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

FUELS AND PROPULSION SYSTEMS

A Report of the Blue Sky Maritime Coalition

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

April 2022

BLUE SKY
MARITIME COALITION

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I. ABOUT THIS REPORT

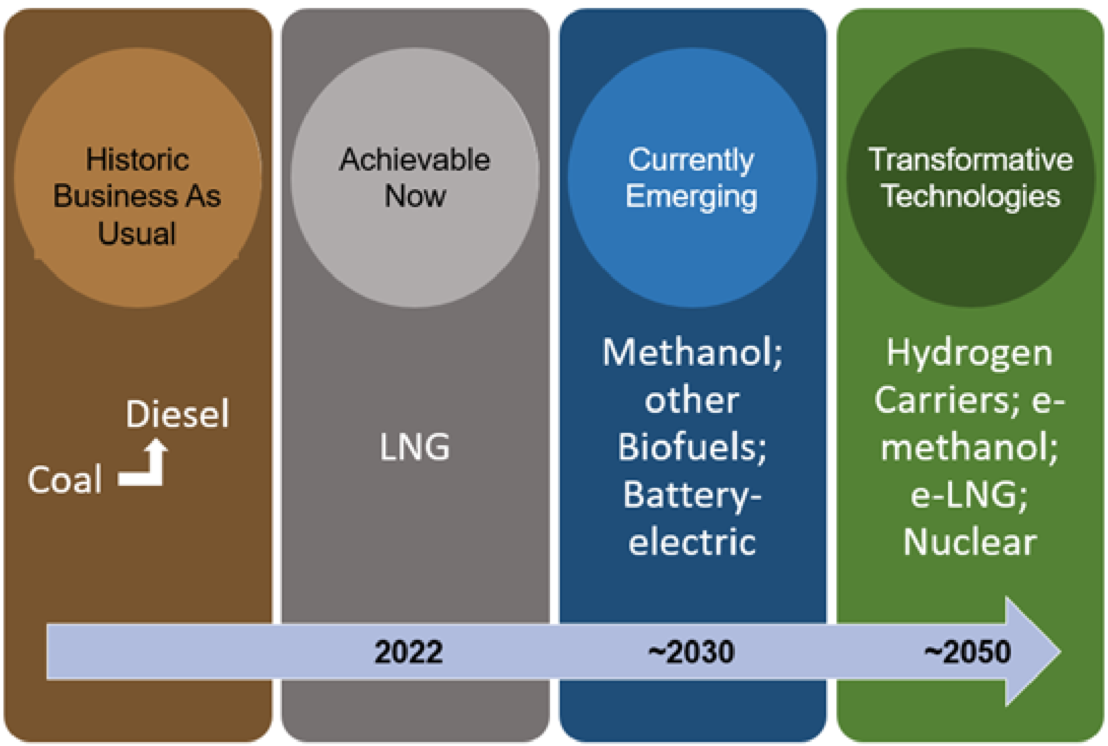
Blue Sky Maritime Coalition (BSMC or Blue Sky) launched in June 2021 with a goal to facilitate needed collaboration across the entire North American marine shipping value chain in order to achieve commercially viable net-zero carbon emissions by 2050. Recognizing the unique challenges to decarbonization that exist in the United States and Canadian markets, BSMC 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 manufactures, 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 workstreams to identify pathways, opportunities, and barriers to decarbonization. Blue Sky's work encourages innovation in commerce and acceleration of needed investments in vessels, infrastructure, and pilot projects to deliver near-term greenhouse gas (GHG) emission reductions. Our members recognize the value of collaboration with their customers, within their operations, and for 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 in the value chain.

This Report on Alternative Fuels is the first in a 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 life-cycle emissions basis from "well-to-wake"—by 2050. Net-zero also includes a commitment to avoid GHG emission reductions achieved through other climate-impacting activities (such as increasing black carbon deposits on ice and thereby reducing albedo (sunlight reflection)). The second report is expected to define a catalog of vessels and operational categories, along with GHG emission profiles. The third report will focus on the use of advanced data, machine learning, and artificial intelligence technologies that have the potential to vastly increase operational efficiency and thereby drive down fuel use and emissions. Future fuels and propulsion systems are foundational to GHG emission profiles and to operational efficiency; each report is expected to inform the next and ultimately contribute to the iterative Blue Sky roadmap to 2050.

