DECARBONIZATION OF THE INLAND WATERWAY SECTOR IN THE UNITED STATES

A REPORT FOR ABS PREPARED BY VANDERBILT UNIVERSITY

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DECARBONIZATION OF THE INLAND WATERWAY SECTOR IN THE UNITED STATES – PATHWAYS AND CHALLENGES TO A ZERO-CARBON FREIGHT FUTURE

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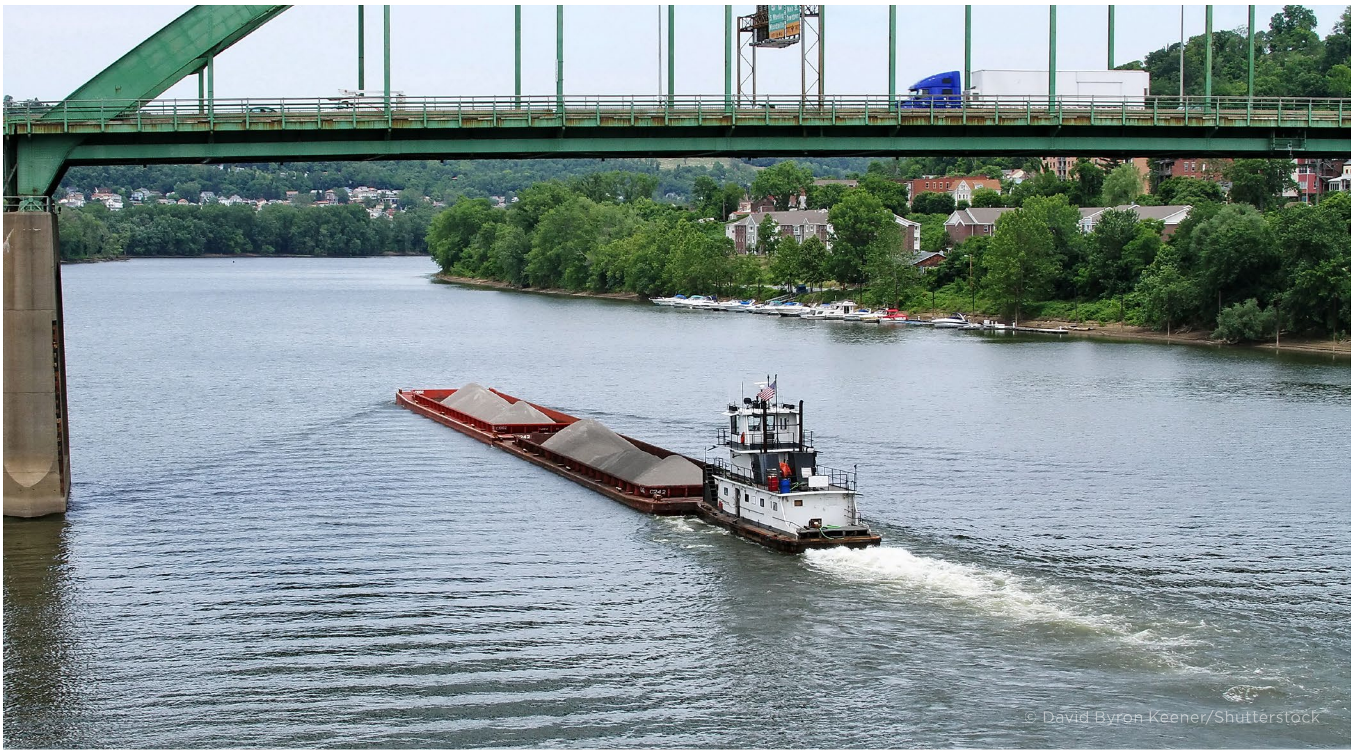
EXECUTIVE SUMMARY

Ocean shipping, along with many other economic sectors, has been focused for several years on decarbonization, consistent with the United Nations Sustainable Development Goal 13 (taking urgent action to combat climate change) and the United Nations Framework Convention on Climate Change (UNFCCC). The International Maritime Organization (IMO) and numerous ocean carriers and shippers have, for some years, been evaluating and working towards aggressive goals and strategies to dramatically reduce greenhouse gas (GHG) emissions in international shipping. In support of these efforts, ABS has issued comprehensive reports on different pathways to lower (and ultimately eliminate) GHG emissions in ocean shipping.

Market pressures and international policy and regulations are largely driving the decarbonization initiatives in the international shipping sector; however, those drivers are only recently beginning to emerge for domestic shipping, especially with respect to freight shipping on inland waterways in North America (and the U.S. in particular). Examination of pathways toward decarbonization of the inland waterway sector is in its infancy. This report aims to inform key stakeholders by identifying challenges and opportunities that will be faced in moving toward a carbon neutral and zero-carbon future on the inland waterways. The report also includes prospects for furthering the sustainability advantages that barge transport has relative to other surface transportation modes.

To develop this report, ABS and Vanderbilt University, through the Vanderbilt Climate Change Initiative ("VCCI") and the Vanderbilt Center for Transportation and Operational Resiliency ("VECTOR"), formed an expert working group to build a baseline assessment against which future zero-carbon pathways can be evaluated. The working group that contributed to this report consisted of researchers with substantial experience in transportation infrastructure and resilience, data analysis and climate change, as well as professionals with extensive industry experience within the inland waterway sector.

This report establishes a supportable estimate of the current GHG emissions profile for the inland waterway fleet. The report also evaluates the potential for currently available and possible future propulsion technologies and alternative fuels that may reduce carbon emissions on the inland waterways, and sets forth existing policy challenges, infrastructure needs and competitive market realities and trajectories that present opportunities for and challenges to decarbonization. In particular, the report demonstrates the feasibility of near-term electrification of smaller vessels operating on the inland river system through a case study and renderings of a weighted and balanced electrified boat in a retrofit application. As battery technologies continue to improve, this approach has potential application in even the largest operating towboats.



KEY CONCLUSIONS

- The current GHG emissions profile of the inland waterway sector is low compared to other freight modes.
- The inland waterway sector faces unique challenges that differ from the coastal and trans-ocean shipping sector. These include limits on the vessel length (and overall dimensions), weight and draft. These physical attributes of the towboat are constrained in most locations by river depth, width and the size of navigable lock chambers.
- Electrifying certain inland river boats (smaller boats known as "fleet boats") can be technically accomplished in the near-term, through retrofitting of existing boats. Converting all fleet boats to electric propulsion is estimated to reduce total annual industry fuel consumption by approximately 20 percent, resulting in a similar reduction in total industry GHG emissions depending on the mix of fuel used to generate the electricity.
- Electrifying larger river boats may not be feasible with current technology due to the size of batteries required but could potentially become achievable as battery technologies continue to evolve.
- Biofuels and methanol are feasible, non-fossil fuel alternatives because they can be used in some existing marine engines and are supported by current infrastructure.
- Ammonia, hydrogen and liquefied natural gas (LNG) may not be possible as retrofit applications for use in existing towboats because the comparative energy density of these fuels is substantially lower than that of marine diesel, resulting in the need for larger fuel tank volumes that cannot be accommodated on existing boats. Existing fuel tanks are also not the specialized tanks required for ammonia, hydrogen or LNG. One possible approach to overcome this challenge and successfully use these fuels is to include an alternative fuel barge known as a Portable Energy Module (PEM) within the tow that would generate power on the barge and supply it, in the form of electricity, to the towboat. This approach is technically feasible now but faces economic challenges that will need market or regulatory incentives to develop.
- The market for inland waterways is likely to remain stable, so market shifts or growth alone are not likely to justify new alternative fuel vessels.
- The inland river mode based on its low emissions profile can be leveraged to attract some shippers, but there is not likely to be a significant market improvement based solely on the demand for low-carbon inland waterway shipping.
- Decarbonizing the inland waterway sector will likely require new regulatory or market-based incentives, similar to those emerging in other economic sectors around the globe, in order to make decarbonization economically viable.

THE U.S. INLAND RIVER NAVIGATION SYSTEM: BACKGROUND AND HISTORICAL PERSPECTIVES

Over the last 10 years, there has been a growing focus on decarbonization in the transportation sector, including in the international shipping arena. With the exception of some attention from the European Union, there has been little focus on decarbonization pathways in the shallow draft inland navigation sector. While inland river navigation shares some similarities with trans-ocean shipping, there are important challenges and opportunities unique to the inland sector that are primarily attributable to the development of the physical infrastructure in each geographical river area and the outlook for the markets served. To help understand the opportunities and constraints applicable to inland river decarbonization trajectories, a brief historical overview is provided in this section, with a historical market review and projected market outlook in the U.S. Inland Waterway Freight Market Overview section. The drivers of tonnage demand are critical considerations to achieving a low- or zero-carbon future on the inland rivers.

HISTORICAL DEVELOPMENTS LEADING TO A STANDARDIZED SYSTEM OF CHANNELS, LOCKS, BARGES AND TOWBOATS

Commercial use of the nation's inland waterways originated with the country's founding—beginning with rivers along the eastern seaboard and continuing with the construction of elaborate canal systems that extended these waterways. Construction included the Erie Canal in New York, and quickly extended to the westward frontier down the Ohio River and beyond to the Mississippi River. Flat-bottom boats allowed one-way travel all the way to New Orleans, and round-trip travel emerged with the arrival of steamboats in the 19th century.[1]

The Federal Government, through the U.S. Army Corps of Engineers (Corps), became responsible for establishing the infrastructure to allow commercial navigation on designated waterways such as the Ohio and Mississippi Rivers. The Corps' work in the early 20th century began with a series of 53 "wicket" dams constructed along the Ohio River, with locks to allow passage during low water when the wickets were raised. The first projects achieved a channel depth of six feet, but Congress legislated a nine-foot channel in the Rivers and Harbors Act of 1910, which became the minimum channel depth adopted on the Ohio River and applied to new projects on the inland river network. This nine-foot design standard survives to this day.

The construction of a modern system of navigational dams along the Mississippi River began during the Great Depression, and by the start of World War II (WWII), a total of 27 lock and dam projects were constructed between St. Louis and the Twin Cities (Minneapolis and St. Paul, Minnesota). Lock and dam projects followed on the Illinois River, allowing connection to the Great Lakes at Chicago and on the Tennessee and Cumberland Rivers, which coincided with the creation of the Tennessee Valley Authority in the 1930s.

In the post-WWII era, a comprehensive modernization program commenced on the Ohio River, and the 53 wicket dams were replaced by 20 fixed dams with navigation locks, which were finally completed in the 1970s. This upriver system extended north from New Orleans and reached Pittsburgh, Chicago and Minneapolis. This system also was connected to a shallow draft navigable channel established along the Gulf Coast from Brownsville, Texas, to the Florida Panhandle, called the Gulf Intracoastal Waterway. The timing and the network's extent are shown in Figure 1.

[1] The History of Large Federal Dams: Planning, Design, and Construction in the Era of Big Dams. U.S. Department of the Interior (2005).

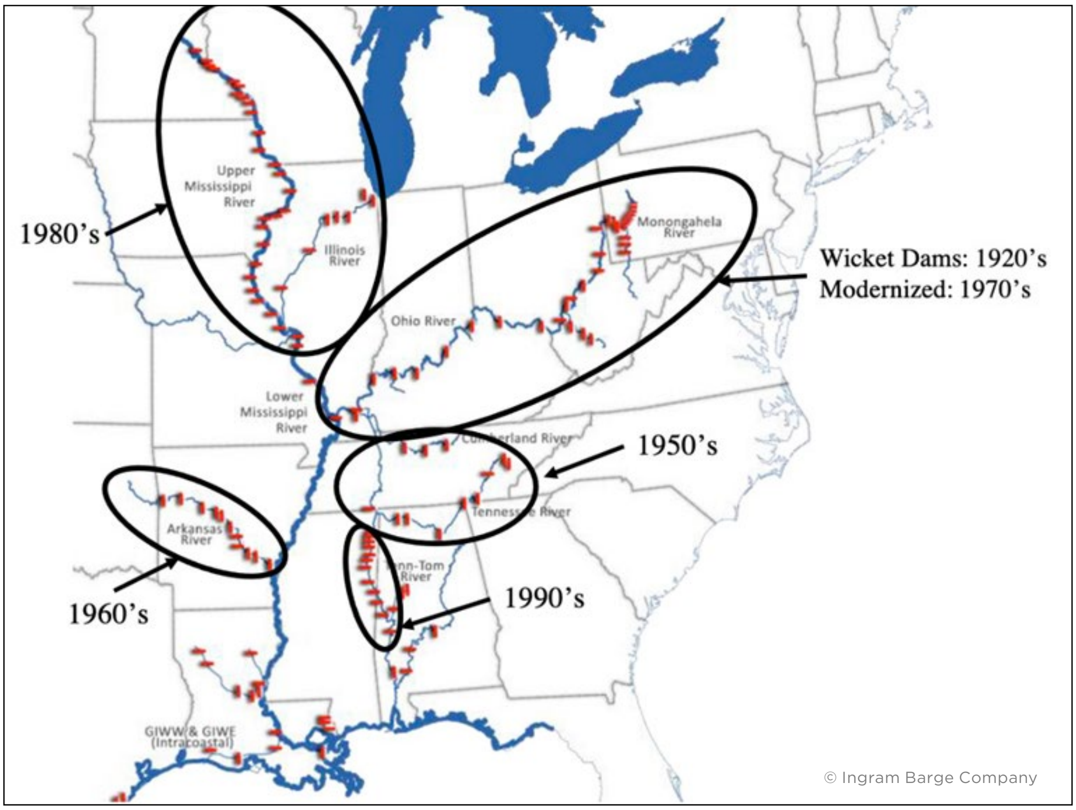


Figure 1. Evolution of the U.S. Inland Navigation System

BARGE STANDARDIZATION: KEY TO THE SYSTEM'S SUCCESS

As noted previously, a nine-foot channel was guaranteed through a statutory mandate enacted more than 100 years ago along this network of more than 12,000 interconnected miles. A uniform lock chamber size was not mandated by law, but the earliest locks built along the Ohio River were built with a width of 110 feet and length of 600 feet, and this became the standard minimum size as new locks were constructed on various segments. In many cases, longer locks up to 1,200 feet in length were constructed where conditions permitted, and where anticipated traffic volumes justified the expense, but lock width has never varied.

Commercial users of these waterways converged on standardized sizes for the barges that would best utilize the system. Limited by the size of the lock, two barge sizes emerged. The most common was 195 feet by 35 feet, often called "Jumbo" barges. The second, larger barge size was 295 feet by 54 feet, often called "Oversize" barges. A group of nine Jumbo barges or four Oversize barges, assembled as a unit, could fit into the lock chamber, and various operational strategies emerged that allowed tows (an assembly of barges tied together) of up to 15 Jumbo barges or eight Oversized barges to be moved by a single towboat on most locking rivers.

The amount of freeboard, or height from waterline to deck level, that was considered necessary for safe vessel operations was two to three feet when the vessel was fully loaded. Because the system was guaranteed to maintain a nine-foot channel everywhere, barges were built with 12-foot hulls so that when loaded to a nine-foot draft they would maintain two feet to three feet of freeboard. In recent years, some operators have built deeper barges with up to 14-foot hulls, recognizing that channels in some locations and during some parts of the year are often deeper than the nine-foot minimum guaranteed by statute and maintained by the Corps. When allowed, these deeper barges can carry up to 20 percent more cargo.

EVOLUTION OF THE TOWBOAT FLEET: OPTIMIZING OPERATIONS ON THE INLAND SYSTEM

Until the 1930s, barges were pushed by steam-powered sternwheelers, the largest of which generated less than 1,000 horsepower (hp). See Figure 2.

Figure 2. Picture of early sternwheel towboat in the Nashville Harbor.

During the 1940s and 1950s, diesel-powered towboats displaced the steam-powered vessels, much as diesel electric locomotives replaced steam engines on the nation's railroads. Much larger twin and triple screw vessels were possible, and the deployment of flanking rudders allowed them to maneuver much larger tows despite the narrow channels found in many locations.

Because most of the locks on the river system could accommodate tows of 15 Jumbo barges or eight Oversized barges, operators determined that the towboats best deployed along the locking rivers consisted of 4,000 to 6,000 hp boats. Along the Gulf Intracoastal Waterway, a narrow channel, smaller towboats of approximately 2,000 hp are employed. Figure 3 shows the operating territories highlighted with associated tows (the barge assembly) assigned to achieve the lowest possible unit towing cost.

