Decarbonization Pathways for Recreational, Ferry, and Commercial Vessels in the Michigan Maritime Strategy

by

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Acknowledgements

This paper summarizes the Michigan Maritime Strategy, its drafting process, and then elaborates on the pathways for decarbonization for the three main maritime sectors. The Michigan Maritime Strategy was a large joint effort created by a cross-campus team between the Center for Sustainable Systems (CSS) and the Naval Architecture and Marine Engineering Department (NAME) at the University of Michigan. The project was part of a large State effort led by the Office of the Great Lakes (OGL) in Michigan's Department of Environment, Great Lakes, and Energy (EGLE) with support from other EGLE divisions, the Michigan Department of Transportation (MDOT), the Michigan Department of Agriculture, and Rural Development (MDARD), the Michigan Department of Natural Resources (DNR) and the Michigan Economic Development Corporations Office of Future Mobility and Electrification (OFME). Table 1 and 2 below indicate members of these Project Teams.

Table 1: Interagency Maritime Work Group

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Abstract

This paper provides a summary of the 2026 Michigan Maritime Strategy (MMS; draft published January 27th, 2026) including the strategy development process and the final strategy outcomes. Building upon foundational research to develop this strategy, an in-depth analysis of decarbonization fuels and pathways is conducted for three important sectors of the Michigan Maritime Strategy: recreational boats, ferries, and commercial ships. Decarbonization pathways for each sector are examined with their challenges, and opportunities, as well as successful alternative fuel and vessel demonstrations. Deployment scenarios and rates were evaluated against the carbon reduction timelines set out in the 2018 special report from the International Pannel on Climate Change (IPCC), which aimed to limit global warming to less than 1.5° Celsius above pre-industrial levels. The IPCC found that, to reach this goal, emissions will have to decline by approximately 45% from 2010 levels by 2030 and reach net-zero by 2050.

This paper found no singular solution for decarbonizing each individual maritime sector. In order to fully decarbonize, the recreational fleet has high electrification potential, the ferry fleet has electrification and hydrogen fuel potential, and the commercial fleet should look towards the use of ammonia and methanol fuels. Each of these options have significant challenges to overcome as well as opportunities which make them exciting prospects.

While the MMS adopted the IPCC 1.5° C reduction targets it did not critique their feasibility. An analysis was conducted to determine the vessel replacement rates required to align with the IPCC carbon reduction trajectories assuming fully decarbonized propulsion. The Michigan maritime ecosystem cannot feasibly meet the 2030 IPCC timeline for the 1.5° Celsius goals as demonstrated by an analysis of the Michigan recreational vessel fleet. This analysis showed the need to replace over 420,000 recreational vessels or convert them to electric power by 2030. The high capital costs, long service lives, turnover needs, and logistics of this conversion make the 2030 goals unrealistic to achieve. This finding is intensified when accounting for the high capital costs and even longer service lives of ferries and commercial ships across Michigan.

Achieving the IPCC's 2050 timeline is contingent on fleet turnover of vessels with extremely long service lives as well as high capital costs and technical restraints. Without industry leadership and aggressive policy support from the state or federal level, the 2050 timeline will also be challenging to meet. Federal and state level incentives and regulations are necessary to accelerate vessel retrofitting and replacement and address high capital costs. Setting targets, collecting data, and tracking progress are pivotal steps when considering the level of action needed to decarbonize each sector and to drive meaningful progress. In addition to climate action, recognizing the long-term benefits from growing alternative fuel production, creating alternative boat and ship manufacturing, industries, workforce opportunities, green tourism, improved air quality, and establishing a green maritime ecosystem is essential to spur action in an industry that currently has limited incentives to decarbonize. Decarbonization solutions, the viability per sector, and a critical analysis of their ability to meet the IPCC 1.5° Celsius timelines for both 2030 and 2050 are explored in detail within the paper below.

Table of Contents

1. Introduction *6*

1.1 Goal 6

1.2 Context 6

1.3 The Michigan Maritime Ecosystem 6

1.4 National and International Importance 7

1.5 IPCC 1.5° Celsius Stabilization Goals 8

2. Methods *9*

2.1 Overview of the Michigan Maritime Strategy Development Process 9

2.2 Final Michigan Maritime Strategy Product 10

3. Results *11*

3.1 Decarbonization Pathways for Recreational Boats 11

3.1.1 Fuels and Decarbonization Opportunities 12

3.1.2 Challenges 14

3.1.3 Models 15

3.2 Decarbonization Pathways for Ferries 16

3.2.1 Fuels and Decarbonization Opportunities 16

3.2.2 Challenges 17

3.2.3 Models 19

3.3 Decarbonization Pathways for Commercial Shipping 19

3.3.1 Fuels and Decarbonization Opportunities 21

3.3.2 Challenges 22

3.3.3 Models 23

3.4 Urgency Needed to Meet IPCC Targets 24

3.5 Benefits and Opportunities of Maritime Decarbonization 26

4. Conclusion *27*

5. References *29*

1. Introduction

1.1 Goal

As a precursor to the main findings, this report will first summarize the research and stakeholder outreach processes that preceded the Michigan Maritime Strategy[1] with a focus on the decarbonization portion of the strategy. It will then present the results of the strategy itself. Building off the research used to develop the Michigan Maritime Strategy, this report will provide a characterization of decarbonization pathways of the three main vessel sectors (recreational boats, ferries, and commercial shipping) and evaluate the challenges and opportunities to meet the IPCC 1.5° Celsius goals. These goals have the overall aim to limit human-caused global warming to 1.5° Celsius above pre-industrial levels and have established targets in both 2030 and 2050 which will be assessed in this study.

1.2 Context

In September of 2024, the Michigan Department of Environment, Great Lakes, and Energy (EGLE) awarded a grant of $199,993 to a cross-campus team between the Center for Sustainable Systems and the Naval Architecture and Marine Engineering Department at the University of Michigan to develop the Michigan Maritime Strategy. As stated in the grant announcement, this maritime strategy set out to support Michigan's blue economy, advance greening, electrification, and decarbonization of the maritime industry, improve equity and environmental justice, and support the long-term sustainability of the maritime sector including recreational boating, ferrying, and commercial shipping.[2] This strategy was set to be broad and all-encompassing focusing not only on the sustainability of the vessels themselves, but also the land and water infrastructure, the impacted Michigan towns, the Michigan economy, the efficient movement of goods, and the improvement of people and affected communities through job availability, clean recreational opportunities, and a healthy environment.

1.3 The Michigan Maritime Ecosystem

The core elements of the Michigan Maritime ecosystem defined by the Michigan Maritime Strategy include "ports and their operations, cargo handling equipment and supporting infrastructure for fueling and operations, production and transportation of fuels (including electricity), vessels that provide freight, passenger transportation, and recreation, and small harbors and marinas." [3]

The focus of this paper narrows in on the vessels and discusses their fuel options which provide mechanisms for decarbonization. The paper will consider the three main vessel sectors: recreational boats, ferries, and commercial ships (often freighters, bulk carriers, and container carrying ships on the Great Lakes).[4] These three classes of vessels can serve as proxies for other types of vessels. Other vessels such as tugboats, barges, and commercial fishing vessels exist

within the maritime ecosystem but were not specifically analyzed within this report. The three sectors that are the focus of this paper can act as broad categories that cover small and short distance boats (recreational boats), medium distance and size (ferries), and large distance and size (commercial shipping).

1.4 National and International Importance

The development of the Michigan Maritime Strategy came at a time of intense national and international transition regarding the maritime industry, economic priorities, and environmental goals. It is useful to highlight some of these notable events in order to understand global circumstances in which the Michigan Maritime Strategy was developed under.

The development of the Michigan Maritime Strategy occurred during the second Trump Administration where two executive orders regarding the greater maritime ecosystem were executed. First was the second withdrawal from the Paris Agreement effective January 27th, 2026, eliminating US participation[5] in a treaty which aimed to limit global warming to 1.5° Celsius through the peaking of greenhouse gas emissions before 2025 and a 43% decline by 2030.[6] Another significant maritime related executive order enacted by the Trump Administration includes the "Restoring America's Maritime Dominance" order.[7] This order set forth the groundwork to improve America's industrial commercial shipbuilding capacity while strengthening maritime workforce recruitment, training, and retention. In a time where the People's Republic of China produced over half of the world's ships (54% in 2024) and the United States produced <1% of ships according to the UN Trade and Development (UNCTAD) Data Hub,[8] the Trump Administration made United States maritime prosperity a priority for economic and national security reasons. This executive order also laid the groundwork for the Shipbuilding and Harbor Infrastructure for Prosperity and Security (SHIPS) for America Act introduced by Senator Mark Kelly on April 30th, 2025 which intended to, "…support the national defense and economic security of the United States by supporting vessels, ports, and shipyards of the United States and the U.S. maritime workforce." [9]

Finally, in July of 2025, the U.S. Environmental Protection Agency (EPA) Administrator Lee Zeldin announced the proposal to rescind the 2009 Endangerment Finding.[10] Supporters of this action argue that this rescinding would save more than $54 billion dollars annually through the repealing of greenhouse gas emissions regulations for motor vehicles and engines. Others argue that this action will have a wider implication and stall the potential electrification transition across all modes of transportation including maritime.[11]

While these are only a few of the key national and international events, they underpin the volatile yet promising future for the maritime industry within the United States. The Michigan Maritime Strategy was created at this time, aiming to combine the national momentum to restore the American Maritime Industry with the thriving blue economy and water-centered culture within the state of Michigan. Nationally, priorities show goals to restore maritime dominance while balancing sustainability and economic goals.