II. INTRODUCTION

Achieving net-zero means a transition to low- and no-carbon fuels and propulsion systems, but alternative fuels require the surrounding value-chain infrastructure to support delivery, regulation, and onboard use of those fuels. Blue Sky believes this transition is likely to occur over the following three time horizons towards 2050: in the immediate and near term (0-10 years), low-carbon fuels that are currently available and can be used with no or minimal infrastructure adaptations are likely to see increased use—this includes liquefied natural gas (LNG) and certain "drop-in" fuels such as biodiesel. In the intermediate term, within 5-15 years, fuels that require more substantial retrofits and new vessel and propulsion system construction will see a more significant uptake and can already be predicted based on current investments (such as new vessel orders). These mid-term fuels will include more widespread use of LNG, development of bio-LNGs and carbon-neutral methanol, together with increased reliance on carbon capture, use, and sequestration (CCUS), in particular to avoid the emissions associated with fossil-based LNG (production, transportation, and combustion). In the long term towards 2050 (beginning 15+ years from now), we expect hydrogen-powered vessels to see a substantial uptake and drive the long-term infrastructure and value chain shifts that are expected to be in place by 2050. Electric-powered vessels also are emerging now and are likely to see increasing use by 2050 in particular applications. An industry shift in fuels and propulsion systems is dependent on many factors, and while this report sets forth Blue Sky's current position on the pathway to decarbonization, advances in technologies, government policy changes, and other factors are expected to change the 2050 outlook over time.



Critically, Blue Sky recognizes that there is currently no single fuel/propulsion system or approach to decarbonization that will be suitable for all marine shipping stakeholders; indeed, the vast differences between vessel types, sizes, operating conditions, and standards make the marine shipping industry one of the most difficult sectors of the economy to decarbonize. A technology that is appropriate for an ocean-going container ship traversing thousands of miles may not be possible on a towboat that pushes barges through narrow, shallow, locking rivers. Harbor tugs and ferries have their own unique operational constraints. These complexities make the collaborative approach of Blue Sky even more important, and this series of reports is aimed at serving all Blue Sky members and advancing the decarbonization mission of the coalition.

III. CURRENT FUEL AND PROPULSION SYSTEMS IN THE U.S. AND CANADIAN MARINE SECTOR

Recent studies and reports of global classification societies report that between 0.5-2% of the currently operating global marine shipping sector use alternative fuels. See Figure 1. This small number is attributable in large part to the large-scale investments (public and private) in fossil fuels and their infrastructure that date to the beginning of the Industrial Revolution, and the particularly long-lived infrastructure in marine shipping.

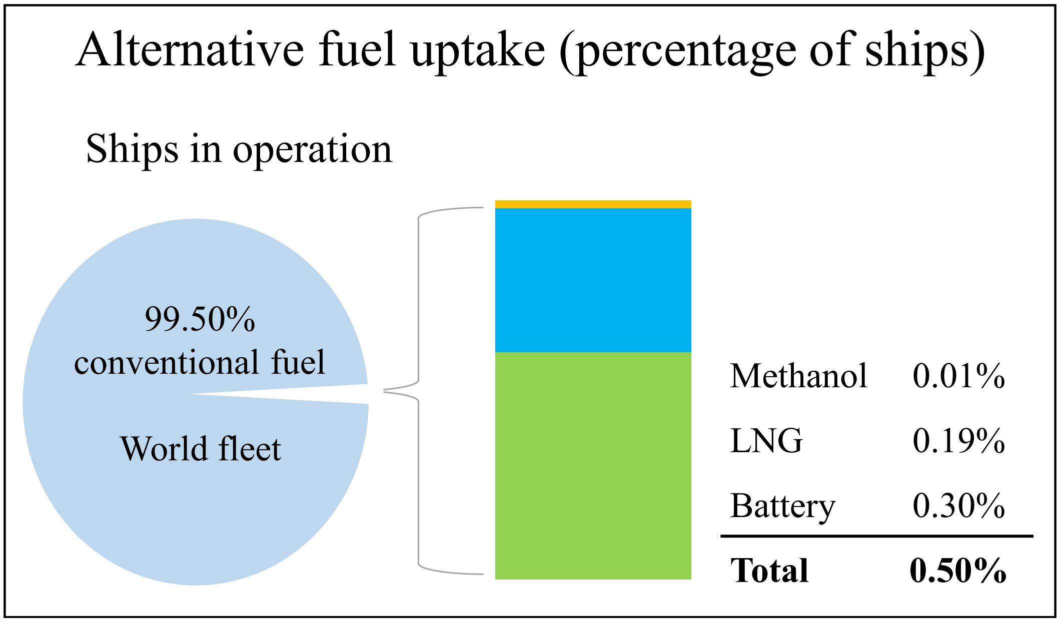


Figure 1. Yellow bar is percent of currently operating ships using alternative (low or no carbon) fuels. Source: DNV, Maritime Forecast to 2050, Energy Transition Outlook 2021