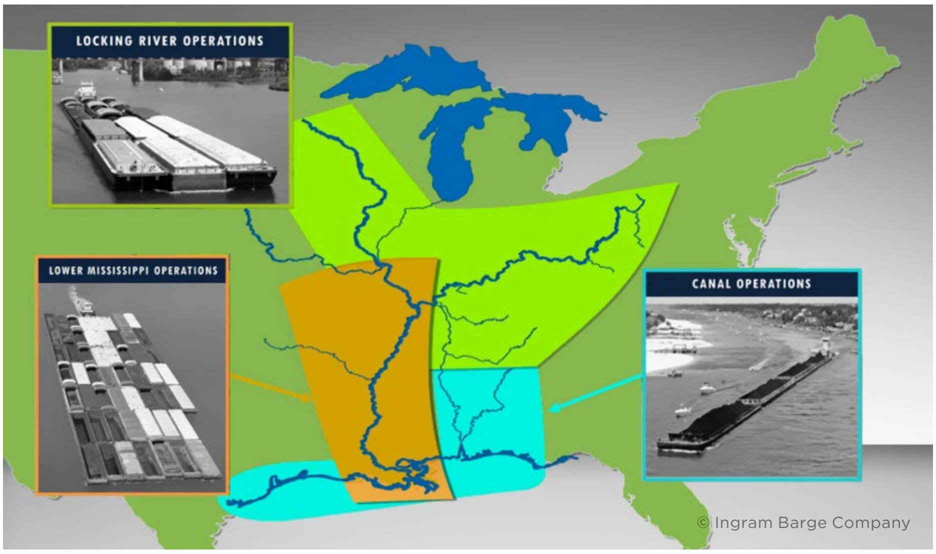


Figure 3. Map of the inland waterway operating territories.

The Mississippi River between St. Louis and New Orleans was navigable without the locks and dams which limited tow sizes. Operators learned that the maximum safe tow size was about 40 Jumbo barges and required a towboat of 9,000 to 10,500 hp. These impressive units, as pictured in Figure 4, have a footprint larger than a U.S. aircraft carrier and push as much cargo as the largest ships that transit the Panama Canal.

Figure 4. High horsepower towboat pushing 42 Jumbo barges.

Assembling groups of barges together – often with different barges serving different customers – permitted operators to achieve the maximum efficiency possible during the linehaul (river) portion of the voyage. However, this assembly process required the establishment of a network of hundreds of docks as well as fleets to load and stage the barges. Each dock and fleet required one or more smaller towboats (800-1,400 hp), often referred to as "fleet boats," that were smaller and could efficiently assemble the barges.

As shown in Figure 5 below, most towboats that are in service today were built during the 20-year period from 1970 to 1990, both to replace older, smaller equipment constructed prior to the completion of the waterway network, and to account for the rapid growth in tonnage that took place beginning in the 1970s. Unlike barges, the towboat effectively has an indefinite useful life if properly maintained. The sections below discuss in more detail towboat longevity as a factor in the development of decarbonization strategies.

Despite their age, the size and hull configurations have not changed materially since the 1960s, and operation in freshwater limits hull wastage (corrosion). Operators have thus been incentivized to repower and upgrade propulsion and other systems over the years rather than retire older vessels outright. This of course has significant implications with respect to conversion to new lower carbon propulsion systems.

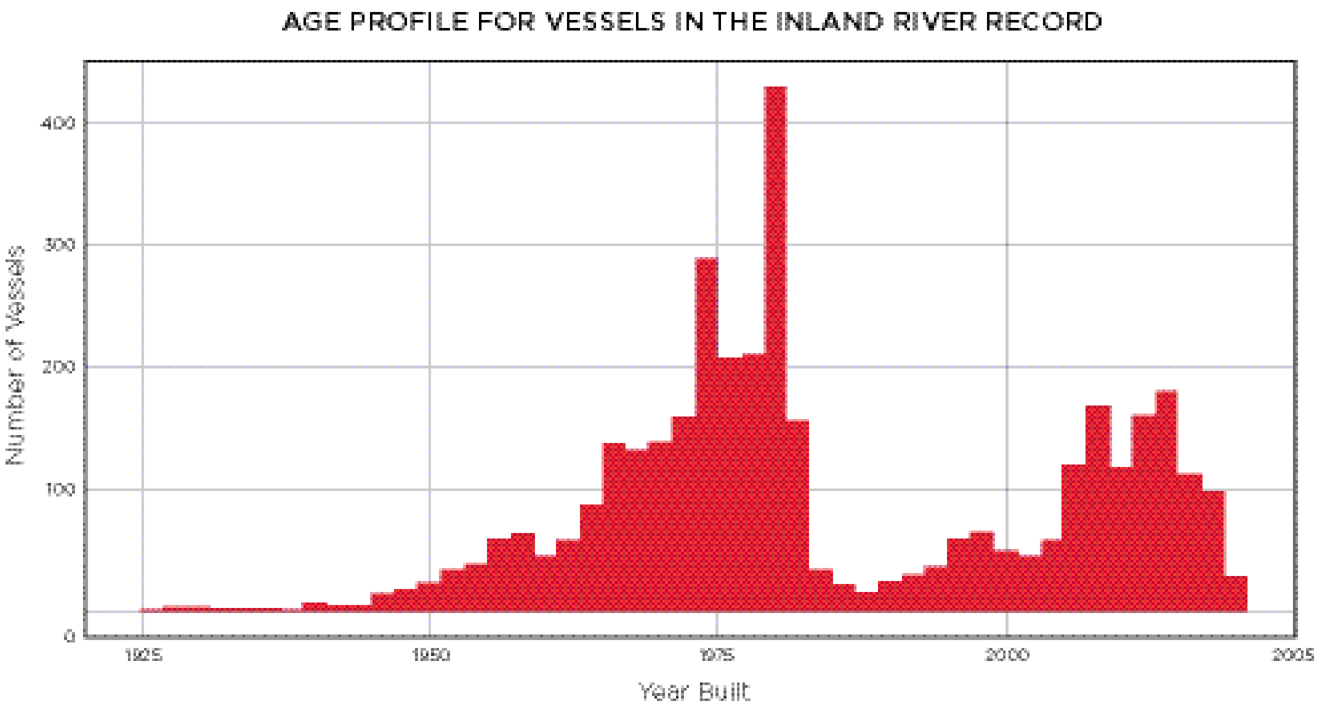


Figure 5. Age profile for inland waterway vessels. Source: Inland River Record.

HISTORY OF U.S. EMISSIONS POLICIES AND THEIR IMPACT ON THE INLAND RIVER FREIGHT SECTOR

In 2007, the Supreme Court's decision in Massachusetts v. EPA, holding that the federal Clean Air Act (CAA) authorized the U.S. Environmental Protection Agency ("EPA") to regulate greenhouse gases (GHG), ushered in a series of agency rulemakings aimed directly at reducing GHG emissions from mobile sources (both road and non-road). Prior to those rulemakings, GHG emissions were not regulated by EPA; however, a number of laws and regulations directed at reducing other air pollutants or increasing efficiency in certain mobile sources had the effect of decreasing greenhouse gas emissions, simply as a result of reducing the amount of fuel burned. Since the Supreme Court's decision, more regulations have ermerged that are directed expressly as reducing GHG emissions, particularly from mobile sources. This section sets forth a history of emissions regulation as it has impacted the marine industry, in particular engine emission control technology, focusing on the U.S. inland waterway sector, and the potential for further developments.

ADOPTION OF THE FEDERAL CLEAN AIR ACT TO ADDRESS AIR POLLUTION

Modern federal environmental regulation began in the U.S. during the late 1960s and early 1970s after a number of environmental incidents raised public awareness and concern about pollution, particularly in cities. Congress adopted the Clean Air Act (CAA) in 1970 (by updating an earlier air pollution law adopted in 1963) with the stated goal "to protect and enhance the quality of the Nation's air resources . . . .". [2] The CAA focused primarily on air pollution that impacted human health. Accordingly, the CAA framework directed the newly established EPA to identify a list of pollutants that endanger human health and that result from "mobile or stationary sources." The pollutants on that list are known as the "criteria pollutants," and the CAA framework requires the EPA to establish National Ambient Air Quality Standards (NAAQS) – maximum levels that may be present in the ambient air over an identified time frame – for those criteria pollutants. The six "criteria pollutants" are carbon monoxide, lead, nitrogen oxides, particulate matter, ground level ozone and sulfur dioxide.[3] Virtually all emission regulations were accordingly focused on these pollutants. Greenhouse gases were not yet considered a pollutant under the CAA and accordingly were not regulated.

States are required to develop plans, known as State Implementation Plans, for EPA approval to meet and maintain the NAAQS. Based on air quality monitoring and modeling data, the EPA designates areas of the country as either meeting the NAAQS for each criteria pollutant (an "attainment area") or not meeting it ("non-attainment" area).

REGULATION OF POLLUTION FROM MOBILE SOURCES

The Clean Air Act is effectively a collection of six different programs, referred to as "Titles," that regulate in different ways, use different terminology, and can apply different technological standards, resulting in a complex environmental scheme. Title II of the CAA governs motor vehicles and is titled "Emission Standards for Moving Sources." Title II confers on EPA authority to regulate road and non-road mobile sources of air pollution, including marine engines.

When the modern Clean Air Act was adopted in 1970 (and subsequently amended in 1977), it did not cover non-road vehicles. With respect to pollution from road vehicle emissions, it provided certain absolute emissions limits (e.g., total limits on hydrocarbon emissions), but also conferred on EPA the authority to develop "technology based" standards, and to differentiate emission standards between classes and categories of vehicles and engines.[4] Such differentiation was needed because, for example, diesel engines produce a different emissions profile than traditional gasoline engines, emitting substantially more particulate matter, but less carbon monoxide. After 1970, the EPA also began studying vehicle fuel economy, and by the mid-1970s, lead was being phased out of gasoline and the Corporate Average Fuel Economy (CAFE) standards were developed to improve fuel economy.

NON-ROAD DIESEL ENGINES AND THE 1990 CLEAN AIR ACT AMENDMENTS

Regulation of heavy duty diesel engines began in the mid-1970s, and the 1977 Amendments to the CAA directed the EPA to focus on diesel emission reductions and to set additional standards for heavy-duty vehicles, but also required a four-year lead time for compliance once the new emission standards were promulgated[5]. Delays ensued for a variety of reasons, prompting a successful lawsuit against the EPA to develop those standards, and on March 15, 1985, the EPA issued its final rule regulating nitrogen oxides and particulate matter from heavy-duty engines.[6]

[2] 42 U.S.C. § 7401(b)(1).
[3] 40 C.F.R. § 50.4 - §50.19.
[4] 42 U.S.C. § 7521
[5] 42 U.S.C. § 7521(a)(3)(C).
[6] 50 Fed. Reg. 10606 (March 15, 1985).

A major set of amendments to the CAA was enacted in 1990, extending CAA regulatory authority to non-road (e.g., marine and locomotive) engines, and directed the EPA to establish stricter emissions standards for diesel trucks (heavy-duty diesel engines). Based on this new 1990 CAA authority, the EPA engaged in a series of rulemakings to set emission standards for non-road engines, and to further reduce heavy-duty truck engine emissions.

TRUCKS, TRAINS, AND MARINE ENGINES – POLLUTION REDUCTION

Trucks: On October 21, 1997, the EPA issued a final rule adopting new emission standards for heavy-duty diesel trucks applicable beginning with model year 2004 vehicles.[7] The rule focused on the prevention of ozone (formed by NOx and VOC emissions) and particulate matter, and provided two alternative standards to which engine manufactures would be required to certify their engines beginning with 2004 models.[8] In 2000, new emissions reductions were introduced, including requirements for low sulfur diesel fuel and exhaust diesel particulate filters, that would apply to model year 2007 and later.

A major enforcement action in 1997 against diesel engine manufacturers, and the subsequent settlement in 1998, had a significant impact on emission standards development for diesel truck engines and non-road engines, including marine engines. The EPA and the U.S. Department of Justice sued virtually all the major manufacturers of heavy-duty diesel engines in the United States for allegedly utilizing an illegal "defeat device" to avoid certain emission requirements. The EPA asserted that the engines were designed to recognize testing conditions, so that during EPA emission testing, the engines passed emission standards. However, during on-road, highway driving conditions, the engines were programmed to maximize fuel-efficiency, which resulted in higher NOx emissions in excess of applicable standards. The settlement of this case resulted in a Consent Decree (a settlement between the parties in the form of an enforceable court order), the terms of which the parties agreed to extend to non-road diesel engines.

In January 2020, the EPA issued an advanced notice of proposed rulemaking[9] announcing the Cleaner Trucks Initiative. The EPA has been working with engine manufacturers, end users, health organizations, and others to reduce NOx and other emissions from heavy-duty diesel trucks and to develop the proposed rule, which is expected in 2021.

Locomotives: Two months after the 1997 heavy-duty highway engine rule was promulgated, the EPA also finalized its diesel locomotive standards (proposed in early 1997) to be phased in starting January 1, 2000. The final rule was signed by the EPA on December 17, 1997 but formally promulgated in 1998.[10] The rule established standards for NOx, HC, CO, and smoke emissions from all new locomotive engines (manufactured after the effective date of the rule, June 15, 1998, and from old locomotives originally manufactured after January 1, 1973 but remanufactured[11] after June 15, 1998.[12] The rule was intended to capture the remanufacturing practices of Class I railroads only, and certain small railroads were exempted from the rule.

The 1998 locomotive rule established three sets of standards known as Tier 0, Tier 1, and Tier 2 emission standards,[13] with the date of engine/locomotive manufacture determining which Tier regulation would apply. Tier 0 standards applied to engines manufactured (or remanufactured) from 1973-2001; Tier 1 applied to original manufacture from 2002-2004, and Tier 2 applied to manufacture in 2005 or later. Each Tier's emissions limit for hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter were progressively stricter (i.e., lower emission limits).

In 2008, the EPA adopted additional regulations that further lowered emission limits in Tier 0-2 trains, and introduced Tier 3 and Tier 4 standards, applicable to 2012-2014 engines (Tier 3) and to 2015 or later (Tier 4).

[7] 62 Fed. Reg. 54694 (Oct. 21, 1997) (Control of Emissions of Air Pollution from Highway Heavy-Duty Engines).

[8] The standard was described as the nonmethane hydrocarbon ("NMHC") plus nitrogen oxides standard and required engines to be certified to either (1) 2.4 g/bhp-hr NMHC+NO, or (2) 2.5 g/bhp-hr NMHC+NOX with a limit of 0.5 g/bhp-hr on NMHC.

[9] 85 Fed. Reg. 3306 (Jan. 21, 2020).

[10] 63 Fed. Reg. 18978 (April 16, 1998) (Emission Standards for Locomotives and Locomotive Engines).

[11] Remanufactured means a "process in which all of the power assemblies of a locomotive engine are replaced with freshly manufactured (containing no previously used parts) or refurbished power assemblies or are inspected and qualified." 63 Fed. Reg. at 18980.

[12] 63 Fed. Reg. 18978 (April 16, 1998).

[13] The "Tier" approach of the locomotive rule emerged from the 1990 CAA Amendments and subsequent EPA regulations initially established for vehicles that were to be phased in for vehicle models 1994-1998, known as "Tier 1" standards. The CAA standards existing prior to the 1990 Amendments and subsequent regulations were then referred to as "Tier 0", or pre-Tier, standards. Tier 2 standards for vehicles were promulgated on December 21, 1999 and phased in between 2001-2009 (later phase in dates for certain passenger trucks), and Tier 3 standards were promulgated on March 3, 2014 (to be phased in 2017-2025). The law required the vehicles to meet the applicable Tier standards for a certain number of years, or miles, whichever occurred first.

Marine Engines: The EPA's marine diesel engine rule was issued on December 29, 1999[14] and applied to manufacturers of marine diesel engines. Because the marine engines subject to the rule were diverse in terms of size, technology and costs to reduce emissions, the EPA established three engine categories in the rule, based on displaced volume per-cylinder (Table 1).

Table 1. Marine Diesel Engine Emission Standards-Engine Category Descriptions

Engine Category	Displacement per Cylinder
1	disp. < 5 liters (and power ≥ 37 kW)
2	5 ≤ disp. < 30 liters
3	disp. ≥30 liters

Category 1 engines are typically used on small commercial vessels, including some tugboats. Category 2 engines are larger engines typically used in the inland marine fleet, on harbor vessels and on vessels operating on U.S. coastal waters. The EPA expressly recognized that Category 2 engines are similar in size and technology (including emission control technology) to locomotive engines. Indeed, the same engines used in some locomotives are used in marine application. Category 3 engines are the largest engines used exclusively in trans-ocean shipping.

Category 1 and 2 engines were further divided into subgroups. Category 1 subgroups were divided based on the same subgroups used in land-based, non-road engines, but using per-cylinder displacement rather than engine power for the groupings. Category 2 marine engines were also categorized, with stricter emissions standards for the larger engines.

