PATHWAYS TO NET-ZERO 2050 IN THE NORTH AMERICAN MARINE SHIPPING INDUSTRY:

Optimizing Technology and Operations to Achieve Emission Reductions

A Report of the Blue Sky Maritime Coalition

Prepared for Blue Sky Maritime Coalition
by the Vanderbilt University Climate Change Initiative

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BLUE SKY MARITIME COALITION

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TABLE OF CONTENTS

I. ABOUT THIS REPORT

Blue Sky Maritime Coalition (BSMC or Blue Sky) launched in June 2021 with the goal to facilitate needed collaboration across the full North American marine shipping value chain to achieve commercially viable net-zero carbon emissions by 2050. Recognizing the unique challenges to decarbonization that exist in the United States and Canadian markets, Blue Sky brings together industry leaders representing the wide range of businesses that are integral to marine shipping: from vessel builders, operators, and port authorities to fuel providers, finance institutions, engine manufacturers, customers of marine shipping, classification societies, and more. Blue Sky emerged from the reality that no one of these stakeholders can achieve decarbonization without concerted, targeted, and collaborative efforts between them all.

As a non-profit, Blue Sky's mission is action-oriented and membership-based, and we engage across four topical work streams to identify pathways, opportunities, and barriers to decarbonization. Blue Sky's work encourages innovation and acceleration of needed investments in vessels, infrastructure, and pilot projects to deliver near- and long-term greenhouse gas (GHG) emission reductions. Our members recognize the value of this collaboration to their customers, their operations, and to their ability to thrive in an increasingly carbon-constrained economy. Each member stands to benefit from collective knowledge sharing and a better understanding of the long-term decarbonization pathways likely to be supported within the value chain each depends on.

This Report on "Optimizing Technology and Operations to Achieve Emission Reductions" is the third in our series of three reports aimed at identifying the pathways and approaches that Blue Sky has initially identified as most likely to accelerate significant GHG emission reductions and serve the North American marine shipping sector in achieving net-zero—measured on a lifecycle emissions basis from "well-to-wake"—by 2050.

The first Report, "Fuels and Propulsion Systems," was published in April 2022 and examined and identified the marine fuels and propulsion systems that Blue Sky expected to most effectively accelerate the transition to net-zero emissions by 2050. The Fuels and Propulsion Systems report recognized that due to significant inherent differences in vessel categories and their operating conditions, there is no "one-size-fits-all" approach to future low- and zero-carbon marine fuels. Rather, flexibility and a range of fuels and propulsion systems will be appropriately adopted. Technology advances or adoption of new regulatory incentives that facilitate particular fuel or propulsion system pathways may impact the choice of selected fuels and propulsion systems over time.

The second Report, "Vessel Inventories and Emissions – Pathways and Challenges," was published in November 2022 and identified the wide variety of vessel types and operational needs and constraints that directly relate to fleet emissions and decarbonization potential. From small, low-horsepower "fleet boats" that operate in limited geographical areas and in close proximity to shore infrastructure to ocean-crossing vessels that must operate long distances without refueling options, to vessels that navigate locking river systems and shallow water depths, the huge variation is unmatched in other transportation modes. Decarbonization pathways available to one vessel type may not be feasible for another. This second Report categorized vessels according to criteria relevant to greenhouse gas (GHG) emissions, and estimated GHG emissions within each vessel category. The Report also identified decarbonization pathways likely to be applicable within each vessel category.

This third Report builds on the understanding of the future fuel and propulsion system pathways presented in the initial Report, and the identification of vessel categories, and emissions inventories set forth in the second Report. It sets forth a more detailed assessment of the role of operational, technological, and digitization trends that are likely to have profound impacts on energy efficiency and thus, vessel emissions–both over the short and long term. This Report also summarizes the work of the major national and international bodies that are directly addressing energy efficiency as a means to decrease maritime GHG emissions.

II. INTRODUCTION

Maritime shipping is critical to the U.S., Canadian, and global economies. Today over 80% of the world's goods are transported by water. In the U.S., maritime shipping represented nearly 2% of U.S. Gross Domestic Product (GDP) in 2019.[1] In Canada, the figure is about 1.8% of GDP.[2] Additionally, about two-thirds of all U.S. imports arrive by water and over 70% by tonnage; 41% of total exports (by value) depart the country by water.[3] Major critical sectors within the U.S. also rely heavily on the inland waterways in particular, such as energy (coal and fuel oils) and agriculture.

Maritime transportation is not only foundational to the transport of goods across and within North America, it is already the most environmentally sustainable, lowest GHG-emitting, and often the lowest-cost freight transportation option available. However, as global trade increases and the urgency to decarbonize becomes ever more pressing, there is little doubt that, without intentional efforts, emissions associated with maritime shipping will increase. This is especially true as customers, similarly responding to the need to decarbonize, are selecting waterborne transportation in lieu of other, more carbon intensive methods of shipping.

Improving energy efficiency—the ability to do the same work with less fuel—is one approach to reducing emissions, and is the focus of this Report. Energy efficiency measures do not address the source of energy being used (i.e., the fuel), but have incredible potential to drive down GHG emissions from maritime shipping, and across the economy, even while economic growth expands. Indeed, all the major national and international bodies that focus on decarbonization issues, within and beyond the maritime sector, recognize the critical role of energy efficiency in achieving decarbonization goals. The International Energy Agency (IEA) thus refers to energy efficiency as the "first fuel of all energy transitions": it is the "fuel you do not have to use—and in terms of supply, it is abundantly available and cheap to extract" (IEA, 2019).

