Intelatus Global Partners

Sizing the U.S. and California Harbor Craft Market

August 2023

CALSTART

CALIFORNIA CORE

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Acknowledgments

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This report was developed by Intelatus Global Partners for CALSTART. This report is funded in part by the Clean Off-Road Equipment Incentive Project (CORE). CORE is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.

About CALSTART:

For over 30 years, it has been CALSTART's mission to develop, assess, and implement large-scale zero-emission transportation solutions to mitigate climate change and support economic growth. CALSTART works with businesses, organizations, governments, and communities to create real-life impact toward clean air and equitable access to clean transportation for all. CALSTART provides scientific, technical, and policy support for regulatory development of clean technology and infrastructure acceleration.

About Intelatus Global Partners:

Intelatus is a firm of business consultants specializing in strategic planning and market analysis. Intelatus provides its global clientele with accurate, up-to-date business intelligence and consulting services. Intelatus has a focus on the marine and offshore industry sectors and conducts projects covering all aspects of the market.

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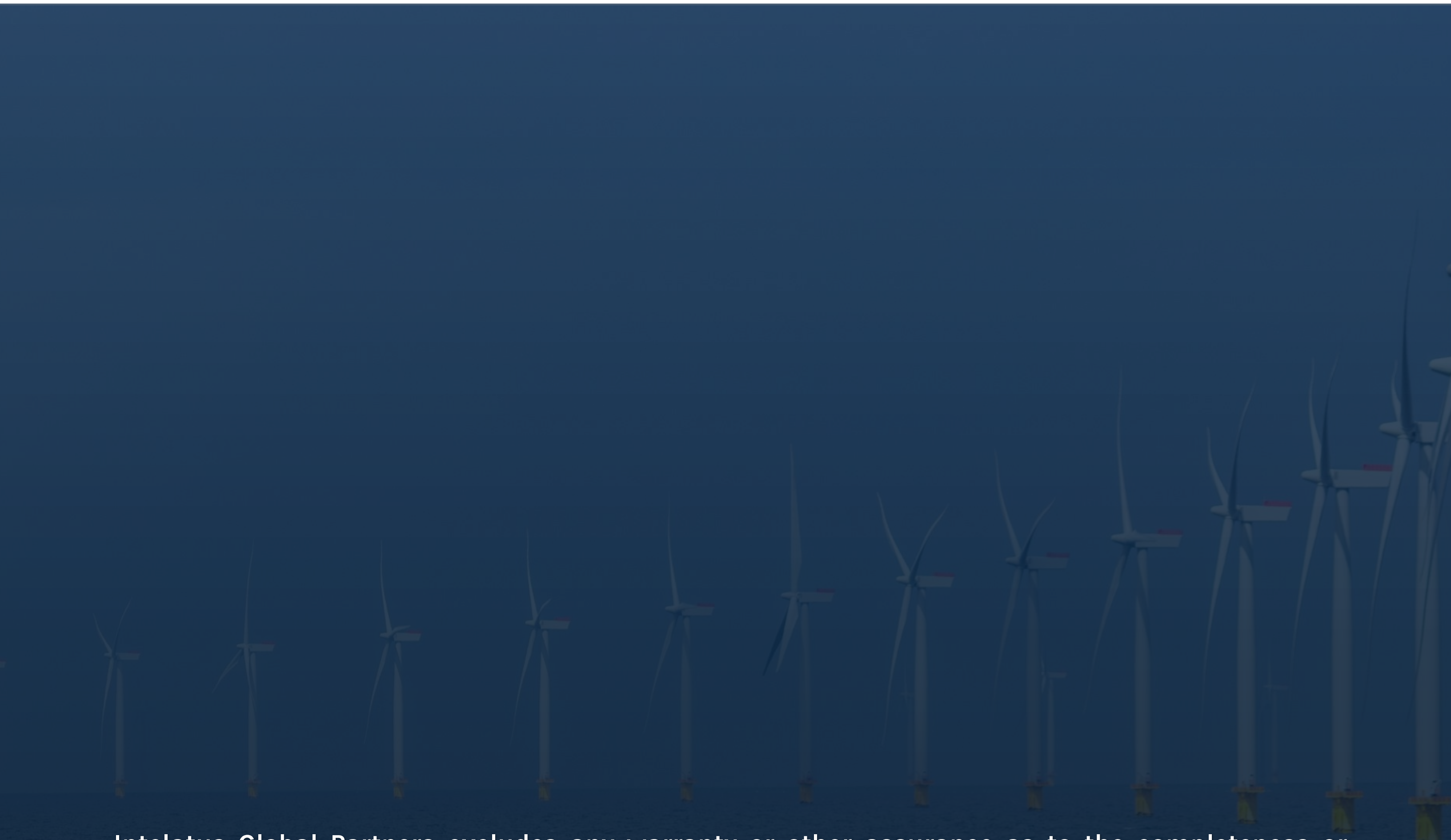

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List of Exhibits

Glossary of terms used in the report

ABS	American Bureau of Shipping
AIS	Automatic Identification System
AHT	Anchor handling tug
AHTS	Anchor handling tug and supply
ATB	Articulated tug and barge
BTS	Bureau of Transportation Statistics
CARB	California Air Resources Board
Cat	Category, as in Cat 1, C2 and Cat 3
CHC	Commercial harbor craft
CO	Carbon monoxide
CO2	Carbon dioxide
CTV	Crew transfer vessel
DOE	Department of Energy
DOT	Department of Transportation
DPF	Diesel particulate filter
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
GT	Gross tonnage
GW	Gigawatt (1,000 MW)
H2	Hydrogen
HC	Hydrocarbons
HFO	Heavy fuel oil
ICE	Internal combustion engine
IGF Code	International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels
IMO	International maritime Organization
ITB	Integrated tug-barge
kW	Kilowatt (1,000 watts)
kWh	Kilowatt hour
LNG	Liquified natural gas
LOHC	Liquid organic hydrogen carriers
LPG	Liquified petroleum gas
MARAD	U.S. Maritime Administration
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine diesel oil
MEPC	Marine Environment Protection Committee, the group of member countries within the IMO with accountabilities, among others, for marine pollution prevention, safety and security
MGO	Marine gas oil
MPSV	Multi-purpose offshore support vessel
MW	Megawatt (1,000 KW)
NAAQS	National Ambient Air Quality Standards
NOx	Nitrogen oxides
NT	Net tonnage
OCV	Offshore construction vessel
OSV	Offshore support vessel
PEMFC	Proton exchange membrane fuel cell
PM	Particulate matter
SCR	Selective catalytic reduction
SMR	Small, modularized reactor
SOLAS	Safety of Life at Sea
SOV	Service operations vessel
SOx	Sulphur oxides
USCG	U.S. Coast Guard

Executive Summary

CALSTART in March 2023 engaged Intelatus Global Partners to size and analyze the total U.S. and California harbor craft, inland and near shore vessel fleet above 600 kW or 805 bhp to understand the potential market for zero-emission vessel solutions, such as the hydrogen fuel cell-powered zero-emission tug (HyZET).

This report is funded in part by the Clean Off-Road Equipment Incentive Project (CORE), part of a statewide initiative aimed at reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment.

The Regulatory Environment

Global, regional, national and local agencies are promoting a variety of measures aimed at reducing emissions from the maritime sector that harm the environment and public health.

In the USA, the focus of standards is tilted towards the reduction of NOx and particulate matter. California is in a unique position that it can set its own emission standards, which are currently higher than those mandated by the federal Environmental Protection Agency. Where feasible, California encourages the use of zero-emission options.

Zero-Emission Energy Carriers

Vessel owners are faced with a variety of energy carrier and converter options when seeking to minimize harmful emissions from marine operations.

In the short-sea and inland segment, the most suitable zero-emission options include renewable based hydrogen, hydrogen-based fuels and renewable electricity stored in battery energy storage systems.

All the options have advantages and disadvantages, chief among which is the cost and availability of zero-emission fuel, the certification that a fuel is truly zero=emission and the availability of infrastructure and equipment to produce, distribute and convert zero-emission fuels. As the energy transition continues to gather pace, these challenges will, in theory, be addressed.

Certification of Zero-Emission Fuels

The direction of global, regional and national shipping regulations is shaped by the International Maritime Organization, which is moving to roll out net zero-emissions target by or around 2050 on a well-to-wake basis. Although this is generally not a specific issue for U.S. or Californian harbor craft, the question of whole-life emissions, and the certification of a fuel as zero-emission on a whole-life basis, is likely to become increasingly important.

Well-to-wake emissions calculate emissions from the production (feedstock extraction, cultivation, acquisition or recovery) through to transporting a fuel or energy carrier to the ship and using the energy source in the ship.

In considering how a fuel such as hydrogen is made, well-to-wake certification of a fuel will, in the future, seek to identify whether the hydrogen has a low or high carbon intensity.

- High-carbon intensity hydrogen is made from coal or natural gas and is responsible for most of the hydrogen produced today.
- Hydrogen with a low carbon intensity can be made from renewable electricity (wind, solar, etc.), biomass and natural gas with carbon capture and storage. Relatively little low carbon intensity hydrogen produced globally today.

  Low carbon intensity is further broken down into renewable hydrogen, which is green hydrogen (for renewable electricity and electrolysis), bio-syngas (gasification or reforming of biomass), blue hydrogen (natural gas with carbon capture and storage) and pink hydrogen (nuclear power directly or with electrolysis).

Hydrogen Vessels

As a result of the regulatory environment and technical and financial challenges, the adoption of zero-emission vessels is accelerating, but from a relatively small base. Globally, there are currently close to 35 vessels operating wholly or partly with hydrogen that are either active or on order.

The U.S. Harbor Craft, Inland and Nearshore Vessel Segment

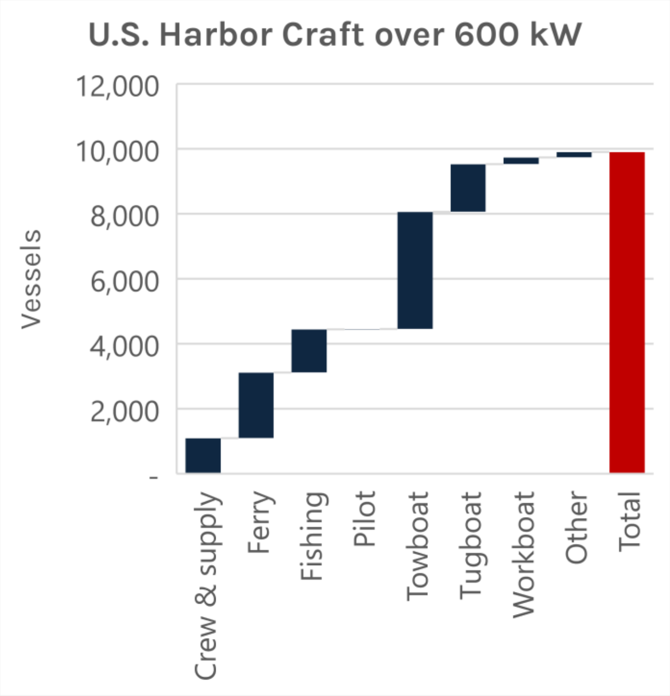
There are over 12 million vessels accounted for in the United States.

Within this group are close to 10,000 harbor craft operating in the United States that are above 600 kW, or 805 horsepower, including crew and supply boats, ferries and excursion vessels, fishing vessels, pilot boats, towboats, tugboats, workboats and other vessel types. We analyze this vessel segment in our report.

Around 12 million recreational and pleasure craft, 34,000 non-self-propelled vessels and barges, deep sea U.S. vessels and international vessels are excluded from our analysis.

The importance of the demand arising from inland waterborne trade can be seen when breaking down the harbor craft segment into the eight categories analyzed within this report.

In Service Cat 1 California Harbor Craft



Source: Intelatus Global Partners

The U.S. is home to over 150 large coastal and inland ports and a network of 25,000 miles of rivers and canals, of which around 12,000 miles supports inter- and intra-state commerce.

Most inland waterborne trade is concentrated in the eastern half of the country and especially within the Mississippi River System. In the western half of the country, inland waterborne trade is concentrated in the Columbia and Snake River System, and to a lesser extent, on the Sacramento River.

Not all harbor craft are confirmed to be active. The activity of close to a third of the vessels in our dataset cannot be confirmed due to the lack of suitable automated vessel tracking equipment. These vessels may well be active and equally may well be idle or in long term lay-up.

Harbor Craft Status

Status	Number	%
In Service	5,562	56%
Idle	204	2%
Laid-up	1,071	11%
Unknown	3,068	31%
Total	9,905	**100%**

Source: Intelatus Global Partners

The U.S. Zero-Emission Vessel Potential

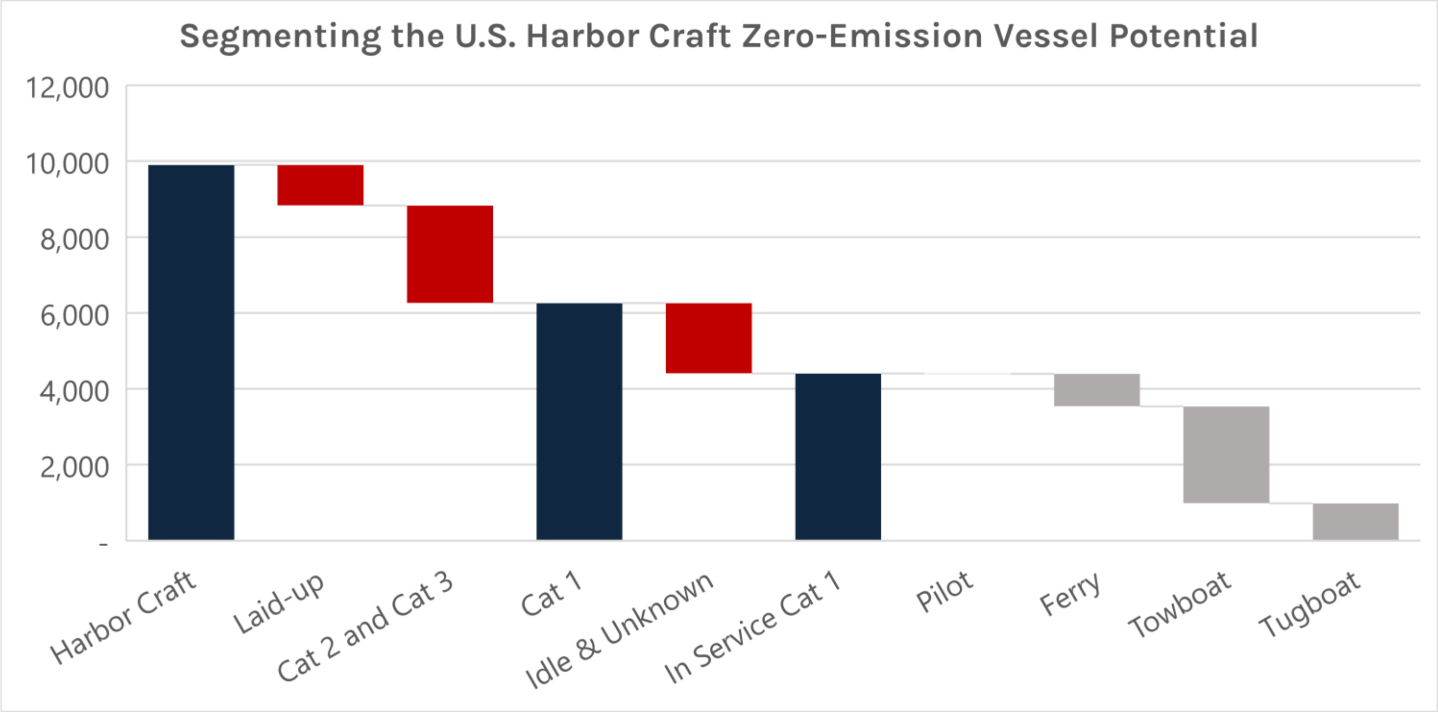
We have grouped the U.S. harbor craft by operational status (In Service, Idle, Unknown and Laid-up) and category (Cat) reflecting suitability for zero-emission technology. This is a high-level subjective grouping and is subject to further technical review:

- Cat 1: the most suitable for hydrogen or electric zero-emission operations. This group of 4,405 vessels includes ferries, pilot boats, towboats and tugboats.
- Cat 2: medium suitability for zero-emission operations. This segment covers crew and supply vessels and workboats.
- Cat 3: lower suitability for zero-emission operations and includes fishing vessels and other vessels, not categorized in the other

seven core segments.

The following chart identifies the 4,405 In Service ferries, towboats and tugboats that have the highest attractiveness for zero-emission technologies such as HyZET.

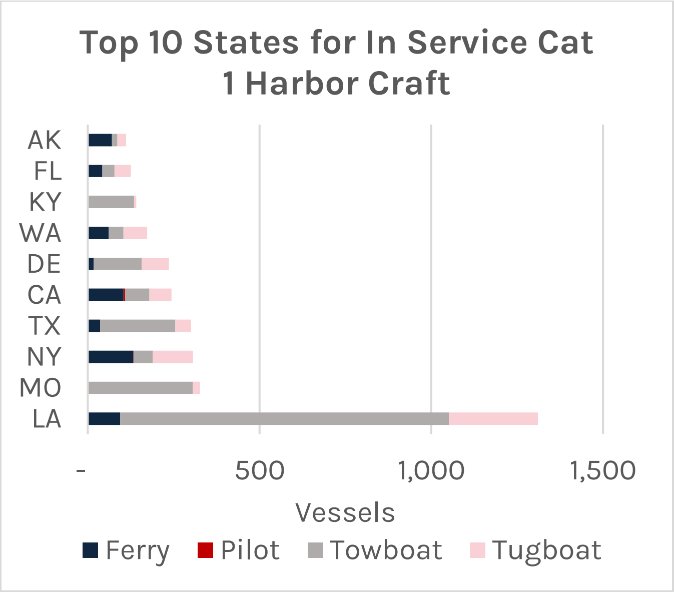
Segmenting the U.S. Harbor Craft Zero-Emission Vessel Potential



Source: Intelatus Global Partners

Registered harbor craft are present in all 50 U.S. states, but nearly three quarters of In Service Cat 1 harbor craft are in 10 states.

Harbor Craft by Type and Status



Source: Intelatus Global Partners

Drilling down in to the 4,405 In Service Cat 1 vessels, we see that towboats account for around 58% of the vessels and that 56% of In Service Cat 1 vessels are 25 years of age or older. The 2,462 older vessels represent the lower hanging fruit in terms of suitability for replacement or repowering with zero-emission solutions, whether hydrogen, fully electric or other zero-emission technology.

In Service CAT 1 Harbor Craft by Age Group

Age Group	Ferry	Pilot	Towboat	Tugboat	Total
0-5	56	2	199	7	**264**
6-10	85		331	67	**483**
11-15	46	1	317	113	**477**
16-20	78		205	138	**421**
20-25	98	2	118	80	**298**
≥25	500	1	1,385	576	**2,462**
Total	**863**	**6**	**2,555**	**981**	**4,405**

Source: Intelatus Global Partners

California

There are 676 registered harbor craft in California that meet the criteria of this study. Of these vessels, 53% or 360 are In Service, of which slightly more than two thirds are classed as Cat 1 vessels.

In Service Cat 1 California Harbor Craft

Age Group	Ferry	Pilot	Towboat	Tugboat	Total
0-5	3	2	5	1	**11**
6-10	10		3	5	**18**
11-15	5	1	9	4	**19**
16-20	7		5	11	**23**
20-25	13	2	3	9	**27**
≥25	66		45	35	**146**
Total	**104**	**5**	**70**	**65**	**244**

Source: Intelatus Global Partners

The 65 tugboats are the closest segment technically for the adoption of the HyZET technology.

As the towboat segment in California also features a number of ocean-going ATBs, this segment may prove less ready for the HyZET concept as, for example, towboats operating on the Mississippi River System.

The ferry and excursion vessels and pilot boats, especially those operating on the routine ferry routes, are generally well suited for zero-emission technologies, such as hydrogen and electricity. That said, some of the excursion vessels that venture further offshore may be less suited for short- and medium-term transition to hydrogen or fully electric technology.

A Closer Look at Engine Tiers

We have performed an analysis on the CHC CARB Reported Vessel Data dated June 20, 2023, to better understand the types of engines installed on harbor craft. This dataset records all vessels, whether above or below 600 kW.

The analysis indicates that 6% of engines are EPA Tier 4 compliant, currently the most stringent federal marine emission standard. A further 44% Tier 3.

Focusing on the Cat 1 vessels, the CARB CHC dataset records 744 engines, of which 402 are main engines. Of these 402 engines, 5% are Tier 4 compliant and 45% Tier 3 compliant, reflecting the opportunity for zero-emission technologies.

1. Introduction

1.1. Purpose of the Assessment

This report is funded in part by the Clean Off-Road Equipment Incentive Project (CORE). CORE is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment — particularly in disadvantaged communities.

The State of California has responded to the problem of air pollution and its consequential impacts on public health in a number of ways, including the support of the adoption of zero-emission transportation technology. Supported technologies within the road transportation segment have included battery electric or fuel cell buses and trucks. However, some segments, including the harbor craft segment, have presented significant challenges in terms of transitioning to zero-emission solutions.

California aims to reduce harmful air pollution in the maritime segment by supporting the development and deployment of zero-emission harbor craft. The "first mover" focus by the state is on vessels with predictable duty cycles and which generally return to base daily, including tugboats and ferries.