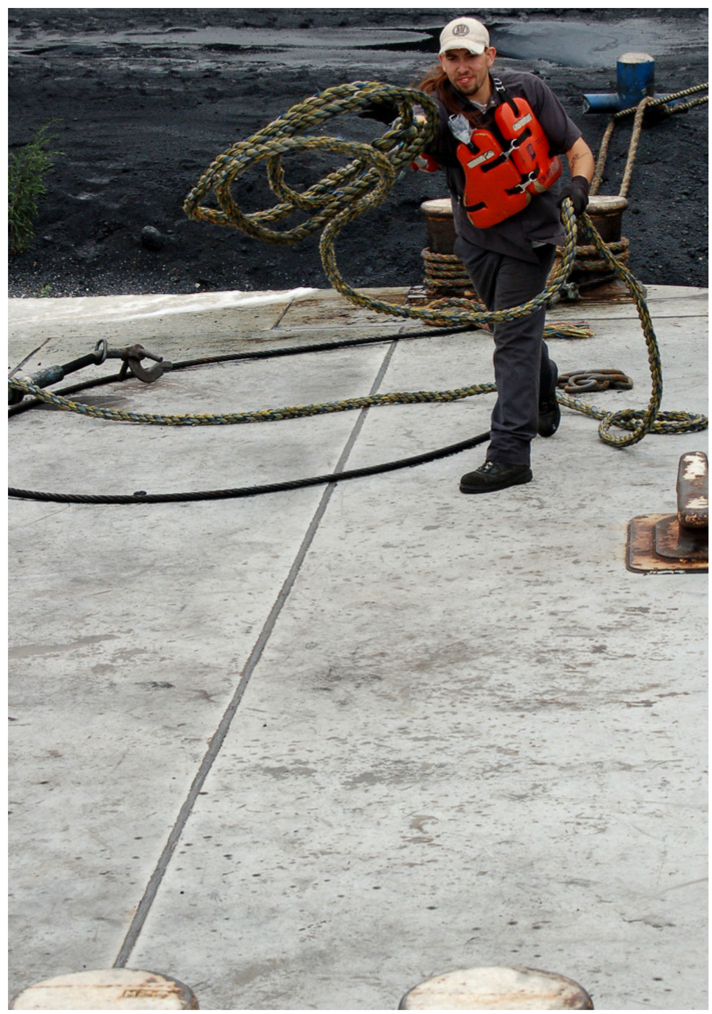
For over a century, coal and oil or gas have been nearly the only fuels available to meet industrial applications, and the marine shipping sector (and the entire modern economy) developed through the use of fossil fuels. Infrastructure such as vessels, their engines, fuel bunkering systems, and land-based fuel refining and transportation systems (pipelines, tank trucks, and rail tank cars) are interdependent and built for the chemical and safety profile of petroleum distillates. This infrastructure is connected, expensive, and long-lived, making change challenging. Accordingly, alternative fuels that can be utilized by existing or minimally retro-fitted infrastructure have the most promise in the near term to address decarbonization goals. However, as shown in Table 1, the energy density of alternative fuels as compared to marine diesel impacts whether and how the alternative fuel can be adopted in certain applications.

Fuel type	Energy density as a percentage of marine fuel
Marine Diesel Biofuel	100%
LNG	95%
Methanol	54%
Ammonia	39%
Hydrogen	23%

Table 1. Energy density of alternative fuels as % of marine fuel. Source: American Bureau of Shipping (ABS)

The fuels with lower energy density will require significantly more fuel tank capacity to provide the same speed and operating distance and time between re-fueling ("operational duration") as marine diesel currently provides. Existing fueling infrastructure, vessel operations, and commercial viability depend on present operational durations. In addition, fuels with both lower energy density and different safety profiles that require pressurized and special tanks (such as LNG or Hydrogen) further constrain the ability of retrofitting in certain applications where vessel size, weight, and draft are limited (such as in the inland waterway sector).