Section III of this report discusses the role of energy efficiency in driving down emissions from the maritime shipping sector and current approaches from major national and international bodies. Section IV identifies specific approaches likely to be increasingly adopted within the U.S. and Canada, and Section V discusses the expected GHG reduction potential of a variety of approaches to energy efficiency.

1 Data from 2019 represents the most recent year not impacted by the pandemic and that was available from the Marine Economy Satellite Account (MESA) data produced by the U.S. Bureau of Economic Analysis and the U.S. National Oceanic and Atmospheric Administration (NOAA). Such data includes only coastal activities within the Exclusive Economic Zone (EEZ) and Great Lakes and does not include inland waterways.

2 According to Canada's Angus Reid Institute, a non-profit independent research foundation.

3 American Society of Civil Engineers, ASCE (based on data from the Freight Analysis Framework of the Bureau of Transportation Statistics, U.S. Department of Transportation).

III. THE ROLE OF ENERGY EFFICIENCY IN DECREASING GHG EMISSIONS IN THE MARITIME SHIPPING SECTOR

Energy efficiency is a central component of achieving decarbonization goals, within the maritime sector and beyond. It is a proven and effective tool to reduce fuel use (and associated emissions) that can be adopted now through a wide range of measures, but also has the potential for further emission reductions as the shipping sector adopts more advanced optimization technologies (discussed in Section V below).

In January 2023, the Department of Transportation, the Department of Energy, the U.S. Environmental Protection Agency, and the U.S. Department of Housing and Urban Development collectively issued the first *U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation* (the U.S. Blueprint or Blueprint). Recognizing the transportation sector as the single largest sector contributor to U.S. emissions (at 29% of 2021 totals[4]), the Blueprint attributes 3% of total U.S. transportation sector emissions to U.S. maritime emissions.[5]

The Blueprint adopts a three-pronged comprehensive strategy to achieving its goals of a clean electric supply grid by 2035 and net-zero carbon emissions by 2050—and improved energy efficiency is one of the three central pillars of the Blueprint. Indeed, energy efficiency is recognized as one of the "priority actions and levers" to achieve maritime decarbonization in the U.S. Specifically, the Blueprint identifies waste heat recovery, improved hull design or coatings, higher efficiency HVAC, power management systems, and speed reduction as key energy efficiency management tools (further discussed in Section IV). The Blueprint also expressly includes goals of increased incentives for the U.S. commercial fleet to lower GHG emissions and targeted U.S. efforts to raise the IMO's ambition to achieve net zero emissions by 2050 (rather than 2100 as is IMO's current goal).

The IMO's current goal to achieve 50% GHG emission reductions by 2050 (from 2008 levels) also relies heavily on energy efficiency measures. IMO has adopted mandatory energy efficiency measures to be phased in over time: the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP), and the Energy Efficiency Existing Ship Index (EEXI) and related Carbon Intensity Indicator (CII). The EEDI is a design index that applies only to certain types of new ship builds, and requires the new ship to meet or exceed the energy efficiency performance of a particular reference baseline (which is developed based on estimated grams of CO_2 emitted per ton-mile per ship type/size).[6] The SEEMP is a required, ship-specific plan to improve the energy efficiency of a vessel, and is developed by vessel owners or operators. The recent EEXI and CII ratings apply to existing ships. The EEXI requires existing ships to calculate their energy efficiency according to the specified index, and to achieve a minimum energy efficiency based on the applicable reference line (the reference line will vary by ship type and category and generally align with the EEDI Phase 2 limit). The SEEMP requires data collection and reporting for the establishment of the ship's carbon intensity indicator (CII) (which is expressly intended to link carbon dioxide emissions to the volume and distance of cargo carried). Vessels will receive a CII rating starting in 2024 that will be required to be part of the vessel's SEEMP. IMO has already identified measures such as hull cleaning, speed optimization, low energy light bulbs, and auxiliary alternative power sources that could improve a vessel's CII rating.

4 EPA, Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, EPA 430-D-23-001.

5 There is a recognized need for improvements in measuring the GHG emissions associated with maritime shipping, in particular within the U.S. Blue Sky has previously issued two reports on accounting for GHG emissions within the North American Waterborne Transportation sector, and recently submitted formal comments to EPA on this subject as EPA prepares to finalize its most recent annual Inventory of U.S. Greenhouse Gas Emissions and Sinks (see note 4, above).

6 The CO_2 reduction level attained by adherence to EEDI is further reduced until 2025-2030, when new ships must achieve a 30% reduction from the carbon intensity average of ships (of specified types) built from 2000-2010.

Blue Sky has examined the IMO rating methodologies for fuel efficiency in a series of 2022 reports (Blue Sky Maritime Coalition, 2022a) concluding that, among other things, the lack of availability of actual emissions data combined with certain assumptions made in developing the methodology can result in poor correlations between the ratings and a vessel's actual emissions or efficiency. For example, by not adequately accounting for a vessel's operating conditions (penalizing short haul trips and incentivizing activity that may result in higher total emissions), the approach can lead to wide variety in ratings even among nearly identical vessels.