Under the California Air Resources Board's plan to expand zero-emission operations within the maritime freight segment, CALSTART and its partners within the hydrogen fuel cell-powered zero-emission tug (HyZET) project are developing an actionable liquid hydrogen fuel cell-powered tugboat design that will be ready for construction and implementation at the San Pedro Port Complex, which includes the Port of Los Angeles and the Port of Long Beach. The project will identify and address challenges related to producing, delivering, transferring and storing liquid hydrogen to power a zero-emission tugboat as one pathway to decarbonize the maritime segment. The electrically driven hydrogen fuel cell-powered zero-emission tug features 2,400 kW fuel cell power and 1,740 kWh of battery energy storage, capable of providing up to 5,220 kW for 13 minutes.

The purpose of this analysis is to size and analyze the total U.S. harbor craft, inland and near shore vessel fleet to understand the potential market for zero-emission vessel solutions, such as HyZET.

1.2. Methodology

This report is written as a quantitative analysis of the U.S. harbor craft segment and the potential market size for zero-emissions technology.

Given that the vast majority of harbor craft in the U.S. currently feature traditional high and medium speed marine engines operating on marine diesel and marine gas oil, the whole segment effectively represents the longer-term opportunity for zero-emission technologies.

The data

The project data has been extracted from proprietary databases of Intelatus Global Partners and its companies and represents the culmination of over 80 years of information gathering, which have been supplemented by a variety of data sources, including:

- USCG Vessel Database.
- US Army Corps of Engineers, Institute for Water Resources, Vessel Characteristics.
- Output from the database for Airborne Toxic Control Measure for Diesel Engines on Commercial Harbor Craft Operated within California Waters and 24 Nautical Miles of the California Baseline for 2021 in accordance with the Commercial Harbor Craft Regulation. The effective date for the data provided is July 25, 2022. The new CHC Reporting Database, with a company reporting deadline of March 31, 2023, is in process at the time of development of this report and has not been seen or used for this analysis.

  It should be noted that this dataset addresses vessels operated within California waters and can include data for vessels registered within another state. Our dataset assigns a vessel to a state based on registry.
- State of Alaska Commercial Fisheries

Statistics and Data.

- Noth Atlantic Area region fisheries data.
- International Telecommunications Union.

Data challenges

One issue that has been addressed by this exercise is the inconsistency and incompleteness of data between various sources. This manifests itself as spelling mistakes in names, different vessel delivery data and differences in vessel characteristics. We have endeavored to clean up these inconsistencies.

A further issue to note is the issue of identifying the owners of certain vessels, particularly in the fishing fleet. The reason is that certain vessels are registered to an individual person rather than a corporate entity. In this case there are confidentiality provisions in place that result in us not being able to identify all these owners in the database. However, some individual names remain. Due to this privacy issue, CALSTART may wish to consider hiding the vessel owners' names in the dataset if made publicly available.

Are all the vessels database active?

Our database questions the status of a vessel.

We have grouped the vessel data into four sub-categories of activity: In Service, Idle, Laid-up & Inactive or Unknown. The basis of this segmentation is an analysis of AIS signals and in particular when a last AIS signal was received for a vessel.

AIS, or the Automated Identification System, is a digital positional awareness system. AIS supports the identification and tracking of ships and is an aid to safe navigation, security monitoring and search and rescue operations. In short, vessels equipped with the correct AIS system can be tracked and their activity status verified.

However, not all U.S. harbor craft transmit AIS signals that allow their activity to be recorded.

Under the International Maritime Organization SOLAS convention, all vessels of 300 gross tons and above engaged on international voyages and all passenger ships of 150 gross tons or more when carrying more than 12 passengers on an international voyage must carry an AIS Class A onboard.

Non-SOLAS vessels, including pleasure craft, generally use AIS Class B systems, which provide limited functionality.

The U.S. Coast Guard clarifies IMO requirements for vessels in the USA to operate with an AIS Class A device:

- Self-propelled vessels engaged in commercial service that have an overall length of 65 feet or more.
- A towing vessel engaged in commercial operations with an overall length of 26 feet or more and more than 600 horsepower (close to all of the towboats in our database).
- A self-propelled vessel certified to carry more than 150 passengers.
- Self-propelled vessels undertaking dredging operations in or near a commercial channel.
- Vessel carrying certain dangerous goods and flammable or combustible liquid cargos.

Vessels permitted to operate with a Class B system and therefore less easy to track include:

- Commercial fishing vessels.
- Vessels carrying less than 150 passengers and operating below 14 knots.

Our database segments data into four categories to reflect activity:

- In Service: Active with AIS signal received within the last three months reflecting movement.
- Idle: Last AIS signal received between three and six months. This indicates that vessel could be temporarily idle for commercial or technical reasons, under repair or upgrade, or trading outside the coverage of AIS.
- Inactive and Laid-up: Last AIS signal received six months or more ago and categorized as inactive or laid-up in the USCG database. Traditionally, for vessels required to transmit AIS signals one would group these vessels as inactive or scrapped in place.

- Unknown: Last AIS signal received six months or more ago.

  As we have established, not all harbor craft require AIS Class A, for which there are several possible scenarios regarding the status of the vessel. The vessel could be lost or demolished, on long-term lay-up or scrapped in place, trading outside of the USA or simply does not need to feature AIS Class A.

As part of our data cleaning exercise, we have removed a large number of vessels that are still within federal databases but are either trading overseas or have been lost at sea, abandoned or scrapped.

2. The regulatory framework for zero-emission vessels

Marine vessels have traditionally contributed significant amounts of greenhouse gas (GHG) emissions and air pollutants. GHG emissions refer to carbon dioxide (CO2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases. GHG emissions are collectively reported as CO2e or carbon dioxide equivalent. The most recent estimates for shipping emissions are contained within the Fourth IMO GHG Study (2020)[i], which identified that shipping contributed to 2.9% of 2018 global GHG emissions. Vessel-based international shipping accounted for 87% of total shipping emissions.

Due to the impact of emissions from international shipping, it is not surprising to see that the IMO has focused largely on emissions reduction from international shipping, leaving regional, national or local administrations to administer domestic shipping – either by accepting the IMO position or implementing specific regulations.

Within the United States, shipping is essentially governed by Title 46 of the Code of Federal Regulations (46 CFR) and addresses the role of the U.S. Coast Guard, the U.S. Maritime Administration and the Federal Maritime Commission.

Title 33 of the Code (33 CFR) governs navigation and navigable waters within the United States and addresses the role of the USCG, the Army Corps of Engineers and the Saint Lawrence Seaway Development Corporation.

The U.S. Coast Guard (USCG) is the main regulatory body for vessels sailing within the United States. However, maritime regulations are also governed somewhat by the United States' participation in the International Maritime Organization (IMO).

2.1. The IMO strategy

The origins of global shipping GHG reduction by the IMO can be found in the 1997 Kyoto Protocol, which entered into force in 2005. The protocol translated the United Nations Framework Convention on Climate Change to limit and reduce GHG emissions. The protocol contains provisions for reducing GHG emissions from shipping.

The foundation for the decarbonization of the policies of the international maritime industry is the Initial IMO Strategy of Greenhouse Gas Emissions from Ships (2018). The strategy set firm targets for 2030 and 2050 against 2008 levels:

- Mid-term target (2023-2030) - CO2 emissions reduction by at least 40% by 2030.
- Long-term target (2030-2050) - At least 50% GHG reduction from shipping and a 70% carbon intensity reduction by 2050 from 2008 levels.
- Longer-term aim - To achieve zero CO2 emissions as soon as possible after 2050.

The IMO's Marine Environment Protection Committee agreed in July 2023 to revised policy ambitions aimed at reducing GHG emissions and carbon intensity from shipping. This revised policy direction should be translated in the coming years through new or revised IMO regulations, the majority of which only impact international shipping from after the middle of the decade. At a high-level, the IMO's ambitions are:

- To reach net zero-emissions compared to 2008 by or around 2050 on a well-to-wake basis. Current IMO regulations only address tank-to-wake CO2 emissions from fossil fuels or emissions from burning or using an energy source in a ship. Well-to-wake emissions calculate emissions from production (feedstock extraction, cultivation, acquisition or recovery) through to transporting a fuel or energy carrier to the ship and using the energy source in the ship.
- 40% carbon intensity reduction by 2030 on well-to-wake basis versus 2008.
- 5-10% uptake of zero or near zero GHG emissions technologies, fuels and/or energy sources by 2030 versus 2008.
- Interim reduction targets for absolute GHG emissions versus 2008 of 20-30% by 2030 and 70-80% by 2040.

As the shipping sector takes tentative steps to adopt low and zero-emissions fuels, IMO's guidelines and regulations addressing the use of hydrogen and hydrogen-based fuels are being updated. Interim guidelines currently address the installation of fuel cells on vessels and the fuel storage and supply to the fuel cells. However, the agreement of specific guidelines on the use of hydrogen and hydrogen-based fuels by the IMO would help clarify the regulatory landscape further.

For vessels only trading in U.S waters, the alternative design approach allowed for under 46 CFR will be required for hydrogen fueled vessels seeking a U.S. Certificate of Inspection.

2.2. MARPOL

Coming into force in 1973, MARPOL, the International Convention for the Prevention of Pollution from Ships, is the main international convention covering the pollution of the marine environment, including GHG emissions. MARPOL is the foundation for global engine maker and ship designer technological developments.

Global standards are presented within the International Convention on the Prevention of Pollution from Ships and are referred to as MARPOL. MARPOL Annex VI (2005) defines the requirements for engines and vessels related to NOx, SOx and PM.

The U.S. EPA and the Coast Guard administer IMO MARPOL Annex VI compliance in the United States. MARPOL Annex VI is applicable to U.S. flagged vessels trading in international waters as well as foreign flag vessels operating within the U.S. Emission Control Area.

U.S. flagged vessels that only operate within U.S. waters comply with the EPA's domestic emission standards (NAAQS) under the Clean Air Act and 40 CFR in lieu of compliance with MARPOL requirements. The NAAQS regulate emissions from hazardous air pollutants but do not yet cap GHG emissions.

It should be noted that the focus of EPA standards is tilted toward NOx and PM.

The EPA has four tiers for exhaust emission standards: Tier 1 (implemented in 1996), Tier 2 (phased in from 2003 to 2008), Tier 3 (2004 to 2008) and Tier 4. Each new tier of engine brings stricter emissions standards and requires more advanced technology.

The EPA regulations divide marine engines into three categories based on displacement per cylinder.

- Category 3 marine diesel engines are typically large marine diesel engines used to power deep-sea ships. Typical engines range in size from 2,500 to 70,000 kW or 3,000 to 100,000 hp.
- Smaller vessels, such as harbor craft, tend to feature Category 1 and 2 engines, which are generally high- and medium-speed engines. Category 1 and 2 marine diesel engines typically range in size from around 500 to 8,000 kw or 700 to 11,000 hp. Categories 1 and 2 are further divided into subcategories, depending on displacement and net power output.

Tier 4 regulations are applicable to a variety of vessels, including ferries, tugboats and deep-sea vessels. Tier 3 requirements generally apply to smaller vessels such as recreational vessels.

Tier 3 and Tier 4 emissions standards for marine engines in Categories 1 and 2 were first introduced in 2008 regulations. Modeled on the 2007/2010 highway engine program and the Tier 4 nonroad rule, there is focus on deploying emission after treatment technology. The use of catalytic aftertreatment was facilitated by the sulfur cap for marine fuels established by the EPA.

Tier 4 regulations, effective from 2014, are currently the most stringent federal marine emission standards.

For Category 1 vessels, EPA Tier 4 emission regulations apply to new engines with a power output of 600 kW or 800 hp and above. Tier 4 standards require a 63% reduction in PM over Tier 3 regulations and a 64% reduction in NOx and PM emissions.

In addition to the EPA requirements, the California Air Resources Board (CARB) enforces its own clean air regulations, which are discussed later in this chapter.

Exhibit 1 summarizes the specific exhaust emission components that MARPOL Annex VI and 40 CFR seek to regulate.

Exhibit 1 Exhaust Emission Components

Component	The issue	Primary mitigation solutions	Secondary and tertiary mitigation solutions
NOx	Respiratory issues. Acid rain. Toxic ground ozone formation.	Temperature reduction during the combustion process. Exhaust gas recirculation.	Aftertreatment including selective catalytic reduction. Alternative fuels.
SOx	Respiratory issues. Acid rain.	Fuel injection control.	After treatment including exhaust gas scrubbers. Alternative fuels.
PM	Air pollution. Respiratory and heart issues.	Fuel injection control.	After treatment including direct particulate filter. Alternative fuels.
HC	Volatile organic compounds. Some are proven carcinogens. Others can cause ear, nose and throat irritation and liver and kidney damage.	Fuel injection control and engine maintenance.	Oxidation catalyst. Alternative fuels.
CO	Toxic ground ozone formation.	Fuel injection control. Low load avoidance.	Oxidation catalyst. Alternative fuel.
CO2	GHG contributing to climate change.	Various measures including carbon capture and storage aftertreatment, hydrodynamic design, voyage planning, maintenance, alternative fuels.	

Source: Intelatus Global Partners interpretation of MarineLink information

2.3. Other authorities regulating marine emissions

Outside of the IMO and the U.S. EPA, the European Union and Chinese Ministry of Ecology and Environment regulate emissions within their territories. The myriad of regulations, even though sharing common DNA, increases compliance requirements for engine makers.

2.4. IMO SOLAS

Whereas MARPOL seeks to mitigate the impact of emissions through encouraging the adoption of operational and technical measures, including the adoption of alternative energy carriers to fossil fuels, the safety of a vessel and its crew is governed by the International Convention for the Safety of Life at Sea. In the context of adopting hydrogen as a maritime fuel, SOLAS will govern the design requirements for the fuel storage and handling system. The U.S. Coast Guard administers MARPOL compliance in the United States.

Till now, there have been no specific SOLAS regulations governing the use of hydrogen as a marine fuel. Where vessel designs deviate from the prescribed rules, there is allowance for a risk management based "Alternative Design" approach.

Within the United States, the USCG Marine Safety Center holds the responsibility for ensuring the safety of vessels, regardless of their propulsion technology. The Marine Safety Center is tasked with updating the Code of Federal Regulations to address the commercial adoption of such new technologies as hydrogen, fuel cells and battery energy systems.

2.5. IMO IGF

The basis for accepting the Alternative Design approach for using hydrogen as a marine fuel is the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IGF code). Developed by the IMO's Marine Safety Committee, the IGF code provides the regulatory framework for low flashpoint marine fuels. However, the IGF Code does not yet include guidelines for the safety of ships using hydrogen in liquefied and gaseous form as fuel. Draft interim guidelines to include fuel cells in the IGF code have been agreed by the IMO's relevant sub-committee.

The USCG administers compliance with the IGF code in the U.S. There are currently no existing U.S. federal regulations that specifically address the design and operation of hydrogen powered vessels.

In the U.S., the Alternative Design must establish equivalency to the design standards of Chapter 46, Code of Federal Regulations – Shipping (46 CFR).

Hydrogen may be transported in containment systems that comply with the Hazardous Materials Regulation in 49 CFR.

2.6. A word on California

The Clean Air Act ties most states into compliance with EPA standards given that the Act prohibits individual states from setting their own emission standards with the exception of any state that had emission standards pre-dating March 30, 1996. California is the only state to meet this criterion as California had already enacted emission standards to address poor air quality before the federal government passed the Clean Air Act.

However, once a standard is implemented in California, other states may adopt California's emissions standards without applying for a waiver. States may also create regulations that control the use of used engines, referred to as "in-use" engines.

As a result of its unique position, California is leading the way in the U.S. in terms of addressing the pollution from marine engines. In short, California is promoting performance that is cleaner than EPA Tier 4 emissions standards.

Under CARB's plan to expand zero-emission operations for freight transport, CARB divided the program into five categories:

- Oceangoing vessels.
- Heavy duty trucks.
- Cargo handling equipment.
- Locomotives.
- Harbor craft – the focus for harbor craft is fuel standards and the vessels themselves, which include a zero-emission ferry and the hydrogen zero-emission tug.

First adopted in 2008 and subsequently amended in 2010, the Commercial Harbor Craft Regulation has created a unique situation in State of California whereby vessel owners have been encouraged to replace older, more polluting engines with new and cleaner engines that reduce pollutants such as PM, NOx, SOx and GHGs. The original regulations provided the foundation for vessel owners to accelerate a transition from Tier 2 to cleaner combustion Tier 3 engines for certain vessel categories, covering all commercial harbor craft categories.

In response to public health concerns, CARB approved amendments to the Commercial Harbor Craft Regulation in 2022. The amendments, which became effective on January 1, 2023, are forecast to drive an 89% reduction in PM and a 54% reduction in NOx.

The Commercial Harbor Craft Regulation amendments promote zero-emission options where feasible and Tier 3 (mainly limited to the commercial fishing and new excursion vessels) and Tier 4 engines with diesel particulate filters on all other vessels. The phase-in for the new amendments is 2023-2032, with specific date for vessel categories and year of manufacture.

Exhibit 2 summarizes the Tier 4 standards required for Category 1 and 2 engines i.e., those generally found in harbor craft.

Exhibit 2 EPA Tier 4 Standards for Category 1 and 2 Engines

kW	Nox (g/kWh)	HC (g/kWh)	PM (g/kWh)
600-1,399	1.8	0.19	0.06
1,400-1,999	1.8	0.19	0.04
2000-3,699	1.8	0.19	0.04
≥3,700	1.8	0.19	0.04

Source: Intelatus Global Partners interpretation of EPA information

Compliance extensions for certain vessel categories may be considered subject to certain conditions.

- Delays in developing shore power and/or zero-emission infrastructure may result in a one-to-two-year compliance extension.
- Availability of certified engines and/or diesel particulate filters may result in a two-year renewable compliance extension.
- Commercial fishing vessels (charter or sport fishing vessels), if equipped with a Tier 3 engine by the end of 2024, may receive a one-time ten-year extension option for compliance to 2035.
- Vessels equipped with Tier 4 engines that have recorded limited running hours and where the addition of a diesel particulate filter triggers a vessel replacement may result in a two-year renewable compliance extension.
- Manufacturer or shipyard delays impacting compliance may result in a one-year renewable compliance extension.

There are additional requirements for short run ferries and new excursion vessels (such as those used for whale watching and dinner cruises):

- Short run ferries, including those with a single voyage of less than three nautical miles will be required to be fully zero-emission by the end of 2025.
- New excursion vessels are required to be able to operate with a minimum of 30% zero-emission power source.

Under the regulation, alternative control of emissions that meet or exceed the PM and Nox reduction targets can be considered. These include:

- Engine modifications. Primary methods for reducing the formation of Nox emissions in an internal combustion engine include primary design i.e., adopting of Tier 3 or Tier 4 engines.
- Exhaust gas emission control: Water injection or exhaust gas recirculation are technical options for NOx reduction. Selective catalytic reduction has become a common solution within the deep-sea fleet but is often considered an impractical solution for the short sea segment.
- Engine repowering or rebuilding to a more stringent/higher EPA Tier standard.
- Shore-side power.
- Fleet averaging, whereby vessels featuring zero-emission and advanced technology generate credits to being overall fleet performance within compliance.
- Other measures that sufficiently reduce emissions.

2.7. Carbon pricing

At a global level, the IMO's MEPC has agreed that the generation of emissions should have a price. However, there is disagreement on the mechanisms and costing for such measures. Despite these differences among members, MEPC members have set the ambitious target of adopting a mechanism for carbon pricing by 2025 with an entry into force by 2027.

Unlike the European Union, which is extending its carbon pricing Emissions Trading System to the maritime segment including offshore support vessels, the United States has no federal mechanism pricing carbon emissions. Carbon pricing is currently managed at the state level. Several states notably do operate cap-and-trade programs, whereby companies purchase allowances equal to their GHG emissions. Outside of California, these programs generally do not impact the harbor craft segment.

3. Zero-emission energy carriers

Till now, most large commercial ships have operated on heavy fuel oil (HFO), marine diesel oil (MDO) or marine gas oil (MGO). Numerous alternative fuels are being evaluated with an aim of reducing carbon emissions from shipping.

Described in this section are the trends and developments in alternative fuels to HFO, MDO and MGO for shipping.

