and heat, which is a byproduct of a process that is less than 100 percent efficient. A typical fuel cell efficiency is about 50 percent. For comparison, a car's gasoline engine averages around 15 percent to 20 percent efficiency, gas turbines are around 35 percent, and very large engines like those on ocean-going vessels may have efficiencies above 45 percent. Another difference between fuel cells and combustion engines is that in a fuel cell the fuel and air never mix, which adds a new level of safety.

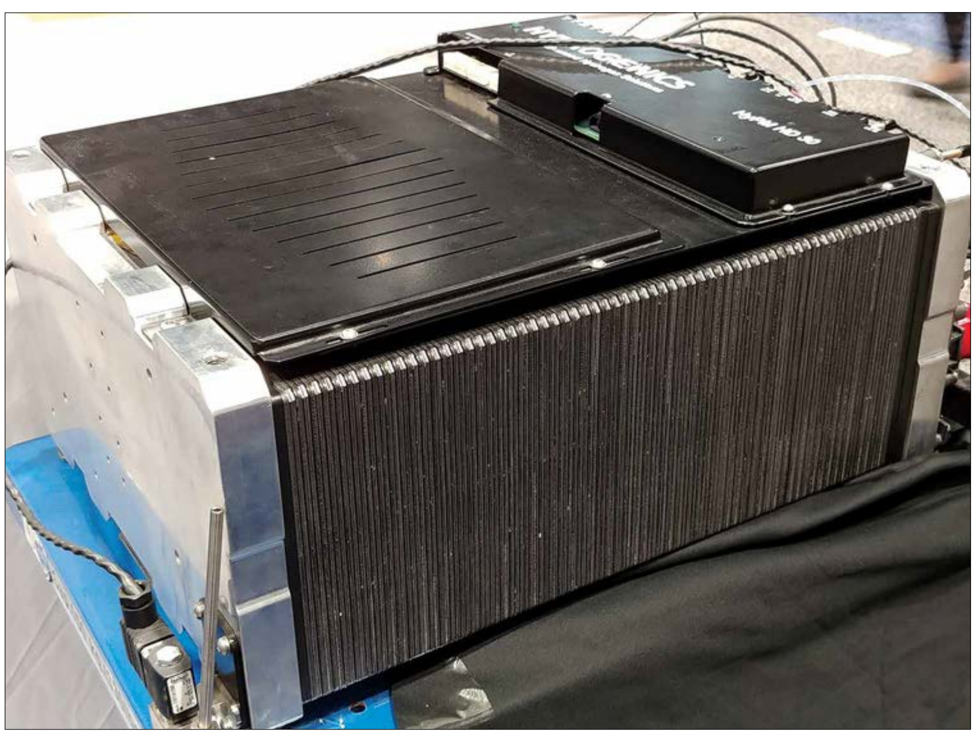
A single fuel cell is like a single battery with an output of around 1 volt. To create higher voltages and more power, fuel cells are stacked up like slices in a loaf of bread. More cells in a stack provides a higher voltage. Making each cell larger will produce higher current. Thus, adjusting the area and number of cells allows fuel cell stacks to be built in a variety of configurations with power levels from just a few watts up to hundreds of kilowatts. The stacks can then be combined in series or parallel to create multi-megawatt arrays, which can in turn be combined to ever higher levels.

Advantages of Fuel Cells

Because the only exhaust from a fuel cell is water, it is considered a zero emission, environmentally friendly technology. There are no air pollutants like CO, NOx, SOx, or particulate matter, and there is no carbon, meaning no CO_2 or greenhouse gas emissions. In addition to the environmental benefits, the solid-state, all-electric, and modular nature of fuel cells provide added advantages.

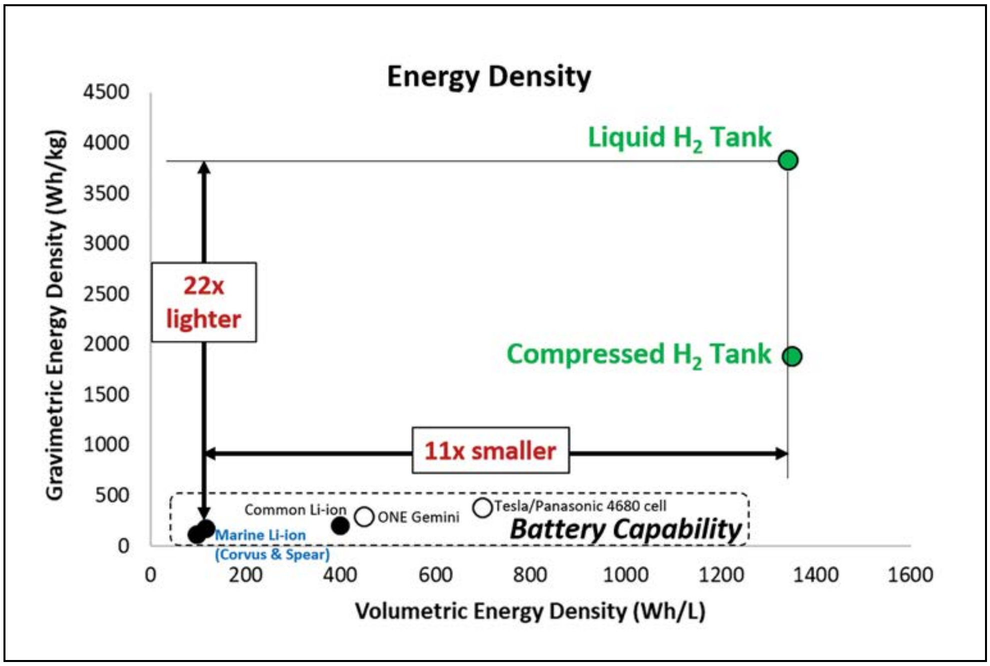
The modularity of fuel cells allows for completely reimagined hull designs, eliminating the need for an engine room. Fuel cells can be distributed around the vessel to achieve optimal weight distribution, trim, and vessel performance. In some applications, a distributed power system also provides an inherent resilience, allowing the vessel to continue operation despite attack or damage.

Fuel cell systems also reduce maintenance costs and downtime, partially because they have so few moving parts which means fewer things to fail and diagnose if there is a failure. Even when considering the air and the cooling systems attached to it, a fuel cell system might have only 5–10 moving parts compared to the hundreds found in a combustion engine. If a single fuel cell fails, it is only one part of a larger array so the vessel can keep operating without a noticeable effect in performance and the faulty stack can be replaced once in port, or in some



A hydrogen fuel cell stack made by Cummins, shows 128 individual fuel cells stacked together to provide about 30 kW of power. Photo courtesy of Joseph Pratt, Ph.D.

cases, even hot-swapped while the system is underway. Finally, fuel cells rarely fail suddenly. Their performance gradually diminishes which means that with today's connected real-time monitoring and data analysis technology, a problematic or underperforming cell or stack can be identified and replaced long before it ever affects vessel performance.



This chart compares the energy density of today's common and most advanced batteries with that of commonly available hydrogen storage tanks. The low energy density of batteries makes them physically unable to provide the needs of most marine vessels. Graphic courtesy of Joseph Pratt, Ph.D.

Introduction to Hydrogen

Hydrogen is a colorless, odorless, non-toxic fuel. It is the simplest element, consisting of just a single electron orbiting a single proton. In the United States and around the world, hydrogen is measured by the kilogram. Through a coincidence of conversion units, a kilogram of hydrogen contains about the same amount of energy as a gallon of diesel. The efficiency advantage of fuel cells over combustion engines means less hydrogen is needed to achieve the same range. For example, a 500 kg hydrogen tank provides as much range as an 800- to 1,000-gallon diesel tank.

At 14.4 times lighter than air, hydrogen is the lightest gas. It is so light that it will rise out of the Earth's atmosphere and leak into space. Methane, or natural gas, is the next lightest fuel and is 1.8 times lighter than air.

This extremely high buoyancy is why hydrogen is very difficult to contain in small spaces. From a safety perspective, this is a good thing because once it reaches free air it immediately zooms upward, leaving no traces around to flare up and cause problems. But to store hydrogen for later use, such as in a car or boat, this means it takes up a lot of space.

One way to reduce the size of hydrogen is to increase the pressure. For example, today's hydrogen fuel cell cars store hydrogen in thick carbon fiber tanks at 10,000 psi. But this comes at a cost because it also takes quite a bit of energy and machinery to get the hydrogen up to 10,000 psi.

Another solution is to turn hydrogen into a liquid. However, liquefying hydrogen is an even more intense process than pressurizing it to 10,000 psi. Unlike propane, hydrogen will not automatically liquefy when pressurized. It must be cooled to -423 F, just 36 F above absolute zero. Liquefying hydrogen requires a lot of energy—1.5 to 2 times that of compressing it to 10,000 psi.

Despite the energy penalty and resulting cost increase, liquid hydrogen (LH_2) is still the fuel of choice for many applications. Stored as a liquid in one tank, hydrogen would be about half the volume of that stored as a gas at 10,000 psi in another tank. Weight is another issue. A tank of hydrogen compressed to 10,000 psi weighs nearly three times more than a tank of the same amount of liquid. So, despite the higher initial cost, transporting and storing large volumes of hydrogen is more cost effective when done as a liquid than as a compressed gas.

Onboard Hydrogen Storage Options

Once the hydrogen is produced and transported, it must be loaded onto the vessel. When it comes to deciding whether to store hydrogen as LH_2 or compressed H_2 on board a vessel, ZEI has developed a rule of thumb: Applications requiring less than 300 kg are probably better suited for compressed gas, while LH_2 is likely a better choice for applications over 500 kg. This, of course, is notwithstanding the other considerations discussed above. Between 300 kg to 500 kg the choice becomes more complicated but becomes clearer with a deeper understanding of the tradeoffs.

For example, let's look at a 600-passenger tourist boat that uses about 200 kg per day. The boat has sufficient space for about 260 kg of compressed gas at 5,000 psi, or in the same space it can fit about 1,000 kg of LH_2. Compressed gas will work and will probably be cheaper than LH_2, so do we go with that? Looking a little deeper, going with compressed gas means refueling every day.

But with 1,000 kg of LH_2 on board the refueling could be spaced out to every four or five days. Today's delivery logistics are structured such that there are two components to the cost, the hydrogen and the truck. In this case, the four- or five-times higher delivery cost of getting compressed H_2 every day will certainly dwarf any cost savings of the hydrogen itself, resulting in a higher overall cost to the operator.

Though storing hydrogen as a liquid or compressed gas are, by far, the most common methods today, they are not the only options. It can also be stored in reversible—rechargeable—materials like chemical hydrides, sorption materials, metal hydrides, and organic liquids. There are also substances made from hydrogen, like ammonia and synthetic methane, where hydrogen is stored as a compound that is irreversibly broken apart later for use.

Sources and Costs of Hydrogen

Hydrogen can be produced anywhere, by anyone, and in several ways. Currently, the most popular form of hydrogen production is via natural gas steam methane reformation (SMR), which is cheap, but not a zero-emission process. In this two-step process, methane, or CH_4, is combined with water and the products are H_2 and CO_2, along with some air pollutants.

In contrast, electrolysis of water allows zero-emission hydrogen production which can be done anywhere and by anyone with access to water and electricity. The only outputs of electrolysis are O_2 and H_2. When renewable electricity—solar, wind, or hydro power—is used, the process is completely renewable. Hydrogen production can be done centrally and distributed via the infrastructure used to move fossil fuels today. Alternately, it can be done locally, for example right at the dock where the vessel will refuel, creating a completely grid-independent operation.

Because hydrogen is created from an energy source, whether a fossil fuel or the sun, the cost of hydrogen depends directly on the cost of the energy source used to produce it. Natural gas is relatively cheap today, making SMR-produced hydrogen one of the least expensive options, at about $1.50/kg at the manufacturing plant. But because the cost of renewable energy is becoming so low, it is widely expected that hydrogen produced via electrolysis powered by renewable energy will soon be less expensive than that produced by fossil fuels.

It should be noted that the $1.50/kg mentioned above is what it costs to make the hydrogen. The transportation, compression and/or liquefaction, and final vessel fueling infrastructure all add cost along the way such that the final price of the delivered hydrogen will be higher. To help reduce this added cost, ZEI designed the fueling system onboard the *Sea Change* to be fueled by any hydrogen truck without any shoreside infrastructure, saving millions of dollars and years of additional work.

> A kilogram of hydrogen contains about the same amount of energy as a gallon of diesel.

Hydrogen and Fuel Cells for Maritime Uses

The International Maritime Organization has put forth a plan to lower carbon emissions from shipping to 50 percent of current levels by 2050. That is despite what is projected to be a five-fold increase in shipping over that same period. Combining this reduction goal with the estimated growth means there will be a need for a 90 percent cut in carbon emissions on an average per ship basis by 2050. This is only realistic with zero-emission technology.

For commercial vessels, the only options for zero-emission propulsion are batteries and hydrogen fuel cells. Unfortunately, batteries have several limitations making them unsuitable for all but a few marine applications including poor scaling ability and the requirement for shoreside infrastructure. As hydrogen systems scale, their cost, weight, and volume all decrease per unit of energy while those of battery systems remain unchanged. While hydrogen is transported and can be used to fuel vessels in the same way as diesel—directly from a truck with a hose—the shoreside infrastructure required for battery systems can be millions of dollars and reduces the flexibility of a vessel to change routes in the future.

In a Sandia National Laboratories study, it was shown that today's hydrogen fuel cell powertrains can meet the propulsion power and energy storage requirements of a wide range of vessels, from small passenger ferries to the largest cargo ships.[2] Technologically, nothing is preventing hydrogen fuel cells from being deployed today in the maritime. However, regulations are proving to be a significant hurdle.

The use of hydrogen as a marine fuel is not specifically addressed in the Code of Federal Regulations (CFR). Efforts have been underway since 2013 to provide the Coast Guard with the scientific and practical understanding of hydrogen needed to craft safe regulations. However, today a design proposal to the Coast Guard for any vessel using hydrogen must still be considered on a case-by-case basis as an equivalency to the CFR. This pathway is to first develop a design basis for the vessel that lays out a framework of design standards and requirements for the equivalency. Once the design basis is approved by the Coast Guard, the designers can use it to develop detailed vessel plans. Finally, the Marine Safety Center will use the design basis when approving vessel plans, and the local Officer in Charge, Marine Inspection will use it when conducting inspections during vessel construction. The process adds time and uncertainty to any vessel project.

Although substantial changes to the CFR can take significant time, guidance and policy documents can have the same practical impact. This has been done in many areas, including recently with the handling of Li-ion battery installations. First, a design guidance document based upon initial best practices was written, followed by a formal policy letter (02-19) incorporating additional learnings and referencing an accepted standard.

The issuance of these kinds of documents can alleviate compliance hurdles and, as illustrated, can provide the needed flexibility to be updated as new information becomes available. This means designers can finalize designs up front, builders can proceed without a threat of rework, and Coast Guard reviewers are on the same page as designers and builders. All of this means that vessel projects are built faster and with lower cost making them financially viable for owners to undertake in the first place.

The only thing worse than no policy at all would be one that was poorly crafted, not based in science, and overly conservative. Therefore, a key component to the success of this approach is that the personnel writing the guidance and policy, crafting the design basis agreements, evaluating the designs, and conducting inspections should all have in-depth knowledge of this technology. While some members of the Coast Guard have the extensive knowledge of hydrogen necessary to create the policy, more are needed, especially in other parts of the review process.

Thankfully, the United States has some of the best hydrogen technology expertise in the world due to its longstanding use of hydrogen, which began with the space program in the 1950s. Scientists and engineers at NASA and the Department of Energy's National Laboratory system have spent decades developing an understanding of hydrogen's fundamentals. Those learnings have been used to develop science-based hydrogen codes and standards in multiple other industries, as well as hydrogen technology training courses.

Hydrogen's Impact

The decline of the U.S. maritime industry over the past 50-plus years has been widely noted. The effects of this are numerous, including the loss of supply chain control, loss of jobs, a reduced economic impact, and elimination of the ability to quickly produce maritime assets in times of crisis.

The hydrogen industry, having come into its own in the 1950s in support of the space program, can help the United States regain its competitive maritime edge. Because of the industry's extensive history, the United States has a unique hydrogen expertise which can be immediately leveraged to make its shipyards and regulators proficient in the technology. Clearly, hydrogen will play a large role in a future decarbonized world vessel fleet and this proficiency can once again propel the U.S. maritime industry to a world-leading position.

Marine deployment of hydrogen also enables U.S. energy independence. Hydrogen can be produced at massive scale with our domestic renewable energy resources (e.g., solar, onshore and offshore wind), eliminating the need to import foreign energy. At the same time, marine vessels are enormous consumers of fuel. The demand created through just a few ferries, pushboats, or patrol vessels is more than that created by thousands of hydrogen cars. Because hydrogen cost decreases with scale, marine vessel usage enables the roll-out of a cost-effective national hydrogen production and distribution network from the beginning.

Conclusion

Hydrogen fuel cell technology provides a viable pathway to a zero-pollution, decarbonized marine fleet. It can be created anywhere through renewable electricity to provide a low-cost, resilient fuel enabling U.S. energy independence. Additionally, the solid-state nature of fuel cells provides operating benefits, including higher efficiency, lower maintenance, and reduced downtime. The transition of the U.S. maritime sector to hydrogen fuel cell technology supports a regrowth of a declining industry, while a concentrated effort to develop relevant regulations will remove the current bottleneck to widespread commercial adoption.

About the author:
Joseph Pratt is the founder, CEO, and CTO of Zero Emission Industries, formerly Golden Gate Zero Emission Marine. With more than 20 years of experience, including 8 years at the U.S. Department of Energy's Sandia National Labs, he has academic, research and development, and commercial expertise in hydrogen fuel cell maritime technology.