Tier 2 non-road engine standards applied to Category 1 and 2 marine engines, while Category 3 engines were exempted from the rule (and ostensibly covered by rules of the International Maritime Organization's Convention for the Prevention of Pollution from Ships (MARPOL)). EPA later issued a rule in 2003 applying certain emissions standards equivalent to MARPOL requirements to Category 3 engines.

Tier 3 and Tier 4 engine standards – applicable to both locomotive engines and marine engines less than 30 liters per cylinder (excluding Category 3 engines) – were introduced in 2008 and focused on NOx and PM. Certain standards applied to new engines manufactured in 2009 or later and existing engines when remanufactured. Longer term standards applied to engines manufactured in 2014 (for marine diesel engines) and 2015 (for locomotives). Tier 3 and 4 standards include the use of catalytic exhaust treatment technology. An earlier non-road engine rule had lowered sulfur limits in marine fuel to enable certain exhaust treatment technologies.[18]

[14] 64 Fed. Reg. 73300 (Dec. 29, 1999) (Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or Above 37 kW).

[15] Although the applications have different considerations, rail and shipping have close links and many of the same technologies being evaluated for decarbonizing the inland river sector are also being considered for the rail sector. Rail is currently looking closely at both electric and hydrogen, and the world's first hydrogen powered train (passenger) has been in service in Germany since 2018, with manufacturer Alstom set to deliver more.

[16] 64 Fed. Reg. 733300 at 73306.

[17] 73 Fed. Reg. 25098 (May 6, 2008).

[18] See e.g., 40 C.F.R. § 1042.101 (Exhaust emission standards for Category 1 and Category 2 engines).

[19] 75 Fed. Reg. 25324 (May 7, 2010).

[20] The Energy Independence and Security Act of 2007 separately directed NHTSA to study fuel efficiency standards for heavy duty trucks, and to set standards that reflect the "maximum feasible" achievement by manufacturers in the applicable year. 49 U.S.C. § 32902

GREENHOUSE GAS REGULATIONS

The first action taken to regulate GHGs from mobile sources occurred in 2010, when the EPA and the Department of Transportation's National Highway Traffic Safety Administration issued new CAFE standards and greenhouse gas emissions standards, applicable only to light-duty vehicles.[19] The rule established a fleet-wide average carbon dioxide emission standard, and maximum tailpipe nitrous oxide and methane emissions. Importantly, the rule was jointly issued through the DOT's authority to issue CAFE standards[20] and the EPA's authority to issue emission standards, with both agencies recognizing the direct relationship between fuel efficiency and CO_2 emissions from mobile sources.

The first GHG emissions rules applicable to heavy-duty engines were issued in 2011, also jointly by the EPA and the DOT, known as the Greenhouse Gas Emissions Standard and Fuel Efficiency Standards for Medium and Heavy-Duty Engines and Vehicles[21]. The rule applied to "all motor vehicles with a gross vehicle weight rating of 8,500 pounds or greater, and the engines that power them,"[22] which included heavy-duty trucks.[23] The 2011 rule was considered Phase 1, and Phase 2 rules were finalized in 2016 (which also updated and clarified certain marine diesel emission standards).[24] The 2016 standards applied to model years 2021-2027 for certain heavy-duty trucks. In general, the industries impacted by these rules were involved in their development and were supportive of a single national program to address GHG emissions and fuel efficiency.

The U.S. has rejoined the Paris Agreement and submitted a new Nationally Determined Contribution (NDC) which is the country's goal for emission reduction. The U.S. has pledged to reduce greenhouse gas emissions by 50-52 percent below 2005 levels by 2030, and to reach net-zero emissions by 2050. Achieving this goal will require substantial reductions from the transportation sector.

A focus on lower-carbon fuels is an important strategy being pursued to reduce GHG emissions. Because of the long life of inland marine vessels, technology improvements applicable to new models has a slow impact on GHG emissions reductions. A change of fuel, however, can have an immediate impact. California's Low Carbon Fuel Standard takes this approach, and may ultimately find its way to EPA regulations.

[21] 76 Fed. Reg. 57106 (Sept. 15, 2011).
[22] 76 Fed. Reg. 57106.
[23] 42 C.F.R. §1042.1. The emission standards promulgated in 2010 applied to Category 2 engines beginning with Model Year 2013 engines.
[24] 81 Fed. Reg. 73478 (October 25, 2016).

U.S. INLAND WATERWAY FREIGHT MARKET OVERVIEW

THE 21ST CENTURY MISSISSIPPI RIVER MARKETS: A PERIOD OF STABILITY AND RESILIENCE

Like most freight transportation activity, commodity movements by barge are demand triggered by final or intermediate consumer needs. Because the typical single barge carries more than 1,500 tons, the cargoes that typically move by barge are bulk commodities used in large quantities. The most common commodities are agricultural products and raw materials used in manufacturing, construction, refining, or in the generation of electricity.

Because barge shipping requires large quantities of cargo to make it economical, there is typically significant investment in the terminal facilities that must be erected along the waterway to support loading and unloading activities. To maximize the economic benefit of low-cost waterway transport, the producing or consuming facilities themselves – steel mills, power plants, refineries, etc. – were often also located adjacent to the river, further minimizing transportation costs. The vast majority of investments in these facilities occurred during the latter half of the 20th century as the U.S. enjoyed a period of significant economic growth and a largely self-sufficient domestic economy, factors reflected in the corresponding robust growth in barge traffic.

The completion of the modern inland waterway network described above, and the deployment of a uniform towboat/barge system through the agricultural and industrial heartland of the country, stimulated the nation's post-WWII success and saw dramatic increases in system usage and corresponding growth in the fleets of required towboats and barges.

The expansion of the waterway system's capacity over this period coincided with rapid growth in steelmaking, refining and other industrial and manufacturing activities. Tonnage growth during this time was most pronounced in the coal sector. As the steel industry blossomed, coal demand rose to serve the steel sector, and was transported by barge in addition to the tremendous amount of coal required to fuel the numerous coal-fired power plants built along the network – especially along the Ohio River. Coal became the inland river shipping industry's largest commodity carried, and overall tonnage increased steadily during the last third of the 20th century. By the year 2000, coal cargo shipments exceeded 500 million tons, which proved to be the high-water mark for use of the inland system.

To accommodate this growth, the barge fleet expanded to approximately 20,000 barges. More than three-quarters of these barges were open and covered hoppers handling dry bulk cargos and the remainder were tank barges. A detailed discussion of the various markets served, and their respective outlooks is provided below in Table 2.

As shown in Figure 6, despite the evolving shift of the U.S. economy toward imports and services over the last 20 years, the large collateral investments, natural efficiency, and low cost of barge service has resulted in remarkably stable barge demand, for most commodities, over the last 20 years after the industry's peak years early in the 21st century.

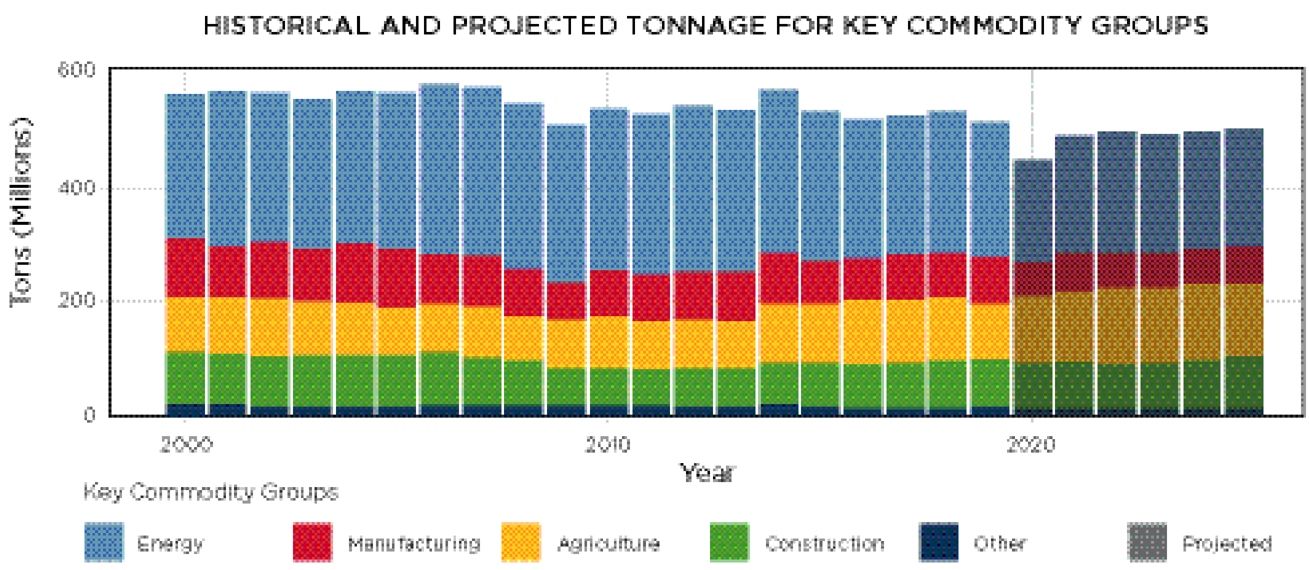


Figure 6. Historical and projected tonnage for key river-served markets.

Table 2 (below) provides a detailed look at market demand by commodity for the years 2000, 2010, and 2019 (the last year for which full historical records were available at the time the marketing forecasts were made), and the projected demand in 2025. The decadal snapshot detailed below illustrates the overall market dynamics and realities that also determine overall towboat demand.

Table 2. Decadal Summary of Inland Market Demand (Millions of Tons and Billions of Ton Miles)

		2000	2010	2019	2025 (Forecast)	2025 as % of 2000
ENERGY	Utility Coal	146	154	85	71	49%
	Crude Oil	16	15	30	27	169%
	Refined Petroleum Products	45	56	70	57	127%
	Residual Fuel Oil	28	32	24	19	68%
	Other Energy	19	25	29	32	168%
	Total Energy	**254**	**281**	**238**	**206**	**81%**
MANUFACTURING	Metallurgical Coal/Coke	42	34	24	24	57%
	Raw Materials	25	18	20	23	94%
	Chemicals	26	24	26	25	97%
	Steel	10	4	11	8	84%
	Total Manufacturing	**102**	**80**	**81**	**81**	**79%**
AGRICULTURE	Farm Products	78	72	74	86	110%
	Fertilizer	10	12	16	17	168%
	Other Agriculture	8	6	6	6	80%
	Total Agriculture	**96**	**90**	**96**	**109**	**113%**
CONSTRUCTION	Cement	10	6	9	10	96%
	Limestone	25	25	25	27	110%
	Asphalt	7	6	12	13	171%
	Sand/Gravel	46	27	38	41	88%
	Forest Products	6	2	2	2	38%
	Total Construction	**84**	**66**	**85**	**92**	**98%**
	Other	**17**	**18**	**14**	**14**	**81%**
	Total Tons (Millions)	**563**	**535**	**514**	**502**	**89%**
	Total Tons Miles (Billions)	**291**	**255**	**244**	**256**	**88%**

DECADAL HIGHLIGHTS: 2000 TO 2010

After a long period of sustained growth in the latter third of the 20th century, overall barge traffic volumes on the inland waterway system peaked around 2000 and remained stable until the recession years of 2008-2010. Approximately one-half of all the tonnage carried in 2000, 2010, and 2019 were related to energy production and use, with the rest split relatively evenly between the agricultural, manufacturing and construction/other markets. Traffic patterns for each commodity segment varied; for example, most movements of construction-related products were of low-value commodities that involved relatively short distances of a few hundred miles. By contrast, movements of farm products involved high-value feed crops like corn and soybeans and were transported over distances greater than a thousand miles – from the Upper Midwest to New Orleans. A substantial amount of grain is moved to New Orleans for foreign export, with the Lower Mississippi ports between Baton Rouge and New Orleans serving as the U.S. gateway for grain exports, through which nearly three-quarters of all U.S. grain exports travel. Due to the significant worldwide recession in 2008-2010, overall grain volumes in 2010 were 17 percent lower than in 2000.

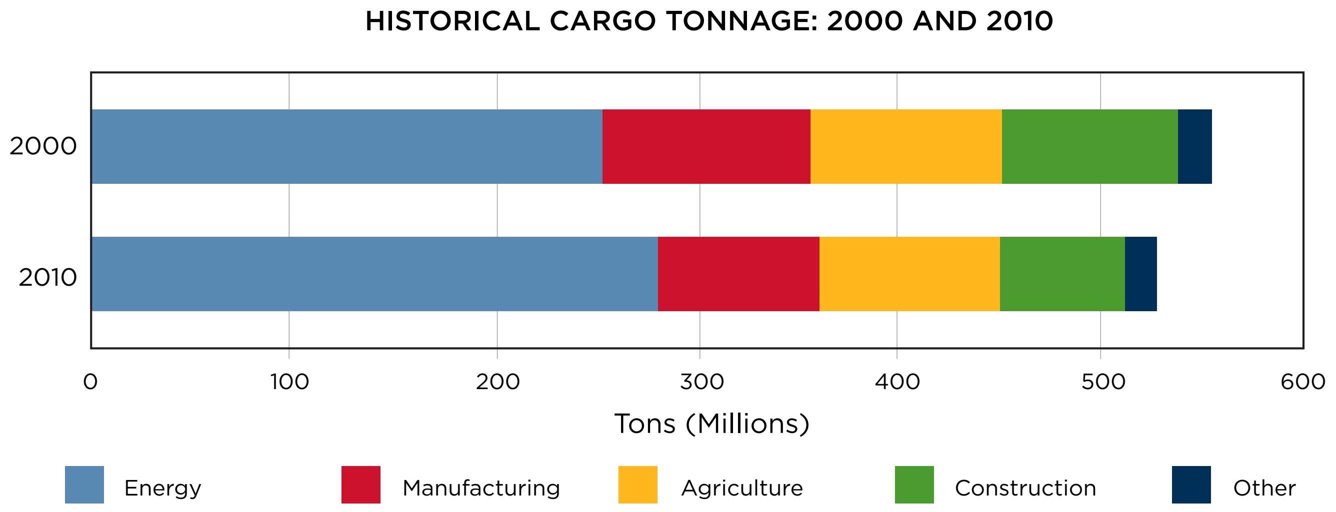


Figure 7. Historical cargo tonnage comparison: 2000 and 2010.

As shown in Figure 7, the construction segment certainly suffered most directly from the effects of the recession, with tonnages down more than 30 percent. Additional declines in every part of the manufacturing sector (with many commodities declining in tonnage by 20 percent or more from 2000 to 2010) can also be attributed to the well-known effects of trade liberalization and offshoring of domestic manufacturing. During this period, energy sector tonnages actually increased, with stable volumes of coal to serve the electric utility sector and significant growth in petroleum-related commodity areas that would accelerate beyond 2010.

DECADAL HIGHLIGHTS: 2010 TO 2019

Figure 8 below shows that despite the extraordinary macro changes in the overall U.S. economy between 2010 and 2019, total tonnages in 2019 relative to 2010 were down by only four percent overall. Manufacturing volumes did not recover, but construction and agriculture both rebounded, construction by approximately 30 percent and agriculture by nearly seven percent. These increases were sufficient to offset the decline in energy tonnages of around 15 percent.

Within the energy sector, however, dramatic shifts are apparent, as shown in Figures 9 and 10. The utility coal sector declined more rapidly than experts anticipated, due primarily to advances in hydraulic fracturing technology that substantially increased access to U.S. natural gas reserves that previously were uneconomical to produce. Natural gas was both cheaper and cleaner than coal, making coal less competitive with respect to both economics and environmental considerations. An overall decline of nearly 45 percent in coal delivered to power utilities was unexpected and disruptive.

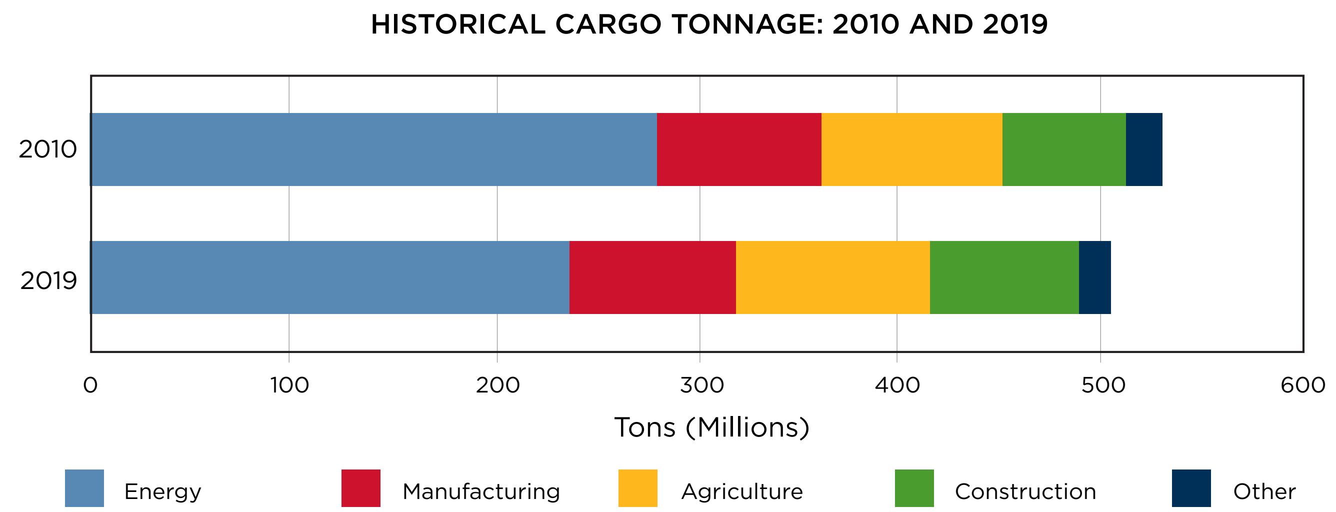


Figure 8. Historical cargo tonnage comparison: 2010 and 2019.