1.5 IPCC 1.5° Celsius Stabilization Goals

As stated previously, this paper will explore pathways for decarbonization for the main three sectors of maritime vessels. To accurately measure impact, one must use a baseline or a goal. For this paper, decarbonization pathways will be explored that have the ability to reduce maritime emissions and meet the Intergovernmental Panel on Climate Change (IPCC) 1.5-degree Celsius goals.[12] These goals set out in the 2018 IPCC Special Report aim to limit human-caused global warming to 1.5° Celsius above pre-industrial levels. This IPCC report found the need for urgency and sectoral changes ranging from electrified transportation, decarbonization of many industries, to carbon dioxide removal technologies among other pathways. The IPCC found that, to reach this goal, emissions will have to decline by approximately 45% from 2010 levels by 2030 and reach net-zero by 2050. As an important distinction, while the Michigan Maritime Strategy does not discuss reaching IPCC goals, this paper will discuss these goals as a baseline for measurement of decarbonization potential. Ultimately, this paper will discuss whether sector-specific pathways enable the Great Lakes maritime ecosystem to have a 45% reduction of maritime emissions by 2030 and net-zero emissions by 2050 as set by IPCC targets.

Numerically, this goal can be seen in Figure 1 below. As concluded in the Michigan Maritime Strategy supplemental information document, a 2022 "analysis of three major emissions inventories (EPA, ICCT, and EIA) establishes that total regional maritime operations (including Great Lakes states and the St. Lawrence Seaway) currently generate between 1.1 and 1.6 million metric tonnes of CO_2 annually, with the range reflecting differences in geographic and operational scope rather than fundamental measurement disagreements." [13]

It is important to note that this estimation is for the Great Lakes maritime ecosystem as a whole. There is currently no literature which accurately accounts for Michigan specific emissions alone due to the interstate and international movement of vessels, as well as questions regarding how to allocate emissions to ships which only stop at Michigan ports for a short time and then move to other states or countries. Similarly, in the absence of accurate emissions data from 2010, this analysis constructs a proxy baseline by back casting the 2022 emissions estimate assuming a non-changing linear projection between 2010 and 2022. The 2010 baseline is not observed nor measured but instead assumed to be equivalent to 2022 emissions and represented by the dashed line from 2010 to 2022 in Figure 1 below.

Using the largest estimate as a starting point to be conservative, Figure 1 below shows what it would look like for the Great Lakes maritime emissions to follow the trajectory set out by the IPCC to meet the 1.5° Celsius timeline.

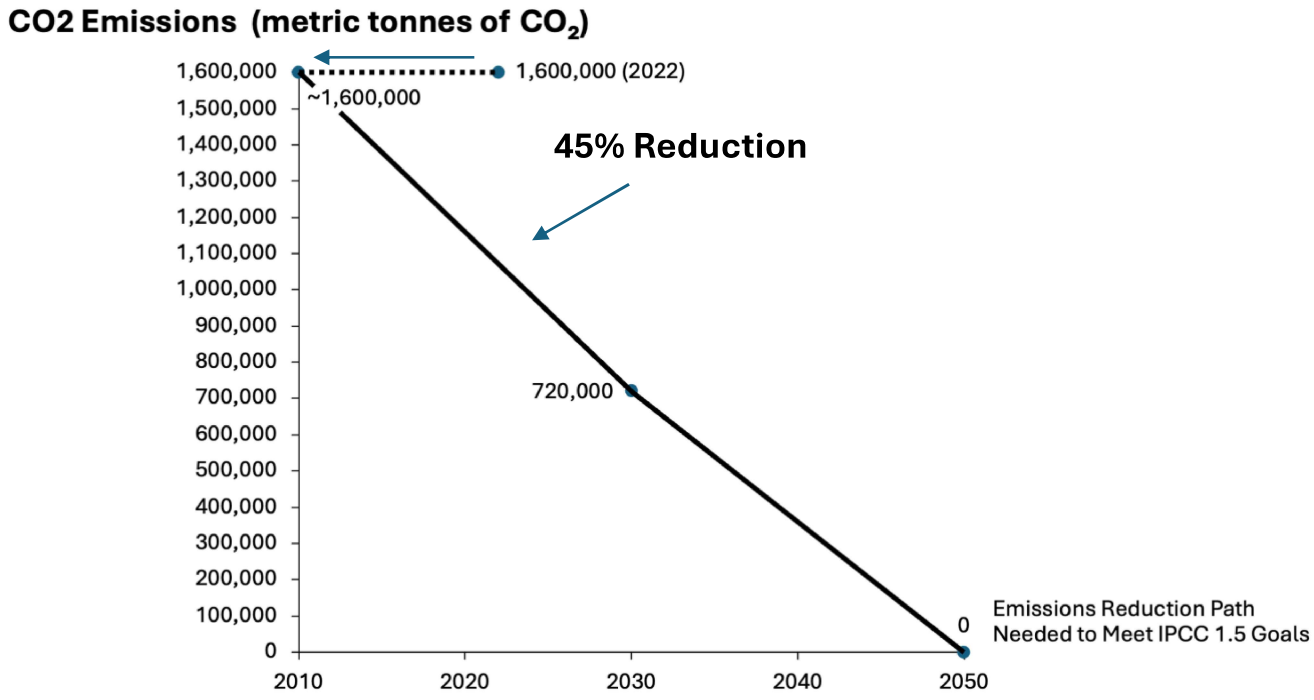


Figure 1. Illustrative Great Lakes Region Emissions Pathway aligned with IPCC 1.5° Celsius Goals

2. Methods

2.1 Overview of the Michigan Maritime Strategy Development Process

In order to create a comprehensive and inclusive Maritime Strategy, the University of Michigan team developed a rigorous year and a half long process to research, engage with stakeholders and co-managers, and iterate drafts of the final Michigan Maritime Strategy. This process began with a literature review in late 2024 which researched the past and present maritime ecosystem and its financial, social, cultural, and environmental impacts. This research included but was not limited to reviewing previous maritime plans (both within and outside of the state), accounting for active ports, harbors, ferry, recreational boats, and commercial ship numbers, and assessing Maritime's economic impact. It also included research on current maritime efforts across the state from port decarbonization projects to just-in-time commercial shipping strategies. Finally, this literature review dove deep into environmental impacts related to maritime travel including invasive species, air and water quality, water level changes, and climate change impacts.

After the literature review concluded, the strategy development team moved on to stakeholder mapping and stakeholder/co-manager outreach. By the end of this process, the strategy development team engaged with over 200 unique participants representing a wide range of sectors, organizations, communities, and interests connected to Michigan's maritime industries

and ecosystems.[14] This included field visits with stakeholders and community members, in-person and Zoom meetings, and an in-person, full day stakeholder workshop held on March 14, 2025. Information gathered culminated into a needs assessment report which included the needs, wants, priorities, challenges, and preferred solutions discussed from the perspective of and as identified by stakeholders. These steps, the literature review, stakeholder mapping, and needs assessment, were deliberately taken to create a strategy based on a strong knowledge base, understanding of the industry, and achieve multistakeholder support and consensus for actions. With these steps accomplished, a document was produced which state legislature, maritime industries, waterway co-managers, and community groups all had the opportunity to provide input into the Michigan Maritime Strategy. This collaborative process aimed to create action through a sense of belonging and to aid the desire for all parties involved to carry out actions laid out in the final strategy.

With this knowledge base, the final strategy was drafted in an iterative process with drafts going back to stakeholders, co-managers, and community groups for review and input that may be accounted for in the final report. This furthered the support and consensus for the final strategy. The results of the final draft of the Michigan Maritime strategy can be found on EGLE's website and is summarized below in Section 2.2.