These measures, like most IMO rules and policies, are not mandatory for much of the U.S. domestic shipping fleet, nor for Canadian vessels operating only in Canadian waters. Indeed, as a Technical Report by Transport Canada found, applying these international standards to domestic vessels that are smaller and take shorter voyages could actually increase GHG emissions. However, IMO approaches can provide important information and guidance as to effective energy efficiency measures.

Blue Sky's second position paper also recognized the lack of consistency between emissions reporting approaches and the resulting wide variety of total GHG emissions attributable to the U.S. maritime shipping industry.[7] The digitalization trends discussed herein are likely to improve not only the total GHG emission accounting, but lead to greater accuracy and precision in understanding and comparing vessel fuel and emission efficiencies.

7 Blue Sky's paper identified a number of reputable reports and studies (from EPA, UMAS, and others) that calculated very different emissions associated with U.S. maritime shipping, using a variety of methodological approaches and geographical boundaries (Blue Sky Maritime Coalition, 2022b).

IV. ENERGY EFFICIENCY MANAGEMENT STRATEGIES

Energy efficiency measures are typically divided into two categories: technical and operational. Technical measures are approaches that impact a physical component of the vessel, such as advanced hull paints or engine re-design. Operational measures seek fuel savings through changes to how the vessel is operated, such as speed adjustments or routing changes. A third category of approaches that are necessary to substantially advance maritime (and other sector) decarbonization goals is to increasingly evaluate fuel efficiency goals from a systems perspective, rather than encouraging individual operators or companies to focus on their own emissions in silos. Digitalization is especially likely to have substantial impact on technical, operational, and systems-thinking approaches to decarbonization.

This section identifies measures in each category that may, especially when combined, provide significant emissions reduction through reduced fuel consumption. As discussed in Section V, however, the emission reduction potential with respect to some approaches may be difficult to quantify. Nevertheless, fuel is typically the largest single cost to any shipping company so annual fuel savings of even 1% are likely to translate to significant cost savings as well as emission reductions. Advancements in digitalization are likely to increasingly inform what measures may be the "best" for a particular vessel type and operational conditions.

A. HULL OPTIMIZATION

Techniques that reduce calm water and wave resistance against the hull can decrease the drag of the vessel and consequently reduce fuel consumption. Hull-related approaches include:

- <u>Hull design.</u> New ship designs can develop hull shapes/weights that improve efficiency and reduce fuel costs. Advanced automated modeling simulations and even artificial intelligence can be used to support both design and performance testing through computational fluid dynamics before a vessel is constructed in the "real world." Designing or retrofitting a vessel with a bulbous bow can also offer fuel savings on larger vessels depending on the vessel's operational profile, but may not be applicable to smaller, slower-speed vessels (including many that operate on the U.S. inland waterways).

- <u>Interceptor trim plates.</u> These can be installed either on new-build vessels or retrofitted on existing vessels and have the advantage (where automated) of engaging when the operational parameters of the vessel can be improved (e.g., at speeds where the existing hull design does not deliver optimum energy efficiency). The plates are installed at the rear of the hull and direct the high pressure flow from the vessel downward, creating lift. However, the plates are less effective at slower speeds.

- <u>Hull coatings</u>. High performance hull coatings can be used on all vessel types and reduce the hull's resistance in the water, improving fuel efficiency. Older ships may require hull sandblasting to smooth the surface prior to coatings. Hull coatings are a well-recognized efficiency measure that can have an immediate impact on fuel savings and a vessel's Carbon Intensity Indicator (CII) rating.

- <u>Hull cleaning.</u> The growth of algae and shellfish on the surface of the hull increase the vessel's drag and reduce fuel efficiencies.[8] Physical corrosion of the surface also can increase friction and reduce fuel efficiency.

8 Studies have shown that shell life on a hull can increase vessel drag by up to 40%, algal weeds up to 10%, and slime layers by 1-2% (Willsher, 2008).

- Air lubrication. This relatively new technology directs air bubbles down and across the underside of the vessel, reducing drag, but is not suited to all vessel types.

B. WASTE HEAT RECOVERY SYSTEMS

Waste Heat Recovery Systems (WHRC) recover and use heat that is generated by existing vessel systems and otherwise lost. Heat can be collected from exhaust gases, excess steam, or cooling water and used to generate electricity on board, typically for auxiliary engines that would otherwise rely on marine diesel fuel.

C. OPTIMIZING OPERATIONS

A number of practices impacting vessel operations within specified conditions have demonstrated fuel saving impacts. Two of the most frequently cited and studied include speed and routing changes that are intentionally designed to reduce fuel consumption (and thus GHG emission reductions) for the same voyage and cargo volume:

- Speed (or "slow steaming"). Vessels and vessel engines are typically designed to operate within certain speed ranges (or power loads for the engine) based on the relationship between speed and the resistance coefficient of the water on the vessel hull (the hydrodynamic boundary speed of the vessel). Because water resistance increases as a ship increases speed, more power (and fuel) is required. It is well accepted that in some operating conditions speed reductions will realize substantial fuel savings and carbon emissions reductions. As discussed in Section V, however, there is a lack of agreement in quantifying the extent of that benefit. In addition, consideration must be given to potential negative impacts to vessel engines that may not be designed for slow steaming, and lengthier delivery periods for cargo. Translating engine and scheduling impacts to carbon emissions can be challenging.[9]

- Routing. Using weather, current, wave and other forecasting capabilities, ship operators can revise planned routes to minimize water and air resistance from these forces, reducing fuel consumption. Combining routing factors with arrival time considerations (such as berth availability or contractual obligations for cargo delivery) can balance and optimize fuel savings and economics. Like many of the strategies discussed in this report, digitalization technologies are likely to increase the emission reduction and cost savings potential of this approach.