References

Zero Emission Industries, "A Q&A: Does Hydrogen Make Sense for Passenger Vessels?" *MarineLog*, October 2021, 33–34

R. Elder, "Enabling Hydrogen Adoption for a Brighter Tomorrow," *MarineLog*, November 2021, 45–47

Endnotes:

1. J. Pratt and L. Klebanoff, "Feasibility of the SF-BREEZE: a Zero-Emission, Hydrogen Fuel Cell, High-Speed Passenger Ferry," Sandia National Laboratories report SAND2016-9710, 2016

2. J. Minnehan and J. Pratt, "Practical Application Limits of Fuel Cells and Batteries for Zero Emission Vessels," Sandia National Laboratories report SAND2017-12665, 2017

A Breeze of Fresh Air

Addressing climate change with green sailing solutions

by LCDR Dimitrios Wiener
Staff Engineer, Office of Design and Engineering
U.S. Coast Guard

Throughout civilization, using sails to harness the power of the wind has been vital to the growth of society. To keep up with the needs of today's global markets, commercial shipping relies on various propulsion systems, a majority of which require burning fossil fuels. In most parts of our modern world, sailing is a nod to a bygone era and has been relegated to leisure and prestigious competitive sports.

We are beginning to see a shift in social trends, however. As climate change concerns come to the forefront of discussions, national and international policymakers are pushing to address the impact of emission pollution on the planet before it brings us to the brink of environmental disaster.

Through Executive Order (E.O.) 14008, issued January 27, 2021, the United States reentered the Paris Agreement which was ratified April 22, 2016, thus prioritizing the climate crisis with regard to both national security and foreign policy. In Part II of E.O. 14008, the administration aims to "… put the United States on a path to achieve net-zero emissions, economy-wide, by no later than 2050."[1] At the president's April 2021 Leaders Summit on Climate, the administration established additional plans to, by 2030, reduce the 2005 greenhouse gas (GHG) levels by 50 to 52 percent. The summit also highlighted the need to revitalize the transportation sector by working with the International Maritime Organization (IMO) to achieve net-zero emissions from international shipping in the same timeframe.[2]

Internationally, the United Nations' (U.N.) and the IMO have been working diligently to address climate change, beginning with the 1997 Kyoto Protocols which addressed the reduction of GHG emissions. In 2011, during its 62nd session, the IMO's Marine Environmental Protection Committee made mandatory the Energy Efficiency Design Index and the Ship Energy Efficiency Management Plan.[3] In the committee's 72nd session in 2018, it adopted an initial strategy on the reduction of GHG emissions from ships, marking the first steps for the international shipping sector's alignment with the goals of the Paris Agreement.[4]

As nations and companies race against the clock to meet the GHG reduction milestones, engineers the world over are innovating technologies the international shipping community can use to reduce its carbon footprint. Currently, international shipping accounts for approximately 3 percent of GHG emissions annually.[5]

As a first step in reducing GHG to meet the 2030 and 2050 goals, shippers are currently planning to implement a strategy known as "slow steaming," or lowering vessels' sailing speeds. This tactic provides some GHG reduction as it allows for reduced fuel consumption and cuts carbon emission, but sacrifices time, as an Atlantic crossing could take 10 days as opposed to the current average of six to eight. To address further GHG reduction, some firms are seeking to harness new green fuel technologies, while others are reconsidering nuclear propulsion plants to power vessels. Still others are seeking new ways to harness the renewable power of the wind to sail us to a cleaner future. This article explores three innovative wind-capture methods currently being tested around the globe.

Vertical Sails

Created by Michelin Research and Development with the assistance of two Swiss inventors, the Wing Sail Mobility (WISAMO) system includes an inflatable wing sail that can be used on both commercial and recreational vessels. The system can be installed during initial construction or retroactively. The company claims the technology can be used on any shipping route and may improve a vessel's fuel economy by 20 percent if certain design, weather, and route conditions are met.[6] The company plans to test the sail on commercial vessels this year. This is not the only sail initiative by Michelin, though. As a testament to its commitment to carbon free shipping, the company promises to also ship its tires across the Atlantic aboard sailing vessels operated by the company Neoline. Using the WISAMO, the first of these Neoline vessels is scheduled to be in operation by 2023. The sail system consists of 4200m^2 of sail area, which at an average of 11 knots, will allow for a 14-day trans-Atlantic journey. Compared to similarly sized vessels, the Neoline vessels are expected to release 90 percent less carbon.[7]

Oceanbird, by Wallenius Marine, also features a vertical sail design. Expected to set sail in 2024, this

200-meter-long, roll-on, roll-off (RORO) vessel is designed to carry up to 7,000 cars across the Atlantic in 12 days at an average speed of 10 knots. The *Oceanbird* uses five rigid, telescopic wing sails that can be lowered from 105 meters to 45 meters above the waterline to navigate obstacles like bridges while coming into port. The five sails can rotate 360 degrees and will use state-of-the-art programing to catch the wind in the most optimal way. The vessel has only an auxiliary engine which is a necessity to aid with safe maneuvering in navigation channels and ports. In addition to the sails, the vessel has a unique hull design that, when working in conjunction with the sails, is expected provide a 90 percent reduction in emissions compared to other vessels in its class.

eConowind, a company in the Netherlands, is developing an alternate approach to Michelin and Wallenius Marine's tall sail methodology. eConowind has developed three versions of its 'Ventifoil' sail system that can be added to an existing vessel. One such option is a containerized unit that stores all system components for two wing-shaped Ventifoil sails. Both sails are approximately 33.8 feet in height and use programing and automation within the containerized housing unit to find the best wind angles to

The *Oceanbird*, by Wallenius Marine, is a 200-meter-long car ferry powered by rigid telescopic wing sails and is expected to set sail in 2024. Photo courtesy of Wallenius Marine

Two eConowind VentiFoils mounted on the bow of the M/V *Ankie*. Each sail is approximately 33.8 feet in height and uses programming and automation to find the best wind angles to reduce engine power. Photo courtesy of eConowind reduce engine power. During inclement weather, these sails can be folded down and stored in their housing. With the footprint of a common 40-foot container, this unit could see adoption within the container fleet where any number of these units could be placed on a vessel to assist as needed. Another option from eConowind permanently adds foils on the bow of a vessel's structure. As permanent structures, the Ventifoils are not constrained to the dimensions of a shipping container, and the sails provide more surface area to catch wind. In foul weather, these sails can also be lowered and secured.

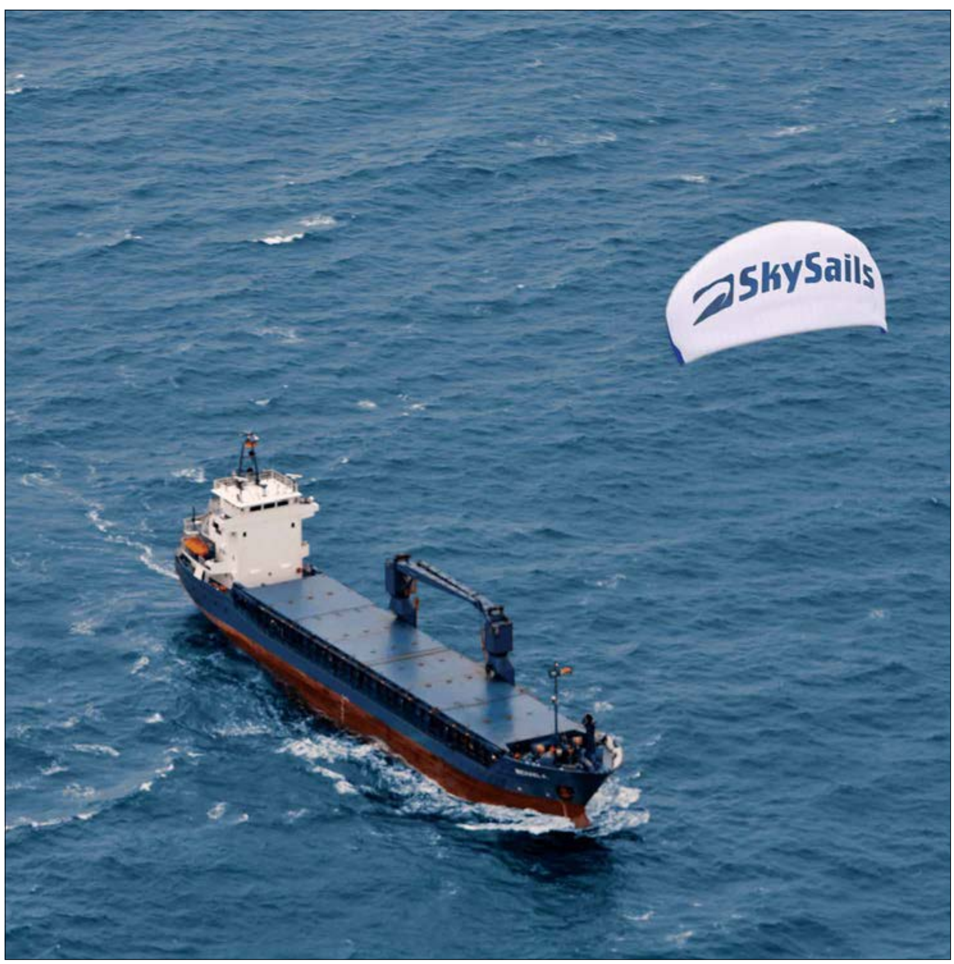
The company provides a third option, the Flatrack Ventifoil unit, which is almost a hybrid of the two previous designs. The base of the Flatrack unit is designed to be secured to the port and starboard sides of a vessel's deck using shipping container twist-locks. In foul weather, they can be secured across the breadth of a vessel. Since late 2019, all three systems have been deployed on vessels, including the M/V *Ankie*, which has had two 10m high foils installed near her bow. The system is expected to produce up to 30 percent of the vessel's propulsion, while increasing fuel economy by 15 percent.[8]

Kite Sails

Commercial shipping companies are also investigating the kite sail design. Connected by a towline and hitched to the bow of a vessel, these sails overcome certain visibility issues that may occur with vertical sails. A benefit of using a towline at the bow of a vessel is that the cargo areas of a ship are not impacted by machinery or additional supporting structures, yet total sail area could be sacrificed for this convenience.

SkySails, of Hamburg, Germany, has been pursuing the use of this technology since 2001 in both ashore and seaborne applications. The company's marine division states that its kites, which can range up to 1000m^2, can produce 25 times more energy per square meter than a conventional sail. This would cut fuel consumption by half on a good day, with up to 20 percent in fuel savings annually. The concept was realized and tested in 2008 aboard the MS *Beluga SkySails* when the kite sail was used for eight hours a day on a voyage from Bremerhaven, Germany, to Guanta, Venezuela. The total fuel savings for the vessel was approximate 2.5 tons per day.

In France, with backing from Airbus, AirSeas' Seawing Kite System, seeks to enter the market, as well. The company signed a 20-year agreement with Kawasaki Kisen Kaisha, Ltd. (K Line), in mid-2019 to test the technology on one commercial vessel.[9] Upon successful delivery and satisfactory operation, it is estimated that these kites will reduce CO_2 emissions by 5,200 tons per vessel, per year. In July of 2021, it was announced that a long-term charter between K Line and the JFE Steel Cooperation for a liquid natural gas (LNG) bulker scheduled for delivery in 2024 would include the Seawing Kite System.[10]



The MS *Beluga SkySails* uses the SkySails system during a 2008 transatlantic voyage from Germany to Venezuela. This kite sail design saved approximately 2.5 tons of fuel per day. Photo courtesy of SkySails Group

Rotor Sails

While vertical and kite systems might be considered more traditional sail styles, rotor sails, both in concept and design, may seem like something out of a science fiction novel. The truth is, this technology is almost a century

Ore carrier *Sea Zhoushan* is the latest vessel to be equipped with five Norsepower rotor sails. The project's goal is to reduce CO_2 emissions by 3,400 tons per year and increase the efficiency of the vessel's propulsion system by 8 percent. Photo courtesy of Norsepower Oy Ltd.

old. Originally designed in 1926, the Flettner Rotor, colloquially known as the rotor sail, uses the Magnus effect on a rotating cylinder to produce a thrusting force perpendicular to the direction of the wind. Norsepower, out of Helsinki, Finland, is seeking to revive this technology, with the utility of other modern marine engineering systems

Since the company's 2012 founding, Norsepower has installed its rotor sail on four vessels. In 2014 and 2015, the company installed two 18m×3m rotors on the RORO M/V *Estraden*, which saw an approximate 6.1 percent emission reduction on its North Sea route.[11] Working with Maersk, the Energy Technologies Institute, and Shell Shipping & Maritime, the company installed two 30m×5m rotors aboard the Maresk *Pelican* in 2018. The vessel's fuel consumption was reduced by approximately 8.2 percent when independently monitored by *Lloyd's Register*.[12]

Also in 2018, the passenger ship *Viking Grace* was fitted with one 24m×4m rotor sail, making it the first

The Magnus Effect

The Magnus effect, first described by German physicist Heinrich G. Magnus in 1852, describes how a spinning object moves through a fluid. When an object spins while moving through a fluid, like air, its rotation causes pressure differences to occur around it, causing a lift force and diverting the object from its original direction of motion. It is an applied example of Newton's 3rd law of motion, as well as Bernoulli's theorem.

We have all witnessed the Magnus effect in many of our favorite sports, from golf to baseball, athletes put a spin on a ball to cause it to curve in a particular way. This curve we witness is the Magnus effect!

LNG/wind hybrid vessel. In a two-year trial period, the rotor sail helped cut the vessel's annual emissions by an average of 900 metric tons. The company is now moving to install five 24m×4m rotor sails on the new build *Sea Zhoushan*, a very large ore carrier being constructed in China. The intent is to reduce CO_2 emissions by 3,400 tons per year and increase the efficiency of the vessel's propulsion system by 8 percent. If trials are successful, the vessel's owner, Vale, could seek to outfit 40 percent of its ore-carrying fleet with this technology.[13]

Regulation of Wind Harnessing Technologies

As these new technologies continues to evolve, nation states and classification societies must also develop standards for the construction, installation, and inspection of these highly complex engineering systems. The American Bureau of Shipping (ABS), one of the United States' recognized organizations, has developed a guide[14] for wind-assisted systems, which works in conjunction with its steel vessel rules. This classification society has established three differing levels of notations for vessels starting with *Wind-Assisted Ready*, then onto *Wind-Assisted*, and the highest level, *Wind-Assisted+*. Considerations for all aspects of sail and vessel design, as well as surveying and testing, are included in this guidance, which harmonizes well with the existing steel vessel rules. ABS is not the only classification society to develop guidelines for sail technology. Around the world, many classification societies are working to find the ways and means to achieve the goals of the Paris Agreement.

The ability to add considerations to existing rules, versus the need to develop new ones, makes it easier for new and existing vessels to incorporate the technology into their design and operation. Owners soon may be requesting that the *Wind-Assisted Ready* notation be provided on their current fleets as a step towards the goal of reduced GHG emissions.

At the national level, there are no current laws, regulations, or proposed rules on the books to address the integration of these wind technologies aboard U.S. vessels. And at present, the U.S. Coast Guard does not have any standing procedures on the design review, approval, or inspection of such systems.

Conclusion

As using sail technology and the wind helps reduce vessel GHG emissions, it may be one of the quickest and most simply implemented technologies available to the shipping industry to help it meet the Paris Agreement's goals. There is no doubt that auxiliary sail technology provides ships with a means to reduce GHG emissions and cutting fuel costs. However, the international community must weigh the economic, logistical, and social factors tied to longer shipping time if sails were to return as the primary mode of shipping.

International shipping could leverage wind power as a primary mode of propulsion if the global economy can support transatlantic transits of 12 to 14 days. As noted earlier, one viable strategy available to shippers in the reduction of GHG is slow steaming, which increases the transatlantic sailing time by approximately 40 percent compared to current shipping averages. Companies and consumers must be willing to accept an increase in shipping times of more than 70 percent should sails return as the primary propulsion system.

The forecasts show a growth in commercial shipping, driven by a need to trade goods due to food and water stresses caused by the very climate crisis the Paris Agreement is trying to mitigate. Perhaps a large fleet of smaller wind-powered sailing vessels, like those of a bygone era, could be the solution we are looking for.

About the author:

LCDR Dimitri Wiener has served in the U.S. Coast Guard since 2011. He has a B.S. in marine engineering from the U.S. Merchant Marine Academy, as well as two M.S.Es—naval architecture and marine engineering, and industrial and operational engineering—from the University of Michigan.

Endnotes:

1. Exec. Order. No. 14008, 86 Fed. Reg. 7619 (January 17, 2021)
2. The White House, Office of the Press Secretary. (2021). *Leaders Summit on Climate Summary of Proceedings* [Press release]. Retrieved from www.whitehouse.gov/briefing-room/statements-releases/2021/04/23/leaders-summit-on-climate-summary-of-proceedings/
3. *Energy efficiency measures*. International Maritime Organization. (n. d.) Retrieved from www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx
4. International Maritime Organization. Marine Environmental Protection Committee. (2018). *MEPC 72-12 Report of the MEPC*
5. *Fourth Greenhouse Gas Study 2020*. International Maritime Organization. (2020) Retrieved from www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study 2020.aspx
6. Michelin Group. (2021). *2021 Movin'On: Michelin presents two innovations to accelerate the development of sustainable mobility* [Press release]. Retrieved from www.michelin.com/en/press-releases/2021-movinon-michelin-presents-two-innovations-to-accelerate-the-development-of-sustainable-mobility/
7. "Michelin Commits to Shipping Product Transatlantic on Sail Cargo Ship." *Maritime Executive*. (2021). Retrieved from www.maritime-executive.com/article/michelin-commits-to-shipping-product-transatlantic-on-sail-cargo-ship
8. *Wind propulsion ventifoils aboard M/V* Ankie. Royal Wagenborg. (2020). Retrieved from www.wagenborg.com/news/wind-propulsion-ventifoils-on-board-mv-ankie
9. AIRSEAS. (2019). *"Breakthrough in green shipping" the Japanese KAWASAKIG KISEN KAISHA, LTD. ("K" LINE) signs for up to 50 automated kiest from AIRSEAS* [Press Release]. Retrieved from www.airseas.com/pdf/kline.pdf
10. "Seawing Kite System Chosen for LNG-Fuelled K Line Bulker." (2021). *Ship and Bunker*. Retrieved from https://shipandbunker.com/news/world/934438-seawing-kite-system-chosen-for-lng-fuelled-k-line-bulker
11. Ro-Ro vessel. (n.d.). Norsepower. Retrieved from www.norsepower.com/roro/
12. Tankers. (n.d.) Norsepower. Retrieved from www.norsepower.com/tankers/
13. Schuler, M. "Newbuild Vale VLOC Released as Bulk Carrier Getting Five Tilting Rotor Sails." (2021). *gCaptain*. Retrieved from https://gcaptain.com/newbuild-vale-vloc-revealed-as-bulk-carrier-getting-five-tilting-rotor-sails/
14. *Guide for Wind Assisted Propulsion System Installation*. American Bureau of Shipping. (2021). https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/315_gn_wind_assisted_propulsion_system_installation/wind-asisted-propulsion-guide-aug21.pdf

Why Hydrogen as a Ship Fuel?

by Mónica Alvarez Cardozo
Principal Engineer
Piping Systems and Alternative Fuels, Approval
DNV

Nathaniel Frithiof
Senior Consultant
Maritime Environmental Advisory
DNV

Hans-Christian Wintervoll
Senior Consultant
Maritime Environmental Advisory
DNV

All arrows point to the end of the days of one dominant fuel. The need for decarbonization of shipping is pushing the industry to find new, greener energy carriers. While tomorrow's fuel mix will be complex, and difficult to predict for several decades, hydrogen has been debated for years as an energy carrier. If it is produced from renewable resources, it is one of the few zero-emission fuel options. The use of hydrogen as ship fuel now signals a conscious effort to tackle decarbonization ahead of regulatory timelines.