2.2 Final Michigan Maritime Strategy Product

The Michigan Maritime Strategy has a vision statement which reads, "Michigan will lead the nation in sustainable, innovative, equitable, and collaborative maritime solutions, ensuring a robust maritime economy and healthy Great Lakes Ecosystem." [15] Following this vision, 4 main objectives were developed for the strategy including:

1. Support economic development through the modernization of maritime infrastructure, intermodal transportation connectivity, leveraging manufacturing capability, and supporting supply chain resilience.
2. Accelerate the clean energy transition in maritime uses by demonstrating and deploying infrastructure and vessels that support Michigan's path to economywide carbon neutrality by 2050.
3. Invest in maritime research, innovation, education, and workforce development by expanding maritime programs, supporting advanced research and technology, and building partnerships.
4. Enhance Great Lakes ecosystem health and resilience by supporting environmentally sustainable practices and increasing resilience and revitalization of ports, harbors, and waterfronts.

Finally, the strategy lays out 6 main Goals. With each goal comes a set of recommendations for specific actions that can be taken to accomplish the overall goal. A chart is also set up for each overarching goal to account for implementation metrics to accomplish the goals and designate

the lead actor who will lead the charge in accomplishing the goal. The 6 main goals of the strategy are as follows:

1. Modernize Ports and Invest in Intermodal Infrastructure
2. Grow Michigan's Maritime Manufacturing Economy
3. Accelerate Adoption of Advanced Vessel Technologies and Fuels
4. Lead the Nation in Recruitment, Training, and Retention of the Maritime Workforce
5. Cultivate a Thriving Maritime Innovation Ecosystem
6. Increase Sustainability, Resilience, and Revitalization of Waterfronts, Recreational Harbors, and Marinas

3. Results

Above sections summarize the Michigan Maritime Strategy. As stated in Goal Section 1.1, the results of this paper aim to expand upon the Michigan Maritime Strategy and provide a characterization of decarbonization pathways of the three main vessel sectors and evaluate the challenges and opportunities to meet the IPCC 1.5° Celsius goals. The below results used research, data, and lessons learned from the literature review, needs assessment, stakeholder outreach, and strategy drafting process to determine options for decarbonization for each sector main maritime sector within the Michigan Maritime Strategy. These results will then discuss if sectoral decarbonization pathways allow for a 45% reduction of maritime emissions by 2030 and net-zero emissions by 2050 in order to meet targets set by the IPCC 1.5-degree Celsius Goals.

3.1 Decarbonization Pathways for Recreational Boats

Michigan is a leader nationally in the recreational boating industry, ranking within the top five states for registered boats, as reported by the National Marine Manufacturers Association (NMMA). According to the NMMA, Michigan boasts over 800,000 registered boats, which generate an annual economic impact of $11.7 billion. This substantial economic contribution encompasses direct, indirect, and induced spending, and supports approximately 45,000 jobs, including both direct and indirect employment.[16]

The number of recreational vessels registered in Michigan in 2024 by type and length are shown in Figure 2 below.

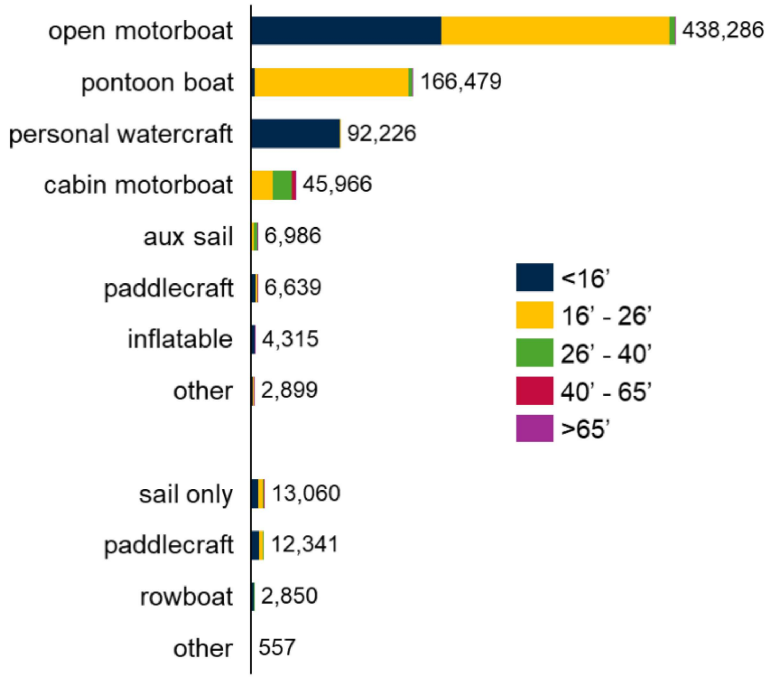


Figure 2. Michigan recreational vessel registrations, by type and length, 2024[17]

3.1.1 Fuels and Decarbonization Opportunities

With a thriving recreational boating culture and industry comes many opportunities for innovation to drive decarbonization. There are already many innovations on the market that demonstrate clean and carbon free boating options. Once these options are made technologically viable and made market ready, it is vital to encourage demonstration and adoption of these practices. As learned through the Michigan Maritime Strategy development process, it is not sufficient to simply have carbon free boating options available, but they must also be demonstrated, incentivized, and encouraged for adoption to make a true impact. One way for Michigan to do this is to make the innovative carbon free boating opportunities part of the Pure Michigan Campaign.[18] Michigan already has a culture centered around lakes, clean living, and a blue economy, and adding encouragement to adopt clean boating would only aid the Pure Michigan cause. Not only will these strategies help reach IPCC goals and decarbonization targets, but they will support the Michigan economy. Michigan has a strong automotive manufacturing, shipyard history, and EV economy already established ranking 6th in the nation for employment in industries related to electric vehicle battery manufacturing with 1,500 workers spread across Michigan battery manufacturing and OEM locations statewide.[19] Building on workforce demands, manufacturing, EV momentum, and carrying that to the maritime sector can help strengthen the economy and grow job opportunity for Michiganders. With this need to incentivize, promote, and encourage in mind, below sections discuss decarbonization options for Michigan's recreational vessels.

Electrification

Due to the smaller size and generally shorter distance traveled when compared to commercial cargo shipping, electrification in not only viable for recreational boats but has vast decarbonization potential. Additionally, electric boating has already made substantial progress within Michigan with innovations and examples already plentiful across the state. Electrification of the recreational maritime industry can take many forms as seen in the "Models" Section 3.1.3 below. While the current fleet is mainly fossil fueled watercrafts, retrofitting boats with parts such as electric outboard motors offers partial decarbonization impact. Similarly, new vessels can and should be produced as electric boats. As fossil crafts retire or new buyers are looking at their options, boaters can choose to instead opt for an electric craft.

With recreational boat electrification will come the need for harbor infrastructure upgrades. Michigan harbors and marinas will need to implement or continue to implement (for those that currently have it) electric boat chargers at their docks. It is important to note that true decarbonization of this sector will also depend on the electrical grid to come from fossil free energy sources to truly be a decarbonization option. In line with the IPCC targets, the MI Healthy Climate plan has codified the target of net-zero greenhouse gas emissions by 2050 with 100% clean electricity by 2040.[20] Thanks to this push from the Governor's Office, both DTE[21] and Consumers Energy[22] have set aggressive grid decarbonization targets for their electricity production statewide. Currently, the carbon intensity of the Michigan grid in 2024-2025 was 408 gCO2 eq/kWh with 35% of electricity being supplied by low-carbon electricity.[23] The shore power transition will require extensive collaboration with utilities to be able to meet electricity demand at ports and harbors as well as to provide clean fossil-fuel free electricity from the grid.

Other Decarbonization Opportunities for Recreational Boating

While electrification may be the most exciting pathway for recreational boats to decarbonize, there are other fuel options out there. Drop in biofuels or renewable diesel could offer a short-term alternative to fossil fuels before recreational boats are converted to use electricity. Since the current fleet of recreational boats will not turn over immediately, and boat owners will not simply get rid of their old boat simply to buy an electric one, a short-term drop-in alternative may be effective to implement. While values vary across literature and are dependent on feedstock and fuel type, The American Bureau of Shipping (ABS) reported in 2024 that biofuels typically have carbon emission factor of around 30-40 gCO2e/MJ which is an estimated 65% reduction when compared to currently used fossil fuels which has an emissions factor hovering around 95 gCO2e/MJ.[24] Similarly, a National Renewable Energy Laboratory (NREL) 2018 study found that renewable diesel reduces carbon intensity on average by 65% when compared to petroleum diesel.[25] While these drop in fuels are not carbon neutral, they are a better alternative for the short-term while still pushing carbon-neutral opportunities as swiftly as possible.

Other options such as fueling watercrafts by hydrogen are in development across the nation. While currently not scalable or market ready for recreational boats, these options are in

development and should be closely watched for decarbonization potential and market availability.