- Other. While this report is not intended to be a comprehensive analysis of every carbon emission reduction strategy available, a number of other techniques that are currently emerging or already offer fuel and emission savings include:

  » Wind or solar propulsion assistance. Wind and solar can be used to increase the efficiency of fossil-fuel based propulsion systems. Adding kite sails to existing vessels can reduce the power demand from engines and may save fuel, but will likely only be feasible on smaller vessels where sustained directional wind is available. Similarly, adding photovoltaic cells can reduce onboard power needs but will require adequate vessel space for installation and routes with high solar potential. Thus, wind and solar may have energy efficiency applications even where the primary propulsion system is fossil-fuel based.

  » Reducing onboard power needs. The U.S. Department of Energy and the U.S. Maritime Administration (MARAD) have developed maritime modifications that enable use of DOE's EnergyPlus model (designed to model

9 Recent research is beginning to examine these factors (e.g., Dere, et al., 2022.) and digitalization trends that will enable real-time analysis and gathering of large datasets are likely to further advance our understanding of the carbon emission reduction impacts of slow steaming and other energy efficiency strategies.

energy performance of buildings) on marine vessels.[10] Energy modeling can assist operators identify and reduce energy inefficiencies associated with heat loss, HVAC operations, lighting, and more.

» Scaling. "Economies of scale"[11] refers to using larger ships to increase energy efficiency per unit of fright moved. Researchers have found that doubling cargo-carrying capacity leads to only a 2/3 increase in required power and fuel.[12] Of course such size increases are typically feasible in new builds and would not be feasible for many vessel types (such as inland waterway vessels that operate with constraints on size imposed by, among other things, river depths).
» Optimizing maintenance schedules. Intervals between certain maintenance activities (such as hull cleaning) can be optimized with fuel consumption impacts in mind.[13]

D. DIGITALIZATION AND ADVANCED TECHNOLOGIES

More than any other approach or strategy discussed in this report, the emergence of digitalization is likely to transform maritime shipping, with significant beneficial impacts on energy efficiency, GHG emissions reductions, and cost savings throughout the value chain. As these advanced technologies and novel applications to maritime shipping continue to be developed and adopted more broadly throughout the value chain, the environmental benefits are likely far reaching and not yet well understood. Digitalization will also inevitably raise new challenges, some of which can be anticipated (such as increased energy use to power computers, servers, and advanced digital networks) and others are not yet foreseeable. However, with careful attention to implementation, the benefits are likely to impact all aspects of marine shipping, from safer workplaces to healthier environments, reduced carbon emissions, and more secure and efficient business transactions.

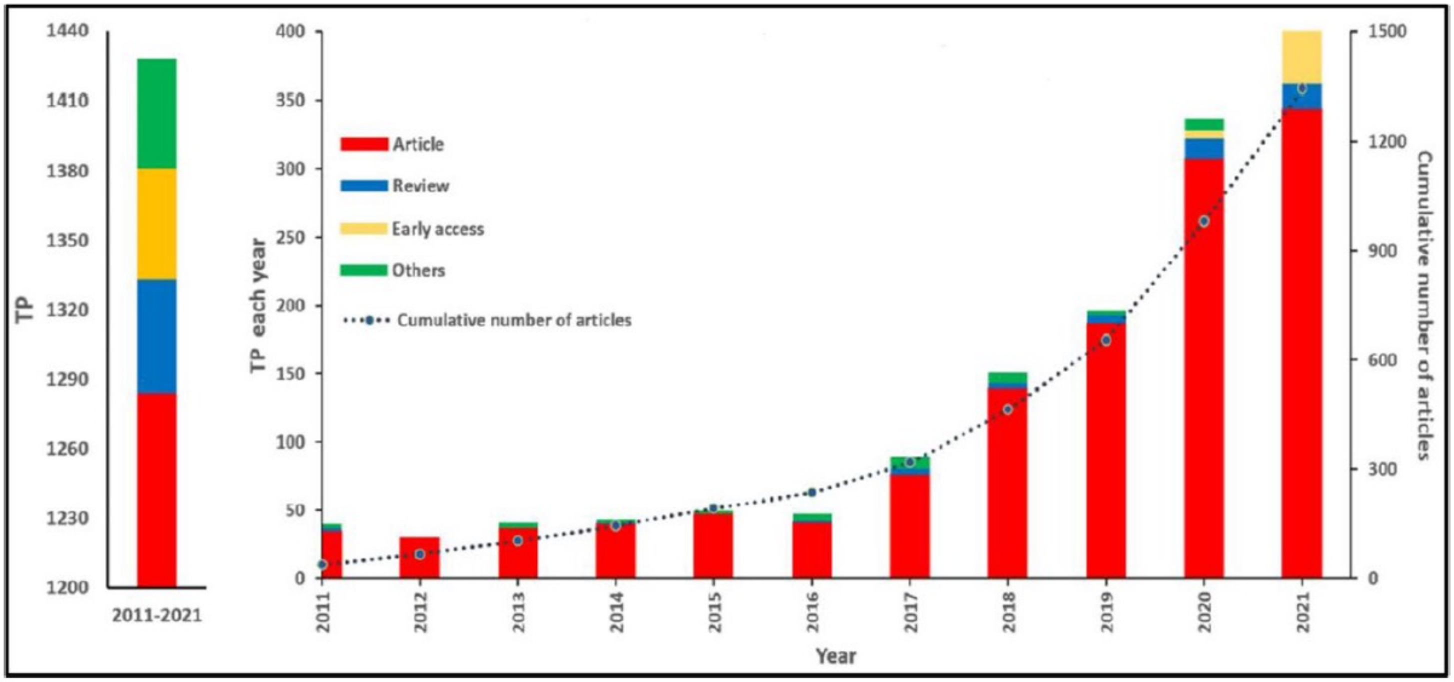
Digititalization refers to the operational and technical outcomes that can be achieved through the use and interconnection of digital data.[14] Digitalization includes a vast number of technologies such as artificial intelligence, autonomous shipping operations, blockchain, advanced supply chain management, the Internet of Things (IoT) (including the use of advanced sensors and actuators), leveraging "big data," cloud computing, development of cyber-physical systems, 3-D printing, machine learning, and more. Digitalization is often considered synonymous with Industry 4.0 (or I4.0)—the recognition that society is moving into the next (or Fourth) industrial revolution.[15] For purposes of this paper, the terms Industry 4.0 and digitalization are used synonymously.