Hydrogen's introduction to the energy mix has the potential to contribute to solving some of the challenges we are facing in the age of decarbonization. However, like all alternative fuels it introduces other issues, including technical, economic, and safety. Although the implementation of hydrogen as a fuel might result in high fuel costs in the short term, avoiding transitional fuels might prevent ship owners from going through costly retrofits during a vessel's lifetime.

The 2021 DNV Energy Transition Outlook indicates that by 2050 hydrogen, being a carbon-free molecule, will have a significant share in the fuel mix as a building block for synthetic fuels. This is due to the challenges of supplying the market with large amounts of biofuels produced from sustainable carbon sources.

Hydrogen's strong points are numerous and attractive. It can be produced from water and energy alone and, at the point of conversion to energy, only emits water. Given the availability of sufficient amounts of renewable energy and water, green hydrogen can be produced anywhere in the world. The drawback is that the energy demands in the production process are considerable and thus generate substantial amounts of energy loss from production through liquefaction/compression, and conversion back into useful energy. There are also concerns about the safety and storage of hydrogen due to its low gravimetric and volumetric energy density. Economically and energy-wise, the high cost is currently the greatest obstacle to widespread adoption of hydrogen as an energy carrier. However, the increasing push for decarbonization and the declining cost of hydrogen production will make hydrogen a contender, especially in sectors where electrification is not feasible due to the low energy density of batteries.

Decarbonization Policies in Norway and the EU

Norway's target is to reduce greenhouse gas (GHG) releases by 55 percent by 2030. The government's principal decarbonization policy is to connect emissions to a cost. More than 80 percent of the GHG emissions in Norway are either taxed or are part of the common European Union Emissions Trading System. This system caps the emissions from power production, industry, and aviation, and every release of GHG requires an allowance, which is reduced in number every year. In 2030, the total amount of GHGs accounted for in the European allowances will correspond to 43 percent of the GHG emissions of 2005.

The European Union (EU) is currently working on a legislative package called "Fit for 55." Among other things, it is expected to include an emission trading system for shipping in the EU, which aims to expand the use of sustainable fuel through increasingly stringent requirements. The goal is proposed to be a reduction of 50 percent of the GHG emissions for shipping in and out of the EU, and 100 percent of the emissions for shipping within the EU and when in EU ports. The draft proposals will be considered by the EU Council and Parliament before final adoption.

Funding Mechanisms in Norway

One of the largest environmental public funding schemes available in Norway is the ENOVA public fund, owned by the Ministry of Climate and Environment. Established to reduce business risk when individual businesses start using the newest and most climate-friendly technologies, ENOVA can make a financial contribution so that projects can be realized. Each year, ENOVA invests more

Owned by Norled, MF *Hydra*, the world's first hydrogen-powered ferry, has been operating between Hjelmeland, Skipavik, and Nesvik, on Norway's southwest coast under electrical operation, with hydrogen installation onboard expected in 2022. Photo courtesy of Norled

than NOK 3 billion, or $335 million, of public resources in environmentally friendly projects, and a prerequisite for support is that the project would not have been realized without it. ENOVA sees hydrogen as a potentially vital energy carrier in the process of decarbonizing the maritime sector and has launched a separate program to support investments in hydrogen fuel production for maritime transportation. One of the reasons for specializing in maritime transportation is the large quantities of fuel consumed by each ship. Fewer maritime consumers are needed to reach the production volume required to build a viable business than would be the case for land-based transport.

In addition to ENOVA, the municipalities in Norway can apply for state-funded, climate-positive investments, through an initiative called "Klimakur," a Norwegian expression best translated to "Heal the Climate." This is important as the municipalities along the coast of Norway are major players for the procurement of passenger transport along the coast.

Another tool for realizing the green shift in Norway is the Green Shipping Programme (GSP), a public-private venture funded by the government and under the management of DNV. The GSP initiates pilots, solidifies theoretical findings and learnings, and facilitates dialogue and collaboration between all stakeholders. The programme's vision is to develop and strengthen Norway's goal of establishing the world's most efficient and environmentally friendly shipping. There are currently several hydrogen pilot projects funded through the programme.

Examples from Norway

In 2011, the Norwegian Public Roads Administration (NPRA) launched a competition to develop, build, and operate the world's first electric and zero-emission car ferry. The result was M/V *Ampere*, which was put into operation in 2015 and today operates between Lavik and Opedal.

In 2017, the NPRA again aimed to pave the way for new environmentally friendly technology and launched another competition to develop and operate the ferry connection between Hjelmeland, Skipavik, and Nesvik, on Norway's southwest coast, this time by a hydrogen-electric ferry. Norled, a Norwegian shipping company specializing in ferry transport won the contract. The development and building of MF *Hydra* concluded in 2021, and it has been operating the connection since July 6. For the time being, it is under electrical operation only and is charged from shore. Hydrogen installation onboard the *Hydra* is expected in 2022.

In addition to the demonstrators and pilots covered by the NPRA and the GSP, the Getting to Zero Emissions Coalition maps many more hydrogen fueled vessels covering cargo and passenger transport needs that are being developed both within and outside of Norway. The Coalition is an alliance of more than 150 companies within the maritime, energy, infrastructure, and finance sectors that is supported by key governments and international governmental organizations.

H_2 Value Chain

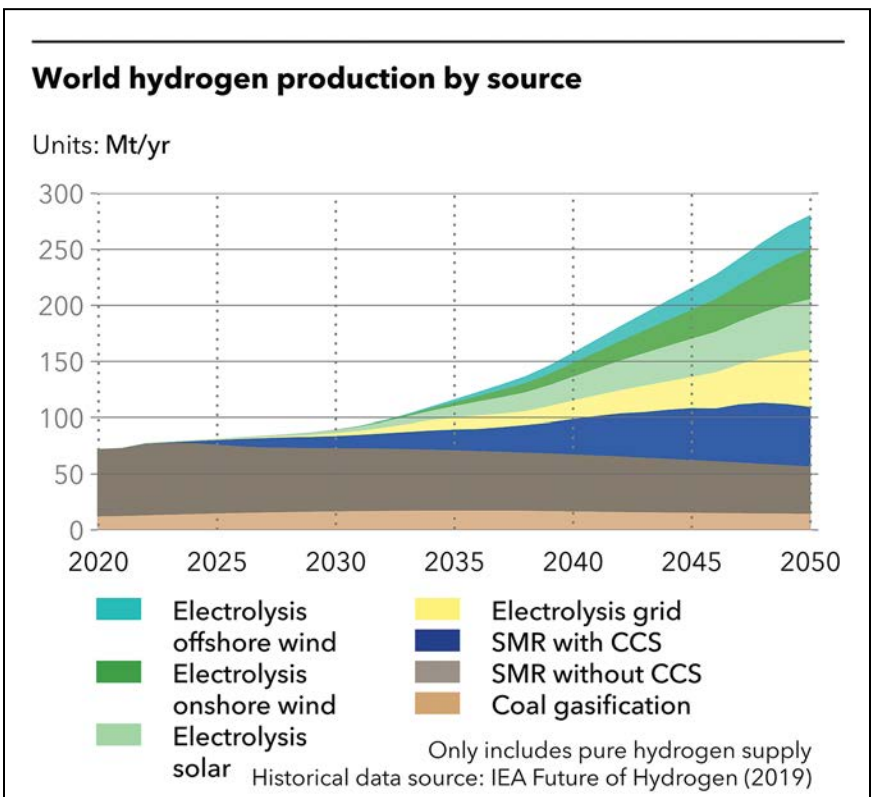
Today, most of the hydrogen production is via steam methane reforming (SMR), where hydrogen is derived from methane. Due to low gas prices, this method is economically favorable, but results in carbon dioxide (CO_2) emissions. However, the emissions from SMR can be captured and stored. The overall costs of carbon capture and storage (CCS) are expected to fall and hydrogen production from SMR will gain momentum in the short term.

The practice of creating hydrogen via electrolysis has been picking up for some years and will be the dominant method for producing the gas by the mid-2040s. Production costs of manufacturing hydrogen via electrolysis are still higher than via SMR, but increased availability of cheap electricity will make electrolysis more competitive.

Coal gasification has a large market share in China due to its low cost, but a very limited presence in other regions. This technology is expected to adopt CCS towards 2050, and will keep its absolute volumes, but will lose its market share as other production methods increase their volumes.

Long term trends that promote the competitiveness of hydrogen as a ship fuel include cheaper costs of electrolyzers, increased time periods for low- to zero-cost electricity due to surplus production, and penalization of carbon emissions through CO_2 tax regimes. In addition to availability and cost of renewable energy, carbon price is highly significant for hydrogen uptake over the next decades. Quadrupling the carbon price in all regions will more than double the global hydrogen demand.

Apart from the safety concerns around using hydrogen, there are multiple technological and market barriers that need attention. These barriers include, among others, the need for relevant infrastructure at the ports to store and bunker hydrogen fuel and available transportation of hydrogen from production sites to the ports, either through pipelines, automotive, or waterborne transportation.



Success Depends on Collaboration

When novel technologies enter new applications, as in the maritime adoption of hydrogen as fuel, widespread industry collaboration with public and private stakeholders is critical for success. This includes sharing safety findings and engaging with large scale tests that can be too expensive for individual companies to perform. One accident in the early phase of technology uptake can stop investments and negatively affect the public perception. It is therefore important that safety is prioritized and transparent sharing of experience is facilitated across the industry.

DNV supports several such activities with regard to the use of hydrogen as ship fuel, including the Maritime Hydrogen Safety project, or MarHySafe, the joint industry development project initiated by DNV. MarHySafe was created to demystify the alternative design approval process that hydrogen fuel designs face in lieu of available prescriptive regulations or rules. Through its first phase, the project established a publicly available *Handbook for Hydrogen-Fuelled Vessels* that gathers the industry knowledge available today. The handbook describes the regulatory processes that early adopters must go through and provides guidance on how to achieve approval through risk assessments and detailed design analysis.

In Phase 2, MarHySafe aims to close some of the identified knowledge gaps through further safety work on quantitative risk assessments, paired with physical testing where needed. The second phase will also include extensive work on bunkering requirements through the publication of a best industry practice reference for both liquefied and compressed hydrogen storage solutions. In the end, MarHySafe hopes to produce concrete recommendations for future rule developments.

Regulatory Outlook

Hydrogen is a low flashpoint fuel and is therefore regulated by the International Code of Safety for Ships using Gases or other Low flashpoint Fuels, or the IGF Code. The IGF Code is a goal-based regulation whose main content is prescriptive regulations for the use of liquefied natural gas (LNG) as ship fuel. Fuels that are not covered by the prescriptive content shall comply with the functional goals of the same code. Demonstrating compliance with the goals and functional requirements of the code implies the use of the alternative design approval process—the IMO instrument to be followed to obtain an equivalent approval from the flag state administration. One of the main challenges of the goal-based approval process is to confirm that the new system's safety level is equivalent to that achieved with comparable conventional oil-fuelled machinery systems as required by the code.

Hydrogen is in many ways a more hazardous fuel in comparison to other low flashpoint fuels. To design arrangements for which safety can be comparable with the current fuel and machinery installations, additional safety barriers and protective measures not used in the existing hydrogen applications for other transport sectors will need to be applied.

Hydra, the first liquefied hydrogen-fuelled ferry built for domestic operation in Norway, has been following a risk-based design due to the implications and the lack of prescriptive regulations that could be used for hydrogen fuel arrangements. The risk-based design uses advanced risk analysis to meet the safety objectives during the design process and in a cost-effective manner. For approval, the alternative design process has been followed. The project owner has been requested to carry out a quantitative risk assessment so that safety is measurable and the acceptance criteria comparable to other installations.

So far, the compliance of alternative fuels and arrangements other than hydrogen, with the mentioned goal and functional requirements of the IGF Code, is achieved by the use of adequate prescriptive regulations verified through approval and supported with qualitative risk assessments.

Safety and Technological Challenges

Hydrogen has a wide flammability range and it is easily ignitable. Considering its high reactivity, especially for concentrations in air above 15 percent, it has a more significant explosion potential than currently available alternative fuels for shipping.

There are significant specific hydrogen safety challenges for ship applications. The first is due to the inherent characteristics of hydrogen. Another is due to ship-design constraints, like the need to store large quantities of hydrogen in enclosed spaces and in relatively close proximity to crew and passengers. Environmental design loads and operational conditions can also significantly impact the total risk of ships using hydrogen fuel.

For ship applications, hydrogen is primarily being stored either compressed, typically in the ranges from 250 bar to 700 bar, or stored liquefied at cryogenic temperatures close to -253 C, or -423 F. These two main storage methods have different advantages and disadvantages when used as fuel.

The feasibility of liquefied hydrogen-fuelled vessels is currently being demonstrated in several publicly funded projects in Norway. Generally, the LNG fuel baseline

Siemens Gamesa-commissioned REM *Energy*, a new hydrogen-ready service operation vessel, is technically ready to operate emission free thanks to fuel cells and battery technology. Photo courtesy of REM Offshore AS

Liquid Hydrogen Carrier vessels are still in the concept phase, but could look something like this rendering when they become reality. Photo by audioundwerbung | istock / Getty Images Plus

requirements can be used with additional hydrogen-specific requirements for protection of components and equipment, leak prevention, and a higher degree of automation. Vacuum insulated C-type tanks are used for both liquid hydrogen (LH_2) and LNG fuel. Besides the safety challenges, the main technological challenges are loss of vapor pressure in the tanks due to cool-down of the gas when liquid sloshing takes place.

Safety is a crucial concern for compressed hydrogen (CH_2) solutions. A single leak in the air can result in high-speed flame combustion events and high energy releases. Explosions should be prevented by design; single failures should not create them, as hydrogen explosions are difficult to predict, difficult to model, and the safety quantification of escalated events is not an exact science. Most of the demonstration projects have placed hydrogen storage and systems in fully ventilated open-air locations. The negative effects of congestion and confinement should not be underestimated in new projects.

Compressed hydrogen is available in several locations, which is a vital advantage that outweighs the disadvantages it has in comparison to LH_2. The number of demonstrator projects with CH_2 is increasing in comparison to LH_2. However, the new application of the technology also comes with challenges. The low gravimetric and volumetric energy density increases the space needed for fuel storage. In addition, the refuelling rates inherent to transporting low-density gas is a key disadvantage. With CH_2, one may consider refuelling in terms of days instead of hours, so innovative ideas such as container swapping are being studied. However, container swapping as bunkering solutions needs new regulations, new safety approaches, and new regulatory regimes.

Generally, a key advantage of hydrogen fuel compared to new alternative fuels for shipping, such as ammonia, is that hydrogen-fuelled ships can use fuel cells without the need for fuel reforming. For instance, Proton Exchange Membrane (PEM) fuel cells are widely used in land applications and are suitable for ship applications because of their small volumes and low temperatures. PEM fuel cells require up to 99 percent hydrogen purity, which at the moment, constrains its application with reformed fuels.

Conclusion

As indicated in the DNV's *Maritime Forecast to 2050*, hydrogen will play a significant role in the decarbonization of shipping and can be used in its pure form or as a building block for synthetic fuels such as ammonia and carbon-based biofuels.

Green hydrogen is a truly zero-emission alternative fuel. However, there is a clear need for industry cooperation to tackle the new application's safety challenges and help hydrogen fuel become a competitive and available alternative fuel in the near future.

About the authors:

Mónica Alvarez Cardozo is a principal engineer in piping systems and alternative fuels with DNV. A former Colombian Navy officer with a background in naval architecture, she is currently working with rule development and approval of hydrogen fuel systems and alternative fuels for shipping.

Nathaniel Frithiof is a senior consultant in maritime environmental technology with DNV. With a background in naval architecture, he is working with safety and reliability of novel technologies and alternative fuels for shipping and currently running Phase 2 of the Maritime Hydrogen Safety Joint Development Project, or MarHySafe, as project manager.

Hans-Christian Wintervoll is a senior consultant in maritime environmental technology with DNV. He holds an M.Sc. in mechanical engineering. His background also includes maritime approval in DNV Classification (Piping Systems and Alternative Fuels) and inspection engineering outside of DNV, working with risk calculation and mitigation.