3.1. A multitude of choices

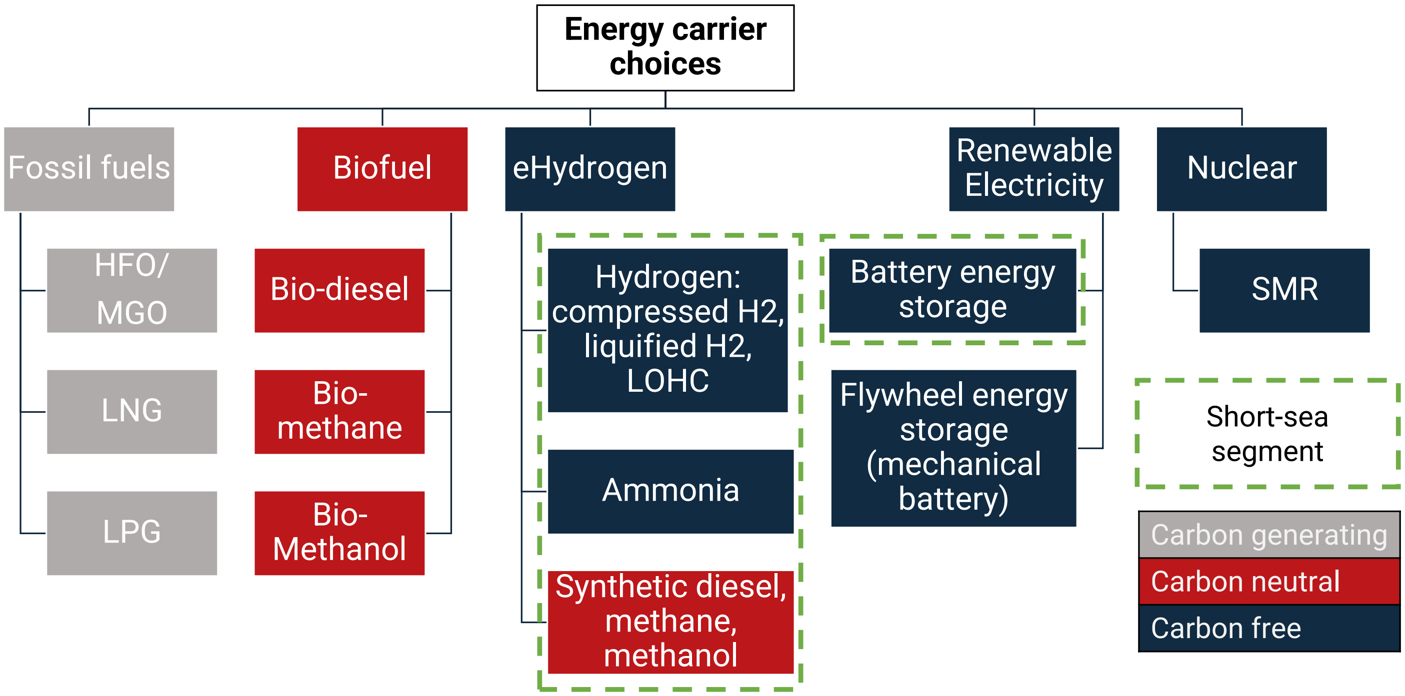
There is a distinction between short-sea shipping and deep-sea shipping when considering the use of various alternative fuels.

The deep-sea shipping segment mainly includes large, oceangoing vessels that require fuel that is globally available. The fuel used on these vessels must have a sufficiently high energy density to minimize storage volume and maximize available cargo space. This is driving interest in LNG, LPG (for certain ship types), methanol and ammonia. These ship types – such as container ships, bulk carriers and tankers – generally fall outside of the scope of study of this report.

Vessels in the short-sea and inland shipping segment generally operate in limited geographical areas and make regular port calls – such as harbor craft, passenger ferries, offshore vessels, etc. This segment is more suitable for energy storage systems that cannot be used on the deep-sea shipping segment due to energy storage limitations – such as pure electric power and hydrogen.

Exhibit 3 presents at a high level the energy carrier choices that a ship owner can make.

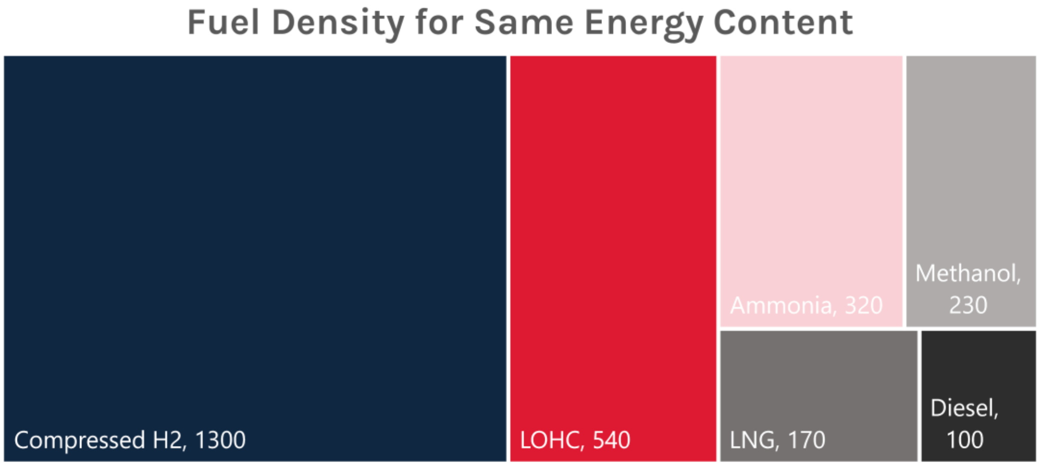
Exhibit 3 Energy Carrier Choices



Source: Intelatus Global Partners

The suitability of an energy carrier is somewhat linked to the storage requirement for different fuel options. Exhibit 4 compares the storage volumes required for a variety of fuel, where the larger the storage volume becomes, the less suited it is for the deep-sea segment.

Exhibit 4 Hydrogen



Source: Intelatus Global Partners of data from SALT Ship Design

In deciding on what energy carriers to invest in, ship owners in the short-sea and inland segment must weigh a number of advantages and disadvantages for the different options.

Exhibit 5 examines some high-level advantages and challenges to using hydrogen.

Exhibit 5 Hydrogen

Advantages & opportunities	Disadvantages & challenges
• Suited for short-sea applications. • High energy content. • Zero-carbon tank-to-wake emissions. • No CO2, Nox, SOx and PM when used in fuel cells. • Some ICEs can use H2 blended with conventional fuels or gases. • Can be stored as a cryogenic liquid, a compressed gas, or bonded with other chemicals to carry energy. • **Scale of fuel cell supply** – commercial availability expected shortly after mid-decade. • H2 disperses if leaked. • H2 electrolyzer capacity is growing. • Liquid H2 tankers are being built.	• Nox emissions produced when used in an ICE. • Highly combustible. High explosion risk in confined spaces. • Compression or cryogenic storage is energy intensive and expensive. • Requires large storage volume. • Limited bunkering infrastructure. • Susceptibility of certain materials to H2 embrittlement. • H2 proton exchange membrane fuel cells use expensive platinum. • Competition for renewable H2 with other sectors. • Immaturity of current safety regulations. • Fuel cost uncertainty. • Certifying green fuel.

Source: Intelatus Global Partners

Exhibit 6 looks at some of the high-level advantages and challenges to using ammonia.

Exhibit 6 Ammonia

Advantages & opportunities	Disadvantages & challenges
• Carbon free and zero-emission tank-to-wake. • Low flammability risk. • Can be stored and transported as a liquid. • High level of maturity in many aspects of ammonia storage and transport infrastructure. • A flexible energy carrier with solutions available for ICEs and cracking into H2 and running through fuel cells. • 2-stroke ICE commercially available by 2025 and 4-stroke by 2026. • When used directly in a SOFC, no pre-treatment is required. • SOFCs do not require the use of expensive metals.	• The scale of green ammonia supply & bunker infrastructure is limited. • Toxicity. • Corrosive to certain materials. • Lack of safety regulations – expected after the middle of the decade. • Large storage volume. • Capex of fuel containment, supply and safety systems. • Engine development is low maturity. • ICEs require pilot fuel, with Nox emissions. • Scale of fuel cell supply. Commercial availability of fuel cells is not expected before mid-2030s. • H2 conversion equipment required for fuel cells. • Acid scrubbers are needed for product gas. • PEMFCs use expensive platinum. • High fuel costs. • Certifying green fuel.

Source: Intelatus Global Partners

Exhibit 7 summarizes some high-level advantages and challenges to using methanol.

Exhibit 7 Methanol

Advantages & opportunities	Disadvantages & challenges
• Lower ICE tank-to-wake emissions than oil fuel. • Synthetic/e-methanol has reduced CO2 emissions. • Virtually sulfur-free. • Produces almost no PM and low amounts of Nox. • Suited to storage in near conventional fuel tanks. • Growing ICE supply 2-stroke engines available commercially today. 4-stroke ICE by 2024. • Solutions available for cracking into H2 and running through fuel cells. Fuel cells commercially available around 2030. • Easier to store and handle than ammonia and hydrogen. • Available at certain ports. • High safety regulatory maturity. IGC and IGF codes give framework to using methanol. • Biodegradable in the air and sea.	• ICE produces tank-to-wake CO2 emissions. • Conventional methanol has higher well-to-tank emissions versus other oil-based fuels. • Larger fuel tanks than conventional fuels and LNG for the same energy content. • Uncertainty about fuel cost. • Scale of renewable H2 production (for green methanol production). • Limited bunkering infrastructure. • Scale and cost of fuel cell production. • Corrosive to some materials. • Nox emissions require SCR or EGR systems. • Highly flammable. • Toxic and can be lethal if ingested. • Certifying green fuel.

Source: Intelatus Global Partners

Electricity stored in battery energy storage systems provides another choice for vessel owners, either for deployment in a hybrid system featuring other energy carriers or in a pure electric vessel. Exhibit 8 presents a high-level summary of the advantages and disadvantages of electricity as the main energy carrier.

Exhibit 8 Batteries and Electricity

Advantages & opportunities	Disadvantages & challenges
• Ideal for short-sea segments. • Zero operational emissions. • Electric power systems using batteries provide increased control and optimized operational and safety performance. • Battery technology is developing rapidly; production is scaling up and prices are falling. • Charging is safe/ Class societies have developed battery safety regulations. • Batteries are technically easy to replace. • Growing port based electrical charging supply. Emissions cut further when shore power is produced from green electricity.	• Competition from other transport segments for batteries. • Sustainability of production chain for lithium-ion battery materials – graphite, cobalt, lithium, and nickel. • Scale of renewable energy electricity supply.

Source: Intelatus Global Partners

3.2. Certification of zero-emission fuels

Using the HyZET project as an example, initially it is estimated that the tug will reduce emissions at the Port of Los Angeles by 476 tons CO2e annually. However, when green hydrogen becomes available in the future, emissions will be reduced by around 2,204 tons CO2e.

But the nature or source of a fuel is an important distinction when considering well-to-wake emissions for future fuels such as hydrogen, methanol and ammonia. It will also become an important factor and challenge in certifying the nature of a low or zero-emissions fuel:

- Grey fuels are the most commonly produced future fuels and are made from burning natural gas without carbon capture and storage. Brown/black fuels are made from coal and oil.

- Blue fuels are produced from natural gas or coal with carbon capture and storage. Synthetic/e-fuels produced with CO2 from carbon capture from another combustion process are classed as blue fuels. The focus on blue fuels is relatively high in the United States.

  In its white paper on hydrogen as a marine fuel[ii], ABS explains that hydrogen can be seen as "having a very low tank-to-wake emissions impact." ABS goes on to explain that hydrogen produced from fossil fuel sources is not carbon free on a well-to-tank basis and clearly explains that "When both well-to-tank and tank-to-wake emissions are eliminated from the fuel life cycle, a zero-carbon well-to-wake fuel option is created."

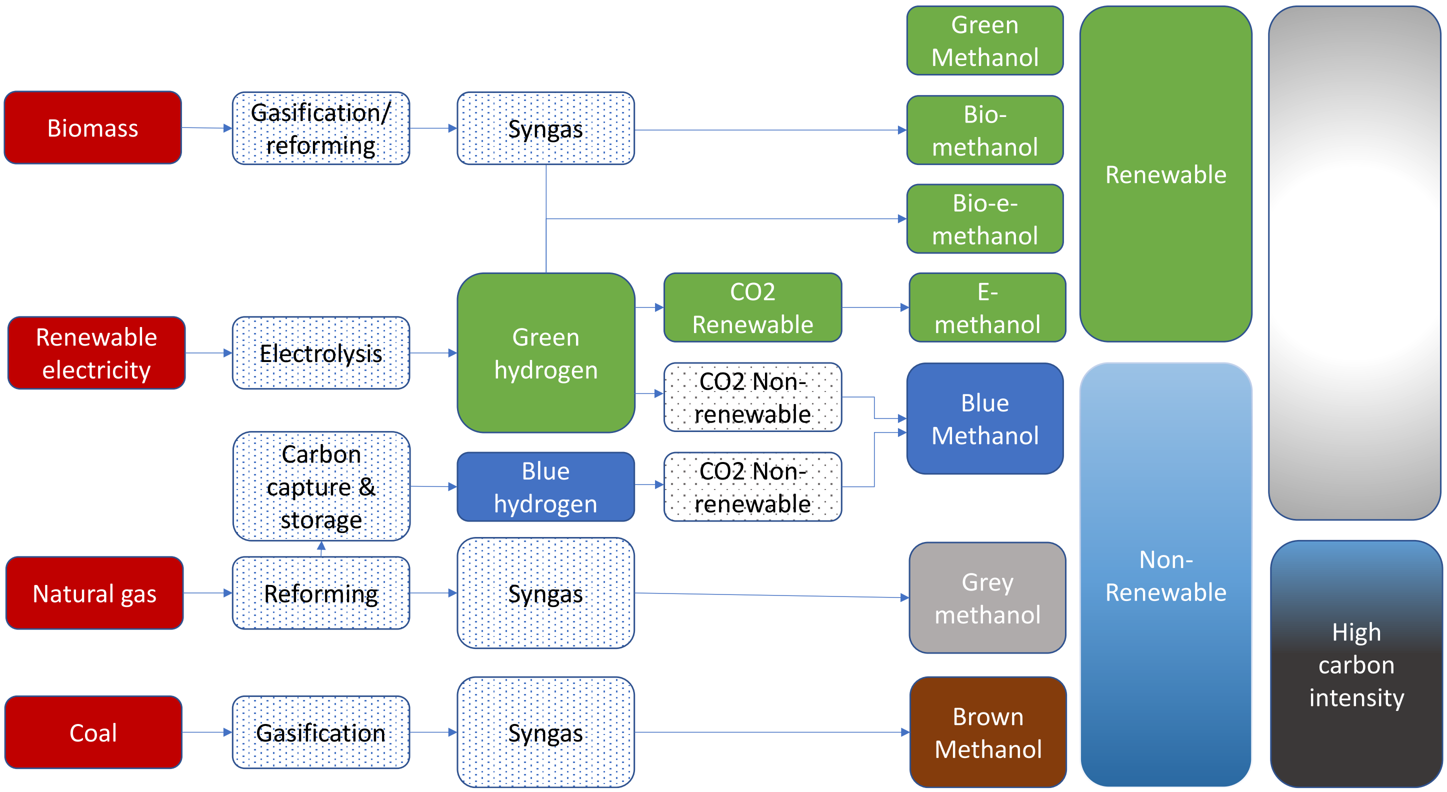
  ABS explains that the well-to-tank emissions for traditional marine gas oil are 14.2 kilograms CO2 per megajoule of fuel. Hydrogen produced from renewable electricity or nuclear have zero-emissions. Hydrogen produced from natural gas with carbon capture, utilization and storage technology can reduce carbon dioxide emissions to around 35 grams $CO2/MJH_2$ with a 56% capture rate and around 10 grams$CO2/MJH_2$.

- Green fuels are produced from carbon free electricity, such as wind or solar, and do not take from existing grid supply. Green synthetic/e-fuels are produced with CO2 directly extracted from the atmosphere. Green biofuels are those that meet sustainability requirements.

- Purple/pink fuels are produced from electrolysis powered by nuclear energy.

The chart in Exhibit 9 uses methanol as an example to show the process to produce green, blue, grey and brown methanol. The chart also shows the production routes for green and blue hydrogen. As well-to-wake emissions reporting evolves, understanding the source and color of hydrogen will become more important.

Exhibit 9 The Methanol Production Process



Source: Intelatus Global Partners interpretation of IRENA source information

As the International Renewable Energy Agency (IRENA) and the Rocky Mountain Institute (RMI) address in their 2023 report entitled Creating a Global Hydrogen Market – Certification to Enable Trade[iii], hydrogen and hydrogen-based fuels will play an increasingly important role in the energy transition. As end user demand grows, the trade of hydrogen and its derivatives will increase. As trade grows so will the need to give confidence to the end user that the hydrogen or hydrogen derivative is in fact made from renewable sources. Certification will assist the process.

According to IRENA and RMI, "Certification will contain information on compliance with standards and regulatory requirements, and enable verification through data on suitability criteria, such as carbon footprint and renewable energy content, thereby allowing differentiation from other less green products."

Based on a global survey of certification regimes, IRENA and RMI conclude that significant certification gaps exist for which the partners identify recommend actions. The gaps include:

- Clear information on GHG emissions produced during hydrogen production and/or transportation.
- Common standards used: emissions thresholds, power supply requirement for electrolysis, hydrogen production pathway and chain of custody model.
- Ecolabelling.

- Compliance with environmental, social and governance criteria.

IRENA and RMI point to a variety of voluntary as well as mandatory certification regimes for hydrogen production:

- Voluntary (in alphabetical order): Aichi Prefecture Low Carbon Hydrogen Certification, Australia Clean Energy Regulator is developing the Hydrogen Guarantee of Origin certificate, CertifHy Green and Low-Carbon Hydrogen Certification, CEN-CENELEC is developing Joint Technical Committee 6, the China Hydrogen Alliance Standard and Assessment for Low Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen Energy, Green Hydrogen Organization Green Hydrogen Standard, Smart Energy Council Zero Carbon Certification Scheme and TUV Sud CMS 70.
- Mandatory (in alphabetical order): California Low Carbon Fuel Standard, the European Commission is developing the Renewable Energy Directive, the UK Department for Business Energy & Industrial Strategy Low Carbon Hydrogen Standard, the UK Department of Transport Renewable Transport Fuel Obligation and the U.S. DOE is developing specific program eligibility for its Clean Hydrogen Production Standard,

3.3. Hydrogen production

Global

According to the International Energy Agency[iv], the demand for hydrogen currently amounts to around 94 million tons of hydrogen per year. Much of the current demand comes from traditional uses, mainly refining and industry.

The IEA forecasts demand for hydrogen to grow to around 115 million tons by 2030. However, new uses are forecast to amount to less than two million tons.

Examples of new uses of hydrogen include steel making using pure hydrogen for direct reduction of iron, the first fleet of trains featuring hydrogen fuel cells in Germany and around "100 pilot and demonstration projects for using hydrogen and its derivatives in shipping, and major companies are already signing strategic partnerships to secure supply of these fuels."

In its review, the IEA points to an increasing interest in the maritime sector in the use of hydrogen and hydrogen derived synthetic fuels (including synthetic ammonia, diesel, methane and methanol). However, the IEA believes that the technologies for maritime "are less mature than those for road and rail." The IEA report continues to point out that based on current actions, hydrogen will only make a "small penetration" in the shipping sector by 2030. In the more positive case, where aspirational targets are met, annual shipping demand for hydrogen and hydrogen-derived fuels is expected to reach close to five million tons by 2030.

Of note, the IEA raises concerns that hydrogen demand will fall short of existing climate pledges put forward by the world's governments, which identify 130 million tons per year by 2030 of which 25% for new uses. Further, the estimated production required for the world to keep on a net zero pathway by 2050 is 200 million tons of annual hydrogen production by 2030.

The IEA points to the majority of hydrogen demand currently being met by hydrogen produced from unabated fossil fuels. Low-emission hydrogen production, which amounts to around one million tons, mostly comes from fossil futures with carbon capture, utilization and storage.

According to IEAs report, "If all projects currently in the pipeline were realized, by 2030 the production of low-emission hydrogen could reach 16-24 million tons per year, with 9-14 million tons based on electrolysis and 7-10 million tons on fossil fuels with CCUS." The 9-14 million tons of hydrogen forecast to be produced by electrolysis will require an installed electrolyzer capacity, powered by new renewable energy capacity, of 134-240 GW. Today, electrolyzer capacity stands at around 8 GW annually, and current industry announcements indicate over 60 GW of annual capacity is required by 2030. As a result, more renewable electricity capacity needs to be added to the project pipeline to support the required growth in electrolyzer capacity.

At a high level, current industry plans fall two to four times short of total pipeline capacity, which does not meet government pledges.

The USA

Currently, the U.S. produces around 10 million tons of hydrogen each year, most of which from fossil fuels.

The federal Bipartisan Infrastructure Law and the Inflation Reduction Act contain several provisions supporting the production and use of clean hydrogen:

- The establishment of a National Clean Hydrogen Strategy Roadmap – completed in June 2023[v].
- $1 billion of funding for electrolysis.
- $7-8 billion of funding for the establishment of six to ten regional clean hydrogen hubs or H2Hubs. The hubs will demonstrate the production, processing, delivery and storage and end-use of clean hydrogen.

  The DOE is planning to review applications from July 2023.

  California is expected to feature as one of the hubs. Within the potential California hydrogen hub, the Port of Long Beach and the Port of Los Angeles have recently prepared a joint proposal for federal funding to demonstrate the benefits of using hydrogen to power trucks and terminal equipment. One can only assume that, if successful, expansion of the capabilities will only benefit the adoption of the HyZET concept.

  It should be noted that the H2Hubs are expected to produce blue, pink and green hydrogen.
- Up to $3 per kilogram in tax credits to produce clean hydrogen. The available tax credits are linked to the carbon intensity of the produced hydrogen.

The federal government has set a target of net zero-emissions by 2050 and a 50-52% reduction in emissions by 2030. This translates as a reduction in GHGs of around 5.5 gigatons of CO2e by 2050.

The Department of Energy is leading the strategy to support these targets being met.

The DOE National Clean Hydrogen Strategy and Roadmap identifies the opportunities for the domestic production of 10 million tons of clean hydrogen per year by 2030, 20 million tons by 2040 and 50 million tons by 2050. Further, the strategy targets reducing the cost of producing clean hydrogen to $1 per kilogram by 2031 (the so-called Hydrogen Shot). The main short term (2022-2025) actions include:

- Support R&D to demonstrate clean hydrogen production.
- Identify and prioritize barriers to delivery and storage infrastructure roll-out and start to address the challenges by supporting the development of regional infrastructure hubs.
- Engage regulators to lay the groundwork for adoption across sectors, including hard to abate industries.
- Engage stakeholders, address safety standards and develop critical supply chains.