10 The agency's findings were published at Suder, et al. (2018).
11 Term adopted from Bouman, et al. (2017).
12 Bouman, et al. (2017).
13 Indeed, in the context of ocean-going oil tankers, some researchers have found that hull cleaning at regular intervals resulted in substantial reductions in daily fuel consumption (Adland, et al., 2018).
14 Digitization, often confused with digitalization, is the process of creating digital records of analog or physical versions. The shipping industry has existed for centuries relying on analog records (log books, hand recorded temperature or speed readings, etc.) but storing records in this way makes it challenging or impossible to store or search large data sets easily, quickly find useful information, learn from data over time, or compare large data sets collected across many vessels.
15 The term "Industry 4.0" refers to four stages of manufacturing - or four industrial revolutions: the first transition (18th century) moved from creation of things nearly entirely by hand to machine produced goods; the second (1871-1914) resulted from the addition of transportation and communication networks (telegraphs); the third (1970s to today) is characterized by mass access to computers and cell phones; and Industry 4.0 is commonly understood to mean the shift to deeper interconnections between machines and people and the ability of cyber-physical systems to undertake decision making autonomously.

Research on digitalization and interest from the maritime industry have both increased significantly in recent years (Figure 1), and these trends are expected to continue. Ultimately, adoption of Industry 4.0 technologies is likely to become a necessity for maritime shipping stakeholders to fully participate in and benefit from the maritime value chain.

Figure 1.

Research and attention to Maritime Industry 4.0 has exploded in recent years and is likely to continue. Graph shows publications trends (focused on Maritime Industry 4.0) from 2011 - 2021.



Source: Razmjooei et al., 2023.

Some Industry 4.0 technologies are already being used in the maritime industry, such as the Automatic Identification System (AIS) which allows transmitting and exchanging of some data, including real time vessel location data, ship type, speed, or course. AIS data is currently being leveraged to better estimate GHG emissions from vessels, using location tracking, activity duration, and engine types to estimate a specific vessel's fuel consumption. The U.S. Environmental Protection Agency (EPA) has used this approach in its most recent National Emissions Inventory (EPA-NEI) and DNV also has recently taken this approach in a study to estimate maritime emissions in Canada.

Currently available, more advanced applications are improving the accuracy of emissions reporting through direct measurements rather than estimations.[16] Real time, exhaust-stack sensors can now continuously monitor the composition of the gases in vessel emissions in real time, providing detailed insight into not only the volume of carbon emissions, but the efficiency of the combustion reactions producing those emissions. Through sophisticated user-interfaces, this technology also can provide immediate feedback to vessel operators to optimize vessel speed, but also to optimize other on-board power usage (e.g., in multi-engine vessels, which combination of engines or generators to have in operation at any particular time). Real-time emissions data can also provide information about maintenance issues. For example, high amounts of methane can be indicative of methane slip and unburned hydrocarbons can show incomplete combustion of fuel. Emissions

16 Most carbon dioxide emissions today are estimated using standard "emissions factors" for various fuel types. Emissions factors are published by the U.S. EPA and specify a certain amount of carbon dioxide (or other greenhouse gas) per unit of fuel burned. See EPA Emissions Factors Hub, available at https://www.epa.gov/climateleadership/ghg-emission-factors-hub.

measurements can alert crews about when to fix issues or upgrade certain parts in real-time. This information mitigates increased emissions from these issues and ensures that maintenance issues do not get worse. Harvey Gulf is one example of an operator that has started collecting this real-time emissions data on its offshore support vessels, through platforms offered by SailPlan. With more accurate emissions data collected through direct measurements, machine learning (discussed below) can then be "trained" on this data to provide far more accurate emissions estimates than can be accomplished through the use of emissions factors.[17]

More advanced technologies and applications are being developed that are expected to reduce carbon emissions and increase business efficiency. However, scaling these approaches industry-wide is challenging because many vessels do not have the on-board software and processing systems—the Industry 4.0 architecture—that is needed for advanced on-board data collection and the complex integration of physical and digital systems on the ship and shore that can improve operational efficiency. Moreover, the full benefits of digitalization can only be realized where developed and adopted in collaboration across the value-chain. For this reason, classification societies such as the American Bureau of Shipping (ABS) and DNV are working to support the move to increased digitalization throughout the industry. Grants and other policy incentives will be needed to make this important investment in state-of-the-art technologies on vessels, in ports, and throughout the value chain.