Expanding boat sharing models is another great way to work towards decarbonization for recreational boating. Some hidden carbon emissions that can be attributed to recreational boating include the drive to and from the boat storage facility to the lake multiplied by the number of times per year that trip happens. The transportation of a recreational boat often takes a larger truck and trailer set up fueled by a gas vehicle producing carbon emissions. Similarly, some boat owners only get out onto the lake a few times a year while still paying the price for boat storage, transportation, docking, maintenance, and much more. If Michigan marinas offered affordable and convenient boat sharing models where boats are available for rent at the marina, this could allow boaters to get out onto the lakes, avoid transportation emissions, get their money's worth for the amount they boat, and enjoy the opportunities Michigan's waterways offer. To go one step further, these boat sharing models could offer electric boating opportunities to decarbonize their operations individually as well. One current example of a boat sharing model active in Michigan that does not currently host electric boats is Freedom Boat Club with multiple membership style boat rental locations across the state.[26]

Finally, as already exists, motor free recreational boating can continue to be encouraged. Kayak routes can be maintained and publicized. Sailing can grow within the state. Canoe and kayak rental opportunities can grow at marinas. These options offer carbon free recreation that continues to get Michiganders out of the lakes and enjoying the pristine nature the state has to offer.

3.1.2 Challenges

Challenges to recreational boat decarbonization are less substantial when compared to commercial shipping, and more easily mitigatable with expanding innovations. Understandable fears such as range anxiety and power worries exist when boaters consider switching from diesel to electric boating. How far can they get on a single charge? Where is the next marina charger they can get to? Will the electric boat provide enough power and wake for the type of recreation one hopes to participate in? Luckily, technology and innovations can quell many of these worries. Boating options on the market today can be seen below in Section 3.1.3 which offer the power and range that boaters need to optimally participate in their desired type of maritime recreation.

Additionally, the transition to electric boating will need to be multifaceted so that a "chicken and egg" situation does not occur. Currently, boaters worry about marinas having chargers before they buy electric crafts, and marinas are waiting for sufficient demand before they implement electric chargers. The transition must occur together so that marinas and boaters do not worry about their counterpart being ill-prepared. This may take demonstration, encouragement, and incentivization to dispel this worry. Additional incentives may be required to lower the cost of entry into electric boating as an electric boat typically costs more upfront by 20-50%[27] (while the

ROI in terms of maintenance and fuel costs usually evens out the lifetime cost).[28] Marinas, boat sharing providers, and everyday boaters may need to be encouraged, educated, and incentivized to invest in decarbonized options over fossil-fuel options. This could take the form of federal or state grants among other incentive structures. One example of this already completed in the state is the Fresh Coast Maritime Challenge Grant Program[29] that will be expanded on in section 3.1.3 below.

The final challenge will be to educate boaters on the options that exist and encourage them to choose carbon free boating opportunities. This will take a conscious effort from industry and the state to demonstrate, educate and encourage these options. This could take the form of demonstration events, educational signage, social media highlights, and many other options. This effort will need to be invested in to encourage adoption of carbon free boating practices.

3.1.3 Models

Despite the challenges, many models exist today to exemplify the ability to decarbonize recreational boating without sacrificing the range and power needed by boaters. As stated above, there are already many innovations on the market that demonstrate carbon free boating options. In terms of products already available on the market for electric boating there is an "ArcOne" electric boat from the Arcboats company, which boasts the ability to seat 12 people with a 220-kWh battery providing 500 horsepower and a 40-mph top speed.[30] Similarly, the "AEW24" electric boat from voltaic marine provides a high capacity 300 kWh battery system providing up to 8 hours of runtime with rapid charging capabilities.[31]

To quell worries about range and power, the Fortescue Zero's Marine Battery Pack is planned to be the first product built in a new Detroit Manufacturing center. Per their claim in an announcement made on October 7th, 2024, "advanced marine propulsion expert EVOA is the launch customer and will use the Marine Battery Pack as part of their high-performance marine powertrain." [32] This battery technology can deliver 30-40 kWh and has been engineering to provide up to 1,000 horsepower. It can also charge in less than 30 minutes and has the ability for multiple smaller battery packs to be combined to support smaller or larger vessels.[33] A different approach to carbon free non-motorized boating can be seen with Lilypad Solar boats. These boats offer relaxing 5 mph small cove boating for up to 6 adults fueled solely by the sun and a set of 1640 watt monocrystalline array of solar panels and a "LiFePO4 EV cell" battery.[34]

Above are available products that show proof of concept for all types of carbon free boating already present within Michigan. As stated above, demonstration and encouragement of these technologies and innovations is required to achieve successful adoption of these practices. One place that is doing just that is Elk Rapids Marina.[35] Starting in 2022, Elk Rapids Marina became one of the early adopters and champions of electric boating in Michigan by unveiling an all-electric X-Shore EELEX 8000[36] boat in their harbor for demonstration purposes. Then, in late 2022, Elk Rapids Marina implemented an Aqua superPower high power DC charger[37] for electric boats on its docks. Next, in 2023 Elk Rapids Marina hosted its first e-boat summit which was the

largest gathering of electric boats in the water at one time. Again, this summit was hosted in 2024 as a free, open to the public demonstration with e-boat companies such as Arc, Lilypad, X-shore, and Hercules.[38]

One final model that has made a large impact within the state is the Fresh Coast Maritime Challenge Grant Program.[39] In August of 2023, Governor Gretchen Whitmer announced a grant meant to support establishing Michigan's "Fresh Coast Corridor." Michigan allocated $506,000 in grants to six companies under the inaugural Fresh Coast Maritime Challenge, aiming to decarbonize the state's waterways by supporting electric boating infrastructure. The initiative includes deploying e-boats, installing fast marine chargers, and conducting technology demonstrations at marinas across Northwest Michigan, with the goal of establishing a sustainable and interconnected water transportation network. This grant program was set out to help achieve goals set in the MI Healthy Climate Plan[40] and the MI Future Mobility Plan.[41] This combined effort by the state and private companies illustrates the success a multifaceted approach to decarbonization can achieve while lowering the costs of entry to marinas, boaters, and companies who wish to decarbonize their operations.

3.2 Decarbonization Pathways for Ferries

Ferries represent the middle sector of the Maritime Industry when considering size and distance traveled with common ferry trips under a mile to and from Mackinac Island and larger trips across Lake Michigan (like the S. S. Badger) traversing 60 miles of Lake Michigan. Michigan is a prime location within the Great Lakes with many islands making ferries an indispensable component of the maritime ecosystem. Ferries around the state provide crucial access for island inhabitants to essential mainland services while providing tourists the opportunity to visit some of Michigan's more isolated corners. This is accomplished through 63 ferries and passenger carriers (60 registered in Michigan, 3 other GL states)[42] plying 16 different routes. When considering decarbonization, setting of targets and tracking for both demonstration and deployment of alternative-fueled ferries would aid implementation and increase accountability.

3.2.1 Fuels and Decarbonization Opportunities

After research performed through the development of the Michigan Maritime Strategy, and in alignment with the U.S. Maritime Plan, "An Action Plan for Maritime Energy and Emissions Innovation," [43] possible fuel types for ferries include electricity, drop in biofuels/renewable diesel, methanol, ammonia or hydrogen. The choice of fuel has a lot to do with passenger counts, distance traveled, and route-specific ferry needs.

Electricity

For smaller ferries with shorter distances traveled, electricity is still a premium option when considering decarbonization. For short distances, when comparing electric ferries to hydrogen ferries (which is a rivaling option for decarbonization), due to low volumetric energy of hydrogen and the short distance needed, electric ferries are energetically superior to hydrogen-

based options.[44] At small distances with fewer passenger needs, ferry vessels would have the ability to charge at port and get sufficient range and power to complete their routes.