The DOE strategy embraces multiple green, blue and pink sources of hydrogen production, including renewable energy (wind, solar, wave, waste, etc.), nuclear, fossil fuel with CCUS and conventional storage. As with the inputs, the uses of hydrogen are expected to be multiple, including shipping, where the maritime sector is identified in a group of "emerging demands and potential new opportunities."

The DOE identifies opportunities for hydrogen and hydrogen carriers "ranging from inland and harbor vessels to recreational and pier-side applications."

DOE has been collaborating with the Department of Transportation's Maritime Administration (MARAD) to develop and demonstrate hydrogen fuel cell technologies. These are discussed in more detail in Section 3.2.

According to the DOE, U.S. electrolyzer capacity currently stands at around 650 MW, which is around 7.5% of global capacity.

The DOE cites examples of hydrogen fuel cell deployment as including over 50,000 forklift trucks, 15,000 cars and 80 buses.

3.4. An example of a port's efforts to support hydrogen

The Port of Rotterdam is Europe's largest port, offering facilities for liquid bulk, dry bulk, Ro-Ro, and container shipping. The port is a major industrial hub with many types of value-adding activities within or near the port. Rotterdam is also Europe's largest bunkering port. The Rotterdam-Mooerdijk port industry cluster causes around 20% of CO2 emissions in the Netherlands.

Rotterdam Port Authority has been very active in promoting actions to reduce marine emissions and promote carbon neutral industrial operations. Early among the port's initiatives has been to encourage the transition from HFO to LNG as a shipping fuel by developing LNG bunkering infrastructure. Alternative fuels currently supplied in the port include LPG, methanol and biofuels.

The port is working on a number of projects targeting energy transition, where industry switches to electricity, hydrogen, and green hydrogen. CO2 capture and storage will be used to make blue hydrogen. Green electricity supply will be underpinned by the Netherlands's land and offshore wind farms. The initiatives include:

- Onshore wind, growing from 200 MW of turbines to over 350 MW within the port area.
- The Port of Rotterdam is a partner in the North Sea Wind Power Hub consortium along with Gasunie and transmission system operators TenneT and Energienet. The consortium is promoting the development of an energy transmission network connecting the Netherlands, Germany, Denmark, and the U.K. through the gradual roll-out of 10-15 GW offshore wind transmission hubs. The consortium aims to develop 70-150 GW of capacity by 2040.
- The port is a partner in the H-Vision project, where 16 parties mostly working within the Port of Rotterdam industrial area are researching the production and use of blue hydrogen produced from natural and refinery gas by 2030.
- In September 2021, the Port Authority announced an agreement with Uniper to develop a green hydrogen production facility at Maasvlakte – a two-phase development initially producing around 13,000 tons of hydrogen a year growing to around 65,000 tons.
- The Port Authority and Gasunie are collaborating to develop a hydrogen pipeline grid for the port, to be operational as early as 2024. The first customer for the pipeline will be Shell, who has announced a plan for a green hydrogen plant at Maasvlakte 2. The second customer is expected to be the H2 Fifty project in 2025. H2 Fifty is a BP/Nouryon project to build 250 MW of electrolyzer capacity to produce around 32,000 tons of green hydrogen annually at the BP refinery in Rotterdam.
- As part of its plan to create a green hydrogen hub in the Port of Rotterdam, Shell is also planning to locate a 200 MW electrolyzer in the port to produce 50-60 tons of green hydrogen a day by 2023. The electrolyzers will be powered by Shell's Hollandse Kust Offshore windfarm.
- In August 2021, the Port Authority signed an MOU with Norwegian energy player Horisont Energy to supply blue ammonia produced from natural gas with carbon capture from Norway to Rotterdam. Under the agreement, blue ammonia will be shipped from the Barents Blue project in 2025. Barents Blue is expected to produce one million tons of ammonia per year. The ammonia will be used either as a marine fuel or broken down, with hydrogen being the main product.
- The Port of Rotterdam, Koole Terminals, Chiyoda Corporation and Mitsubishi Corporation signed an MOU in July 2021 to study the commercial-scale import of hydrogen from overseas and storing at one of Koole's terminals in the port using Chiyoda's SPERAHydrogen storage and transport technology. The companies have an ambition to import 300,000-400,000 tons a year by 2030.
- The port announced an agreement with the Government of Western Australia to invest in renewable hydrogen production and storage in Australia and transport to Rotterdam in early December 2021. The Port of Rotterdam estimates that it will handle around 20 million tons of hydrogen annually by 2050, of which 90% will be from imports.

- The Port of Rotterdam is a member of the Fieldlab project with Deltalings, Innovation Quarter, FME and TNO. Fieldlab aims to test new technology for industrial electrification by replacing fossil fuels with processes powered by green electricity. The process being studied includes power-to-heat, power-to-hydrogen, and power-to chemicals.
- The Port Authority is a member of the Dutch Green Maritime Methanol consortium, launched in February 2019 to conduct research into the use of renewable methanol as a maritime fuel. The consortium successfully tested 100% methanol in a spark ignited engine, utilizing a Caterpillar 3508 spark-ignited high-speed gas engine.

3.5. Fuel supply security

The supply of zero-emission fuel is currently limited.

In the deep-sea segment, we note several public and private initiatives to promote the use of low and zero-emission fuels in shipping. Examples include:

- In Norway, Yara is developing partnerships for the long-term supply of clean ammonia for the shipping segment.
- A core focus of Japan's green transformation program is the widespread use of ammonia as a shipping fuel.
- Several large deep-sea shipping companies have invested in methanol-enabled new buildings, including CMA CGM, COSCO Shipping, HMM, Evergreen and Stena Bulk.
- Maersk, one of the world's largest shipping companies, has signed agreements for 1.4 to 2 million tons per year of methanol to fuel their new generation container vessels, summarized in Exhibit 10. Maersk is also reviewing another 30 partnerships for fuel supply, including locations in Europe and Suez.

  The Maersk supply agreements cover bio-methanol (from agricultural and forestry residue and municipal waste), e-methanol (solar, wind and renewable CO2) and green methanol (using biogenic CO2).

  The first of Maersk's current orderbook of methanol capable vessels—a 2,100 TEU feeder vessel built in South Korea—has recently been delivered and commenced its maiden voyage during Q3-2023.

  However, not so many companies have the scale of operation of Maersk and cannot always consider long-term fuel supply agreements. In this scenario, public support is required to develop fuel availability and bunkering infrastructure.

Exhibit 10 Maersk's long-term methanol supply

Partner	kTPA	Location	Maersk Offtake	First Production
SunGas	390	USA	100%	2026
Carbon Sink	100	USA	100%	2027
Debo	200	China	100%	2024
CIMC ENRIC	50-250	China	100%	2024
European Energy	200-300	Brazil & USA	100%	2023
Green Technology Bank	50-300	China	100%	2024
Ørsted	300	USA	100%	2025
Proman	100	North America	50-75%	2025
WasteFuel	30	South America	100%	2026

Source: Intelatus Global Partners interpretation of data from Maersk

3.6. What else can a ship owner do to reduce emissions?

The IMO's strategy to identify and develop mechanisms to limit and/or reduce GHGs from shipping does not prescribe solutions to the challenges. Rather, the IMO has initiated several energy efficiency initiatives that have encouraged vessel owners to investigate both fuel and non-fuel options to improve the performance of the, at least, the larger vessel segments.

Tools include the Energy Efficiency Design Index (EEDI) for new buildings, the Energy Efficiency Ship Index (EEXI) for all existing ships, the Ship Energy Efficiency Plan (SEEMP), mandatory data collection and the Carbon Intensity Indicator (CII) rating. Compliance levels for carbon intensity of a vessel are tightened periodically.

Outside of choices around energy carrier and energy converter, shipowners have investigated a wide variety of design, operational and economic solutions to improve energy efficiency and reduce emissions.

Exhibit 11 summarizes at a high-level some of the more popular measures selected by vessel owners. However, it should be noted that many of these are more suited to the deep-sea segment.

Exhibit 11 Energy Efficiency Measures

Ship design & hydrodynamics	Energy assistance	Logistics & digitalization	Secondary recovery	After treatment measures
• Hull-form, ship size, propulsion improving devices (ducts, fins and bulbs), propellers, rudders and material optimization. • Air lubrication (microbubble drag reduction, air cavity, air layer and air chamber). • Hull coating and cleaning to reduce biofouling. • Propeller cleaning to reduce biofouling.	• Wind assisted propulsion (rotor sails, kites, rigid sails, soft sails and suction wings)[1]. • Solar (secondary solution for auxiliary power).	• Speed reduction. • Just-in-time arrival. • Weather routing. • Trim, draft, and ballast optimization. • Autopilot software. • Engine de-rating. • Vessel utilization. • Vessel size.	• Waste heat recovery. • Kinetic energy recovery from shipboard equipment.	• Post combustion carbon capture and storage.

Source: Intelatus Global Partners

[1] Hornblower Cruises and Events operates a diesel-electric hybrid that features vertical axis wind turbines and solar cells in San Francisco.

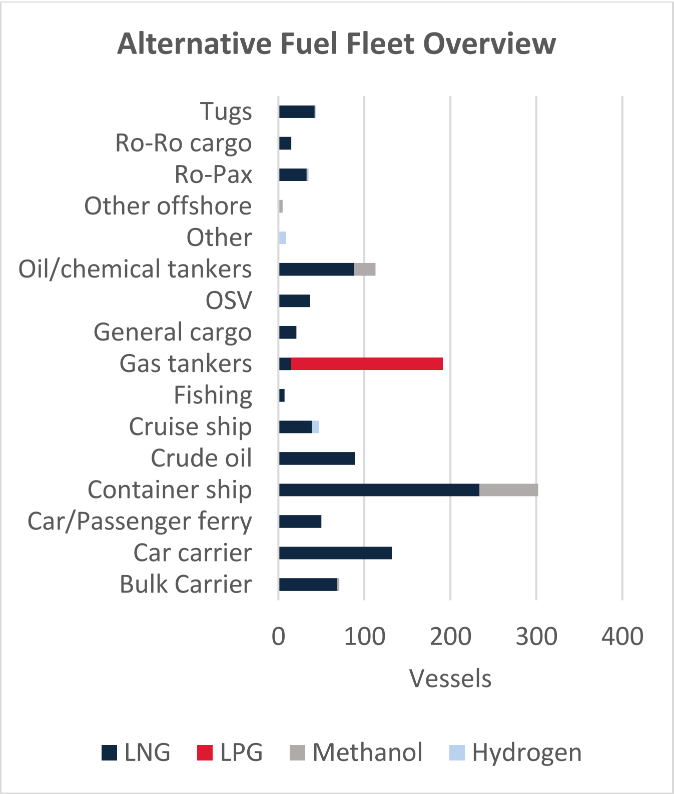
4. Global low and zero-emission vessels

In this chapter we present a summary of the status of the low and zero-emission fleet today.

It should be noted that the number of ships capable of operating on future fuels, either in operation or construction, is still relatively small and is largely concentrated in the deep-sea segment.

There are around 1,160 vessels trading in the deep-sea, short-sea and inland segments that feature alternative fuels power systems that are active or are on-order today. Hydrogen vessels account for around 2% of the total. This is summarized in Exhibit 12.

Exhibit 12 Alternative fuel fleet overview



Source: Intelatus Global Partners interpretation of data from DNV's Alternative Fuel Insight

According to the Getting to Zero Coalition, of 100 pilot and demonstration projects currently ongoing, the majority of the 45 hydrogen projects focus on small vessels, ammonia on the deep-sea segment and methanol is split between both short- and deep-sea segments.

There are also an additional 185 pure electric powered vessels out of a total 800 pure, plug-in hybrid and battery hybrid vessels.

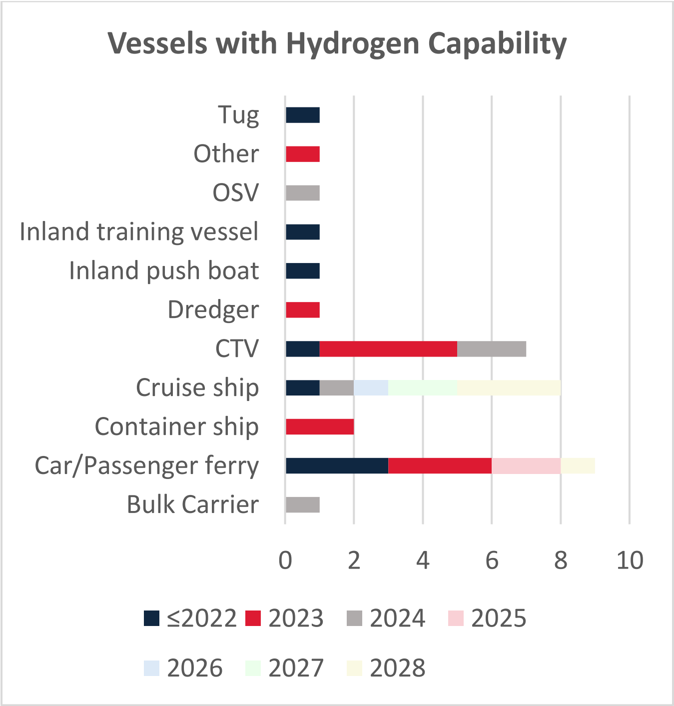
In the USA, the U.S. Coast Guard is generally supportive of new technologies. However, as new energy carrier and converter solutions are brought to market, some delays are to be expected as the agency approves first-of-kind technologies on a case-by-case basis. There are reports that the federal administration has directed the Coast Guard to intensify efforts to accelerate this process to hasten the uptake of clean energy projects in the U.S. maritime industry.

4.1. Vessels operating with H2

Globally, there are currently close to 35 vessels operating with hydrogen that are either active or on order.

Exhibit 13 summarizes the breakdown of the vessels by category and expected year of delivery.

Exhibit 13 Vessels with hydrogen capability by delivery year

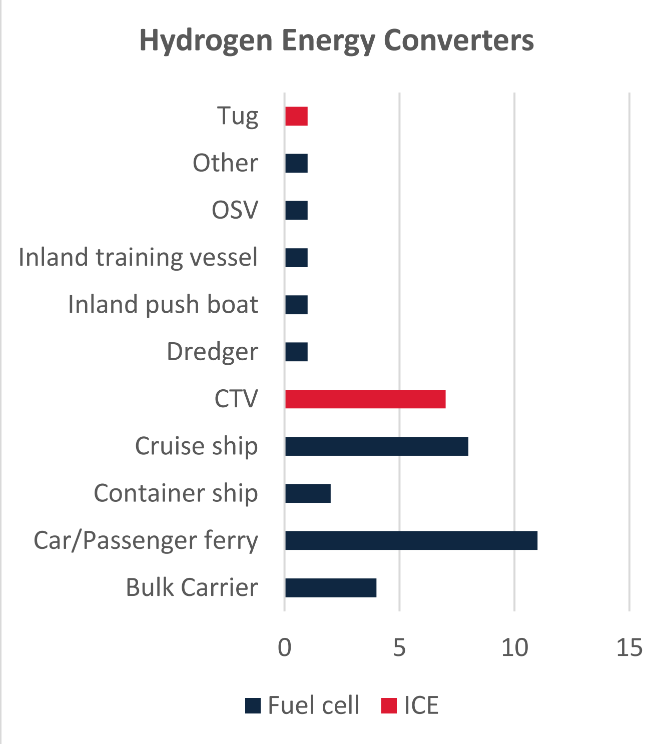


Source: Intelatus Global Partners

Exhibit 13 shows us that car/passenger ferries and offshore windfarm crew transfer vessels account for the largest number of vessels operating on hydrogen in the short-sea and inland segment. For the deep-sea segment, eight cruise ships will be equipped with hydrogen fuel cells to supplement internal combustion engines burning either VLSFO or LNG.

Most vessels aiming to use hydrogen as an energy carrier are choosing fuel cells to convert the energy. However, it should be noted that there is a growing number of vessels featuring dual fuel capable internal combustion engines, as shown in Exhibit 14.

Exhibit 14 Hydrogen energy converters

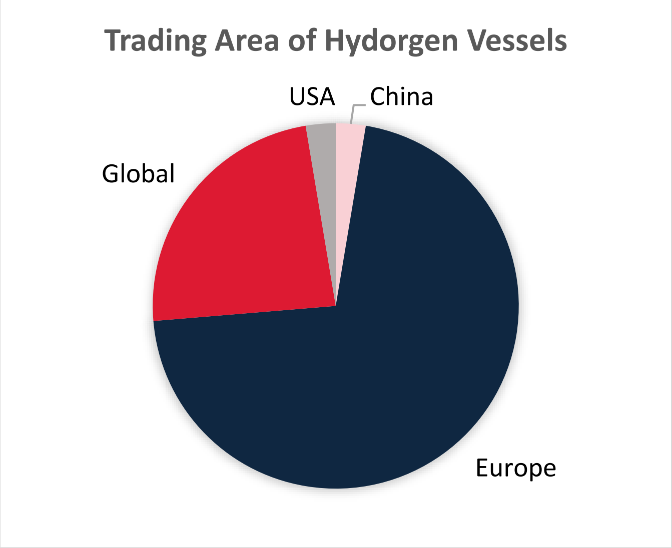


Source: Intelatus Global Partners

Around 70% of the vessels are expected to trade within the European Union and Norway, as shown in Exhibit 8. Norway has the largest single country share at seven vessels.

Vessels identified as "Global" in Exhibit 15 are mainly cruise ships and container vessels who have no set region of operation.

Exhibit 15 Trading areas of hydrogen vessels



Source: Intelatus Global Partners

4.2. Hydrogen powered vessels

Active vessels in the USA

In the U.S., the SWITCH Maritime owned *Sea Change* is the first operational vessel featuring a hydrogen fuel cell.

Operated by SF Bay Ferry and funded within the Advanced Technology Demonstration and Pilot Project – Zero Emissions Ferry (ZEF), the 75-person passenger ferry commenced its demonstration in Spring 2023.

SF Bay Ferry has a plan to replace most or all of its 16 diesel ferries with ZEVs by 2035.

The ferry was built at Bay Ship & Yacht Shipyard (CA) and All American Marine (WA). It features a total installed fuel cell capacity of 360 kW, a 100 kWh Li-Ion battery energy storage system and two 300 kW (400 hp) shaft motors feeding the electric propulsion system that drives the propellors.

The vessel has a range of around 150 nautical miles at 12 knots. Its max speed is 22 knots.

Initially planned for operations in 2022, the launch of the vessel was reportedly delayed by a lack of existing regulation and approval by the U.S. Coast Guard. As noted previously, as new technological solutions are brought to market, delays are to be expected as the USCG approves first-of-kind technologies on a case-by-case basis.

It is reported that *Sea Change* will potentially be refueled by the DOE Office of Energy Efficiency & Renewable Energy funded SF Waterfront Maritime Hydrogen Demonstration Project. If built, it is also reported that Hornblower's *Discover Zero,* a four 30 kW fuel cell hybrid equipped with 1.6 MWh battery energy storage will also be refueled by the barge.

Based in the Port of San Francisco and running for four and a half years from 2021 to 2025, the project has two main goals, according to the project team[vi]:

- "To demonstrate the feasibility and viability of hydrogen production, storage, and fueling in a maritime context, establishing robust science-based protocols, procedures, operating parameters, and attendant training materials for the safe and routine generation and storage of electrolyzed hydrogen, and handling of water-to-water and water-land hydrogen and fuel-cell power transfer."
- "To catalyze a "green hydrogen ecosystem," via localized production of renewable hydrogen at the San Francisco Waterfront, encompassing San Francisco and the surrounding Bay Area for both maritime and landside users."

The project aims to develop a 130-foot-long refueling barge located at Pier 68 in San Francisco that can produce around 500 kilograms per day of renewable hydrogen for a 1.2 MW NEL electrolyzer. 200 kilograms per day of the hydrogen will be dedicated to fuel vessels with renewable hydrogen and recharge the batteries of diesel-electric hybrid vessels. Electricity will be produced by a 1.2 MW fuel cell. The balance of 300 kilograms of produced hydrogen will be delivered to land-based fuel cell applications to support port operations. The barge will not be classed as inspected under 46 CFR.

Research projects in the USA

Among a raft of energy transition and decarbonization technology research projects, the U.S. Department of Transportation, through the Maritime Environmental and Technical Assistance (META) Program, has funded six research and development projects to advance the deployment of hydrogen fuel cell applications in the maritime segment:

- Hydrogen Fuel Cell for Port and Shipboard Marine Applications (2014-2017)[vii]: Co-funded by the DOE, the project designed, developed, built and tested a 100-kW barge-mounted containerized fuel cell, featuring 72 kilograms of hydrogen storage, to provide electrical power to the refrigerated containers loaded on vessels while calling in Honolulu Harbor, Hawaii. The containerized fuel cell system was deployed on an inter-island barge service in Hawaii during 2015 and 2016. Several technical challenges limiting the use of the system were faced during the demonstration period and lessons learnt have been identified for sharing with other hydrogen-based projects. However, at a high level, the project established the technical viability of the concept.
- *SF Breeze* feasibility study for a 4.8 MW hydrogen fuel cell ferry[viii]: A 2015 feasibility study to design a 150 passenger 4.8 MW zero-emission hydrogen fuel cell ferry and to establish a hydrogen fueling capability in San Francisco Bay. A further project aim was to advance the development of both federal and state codes and standards for hydrogen fueled vessels.
- Feasibility Study of a Coastal Class Zero Emission Research Vessel (ZERo/V): The 2017 feasibility study for an oceangoing hydrogen powered research vessel led the Feasibility Study of Replacing the *R/V Robert Gordon Sproul* with a Hybrid Vessel Employing Zero-emission Propulsion Technology (2020)[ix]: The feasibility study sought to address several boundary conditions for the vessel, including 1) vessel performance of 34 individual science missions/14 unique mission profiles, 2) capital expenditure limited to $30 million, 3) GHG reduction when compared to the *R/V Robert Gordon Sproul* and 4) compliance with the regulations for a 46 CFR Subchapter C uninspected vessel.