For more information

***Handbook for Hydrogen-Fuelled Vessels* can be viewed at www.dnv.com/maritime/publications/handbook-for-hydrogen-fuelled-vessels-download.html**

The Role of Methanol as a Marine Fuel

Today and in the future

by Joshua Padeti
Senior Engineer
ABS

LCDR Jason Ryu
Liquid Gas Carrier NCOE
U.S. Coast Guard

Lee Kindberg, Ph.D., GCB.D
Environment and Sustainability for North America
Maersk

As the world moves towards a low carbon economy, how does Methanol fit into the crowded mix of alternative fuels?

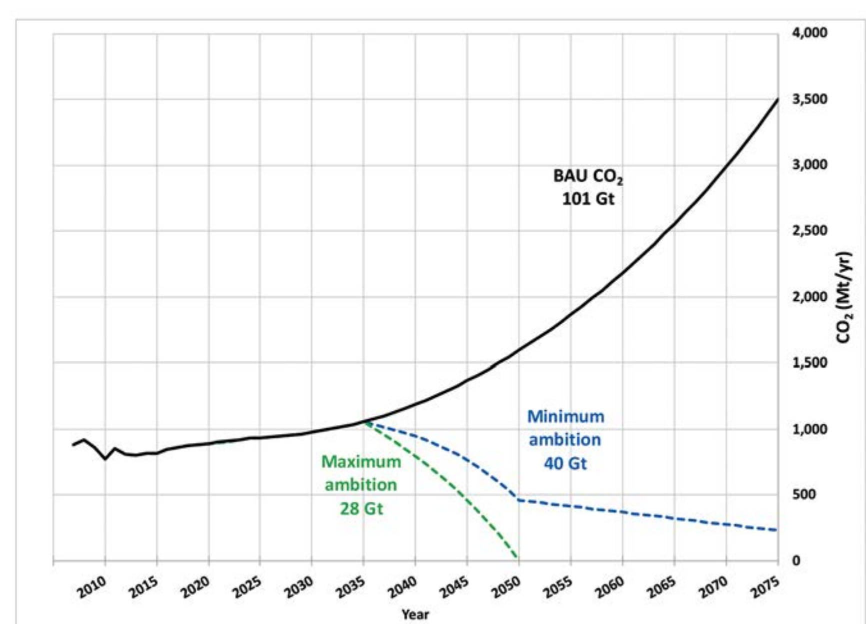
The International Maritime Organization's fourth greenhouse gas (GHG) study, conducted in 2020, found that GHG emissions from maritime shipping rose 9.6 percent between 2012 and 2018, mostly due to a continuous increase of global maritime trade. The shipping industry is increasingly aware of its environmental responsibilities for both air quality impacts and GHG emissions. This is why the International Maritime Organization's (IMO) GHG strategy includes initial targets to reduce the average CO_2 emissions per 'transport work' at least 40 percent by 2030 compared to 2008 levels, with an aim to attain a 70 percent reduction by 2050. The strategy also includes an ambition to reduce total annual GHG emissions from shipping by at least 50 percent by 2050.

Moving beyond the IMO requirements, several carriers have set even more ambitious goals of achieving zero GHG emissions by 2050 or sooner. Existing technologies and strategies can help the maritime industry reach the IMO GHG targets for 2030, but the more ambitious emissions goals set for 2050 lie beyond the reach of current technology and fuels. To achieve those goals, new technology will need to be developed with the main thrust of research and innovation occurring before 2030, giving any new products and ideas time to develop and mature.

Methanol presents a potential low carbon fuel for this cleaner air future. This article discusses the characteristics of methanol, regulatory perspectives from the United States Coast Guard and American Bureau of Shipping (ABS), and the availability and viability of green methanol fuel production in the United States.

All alternative fuels and energy sources have

CO_2 Emissions from International Shipping

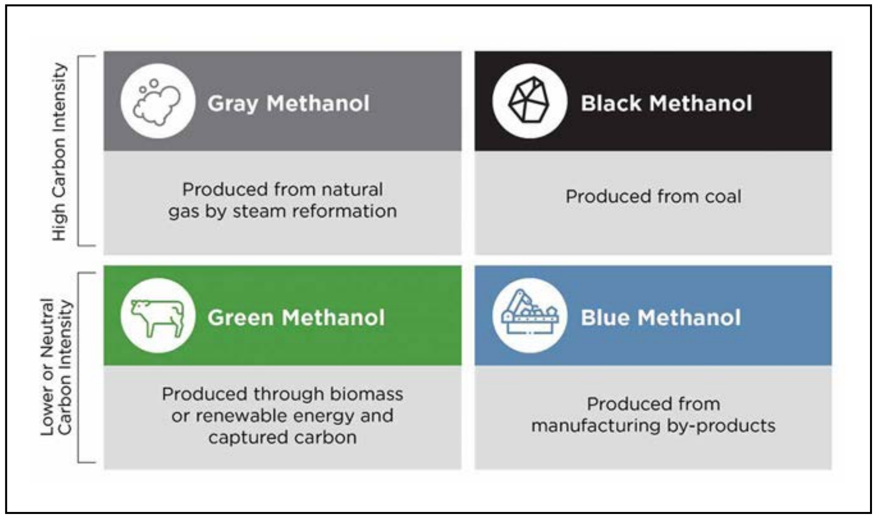


CO_2 emissions from international shipping under IMO's initial GHG strategy (blue and green) vs. BAU (black), with cumulative emissions 2015 through 2075.

Graphic courtesy of ICCT

shortcomings in terms of practical application for international shipping, from onboard storage and energy density to supporting infrastructure and supply systems. Currently there is no obvious fuel choice for the global fleet of the future. It is entirely possible the global solution to shipping's emissions challenge will be found by combining several strategies and future technologies, including new fuels.

Types of Methanol



Courtesy of ABS

Why Methanol?

From the operational perspective, four factors are key in selecting the fuels for a zero- or low-carbon future. These are economics, scalability, sustainability, and technical viability. Future fuels must be found at realistic prices and be available at the needed scale. Methanol offers several advantages and can enable relatively rapid implementation.

Methanol is a colorless liquid at ambient temperature and pressure, and it is relatively low in toxicity when compared to ammonia. It can be handled, stored, and pumped like other liquid fuels, and the risks associated with methanol spills are lower when compared to oil spills due to methanol's biodegradability and water solubility. Fuel storage and piping do require some special attention due to the lower flashpoint, but unlike cryogenic or pressurized fuels, methanol does not require refrigeration, liquefaction, or vaporization equipment similar to liquefied natural gas (LNG), hydrogen, or ammonia. Nor does it require large, pressurized storage tanks.

Methanol is one of the top five chemical commodities shipped and is available for bunkering in over 88 of the world's top 100 ports with minor infrastructure modifications.[1] Unlike other alternative fuel sources, only minor modifications to existing infrastructures would be required to have a fully functioning methanol transport facility. Marine engines are already operating on methanol at smaller scale in commercial service, so adoption for larger vessels is a matter of scale rather than new design.

By its chemical composition, methanol has the lowest carbon content and the highest hydrogen content of any liquid fuel, and has the benefit of liquid storage at atmospheric pressure. It is an excellent replacement for diesel fuel or mixed fuel engines, and its combustion in marine diesel engines can provide high engine efficiency and lower emissions compared to diesel fuel. These factors all simplify the transition to this future fuel and will enable rapid adoption once the new fuel supply chain is established. One factor to consider however, is that when compared to petroleum-based fuels, methanol's energy density is low enough that twice the storage space is required for these fuels to provide the same amount of energy.

Properties of Methanol Compared to LNG, Diesel

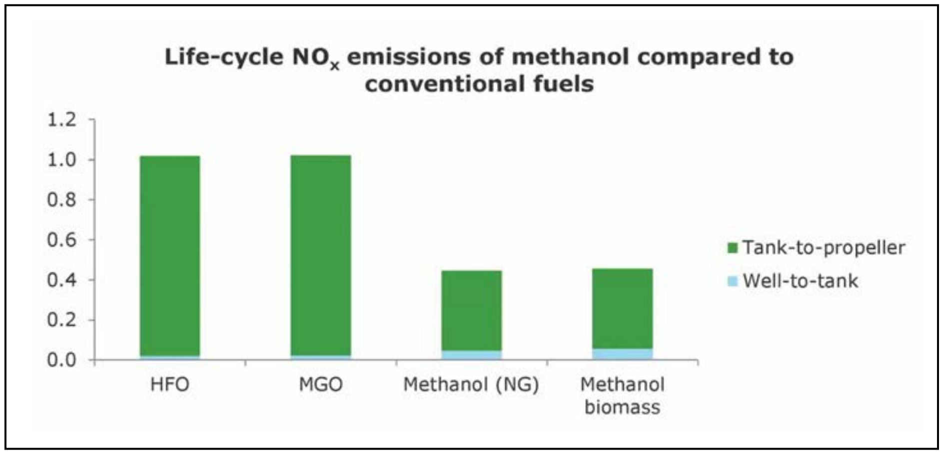
Properties	Methanol	LNG	Diesel
Molecular Formula	CH_3OH	CnHm; 90-99% CH_4	CnH1.8n; C8-C2O
Carbon Content (%)	37.49	≈75	86.88
Boiling Point (°C) (101.3 kPa)	64.5	-160 (-161)	163 to 399
Flammability Limits (vol % in air)	6.72-36.5	4.2 to 16.0	1.0 to 5.0
Auto ignition Temp (°C)	46.4	580	257
Flashpoint (°C)	11	-136	52 to 96
Energy Density (MJ/L)	15.7	20.3-22.5	32 to 40
Sulfur Content (%)	0	<0.06	Varies, <0.5 or <0.1

Courtesy of ABS

MARPOL

IMO's International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, Regulations for the Prevention of Air Pollution from Ships, is the primary international regulatory mechanism for controlling air pollution from ships. When used as a primary fuel source, methanol can reduce CO_2 emissions by 10 percent compared to conventional fuel oils.[2] Much greater reductions, up to full carbon neutrality, are available when methanol is produced via renewable methods to make green methanol. However, these carbon-neutral forms are not yet available in the significant volume necessary for use as marine fuel.

Methanol fuel combustion produces low levels of nitrogen oxide (NO_X) emissions, and industry studies indicate that life-cycle NO_X emissions for methanol are about 45 percent that of conventional fuels per energy unit. While the NO_X levels are similar to LNG, the CO_2 levels dramatically decrease with the use of green methanol. That said, NO_X reductions using methanol are not large enough to get to IMO Tier III level compliance as specified in MARPOL Annex VI, and thus would require exhaust after-treatment, or blending water with methanol.



Courtesy of DNV IMO Report No 2015-1197, Rev. 2

Ship owners and operators have various options to meet the IMO sulfur cap requirements. These options include the use of compliant low sulfur fuels or alternative fuels without sulfur. One of the advantages of methanol as a marine fuel source is that it produces little to no sulfur emissions. Compared to conventional fuels, the use of methanol fuel will reduce SO_X levels by approximately 92 percent. It is therefore compliant with current emission reduction measures set by MARPOL Annex VI.

Regulations

The International Code of Safety for Ships Using Gases or Other Low-Flash Point Fuel (IGF Code) currently only includes detailed prescriptive requirements for natural gas (methane) applications. All other low flashpoint fuels or gases must demonstrate an equivalent level of safety by application of the alternative design methodology as specified in IMO's International Convention for the Safety of Life at Sea (SOLAS) Chapter II-1 regulation 55, and guidelines referenced by footnote MSC.1/Circ.1212 or associated guidelines MSC.1/Circ.1455.

However, where other prescriptive IMO requirements exist for particular gases or other low-flashpoint fuels, either by regulation or as interim guidelines, these may be applied in lieu of the alternative design criteria, subject to agreement by the flag administration. The November 2020 adoption by IMO's Maritime Safety Committee of MSC.1/Circ.1621, the interim guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel, has established the goals and functional and prescriptive requirements for the application of methanol or ethanol as marine fuels. Several standards and technical specifications also have been developed to support the application of low-flashpoint fuels to the marine sector.

Classification societies have been developing guides and assigning fuel-specific notations to further support the application of methanol or ethanol as fuel, as well as incorporating the IMO MSC.1/Circ.1621 interim guidelines through a goal-based approach. These guidelines are intended to provide guidance for the design, construction, and survey of vessels using methanol as fuel.

Safety

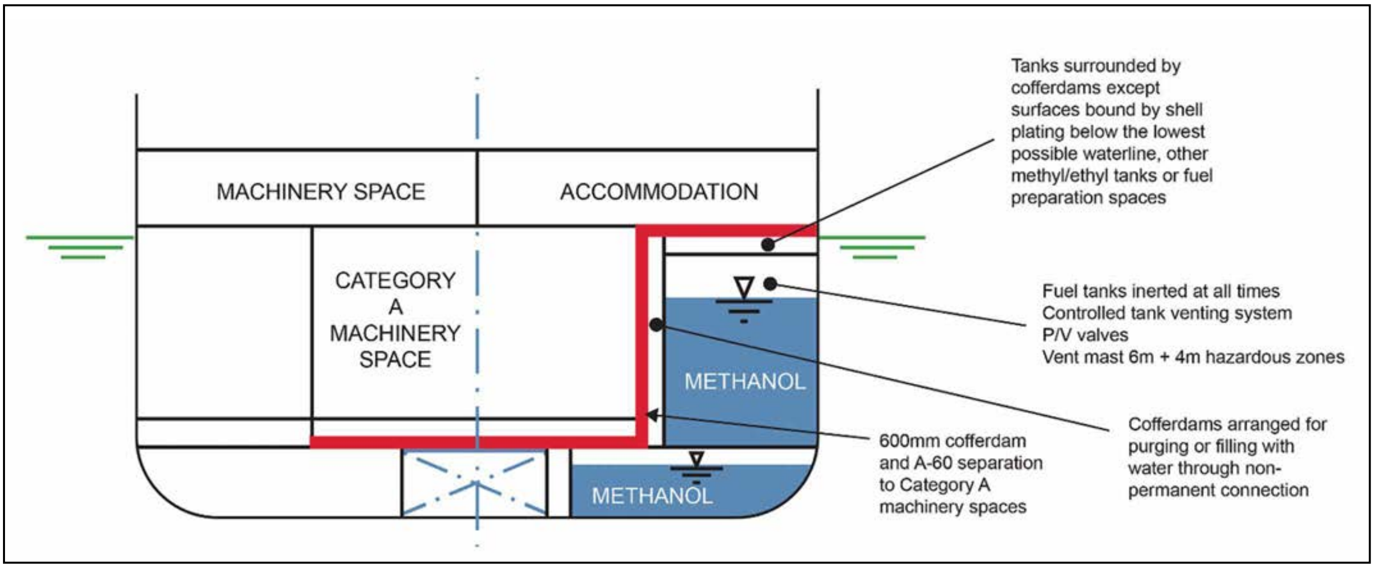
While relatively low in toxicity when compared to ammonia, methanol must be handled carefully if spilled or leaked in confined spaces or on deck. Exposure to liquid methanol can cause skin irritation, dryness, cracking, inflammation, or burns. Crew training and awareness of the additional hazards and characteristics of methanol, including in the case of leaks, spills, or exposure, is necessary.

Methanol is corrosive to certain materials, and its use as a marine fuel may require the redesign of some combustion engine parts. Storage tanks holding methanol are to have an appropriate grade of stainless steel or methanol-resistant coating. The corrosive properties of methanol mean that special considerations may be required for tank coatings, pipes, and piping fixtures. Non-metallic materials, consisting of appropriate methanol-compatible materials like nylon, neoprene, or non-butyl rubber, are necessary. If coatings are used, it is important to consider that any acidic impurities can damage the coating material, and this damage may need to be addressed quickly before accelerated corrosion occurs, including pitting, iron pick-up, and further methanol contamination.

Fire Safety

Methanol vapor is heavier than air and tends to accumulate at low points, like the bottoms of tanks or low pipe

Methanol Fuel Installation



Courtesy of ABS

points. Therefore, special attention needs to be given to the placement of ventilation and detection arrangements in spaces where methanol leakage may occur. Methanol flames are particularly hazardous, as methanol burns at low temperatures with a flame that is nearly invisible in daylight with no smoke. These flames often go undetected until they have spread to adjacent materials that burn in a wider spectrum of light. A methanol-water mixture of 25 percent methanol, or greater, is still capable of burning, so special fire extinguishing practices are to be followed, including the use of alcohol-resistant foams.

Because methanol flames produce no smoke or soot, a smoke detector is not likely an effective source of fire detection. Unlike petroleum-based fuel, methanol flames are easily detected in infrared light, making it an ideal method to monitor for methanol flames. Vapor detection can also be used simultaneously for leak and fire detection by monitoring oxygen and carbon dioxide levels.

Including gas detection systems near expected leak points, as well as near the ceiling and surrounding low points, offers protection against leaks adjacent to methanol tanks or pipes. Adequate tank overflow and leak protection provisions for the holding arrangement helps prevent flammable conditions in areas with potential ignition sources.

In some cases, additional safety measures for cofferdams are needed to prevent a potentially dangerous buildup of methanol liquid or vapor. Flammable vapors burn over a methanol pool and the liquid evaporates due to the heat, contributing to the burn. Therefore, the most effective ways of fighting a methanol fire are to smother the vapors or dilute the flammable substances below their lowest flammable limit.

Portable dry chemical or CO_2 extinguishers can be used for small methanol fires where there is less risk of methanol pool evaporation. For larger volumes of methanol, water extinguishers may be used, if the volume of water is at least four times the size of the methanol pool. Alcohol Resistant Film Forming Foam (AR-FFF) extinguishers with foam water proportioning equipment are a highly recommended method for large methanol pool fires, such as a potential fire below methanol fuel tanks.

Projected Role of Methanol as a Marine Fuel

An increased number of methanol carriers are using methanol for propulsion and power generation. If methanol is produced renewably, these vessels could have an even greater potential to reduce life-cycle emissions while concurrently improving the renewable methanol fuel supply chain for other applications.