Hydrogen

As stated above, hydrogen is a prominent fuel in the discussion of decarbonization options for vessels such as ferries. The International Maritime Organization (IMO) with its Sub-Committee on Carriage of Cargoes and Containers (CC9) has been working on development of safety guidelines for alternative fuels including hydrogen.[45] This group has introduced initial standards for fuel cell propulsion systems with safety guidelines in the works. Hydrogen fuel is produced through the electrolysis of water (use of an electric current) to split water (H_20) into hydrogen gas and oxygen separately.[46] For true decarbonization potential, the source of electrical current that splits water must either come from renewable resources such as solar or wind (green hydrogen) or nuclear power (pink hydrogen). Green hydrogen is often seen as the future zero-emission option while pink hydrogen can provide the steady baseload power that overcomes the intermittency issues that may come with renewable resources.[47] Overall, this electrolyzed hydrogen can then be used directly in fuel cells and combustion engines, or indirectly in the form of synthetic fuels. This indirect option takes hydrogen, combines it with carbon dioxide or nitrogen, and converts it into liquid synthetic fuels like e-methanol, e-kerosene, or e-ammonia.[48] This indirect use of hydrogen allows for easier adoption potential due the lack of need for changes in vessel or fueling infrastructure.[49]

Methanol, Ammonia, and other Drop In Fuels

Methanol and ammonia are developing options when considering marine fuel for vessels such as ferries. Methanol can be used in an internal combustion engine and has potential with future development to be used in fuel cells.[50] For true decarbonization potential, methanol fuels would need to be produced by renewable sources not fossil fuels, like they often are today due to cost constraints. Like methanol, ammonia can be used in internal combustion engines and fuel cells with further development. Direct combustion of ammonia is a currently viable fuel option while incorporation of ammonia as a hydrogen carrier is also a future option with further technological developments. Methanol and ammonia are less developed, but both have advantages over hydrogen as they avoid the need for storage of cryogenic hydrogen on board. While many of the above fuel options need to be placed into newly designed vessels with new parts, some options also offer retrofitting potential with simply changing a few vessel parts to accompany the change in fuel. For legacy vessels with long service lives, just like in recreational boats, drop in fuels like biofuels or renewable diesel are option to lower a vessels carbon footprint, while they will not achieve net zero emissions.

3.2.2 Challenges

Electricity challenges

Electric ferries have vast potential but also have roadblocks to overcome. Some of these roadblocks include cost and refueling time constraints. To commission an electric ferry has

significant costs for ferry owners. The electric vessel itself not including dock and grid upgrades can run a cost in the range of $5–10 million as cited in the Great Lakes St. Lawrence Governors and Premiers 2024 Ferry Electrification Potential report.[51] This report also cited successful projects such as electric ferries currently running at Niagara Falls and shares that ferry electrification becomes feasible with diverse funding sources and government support. Electric ferries would also require time to fuel at ports. Do ferries, like the extremely busy Mackinac Island ferries, have the time to sit at port and recharge? Will costumer be willing to pay a "greenium" on their ticket as overhead electric costs will be passed on to consumers in ticket prices? Do all ports have the infrastructure needs to support electric ferries and their need to recharge? All of these questions must be addressed and some of these barriers must be lowered before ferry companies commit to an electric transition. Incentives and grants to quell these worries could go a far way for ferry owners to make the change.

Technically, electric ferries face the challenge of increased vessel weight when compared to combustion engine boats as the batteries weigh considerably more than current combustion engines while electric vessels also save weight in the reduction of moving parts.[52] Will this impact the number of passengers that are allowed on each trip and impact the economics for ferry companies? Some ferries, given they can be large enough and have deep enough water to traverse, have proven this worry unnecessary like the Hull 96 ferry described in Section 3.2.3. Still, boat size, distance traveled, and route constraints will determine which fuel is probable to use and why.

Hydrogen Challenges

Despite hydrogen's vast potential in ferry vessels, there are still associated challenges. The primary challenge with implementing hydrogen into marine applications lays with hydrogens low volumetric energy density. As determined in a 2025 publication by Timothy J. Wallington et. al. on hydrogen as a sustainable transport fuel, hydrogen's volumetric energy density of 0.0098 MJ/L which is only a small fraction of diesel or marine bunker fuels which sit at a volumetric energy density of 35.8 and 39.1 MJ/L respectively.[53]

This challenge noted above results in complex tank design considerations and the need to carry a much larger volume of hydrogen onboard while traveling. In terms of indirect use of hydrogen (hydrogen is combined with carbon dioxide or nitrogen, and to produce, currently no commercial or large-scale synthetic fuel production facilities are active to date. While uncertainties circle around energy density, safety, and marketability, large amounts of research into hydrogen usage offers confidence in future technological improvements leading to possible if not probable large-scale marketability and use.

Finally, just as described in the electric section above, hydrogen ferries would require sufficient hydrogen fueling infrastructure at their ports and the high cost of entry for new vessels and upkeep may need to be incentivized and invested in at the state and federal level before individual companies make the change themselves.

3.2.3 Models

The current international example of a large electric ferry is called Hull 96. Hull 96, launched by Australian shipbuilder Incat is the world's largest fully electric ferry, measuring 130 meters in length. Commissioned by South American operator Buquebus, the vessel will transport up to 2,100 passengers and 225 vehicles between Argentina and Uruguay, powered entirely by batteries with a capacity exceeding 40 MWh.[54] This launch represents a major leap forward in sustainable maritime transport, showcasing the potential for fully electric, zero-emission vessels to significantly reduce the environmental impact of maritime travel. By replacing traditional fossil fuel engines with a 40MWh battery-powered system, Hull 096 exemplifies how large-scale electric ferries can help decarbonize a sector historically reliant on heavy fuels. As global demand grows for cleaner maritime transportation, this vessel sets a new benchmark for carbon-neutral innovation, positioning electric ferries as a viable, scalable option for reducing maritime emissions.

Within Michigan there are several efforts to decarbonize ferry transportation as well. In 2023 and 2024, federal or state grants were awarded to both the Beaver Island Ferry and Mackinac Island ferries to assess more efficient and environmentally preferable ways for the respective ferry routes.[55] [56] The Mackinac Island ferry was assessed to consider electric propulsion while the result of the study also showed current limitations due to cost and infrastructure as described above in section 3.2.2. Similarly, the SS Badger had a MARAD grant awarded to them to assess the feasibility of converting the last coal-powered freight and passenger ferry in the United States to a less carbon intensive fuel. Results of this study indicated technologies such as battery electric, diesel-electric hybrid, or carbon capture technologies to be a current feasible result.[57]

As a final example of maritime decarbonization progress that could assist the ferry industry in decarbonization, the U.S. DOE recently awarded $1B to the Midwest Hydrogen Hub to support decarbonization of industry and heavy-duty transportation[58] which potentially includes technologies that could be used in maritime transportation. While the current implantation planning of this hub is uncertain, these studies show that green propulsion techniques are being actively researched and encouraged by industry, the government, and innovators alike. The important next step is to continue to lower roadblocks such as infrastructure needs, cost, and retrofitting needs to allow the transition to occur in the accelerated manner needed to meet the IPCC 1.5° Celsius timeline for decarbonization.

3.3 Decarbonization Pathways for Commercial Shipping

The largest, furthest traveled, and arguably the most complicated sector of the Michigan maritime ecosystem is commercial shipping. Commercial ships need large amounts of power, have a long service life, and travel very long distances. This makes the fuels available for movement limited to ones that can achieve those needs. Before diving into what fuels could be used for commercial shipping, it is important to recognize commercial shipping’s importance in Michigan.

Millions of tons of cargo pass through the 33 ports in the state every year. Six Michigan ports imported 631 foreign containers and exported one container for foreign markets.[59] Michigan outbound and inbound tonnage (short tons) of non-containerized cargo shipped over the period 2018-2022 is presented by destination in Figure 3 and by origin in Figure 4 below.

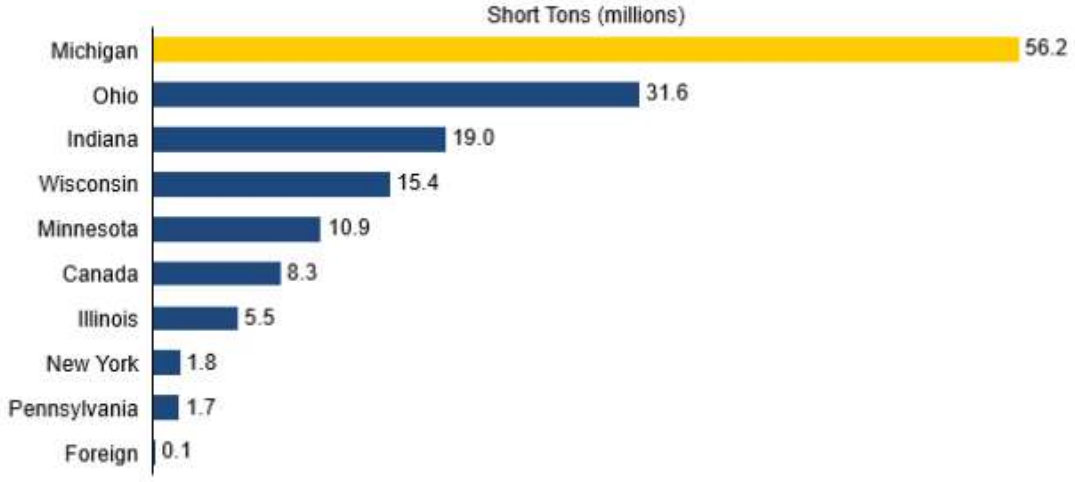


Figure 3. Michigan cargo tonnage (short ton), by destination, 2018-2022[60]