The practical reality is that the transition process will take time, funding, and regulatory/government incentives (e.g., tax credits, low-interest loans, and grants) given the life-span of existing vessels—which is much longer in North America than the global average. While it is impossible to predict with any accuracy how much time this will take, the American Bureau of Shipping (ABS) reports that it took a decade for LNG bunkering infrastructure to develop just to serve under one percent (1%) of the global vessel fleet. However, technical feasibility of low and no-carbon fuels is now here and economic viability is approaching. Over time, low- and no-carbon fuels, along with CCUS will likely dominate the shipping industry, but transition to no-carbon fuels will require new vessels, significant technological upgrades, fueling infrastructure, and training, especially as no-carbon fuels with different safety concerns are adopted. The transition to new fuels also must consider local communities and the potential for negative unintended environmental consequences. Existing regulatory structures—needed incentives but also technical standards and approval pathways—lag behind currently available technology for some low and no-carbon fuels, but are needed to facilitate the move to a low-carbon and no-carbon future.

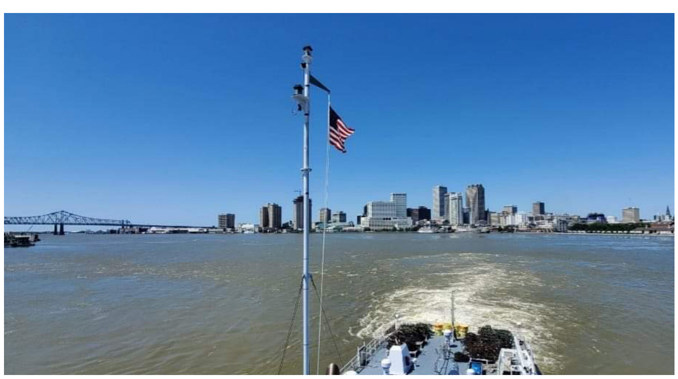


A. EMERGING DRIVERS IN NORTH AMERICA

In the U.S., the energy transition has not occurred at the pace needed to meet the commitments that the U.S. has made to the Paris Agreement (50-52% GHG emission reduction from 2005 levels by 2030), and there currently remains no comprehensive national policy to address or incentivize a move away from fossil fuel dependency. However, the current U.S. administration has publicly made climate change one of the administration's top priorities, adopting a "whole of government" approach, including using the procurement power of the federal government to drive decarbonization. The recent U.S. infrastructure bill provides substantial investment in electrification and the development of regional hydrogen hubs. Many U.S. states have also adopted their own decarbonization approaches, including California which has a target to reach net-zero by 2045 and will require most vessels to connect to shore power in southern California ports by 2025, and some as early as 2023.

Canada adopted a national carbon pricing scheme effective in 2019, and announced at last year's United Nations climate negotiations in Scotland in 2021 (COP26) the country's commitment to achieve net-zero carbon emissions by 2050. As the largest importer of U.S. goods, this commitment is likely to influence decarbonization across North America.

In addition to national and U.S. state or Canadian province developments, the private sector is also driving the need to decarbonize. Shipping customers are increasingly demanding that their selected carriers establish and meet decarbonization goals, and lenders and finance institutions are concerned about long-term valuation of high-emitting assets in their portfolios. The U.S. Securities and Exchange Commission (SEC) issued on March 22, 2022 new, proposed climate-risk disclosure requirements applicable to publicly-traded companies that would mandate extensive reporting in SEC filings of climate-related information, including Scope 1 and Scope 2 emissions.[1] The rule would require reporting of Scope 3 emissions where "material" to the company, and reporting regardless of materiality if a company has previously been accounting for Scope 3 emissions to meet voluntary or other emission targets.[2] If adopted as proposed, these regulations are likely to have substantial impact throughout the North American marine shipping value chain, including to the non-public companies that serve the supply chains of companies that will be subject to the regulation. In addition, voluntary disclosure of corporate Environmental, Social, and Governance (ESG) information related to climate change is increasingly common, as is the reliance on particular reporting frameworks such as those established by the Task Force on Climate Related Financial Disclosures (TCFD) (referenced in the proposed SEC rule), the Sustainability Accounting Standards Board (SASB), and the Global Reporting Initiative (GRI). Market and regulatory forces are likely to continue to be an increasing source of decarbonization pressure throughout the marine shipping value chain.



1 Scope 1 emissions are direct GHG emissions from equipment owned or controlled by a company (for example, the vessel smokestack direct emissions). Scope 2 emissions are the GHG emissions associated with the generation of electricity a company purchases from a separate entity (such as a utility provider).