The use of methanol as a fuel in dual-fuel marine engines may allow for robust operations with various types of alternative fuels in the future. Such applications may use methanol when it is available, with the option to burn other fuels according to availability and economy. The advantage of methanol over LNG or other gas fuels is its liquid state and ability to re-purpose existing infrastructure to include engines and vessels with efficient retrofits. Methanol is significantly easier and more economical to store on board than gas, and retrofitting a vessel's tanks from conventional fuel oil, ballast, or slop to hold liquid methanol fuel is also easier than installing LNG tanks.

Ongoing research is striving to rapidly scale up methanol availability in terms of infrastructure as well as onboard applications and installations.

Methanol Advancements

Maersk plans to launch its new carbon-neutral vessels in 2023 and 2024—its first feeder vessel and eight 16,000 TEU vessels, respectively. The company has announced that these vessels will have dual fuel capability to enable operations on either green methanol or standard marine fuels. Engines of this type are already in use in methanol carriers, although none are of the sizes required for the new 16,000 TEU vessels. Once the green methanol supply chain is fully established, Maersk estimates that full carbon neutral operations of the eight large container vessels will reduce the total fleet carbon footprint by one million metric tons of CO_2 per year.

Engine manufacturers have advanced projects to commercialize methanol as a marine fuel. Projects such as MethaShip's cruise ship in Germany and Methanex's tugs in China have focused on the development of alternative marine fuel-powered vessels to help advance a sustainable process to address the current challenges for methanol as a marine fuel.

Coast Guard Perspective

Currently the Coast Guard has not received any proposals for methanol fueled vessels, nor has it published any policy to address U.S. vessel designs proposing the use of methanol. However, the process that would be used would involve concept review and approval of the design basis that lays out standards and requirements for an equivalency under 46 Code of Federal Regulations.

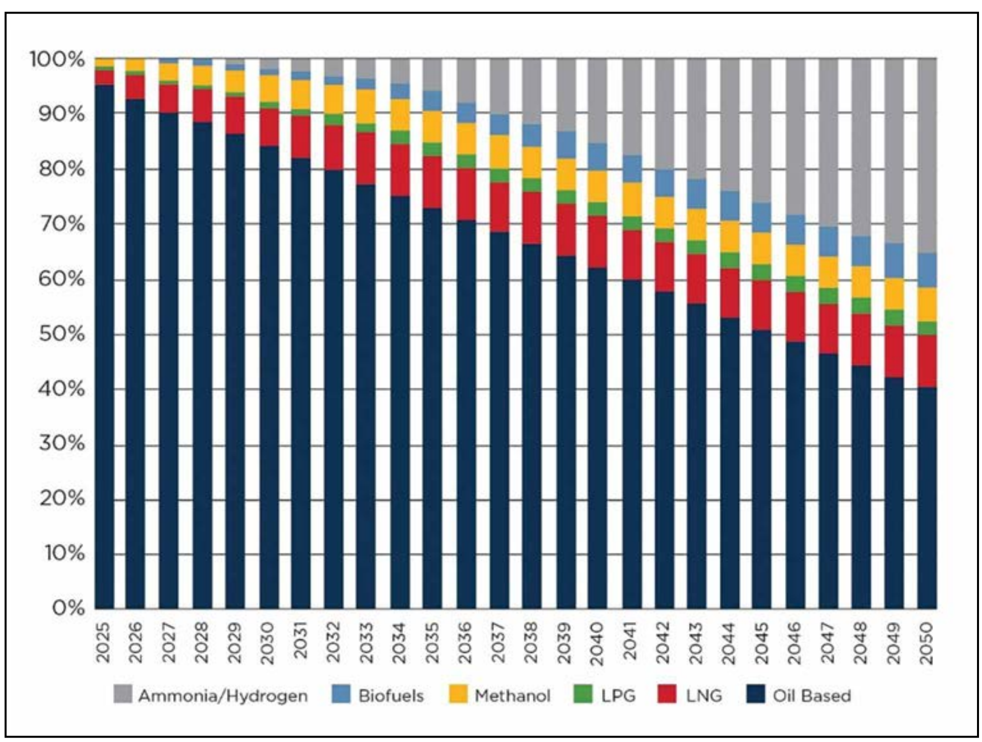
Consequently, there are no current Coast Guard regulations that cover vessels using methanol as fuel. However, existing regulations that apply to transfer operations of LNG and liquefied hazardous gas can be used as applicable. With the adoption of the IGF Code, ships using gases or other low-flashpoint fuels are referencing this code on methods to handle alternative fuels other than LNG. The United States uses the Coast Guard Office of Operating and Environmental Standards' Policy Letter 01-15, Coast Guard Office of Design and Engineering Standards' Policy Letter 01-12 CH-1, and the interim guidelines for the IGF Code as guidance for standards of safety for vessels using LNG as fuel. With additional alternative fuel sources being available and the recently established interim guidelines for Methyl Alcohol as fuel (MSC.1/Circ.1621), the Coast Guard will have to update its policy letters to be in line with the international standards.

Current policy letters and regulations simply address the requirement for credentialed mariners to be familiar with relevant characteristics of the vessel appropriate to their responsibilities. The Coast Guard anticipates additional guidance will be published addressing training and emergency exercises for personnel onboard vessels using low-flashpoint fuels. The Coast Guard will focus its efforts on training its personnel on the proper use and handling of these low-flashpoint fueled vessels whether foreign or domestic. The service relies on its Liquefied Gas Carrier National Center of Expertise offices to assist in the efforts of compliance as well as updating policies, establishing regulatory changes, and developing accelerated training to reflect industry trends and changes set by the IMO's GHG strategy.

Conclusion

With IMO's new initiative to reduce current GHG emissions at least 50 percent by 2050, low carbon-emission fuels are of the utmost importance for the future. Therefore, new approaches like the adoption of methanol-fueled vessels need to be considered. Operations using renewable methanol fuel are expected to reduce

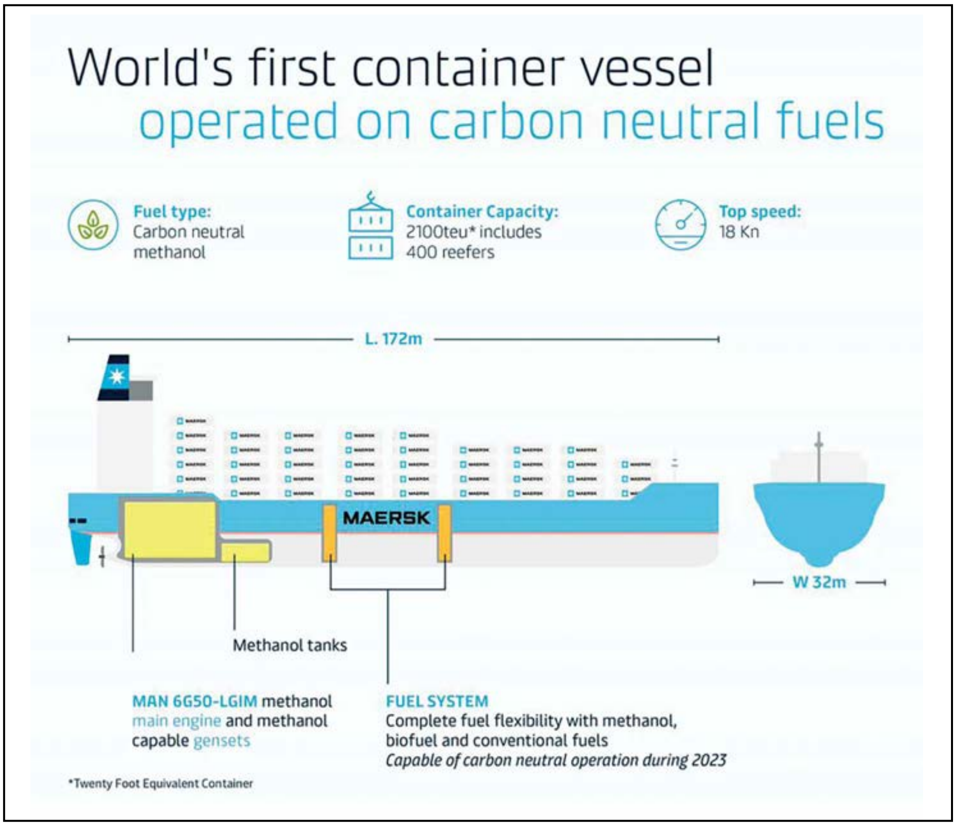
ABS' Projected Marine Fuel Use through 2050



Courtesy of ABS

GHG emissions significantly. Current projections from a Netherlands' maritime report on a methanol-fueled vessel, *Stena Germanica*, expect reductions of SO_X emissions by 99 percent, NO_X by 60 percent, CO_2 by 25 percent, and particulate matter by 95 percent.

While there will undoubtedly be challenges—regulatory, cost, and availability among them—during the transition phase the maritime industry must invest in fuel flexibility and bridging technology options to prepare for a low carbon future. The long-term strategy of achieving zero-carbon emission can be achieved if the focus is on innovative emission reduction mechanisms and continued energy-efficiency measures for new and existing ships, including cleaner fuels such as green methanol.[3]



Graphic courtesy of Maersk

About the authors:

Joshua Padeti is a senior engineer, technology, in the Machinery, Electrical and Systems Engineering group within American Bureau of Shipping. His expertise encompasses a wide variety of topics including sustainability, alternative fuels, emissions, environmental compliance, ship machinery, marine piping, statutory compliance, rule development, fire safety, subsea mining, and transfer of class procedures. He has a Master of Science degree in mechanical engineering from the University of Michigan, Ann Arbor.

Lee Kindberg, Ph.D., currently serves on the Marine Board of the U.S. National Academies of Science, Engineering and Medicine and the Transportation Research Board's Standing Committee on Marine Environment. She served on the U.S. Environmental Protection Agency's Clean Air Act Advisory Committee and Mobile Source Technical Review Subcommittee and co-chaired the EPA Ports Workgroup from 2014–2016. She is also active in Business for Social Responsibility's Clean Cargo Group, a global group dedicated to assessing and improving the environmental impact of shipping.

LCDR Jason Ryu, serves as National Technical Advisor for the Coast Guard's Liquefied Gas Carrier National Center of Expertise, where he currently oversees policy development and training. His expertise includes field assignments as Foreign Gas Carrier Vessel Examiner in the ports of Tampa and Activities Far East. He served as WSA/HAZID facility supervisor in Tampa. He earned his Masters of naval architecture and marine engineering at University of New Orleans in 2021.

References:

ABS. *Sustainability Whitepaper: Methanol as Marine Fuel*, February 2021.

ABS. *Setting the Course to Low Carbon Shipping – 2030 Outlook/2050 Vision*, June 2019.

ABS. *Setting the Course to Low Carbon Shipping – Pathways to Sustainable Shipping*, April 2020.

ABS. *Marine Fuel Oil Advisory*, August 2021

Zincir, Burak, C. Deniz. "Methanol as a Fuel for Marine Diesel Engines." *Energy, Environment, and Sustainability.* Springer, Singapore https://doi.org/10.1007/978-981-16-0931-2_4

IRENA and Methanol Institute (2021), "Innovation Outlook: Renewable Methanol." International Renewable Energy Agency, Abu Dhabi

Green-Marine.org (2021), "Methanol as a Marine Fuel." Methanex. Available Online: methanex_brochure_marinefuel_final2_032521.pdf (menlosecurity.com)

Andersson, Karin and Salazar Carlos M. "Methanol as a Marine Fuel Report;" Methanol Institute, FCBI Energy.

IMO (2021), Fourth IMO GHG Study 2020 Report; Available Online: Fourth IMO GHG Study 2020—Full report and annexes.pdf (menlosecurity.com)

IMO (2019), Initial Strategy on Reduction of GHG from Ships; Available Online: Initial IMO GHG Strategy

Kindberg, Lee and Corbett Jim. Transforming Ocean Shipping-Alternative Energy Sources and Practical Issues; *TR News* 334, July–August 2021

Kindberg, Lee. "Green, Greener, Greenest- What is the Future of Marine Transportation;" *Coast Guard Proceedings of the MSSC*, Vol. 78, No. 2, Fall 2021

Methanol as marine fuel: Environmental benefits, technology readiness, and economic feasibility; DNV IMO Report No 2015-1197, Rev. 2

IMO Resolution MEPC.308 (73), "2018 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships."

Endnotes:

1. www.methanex.com/about-methanol/methanol-marine-fuel
2. IMO Resolution MEPC.308 (73) Section 2.2.1, carbon factor is calculated by comparing fuels in terms of grams-of-CO_2/MJ-of-fuel. HFO carbon factor is 77 g-of-CO_2/MJ-of-HFO and Methanol carbon factor is 69 g-of-CO_2/MJ-of-Methanol. Thereby methanol could potentially achieve a 10 percent reduction in CO_2 emissions when compared to HFO.
3. Zero-emission shipping and the Paris Agreement: Why the IMO needs to pick a zero date and set interim targets in its revised GHG strategy. International Council on Clean Transportation (theicct.org)

Advanced Nuclear Technology for Maritime

'30 knots for 30 years' with true-zero emissions as the standard

by Patrick G. Gerrity
Principal
Pat Gerrity Maritime Advisors, LLC

Over the last 180 years, ships successfully progressed from sail to coal to oil power. Now, over the next two decades it will be necessary for shipping to move away from fossil fuels and toward new sustainable energy sources to reduce greenhouse gas (GHG) emissions that contribute to global warming.

How significant is shipping's contribution to global warming? The Fourth IMO GHG Study 2020 estimated that total shipping emitted 1,056 million tons of CO_2 in 2018, which accounted for 2.9 percent of total global anthropogenic CO_2 emissions. If treated as a country, this would make shipping the sixth largest emitter in the world. Left unchecked, the IMO has indicated that shipping emissions could, by 2050, increase between 50 percent and 250 percent over 2012 levels of 962 million tons of CO_2.

Given the urgency of reducing GHG to limit the effect of climate change, the IMO has declared that GHG emissions must be reduced by 50 percent by 2050. It is expected that in 2023, the IMO will further revise this goal to 100 percent reduction by 2050.

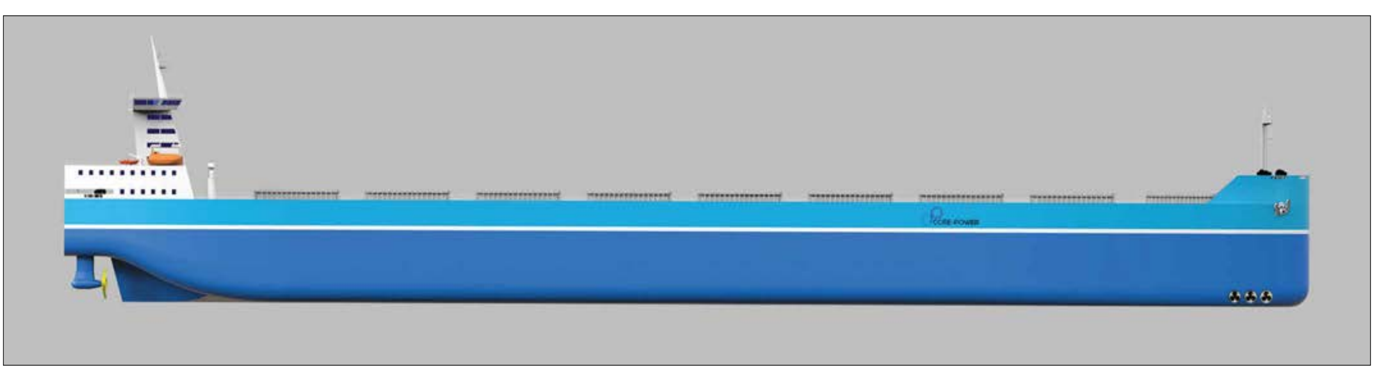
However, we must recognize that ocean transportation is a fiercely competitive business, and technological solutions that lead towards sustainability must come with benefits to match the costs. Otherwise, adoption of these new technologies is doomed to fail.

Batteries, wind, and biofuels, to various degrees, provide some environmental improvements for ships. Electro fuels, like green hydrogen, green methanol, and green ammonia, offer a more substantial carbon and particulate matter emission reduction. Then there is advanced nuclear which is the only true-zero emission energy source that can meet the heavy power demands of large ships.

30 Knots for 30 Years

One of the most impressive statements about new nuclear power is that advanced nuclear reactors could propel large vessels, such as containerships, at speeds of more than 30 knots for over 30 years on a single fuel load, with zero lifetime emissions. If this became a reality, it would transform the value chains of industrial components and durable consumer goods.

The favored option—or combination of options—chosen by ship operators will be dependent on the ship's purpose, route, size, and most importantly, the balance of



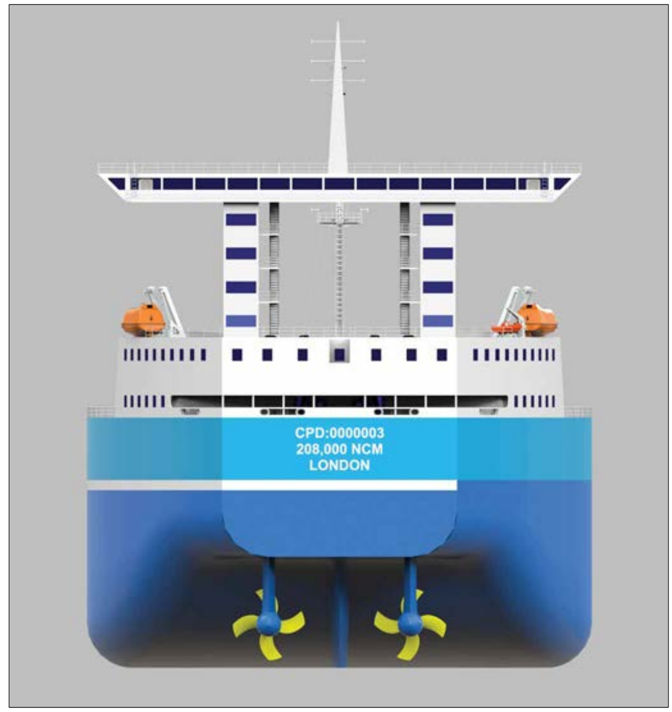
Capesize bulkers are so named because they are too large to navigate the Panama or Suez canals and must sail around Cape Horn or the Cape of Agulhas to transit between the Atlantic and Pacific. The current capesize bulker fleet carries nearly 1.1 billion tons of iron ore a year while emitting more than 100 million tons of CO_2 in the same time. If a single capesize vessel, like this concept vessel, was powered by molten salt reactors (MSR)—nuclear power—it would consume less than 200 Kg of MSR fuel in a quarter decade and produce the same weight in a metallic waste. Image courtesy of Core Power cost and benefit of that option. If alternatives presented are not competitive, ship owners will not choose them even if mandated to do so.