Some emerging and future digitalization technologies include:

- <u>"Big data" analytics through machine learning/artificial intelligence.</u> As sensors advance and are installed on many vessel systems, the ship will be able to communicate with itself, from lightbulbs to HVAC systems to engines, as well as to other ships and shore. The vast amount of data collected through these sensors can be used to develop machine learning models that can in turn recognize patterns and use algorithms to make vessel operations more efficient, faster, and more environmentally friendly—either as recommendations to operators or entirely automated. As the AI's are increasingly "trained" on real-world data, their use and application can expand, for example from making decisions regarding where and when to store or use power from different onboard locations, to fully autonomous vessels that need no human operator and make their own "decisions" to reduce fuel consumption.

- <u>Advanced simulation technologies ("digital twins").</u> This technology replicates the vessel in a simulated environment. Using vessel information combined with modeling techniques, impacts on vessel operations (or structures) from a range of stimuli (vessel traffic, weather or waves, port congestion, etc.) can be projected in advance to enable re-routing or other operational changes that result in increased efficiency, safety, and eventually, automated operations.

- <u>Blockchain.</u> Blockchain has potential to impact the accuracy and speed of cargo movements between ships as well as cargo loading and off-loading, reducing vessel time in harbor (and associated power use), and creating efficiency and security in the financial transactions between customer, ports, and operators. For example, the Port of Long Beach, California, has invested in a data sharing platform that uses blockchain to automate cargo tracking, payments, scheduling and more.[18]

- <u>On-board 3-D Printing.</u> Vessels in need of parts or tools could print them as needed on the vessel, reducing the need to carry spare parts and assuring immediate replacement/repair contributing to continued, efficiency operations.

17 Fletcher , et al., 2018.
18 The platform is aptly titled the Supply Chain Information Highway.

As 5G (5th generation) wireless standards expand, allowing extremely high speed and low latency data transfer between objects and systems, information can be quickly shared between ship, shore, ports, financial institutions, and customers to dramatically increase the efficiency and the speed of transactions and operations, and lower carbon emissions. Combining the use of multiple digital technologies also will reduce fuel consumption and lower carbon emissions (among other benefits). As one researcher noted, digitalization has huge potential in the marine shipping environment, enabling ships to "monitor their own health, establish and communicate what is around [them] and make decisions based on that information to achieve efficient navigation at sea and in the harbor . . . to eventually ensure decarbonization."[19]

Applying the tools discussed above through a systems approach is likely to further advance the industry's decarbonization goals. For example, commercial agreements between value chain entities (customers, vessel operators, fuel providers, ports, and more) could include an evaluation of the total carbon emissions associated with a single voyage (that is, well beyond the direct emissions associated with the vessel's voyage from one point to the next), and could incentivize *all* the value chain entities to *collectively* reduce emissions, rather than assuming the responsibility should belong to only one or a few entities (such as the vessel operator or ship builder). Machine learning and artificial intelligence may increasingly be able to develop novel and creative approaches to advancing such industry-wide efficiency through voyage planning (routes, avoiding empty vessels on return trips, etc.), financial instruments, and port berth waiting time reductions that will serve the decarbonization goals of the entire maritime industry.

V. POTENTIAL EMISSION REDUCTIONS THROUGH ENERGY EFFICIENCY MEASURES

While energy efficiency measures (technical or operational) are important tools to reduce emissions, the emissions reduction potential of these approaches, especially as applied to U.S. and Canadian domestic fleets, are continuing to be studied. Major academic reviews that evaluate the GHG emission reduction potential of a wide range of measures have emerged and are providing valuable information. Like the adoption of alternative fuels and propulsion systems, however, there is no "one size fits all" approach to operational efficiency—approaches that realize major cost savings and GHG emission reduction potential in one vessel type and operating profile may not be the best suited for others, and may even increase negative environmental impacts and costs. It is also clear that no one technical or operational measure will be "enough," to achieve decarbonization goals, but adopting numerous complementary approaches can provide substantial emission reduction and (often) cost savings.