2 Scope 3 emissions are generally those GHG emissions from activities not owned or controlled by the company, but that are in the upstream and downstream supply/value chain.

IV. ALTERNATIVE FUELS AND PROPULSION SYSTEMS: FUTURE OUTLOOK

A. SHORT TERM EMISSION REDUCTIONS—IN USE NOW AND EXPANDING: LNG

LNG is likely to drive the achievement of the near-term (0-10 years) decarbonization trajectory in North America. As shown in Figure 2, switching from diesel to natural gas fueled systems alone decreases overall direct emissions by over 28% (but this number is slightly lower in marine applications and can vary depending on use of 2-cycle or 4-cycle engine). Recent studies however have demonstrated that the decrease in carbon emissions achievable by switching from marine diesel or heavy fuel oil to LNG can vary widely depending on the extraction and refining methods, transportation distances and methods, vessel engine types, and other life-cycle factors. As discussed in Section IV.B., advances in emerging control technologies are likely to continue to decrease total life-cycle carbon emissions related to LNG, there is an increase in Renewable Natural Gas (RNG) production in the U.S. that can displace traditional LNG production emissions, and we expect LNG to be an immediate and high potential transitional fuel in the path to net-zero maritime emissions.

Fuel type	CO_2 Factor (kg CO_2 per mm Btu)
LNG	53.06
Marine Diesel (Distillate Fuel Oil No. 2)	73.96
Residual Fuel Oil No. 5	72.93
Residual Fuel Oil No. 6	75.10
Biodiesel (100%)	73.84

Table 2. Carbon dioxide emissions per fuel based on equivalent energy output.
Source: U.S. Environmental Protection Agency (EPA), GHG Emissions Factors Hub (2021).

LNG is already the leading alternative fuel to marine diesel with substantial long-term investments being made now in LNG shipping. DNV reports that globally, new orders of LNG-powered vessels far exceed new orders of other alternative fuel vessels, with nearly 19% of all new book orders from January-April 2021 for vessels with LNG fuel. Most importantly, the infrastructure necessary to support the production of LNG already exists and is growing. Indeed, as of 2019, the U.S. had the third largest liquefaction capacity, with 46.6 million metric tons per year, behind only Australia and Qatar. Both Canada and the U.S. also have substantial additional liquefaction capacity already under construction or proposed. Growth and expansion of distribution infrastructure, however, is still needed to make LNG available as a marine fuel across all ports.

LPG (liquid petroleum gas) is also making inroads as a marine fuel with carbon emissions reduction potential, as compared to marine diesel. Currently sourced primarily from natural gas and oil, recent studies note that LPG has environmental benefits in the marine shipping industry that include lower carbon emissions but also a reduction in certain harmful, EPA-regulated criteria pollutants (such as particulate matter and sulfur oxides).

The abundance of natural gas within North America and the current and ongoing investment in long-lived LNG infrastructure make LNG a critical emission reduction pathway for marine shipping. LNG will not be suitable for all marine applications. For example, where there are unique midstream fueling operations, or firm constraints on vessel size and configuration, such as the inland waterways, LNG is not likely to be feasible in the short term. Over time, electrification, biofuels, and carbon capture will play an important role in further reducing carbon emissions from LNG applications, including eventual adoption of non-petroleum based LNG (i.e., bio-LNG sourced from plant or human waste streams or synthetic LNG produced with renewable energy).

Although LNG has substantial promise for near-term GHG emission reductions, and is already being heavily invested in by the global marine shipping industry, methane emissions—both unintentional fugitive emissions (leaks) and intentional venting—are occurring throughout the natural gas value chain and a significant concern because methane is a powerful GHG. Some methane fugitive emissions occur in the marine engine, but EPA has identified fugitive emissions from well drilling, extraction, improper well abandonment, pipelines, processing, transportation and more. Fugitive emissions within the value chain will need to be addressed to avoid the potential for such emissions to offset the GHG reduction achieved by switching to from marine diesel to natural gas.

B. CURRENTLY EMERGING TECHNOLOGY (MEDIUM TERM): LNG, METHANOL AND OTHER BIOFUELS

Over the next 5-15 years, increased use of LNG is likely to occur, along with more widespread use of biofuels such as biodiesel, and methanol.