Small ferries on short, fixed routes may find using rechargeable batteries a better choice than green ammonia, mostly due to cost. Cargo ships trading in the Caribbean may find electro fuels like green ammonia most competitive due to a combination of not needing to carry much fuel onboard, the availability of those fuels, and the prohibitive cost of carbon taxes, which are now looming. Large container vessels on global rotations could find that the sheer efficiency, flexibility, and speed advantage provided from advanced nuclear is the optimal choice.

It is widely recognized that just 20 percent of the world's 100,000 ships over 100 gross register tonnage consume 80 percent of the world's marine fuels. Hence, they produce 80 percent of global carbon emissions from shipping.

Digging deeper, we discover that around 7,000 of the largest ships in the world are responsible for almost half of all those emissions. That leaves about 13,000 ships responsible for a third of emissions and 80,000 ships emitting the remaining 20 percent.

Given that, if there was a sustainable and competitive power source for the largest 20,000 ships, it would not only eliminate most emissions from shipping, but it would also create a new dawn for maritime competition. It would be a new "Sail-to-Steam" moment. As advanced nuclear comes of age, let us consider some of the newly emerging nuclear technologies that could be suitable for this segment of shipping.



Capesize bulker viewed from the back and stern. Images courtesy of Core Power

Marine-Appropriate Technologies

To do so we need to apply three basic criteria which solve for the most common challenges of introducing nuclear as a power source for ships.

1. We will need very fuel-efficient reactors with long periods between refueling, if any refueling at all. Avoiding refueling prevents handling of spent nuclear fuels in ports and mitigates issues related to nuclear proliferation.
2. We will need reactor systems that are not pressurized so that the emergency planning zone in ports and narrow waterways can be confined to the ship. In the event of an accident reactors should shut down automatically providing the walk-away-safety assurances that are crucial in a maritime environment.
3. Lastly, we will need to have reactor designs and fuel supply chains that can be industrialized so that the reactors can be small, mass manufactured, and type approved. This will make them affordable, easier to finance and insure, and it will allow for the creation of standardized well-designed and vigorous training regimes for operators and stakeholders.

Two advanced nuclear reactor designs stand out as they meet these three criteria well.

Molten Salt Reactor

A molten salt reactor (MSR) is an advanced nuclear reactor that uses a liquid fuel instead of a solid fuel like most conventional reactors. It is a possible choice for the very largest ships with power demand of more than 20 MW that sail on very long voyages. The fuel salt in an MSR contains the uranium fuel which keeps the fuel salt liquid at high temperature. Unlike conventional reactors, an MSR does not need a fuel assembly, making it simpler, cheaper, and more efficient. It operates at ambient pressure, making it safer and cheaper, and it runs at a very high temperature, meaning it produces heat more efficiently. Because the fuel salt is liquid, it is both the fuel which produces the heat, and the coolant, which transports the heat to the power conversion system that makes electric power. Since the fuel and coolant is combined into one, and the fuel is always locked into the coolant, the reactor cannot melt-down. MSRs can be mass manufactured as small modular machines to the highest quality standards which would substantially lower costs and complexity. Superior safety, increased efficiency, simpler operation, and lower cost could make the MSR an ideal choice to replace fossil fuel power for heavy transport and industry.

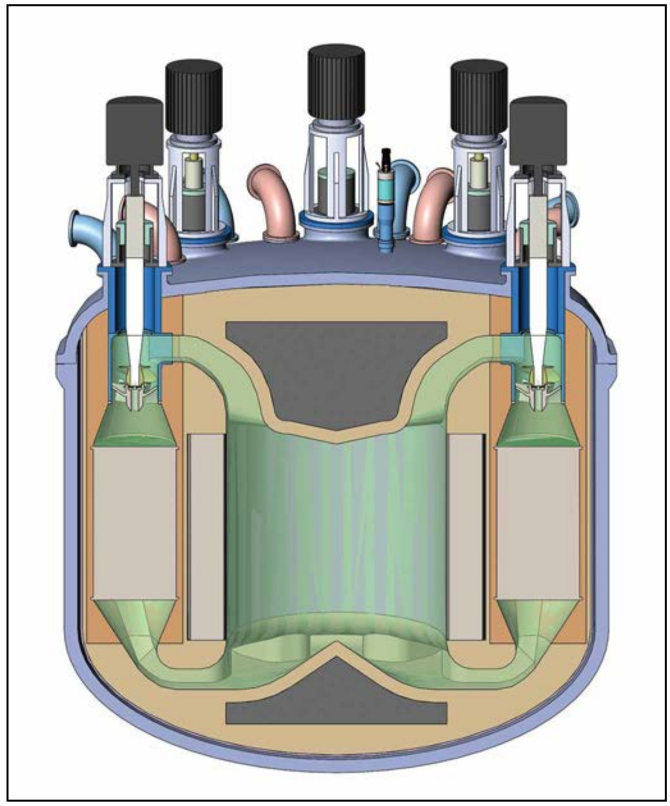
Heat Pipe micro-Reactor

Heat Pipe micro-Reactors (HPR), are an innovative, advanced reactor design combining space-age reactor technologies and over half a century of commercial nuclear systems design, engineering, and innovation. Additionally, they fit well the criteria for ships with power demand between 5 MW and 20 MW. In the most basic terms, an HPR simply turns the heat from nuclear reaction into hot air which can then be used as heat or electricity. The HPR is designed to create competitive and resilient power with superior reliability and minimal maintenance, particularly for energy consumers in remote locations, such as ships. Its small size allows for rapid installation and deployment. The heat pipes make the HPR a "solid-state" reactor with minimal moving parts, allowing for autonomous operation and the ability to adjust power output as electricity demand fluctuates. Being fully factory built, fueled, and assembled, the HPR promises up to a 40-year design life with a 5-10 year refueling interval, and a very small footprint.

Why Advanced Nuclear Is Different

Both MSRs and HPRs are significantly different, both in design and operation, than conventional pressurized water reactors (PWRs) which are those in use on nuclear powered Naval vessels.

First, and most notably, unlike PWRs, these reactors operate at ambient pressure only, and with fuel that is only useful at very high temperatures of around 600 C.



The molten chloride fast reactor is an advanced nuclear reactor that uses a liquid fuel instead of the traditional solid fuel used by conventional reactors. By design, molten salt reactors are simpler, cheaper, more efficient, and safer than their conventional counterparts. Image courtesy of TerraPower

In MSRs the fuel salts are only molten over 400 C, so in an emergency, the fuel salt would cool and 'freeze' into a solid, rather than heat and "melt" the reactor core. With no pressure to expel toxins into the environment in case of an accident, and a fuel which if cooled becomes an inert, solid rock inside the reactor, safety is assured. In the HPR, there is no moving of fuel, and automatic fail safes would shut down reactivity in the reactor instantly in the event of an emergency.

Secondly, both MSR and HPRs are designed to run for very long periods without maintenance. MSRs' fuel can be topped-up while the reactor is operating which eliminates most of the highest risk associated with operating any nuclear reactor—refueling. An HPR functions like a large battery that can be refueled after 10 years of operation. In a conventional PWR, complex fuel assemblies must be changed every two to three years and spent or unused fuel—aka, nuclear waste—must be handled carefully and stored in secure sites. In an MSR, the nuclear fuel is topped up, rather than changed, and is locked into the coolant salt which in turn is impervious to radiation damage and remains chemically stable so that it can be used and recycled for generations. Using a liquid fuel salt where the fuel and coolant are one, instead of solid fuel assemblies, means loss of coolant accidents are impossible. Like a battery, the HPR is simply swapped out for a new machine at the end of its lifespan and used reactors would be reconditioned and recycled for re-use.

The MSR and HPR represent an entirely new era of safe, secure, and civilian-grade reactor designs which can be made small enough to be useful for heavy industry and transport.

Fuel efficiency of more than 95 percent in an MSR compared to less than 2 percent of a PWR, means that MSR fuel cycles are long, and final end-of-cycle waste is minimal. Not having to remove and replace the fuel in an MSR vastly diminishes the threat of proliferation of nuclear materials. The HPR is not as fuel efficient as the MSR but would still perform very well for medium-sized ships over long periods of time.

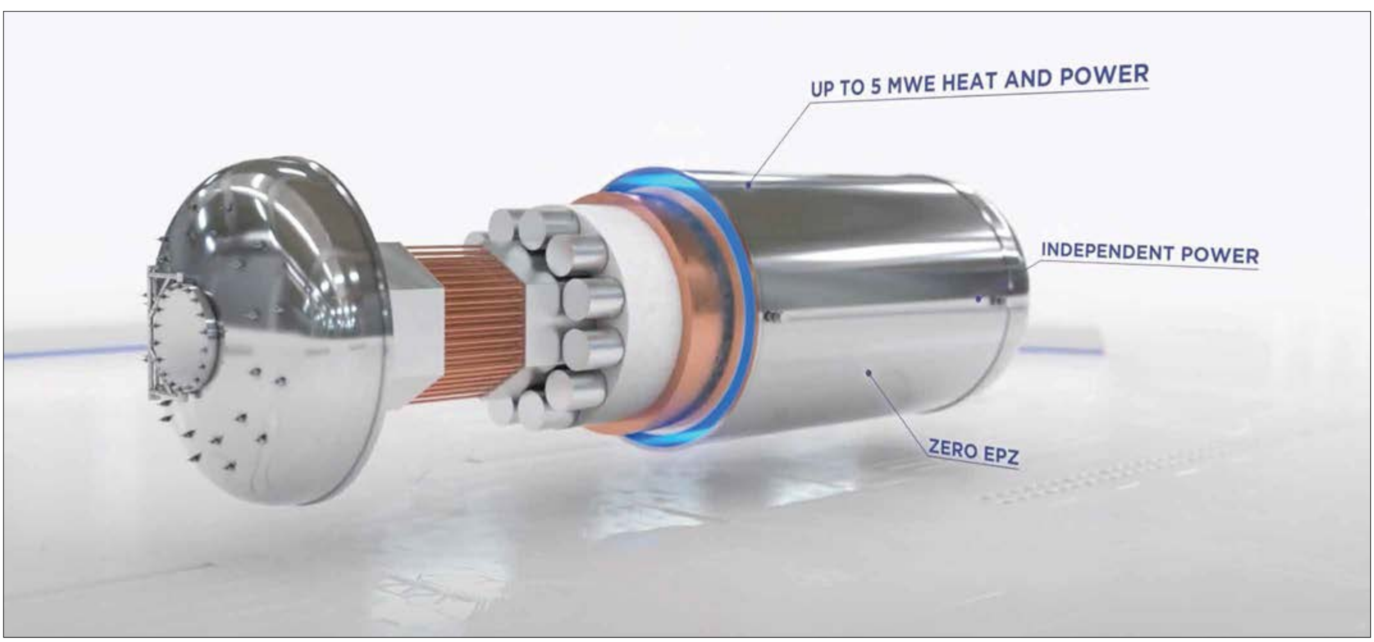
Third, an MSR is naturally fuel agnostic and can be designed to run on various grades of uranium, as well as the thorium fuel cycle, and even spent nuclear fuels. The HPR could run on a variety of fuel types in solid form and is currently being constructed for tri-structural isotropic uranium fuels. Both MSRs and HPRs are small, manufactured machines, as opposed to large construction projects. This makes them cheaper and easier to fabricate, with fewer parts to maintain, and both the MSR and HPR could be scaled to meet the power needs of the segment of shipping which emits 80 percent of emissions. A modular MSR could deliver as little as 20 MW of power over a very long time and as much as 100 MW over a shorter period. The HPR would cover the segment requiring 5 MW–20 MW with between one and four power units installed onboard.

Given their relative simplicity, smaller size, and lower cost, HPRs or MSRs could be used in a variety of ways. For example, one or more could be placed on an offshore platform or barge to provide nearshore and offshore true-zero emission electricity to produce electro-fuels like green hydrogen, ammonia, and methanol for smaller ships. Additionally, these reactors could be located within a major port to provide the energy needed for true-zero emission port operations—including providing shore power to ships.

MSRs and HPRs are not truly new technology. The first MSRs were built in the 1950s and 1960s at Oak Ridge National Laboratory as experimental reactors. However, until recently, due to lack of demand for small, super fuel-efficient, zero-emission energy sources, funding for the next stage of development has been elusive. HPRs were first built and tested at Los Alamos in the 1960s, and much of the work resulting from that research has been deployed successfully across a multitude of applications. Once the PWR was established as the dominant nuclear reactor technology, significant infrastructure came into existence for processing and producing solid fuel to support it, as well as a focus on ever larger machines to achieve economies of scale for utilities. Further exploration of MSR was set aside.

Combining Best-In-Class Expertise

However, things are changing. Driven by the need to find durable and reliable solutions to climate change, both interest in and funding for advanced nuclear reactors has re-emerged. The U.S. Department of Energy,



Westinghouse Electric Corporation's eVinci™, a heat pipe micro-reactor, has many features that could make it an ideal, carbon-free source of maritime power. Its small size makes it easily transportable, is completely built and assembled in a factory, is capable of autonomous operation, and will operate at full power for more than 8 years without refueling. It also boasts minimal moving parts making it a "solid state" reactor. Photo courtesy of Westinghouse Electric Corporation

Westinghouse Electric Corporation's eVinci™ heat pipe micro-reactor is shown installed and ready for use. Photo courtesy of Westinghouse Electric Corporation

in collaboration with private enterprises under a public-private cost-share model, is currently funding the development of five new reactor technologies through its Advanced Reactor Demonstration Program. Both the MSR and the HPR are included in that program with the MSR being developed as a molten chloride fast reactor, one of the most exciting MSR designs, and a world first. The first experimental reactor is planned for completion at Idaho National Laboratory in the middle of this decade.

The U.S. Navy's own nuclear propulsion program, which has operated faultlessly since the 1950s, has become a highly respected and specialized branch of the military, with its own highly enriched fuels and specialized operating procedures. Much is made of that excellent safety record, and it has often been suggested that commercial shipping should adopt a similar approach. However, while the technology used by the nuclear Navy is not suited to commercial shipping, the superior, strict, and rigorous safety, training, and operational regimes that form the basis of the Navy's safety record, are very applicable.

Now, with advanced nuclear technologies emerging as a viable option for commercial shipping, a civilian-flagged nuclear fleet could become an early demonstration to the world of how large ships can be fully decarbonized and operate in a competitive market simultaneously. As both the MSR and HPR are being built in the United States, it is a natural place to start. Under the leadership of the U.S. Coast Guard, the launch of high quality, zero-emission nuclear commercial vessels staffed by highly trained crew adopting the practices and policies proven successful by the U.S. Navy could be expected in the next decade. As routines for vessel design, construction, and operation at sea and in ports mature, the technology and how it is deployed could be exported to other 'flags,' allowing mature maritime nations like the United Kingdom, Japan, and others to also move to true-zero emission shipping.

Combining best-in-class procedures from the U.S. Navy, with state-of-the-art advanced MSRs and HPRs would help create a better and cleaner environment for the oceans, for ship owners and charterers, for seafarers, and for those working in and living near ports around the world. The promise of true-zero emission ships, built to high quality standards, that can travel faster for longer periods of time, with more cargo is the catalyst for a future-oriented shipping industry serving as the clean and green heart of global trade.

About the author:

Pat Gerrity is the principal of Pat Gerrity Maritime Advisors, which provides customized strategic compliance, sustainability, security, and safety services to the maritime industry. He retired from the Coast Guard in 2008 with the rank of Captain and joined Disney Cruise Line as its vice president of Safety, Security, Environmental Policy and Compliance, retiring in 2020.

Historical Snapshot

The Evolution of Marine Safety During World War II

by LCDR Aaron Garnier, P.E.
Executive Officer, Marine Safety Unit Chicago
U.S. Coast Guard

On March 12, 1942, just 25 miles south of Cape Fear, North Carolina, a torpedo from German U-boat *158* struck the 11,000-ton steam tanker SS *John D. Gill*. The impact created a geyser of oil that coated the surrounding water and quickly caught fire, engulfing the tanker.

On his first sea journey, Herbert Gardner found himself part of this horrific scene. Running to the nearest life boat, he attempted to lower it with two men aboard, but the equipment failed, quickly tossing the men into the water. "I saw two of my comrades ground into pieces by the propeller of the ship as they tried to escape the flames."[1] Jumping into the oil-slicked water, he attempted to swim away from the ship. "Every time I'd come up, I'd come up on fire."[2] Finding the life raft, Mr. Gardner survived and was rescued nine hours later by Coast Guard Cutter *Kukui* (WAK-186). His story illustrates the importance of Coast Guard Marine Inspections.