  In early 2023, the Scripps Institution of Oceanography, which operates six research vessels, reported that the new hydrogen-fueled research vessel commissioned in August 2022 and designed by Glosten will be classed by ABS. The hybrid vessel will feature both hydrogen fuel cells and a conventional diesel-electric power plant.

In the 2020 report, the cost estimate for the hydrogen hybrid vessel option was $34.4 million, around 15% above target budget. The new vessel meets three other boundary conditions.

- Algae Flow-way Technology and Fuel Cell Report[x]: MARAD and the Maryland Port Administration partnered on a demonstration fuel cell project to design, build and test a fuel cell that converts algae to energy. One conclusion from the project is that the fuel cell developed in the demonstration project could be used at the Port of Baltimore as an alternative power source to diesel or electric power supplies.
- Hydrogen Gas Dispersion Modelling[xi]: An important modelling project conducted by Sandia National Laboratories to support the deployment of hydrogen fuel cell vessels. Sandia deployed computational fluid dynamics (CFD) modelling to generate analysis that addressed regulatory issues associated with bringing a hydrogen fuel cell vessel through the regulatory approval process. The paper focuses on gas dispersion modelling, including 1) a routine of venting of hydrogen from high-pressure storage tanks and 2) non-routine release of hydrogen. The basis of the modelling included a hydrogen storage solution similar to the one found on *Sea Change*.

Other hydrogen carriers in the U.S. marine segment

In addition to deploying pure hydrogen solutions, there are examples of projects using methanol and ammonia to carry hydrogen in a safe and cost-efficient way.

- e1 Marine is a partnership of Element 1 (a developer of on-demand hydrogen generation through methanol reforming technology), Ardmore Shipping (an owner of medium range product and chemical tankers) and Maritime Partners (provides flexible finance solutions to mainly Jones Act new buildings). The partners are developing a long-range 550 miles/4-day range between refueling) ultra-low emissions towboat that converts methanol in a PEM fuel cell fed by methanol stored in conventional tanks.

  Hydrogen One is a methanol-electric tugboat that will join the fleet of Indiana-based American Commercial Barge Line. The target is to cut steel within 2023 and for the vessel to commence operations in 2024/2025. It is likely that the towboat will move petroleum products in and around Louisiana and Texas.

  Maritime Partners accepts that the technology is currently not cost competitive. However, the company believes that the solution will eventually be cost competitive with a towboat featuring an EPA Tier 4 ICE, especially with the cost differential between Tier 3 and Tier 4 engines.
- We are currently tracking three projects featuring fuel cells fed by liquid ammonia, both initiated by U.S. start-up Amogy.

  Amogy's first marine project is to retrofit a 1 MW fuel cell to a 1957 built shipyard tug. The conversion is planned to be completed by late 2023, when the vessel is scheduled to take an initial voyage in an inland waterway in New York. Yara is providing green ammonia for the demonstration.
- In its second marine project, Amogy is working in partnership with Southern Devall to integrate an ammonia fuel cell system into an inland tank barge for commercial deployment by 2025. Once demonstrated, the companies plan to retrofit ammonia power packs to additional barges and tugboats.
- The Brooklyn, N.Y. based company announced in June that it has entered a preorder contract to supply four of its 200-kilowatt (kW) ammonia-to-power systems to an undisclosed Norwegian shipping company. The Amogy powerpacks will provide the primary power on a newbuild vessel slated for zero-emissions sailing in 2025. The preorder is Amogy's first with a maritime industry customer ahead of planned commercialization in 2024.

Non-U.S. vessels (over 100 kW)

Most of the non-U.S. hydrogen fueled vessels feature hybrid systems, to ensure maximum flexibility in operations. Combinations of fuel cells, dual-fuel internal combustion engines and/or battery energy storage systems are common as we discuss below.

- *MF Hydra*: Operating in Norway, Norled's MF Hydra finally received approval from the Norwegian Maritime Authority in the first half of 2023 and has commenced ferry operations. The ferry features a hybrid power train consisting of 400 kW of fuel cells, two internal combustion engines totaling 800 kW and a 1,456-kWh battery energy storage system. Liquid hydrogen, supplied by road from Germany, is stored in pressurized tanks on board. Bunkering is every three weeks and takes five hours for 3 tons. Norled is reviewing installing an onshore autonomous battery swap system for the ferry.

  The Norwegian government drives the fuel strategy of ferry owners through central procurement requirements. To support its plan to reduce emissions from domestic shipping by 50% by 2030, the government has committed to build five hydrogen hubs to produce hydrogen and provide the infrastructure to fuel between 35 and 45 vessels.

  In response to a government-led procurement process, Norway's Torghatten Nord is building two hybrid vessels featuring 6,000 kW of fuel cell capacity, internal combustion engines to be run on biofuel and a battery energy storage system. The two vessels which will operate on long ferry routes in Norway are due to be delivered in 2025. Torghatten has reported that it is sourcing green hydrogen to power the vessels, which have a capacity of 120 cars and 599 passengers.

  It should be noted that Norway is also supporting the electrification of the domestic ferry network through the procurement process and supporting the roll-out of charging infrastructure throughout the county.

- *Hydrocat 48*: Owned and operated by Windcat Workboats, a CMB subsidiary, *Hydrocat 48* is a crew transfer vessel supporting offshore wind farms in the North Sea. The CTV features two internal combustion engines capable of running on hydrogen with a combined output of 1,498 kW.

  Windcat currently has four CTVs with the same specification as *Hydrocat 48* on order for delivery in 2023 and a further two for delivery in 2024.

  Windcat is also investing in 2+2 service operations vessels for the European offshore wind segment. The SOVs are hybrids, featuring 3 x 1,800 kW conventional ICEs, 1 x 800 kW hydrogen fuel cells and a battery energy storage system.

- *Hydrotug 1*: Operating in the Port of Antwerp, Belgium and another CMB vessel, the 65 tons bollard pull harbor tug stores up to 405 kilograms of liquid hydrogen onboard to fuel two dual-fuel internal combustion engines developing 4,000 kW. CMB built a hydrogen refueling station next to the port to support the tug.

- *Elektra*: The *Elektra* is an inland tugboat owned by BEHALA and operating in Germany. The vessel features three dual fuel diesel-hydrogen internal combustion engines with a total installed capacity of 300 kW.

- *Three Gorges Hydrogen 1*: Owned and operated by China Yangtze Power and Hubei Three Gorges Tourism Group, the 50-meter-long tourist vessel is equipped with a 50-kW hydrogen fuel cell.

- *Viking Neptune*: Owned by Viking Ocean Cruises, the large cruise ship is powered by 23,520 kW of diesel fueled internal combustion engines, supported by 100 kW of fuel cells for port operations and hotel loads. Viking is currently building four additional cruise ships featuring diesel internal combustion engines supported by hydrogen fuel cells. The vessels will be delivered between 2026 and 2028.

- *FPS Maas*: Future Proof Shipping is retrofitting two inland container vessels with hydrogen fuel cells amounting to 1,200 kW per vessel. The first vessel, *FPS Maas* has been renamed *H2 Barge 1* and was launched at the end of May of this year. The vessel will sail between Rotterdam and BCTN's Meerhout terminal in the Netherlands several times a week, carrying

Nike merchandise. Future Proof Shipping has identified further vessel candidates for conversion to zero-emission operations.

- *Cap de Barbaria:* Balearia has built a new car/passenger ferry equipped with a 100 KW fuel cell, internal combustion engines and battery energy storage. The vessel will operate in Spain from 2023. The green hydrogen fuel cell, battery energy storage and cold ironing capability support zero-emission operation during the approach, maneuvering, mooring and stay in port.
- *HyDroMer*: *HyDroMer* is a trailing suction hopper dredger operating for the Occitanie Region in France. The hybrid dredger is equipped with 200 kW of fuel cells, four IMO Tier II internal combustion engines and a battery energy storage system. Delivery is in 2023.
- There are reports of a car/passenger ferry featuring a hydrogen fuel cell currently under construction for the Indian market. However, limited other details are available.
- *Zulu 06:* French owner CFT is building a barge for inland transport that features 400 kW of fuel cells. And a 350-kilogram containerized hydrogen storage unit. Outfitting is currently ongoing in France.
- Silversea is planning to deliver the *Silver Ray* and the *Silver Nova* cruise ships in the 2023 to 2024 period. Both hybrid cruise vessels will be equipped with 4,000 kW of fuel cells, LNG powered internal combustion engines and battery energy storage systems.
- MSC subsidiary Explora plans to deliver the *Explora V* and *Explora VI* cruise ships by 2028. Both hybrid vessels will feature 6,000 kW of fuel cells, LNG powered internal combustion engines and battery energy storage systems.
- *With Orca*: Heidelberg Cement, the agricultural cooperative Felleskjøpet and shipping company Egil Ulvan Rederi have secured Norwegian government funding to build a hydrogen powered bulk carrier to operate between Norwegian ports. The 88-meter-long vessel will feature both a hydrogen ICE and fuel cell, two large rotor sails for wind assisted propulsion and a battery energy storage system. The vessel's tentative delivery schedule is 2024, although we do expect delays on this date, due to an absence of reporting on the vessel design and construction.
- *Loran:* The *Loran* is a design under development for a 229 feet long Norwegian longline fishing vessel. In a project subsidized by the Norwegian Ministry of Climate and the environment, Skipsteknisk designed a 370-kW hydrogen fuel cell and 2,000 kWh battery energy storage system to completement the vessel's conventional diesel engines whilst the vessel is at sea for four to six weeks.

Other hydrogen carriers in non-U.S. vessels

Methanol is already being adopted in some segments of the deep-sea segment with many shipping companies eyeing the potential of ammonia as a long-term zero-emission solution. There are also several examples of projects featuring methanol and ammonia in the short-sea segment. These include:

- SOVs: In the European offshore wind space, there are currently eight new buildings that will feature methanol capable dual fuels ICEs and a further 14 prepared for methanol operation. Many of the methanol fueled SOVs have chosen Liquid Organic Hydrogen Carrier (LOHC) to carry the energy.
- PSV *Viking Energy:* Eidesvik Offshore and Wärtsila are retrofitting a 2,000 kW SOFC running on green ammonia to the PSV *Viking Energy*, working for Equinor in the Norwegian North Sea. The conversion will be completed in 2023/2024.
- Kotug Canada is building two dual-fuel methanol harbor tugs, *SD Aisemaht* and *SD Qwii-Aan'c Sarah*, to enter service in 2025 for the Trans Mountain Westridge oil export terminal.
- *Green Ammonia*: The design for the 120-meter-long ammonia tanker received an Approval in Principle in April 2022. The vessel will feature a Wärtsila dual fuel ICE powered by ammonia. Design and shipyard selection are underway. Construction is anticipated in 2025.
- In China, COSCO Shipping Heavy Industry has been awarded an ABS Approval in Principle for

their ammonia-fueled vessel design and ammonia supply system. The harbor tug will have a bollard pull of 60 tons.

4.3. Other U.S. low emission vessels

In addition to state-wide initiatives, such as those found in California, we discuss below some examples of local initiatives to promote zero-emission shipping.

Northwest Ports Clean Air Strategy (NWPCAS)

NWPCAS is a collaboration between the ports of Seattle and Tacoma in Washington State, the Vancouver Fraser Port Authority in British Columbia, Canada, and the port operator Northwest Seaport Alliance.

The partners have collaborated with the U.S. EPA, the Washington State Department of Ecology, the Puget Sound Clean Air Agency, Environment Canada, the British Columbia Ministry of Environment and Climate Change Strategy, and Metro Vancouver.

Initially focused on diesel particulate matter and greenhouse gas emissions, NWPCAS has broadened its focus to include other pollutants such as NOx, volatile organic compounds and black carbon.

The partners “aim to phase out emissions from seaport-related activities throughout the Georgia Basin-Puget Sound airshed by 2050.” The strategy was updated and refined in 2020, the updated vision for which sets the target to “Phase out emissions from seaport-related activities by 2050, supporting cleaner air for our local communities and fulfilling our responsibility to help limit global temperature rise to 1.5 degrees Celsius.”

The strategy covers six port activities:

- Harbor vessels. The Port of Seattle and Tacoma plan to deploy at least one hybrid or zero-emission harbor tug within the ports by the end of 2025.

  The ports (Seattle and Tacoma) host 14 largely pre-1990s diesel-mechanical tugs operated by two companies.

  The ports see their role as encouraging the operators through making shore connections and repowering funding available.
- Oceangoing vessels.
- Cargo handling equipment.
- Truck.
- Rail.
- Port administration and tenant facilities.

South Carolina Ports Air Quality Initiatives and Electrification Potential

As part of a May 2022 presentation the EPA’s webinar on electrifying America’s ports, South Carolina Ports presented its vision “striving to be the greenest port in the Southeast.”

One element of the plan was an initiative to transport containers by barge between the Wando Welch and Hugh K. Letherman terminals on the Wando and Cooper rivers and in so doing reducing the number of truck movements.

The plan introduced the potential for two electric tug and barge spreads to transport the container. The electric tugs will be supported by a high capacity shoreside battery energy storage at both terminals. The battery system will source green electricity from 3.3 MW of solar photovoltaic array capacity located at both terminals.

Potential partners for the project include Crowley and Shell Marine.

At the time of writing, no further project updates are available.

Other electric harbor craft

In addition to hydrogen, short-sea shipping is also suited to pure electric power options, the power for which can be provided from shore or by port-located power barges similar to those discussed earlier in this chapter. Examples of electric vessels in the U.S. include:

- *eWolf tug*: *eWolf* is a 25-meter-long tug, 70 tons of bollard pull harbor tug, equipped with

Corvus 6.2 MWh battery energy storage system and 600 kW of conventional diesel generators for emergency use and longer voyages. The tug will be operated by Crowley in the Port of San Diego. The vessel replaces a conventional tug consuming around 30,000 gallons of diesel annually. Over the first 10 years of operation, Crowley estimates that that *eWolf* will reduce NOx by 178 tons, PM by 2.5 tons and CO2 by 3,100 tons compared to a conventional tug. Delivery is planned for mid-2023.

- *James V. Glynn* and *Nikola Tesla*: Maid of the Mist's fully electric tour boats, operating at Niagara Falls, are recharged while docking between trips.
- The *Gee's Bend* ferry is the U.S.'s first all-electric vehicle ferry. The 2004-built ferry, which operates on the Alabama River, is owned by HMS (Hornblower Marine Services) Ferries and operates under contract for the Alabama Department of Transportation. Originally operating on diesel ICEs, the ferry conversion was completed in 2019. AC shore power is provided by charging stations at both ends of the ferry route. Power is converted to DC power and stored in two battery banks, each driving two 112 kW (150 hp) electric motors. Total power is 448 kW (600 hp).
- Olympic class ferries: Washington State selected ABB and Vigor Shipyards to design up to five diesel electric ferries. ABB and Vigor Shipyards were also initially selected to build the vessels, but the contract is currently being rebid which could result in a new builder and system integrator being selected.

  The hybrid-electric ferries program aims to replace 13 existing diesel-powered ferries with hybrid-electric newbuilds and convert six others to plug-in hybrids by 2040. The plan is accompanied by a plan to invest in shoreside charging capacity at many ferry terminals. Funding is reported to be available for the first two vessels in the order, the first of which is to be named *Wishkah* and is expected to be delivered in 2027. Subsequent deliveries are expected every 14 months thereafter through late 2031.
- High-speed electric ferry, New York: Operated by New York Cruise Lines and Sweden's Green City Ferries (GSF) through New York Water Taxi, the ferry will operate on the Hudson River between Brooklyn and Manhattan. Featuring Toshiba batteries, the vessel is a Beluga24 catamaran with a capacity of 147 passengers and 28 bicycles. GSF will operate the first Beluga24 in Sweden from 2024.

5. Overview of the U.S. Commercial Harbor Craft Sector

In this chapter, we review the various vessel types that make up our study of commercial harbor craft active in the U.S. and look at the U.S. port network and inland waterway system.

5.1. Grouping and defining harbor craft

For consistency, we have broadly aligned our vessel segment definitions with those of the South Coast Air Quality Management District Technology Assessment: Commercial Harbor Craft (2015)[xii].

We should note that we would traditionally maintain offshore support vessels as a separate category, we have allocated the various OSV segments among the following harbor craft headings.

Crew and supply vessels

Vessels used for the transport of personnel and equipment, consumables and stores to and from offshore and in-harbor locations.

This category includes vessels supporting offshore oil & gas exploration and production rigs and platforms, offshore wind farms and vessels at anchorage.

The offshore wind segment is currently in its infancy, and our database only includes three active offshore windfarm crew transfer vessels. However, as the segment develops, initially in the northeast of the USA, then to the mid-Atlantic, California, Oregon and the Gulf of Mexico, we anticipate a growing fleet of domestically owned, built and operated crew transfer vessels and service operation vessels.

There are currently at least 19 CTVs under construction in U.S. yards, with options for five more. There are also three SOVs currently under construction in U.S. yards for deployment on Atlantic coast projects. The majority of new builds are installing EPA Tier 4 compliant engines, although a handful have opted for more but lower horsepower EPA Tier 3 engines that do not currently require after treatment. Of note, there is no strong evidence that vessel owners are investing in CTVs that feature hybrid battery energy storage systems and/or dual fuel capabilities, although some of the new builds retain space for future addition of battery energy storage systems.

The three SOVs currently under construction all feature EPA Tier 4 engines and battery energy storage and shore power connectivity. This approach varies from the major European market where methanol and ammonia solutions figure in an increasing number of vessels.

Ferry/excursion vessels

Vessels deployed to transport people and/or vehicles within a public transportation system or for tourism and events, which includes sightseeing, whale watching and dinner cruises.

According to the Department of Transport's Bureau of Statistics, over 112 million passengers and 26 million vehicles were transported by ferry during 2019. Washington (38.7 million passengers) and New York (30.5 million passengers) were identified as the states where the largest number of passengers boarded ferries, followed by California, Massachusetts, Texas and Louisiana. For vehicles, the leading boarding states were Washington which accounted for 15.2 million vehicle boardings alone, Texas, Louisiana and New York.

The BTS further reported that nearly half of the ferry segments in the USA were concentrated in five states – Alaska, California, Michigan, New York and Washington. A ferry segment is defined by the BTS as "the direct route that the boat takes between two terminals with no intermediate stops. The assigned state of the segment is that of the origin terminal."

Fishing vessels

Commercial fishing vessels are used to locate and catch fish for the purpose of commercial sale.

Charter fishing vessels are generally available for hire by the public for the purpose of locating and catching fish for personal consumption.

Based on the range of names and definitions applied to various sub-categories, we have refined our definition of the commercial fishing segment to include fishing vessels, charter fishing vessels, passenger fishing vessels, fish processing vessels and fishing tenders. Pure commercial vessels account for the majority of vessels in this segment (over 85%).

Pilot vessels

Vessels used to carry pilots to and from ships.

Towboats/pushboats

Generally shallow draft vessels with a square bow deployed to push barges and pontoons.

Due to design, these vessels are more frequently deployed on inland waterways.

According to the U.S. Army Corps of Engineers, "Towboats push barges lashed together to form a "tow". A tow may consist of four or six barges on smaller waterways up to over 40 barges on the mighty Mississippi below its confluence with the Ohio. A 15-barge tow is common on the larger rivers with locks, such as the Ohio, Upper Mississippi, Illinois and Tennessee rivers. Such tows are an extremely efficient mode of transportation, moving about 22,500 tons of cargo as a single unit."

The U.S. Army Corps of Engineers goes on to argue for the fuel efficiency and environmental benefits of transporting cargo by towboats, saying, "On average, a gallon of fuel allows one ton of cargo to be shipped 59 miles by truck, 202 miles by rail, and 514 miles by barge. Carbon Dioxide emission from water transportation were 10 million metric tons less in 1997 than if rail transportation had been used."

According to the U.S. Army Corps of Engineers, the bulk commodities shipped on U.S. waterways include coal, petroleum, grain and other farm products, construction aggregates, chemicals and fertilizers, ores and finished metal products.

We have grouped the articulated tug and barge (ATB) and integrated tug-barge (ITB) systems within the towboat category. Many of the barge systems tank barges are designed to carry petroleum and chemical products, although ATBs also have been designed to carry other cargos, such as dry bulk cargo and containers. Many ATBs are designed to be seagoing and operate in U.S. coastal waters.

Tugboats

Vessels deployed to assist other vessels in maneuvering and to tow floating structures.

This category includes harbor and escort/ship assist tugs as well as oceangoing towing vessels and anchor handling and supply tugs deployed in the offshore oil & gas.

Offshore oil & gas anchor handlers generally operate in the Gulf of Mexico today. However, as commercial floating wind projects emerge offshore California, Oregon and also in the Atlantic, we anticipate a growing demand for domestically owned, operated and manned large anchor handlers.

Workboats

Vessels deployed to undertake a wide variety of duties including fire & rescue, law enforcement, hydrographic surveys, spills & environmental response, research, training and marine construction support, for both coastal and harbor projects and well as offshore oil & gas and offshore wind. Some of these vessel types may be more suited to hybrid or zero-emission operations than others. Examples include research vessels deployed for scientific, oceanographic and/or environmental studies or training vessels for maritime academy and naval programs.