Although LNG is an important transition fuel that provides for immediate and substantial CO2 emission reduction compared to marine diesel, achieving net-zero requires a shift to RNG adoption and carbon neutral and zero carbon fuels. Continued use of petroleum-based LNG during this intermediate time-frame is likely to occur along with advancements addressing methane fugitive emissions from engines and LNG production/transportation. This time period is also likely to include increasing adoption of bio-LNG and e-LNG (bio-LNG is produced from renewable feed-stock such as landfill gas or forest residue and e-LNG is produced synthetically using renewable electricity and carbon capture during production). Bio-LNG and e-LNG can be directly blended with fossil-LNG and can therefore take advantage of the substantial LNG infrastructure being invested in now. Increased uptake of CCS/CCUS technology to remove and store carbon associated with LNG production is also likely (primarily not onboard vessels but at fuel production facilities).

The U.S. Maritime Administration recognizes the "essential role" of bioenergy to transition maritime to carbon neutrality. Methanol and biofuels show substantial promise but their carbon emission reduction potential is heavily dependent on the life-cycle emissions of their bio-sourced feedstocks (e.g. soybeans, forest residue, etc.). Currently, methanol is sourced nearly exclusively from natural gas in the U.S. (methanol produced in this way is not considered a biofuel, but methanol can be produced from biomass), and while EPA does not provide a CO2 emission factor for methanol, several recent studies suggest the life-cycle carbon emissions from methanol may be comparable or higher than marine diesel (even with plant-based feed-stocks). Figure 3 shows that methane and nitrous oxide emissions are higher for methanol than for gasoline (on a gram-per-mile basis in heavy duty trucks).

Fuel type	CO_4 Factor (g/mile)	N_2O Factor (g/mile)
Methanol	0.0750	0.0280
LNG	3.7000	0.0010
Biodiesel	0.0090	0.0430
Gasoline	0.0326	0.0082

Table 3. EPA methane and nitrous oxide emission factors on a gram per mile basis (Note: data is based on mobile combustion in Heavy Duty Trucks). Source: EPA GHG Emission Factors Hub (2021).

Methanol can achieve carbon emission reduction if renewable feedstock is used (such as forest residue or landfill gas) and if careful consideration is given to the life-cycle or land-use change impacts of the bio-feedstock. According to DNV data, after LNG/LPG and electric battery vessels, methanol is the third largest category of alternative-fuel ships on order globally (at 0.3%).

Biodiesel has near-comparable energy density to marine diesel and can be used in existing engines with few modifications. However, as shown in Figure 2, the CO2 emission factor of biodiesel is nearly equal to marine diesel—but the life-cycle of biodiesel (that is, the draw-down of carbon from the atmosphere as the plant feed-stock grows) has the potential to offset the direct carbon emissions when it is burned in an engine after being harvested and processed into fuel. Currently sourced primarily from soybeans, biodiesel total emissions will thus depend on the life cycle of its feed-stock—including plant (or animal) growing, harvesting, and biodiesel production. The American Bureau of Shipping has issued a white paper on bio-fuels that provide more details comparisons between fuels.

Although renewables such as biodiesel that can be used in existing engines are promising, competition for those fuels from other difficult-to-transition sectors (such as aviation) will impact both price and supply.

C. ACHIEVING NET-ZERO AT 2050 (LONG TERM): HYDROGEN CARRIERS AND OTHER TRANSFORMATIVE FUELS AND TECHNOLOGIES

Longer term (15+ years) we expect the emerging investments being made today in hydrogen fuel technology to substantially transform the marine fuel landscape. Hydrogen fuel vessels have the potential for zero-carbon fuel, but current challenges include cost (including investment in new infrastructure), safety, the need for new training and regulatory standards, and the need for development of green hydrogen produced using 100% renewable energy. Hydrogen today is often produced by steam-reforming natural gas (or from other hydrocarbons), but it can be made from water and renewable energy through electrolysis—a truly zero-carbon fuel. For green hydrogen to be adopted at scale, regulatory/government incentives will be needed to support cost-effectiveness. However, some studies show that, factoring in certain climate targets, in the long term hydrogen may be a highly cost-effective fuel for the shipping sector.

There are already current examples of hydrogen powered vessels such as SWITCH Maritime's Sea Change hydrogen ferry. Scripps Institution of Oceanography is building a hybrid hydrogen fuel cell/diesel electric oceanographic research vessel, with delivery planned in 2025. Maritime Partners is currently designing the first methanol/hydrogen towboat for inland river use, expected in 2023. In that application, Methanol will be used to generate hydrogen for use in a hydrogen fuel cell to produce power. This example demonstrates the long-term place that both methanol and hydrogen are likely to occupy as we approach 2050. A shift to green methanol and synthetic methanol produced using renewable feedstocks and from 100% renewable electricity will support achievement of net-zero GHG emissions. See Figure 4.