Supplying the Front

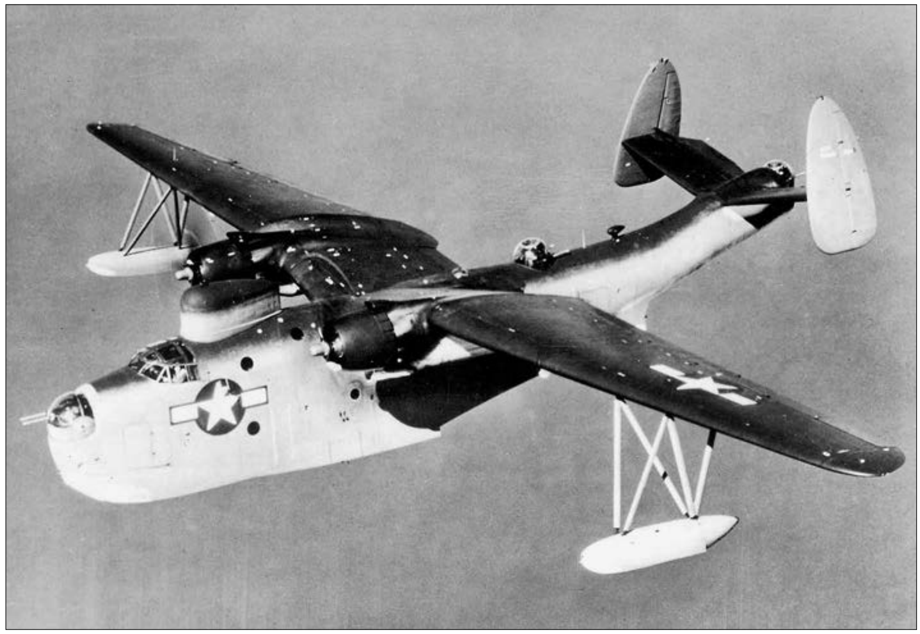
During the early stages of World War II, the Allies relied on aid from the United States to help keep them supplied, a mission carried out by U.S. Merchant Ships crewed by licensed merchant mariners.[3] In an attempt to counter this, the Axis used U-boats to stem the flow of goods from the United States. This fact was only fully realized by the Americans after eight U.S. owned or flagged merchant ships were attacked, killing 27 crew members.[4] President Roosevelt addressed these attacks during his September 11, 1941, *Fire Side Chat* radio address on maintaining freedom of the seas. The Atlantic, he noted, had always been a "free and friendly highway" for the United States.

"These Nazi submarines and raiders are the rattlesnakes of the Atlantic," the president said. "They are a menace to the free pathways of the high seas. They are a challenge to our own sovereignty. They hammer at our most precious rights when they attack ships of the American flag—symbols of our independence, our freedom, our very life."

This alone was not enough to provoke the United States into joining the war. That would happen nearly three months later when Japan struck the U.S. 17th fleet at Pearl Harbor. Only while discussing strategy during the Arcadia Conference, did President Roosevelt and British Prime Minister Winston Churchill realize there were not enough ships, including merchant ships, to carry out their plans. "Shipping was at once the stranglehold and sole foundation of our war strategy," Churchill

Officers of a torpedoed British merchant ship hold onto their heaving raft a little longer as crew members clamber aboard a sub-hunting Coast Guard cutter. Coast Guard photo wrote in his book, *The Hinge of Fate*.

Though the United States already had a merchant fleet, it was insufficient to keep up with supplies needed for the war. In January 1942, President Roosevelt set a goal of constructing and delivering 8 million tons of merchant ships in one year. This more than doubled the standing fleet and placed a new burden on the Bureau of Marine Inspection and Navigation (BMIN). At the time, it was tasked with inspecting and approving vessel construction, strength, stability, repairs, and alterations of passenger vessels over 100 gross tons and propelled by machinery.



PBM "Mariner" patrol-bombers, like this one, were instrumental in the Battle of the Atlantic. Used for anti-submarine warfare, the first German U-boat destroyed by a PBM was *U-158* on June 30, 1942. A typical PBM had a crew of seven, a maximum speed of 205 mph, and a range of 3,000 miles. Navy photo

Executive Order 9082

In February 1942, a month after President Roosevelt's request to double the merchant fleet and on advice from the Bureau of the Budget,[5] Executive Order 9082 was penned to expedite "the prosecution of war efforts" under the president's wartime powers. Militarizing the then-civilian marine inspectors, the order transferred more than 1,000 BMIN employees, as well as those of the Bureau of Customs and the Maritime Commission, to the Coast Guard. This arrangement was to last six months beyond the end of the war.[6]

By absorbing BMIN, the Coast Guard was now responsible for vessel inspection including construction, repair, and alteration; administering load lines; enforcement of regulations for outfitting and operation of motorboats; and the shipment, discharge, protection, and welfare of merchant seamen. These are just a few of the inspection functions outlined in the executive order. In addition to these roles, the Coast Guard took on the responsibility of issuing licenses; certifying officers, pilots, and seamen; suspension and revocation of licenses; and investigating marine casualties. Additionally, the executive order even transferred the training of merchant mariners from the Maritime Commission to the Coast Guard for a year.

Role of the Coast Guard

The attacks on American seamen and ships necessitated the need for improved safety measures to meet the conditions of modern war.

Creating the Bureau of Marine Inspection and Navigation

The Steam Boat Inspection Service, founded on July 7, 1838, preceded the Bureau of Marine Inspection and Navigation (BMIN) and was established to protect the lives of passengers on board steam-propelled vessels.

Its need became clear after the massive death tolls sustained onboard these types of vessels. By 1832, 14 percent of the steam vessels in operation had been destroyed by explosion and more than 1,000 persons killed.[1] Over the years, additional regulations were "written in blood," including the Steam Boat Act of 1852 and the Motor Boat Act of 1910.

Following a 1932 merger with the Bureau of Navigation, the Steam Boat Inspection service became the Bureau of Navigation and Steamboat Inspection. After the tragic loss of nearly 200 lives in the *Morro Castle* and *Mohawk* incidents in 1934 and 1935, respectively, the service again evolved, becoming the Bureau of Marine Inspection and Navigation in 1936. By this time the BMIN inspectors were highly experienced and almost entirely merchant mariners who were required to have licenses ranging from one year as a master or chief engineer to three years as chief mate.

Endnote:

1. Crouch H. Merchant Marine Inspection: A Major Function of the Coast Guard. *U.S. Naval Institute Proceedings*. 1948:823–831

Historic calls for an organization fully and completely responsible for safety at sea came to the forefront,[7] and the need for a more efficient, unified maritime regulatory agency that could modernize an antiquated marine safety program was recognized.

Consisting of several formerly independent services—the Revenue Cutter, Lifesaving, and Lighthouse services—the Coast Guard was administratively placed under the Navy in November 1941. The Coast Guard was the preeminent agency in charge of protecting merchant mariners from enemy attacks.

During the war, the Coast Guard protected merchant mariners, maintained light ships, marked minefields, placed torpedo nets, and changed buoys.[8] On land, the service patrolled beaches on horseback, keeping constant lookout for enemy forces and assisting merchant mariners in distress.

From left, Seamen 1st Class C. R. Johnson, Jesse Willis, Joseph Washington, and Frank Garcia, members of a Coast Guard horse patrol unit, patrolled beaches in the New Jersey area in all kinds of weather. Wartime beach patrols were conducted on foot, by jeep, or on horseback, and often included dogs. These types of patrols date back to the U.S. Life-Saving Service of the 1800s, so the Coast Guard was the logical choice for this duty. Coast Guard photo

Marine Inspections During World War II

The keel of the Coast Guard's inspection program—licensing and investigation—was laid to support Allied operations in WWII. "As an American merchant marine becomes more and more vital to our national safety, so will the importance of marine inspection increase to make the merchant marine reliable and efficient," LT Holmes Crouch, a Coast Guard marine inspector, said.[9] The Coast Guard not only oversaw construction, repairs, licensing, and training of the Merchant Marine, but also conducted rescues.

The face of the United States merchant inspection program was changing. The Coast Guard no longer required a merchant license to be a marine inspector but had health and age standards. The BMIN inspectors, with an average age greater than 62, integrated into the Coast Guard and were offered reserve commissions as lieutenant commanders. More than 400 inspectors accepted this commission.

Coast Guard personnel that were not part of BMIN were assigned to marine inspection offices in increasing numbers. There was an influx of inexperienced personnel, including junior officers and enlisted personnel, into these inspection duties, which quickly changed the face of the program. Quite naturally, some of the "old timers" disapproved of these inexperienced personnel. Yet, despite the conflict in schools of thought, there was some balancing effect.[10] Coast Guardsmen

Coast Guardsmen inspect the Sperry Gyrocompass on a merchant vessel in port for repairs. Coast Guard photo exchanged military experience for inspection information, invoking a bilateral system that proved advantageous to the Coast Guard. The Coast Guard used the strengths of both services to build a robust inspection program. Though there was still some tension between more experienced, formerly civilian, inspectors and newly integrated Coast Guard inspectors, equilibrium was achieved between administrative, military, and inspection experiences. This resulted in revision of policy, unit structures, and the writing of publications.

As the war progressed, U.S. industry met the president's call for ship construction with a record setting delivery of 746 merchant ships by December 31, 1942. This included 542 Liberty Ships, which, by November 1942, averaged a construction time of just 55 days from keel lay to delivery. New vessel inspections increased from 538 to 1,557 in the course of one year, and the equipment inspections doubled over the same time period.

Coast Guard SPAR and two U.S. sailors display new lifeboat supplies for merchant vessels. Coast Guard photo

In addition to reviewing the design and construction of the new merchant fleet, these inspectors conducted several different activities, including alterations for war operations, damage surveys, and structural failure exams. Though not required, the Coast Guard even took on roles of inspecting Army vessels.[11]

Oversight of Vessel Construction

While limited in responsibility due to the urgent wartime needs, the Coast Guard oversaw new vessel construction and vessel repair. In particular, they reviewed safety equipment onboard the massive new fleet of Liberty Ships and conducted reviews of their oil-fired boilers, stability, and hull strength.[12]

Dry dock examinations and damage surveys increased significantly as inspectors analyzed the effects of deterioration, faulty design, and external damage from torpedo and mine strikes. During these inspections, causes of failure were determined, leading to recommendations on how to avoid recurrence. Throughout the repair process inspectors monitored the vessel to confirm appropriate work was being done. Additionally, ships were continually being altered to upgrade safety equipment and increase their survivability. Because skilled laborers were serving in the war, this work was conducted primarily by inexperienced shipyard workers. This work alone was enough to keep Coast Guard offices fully employed.[13]

Steam propulsion systems were being pushed to their limits as merchant ships were continuously underway. This created a massive strain on the boilers and made the usual annual inspections insufficient. The Coast Guard decided to conduct unannounced interim inspections, a new concept at the time,[14] to maintain the safety of these systems. The service used the intelligence gathered to adjust how inspections were being done and improve required and approved equipment.

Licenses and Hearing Offices

As the war progressed, mariners were working on Navy and Coast Guard ships, causing a significant shortage in the merchant marine fleet. As the lead organization for issuing licenses, the Coast Guard established foreign and domestic licensing offices to administer written and oral examinations in an effort to help combat this shortage. These offices not only issued new licenses, but allowed for promotion exams to be conducted in the European theatre, as many vessels did not have the opportunity to return to the United States for testing. Additionally, hearing offices were created around the world to investigate crew misconduct and discipline credentialed merchant mariners as appropriate.

These offices were also gaining valuable intelligence from interviewing those involved in these marine casualities and compiling recommendations to improve safety measures aboard these vessels. Interviews conducted at the hearing office after marine casualties played a key role in the creation of improved safety requirements on merchant vessels.

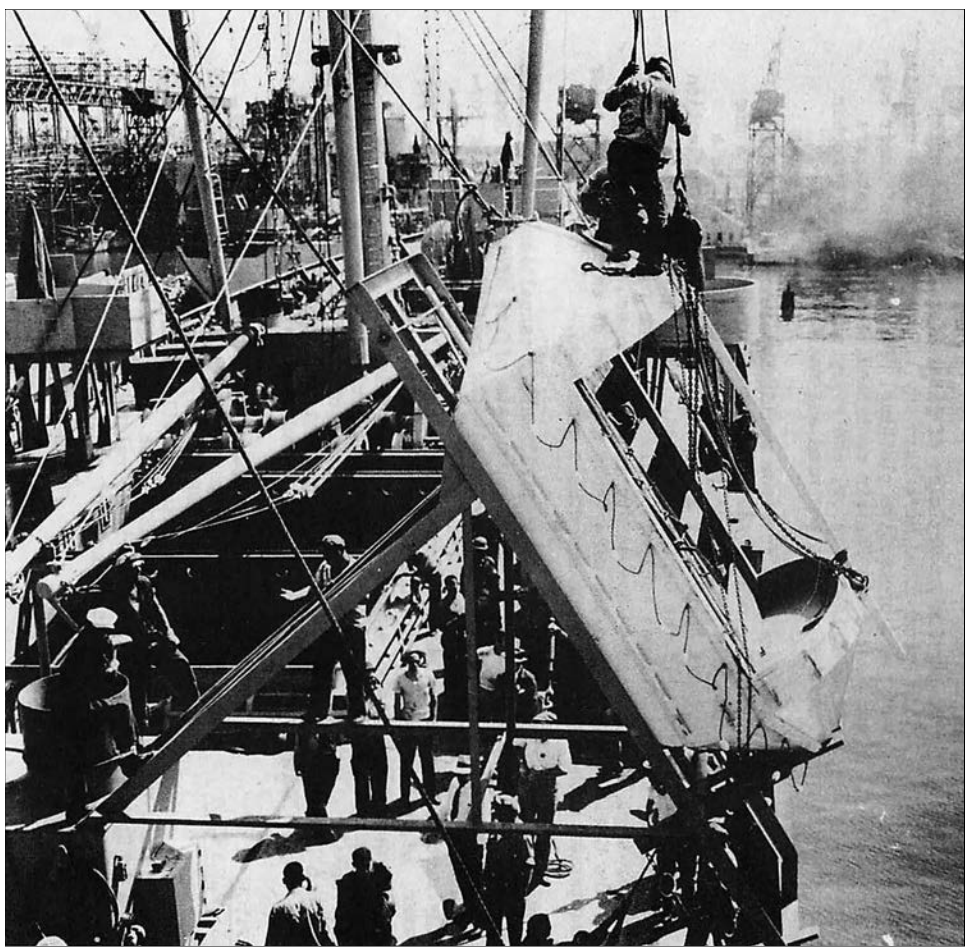
New Safety Equipment Requirements

Despite inspections that continued through 1942, the death tolls from U.S.-flagged ships quickly rose to more than 4,000.[15] This was the first time the maritime community had faced such dire losses during wartime, and it caused the United States to address unprecedented concerns for merchant mariner safety. Interviews with survivors, like Herbert Gardner, provided valuable intelligence used to improve safety measures.

Gardner told the inspection office that the lifeboat davit construction failed, leading to the death of two crew members, information that was relayed to Coast Guard Headquarters. As with the *John D. Gill*, it was common for a vessel to list significantly after being hit by a torpedo or a mine, which impaired the deployment of lifeboats. Because of Gardner's report, new davit plans with "skids" were installed to aid in lowering life boats when a vessel was listing. Eventually, it became a requirement to carry lifeboats in a lowered position on both sides so that the entire crew could escape a severely listing vessel.[16] These lifeboats were also filled with new rations and water filtration systems based on reports of merchant mariners dying of thirst and hunger.

Another consistent concern was the survivability of the crew if they entered freezing waters. Taking into account many new immersion suit recommendations, like adding weights, a

Under the direction of a Coast Guard inspector, two deckhands give a hand-hoisting apparatus for the Phoenix lifeboats a workout. Coast Guard photo



After the sinking of the SS *John D. Gill* in March 1942 shined a light on issues with launching lifeboats during an incident, new lifeboats were designed. One of these new lifeboats is seen above. Coast Guard photo

Members of the boarding party from USS *Pillsbury* secure the tow-line to the bow of captured German *U-505*, which is the same type as U-185. The latter sunk the SS *John D. Gill* on March 13, 1942, and was sunk two months later when U.S. Navy Squadron VP-74 dropped depth charges on the submarine. Navy photo

light, and padding, the Coast Guard approved novel rubber suits to increase survivability, ultimately requiring them onboard all vessels operating in cold waters. Crew members were reported to have "practically lived in them," showing the constant fear of attack surrounding the merchant marine transportation system.[17]

Merchant Marine Wartime Emergency Safety Measures

Collecting information did not save merchant mariners lives on its own, it needed to be researched, analyzed, and shared. This spurred the Coast Guard to compile perhaps one of the greatest wartime publications, *Merchant Marine Wartime Emergency Safety Measures.* Just over 35,000 copies were printed in 1942, and it was, for those that owned it, "second only to food and water as an essential to life."[18]

This seminal work of the Coast Guard Marine Inspection program played a key role in reducing merchant marine losses. It was carried on board vessels and read by crew members who were living in constant fear of being hit by Nazi torpedoes or mines. It was used by inspectors and merchant vessel crews to verify they were carrying the appropriate safety equipment before embarking on their journeys. It was an administrative victory for the Coast Guard.

Permanent Transfer

On September 2, 1945, victory was declared in Japan, marking the end of the war. The Coast Guard's administrative expertise, combined with that of the BMIN commissioned officers, had significantly increased merchant mariner safety. Their actions lead to a decrease of post-incident loss of life by 75 percent between 1942, when

4,300 casualties were reported, and 1944, when there were reports of fewer than 1,000. This result proved the importance of a government oversight organization that could regulate the merchant marine program

These actions laid the foundations of the modern inspections program. Bringing to the table its technical engineering knowledge and administrative abilities, the Coast Guard continued to write memorandums, regulations, and manuals that successfully modernized the inspections program and created national level policy for the merchant fleet.

The end of the war didn't mean an end to inspections and hearings on a significantly larger merchant fleet. Executive Order 9082, written to last just six months past the end of the war, made the decision about whether these functions would revert to BMIN an urgent one. President Harry S. Truman realized this, acknowledging that the Coast Guard administered the missions of BMIN "successfully during the tremendous expansion of wartime shipping, by virtue of improvements in organization and program, many of which ought to be continued."[19] He furthermore indicated that the Coast Guard inspections program proved that marine inspection functions should continue as a role of the Coast Guard.

This was met with harsh criticism from various maritime associations and organizations with some declaring that the militarization of the inspection program could come with a lack of experience, and an intimidation of the merchant marine community. It was argued that the plan to reorganize the Coast Guard marine inspection program lacked requirements for experience as included in previous legislation for the BMIN Board of Supervising Inspectors, traveling inspectors, as well as in requirements for local inspectors (S. Con Res 64, 65, 66). The Coast Guard, however, argued that the officers conducting these exams had degrees in engineering fields that made up for this lack of experience. Others, including Stephen J. Spingarn, assistant general counsel of the Treasury Department, advocated for the permanent transfer, noting that the Coast Guard provided key administrative oversight of the antiquated BMIN while overhauling its inconsistent rules and requirements across the United States.