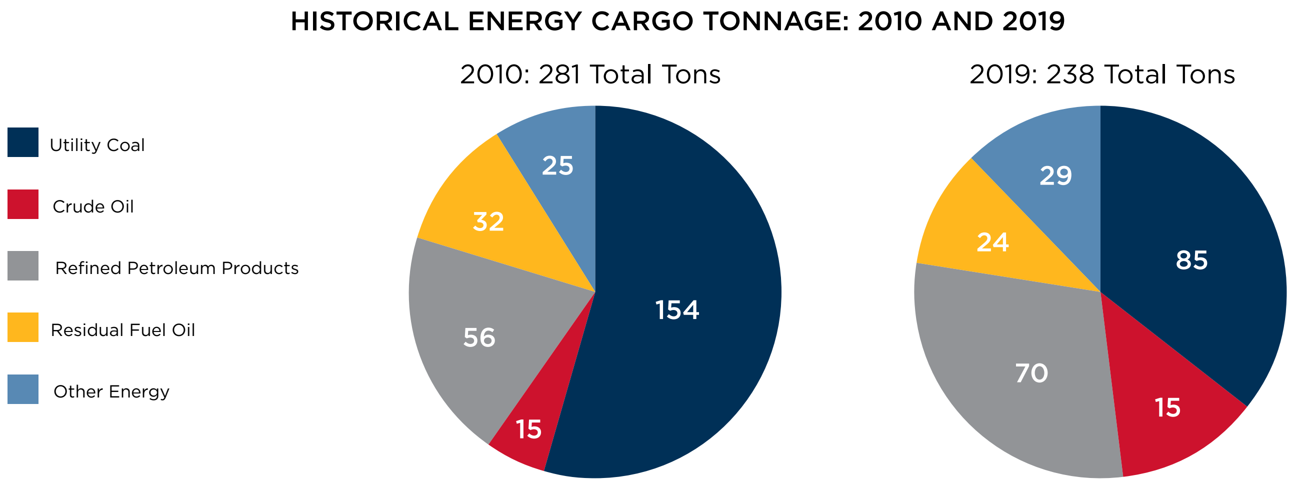


Figure 9. Historical energy cargo tonnage comparison: 2010 and 2019.

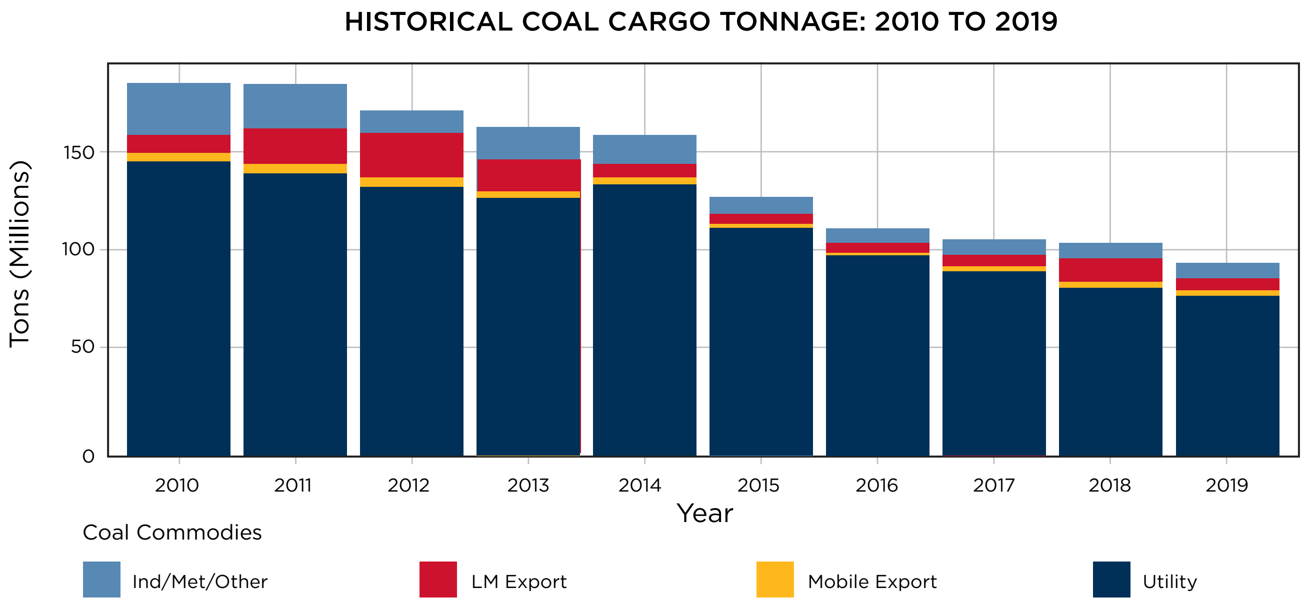


Figure 10. Historical coal tonnage from 2010 to 2019.

Hydraulic fracturing advances also increased access to U.S. oil reserves, so increased tonnage in crude oil and petroleum-related commodities offset some of the substantial coal volume decline (Figure 9). Crude oil volumes doubled from 2010 to 2019 and refined petroleum products increased by 25 percent as a result of the changing production and refining patterns.

OUTLOOK: 2019 TO 2025

The freight forecast in this report extends to 2025 from 2019, which is a relevant timeframe to inform the potential for market influence on near-term decarbonization pathways. This report sets forth a bottom-up analysis of demand drivers by market segment.

The last 20 years validate that the underlying markets relevant to barge demand are stable and resilient, and the summary outlook for 2025 anticipates that tonnages will be slightly lower and ton-miles slightly higher than 2019. The increase in ton-miles is in spite of a reduction of tons and is the result of a generally bullish outlook for the agricultural sector, which is expected to increase by nearly 15 percent. Most agricultural barge transports are also long-haul shipments of 1,000 miles or more. In short, the U.S. is expected to retain its position as one of the world's largest grain exporters (Figure 11).

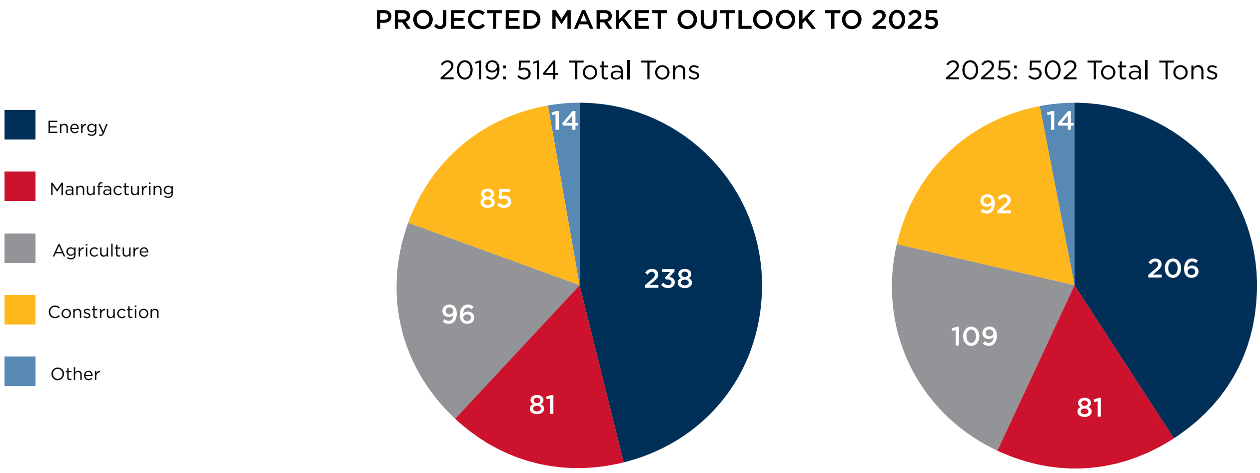


Figure 11. Projected market outlook to 2025 for total ton movement as compared to 2019 observed data.

As shown in Figure 12 below, the energy sector sees the most significant projected change, reflecting a continuing decline in utility coal use, and the beginning of a gradual shift away from petroleum use across numerous economic sectors as decarbonization policies and practices are implemented, impacting overall refined petroleum demand. While there is considerable uncertainty about the long-term reliance on natural gas for power generation relative to other renewable sources, it is clearly favored as a bridge fuel and will continue in the medium term to displace coal as a utility fuel source, leading to the bearish outlook for utility coal.

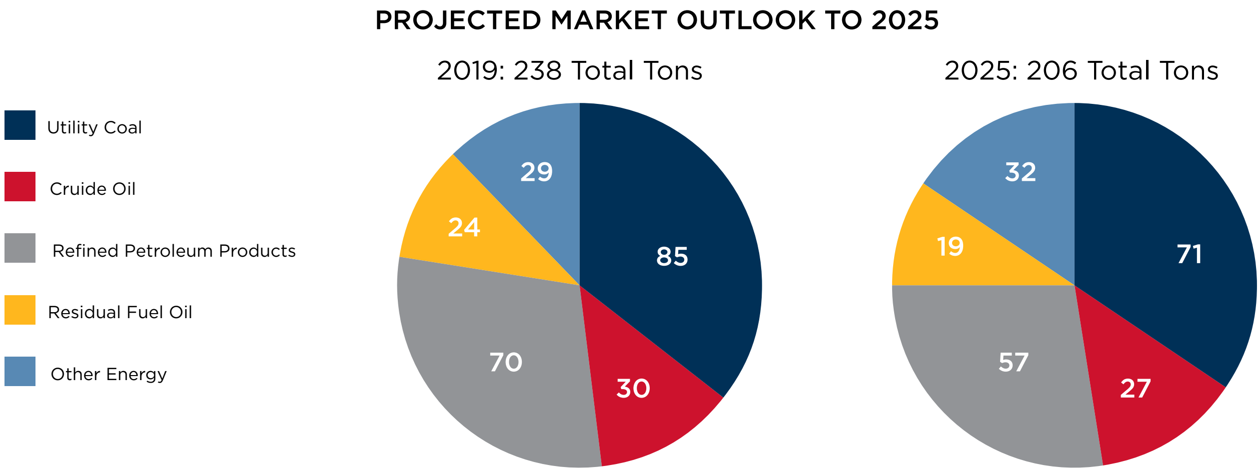


Figure 12. Projected energy market outlook for 2025 as compared to 2019 observed energy market tonnage data.

Manufacturing and construction are expected to be stable over the forecast horizon (Figure 11). A focus on infrastructure reinvestment should also support raw materials movement related to road and other infrastructure construction.

SUMMARY OF THE MARKET ASSESSMENT AND IMPLICATIONS FOR TOWBOAT FLEET NEEDS

The factors and trends which have impacted domestic waterborne commerce over the last 20 years are not expected to change dramatically during the forecast period, or likely beyond. The cost efficiencies of river barge transport are likely to retain the markets that developed to leverage this benefit, such as export-oriented agriculture, construction aggregates, and other low value bulk raw materials necessary for infrastructure reconstruction. Unfortunately, the natural limitations of the geographical reach of the network of navigable waterways will not be expanded and thus limits any expanded opportunities for growth.

From the perspective of the towboats required to support market demand, there will therefore not be a driver for new construction created by market growth. To the extent that the current fleet is adequately sized to meet market demand, it is likely that repowering existing vessels may be the most economic and practical approach to decarbonization.

CURRENT GREENHOUSE GAS EMISSIONS PROFILE OF THE INLAND FREIGHT SECTOR

The EPA annually reports on the U.S. GHG emissions profile by economic sector through a comprehensive inventory of emissions and sinks. The U.S. marine emissions profile (emissions attributable to the "ships and boats" category as designated by EPA) is based on marine fuel consumption data, which in turn is estimated using Fuel Oil and Kerosene Sales data from the U.S. Energy Information Administration. However, the total emissions from U.S. marine fuel consumption as indicated in the EPA's emissions inventory does not differentiate between vessel type or location and therefore includes coastal ships in addition to the inland river fleet. This project aimed to estimate the GHG profile of the inland river fleet which, based on the fleet's small boat size and shorter hauling distances (when compared with trans-ocean vessels), differs in important ways from the international shipping sector. Because the towboat fleet profile is relevant to any decarbonization strategy, a summary of the inland river industry fleet profile is provided below as well as an estimate of the industry's annual fuel consumption and corresponding GHG emissions. Fleet profile data and some fuel consumption data was obtained from the Inland River Record, a database updated annually by industry professionals that lists nearly every commercial towboat and tugboat operating on the Mississippi and Ohio Rivers and their tributaries.

TOWBOAT FLEET PROFILE

As described in more detail in the U.S. Inland River Navigation System: Background and Historical Perspectives section, towboat construction surged in the 1970s and 1980s, yet towboats can (and do) operate for many decades. Indeed, many of the tugboats operating today are over half a century old (see Figure 5). The long lifespan of river towboats is a critical consideration in the decarbonization effort because constructing new boats that could be designed to accommodate particular propulsion technologies where retrofitting is difficult or impossible is not likely to occur. The long lifespan of inland river vessels is attributed to the reality that the river network constraints have not allowed for operation of larger and larger vessels, as has occurred in the ocean-water domain. Operations are also conducted primarily in fresh water, as opposed to ocean vessels that have constant exposure to salty and corrosive ocean conditions (see Figure 13 below). Inland marine engines also have long life spans, and it is not uncommon to find the same engine in a towboat operating for more than 40 years, delaying (nearly indefinitely) shifts to lower-emitting newer engines that have only been required by regulation when an older engine is replaced.

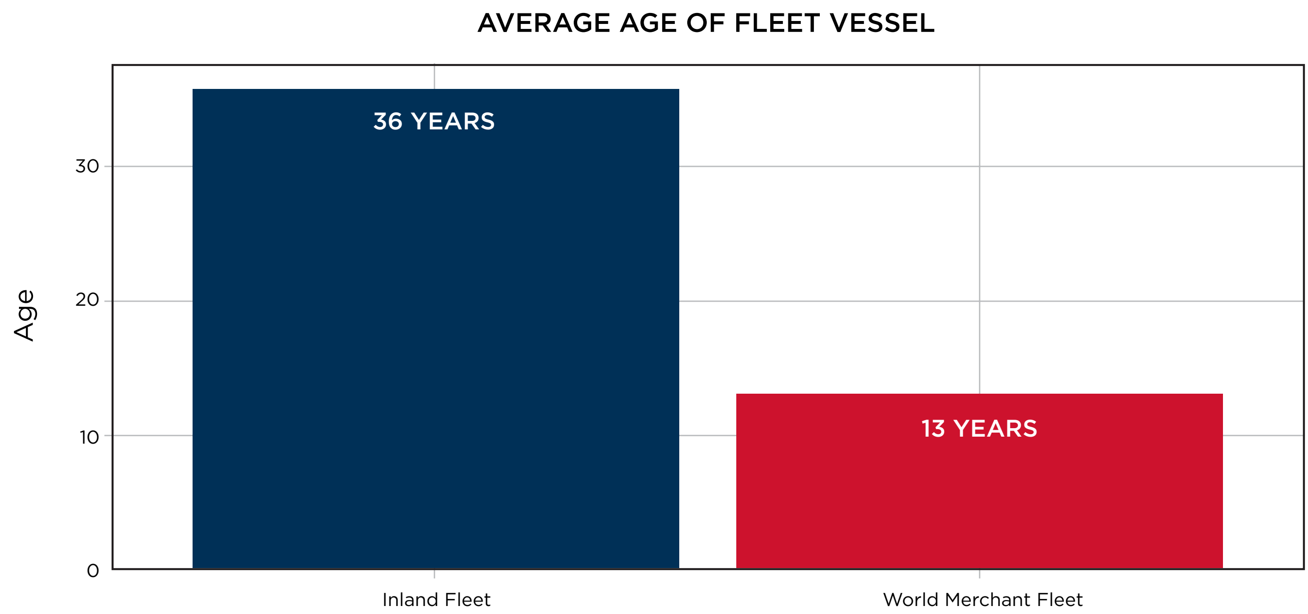


Figure 13. Average age of trans-ocean commercial vessels as compared to average age of inland waterway fleet

[25] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2019, EPA 430-R-21-005, available at https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf.