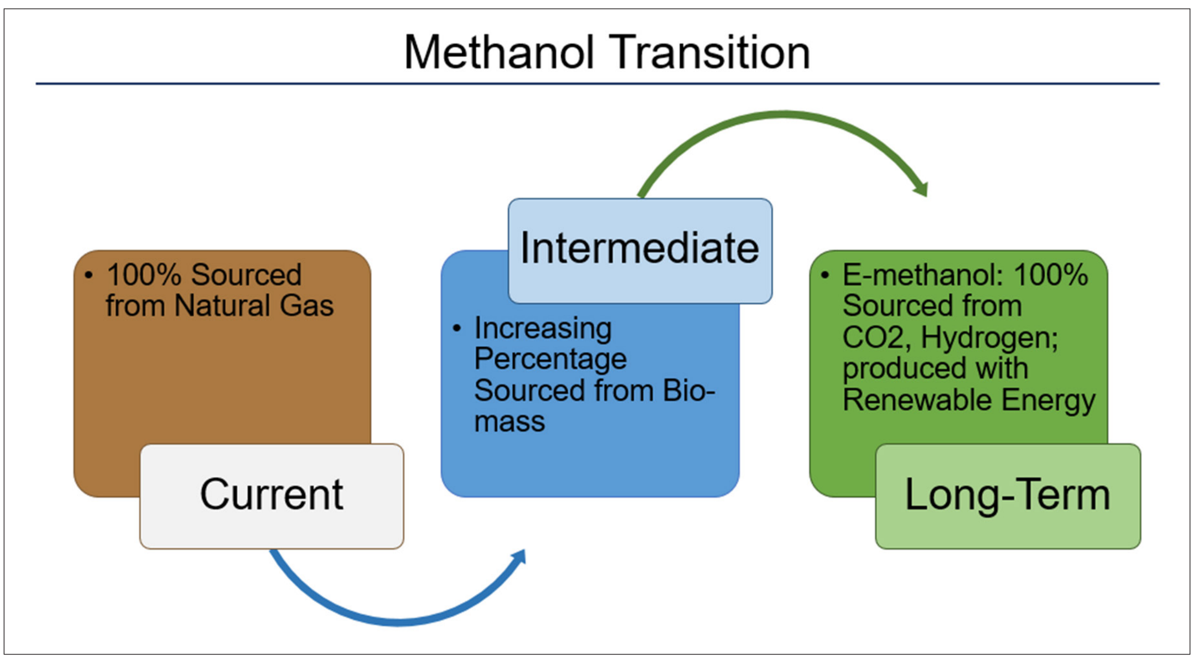


Figure 2. Methanol transition to net-zero GHG emissions

Ammonia is another zero-carbon fuel with potential but additional research and demonstration projects are needed to determine its viability as a marine fuel. There are substantial safety, technical, and cost challenges to widespread adoption of ammonia, but it may have promise in particular applications, such as long-haul operating conditions. Like hydrogen, "green" ammonia must be produced with 100% renewable energy and without reliance on hydrocarbons to reach net-zero emissions. "Blue" ammonia is produced typically by steam-reforming natural gas and is an energy intensive process. Studies also show that ammonia has GHG emission reduction benefits even when used partially, as a dual fuel together with hydrogen, and that like other fuels discussed in this report, production costs are expected to fall long-term.

Hydrocarbon fuel cells and wind energy also show promise for the future. Wind energy has been used since the beginning of shipping to propel ships, but it may also have a place in future vessel technologies. The International Windship Association (IWSA) was formed to advance the use of wind energy in marine shipping, both as a primary propulsion system and wind-assisted systems that offer substantial fuel savings. Of IWSA's nearly 100 members, only a small handful are in the U.S. and Canada. Hydrocarbon fuel cells would rely on natural gas, but avoid combustion—creating electric power through a ceramic separator, resulting in water as an emission stream along with less CO2 that could be more easily captured with CCS technologies.