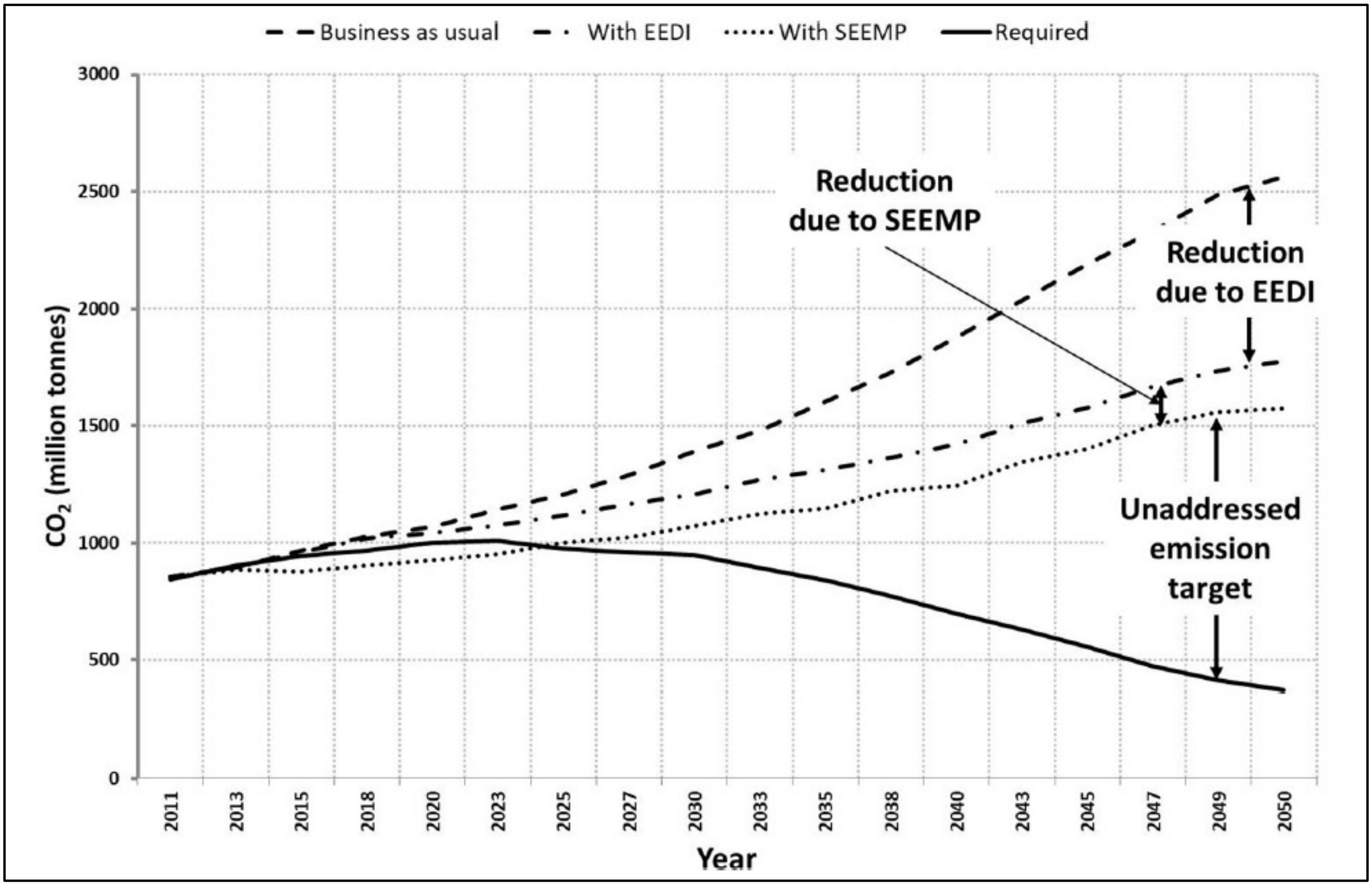
Moreover, just as alternative fuel uptake requires coordination across the maritime shipping value chain, so too does the adoption of energy efficiency measures. As discussed in Section IV, this is especially true as digitalization technologies become an increasing reality and require increased communication and coordination from ships to shore and even to satellite infrastructure.

Figure 2 below sets forth the expected emission reductions achievable through implementation of the IMO's EEDI and SEEMPs, which rely heavily on technical energy efficiency improvements (although the use of low/no carbon fuels or hybrid or electric propulsion engines may also improve a vessel's EEDI). The IMO Regulation has not yet included low/zero emission fuels into the EEDI requirements, and electric propulsion applies (currently) only to cruise ships and LNG carriers.

19 Agarwala, et al., 2021.

Figure 2.

CO_2 emission reduction potential from IMO SEEMP and EEDI.