Conclusion

The Coast Guard's Marine Safety program was established at the onset of World War II when a unified organization to review the massive increase in vessel construction, safety equipment, licensing, training, and hearings was desperately needed. Recognizing this, President Truman signed Executive Order 9082 placing BMIN under the Coast Guard for 6 months beyond the end of the war which, due to its great success, would be made permanent a few years later. This program was highly successful as indicated by the 75 percent decrease in lives lost between the beginning and end of the war. This proved the importance of a government oversight organization that could regulate the Merchant Marine program.

During times of war, it is crucial that the merchant marine fleet is ready to support the transportation of supplies to foreign countries. New vessels will need to be built, damaged vessels will need to be repaired, and existing vessels will need retrofitting to adapt to changing needs. *Semper Paratus*, the Coast Guard continues performing oversight to maintain the safety of the fleet and its crews.

About the author:

LCDR Aaron Garnier serves as executive officer of Marine Safety Unit Chicago. Previously, he was the executive assistant to the Coast Guard's director of investigations and compliance. He also has served as a mechanical engineer in the machinery branch of the Marine Safety Center, and as marine inspector in Portland, Maine. He earned his B.S. in mechanical engineering from the Coast Guard Academy and an M.S. in mechanical engineering from the University of Michigan.

Endnotes:

1. Section H. "The Coast Guard at War Marine Inspection Volume II." 1951
2. Ibid
3. United States Maritime Commission Report to Congress. 1942
4. US Merchant Marine. "U.S. Merchant Marine Casualties during World War II." www.usmm.org/casualty.html. Published 2006
5. "Coast Guard Gets Shipping Duties." *New York Times*. 1942. www.nytimes.com/1942/03/03/archives/coast-guard-gets-shipping-duties-roosevelt-gives-training-of-men.html
6. Ibid
7. "A Challenge and a Responsibility." *Alumni Association Bulletin*. 1942; IV (1):1–4
8. Wasche R. "The Coast Guard at War." *Alumni Association Bulletin*. 1943; V (2):102–105
9. Crouch H. "Merchant Marine Inspection: A Major Function of the Coast Guard." *US Naval Institute Proceedings*. 1948, p823–831
10. Division S. "The Coast Guard At War Marine Inspection Volume I." 1944. https://media.defense.gov/2017/Jul/02/2001772342/-1/-1/0/USCGATWAR-MARINEINSPECTION.PDF
11. Ibid
12. Ferguson J. "Liberty Ships." *Proceedings of the Marine Safety and Security Council* 2004; 61(1):68–71. www.dco.uscg.mil/Portals/9/DCO%20Documents/Proceedings%20Magazine/Archive/2004/Vol61_No1_Spr2004.pdf?ver=2017-05-31-120354-527
13. Section H. "The Coast Guard at War Marine Inspection Volume II." 1951 https://media.defense.gov/2017/Jul/02/2001772342/-1/-1/0/USCGATWAR-MARINEINSPECTION.PDF
14. Ibid
15. US Merchant Marine. "U.S. Merchant Marine Casualties during World War II." www.usmm.org/casualty.html. Published 2006
16. Division S. "The Coast Guard At War Marine Inspection Volume I." 1944. https://media.defense.gov/2017/Jul/02/2001772342/-1/-1/0/USCGATWAR-MARINEINSPECTION.PDF
17. Ibid
18. Series E. "U.S. Coast Guard Wartime Safety Measures for Merchant Mariners." *Alumni Association Bulletin* 1943; v (2):34-38
19. "Reorganization Plan No. 3 of 1946." www.govinfo.gov/content/pkg/USCODE-2010-title5/html/USCODE-2010-title5-app-reorganiz-other-dup7.htm

Chemical of the Quarter

Understanding Epichlorohydrin

by LT Joseph Kolb
Hazardous Materials Division
U.S. Coast Guard Office of Design and Engineering Standards

What is it?

Epichlorohydrin is an organochlorine epoxide with chemical formula C_3H_5ClO. It is a colorless liquid under ambient conditions and releases an irritating chloroform-like odor. As a chiral molecule, it generally exists as a racemic mixture of its left-handed and right-handed enantiomers. With a highly reactive epoxide ring, it is mainly used in the production of epoxy resins, plastics, and glycerol. Due to its flammability, toxicity, and carcinogenic properties, epichlorohydrin is a dangerous good when transported, and is regulated by the U.S. Department of Transportation (DOT) and the International Maritime Organization (IMO).

Why should I care?

➤ *Epoxide resins*

The primary use for epichlorohydrin is in the production of epoxide resins. Epoxide resins are a class of highly reactive polymer intermediates that form thermosetting polymers when reacted with themselves or with other hardeners. They have many applications, including coatings, glues, and maritime repair. Specifically, epichlorohydrin is reacted with bisphenol A to produce bisphenol A diglycidyl ether, which forms the building blocks to the epoxy resin. The epichlorohydrin provides the ether with epoxy groups, which in turn provide desirable adhesive characteristics.

➤ *Synthetic glycerol*

Another major use for epichlorohydrin is in the production of synthetic glycerol. Glycerol is a simple polyol compound used heavily in the pharmaceutical industry. Though a significant waste product of biodiesel production, when collected in this manner, glycerol remains full of impurities, rendering it inadequate for pharmaceutical use as these impurities interfere with active pharmaceutical ingredients. While attempts to remove the impurities have proven unsuccessful, epichlorohydrin has emerged as the primary method to produce highly pure synthetic glycerol suitable for pharmaceutical use.

➤ *Flammability concerns?*

Readily ignited under nearly all ambient temperature conditions, epichlorohydrin is considered a highly flammable liquid and vapor. It has a flashpoint of approximately 70°F and its explosive range is 3.8% to 21.0%. As such, care must be taken when storing and working with epichlorohydrin to avoid contact with sources of heat and ignition.

➤ *Health concerns*

Epichlorohydrin also demonstrates several human health concerns, namely carcinogenic and toxic properties. The U.S. Environmental Protection Agency has classified epichlorohydrin as a Group B2, probable human carcinogen, with an increased number of lung cancer mortalities observed by a study of workers regularly exposed to the chemical. As for toxicity, acute exposure has been shown to cause irritation of the eyes, skin, and respiratory system, with prolonged contact leading to burns. Chronic exposure is associated with respiratory tract inflammation, hematological effects, and hepatic damage.

➤ *Shipping concerns*

Epichlorohydrin is classified as a Class 6.1 poison, inhalation hazard dangerous good and is regulated by DOT's Hazardous Material Regulations and IMO's International Maritime Dangerous Goods Code when transported. Due to flammability and health concerns, these regulations limit the types of packaging permitted to carry epichlorohydrin and specify required labeling and placarding to identify all known hazards. Additional requirements include stowage away from living quarters and placement of a self-contained breathing apparatus near the stowage location. These requirements are designed to maximize the safety of the crew, ship, and environment by minimizing the threat of chemical exposure.

What is the Coast Guard doing about it?

The U.S. Coast Guard is responsible for enforcing maritime transportation requirements for all hazardous materials, such as epichlorohydrin. The Coast Guard Office of Design and Engineering Standards is responsible for voicing maritime transportation opinions to DOT and internationally on behalf of the U.S. while creating and interpreting regulation. Epichlorohydrin is, indeed, a very useful, yet hazardous material, and it is the responsibility of all involved parties to ensure its safe carriage over U.S. waterways.

Additionally, the U.S. Coast Guard operates the National Response Center (NRC), which is the sole federal point of contact for reporting chemical spills. In the event of a spill or emergency involving epichlorohydrin, contact the NRC at (800) 424-8802.

About the author:
LT Joseph Kolb works in the Hazardous Materials Division at Coast Guard Headquarters in Washington, D.C. He was previously stationed at MSU Morgan City, Louisiana, as a marine inspector in 2015. He graduated from the University of Virginia in 2009 with a B.S. in chemistry, and The Ohio State University in 2021 with a M.S. in chemical engineering. He was commissioned into the Coast Guard in 2015 after graduating from Officer Candidate School. This office may be contacted at hazmatstandards@uscg.mil.

References:

PubChem, U.S. National Library of Medicine. https://pubchem.ncbi.nlm.nih.gov/compound/Epichlorohydrin. Visited 18 January 2022.

U.S. Environmental Protection Agency. www.epa.gov/sites/default/files/2016-09/documents/epichlorohydrin.pdf. Visited 18 January 2022.

Outsourcing-Pharma.com. www.outsourcing-pharma.com/Article/2008/10/16/Synthetic-glycerine-is-back-but-never-really-went-away. Visited 18 January 2022.

Pham, H. Q. and Marks, M. J. (2005). *Ullmann's Encyclopedia of Industrial Chemistry*. Wiley.

Nautical Engineering Queries

Prepared by NMC Engineering Examination Team

1. The primary purpose of a control desuperheater installed in the steam drum of a boiler is to ______________________________.

A. assure a constant volume of steam flow through the entire superheater under all load conditions
B. regulate the temperature of superheated steam by adding moisture
C. regulate the superheater outlet temperature by cooling a portion of the superheated steam
D. regulate saturated steam temperature through the desuperheater

---

2. Operating a reciprocating air compressor without an air intake filter can result in a/an ______________.

A. immediate piston damage
B. immediate clogging of the intake
C. possible explosion in the compressor
D. deposit of carbon on the valves

---

3. Carbon dioxide extinguishers must be recharged when the charge weight is less than ________.

A. 80%
B. 85%
C. 90%
D. 95%

---

4. In a four-stroke/cycle diesel engine, the intake valves open ______________________________.

A. before TDC and close after BDC
B. after TDC and close after BDC
C. before TDC and close before BDC
D. after TDC and close before BDC

1.	A. assure a constant volume of steam flow through the entire superheater under all load conditions	Incorrect answer
	B. regulate the temperature of superheated steam by adding moisture	Incorrect answer
	C. regulate the superheater outlet temperature by cooling a portion of the superheated steam	**Correct answer.** *"A typical arrangement which will provide close control of steam temperature and in so doing protect the last passes of the superheater … when the last temperature tends to rise above the set temperature, the control valve opens to permit a portion of the steam to flow to the desuperheater and have its temperature reduced."*
	D. regulate saturated steam temperature through the desuperheater	Incorrect answer

References: Introduction to Marine Engineering, *Latham, p. 4–11 AND Combustion Engineering, Fryling, pages 28-17 & 18*

2.	A. immediate piston damage	Incorrect answer
	B. immediate clogging of the intake	Incorrect answer
	C. possible explosion in the compressor	**Correct answer.** *"… when the percentage of dust becomes sufficiently high an explosive mixture is formed. It is very important, therefore that air filters be fitted on the air intake lines and that they be kept in good condition, in order that air free from dust will be supplied to the compressor"*
	D. deposit of carbon on the valves	Incorrect answer

Reference: Naval Auxiliary Machinery, *USNI, page 11-5*

3.	A. 80%	Incorrect answer
	B. 85%	Incorrect answer
	C. 90%	**Correct answer.** *"Remove a CO_2 extinguisher that is found deficient in agent weight by 10% or more, and replace with a full unit of equal size"*
	D. 95%	Incorrect answer

Reference: Marine Fire Fighting, *1st Ed., IFSTA, page 151*

4.	A. before TDC and close after BDC	**Correct answer.** *"In General, the intake (or inlet) valve begins to open 20 degrees before top dead center (TDC). This is done so that the valve will be fairly well open soon after the piston starts down, or out, on the intake stroke. The intake valve closes 35 degrees after bottom dead center (BDC)."*
	B. after TDC and close after BDC	Incorrect answer
	C. before TDC and close before BDC	Incorrect answer
	D. after TDC and close before BDC	Incorrect answer

References: Diesel Engine Reference Book, *Lilly, page 6/5, fig 6.2 AND* Diesel Engineering Handbook, *Stinson, page 10, fig 1-5*

1. **INLAND ONLY A power-driven vessel proceeding downstream in a narrow channel on the Western Rivers sights another power-driven vessel moving upstream. Which vessel has the right of way?**

    A. The vessel located more towards the channel centerline
    B. The vessel moving downstream with a following current
    C. The vessel sounding the first whistle signal
    D. The vessel moving upstream against the current

2. **Which publication offers information on Great Lakes ice services?**

    A. Light List volume VII
    B. U.S. Coast Pilot #6
    C. National Weather Service, Ice Outlooks
    D. Marine Weather log

3. **What is the correct procedure to follow when manually launching an inflatable life raft?**

    A. Open the canopy relief valves
    B. Pull the painter from the container and make it fast to the cleat provided
    C. Remove the raft from the container to permit complete inflation
    D. Connect the float free link to the vessel

4. **A time diagram is a diagram of the celestial sphere as observed from above which location?**

    A. The north celestial pole
    B. The Greenwich meridian
    C. The south celestial pole
    D. The observer's meridian

Deck Answers

1. A. The vessel located more towards the channel centerline — Incorrect answer
   B. The vessel moving downstream with a following current — **Correct answer.** Inland Rule 9(a)(ii) *"…a power-driven vessel operating in narrow channels or fairways on the Great Lakes, Western Rivers, or waters specified by the Secretary, and proceeding downbound with a following current shall have the right-of-way over an upbound vessel, …"*
   C. The vessel sounding the first whistle signal — Incorrect answer
   D. The vessel moving upstream against the current — Incorrect answer

   Reference: Inland Navigation Rule 9

---

2. A. Light List volume VII — Incorrect answer
   B. U.S. Coast Pilot #6 — **Correct answer.** Winter Navigation: *"The Coast Guard operates a VHF-FM radiotelephone vessel traffic reporting system on Lakes Superior, Michigan, Huron, Erie and the St. Mary's River. The system is designed to provide vessel traffic information, aid in the efficient deployment of icebreaking services and obtain ice information from transiting vessels."*
   C. National Weather Service, Ice Outlooks — Incorrect answer
   D. Marine Weather log — Incorrect answer

   Reference: Coast Pilot 6, *2021 Edition, p.176*

---

3. A. Open the canopy relief valves — Incorrect answer
   B. Pull the painter from the container and make it fast to the cleat provided — **Correct answer.** *"Before launching the raft by hand, pull out the painter from the container and make it fast to the cleat provided (on the cradle)."*
   C. Remove the raft from the container to permit complete inflation — Incorrect answer
   D. Connect the float free link to the vessel — Incorrect answer

   Reference: The Cornell Manual for Lifeboatmen, Able Seamen and QMED's, *Keever, 2nd Ed., page 47*

---

4. A. The north celestial pole — Incorrect answer
   B. The Greenwich meridian — Incorrect answer
   C. The south celestial pole — **Correct answer.** *"The (time diagram) circle is the celestial equator as seen from above the South Pole, with the upper branch of the observer's meridian at the top."*
   D. The observer's meridian — Incorrect answer

   Reference: The American Practical Navigator *(Bowditch), 2002 Ed., page 238*

In the News: Refloating the *Ever Forward*

Coast Guard Sector Maryland commander CAPT David O'Connell and members of Station Curtis Bay oversee a safety zone around the *Ever Forward* on March 16, 2022, after the 1095 foot vessel carrying 4,964 containers ran aground in the Chesapeake Bay. The Coast Guard and Maryland Department of the Environment worked with the ship owner to develop and safely execute a plan to lighter containers and refloat the vessel. *Ever Forward* was freed April 17, 2022. Coast Guard photo by Petty Officer 3rd Class Breanna Centeno

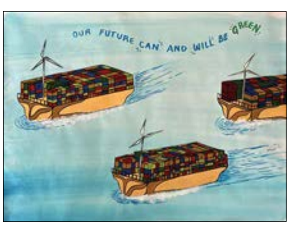
COMMANDANT (CG-5PS-D)
ATTN: PROCEEDINGS
US COAST GUARD STOP 7509
2703 MARTIN LUTHER KING JR AVE SE
WASHINGTON, DC 20593-7509

PRSRT STD
POSTAGE & FEES PAID
U.S. COAST GUARD
PERMIT NO.G-157

Official Business
Penalty for Private Use, $300

New Technologies for Greener Shipping

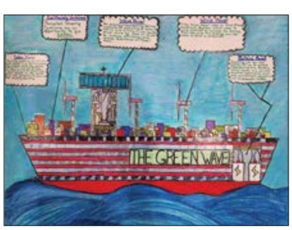
Congratulations to the winners of the 2022 North American Marine Environment Protection Association's annual student art contest! Students in Kindergarten through 12th grade were invited to artistically interpret "the importance of developing new technologies to support a green transition of the maritime sector into a sustainable future, while leaving no one behind." The contest was co-sponsored by the U.S. Coast Guard and The Inter-American Committee on Ports of the Organization of the American States. To learn more see https://namepa.net/education/art-contest/



Madeleine L., 8th Grade
Cupertino, CA
Wind Energy Ships

Nathan B., 1st Grade
Hamilton ON, Canada
Green Shipping Tech Makes the Future

Solomon C., 8th Grade
Cupertino, CA
Green Solar



Sushanth D., 5th Grade
Concord, NC
The Green Wave for Now and Tomorrow

David J., 3rd Grade
Rancho Cucamonga, CA
Save Energy and Save Ocean

Yaru C., 8th Grade
Saint Petersburg, FL
Greener Shipping

Nicholas L., 6th Grade
Philadelphia, PA
Go Solar for Better and Greener Shipping

Shinyee T., Kindergarten
Milpitas, CA
Greener Ocean, Happier Friends

Eva S., 4th Grade
Frederick, MD
Simple, But Effective

Emma J., 8th Grade
Philadelphia, PA
Pollution is No Fun

Sean Z., 2nd Grade
Delta, BC, Canada
Use Less Oil to Save the Ocean

Jiseok S., 6th Grade
Richmond, BC, Canada
If a Ship Can be Run by Broccoli