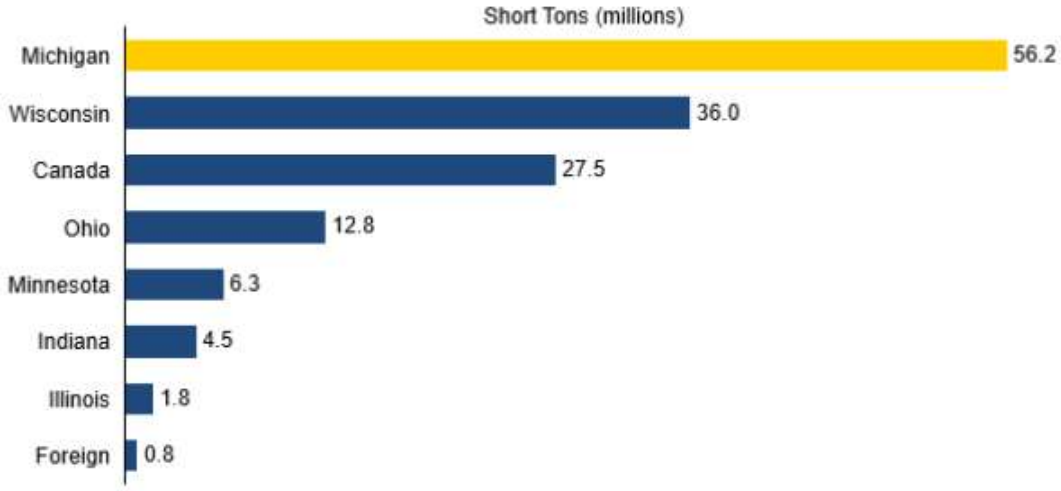


Figure 4. Michigan cargo tonnage (short ton), by origin, 2018-2022[61]

In 2022, 149.5 million short tons of cargo valued at $26.1B moved through the Great Lakes – Seaway system,[62] and 56.3 million short tons were handled in Michigan.[63] This data shows that commercial shipping is vitally important to the state of Michigan, and a crucial part of the Michigan maritime ecosystem. While fuel consumption is hard to measure and modeling depends on how you allocate fuel consumption (is fuel attributed to a vessel at the origin where they purchase it? Where their destination is? Divided over the ships route where it emits the fuel?) the International Council on Clean Transportation (ICCT) estimated that in 2019, 510,000

tonnes of fuel was consumed by ships across the "Great Lakes - Saint Lawrence Seaway" region. This fuel included 83% distillate fuel, 15% residual fuel, and 2% LNG.[64] Decarbonization options for commercial ships involve methanol and ammonia mainly as well as use of short-term drop in fuels.

3.3.1 Fuels and Decarbonization Opportunities

Methanol

As described in section 3.2.1 regarding fuels for ferry section above, methanol can be used in internal combustion engines or in the form of fuel cells. Methanol also has the opportunity to provide the power and distance needs for commercial shipping. Methanol also allows for dual fuel engines to operate on methanol and/or traditional fuels with few modification needs. Additional positive aspects of methanol include the cost competitiveness to traditional fuels, lower environmental harm if a spill was to occur, and the ability to use existing infrastructure for storing and transportation making it a plausible shorter term fuel switch.[65] Methanol will only truly be carbon neutral if the feedstock used to create the fuel is also carbon neutral.

As summarized by the CEO of DNV (Det Norske Veritas (DNV) in a 2025 news article, "as the maritime industry explores pathways to a lower-carbon future, it is important to consider a range of practical and scalable solutions. There is no one-size-fits-all answer, and different shipping segments and geographies will require different approaches. Methanol is one option that draws on established technologies and infrastructure, and it is encouraging to see the industry's growing interest in a variety of alternative fuels." [66]

Ammonia

Like methanol, ammonia can be used in internal combustion engines and fuel cells with further development. Direct combustion of ammonia is a currently viable fuel option, while incorporation of ammonia as a hydrogen carrier is also a future option with further technological developments. As a globally traded commodity it would be easy and cost effective to incorporate ammonia into marine value chains.[67] As with methanol, the true decarbonization potential of ammonia as a fuel source depends on the feedstock and production processes of that ammonia which can be derived from fossil fuels or clean energy.

Drop In fuels

While methanol and ammonia as fuels are possibly carbon-neutral, and exciting prospects, they may or may not be immediately implementable. While ship parts are manufactured for these fuels and shipping companies work towards rectifying these conversations financially, drop in fuels such as biodiesel and renewable diesel may be short term alternatives that lower carbon emissions. These fuels can also be used in commercial ships who will not be removed from service for a long time, or those that cannot convert their parts to be compatible with the new fuels.

Operational Efficiency and other Decarbonization Efforts

As we look at the ways to decarbonize commercial shipping, it is important to note that the fuels are only part of the equation. Improving operational efficiency will allow for less fuel to be used overall. A couple examples of operational efficiency include just-in-time (JIT) port arrivals and improved ship hull designs to streamline the vessel physically.

Onboard carbon capture and storage is a known innovation with proven results. The Action Plan for Maritime Energy and Emissions Innovation shares that onboard carbon capture and storage would be a possible solution for container ships to lower their carbon emissions by designing the lower decks in a way which they support the carbon dioxide storage tanks and containers can stack on top of them.[68]

Off the ship, ports themselves can work to decarbonize. Port operations, drayage equipment, and port vehicles can be decarbonized themselves. As seen in Section 3.3.3 below, there are many examples of port decarbonization efforts and electrified drayage equipment within Michigan and across the nation.

3.3.2 Challenges

General challenges

As discussed in the introduction to Section 3.3, commercial ships are the largest and travel the longest distances. Immediately due to these simple facts, the fuels available for these types of trips becomes limited. It is necessary to provide high power for long periods of time in order to justify using a fuel for commercial shipping. Additionally, commercial ships have extremely long service lives. The Great Lakes fleet, which may never touch saltwater, can stay in operation for 50+ years with very little maintenance needs.[69] This makes it challenging to ask maritime shipping companies to spend capital costs to replace or retrofit their working ships to be able to handle alternative and carbon free fuels if their ships still have 20+ years left before any maintenance or service is needed. This is where policy, incentives, and financial support may be necessary to truly drive industry change.

Not only is the long service life an issue, but so is price of commercial ships. As an example, Presque Isle Freighter was launched in 1973 by the Great Lakes Fleet Company and costs over $260 million in 2025 dollars for construction.[70] Similarly, the Canadian fleet invested in 14 new commercial ships between 2012-2025 with an investment over $1 billion total.[71] The long service life of commercial vessels, combined with the high capital costs of replacement or retrofitting, create substantial barriers to decarbonizing the Michigan fleet.

As with recreational boats and ferries, commercial shipping fuel changes will need infrastructural changes on land, and financial support to make conversions feasible.

Methanol specific challenges

While methanol is promising, there are a few technical and practical challenges to consider. Technically, methanol has a lower energy density when compared to traditional fuels and would thus require larger volumes of fuel to be held on board for longer trips. This might require fuel tanks to be upgraded in size to have more storage space. Similarly, while dual fuel and methanol accepting engine parts are currently on the market today, they are not commonplace.[72] This lack of commonality could lead to wait times, expensive part manufacturing, or new-build requirements to implement methanol into commercial shipping engine parts. Finally, safety is a concern with methanol as methanol burns with a clear flame and large amounts will be required on commercial ships. New or upgraded safety precautions would need to be adopted to safely handle, load, offload, and carry methanol on commercial ships.

Ammonia specific challenges

Ammonia as a fuel has significant barriers to overcome while lowering of these barriers provides the opportunity for carbon neutral commercial shipping transportation. The energy density of ammonia is greater than hydrogen, but lower than methanol and thus much lower than conventional marine fuels. Because of the low energy density, it is probable that current engines in commercial ships would need adjustments and upgrades to be able to carry the larger volumes of ammonia fuel needed for long voyages. These changes of course have costs to the shipping company which may or may not make the fuel currently viable. Additionally, while the ammonia molecule has no carbon and produces no CO2, it does have the potential of producing NOx during combustion which is also a volatile greenhouse gas. Finally, if ammonia was adopted to be used in commercial shipping, global production would have to greatly increase, and new value chains and industry collaborations would have to be forged.[73]

3.3.3 Models

As stated in the United States Maritime Action Plan, methanol interest across the United States is already prolific as seen by the “recent order of methanol-ready ships, establishment of clean methanol production facilities across the United States, and the recent efforts for establishing bunkering standards for methanol” [74]

In terms of port decarbonization efforts, the port of Detroit is a primes example. The Port of Detroit is leading a transformative decarbonization initiative aimed at achieving net-zero carbon emissions by 2040.[75] In collaboration with Tunley Environmental and Southwest Detroit Environmental Vision, the Detroit/Wayne County Port Authority conducted a comprehensive emissions inventory, revealing that drayage trucking accounts for 55% of the port's 27,869 metric tons of CO_2 equivalent emissions. To address this, the port has implemented a strategic plan that includes transitioning to biodiesel fuels, electrifying cargo-handling equipment, and exploring the use of hydrogen and green methanol for port operations.