Other

Vessels that do not fit any of the above categories.

This is a very diverse category of vessels registered in and operating in the U.S. Around 65% of the vessels within this category are coastal oil and chemical tankers and cargo vessels.

5.2. Retrofitting commercial harbor craft

Earlier in this report, we reviewed the opportunities and challenges of adopting various hydrogen-based energy carriers. We have also looked at federal programs to support the adoption of low and zero-emission technologies. One conclusion that can be made is that it is challenging to retrofit smaller and/or older vessels and in some cases a new vessel is the logical solution to replace an existing vessel.

In 2019, the California State University Maritime Academy prepared a report for CARB that addressed the feasibility of installing Tier 4 engines with inbuilt selective catalytic reduction systems (above 600 kW) and diesel particulate filters or retrofitting aftertreatment (DPF and SCR) systems to vessels with Tier 3 engines (below 600 kW) on in-use commercial harbor craft[xiii].

Exhibit 16 California Harbor Craft Retrofit Study Summary

Category	Repower (Tier 4)	Retrofit DPF+SCR	Retrofit DPF
Commercial fishing	N/A	No solution	No solution
Charter fishing	N/A	No solution	No solution
Excursion	Minimal change	Minimal change	Minimal change
Slow speed ferry	Minimal change	Moderate change	Moderate change
High speed ferry	Major change	Major change	Major change
Tugs	Minimal change	No solution	Moderate change
Towboat	Moderate change	Major change	Moderate change
Crew and supply	Moderate change	Major change	Major change
Pilot boat	Major change	Major change	Major change
Workboat	N/A	Major change	Major change

Source: Intelatus Global Partners interpretation California State University Maritime Academy *data*

In short, the study addressed the comparatively easier technical solution that would not impact the fuel tanks, vessel piping system and propulsion drives (mainly mechanical) – most of which will be required for retrofitting an existing vessel for zero-emission operations. Even within this comparatively limited impact, the repowering or retrofitting of many of the harbor craft segments was identified as either a major modification or not technically feasible, as shown in Exhibit 16.

Of note, the California study found that in all cases, the cost of repowering vessels with Tier 4 engines or retrofitting Tier 3 vessels with aftertreatment measures was below that of building a new vessel, which we believe is not always the case for retrofitting vessels for zero-emission operations.

5.3. U.S. ports

The U.S. Army Corps of Engineers has produced a database and report summarizing the tonnage of waterborne cargo handled by the top 150 U.S. ports and for all 50 states. The data filters tonnages by domestic cargo and foreign cargo. Domestic waterborne cargo amounted to around 1.1 billion tonnes in 2021.

The data does not tell us how many vessels call at ports but is a good indicator of a level of activity and by extension where the harbor assist tugs are concentrated.

Appendix 1 lists the top 30 ports, which account for 75% of the cargo handled by the top 150 ports.

The top five ports are shown in Exhibit 17.

Exhibit 17 Top 5 U.S. Ports by tonnage (2021)

Port	Total (million tons)	Domestic (million tons)	Foreign (million tons)
Houston (TX)	266.5	75.9	190.7
South Louisiana (LA)	224.7	115.7	109.0
Corpus Christi (TX)	164.4	22.6	141.8
New York (NY & NJ)	142.3	40.7	101.56
Port of Long Beach (CA)	91.6	14.8	76.7

Source: Intelatus Global Partners interpretation of U.S. Army Corps of Engineers Digital Library data[xiv]

5.4. Ports in California

California has 12 ports, 11 of which are publicly owned. Only the Port of Benicia is privately owned. An overview of the ports can be found in Appendix 2.

Collectively the Port of Long Beach and the Port of Los Angeles account for over 70% of total cargo transported in 2020.

CARB is the agency that regulates port emissions and enforces the state agenda for transitioning to zero-emission technologies within these ports.

Of interest, several of California's ports are planning capabilities to support the future growth in offshore wind activity in California waters.

The California Energy Commission is currently reviewing two pilot arrays located at Vandenberg and federal agencies recently awarded leases for five commercial scale floating wind farms, three in Morro Bay and two in Humboldt, to be constructed around the end of the decade.

Under its Zero Emissions, Energy Resilient Operations Program, the Port of Long Beach is working on the design of a staging and integration facility for floating offshore wind turbines. The project is known as Pier Wind. Construction could begin as early as January 2027, with the first phase operational as early as 2031 followed by a second phase in 2032 and a final phase in 2035.

The Port of San Francisco has identified Piers 68-70, 80, 92, 94/96 to support floating wind projects.

Hueneme is the preferred main port location to support the Vandenberg pilot projects.

Floating wind projects will bring a new category of vessels to California's waters and ports:

- Large project cargo vessels for the import of components and completed substructures.
- Construction vessels including large anchor handling and subsea construction vessels.
- Cable layers.
- Construction and operations & maintenance support vessels including crew transfer vessels and service operations vessels.

Many of these offshore wind vessels will meet the definition of a harbor craft and will need to comply with California's emissions regulations. Certain vessels will need to be built, owned, operated and manned by U.S citizens. This represents both an opportunity but, for technical and commercial reasons, is also a significant challenge.

5.5. Inland waterways of the USA

Exhibit 18 summarizes the evolution of the U.S. waterborne transportation system.

Exhibit 18 Waterborne Transportation System

Item	2000	2010	2020
Navigable waterways (miles)	25,000	25,000	25,000
Ports (handling over 250,000 tons)	197	178	192
U.S. flagged self-propelled vessels	10,410	10,775	10,333
U.S. flagged barges /non-self-propelled vessels	35,008	31,906	34,168
Recreational boats (millions)	12.8	12.4	11.8

Source: Intelatus Global Partners interpretation of DOT BTS Transportation Statistics Annual Report 2022[xv]

In Section 6, our analysis identifies around 10,100 harbor craft.

As we have discussed earlier, Title 33 of the Code of Federal Regulations (33 CFR) governs navigation and navigable waters within the United States and addresses the role of the USCG, the Army Corps of Engineers and the Saint Lawrence Seaway Development Corporation.

Exhibit 19 shows the U.S. inland waterway system.

Exhibit 19 Map of Inland Waterway Connections

Source: U.S. Army Corps of Engineers, Institute of Water Resources

The roles of the leading federal agencies are:

- DOT: Acting through the USCG, the DOT has responsibility for vessel and navigation safety. MARAD, the DOT's Maritime Administration supports port development, intermodal systems and domestic shipping.
- The U.S. Army Corps of Engineers constructs and maintains navigation channels and harbors.

  Out of 25,000 miles of U.S. waterways, around 12,000 miles are used for commercial traffic. Most of the navigable rivers and canals in the U.S. are found in the eastern half of the country. As seen in Exhibit 19.

Many of the rivers in the western half of the USA, such as the Colorado, feature steeper slopes grades, variable flows and dams which render them less suitable for navigation by larger vessels.

Domestic transport of cargo in the U.S. by all modes, whether intra- or inter-state amounted to close to 78 billion tons in 2021, of which waterborne transport accounted for 1.4% or 1.1 million tons. However, for some states, waterborne transport accounts for a significantly larger proportion of domestic transportation within, into and out of a state. Examples using 2021 data extracted from Oakridge National Laboratory's Freight Analysis Framework, produced for a partnership between BTS and the Federal Highway Administration[xvi] include:

- Volume of cargo transported by water within a state: Louisiana (24%), Alaska (14%) and West Virginia (14%).
- Outbound cargo from a state by water as a proportion of total cargo transportation: Alaska (98%), Hawaii (27%), West Virginia (22%), Louisiana (19%) and Illinois (17%).
- Inbound cargo from a state by water as a

proportion of total cargo transportation: Louisiana (32%), Hawaii (22%), Alaska (20%) and West Virginia (20%).

Exhibit 20 ranks the top 15 states over four years on the 2021-2050 timeframe in descending order of total volume of cargo transported by water within, out of and into a state.

The share of the total volume of cargo transported by the top three states in all four analysis years, Louisiana, Texas and Illinois, rises from 54% in 2021 to 58% in 2030, 62% by 2040 and 65% by 2050.

California accounted for around 3% of total U.S. intra and interstate waterborne cargo transport in 2022. Its share is forecast to rise to around 4% in 2030 and 2040 and fall back to 3% by 2050.

Details of all waterborne transport volumes within, to and from states in 2021, 2030, 2040 and 2050 can be found in Appendix 3.

Exhibit 20 Top States for Cargo Transported Within, From and To States by Water

2021	2030	2040	2050
Louisiana	Louisiana	Louisiana	Louisiana
Texas	Texas	Texas	Texas
Illinois	Illinois	Illinois	Illinois
West Virginia	California	California	Michigan
Ohio	Ohio	Michigan	California
Kentucky	West Virginia	Alaska	Kentucky
Michigan	Michigan	Ohio	Ohio
California	Kentucky	Kentucky	Indiana
Indiana	Alabama	Mississippi	Mississippi
Alaska	Alaska	Alabama	Alabama
Pennsylvania	Mississippi	Indiana	Alaska
Mississippi	Indiana	Washington	Washington
Washington	Washington	West Virginia	Missouri
Florida	Pennsylvania	Missouri	Minnesota
Alabama	Missouri	Pennsylvania	Florida

Source: Intelatus Global Partners interpretation of data from the FAF5 Summary Statistics produced by the National Transportation Research Center, Oak Ridge National Laboratory

BTS highlights that many major commodities are shipped at similar volumes all year round. These commodities include coal, chemicals and petroleum. DOT notes that downriver shipments and upriver fertilizer and cement tows were delayed due to low water levels in the lower Mississippi in 2022.

The movement of grain and other farm products is seasonal – and BTS points out that drought conditions resulting in low water levels in the lower Mississippi significantly impacted corn and soybean shipments in October 2022.

The Mississippi River System

The Mississippi River System is an important transportation waterway interconnecting numerous inland ports for domestic trade and also linking inland ports to the import and export gateway ports in the Gulf of Mexico. The system consists of around 250 tributaries and branches.

The DOT reported for 2020 that the Mississippi "carried more than half of the 165.5 million tons of freight that moved between the 12 states touching the Upper Mississippi System and Louisiana. The percentage of freight carried by the river to Louisiana is notably higher for some states: 92 percent for Indiana, 81 percent for Missouri, 80 percent for Illinois, and 75 percent for Kentucky."

However, as discussed above, the DOT comments that drought caused low water conditions in 2022 on the Ohio and Upper Mississippi River systems and resulted in a significant drop in barge throughput, which we assume has a knock-on effect to towboat and push boat vessel utilization.

The Mississippi River System can be subdivided into four zones:

- Upper Mississippi: The Mississippi originates as an outlet stream from Lake Itasca in Minnesota and has a length of around 2,350 miles until emerging in the Gulf of Mexico.

  The Upper Mississippi extends from Lake Itasca to the mouth of the Ohio River at Cario, Illinois.

  The Upper Mississippi connects to the Illinois Waterway which feeds into the Great Lakes Waterway and eventually the Saint Lawrence Seaway, which allows oceangoing vessels arriving from the Atlantic to reach ports in all five of the Great Lakes.

- Missouri: The Mississippi is joined by a large number of river tributaries, including the Ohio and Missouri Rivers. The Missouri River is over 2,500 miles long, rising in western Montana and connecting with the Mississippi River north of St. Louis.
- The Ohio: The 980-mile-long Ohio rises in western Pennsylvania and flows to the mouth of the Mississippi in southern Illinois.

  The largest tributary of the Ohio is the Tennessee River rising in Knoxville, Tennessee and joining the Ohio near Paducah, Kentucky.

  The Tennessee-Tombigbee Waterway joins the Tennessee River in northeastern Mississippi with the old Tombigbee River near Amory, Mississippi.

  The northeastern extreme of the Ohio River extends to Pennsylvania and New York through the Allegheny River.

  The Cumberland River rises in the Appalachian Mountains and joins the Ohio near Paducah, Kentucky.
- Lower Mississippi: The Lower Mississippi flows from the Ohio River to its mouth near New Orleans.

  Connecting Baton Rouge to the Gulf of Mexico, the river allows deep sea vessels to connect with towboats and barges, whether for domestic or international trade.

  Tributaries of the Mississippi River include the Red, Ouachita, Arkansas and White rivers.

  The river joins the Gulf Intracoastal Waterway which connects ports in the Gulf of Mexico, such as Baton Rouge, Corpus Christi, Houston, Mobile and New Orleans, with major inland ports including, Chicago, Cincinnati, Kansas City, Memphis, Pittsburgh and St. Paul.

The Hudson River

The Hudson River, flowing 315 miles north to south in New York, is connected to the Great Lakes by the Erie Canal and is a trade route from the Atlantic Ocean to the Great Lakes region.

The Columbia-Snake River System

The Columbia and Snake River system is a major transportation option for moving barges and containerized cargo for export including wheat, forest products, minerals and soybeans. The system also supports the imports and export of auto parts.

The navigation channel is maintained to Pasco on the Columbia and to Lewiston, 465 miles inland, on the Snake River.

The system connects the Ports of Astoria, Portland and St. Helens in Orgon, Camas-Washougal, Chinook, Kalama, Ilwaco, Ridgefield, Vancouver, Wahkiakum and Woodland in Washington and reaches the Port of Lewiston in Idaho, which at 465 miles from the Pacific Ocean is the most inland port on the west coast.

Sacramento River/Deep Water Ship Channel

The Port of Sacramento is located around 90 miles from San Francisco and the San Pablo Bay. Direct access to Suisun Bay, east of San Francisco, is provided by the Deep Water Ship Channel. According to local authorities, the main export cargo from Sacramento is rice, and import cargo to Sacramento is cement.

6. Segmentation of U.S. Data by Vessel Type

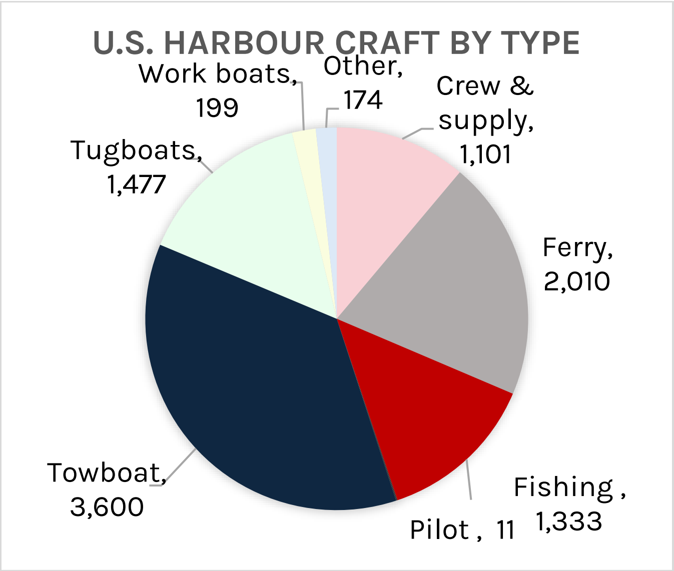
For the analysis, we will segment the data by vessel type. We will analyze the data by age, gross tonnage, and length.

6.1. U.S. Registered Vessels

Total fleet

Our database identifies 9,905 vessels. For clarification, pilot boats cannot be seen in Exhibit 21 as they account for 0.1% of the total harbor craft fleet.

Exhibit 21 U.S. Harbor Craft by Type



Source: Intelatus Global Partners

Exhibit 21 identifies that the towboat segment is the largest harbor craft segment in terms of vessel numbers, accounting for 36% of the total fleet.

Based on vessel numbers only, one can infer that the towboat segment has the greatest potential for zero-emission technologies.

The ferry and excursion segment is the second most numerous category, accounting for 20% of the fleet.

Tugboat, commercial fishing vessel and crew and supply vessels all enjoy similar fleet sizes, respectively accounting for 15%, 13% and 11% of the harbor craft fleet.

What power output do these vessels have?

Exhibit 22 summarizes the minimum, maximum and average horsepower figures for each of the vessel categories in our analysis.

Exhibit 22 U.S. Harbor Craft by Horsepower

Vessel Type	Average HP	Minimum HP	Maximum HP
Crew and supply	3,574	810	21,389
Ferry	1,933	805	43,980
Fishing	1,328	805	11,050
Pilot	1,521	1,060	2,200
Towboat	2,631	808	16,000
Tugboat	3,183	820	21,600
Workboat	3,233	820	19,000
Other	6,252	840	30,000

Source: Intelatus Global Partners

While our analysis starts at vessels with 600 KW of total power output, Exhibit 22 shows that the average harbor craft vessel size within our database can best be described as small to medium.

Whereas the California Air Resources Board harbor craft database allows us to analyze the number of engines per vessel, this is not the case with the Coast Guard or other databases. As a result, our database only identifies the number of engines for around 10% of the vessels.

Are all the vessels active?

Our database segments data into four categories to reflect activity:

- In Service: Active with AIS signal received within the last three months reflecting movement. We have 5,562 vessels or 56% of all the vessels in the database.
- Idle: Last AIS signal received between three and six months. This indicates that vessel could be temporarily idle for commercial or technical reasons, under repair or upgrade, or trading outside the coverage of AIS.

There are not may Idle harbor craft – the total for the U.S. at the time of analysis was 204 or 2% of the vessel dataset.

Idle vessels may return to service once commercial or technical issues are addressed.

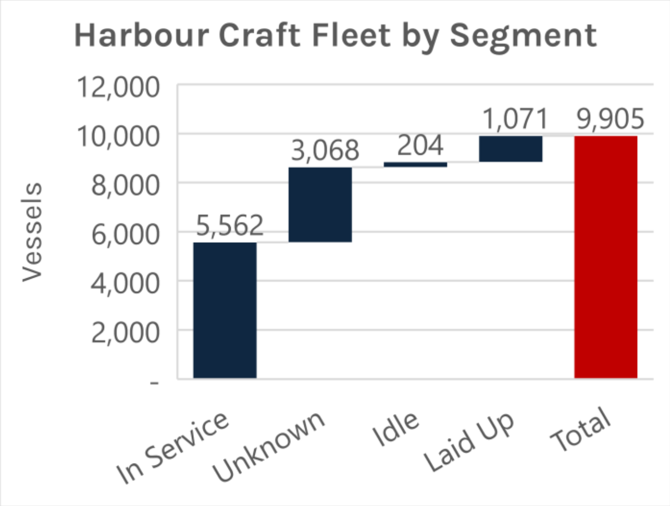
- Inactive and Laid-up: Last AIS signal received six months or more ago and categorized as inactive or laid-up in the USCG database. Traditionally, for vessels required to transmit AIS signals one would group these vessels as inactive or scrapped in place. We have identified 1,071 such vessels, or around 11% of the fleet.
- Unknown: Last AIS signal received six months or more ago. At 31% or 3,068 vessels, this is a statistically significant number of vessels.

  As we have established, not all harbor craft require AIS Class A systems, for which there are several possible scenarios regarding the status of the vessel. The vessel could be, on long-term lay-up or scrapped in place, trading outside of the USA or simply does not need to feature AIS Class A system.

  Around 0.25% of the vessels registered in U.S. states are currently active outside of the United States, most of which are classed as having an Unknown operational status. Three quarters of these vessels are offshore support vessels.

Exhibit 23 presents a breakdown of the total harbor craft segment by activity.

Exhibit 23 U.S. Harbor Craft in Service

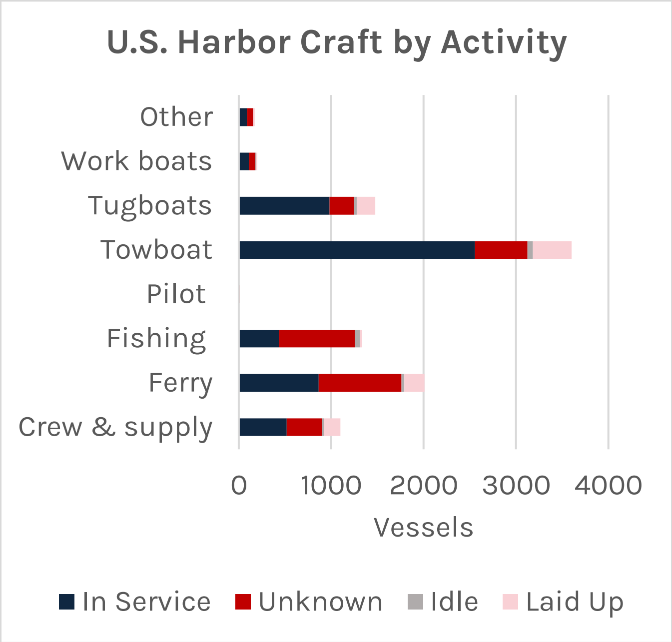


Source: Intelatus Global Partners

Exhibit 24 presents the breakdown of the U.S. harbor craft segment by status and allows us to understand why our database includes some 3,068 vessels with an unknown status. Many do not require an AIS Class A system that would make tracking and status identification significantly easier.

The analysis does confirm the high level of AIS tracked activity for the towboat segment and confirms that this segment merits further review for technical and commercial feasibility for zero-emission operations in the future.