[26] Inland River Record, available at https://www.waterwaysjournal.net/books/inland-river-record/.

[27] Source for average age of merchant marine fleet (ocean vessels) is SAE International, Average Age of Ocean Going Ships, Department of Defense Maintenance Symposium presentation, available at https://www.sae.org/events/dod/presentations/aging-halsch-part3.pdf.

Another fleet profile consideration related to decarbonization goals is the horsepower categories of inland boats. Smaller horsepower boats, known as the "fleet boats" could be retrofitted to electric propulsion systems, but the larger horsepower boats cannot – the size of the batteries needed (with current technology) to provide the required power and range before recharging cannot be presently accommodated while maintaining boat buoyancy. However, because a significant number of the industry vessels are in the lower horsepower range (see Figure 14), electrifying only the fleet boats is estimated to reduce total industry fuel burn by approximately 100 million gallons annually, a substantial overall emissions reduction (approximately 20 percent of overall inland industry GHG emissions). Table 3 sets forth a representative company's range of annual average fuel burn per vessel horsepower category (courtesy of Ingram Barge Company).

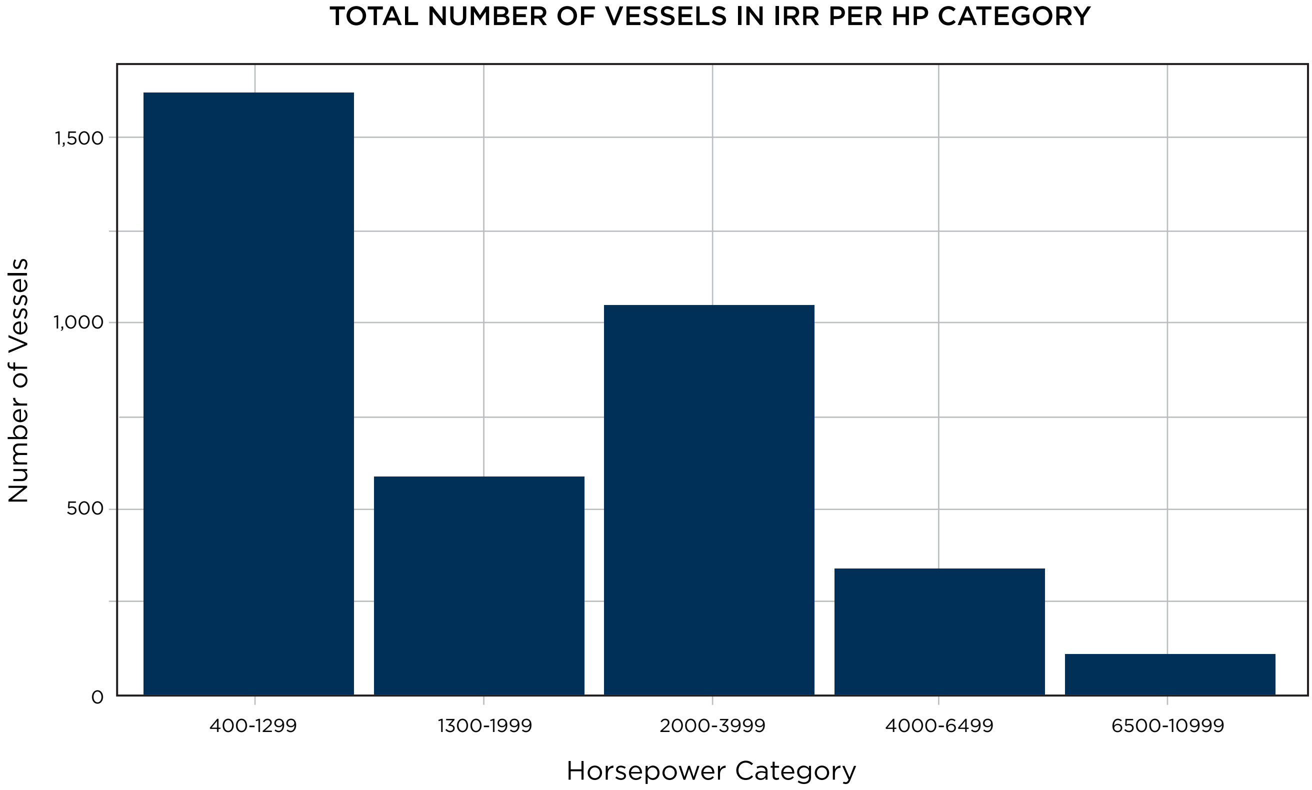


Figure 14. Industry fleet profile: Total number of vessels (as identified in the Inland River Record dataset) in relevant horsepower classes

*Table 3. Approximate annual fuel consumption ranges per vessel horsepower category**

Vessel Horsepower Category	Approximate Annual Fuel Range (Gallons)
400-1299	75,000 - 125,000
1300-1999	150,000 - 275,000
2000- 3999	325,000-450,000
4000-6499	425,000 - 650,000
6500-10999	650,000 - 1,900,000

*Annual average fuel consumption can vary substantially depending on vessel operating days. This figure is intended only to provide general, approximate values. Figures rounded to nearest 25,000.

ESTIMATE OF ANNUAL FUEL CONSUMPTION, CO_2 EMISSIONS AND CARBON INTENSITY

For this report we obtained accurate annual fuel burn data for one of the largest inland barge companies in the U.S. Based on the market share that company represents, we extrapolated total industry fuel and validated that data against fuel tax receipts as reported by the Federal Government. Some estimation was required because not all fuel used in the inland sector is subject to fuel tax (only fuel used for propulsion is taxed and some operating segments are exempt from taxation). Based on total fuel consumption of approximately 550 million gallons, and 10.21 kg of CO_2 released per gallon, total CO_2[28] emissions of the inland waterway sector is approximately 5.67 billion kilograms of CO_2. Using this inland waterway emissions data, and data from the EPA's greenhouse gas inventory for other transportation modes, Figure 16 compares total GHG emissions from various transportation modes.

Because Figure 15 represents total emissions, comparing the carbon intensity (the amount of CO_2 produced per ton of cargo moved) and fuel intensity (the number of gallons of fuel burned per ton of cargo moved) is a more accurate measure of emissions associated with moving freight and provides better comparison between modes. As shown in Figures 16 and 17, the inland river sector has some advantages from this perspective.

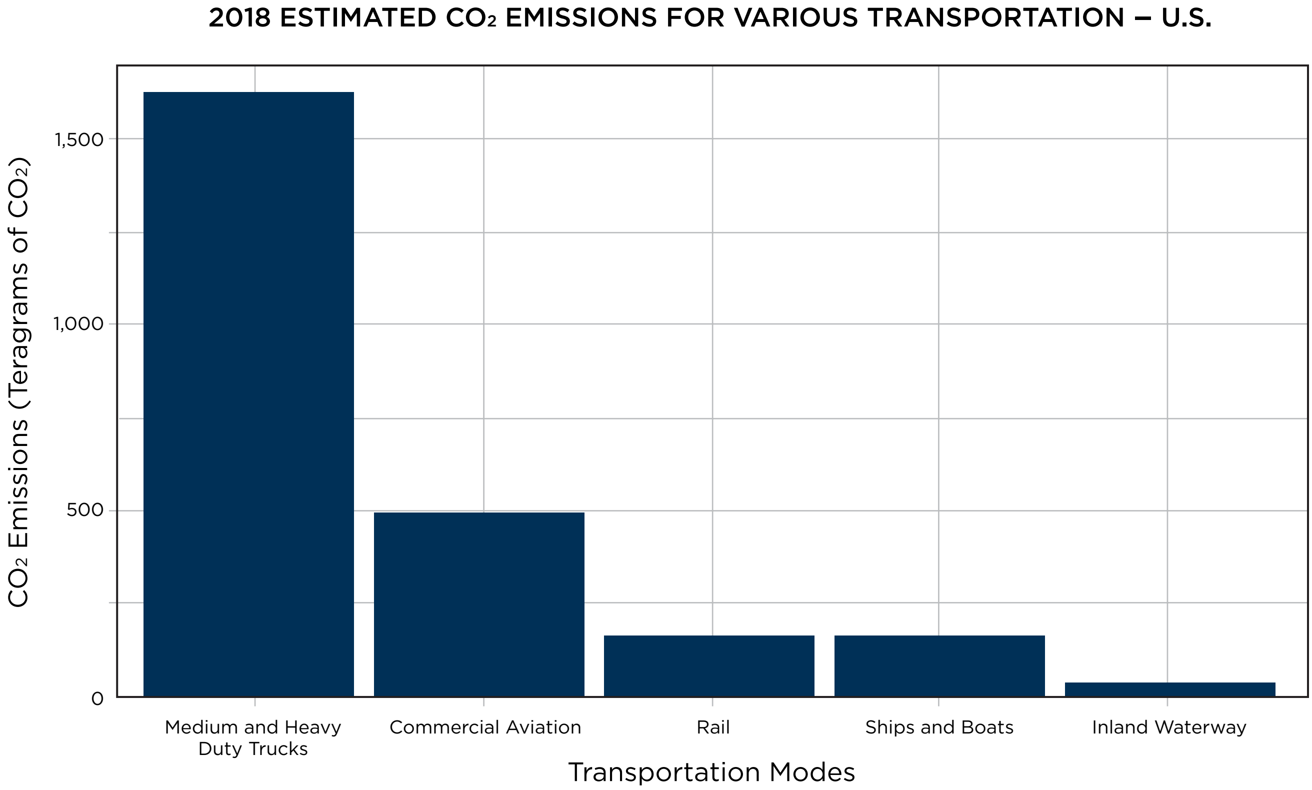


Figure 15. GHG emissions modal comparison. Commercial Aviation does not include passenger air traffic. Ships and Boats category may include some inland waterway. Data for inland waterways was calculated as part of this project; data for other modes was obtained from EPA's annual GHG inventory.

[28] CO_2, GHG and CO_2-e (CO_2-equivalents) are used interchangeably in this report because non-carbon dioxide greenhouse gas emissions are such a small component of the total emissions from the inland waterway sector as not to have a significant impact on GHG emission calculations.

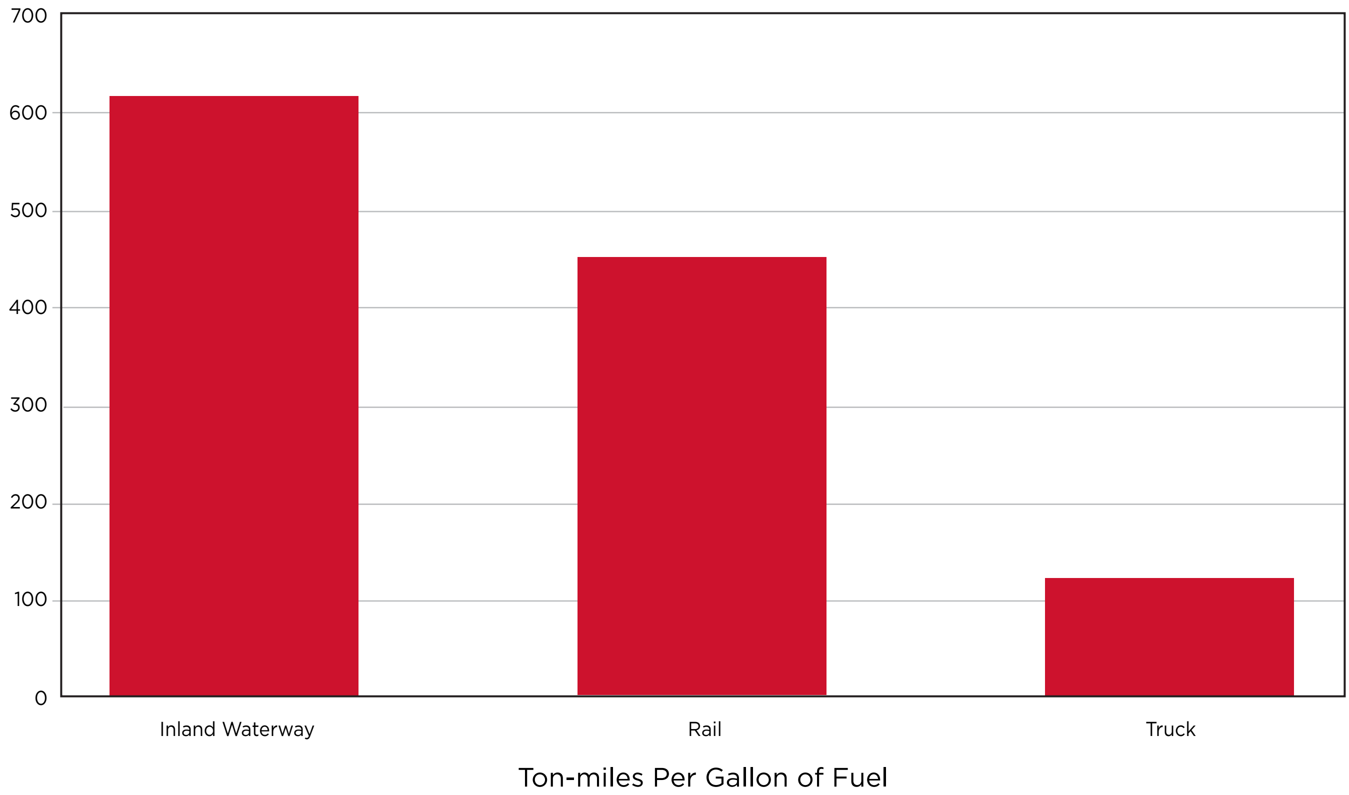


Figure 16. Fuel intensity by transportation mode. Source: Texas Transportation Institute (2017)

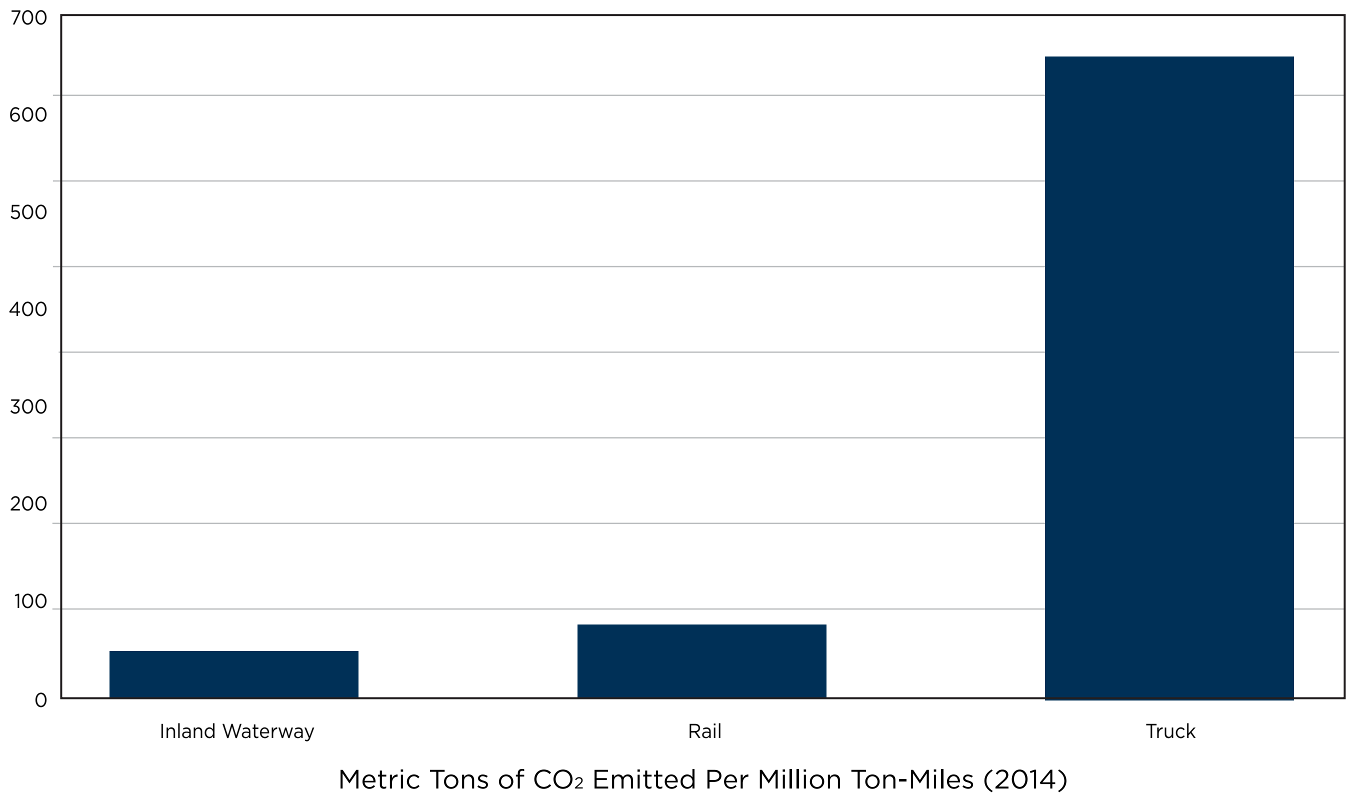


Figure 17. GHG intensity by mode. Source: Texas Transportation Institute (2017)

DECARBONIZATION POLICY AND TRAJECTORY

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and is the international scientific body established to provide reports on the science of climate change to policymakers. Although the IPCC does not conduct independent scientific research, it collects, analyzes and synthesizes the vast amount of scientific literature on climate change and produces periodic reports on the state of climate science, and special reports when tasked to do so by the United Nations and its working groups. In 2018, the IPCC issued a Special Report concluding that in order to limit warming to 1.5°C above pre-industrial average temperatures (the temperature at which some, but not all, of the worst impacts of climate change may be avoided), the world needed to reduce annual GHG emissions by approximately 50 percent of current annual global emissions by 2030, and reach net-zero emission around 2050. The world is not on track to meet this target.