Significant funding supports these efforts. In October 2024, the U.S. Environmental Protection

Agency awarded the port $24 million through the Clean Ports Program, allocating $3 million for planning and $21 million for implementing green infrastructure projects. These projects encompass the acquisition of electric cargo-handling equipment, installation of charging stations, and deployment of solar panels. Additionally, the port has launched an interactive emissions map to enhance transparency and track progress. Through these initiatives, the Port of Detroit aims to improve air quality, reduce greenhouse gas emissions, and serve as a model for sustainable port operations in the Great Lakes region.

Similarly, the Port of Virginia has become the first major U.S. East Coast port to power all its terminals with 100% clean electricity.[76] This accomplishment, announced in January 2024, positions the port eight years ahead of its original 2032 target and supports its broader goal of achieving carbon neutrality by 2040. The transition to clean energy is facilitated through a Power Purchase Agreement with Dominion Energy and a rider with Rappahannock Electric Cooperative, ensuring a reliable supply of renewable energy from sources such as solar, wind, and nuclear power. Utilizing clean electricity has led to a 45% reduction in carbon emissions per container, addressing both Scope 1 emissions and Scope 2 emissions. The port's commitment to sustainability is further demonstrated by its investment in electric equipment, including 116 electric stacking cranes, four electric rail cranes, and 27 electric ship-to-shore cranes, with plans to expand this fleet as part of its ongoing modernization efforts. The Port of Virginia exemplifies the feasibility of integrating sustainability into port operations, setting a precedent for other ports to follow suit.

3.4 Urgency Needed to Meet IPCC Targets

With the paths to decarbonization for the three main vessels included in the Michigan Maritime Strategy outlined above, it is also important to discuss implementation. Aggressive action is needed but the private sector and everyday recreational boaters currently have no mandate to achieve goals and economics do not favor accelerated conversions of fleets. Similarly, the long service lives outlined above negate the urgency to buy new vessel or retrofit old ones for the use of new decarbonized fuels for the short-term. This is where state and federal incentives and regulations become necessary to drive decarbonization solutions. There is also a need to measure and track changes. Aggressive goals are required to support demonstrations and drive deployment.

To demonstrate this point, Figure 5 below shows a scenario where the recreational fleet in Michigan transforms from our current 2024 baseline of nearly all fossil fueled registered vessels to full electric vessels. Admittedly electric boats were present in Michigan in 2024, but they are still far below 1% of the entire fleet. Thus, for this simplified analysis, we will assume all motorized recreational vessels are fossil fueled starting in 2024. Also assumed due to the lack of historical fleet data for 2010, is that the number of registered vessels in 2024 (764,000) is representative of the 2010 baseline fleet. While this implies a steady-state fleet size from 2010 to

2024, it provides a reasonable proxy for evaluating the scale of transition required to meet the IPCC targets.

This optimistic scenario assumes zero-emissions electricity is used and the grid infrastructure is ready to fuel the demand of all these vessels on the given timeline. We will be using the number of registered motorized vessels in 2024 (764,000) as given by the DNR in Figure 2 above and map that onto the IPCC timeline given in Figure 1 above which aims for a 45% reduction of emissions from 2010 to 2030 and then a steady decrease in emissions until net-zero carbon emissions in 2050.

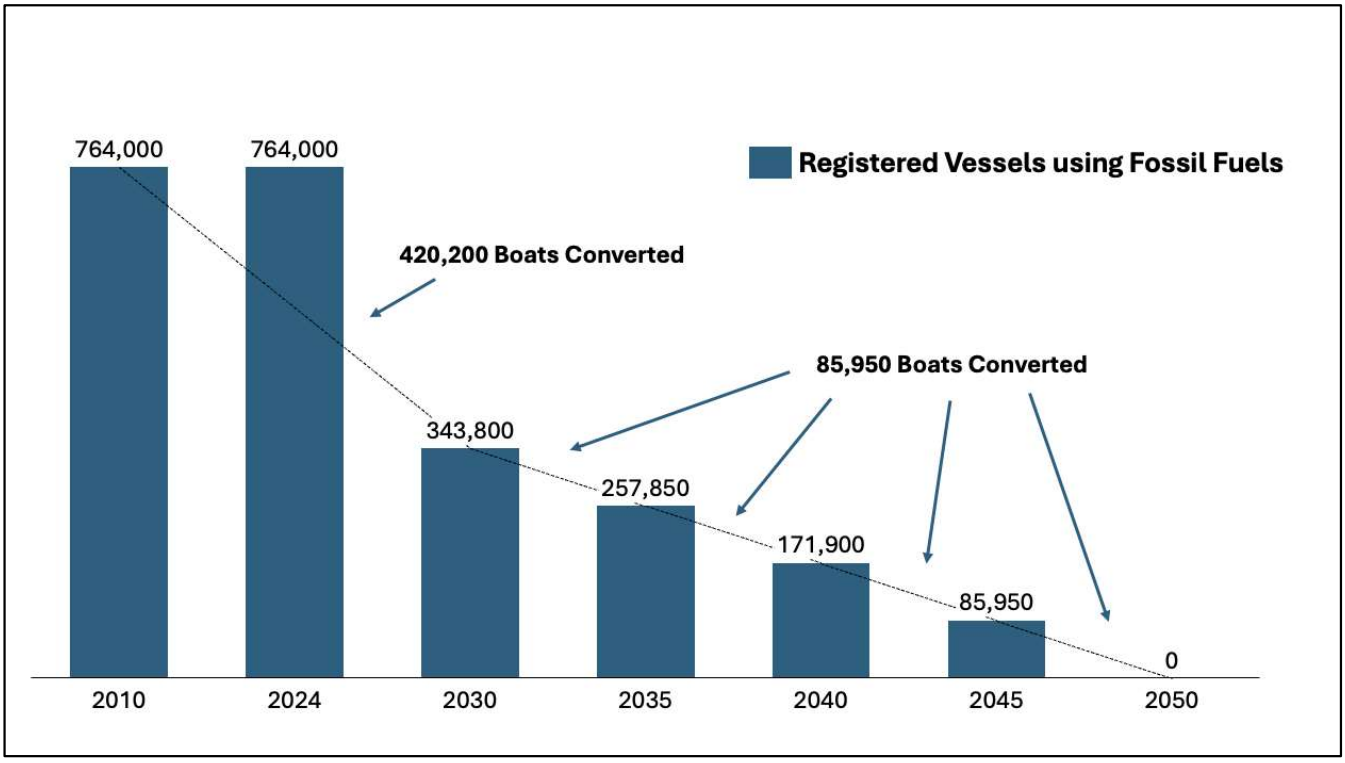


Figure 5. Recreational Boating Fleet Turnover Needed to Meet IPCC IPCC 1.5° Celsius Timeline for 2030 and 2050

Figure 5 concludes that between 2024 and 2030, 420,200 reactional boats must be converted from fossil fueled vessels to carbon-neutral electric vessels. Then, starting in 2030, 85,950 vessels must be converted to carbon-neutral electric vessels every 5 years until the entire recreational fleet is electrified in 2050. If we assume a medium price value on a single recreational electric vessel is $200,000, one can extrapolate that the conversion of 420,200 boats between 2024 and 2030 will cost over $8.4 billion. Not only will this conversion take such a large investment, but the current fleet has a service life that disfavors replacement. Most recreational boats on the water in 2024 will not need to be repaired, retrofit, or replaced by 2030 so vessel owners are not motivated to meet this timeline as well. This analysis, full of optimistic assumptions, paints a stark picture demonstrating that the 2030 timeline to meet the IPCC 1.5-degree Celsius goals is not realistic in the recreational fleet. While meeting the 2050 timeline is

not out of the picture, it is important to recognize the extreme costs and roadblocks like the lack of replacement needs in a short time due to service life. It is unreasonable to put this financial burden and urgent conversion need onto the everyday recreational boaters themselves making it clear that federal or state level incentives and regulations will be necessary to meet the 2050 IPCC timeline.

This case above was exemplified for the recreational fleet. The same, but on a larger magnitude, can be seen for the ferry and commercial fleet of Michigan vessels. The prices of vessels which can handle new carbon-neutral fuels, the retrofit or newbuild urgency, and the long service lives discussed above in the paper will result in a similarly dire picture for these two fleets, just as it did for the recreational fleet. Future (and urgent) research is needed to quantify the Michigan ferry and commercial fleets, their emissions, and the emissions reduction possible per different proposed fuel types. With this data, a similar capital cost requirement for vessel fleet conversion can be demonstrated for these sectors as was shown for the recreational fleet. These studies will prove what was proven for the recreational fleet: Meeting the 2030 IPCC timeline for the 1.5-degree Celsius goals is not probable, and meeting the 2050 timeline will require large capital costs as well as federal and state incentives and regulations to spur action on in a slow moving, carbon intensive industry.