Exhibit 24 U.S. Harbor Craft by Activity



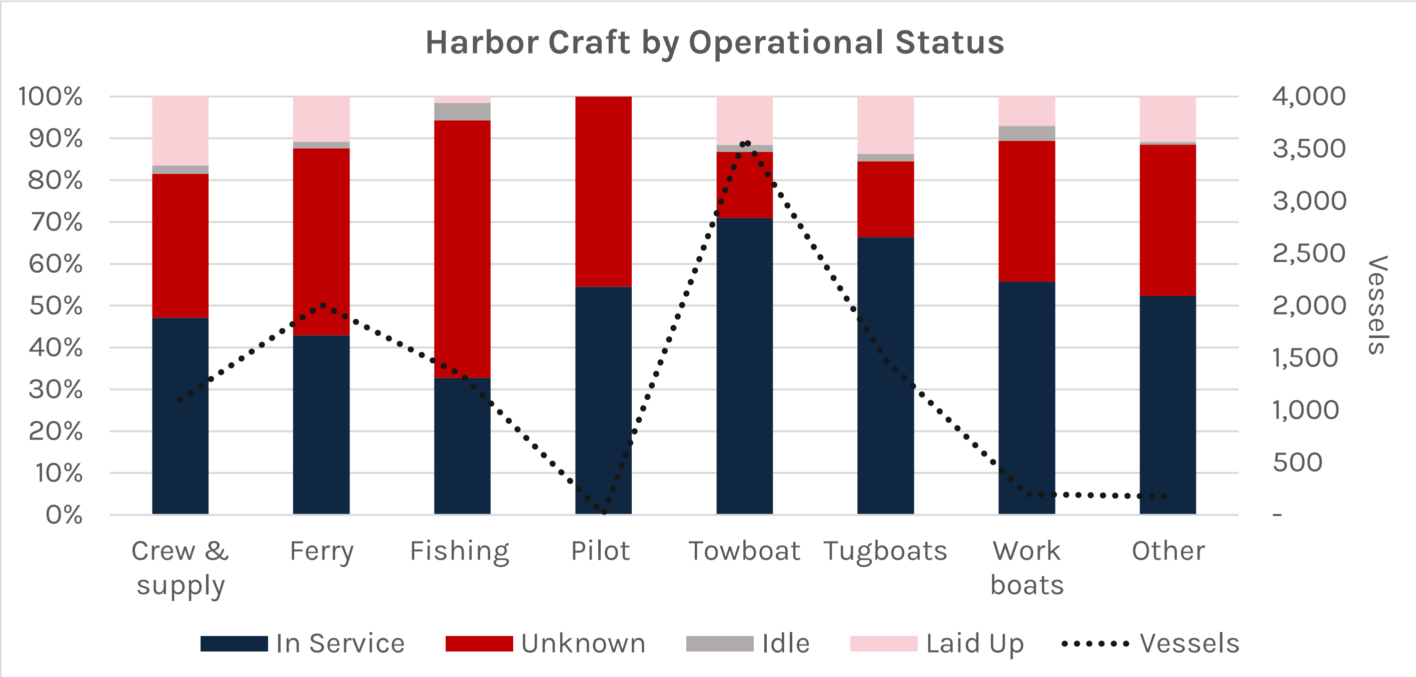
Source: Intelatus Global Partners

Exhibit 25 presents the same core data as used in Exhibit 24 but presents the proportion of fleet that is In Service, Unknown, Idle and Laid-up & Inactive.

We obviously have the highest degree of certainty for vessels that are classed as In Service, Idle or Laid-up. And this is clearly achieved for the tugboat and towboat segments.

It is the Unknown vessels that are the grey area between In Service and Laid-Up.

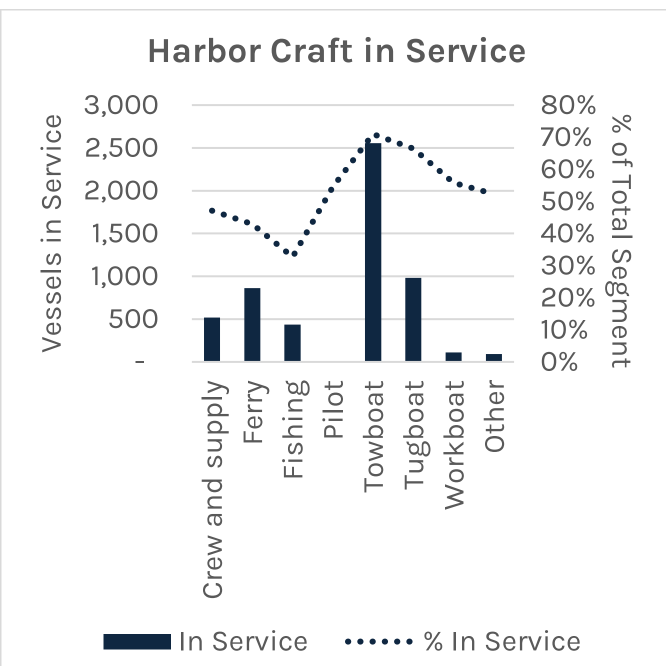
Exhibit 25 U.S. Harbor Craft in Service



Source: Intelatus Global Partners

Focusing purely on the In Service category, Exhibit 26 reviews the 5,562 vessels for which we have identified an AIS signal within the last three months.

Exhibit 26 U.S. Harbor Craft in Service



Source: Intelatus Global Partners

From Exhibit 26, we note that the Towboat segment is home to both the highest absolute number and proportion of vessels in a segment that are confirmed to be In Service.

6.2. Age

When we segment the entire 9,905 vessel population by delivery date, we note that there are many older vessels, many of which have undergone one or multiple repowering operations over their lifetime.

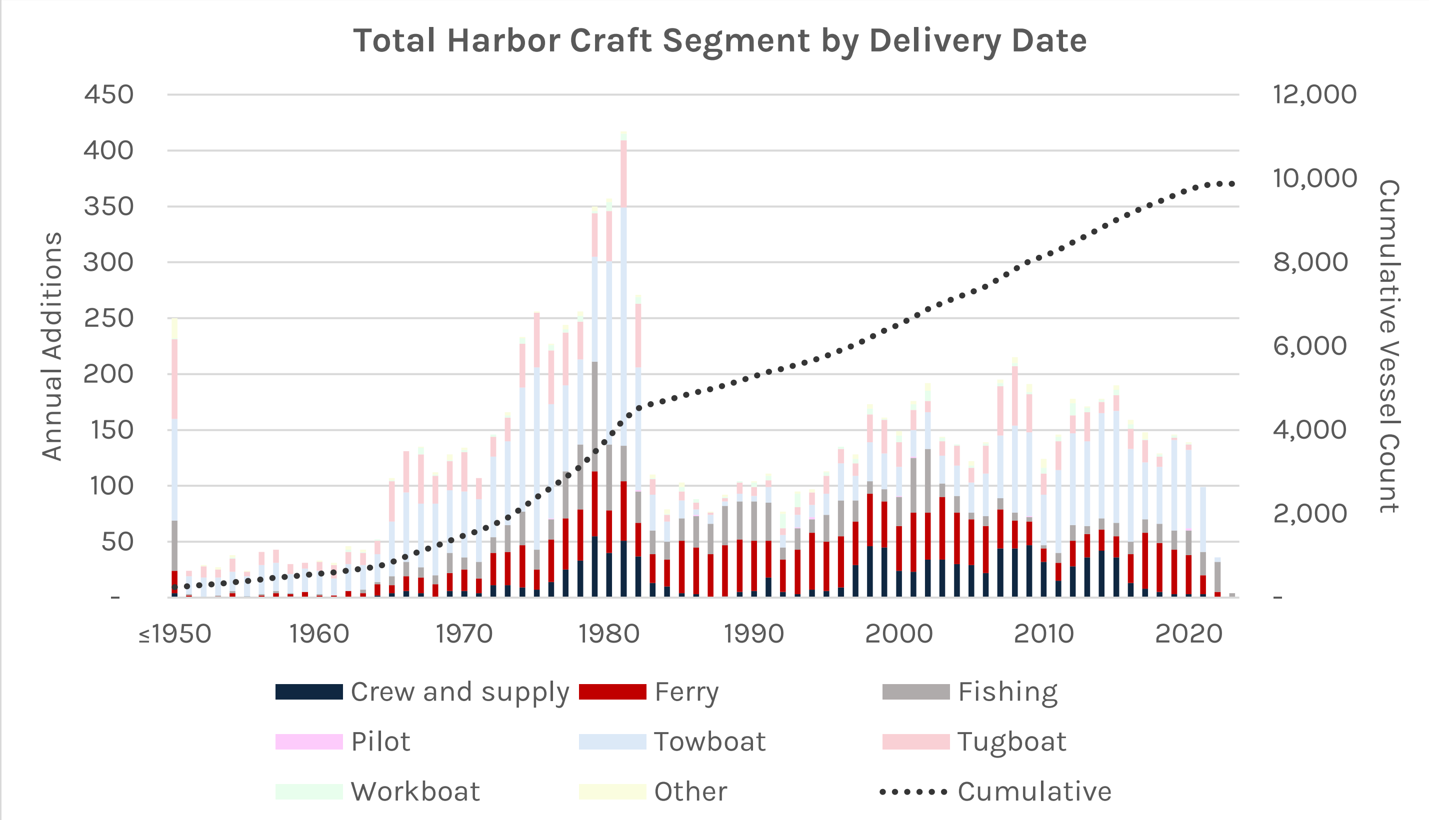
Exhibit 27 profiles the harbor craft segment by age.

There are close to 250 vessels currently still in the database that were delivered in or before 1950.

We also note the building boom in the 1970s, a decade in which over 2,100 vessels that are still in the database were delivered.

From 1990 to 2020, vessel deliveries (for vessels still in the database) generally fluctuated in a range of around 100-200 vessels delivered per year, with only two years of around 75 deliveries.

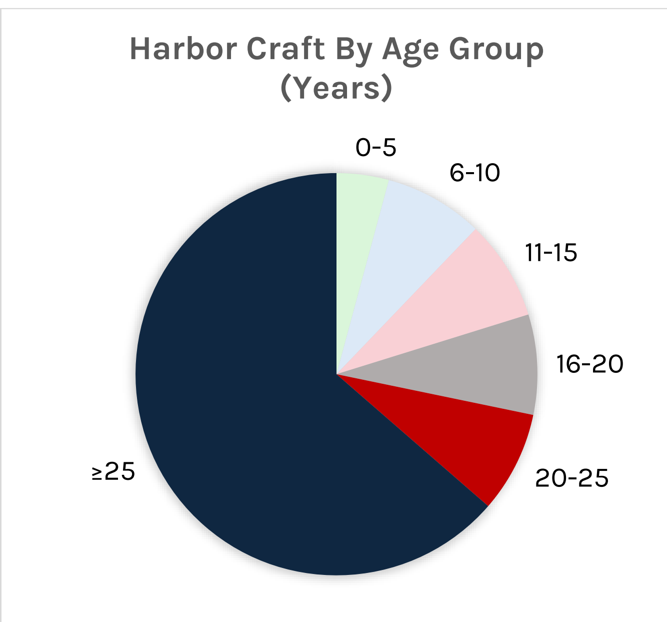
Exhibit 27 U.S. Harbor Craft Segment by Delivery Date



Source: Intelatus Global Partners

Exhibit 28 profiles the harbor craft fleet by age group.

Exhibit 28 U.S. Harbor Craft by Age Group



Source: Intelatus Global Partners

Around two-thirds of the total harbor craft fleet is over 25 years old, which is relatively old in the context of international maritime operations.

Barely 2,000 or 21% of vessels are 15 years old or younger.

The active fleet

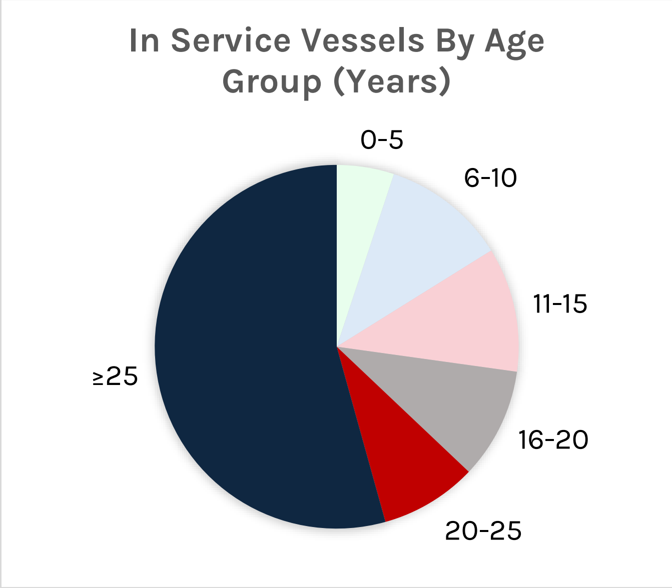
When we look at the In Service harbor craft, we note a slightly younger age profile than the overall fleet.

Around 27% of the 5,562 active harbor craft are 15 years or younger.

The proportion of vessels of 25 years of age or older is 54%.

Exhibit 29 segments the total In Service harbor craft population by age group.

Exhibit 29 In Service Harbor Craft by Age Group

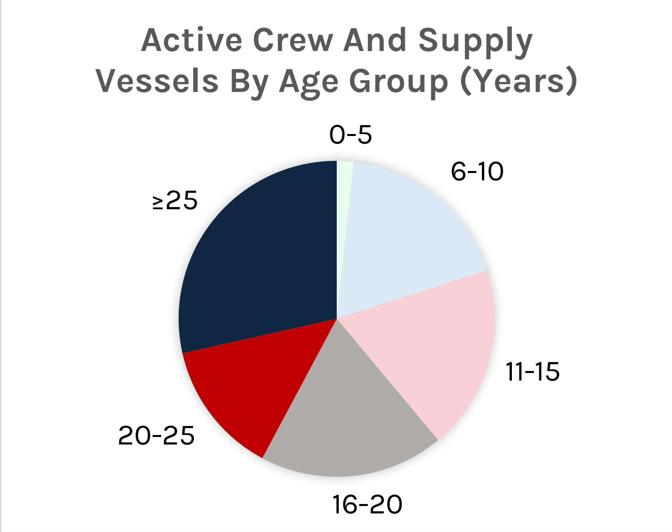


Source: Intelatus Global Partners

Drilling down into the individual segments, we establish that each different vessel category has a different age profile.

We start with the 519 In Service crew and supply boats, where we see a more even distribution than seen for commercial fishing vessels. That said, vessels of 25 years and older still account for close to 30% of the segment.

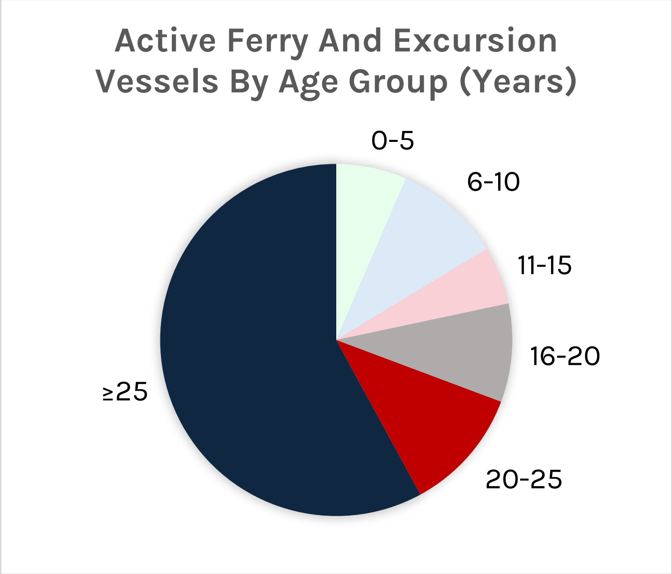
Exhibit 30 In Service Crew and Supply Vessels by Age Group



Source: Intelatus Global Partners

The ferry and excursion vessel segment, accounting for 863 active vessels, also has a high proportion of older vessels.

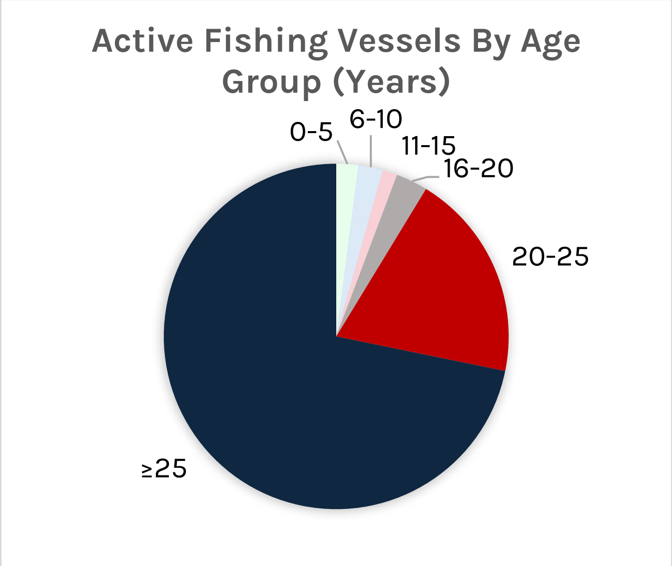
Exhibit 31 In Service Ferry and Excursion Vessels by Age Group



Source: Intelatus Global Partners

Looking at the 436 In Service fishing vessels in Exhibit 32 and note that close to three-quarters of the active vessels are 25 years or older. The indications are that there has been limited new building activity in the last 20 years.

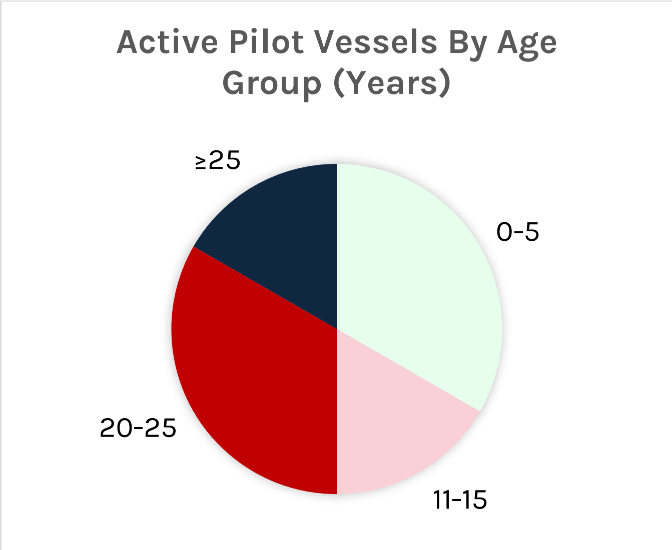
Exhibit 32 In Service Fishing Vessels by Age Group



Source: Intelatus Global Partners

The smallest harbor craft segment, pilot vessels, has six vessels confirmed In Service.

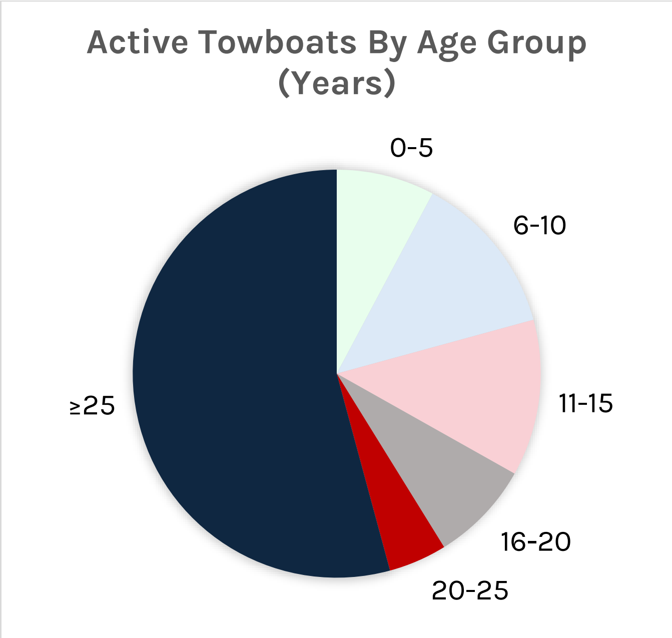
Exhibit 33 In Service Pilot Vessels by Age Group



Source: Intelatus Global Partners

The largest In Service segment encompasses towboats and pushboats, where one third of the segment is 15 years or younger and around 54% is 25 years or older.

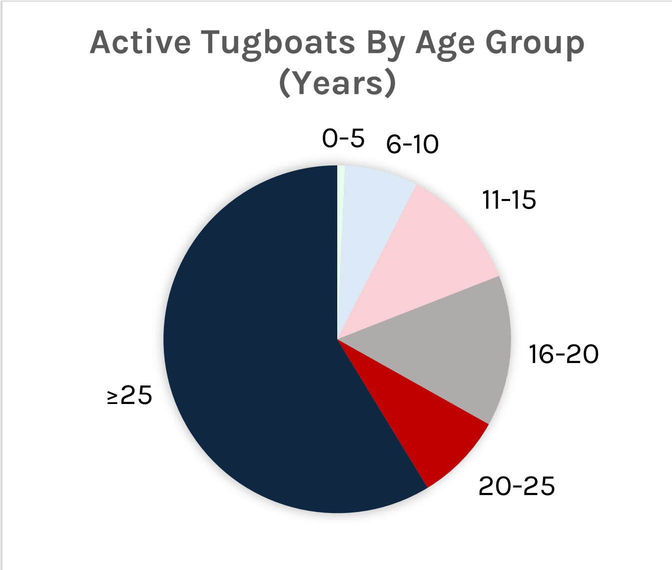
Exhibit 34 In Service Towboats and Pushboats by Age Group



Source: Intelatus Global Partners

Exhibit 35 profiles the 981 In Service tugboats by age and finds that less than 20% of tugboats are 15 years old or younger and that close to 60% are 25 years or older.