The U.S. has identified climate change as one of this administration's top priorities and announced in April 2021 a new U.S. target to achieve by 2030 a 50-52 percent reduction of GHG emissions from 2005 levels. Numerous U.S. states have also actively been pursuing emissions reduction schemes. This section of the report identifies international and domestic policies and trajectories that may impact the inland waterway sector.

INTERNATIONAL AGREEMENTS AND ACCORDS

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty established in 1992 to provide the international framework for countries to cooperatively address climate change. The U.S. became a party in 1992. The treaty set forth an international mechanism for countries to work together to address climate change, and through that framework numerous sub-agreements have been subsequently negotiated and implemented, such as the Kyoto Protocol and the Paris Agreement.

The Paris Agreement, adopted in 2015, is generally recognized as the world's most important international climate change agreement because it represents the first time that nearly every country on earth agreed to reduce their GHG emissions and make progress on climate change. The stated goal of the Paris Agreement is to limit global warming to less than 2°C and included a higher ambition to limit warming to no more than 1.5°C above pre-industrial average temperatures. The Paris Agreement contains very few binding requirements other than the agreement by each nation to develop an emissions reduction pledge, known as Nationally Determined Contributions (NDCs), and then to meet every five years to announce progress towards those NDC goals. Each nation, including the United States, is to determine its own emissions reduction goals, and implement them according to its own internal domestic policy.

The U.S. has re-joined the Paris Agreement effective as of February 19, 2021. In April of 2021, the administration formally communicated its new NDC to the UNFCCC, stating a 2030 emissions target of 50-52 percent reduction of GHG emissions from 2005 levels. The administration has announced a "whole of government" approach to address climate change and will use the federal procurement power as well as work with the private sector and local and state governments to achieve these reductions.

The new U.S. NDC identifies transportation as one of six action areas and includes shipping as one of several transportation modes still heavily dependent on fossil fuels. The NDC also identifies priority policies to decarbonize transportation including investment in infrastructure and funding for research, development, and deployment of low- and zero-carbon fuels. The NDC expressly states that the U.S. is exploring decarbonization routes for the maritime industry both through domestic policies and the International Maritime Organization (IMO).

The IMO is a United Nations agency established as a Convention with 174 member nations, including U.S. delegations led by the EPA. Through the promulgation of standards, the IMO governs many aspects of international shipping including safety, fuels and pollution. The International Convention for the Prevention of Pollution from Ships (MARPOL) is an international treaty established through the IMO that establishes pollution-preventing criteria for both engines and vessels used in international shipping. Finally, the Maritime Environment Protection Committee (MEPC) is a group within the IMO that focusses on maritime pollution. These bodies are responsible for the substantial and ongoing movement in the international shipping sector towards low- and no-carbon shipping. In April 2021, the Biden Administration announced formal support for the IMO to achieve zero-carbon goals, a reversal from the prior administration.

The IMO's MEPC approved new mandatory measures to achieve by 2030 a 40 percent reduction in carbon intensity in international shipping as compared to 2008, with additional goals to reach a 70 percent reduction by 2050. The pathway to meeting these decarbonization goals includes energy efficiency improvements, and an incentive rating system, but also technical and operational changes that will be enforceable through MARPOL. In addition to directives from these regulatory bodies to decarbonize, many countries around the world, especially in Europe, have regulations or policies in place aimed at reducing emissions from the trans-ocean shipping sector. For example, the European Union has an Emissions Trading System (ETS) that emphasizes the need to take action on shipping emissions, and the EU has already issued regulations requiring certain data collection and monitoring of CO_2 emissions, fuel consumption, and more. China has also launched an emissions trading system, and other nations have already adopted or are in the process of adopting GHG emissions requirements. Within this context, international shipping customers are also increasingly working to reduce the carbon intensity of their business and supply chains, which includes reducing emissions from the transportation of their products.

Although the U.S. inland waterway sector is already one of the least carbon-intensive and most sustainable transport modes available for freight, targeted work towards decarbonizing this sector even further, or entirely, is just beginning. In part this is because the international, national and private sector drivers towards a low- or zero-carbon shipping industry are not applicable to the inland waterway. The emissions associated with inland river commercial vessels is small compared to international shipping, and domestic policies aimed at reducing emissions in the U.S. transportation sector have appropriately focused on more emission intensive modes, such as trucks and trains. However, with the U.S. rejoining the Paris Agreement and the prioritization of climate change through a whole of government approach, there will continue to be increasing pressure on all sectors of the U.S. economy to decarbonize.

U.S. FEDERAL, STATE AND REGIONAL INITIATIVES

The emerging trend both internationally and within the U.S. is towards increasingly stringent regulation of GHG emissions. Numerous U.S. states already have adopted statutory GHG reduction goals. California, Massachusetts, New York and the State of Washington are targeting net-zero emissions by 2050, and Hawaii by 2045. Indeed, half the U.S. states and the District of Columbia have GHG reduction targets in place that cover a wide range of industries. State polices to achieve these goals are many and varied, and include incentive-based policies, electric utility regulation and carbon pricing. Many states include policies to promote cleaner transportation, including incentives to purchase electric vehicles or mandatory low-carbon fuel standards (which is in place in California and Oregon). Washington State recently adopted laws establishing an economy-wide cap-and-trade system and a clean fuels program. The Washington clean fuels program requires a 20 percent reduction in the carbon intensity of transportation fuels from 2017 levels by 2038, and is likely to substantially increase demand for low-carbon transportation fuels. The new laws also establish a pilot program for hydrogen-fuel cell vehicles. Fuels used "for the propulsion of . . . vessels", aircraft, and rail are currently exempt until 2028, but the marine industry (and other exempt users) may voluntarily participate in the program and may be eligible to receive emission reduction credits (if certain criteria are satisfied to generate the GHG emission reduction credits). A west coast carbon market led by Washington, California and Oregon could develop in the near term.

Regional alliances between states are likely to increasingly impact GHG emissions across all economic sectors. The Regional Greenhouse Gas Initiative (RGGI) is a cooperative between 11 U.S. states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont and Virginia) that sets mandatory GHG emissions limits within the power sector. RGGI operates as a cap-and-trade program within these 11 states, setting an overall GHG emissions "cap" (maximum total emissions budget) on power sector GHG emissions across the 11-state region. Allowances to emit a specified amount of CO_2 are sold at auction, with the proceeds invested in energy efficiency, renewable energy and other programs. Utilities that cannot operate below an established threshold must purchase these carbon emissions allowances, and those that operate below can sell their "excess" emissions allowance onto the market. The RGGI states and the District of Columbia are considering adoption of a GHG reduction program that will target the transportation sector, known as the Transportation & Climate Initiative (TCI). Massachusetts, Connecticut, Rhode Island and the District of Columbia have initiated the program thus far. Although the TCI is currently focused on on-road transportation modes, the trends towards transportation sector regional and state emissions reduction programs is clear.

At the federal level, many industries have long been advocating for a federal carbon tax, initially starting at a low dollar-per-ton of carbon and increasing steadily to allow companies time to adjust and decarbonize. These stakeholders view some form of carbon regulation as inevitable, and a carbon tax is often viewed as less complex and less administratively costly. Shipping groups – primarily in the international shipping sector – have also called for a carbon tax, with proceeds from the tax used directly to fund research and development to decarbonize the shipping industry.

PATHWAYS TO DECARBONIZATION

CHALLENGES TO DECARBONIZATION SPECIFIC TO THE INLAND WATERWAY SECTOR

The lack of international and domestic regulatory or market pressure to decarbonize the inland river sector may change in the near future as the U.S. seeks to reduce economy-wide emissions. However, several physical challenges make it difficult to decarbonize the inland river vessel fleet. Chief among these are: (i) river and channel depths that limit the maximum depth of the boat draft; (ii) the energy density of existing low- and zero-carbon fuels compared to marine diesel; and (iii) existing infrastructure characteristics, including the vessels themselves and widely dispersed port and bunkering infrastructure.

The first and perhaps most challenging limitation is that the maximum underwater depth (draft) of a tugboat and barge is about 10 feet.[29] The total U.S. navigable inland and coastal waterway network (including Great Lakes and harbors) spans approximately 25,000 miles, but the inland river system is approximately 12,000 miles with a guaranteed depth of only nine feet. This fundamental depth constraint limits the overall size and weight of any vessel operating on the inland waterways. Moreover, vessels operating in the upper Mississippi, Ohio, Missouri and Illinois Rivers must traverse a system of locks built decades ago, most of which are approximately 600 feet long and 110 feet wide, further constraining the length and width of the vessels that are also pushing rows of barges in front of them. Towboats that navigate these locking rivers are constructed to be shorter than the length of a single barge (which is approximately 195-200 feet long) and are typically no more than 180 feet long. The Lower Mississippi River is not lock-constrained, potentially allowing for much longer boats, but the typical boat length is up to 200 feet. Lower Mississippi boats are also wider than the locking river boats, up to 54 feet wide, as compared to approximately 30-40 feet for boats on locking rivers. The larger boats that operate on the Lower Mississippi also burn considerably more fuel annually than the smaller boats in the Upper Mississippi.

The primary constraints on the Lower Mississippi boats are the nine-foot draft, the need for sufficient agility to navigate through tortuous river bends and narrow bridges, all of which limits the size of the tows themselves to around 40 barges. Building a substantially longer and wider boat would be an enormous capital investment and it is not clear that the larger tows required to justify the capital cost could be safely navigated, especially down river.

These vessel size constraints directly limit the size, weight and location of engine and fuel tanks. The freeboard (the distance between the walking surface of the boat and the waterline) is approximately two to three feet when the boat is fully loaded. Unlike larger ocean vessels, inland vessels buoyancy is limited by the river depth constraint – adding more weight, or even distributing existing weight differently – will adversely affect freeboard and trim (see Figures 18 and 19).

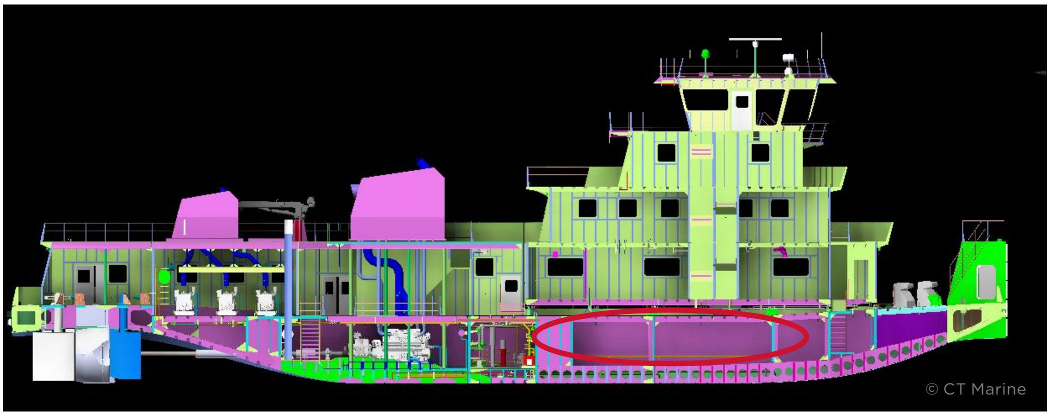


Figure 18. Rendering of internal mechanics of an inland river towboat. The placement of fuel tanks is carefully balanced to the front of the midline of the boat, with other heavy equipment located towards the stern to achieve balanced buoyancy

[29] Although the statutory minimum depth is 9', the Corps dredges to slightly more than 9' because operators load to 10-11' draft when conditions are optimal (during wet, higher river conditions).

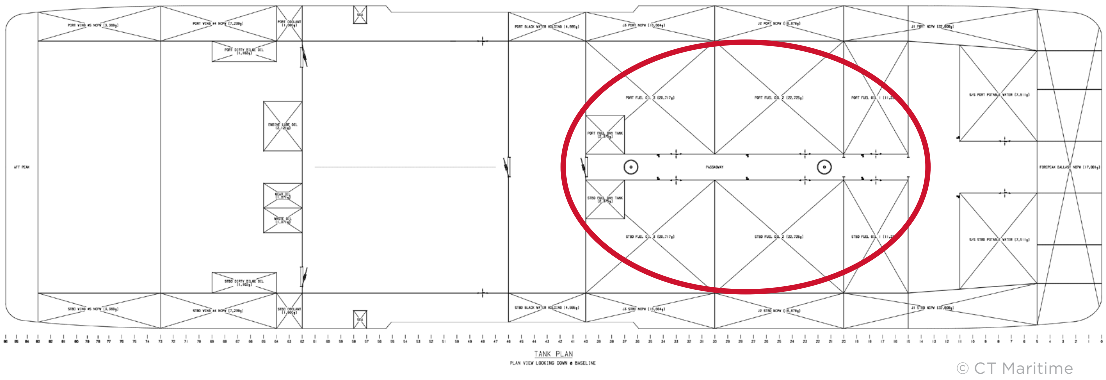


Figure 19. Towboat tank plan (same vessel as indicated in Figure 19). Fuel tank placement is shown circled in yellow (courtesy of CT Marine).

The second obstacle limiting decarbonization options is fuel tank capacity and fuel energy density comparability. The most promising alternative fuels would be fuels that can propel the boats similar distances at similar speeds using existing on-board fuel tank storage. However, as shown in Table 4, the energy density of most of the low- and no-carbon fuel options available today are substantially lower as compared to marine diesel.

Table 4. Energy density of alternative fuels as % of marine diesel fuel

Fuel	Energy Density as a Percentage of Marine Fuel
Marine Diesel	100%
Biofuel	95%
LNG	54%
Methanol	39%
Ammonia	39%
Hydrogen	23%

This lower energy density will require significantly more vessel fuel tank capacity to equal the power delivered by marine diesel. Only biofuels can be currently stored and used in existing onboard fuel tanks and would provide nearly equivalent power.

Moreover, because boats were primarily designed and built during a period of low fuel costs, the majority of fuel carried in the fuel tanks of inland river boats – over 50 percent of the fuel, and upwards of 75 percent on some boats – is ballast fuel. Ballast fuel is used to provide stability as boat weight fluctuates through fuel consumption or cargo loading/unloading operations. Ballast fuel thus represents a substantial portion of the fuel tank volume (half to three-quarters) yet it cannot be used (burned as fuel). This adds substantial complexity to any transition to a less energy dense or lighter (by weight) alternative fuel because the addition of ballast tanks would likely be needed. Adding ballast tanks creates further concerns regarding the trim and freeboard.

The vessel size, tank volume, the need for ballast, and comparable energy densities of alternative fuels serve as constraints to converting existing boats to low- or zero-carbon fuels. See Tables 4 and 5. Table 5 sets forth some of the key operational dimensions of the major categories of inland river boats that impact transition of vessels to alternative fuels. Figure 21 shows three classes of towboats pushing their tows, and a fleet boat.