3.5 Benefits and Opportunities of Maritime Decarbonization

With this urgency discussed in Section 3.4 above comes opportunity. Stakeholder outreach from the development of the Michigan Maritime strategy demonstrated that everyday boaters are ready to make changes and see changes made system wide. Recreational boat owners and marina representatives suggested that Michigan can become the electric boating capital of the world. Non-motorized water recreation, electric and solar powered boating, and green-fueled marinas can be the future of the Pure Michigan slogan. This idea already has momentum within Michigan with state level initiatives such as the Fresh Coast Maritime Challenge Grant Program. In August of 2023, Governor Gretchen Whitmer announced a grant meant to support establishing Michigan's “Fresh Coast Corridor.” Michigan allocated $506,000 in grants to six companies under the inaugural Fresh Coast Maritime Challenge, aiming to decarbonize the state's waterways by supporting electric boating infrastructure.[77] The initiative includes deploying e-boats, installing fast marine chargers, and conducting technology demonstrations at marinas across Northwest Michigan, with the goal of establishing a sustainable and interconnected water transportation network. This grant program was set out to help achieve goals set in the MI Healthy Climate Plan and the MI Future Mobility Plan. This combined effort by the state and private companies illustrates the need for a multifaceted approach to decarbonization, including collaboration, innovation, policy, and incentives.

The push for decarbonization can also fuel innovation and technological improvements. For example, Michigan can build off its strong innovation ecosystem that includes Newlab Detroit and The Traverse City Freshwater Research and Innovation Center. As of July 2024, Newlab

Detroit hosts over 100 member startups, with more than half led by underrepresented founders, collectively raising upwards of $688 million in venture capital. The hub's location and resources have accelerated numerous pilot programs, including autonomous maritime navigation projects.[78] The Traverse City Freshwater Research and Innovation Center is dedicated to advancing maritime decarbonization and fostering collaboration in the blue economy.[79] This facility serves as a nexus for education, research, and innovation, bringing together students, researchers, entrepreneurs, and industry leaders to develop sustainable freshwater and marine technologies. The Center's collaborative environment supports the creation of "Blue Tech" solutions, including electric vessels and autonomous watercraft, aimed at reducing emissions and enhancing water quality. By co-locating high-tech laboratories, maker spaces, and business incubation programs, the Center accelerates the commercialization of these innovations. Partnerships with institutions like Michigan Technological University and Northwestern Michigan College ensure a robust workforce pipeline, while initiatives such as the Discover Blue Consortium promote inclusive engagement and economic opportunity across northern Michigan. The Center is poised to position the Grand Traverse region as a global leader in applied freshwater innovation. Overall, Michigan is already a national leader in electric vehicle manufacturing and battery supply chain development, providing a strong industrial and technological foundation that can support the transition to electrified maritime systems.

A final reason for excitement that will come along with decarbonization is the opportunity to improve, while shifting, the economy. Jobs in green energy development, innovation, port operations, and more would be spurred on by a fuel transition which supports decarbonization. Maritime prioritization could make Michigan the place to be for maritime related jobs. Alternative fuel production value chains and ship manufacturing facilities can grow in Michigan supporting the Michigan maritime workforce. As an example, on July 22, 2024, Governor Gretchen Whitmer, alongside Secretary of the Navy Carlos Del Toro and officials from the U.S. Departments of Defense and Labor, launched the Michigan Maritime Manufacturing (M3) Initiative—a $50 million federal-state partnership aimed at strengthening Michigan's maritime defense manufacturing. This initiative will partner with Michigan’s Community colleges to develop and adapt training programs which focus on technical training applicable to Navy manufacturing. The ultimate path to decarbonization not only improves air and water quality, but can also support the Michigan maritime economy and impacted businesses and communities.

4. Conclusion

The Michigan Maritime Strategy has set a strong president regarding improvement of the entire Michigan maritime economy. This paper takes the three main sectors of Michigan maritime ecosystem (recreational boats, ferries, and commercial ships) and discusses their decarbonization options. The main carbon-neutral fuels identified in this paper include electricity, hydrogen, ammonia, and methanol with the use of drop in fuels such as biodiesel, renewable diesel, or renewable electricity in the short term. As seen in Figure 6 below, in order to decarbonize the

fleets fully, the recreational fleet has high electrification potential, the ferry fleet has electrification and hydrogen fuel potential, and the commercial fleet should look towards use of ammonia and methanol fuels. While these fuels exist and can be used today, the technology can continue to improve making retrofitting and newbuilds easier to implement. There are also substantial challenges that come with each individual carbon-neutral fuel from density to safety issues that must be overcome through technological improvements, incentives, or regulation. It has been found that the maritime sector is much more difficult to decarbonize than land-based vehicles due to long service lives, extreme capital costs, and specialized vessel needs.

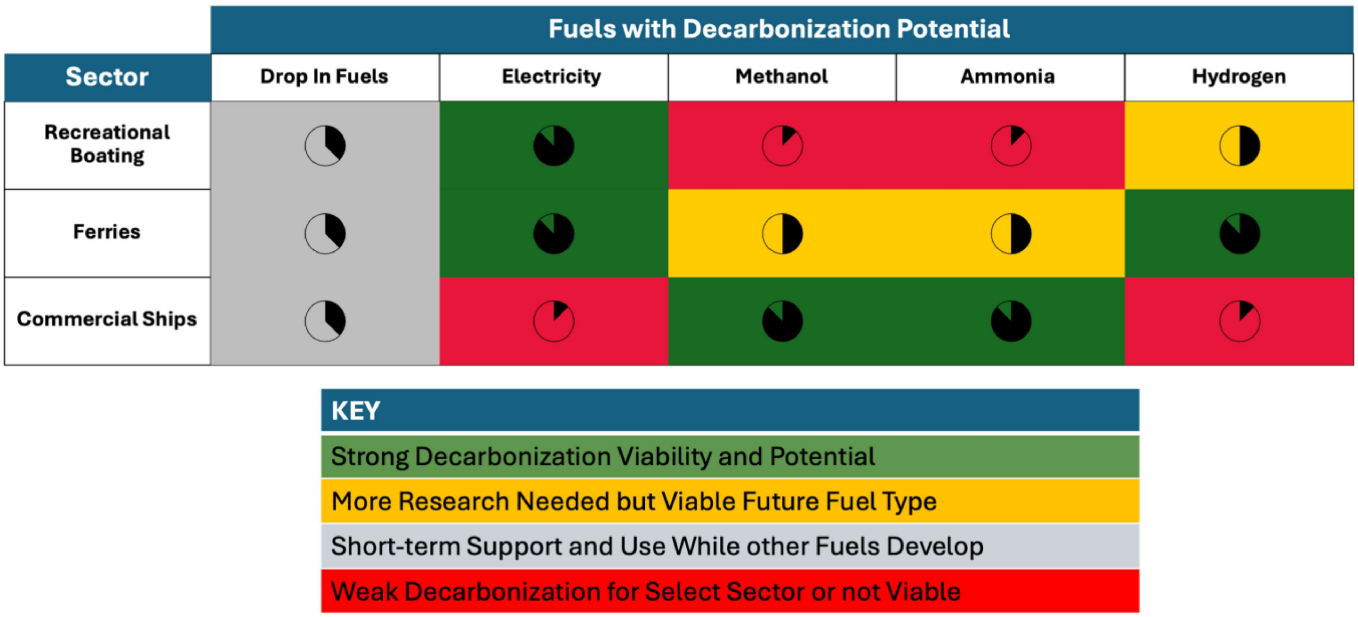


Figure 6: Fuel Considerations per Sector which have the ability to Decarbonize the Michigan Maritime Ecosystem

While the fuels with decarbonization potential exist today with specific challenges and opportunities as outlined above, this paper also found a need to be critical of timelines set out in strategy documents and what meeting that timeline might entail. Section 3.4 outlines the fact that the Michigan maritime ecosystem will fail align with the 2030 IPCC timeline and carbon reduction targets for meeting 1.5-degree Celsius goals. The 2050 timeline will require large capital costs as well as federal and state incentives and regulations to spur quick action in an industry that currently has no incentive to decarbonize. The results of this study clearly demonstrate the need for urgent action to set specific deployment actions and targets (e.g. number of electrified ferries deployed by 2030) as well as policies with strong economic incentives (e.g., federal and state investment opportunities) must be implemented beyond the more generic goals and objectives presented in the MMS.

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