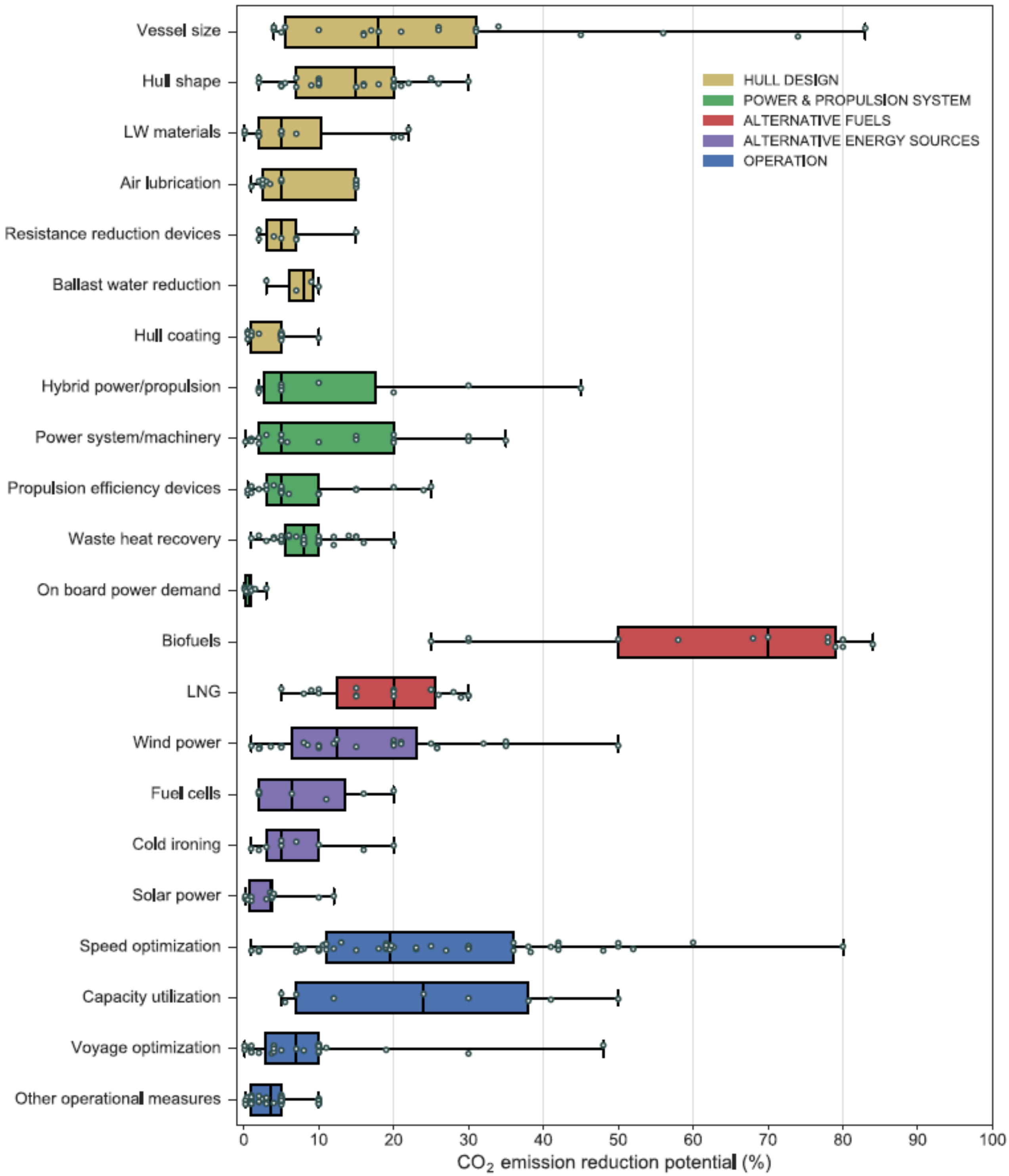


Source: Agarwala et al. (2021), based on IMO, 2018.

To better understand the potential for emission reductions, a 2017 study collected and evaluated the results of over 150 studies on a wide variety of approaches. The study quantified the emission reductions achievable through each selected approach. The results set forth in Figure 3 indicate that for many measures, there is a significant lack of agreement regarding the benefit (in terms of GHG emission reduction) of a particular approach. For example, it is commonly reported that speed reduction (or "slow steaming") always results in substantial emission reduction, but as shown in Figure 3, the benefits of speed optimization (which apart from slow-steaming, takes further parameters into account, such as commercial obligations or port congestion) range from near nothing to 80%. While it is clear the approaches identified in Figure 3 are likely to be well worth the investment on some vessels, the move towards digitalization (discussed in Section IV) can improve the industry's understanding of where particular approaches are most likely to be beneficial.

Figure 3.

Carbon dioxide emission reduction potential from individual selected efficiency measures.



Source: Figure taken from Bouman, et al (2017). The thicker, solid color rectangular bars indicate the range of "typical" emission reduction potential based on all the data points. The longer, thin horizonal black line with vertical endpoints represents the full spread of all data points from the studies reviewed, and thus shows the full range (based on the variety in the studies) of potential carbon emission reduction for the selected measure. Each small point (circle) along the longer thin line represents a data point taken from the individual studies examined for the selected measure.

VI. CONCLUSION

Optimizing operations and improving technology and design to achieve greater energy efficiency is a strategy that can be used across all decarbonizing time frames—existing technologies and approaches can be used now and will likely continue to advance over the medium and long term. Many energy efficiency approaches also come with substantial co-benefits, including cost savings and pollution reduction. Most of the strategies discussed in this report are aimed at reducing the amount of fuel (and thus emissions) required to support a vessel's operation; however, because fuel is typically the largest single expense to a shipping company, approaches that allow a vessel to do the same amount of work while using less fuel will also save money. Greater fuel efficiency also translates to fewer air pollutants emitted, which can have beneficial health impacts, especially in areas around certain ports where air pollution goals are not being met. As optimization technologies (including advanced digitalization) are increasingly adopted, higher electricity demands are also likely and must be factored into any total emission reduction potential. Despite the challenges, accelerating decarbonization goals across the maritime shipping industry is achievable. Factors essential to success include considerable vision, an understanding of the lead-time required for industry-wide adoption of new approaches, and a near-term shift towards systems-thinking about maritime decarbonizing.

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