Table 5. Inland Towboat Fleet: Key Operational Dimensions

Service Class	Horsepower	Approximate industry Fleet Size	Approximate Hull Dimensions			Bunker (Fuel Tank) Capacity	
			Length	Beam	Depth	Total Tank Volume (Gallons)	% Usable
Fleet Boat/ Other	400-1,299 hp	1615	40' to 70'	20' to 34'	7' to 10'	5,000-20,000	30-50%
Canal	1,300-1,999 hp	579	60' to 90'	24' to 34'	7' to 10'	8,000-20,000	30-50%
Small Locking River	2,000-3,999 hp	1036	70' to 130'	26' to 34'	8' to 10'	20,000-50,000	30-40%
Large Locking River	4,000-6,499 hp	326	120' to 170'	35' to 50'	8' to 10'	50,000-150,000	25-40%
Lower Mississippi River Linehaul	6,500-10,999 hp	101	150' to 200'	40' to 54'	8' to 10'	100,000-220,000	25-35%

Finally, because of the extremely long life of the inland river fleet (see Figures 5 and 13; average age of currently operating vessels is 36 years) and the potentially much longer lifespan of existing vessels if maintained properly, even if all future vessel construction were immediately converted to zero-emissions technology, a zero-carbon fleet may not be achievable over any reasonable time period. Switching to low- or no-carbon fuels using existing vessels or retrofitting currently operating vessels will be the most likely path to reach zero-carbon goals. This pathway to decarbonization is technically possible to achieve in the near-term but will face economic barriers to implementation under current market and regulatory conditions. Moreover, the fueling infrastructure system on the inland waterways was developed to transport liquid marine diesel (which does not require pressure or specialized tanks) and was designed for refueling via traditional pumps, often from mobile units while the vessel is underway. Low-carbon or zero-carbon fueling or propulsion options that can utilize existing infrastructure are likely to have a substantial advantage over those that require major changes to vessels or port infrastructure.

Linehaul Towboat

Locking Towboat

Harbor Towboat

Canal Towboat

Figure 20. Examples of four classes of towboat (as referenced in Table 4) and their tows (Harbor towboat/fleet boat shown without barge tow).

ALTERNATIVE FUELS AND PROPULSION SYSTEMS FOR THE INLAND WATERWAY FLEET – FEASIBILITY ANALYSIS

There are several potential marine fuels that could be used as alternatives to marine diesel in the inland transportation fleet. Their adoption depends on energy density, storage tanks, fueling infrastructure, engine availability, pricing and safety. These factors will also determine whether the alternative fuel is applicable as a vessel retrofit or if new construction is required. This section discusses the feasibility of each alternative fuel or propulsion technology – biofuels, LNG, methanol, ammonia, hydrogen, electric battery propulsion, and portable energy modules – within the context of the potential for near-term adoption by the inland waterway sector given its unique considerations.

BIOFUEL

The term "biofuel" generally refers to liquid hydrocarbon fuels produced from biomass. Biofuels have the potential to be carbon neutral in the case where the plant (i.e., a tree or corn) removes CO_2 from the air as it grows and stores that CO_2 in its own tissues and in the soil. When the plant is converted to fuel and burned, the stored CO_2 is then released to the ambient air. The entire process, from atmospheric CO_2 drawdown by the plant as it grows to release of that CO_2 back to the atmosphere when the biofuel is burned, can occur within a few months or years to create a carbon-neutral lifecycle. However, the potential of biofuels to reduce total GHG emissions may be reduced over the entire life cycle based on factors such as the source of the plant (feedstock), the plant cultivation practices (e.g., use of nitrogen fertilizer produced with fossil fuels), the energy used for processing or even potential land use changes encouraged by biofuel use. The recent ABS whitepaper on biofuels discusses these matters in detail.

There are current examples of marine biofuels being tested in international shipping. The energy density of biofuels is nearly equivalent to that of marine diesel, providing 95 percent of the energy provided by marine diesel on a volumetric basis (see Table 4). Accordingly, a roughly equivalent amount of biofuels is needed to produce the same power as marine diesel. The similar energy density means that the volume of biofuel necessary to equal current fuel-energy capacity is similar, and biodiesel can be stored in existing fuel tanks on board the vessels.

The inland waterways' existing fuel transportation and fuel delivery infrastructure also can be used for biofuels. However, emissions of oxides of nitrogen (NOx) can be higher from biofuels. NOx is a "criteria pollutant" under the federal Clean Air Act, meaning they are subject to certain federal regulations and limitations.

LIQUEFIED NATURAL GAS (LNG)

Because of the reduction in GHG emissions that can be achieved by switching to lower-emitting fossil fuel sources, LNG has been extensively explored as a marine fuel and LNG-powered vessels are currently deployed in the international maritime sector. However, LNG presents challenges for use in the inland waterway sector.

The energy density of LNG requires 1.7 times the fuel tank volume of marine diesel to provide the equivalent power. This means that the current size of fuel tanks on existing vessels will not be sufficient. Moreover, LNG must be cryogenically stored in double-walled and pressurized tanks, therefore external tanks would need to be added to the vessels, which presents potential buoyancy problems given the limitation on boat size and draft.

Current infrastructure also does not support LNG bunkering and would require construction of floating, mobile LNG fueling assets. Such infrastructure is technically feasible but faces economic challenges to adoption. Because LNG only provides a carbon reduction of 21 percent compared to marine diesel, it will not achieve zero-carbon emissions; however, it can serve as a transition, or "bridge" fuel on the path towards net-zero carbon emissions. Investment in LNG-powered vessels as a bridge fuel may also be aided by the fact that there are existing marine engines that will burn LNG and additional engines that could be adapted to burn LNG.

The high cost, inability to use existing fuel tanks, lack of fueling infrastructure, and relatively small CO_2 emissions reduction make LNG unlikely to be adopted in the inland waterway sector.

Figure 21 shows an example mock photo of an LNG retrofit of an existing vessel, with centrally located tanks to minimize draft and trim (balance) concerns.

Figure 21. Mock photo of LNG retrofit application on an inland towboat. Mock image prepared for Ingram Barge by CT Marine (courtesy of Ingram Barge Company).

METHANOL

Methanol is currently produced primarily from natural gas. However, it can be produced from renewable feedstocks such as biomass. One of its advantages over LNG is that it can be stored as a liquid at ambient temperature and pressure.

The low energy density of methanol results in 2.5 times the tank volume of marine diesel required to store the same amount of energy, which is the primary challenge to widespread adoption of methanol in the inland waterway sector. However, existing fuel tanks and piping systems could be adapted to use methanol, and there are existing engines that can burn methanol. Other existing engines in inland marine vessels could be modified for methanol use. Methanol is lighter than diesel fuel, raising potential buoyancy concerns, but ballast water can be added to compensate for the different weight distribution.

Methanol is currently transported using inland marine transportation barges, and existing fuel infrastructure systems could be modified to deliver methanol. Accordingly, methanol is a near-term, carbon-neutral solution for existing inland marine vessels if the fuel tank volume on board is increased, if vessels are used in less intense fuel consumption routes, or if refueling frequency is increased. New vessels could also be configured to optimize methanol as a marine fuel, which may reduce the operational constraints that are required to retrofit existing vessels.

Methanol presents a near-term potential for successful application of a "well-to-wake" carbon neutral fuel if the methanol feedstock is sustainably sourced.

AMMONIA

Ammonia (NH3) is a chemical that is primarily used as a fertilizer but can also be used as fuel. With one nitrogen atom and three hydrogen atoms, it is a zero-carbon fuel that can be used in marine transportation. However, the hydrogen used to produce ammonia is currently extracted from natural gas or coal, and the process itself is energy intensive and reliant on fossil fuels, making current ammonia production carbon intensive. There is substantial research underway to make ammonia an entirely green fuel by extracting the hydrogen from water, reducing energy needs for the process, and relying on renewables for production energy needs. Ammonia has significant potential in the maritime sector and more information are presented in the ABS whitepaper on ammonia as fuel. However, with the ship-size, draft, and buoyancy constraints extant in the inland marine sector, ammonia may not be a viable, economical alternative.

The low energy density of ammonia results in 2.5 times the tank volume of marine diesel required to provide the same amount of energy. Like LNG, ammonia fuel storage must be in pressurized vessels, so existing tanks on the inland fleet cannot be used. Also, similar to LNG, there is currently no fueling infrastructure capable of maintaining the temperature and pressure requirements of ammonia.

There are currently no marine engine applications in the inland waterway fleet that burn ammonia as a primary fuel, and while promising work is underway for ocean-going vessels, ammonia is not currently a near-term alternative for the inland sector. However, ammonia can be used in fuel cells to generate electricity for hybrid propulsion applications.

HYDROGEN

Hydrogen is the most abundant element in the universe and when burned for fuel, produces only water as a byproduct. However, the hydrogen production system currently relies primarily on natural gas to produce hydrogen through a high temperature (and therefore high energy) process. Significant research is ongoing to extract hydrogen from clean sources, such as water rather than natural gas, and through less energy intensive processes or through the use of renewable energy. Cost, safety, and storage infrastructure are also concerns with hydrogen, but these challenges may be overcome in the ocean marine transport industry that is investing heavily in research and development of hydrogen powered vessels. Overcoming these challenges in the U.S. inland waterway sector is more difficult, but the inland sector stands to benefit from research and successes that occur in the trans-ocean shipping sector.

The energy density of hydrogen is the lowest of the alternative fuels reviewed for the inland marine transportation market, requiring 4.1 times the tank volume of marine diesel to provide the same amount of energy. Hydrogen can be cryogenically stored or pressurized, therefore, existing fuel tanks cannot be used. The volume of hydrogen that would be required to provide the equivalent energy of marine diesel makes it impractical to modify an existing vessel to accommodate hydrogen tanks.

Hydrogen can be used for propulsion in internal combustion engines or in fuel cells to generate electricity for hybrid applications. Moreover, compact hydrogen generators could be installed on board a vessel to provide power, but they are likely limited to low power applications. This makes hydrogen a potentially viable alternative on fleet boats, although there have been no projects to demonstrate the viability of the technology in the fleet boat application. In addition, like LNG and ammonia applications, there is not yet existing fueling infrastructure to provide hydrogen at needed refueling locations along the inland waterway system.

BATTERY ELECTRIC PROPULSION

The physical constraints of the inland waterway vessels – primarily vessel size, maximum draft and long life span – make many of the zero-carbon shipping options being explored in the international shipping sector difficult to apply to the inland river sector. Electrification of the propulsion system through battery power may be the exception. As demonstrated through a case study, electrification of the existing inland river fleet boats is a technically feasible, near-term strategy to decarbonization that can be applied to existing boats.

Inland river fleets consist of smaller, low power, low operating load factor vessels. While the larger towboats push barges up and down the rivers, fleet boats configure and assemble barges in preparation for river service, or for commodity loading and unloading (see Figure 22).

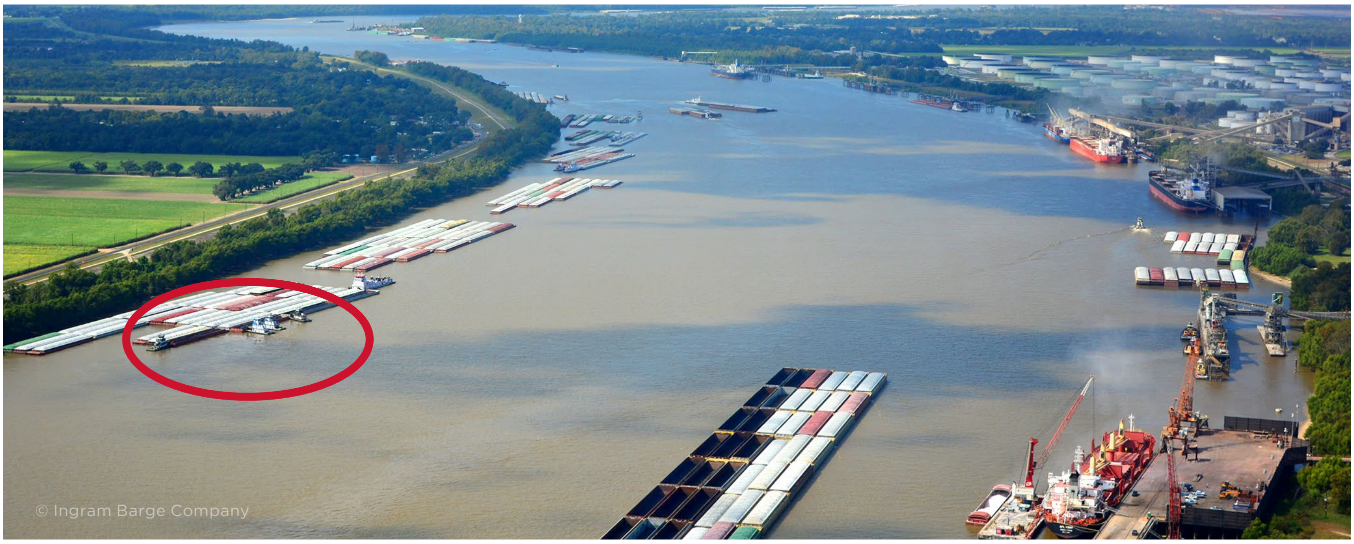


Figure 22. Smaller "fleet boats" (circled in red) assembling barges for a tow.

There are estimated to be 1,000 of these vessels in current service and each consume approximately 100,000 gallons of diesel fuel annually. Therefore, electrifying all fleet boats would result in reduction of diesel fuel use and industry-wide fuel savings of approximately 100 million gallons annually, and 1.02 billion kg of CO_2 emissions (Table 6). Some of these emissions' reductions would be offset depending on the carbon intensity of the mix of fuel used to generate the electricity. Use of renewable energy to generate the electricity required to re-charge the batteries would enable zero-carbon operation. As shown in Table 6, the GHG reduction attributed to fleet boat electrification represents approximately 20 percent of the overall industry emissions, a considerable industry-wide reduction that is supported by current technology and feasible in the near term.

Table 6. Annual estimated potential carbon emissions reduction and fuel savings from conversion of Fleet Boats to electric propulsion systems.

Approximate number of Fleet Boats in service	Annual average marine diesel fuel consumption by Fleet Boats	Potential carbon emissions reduction (if electricity is generated from renewable sources)	Marine diesel fuel savings from electric battery conversion of Fleet Boats	Fuel and GHG emissions reduction as percent of total industry contribution
1,000	100 million gallons (100,000 gallons annual average per boat)	1.02 billion kg CO_2	100 million gallons annually	**~20% reduction in total industry diesel fuel consumption** **~20% reduction in total industry GHG emissions (assumes electricity is renewably sourced)**

Fleet boats are ideal candidates for electrification either by converting existing boats or for new construction because they operate in limited geographic areas, at low engine load factors, and typically crew change every 12 hours, a time when depleted batteries could be recharged. This schedule would provide recharging at the required frequency to power the vessel with the appropriate amount of energy needed.

The power requirements of these boats are also such that the size and weight of current battery technology is technically feasible for retrofit application on existing boats. The number of batteries that could be installed in a vessel would be determined by the vessel size, displacement and trim. The number of batteries and operating load factor would determine the recharging frequency. Batteries would provide the power to electric motors that drive either propellers or azimuth drives. Because azimuth drive propellers only turn in one direction, thus increasing efficiency by eliminating the need to stop propeller movement to change propeller direction, they are a preferable configuration over the conventional propeller drive.

Larger inland river boats, both the towboats that operate throughout the locking system in the Upper Mississippi and the larger towboats that operate in the Lower Mississippi, are not yet viable candidates for electrification with current battery technology. The required batteries' size and weight would render the boat non-buoyant. However, as battery technology evolves (and size and weight decrease without sacrificing available power storage), electrification of the larger inland river boats could become a viable future alternative.

The appendix discusses the viability of the electrification of inland river fleet boats through the design of a "concept electric fleet boat" using the specifications of an existing fleet boat. This design is based on a proven diesel powered fleet boat application that has been modified for electric power. The main engines, gear boxes, electric generators, fuel tanks, and all related pumps and piping have been eliminated. An emergency diesel generator would remain on board but would only be used in the event of an electrical system failure. This work demonstrates that retrofitting fleet boats for electric propulsion is feasible in the near-term as an approach that can begin decarbonization of the commercial, inland river fleet.

The battery layout shown provides the required range and power for currently operated fleet boats. A typical fleet boat consumes approximately 100,000 gallons of diesel annually, or about 270 gallons per day. Approximately 41 kW of electricity provide the same energy output as one (1) gallon of diesel. The battery storage design shown provides 5,677 kW of power to the electric boat. This equates to approximately 150 gallons of fuel used. Because batteries can be recharged during the crew change every 12 hours, the electric boat can provide the same power and range as approximately 300 gallons of diesel per day, making it suitable for current applications.

The costs associated with either retrofitting existing fleet boats or constructing new electric boats were not examined for this project; however, a pilot boat could be constructed based on the design-ready specifications provided in the appendix.

PORTABLE ENERGY MODULES

The primary technical challenges to decarbonizing the inland sector using existing alternative fuels relate to (1) the unique physical and operational constraints of the river towboat (size, draft, and buoyancy requirements) and (2) the long operational life of towboats. These challenges make it difficult to retrofit existing boats, or to construct new boats, in order to utilize low- or zero-carbon fuel technologies. One solution to these constraints that is technically feasible is to locate the power source for the towboat on a barge that is attached to the towboat as part of the tow assembly. This approach is known as a Portable Energy Module (PEM).