Finally, although nuclear propulsion is often overlooked, advances in technology and public acceptance by 2050 are possible. Indeed, nuclear-powered marine vessels have been used safely for more than half a century by the U.S. navy, and the nuclear energy industry overall, especially in the U.S. and Canada, has a good safety record. Recent advancements in small modular reactors (SMR) are compelling and show substantial promise for marine and other applications. There are already a number of SMR projects underway and planned around the world, and at least one in operation—the Russian Akademik Lomonosov operates a SMR on a floating barge that provides 70 MW of power. Although not a currently commercially viable technology, nuclear propulsion technologies have the potential for transformative change. The International Atomic Energy Agency (IAEA) reports that over 70 commercial SMR designs are currently being developed, including many in the U.S. and Canada.

D. CRITICAL TECHNOLOGIES: ELECTRIFICATION, CARBON CAPTURE, AND RENEWABLE ELECTRICITY (OFFSHORE WIND)

Battery-electric powered marine vessels show promise in some marine applications but are not currently viable in others due to size, weight, and range of current battery technology. However, if electricity is sourced renewably (e.g., from offshore wind, solar, or nuclear), electrification has potential to achieve zero-carbon emissions. Current challenges include battery range and size—smaller vessels cannot accommodate the battery size needed for their operating conditions and larger vessels may not obtain adequate range even where battery size and weight is less constrained. Electric battery propulsion is, however, currently viable in some applications and there are several existing examples, with Crowley's e-Wolf being the first fully electric U.S. tugboat, and Canada launched its first all-electric ferry (the Marilyn Bell I) in 2021. The Gee's Bend Ferry on the Alabama River was converted from diesel and was the first all-electric passenger and car ferry in the U.S. in 2019. Two ferries that shuttle tourists to Niagara Falls are also now all-electric, re-charging their batteries with the local hydropower. Ft. Lauderdale, Florida also recently took delivery from Master Boat Builders, Inc., of the first electric-hybrid tug boat in 2022, the Spartan.

Charging infrastructure, plug standardization, and cost (especially related to utility-side demand during high-peak usage) remain critical challenges, but electrification is likely to continue to play an important role in reaching net-zero emissions.

Although there is controversy about the role CCS/CCUS should play in meeting a net-zero target, it is clear that CCS and CCUS are needed to meet global climate change goals. Indeed, the Intergovernmental Panel on Climate Change (IPCC) has found that carbon dioxide removal technologies like CCS are needed to limit global warming to 1.5°C or 2°C above pre-industrial levels given the continued rate of global GHG emissions. Economic viability and technical feasibility remain challenges to adoption of CCS. Although there is an existing tax credit for sequestering carbon dioxide known as "45Q" (28 U.S.C. §45Q) there are currently only limited commercially viable applications of CCS (such as gas plants that have a relatively pure gas stream). However, CCS has substantial promise to support net-zero in the marine sector because it can impact any-carbon emitting source, from the electric-power generation for battery propulsion or production of LNG, methanol, or hydrogen. CCS is currently limited to land-based applications, but recent studies suggest on-vessel CCS is possible medium to long term. Canada already has a carbon taxing program applicable in all Canadian jurisdictions since 2019, and announced in April 2022 a proposed tax credit for investment in CCS and CCUS projects technologies.

Finally, increased availability of renewable energy will be critical to achieving net-zero—from the use of battery technology that depends on electricity production for re-charging to the ability to produce green-hydrogen, synthetic LNG (e-LNG), and e-methanol. Renewable energy is a cornerstone of achieving net-zero. Renewable energy is also inherently linked to nearly all the alternative fuel-sources discussed in this report. For example, there are considerable investments being made now around the globe in hydrogen, and the U.S. Department of Energy views offshore wind energy as a particularly attractive source of electricity for the production of hydrogen. Increased investment in offshore wind is likely to increase hydrogen capacity which supports the growth of hydrogen (and other net-zero fuels) as a marine fuel in the pathway to net-zero.

V. CONCLUSION

This report represents the current Blue Sky position for the fuel transition pathway to net-zero emission in the North American marine shipping industry. Blue Sky recognizes that in any projection of the future, flexibility is inherently needed. This report is not intended to pinpoint the "winning" fuels in a net-zero future, but to identify the marine fuels and propulsion systems that we currently expect to most effectively accelerate the transition to net-zero emissions by 2050. We expect these fuels and propulsion systems will play substantial roles in the lower carbon economy and are likely to find support throughout the value chain. Blue Sky also recognizes the substantial diversity of our membership and their operating conditions, and that there is no "one-size-fits-all" approach. The next report will build on our understanding of this net-zero pathway and provide a catalog of current North American vessel categories and their emissions profile, along with their implications for the marine shipping value chain.

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