Use of a PEM allows the fuel tanks – which could contain either ammonia, LNG or hydrogen – to be located on a specially designed and dedicated barge known as the PEM. The PEM is then attached to the bow (front) of the towboat and included in the tow of barges. Because ammonia, LNG and hydrogen are pressurized and hazardous fuels, existing safety regulations would not likely permit the fuel itself to be transported via a piping system directly from the PEM to the towboat, as both the boat and the PEM are independently movable structures.

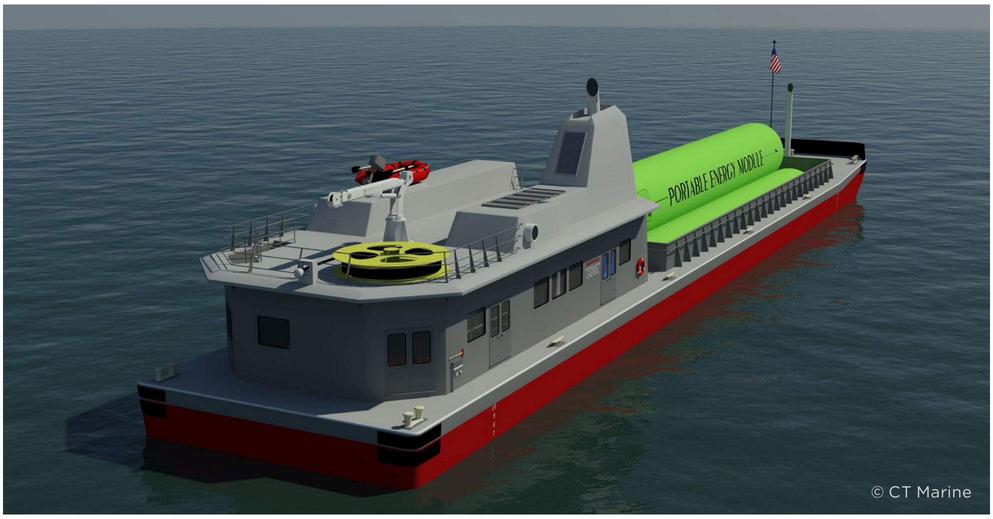
Accordingly, to avoid the potential for fuel pipe rupture, the fuel and power generation system would be contained entirely on the PEM. The existing diesel engine components aboard the towboat would be removed and batteries and an electric drive would be installed. The power generated aboard the PEM would provide electricity to the towboat via an electric cord to the boat (reducing risk associated with fuel piping from PEM to boat). The electricity generated on the PEM would constantly recharge the batteries aboard the towboat, which in turn powers the boat's electric drive motor. Existing battery technology is also sufficient to power even the largest towboats for intermittent or emergency use when the towboat is not connected to the PEM.

There are several benefits to this approach that are consistent with near-term decarbonization solutions. First, PEMs can accommodate ammonia, LNG or hydrogen as fuel sources, allowing flexibility among operators to determine appropriate decarbonization pathways based on fuel pricing, available incentives or other company-specific considerations. Second, any PEM could be used with any hybrid electric towboat. This would allow for "refueling" to take place quickly by merely switching the PEM, without delaying cargo transportation. Finally, while battery technology has not yet evolved to enable the larger towboats to fully electrify, modifying towboats to accommodate PEMs would also position those boats for easy transition to electric if substantial advances in battery technology were to occur in the future.

Although technically feasible, PEMs have never been constructed and face primarily economic obstacles to adoption. The construction and operating costs are likely to be high, but a PEM also permanently displaces a revenue generating barge. However, if the market and regulations shift to reduce the total cost to construct and operate PEMs while simultaneously increasing the cost of diesel operation (e.g., pricing carbon emissions through a carbon tax or emissions trading scheme), the PEM approach may become a more viable alternative.

Because no PEM has been constructed to date, the design and regulatory approval process is likely to take two to three years; however, retrofitting a towboat to operate with a PEM when it became available could be accomplished in a short time period, likely two to three months. Accordingly, PEMs provide a promising near-term technology for decarbonizing the inland sector.

Together, the GHG reduction benefits of a PEM, likely substantial cost, and needed regulatory lead-time for approvals of this new approach, make a PEM a good candidate for federal or other grants to support the construction of a PEM as a pilot or demonstration project. Such a demonstration project is needed to more accurately predict the costs and determine the potential for widespread adoption in the inland sector. Figure 23 shows a rendering of a potential PEM.



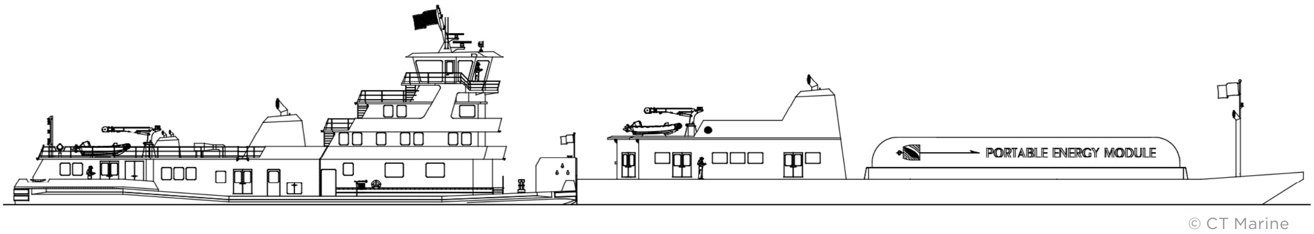


Figure 23. PEM Rendering. The PEM would be attached to the towboat along with the barge assembly.

FUTURE OUTLOOK: MARKET AND REGULATORY INCENTIVES

There are significant existing economic pressures on inland waterway freight operators to reduce fuel consumption, since it is the single largest business cost to the operators, and small gains in fuel efficiency can translate to large savings, especially as fuel costs rise. In addition, like other economic sectors, currently the cost of total decarbonization as compared to the cost of diesel is substantial. There are no current market or regulatory incentives likely to drive a near-term (next 5-10 years) transition to zero-carbon propulsion technologies. However, there are indicators that may be changing. Federal and state policies are now actively being considered that seek to decarbonize the economy to meet the goals of the Paris Agreement. Shipping customers and financiers also are becoming more interested in a zero-carbon transition. This is in part supported by a significant move in the mainstream financial sector to better understand and disclose the short- and long-term risks of climate change to the financial sector and its underlying assets. A combination of new regulatory mandates and incentives, both market-based and regulatory, will be needed before the inland waterway sector can benefit from decarbonization.

Existing incentives include the cost of compliance with EPA's Tier 4 engine standards and customer preferences. Tier 4 engine standards were phased in between 2008-2015 and are applicable to some marine engines. These standards require costly pollution control equipment (including additional tanks and piping) to be installed and maintained. The expense of advanced emissions control technologies by itself will not likely tip the economics towards zero-carbon technologies, especially because the lifespan of both engines and boats are long.

There are also signs that shipping customers are beginning to inquire how the operators are working to decarbonize and promote sustainable business practices. If shippers select carriers in part based on their carbon emissions profile, this could have a large impact on operator decision-making to explore low- or zero-carbon technologies. State and federal GHG reduction polices will also increase pressure on shippers to decarbonize.

In addition, consistent with a global trend, U.S. states are adopting increasingly stringent GHG emissions requirements and establishing carbon trading schemes. Determining whether and how the inland river sector can take advantage of these existing and emerging market-based systems, such as through issuing carbon credits, or buying carbon credits to offset emissions where decarbonization is not feasible, can promote decarbonization.

CONCLUSION

Given the key operational constraints of freight transport on the inland river system, methanol and biofuels present the most realistic near-term approaches to alternative fuels. These fuels present technical challenges to widespread adoption that involve the need for appropriate ballast and challenges regarding existing tank volumes. Electrifying the inland river fleet boats is a technically feasible, near-term alternative that would offer substantial fuel and GHG reduction throughout the industry. A real-world pilot project to demonstrate the feasibility of the electric concept boat set forth in Appendix B could establish both the immediate technical possibility and the cost of electric conversion. If battery technology were to improve substantially in the future, the larger towboats could also be converted to battery-electric propulsion. In addition, it is technically feasible now to construct a Portable Energy Module on a floating barge attached to a towboat that uses a range of low- or zero-carbon fuels to produce power, in the form of electricity, to the towboat. This option may have the potential for economic viability as market and regulatory incentives and pressures to reduce GHG emissions continue to evolve.

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APPENDIX

ELECTRIC TOWBOAT CASE STUDY – CONCEPT BOAT

Throughout the inland marine transportation industry there are hundreds of small, low- horsepower (hp) (400-1,300 hp), low operating load factor towboats working in fleet service, known as "fleet boats." These smaller boats operate in limited geographical areas to assemble barges into the proper configuration for a tow (a grouping of barges tied together that a towboat pushes up and down river). Fleet boats also move barges for loading and unloading cargo. Figure A-1 shows fleet boats near the bank of the river moving barges to assemble the needed tow configuration.

Figure A-1. Smaller "fleet boats" (circled in red) assembling barges for a tow.

Fleet boats typically burn approximately 100,000 gallons of diesel fuel annually. They are ideal candidates for electrification either as a conversion or new construction based on the following characteristics:

- Fleet boats typically work 12-hour shifts and then change crews. Battery re-charging could occur during the crew change process that occurs every 12 hours, with no disruption to existing work schedule.
- Fleet boats typically work in limited geographical areas. Battery charging infrastructure can be installed in one location where fleet boats could access it.
- Fleet boats typically operate at a low average engine load factor. This makes current electric battery technology – the required size, weight, and power output and range –viable for the current operating conditions of existing fleet boats.

This case study examines the specifications for conversion of an existing fleet boat, currently operating on the Mississippi River, to all-electric battery power. The concept design drawings and specifications are courtesy of CT Marine - Naval Architects and Marine Engineers.

BOAT SPECIFICATIONS

Figure B-2 and Figure B-3 represent the conventional diesel, 1,200 horsepower boat that is 68 feet by 34 feet. The boat has 20,000 gallons of diesel fuel capacity in two tanks near the middle of the boat. There are two diesel generators. The boat is powered by azimuth drives (Z-drives) direct coupled to the main engines. The boat was built to a 10-foot depth with an 8-foot fully loaded operating draft.

ELECTRIC CONVERSION PROCESS

To convert to battery-powered electric, the following components are removed:

- Diesel fuel and lube oil
- Propulsion engines, gears, and generators
- Fuel, lube, and waste oil piping systems
- Any other components not required for a fully battery powered towboat

To convert the boat to battery power:

- Install 50 racks with 20 batteries in each rack
- Install the drives, converters, and other electrical components
- Connect 600 horsepower electric motors to the azimuth drives
- Remove and minimize any non-propulsion electric powered items on the towboat

The electrical layout of the converted battery-electric boat is shown in Figure B-4. With this configuration the electric towboat is calculated to have 5,677 kilowatts (kW) of power. This is sufficient power to allow the boat to operate up to a continuous average of 57 percent of the maximum horsepower over 12 hours. The batteries would have to be recharged after each half day shift, 11 hours of operation and one (1) hour of battery recharge. As shown in Figure B-5, this configuration also results in a draft and trim that is the same as the diesel-powered boat when fully loaded with diesel fuel. Figure B-6 shows a mock photo rendering of the final, zero-emissions electric boat next to a conventional diesel-powered fleet boat.

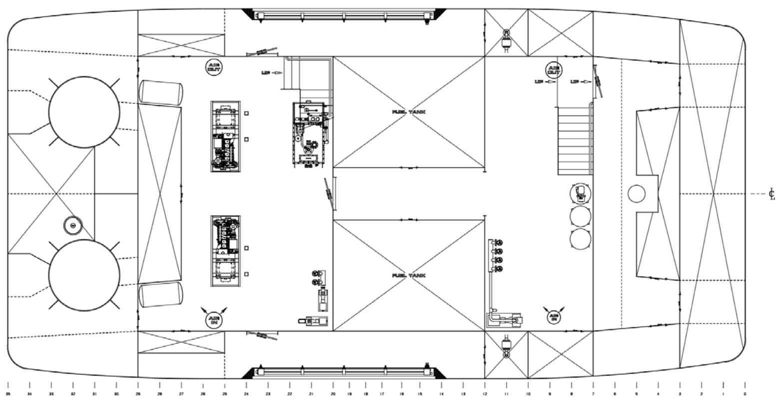

Figure A-2. Conventional Diesel Fuel Boat — Hold and Machinery Arrangement. 68' x 34' x 10' Twin Screw Z-Drive Towboat.

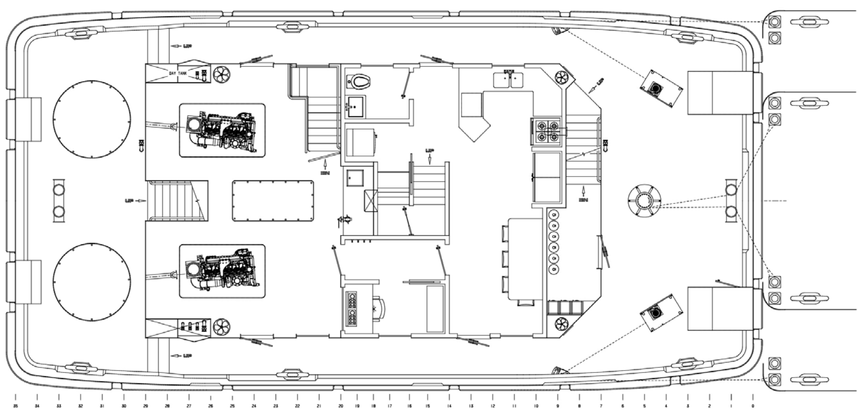

Figure A-3. Conventional Diesel Fuel Boat — Main Deck General Arrangement. 68' x 34' x 10' Twin Screw Z-Drive Towboat.

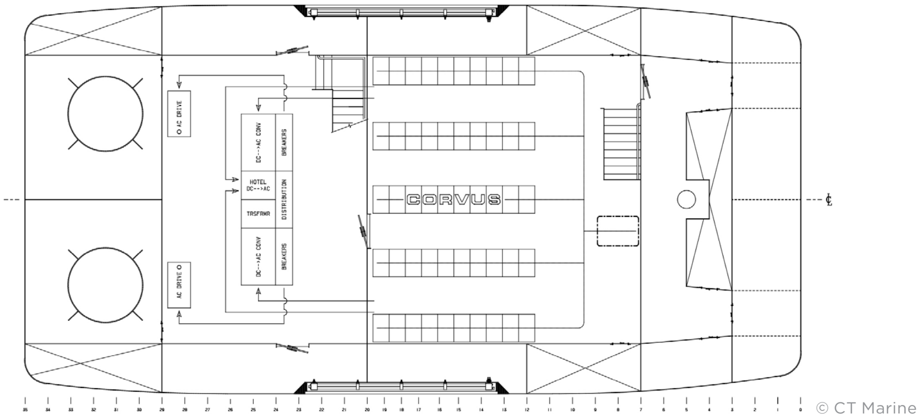

Figure A-4. Converted Electric Boat – Hold Plan. 1220 BHP Zero-Emission Towboat.

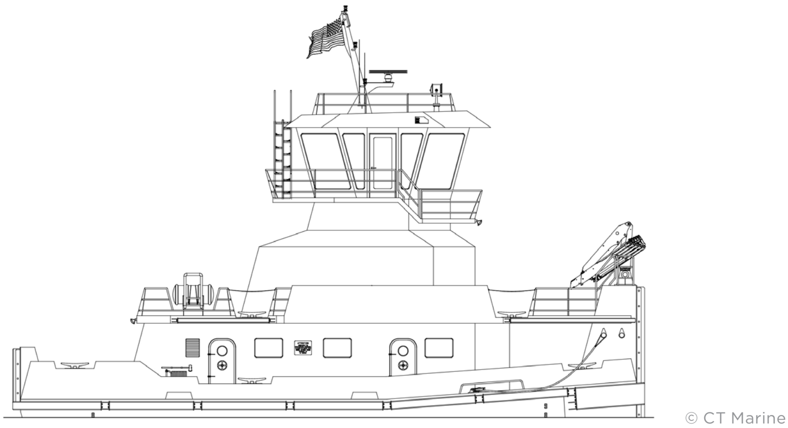

Figure A-5. Converted Electric Boat – Outboard Profile. 1220 BHP Zero-Emission Towboat.

Fully electric, zero-emission fleet boat.

Conventional diesel fleet boat (actual photo).

Figure A-6. Side by side comparison of fully electric, zero-emission fleet boat and conventional diesel fleet boat.

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