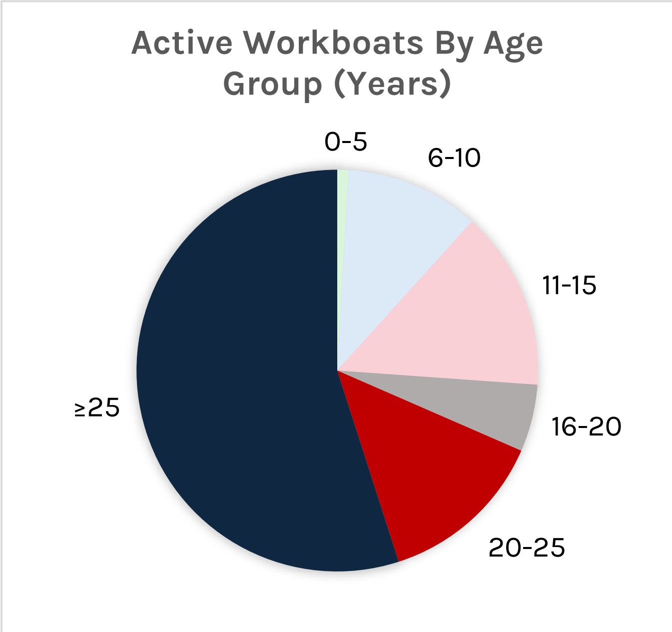
Exhibit 35 In Service Tugboats by Age Group



Source: Intelatus Global Partners

Like many segments, workboats have a high proportion of older vessels as seen in Exhibit 36.

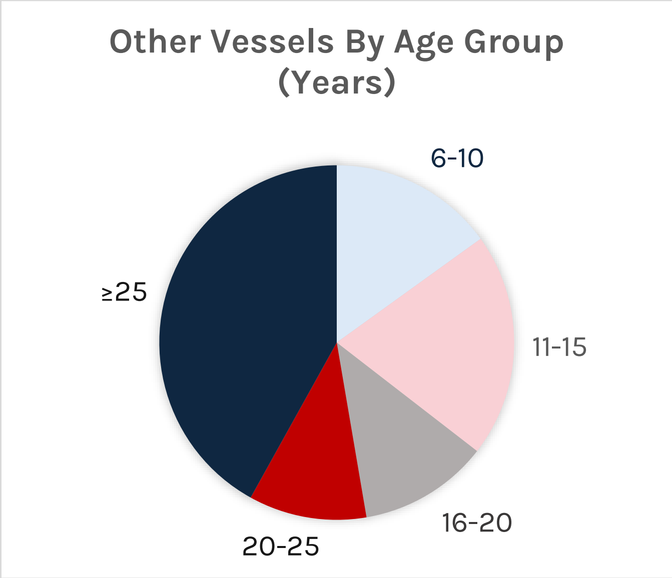
Exhibit 36 In Service Workboats by Age Group



Source: Intelatus Global Partners

Given the variety of vessels covered by the definition of other vessels, one cannot draw too many conclusions with the exception of the general observation that this is a more evenly distributed segment.

Exhibit 37 In Service Other Vessels by Age Group



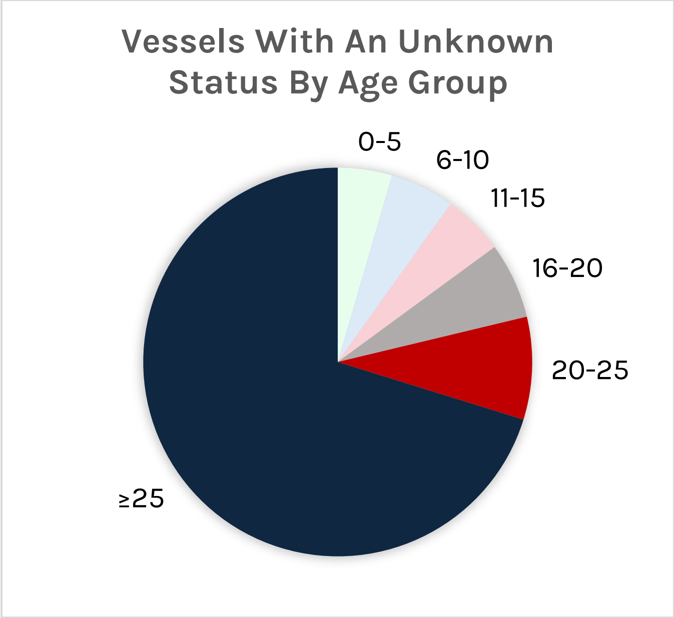
Source: Intelatus Global Partners

Unknown operational status

As noted previously, vessels grouped in the Unknown category may not be inactive and may simply be outside of AIS range for an extended period, overseas or are not equipped with AIS Class A systems that allow for the analysis of vessel status.

Exhibit 38 establishes that over 70% of vessels with an unknown operational status are 25 years old or more and only 14% are 15 years of age or less. By comparison, the In Service vessel segment contains less than 55% of vessels of 25 years or older.

Exhibit 38 Vessels with an Unknown Operational Status by Age Group

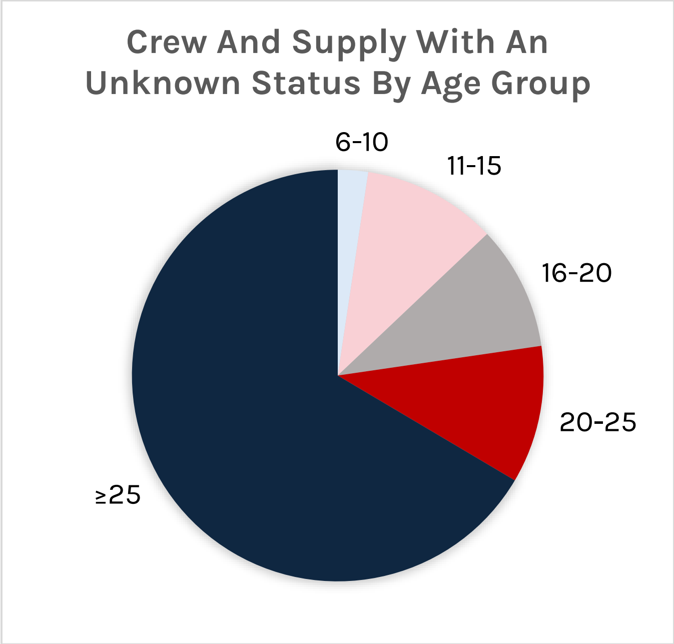


Source: Intelatus Global Partners

As with the In Service vessels, we drill down into the individual segments below.

We start with the crew and supply boats, where the operational status is unknown.

Exhibit 39 Crew and Supply Vessels with an Unknown Operational Status by Age Group

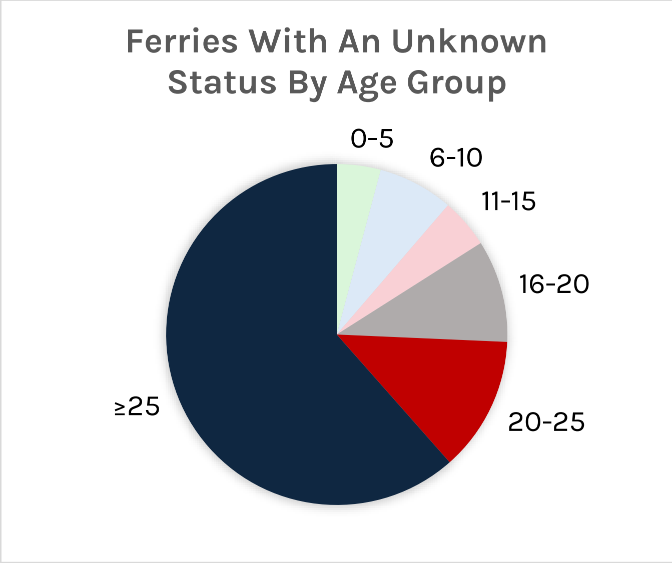


Source: Intelatus Global Partners

We note that two thirds of the vessels in this segment are 25 years of age or older. When we compare to the In Service vessels, we note around 30% in this age group. This suggests that a large number of vessels in this segment may be scrapped in place.

There are 938 ferries and excursion vessels with an unknown operational status. Interestingly, the age profile for this segment is similar to the In Service ferries.

Exhibit 40 Fishing Ferry and Excursion Vessels with an Unknown Operational Status by Age Group



Source: Intelatus Global Partners

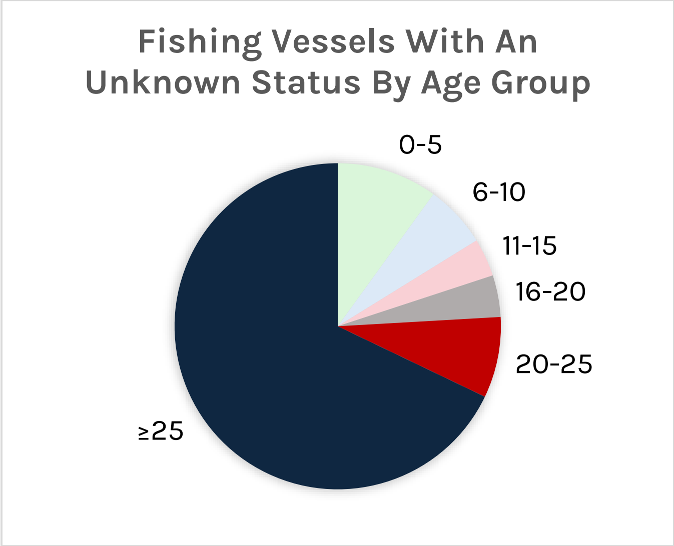
There are a lot of fishing vessels where operational status is Unknown – 822 vessels, which is nearly two times the number of In Service fishing vessels.

It is likely that many of these are active but are not equipped with the AIS Class A system that supports tracking and analysis.

It is interesting to note that 24% of the segment is 20 years of age or younger compared to only 9% of the In Service fishing vessels

Close to 70% of the fishing segment where the operational status is Unknown are 25 years of age or older, which the figure of close to three-quarters of the active fishing vessels. This supports the view that there has been limited new building activity in the last 20 years.

Exhibit 41 Fishing Vessels with an Unknown Operational Status by Age Group

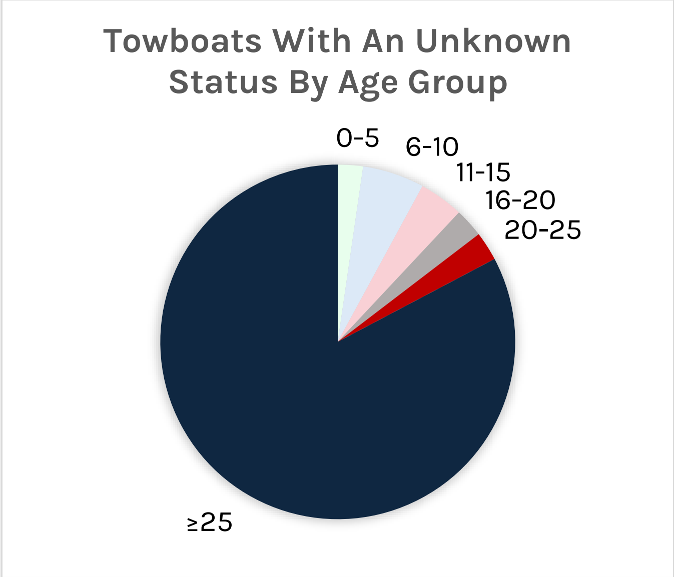


Source: Intelatus Global Partners

All five pilot boats with an Unknown operational status are 25 years of age or older.

We record a comparatively small number of towboats (to the In Service Towboat segment) where the operational status is Unknown. We infer that a significant proportion of over 80% of towboats which are 25 years or older are effectively scrapped in place.

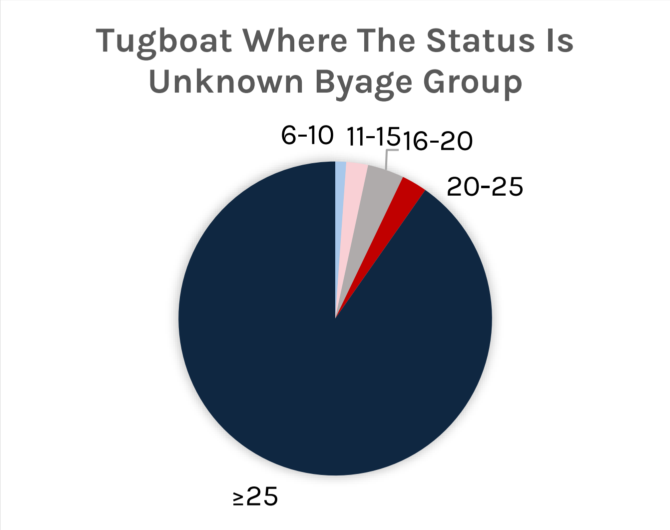
Exhibit 42 Towboats and Pushboats with an Unknown Operational Status by Age Group



Source: Intelatus Global Partners

Exhibit 43 profiles tugboats by age and finds that 90% are 25 years or older. It is likely that many of these are active but are not equipped with the AIS Class A system that supports tracking and analysis or are scrapped in place.

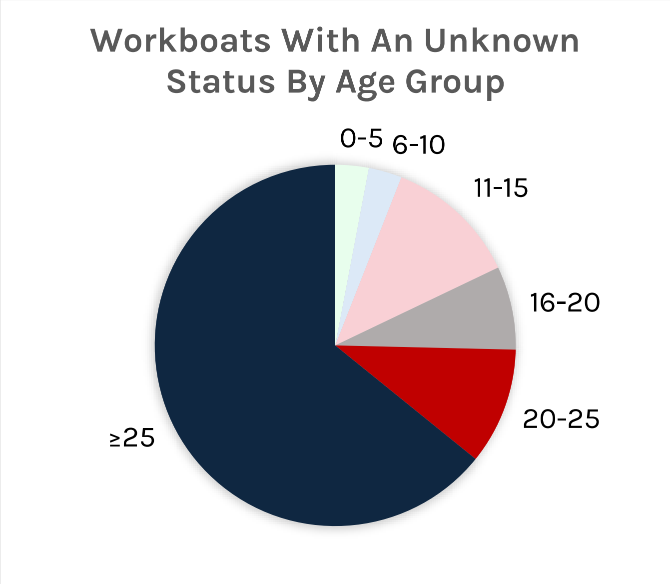
Exhibit 43 Tugboats by Age Group with an Unknown Operational Status by Age Group



Source: Intelatus Global Partners

It is likely that many workboats with Unknown status are not equipped with the AIS Class A system or are scrapped in place.

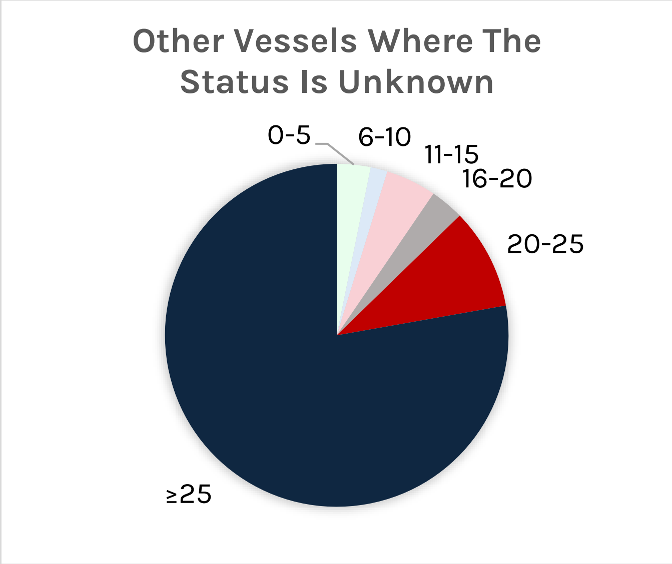
Exhibit 44 Workboats with an Unknown Operational Status by Age Group



Source: Intelatus Global Partners

Given the variety of vessels covered by the definition of other vessels, one cannot draw too many conclusions with the exception of the general observation that it is likely that many of these vessels are not equipped with the AIS Class A system or are scrapped in place.

Exhibit 45 Other Vessels with an Unknown Operational Status by Age Group



Source: Intelatus Global Partners

Idle vessels

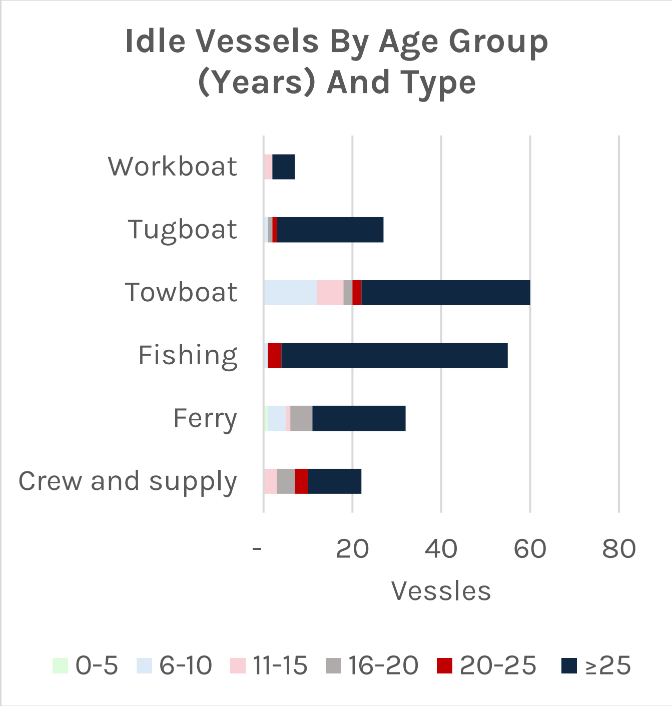
There are just over 200 idle vessels, where an AIS signal has not been received between three and six months. This could be because of dry docking and repair, lack of commercial opportunity or other factors. For fishing vessels, inactivity can be linked to weather and fishing season limits.

It is possible that these vessels will return to active service. However, it is equally possible that they remain idle and move to the Inactive category.

Exhibit 46 establishes nearly three quarters of the vessels are 25 years of age or older.

Vessels at this age generally are more expensive to maintain in working order, which indicates that some are more likely to enter the Inactive and Laid-up category.

Exhibit 46 Idle Vessels by Age Group



Source: Intelatus Global Partners

Laid-up and Inactive vessels

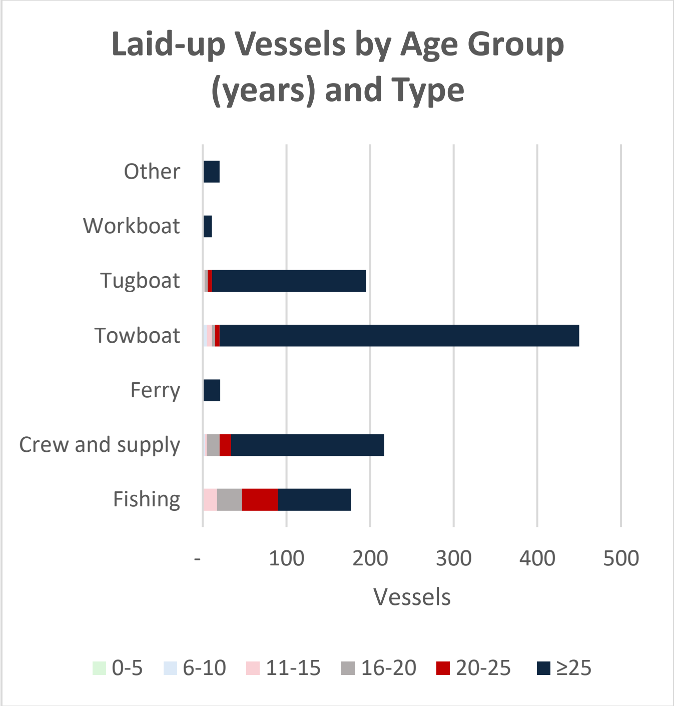
Vessels in this segment are either in declared long-term lay-up or are effectively laid-up through lack of activity.

In some shipping segments, for example the offshore support vessel segment, this activity is often taken to mean that the vessels have effectively been abandoned or scrapped in place. It is unlikely that these vessels will return to the active fleet.

Exhibit 47 establishes that the majority of Laid-up and Inactive vessels (83%) are 25 years of age or older.

We believe that vessels in this category are very unlikely to return to active service.

Exhibit 47 Laid-up Vessels by Age Group



Source: Intelatus Global Partners

6.3. Gross Tonnage

Most IMO regulations, including MARPOL and SOLAS are based on gross tonnage. Gross tonnage is also an important number when considering the requirement for vessels of 300 gross tons and above to deploy AIS Class A systems when engaged in international voyages.

However, given that the majority of vessels within this dataset are not engaged on international voyages, this distinction is not so important for our harbor craft population.

Whereas net tonnage measures the volume of only the cargo-carrying space on a vessel, gross tonnage measures the volume of all enclosed spaces on a vessel – including the engine room and other non-cargo spaces.

Gross tonnage should not be confused with gross registered tonnage, which measures the space available for cargo, fuel, passengers and crew within the hull and enclosed space above the deck of a merchant ship.

The average for all harbor craft in our vessel dataset is 485 gross tons.

It is not surprising that the Other category has high average and maximum GT, given that the segment includes tankers and cargo vessels trading in the USA, but are also capable of international travel.

Exhibit 47 presents the average, minimum and maximum GT by vessel category.

Exhibit 48 Harbor Craft by GT

Vessel Type	Average GT	Minimum GT	Maximum GT
Crew and supply	857	7	8,417
Ferry	238	5	39,012
Fishing	235	4	4,660
Pilot	124	39	295
Towboat	243	16	1,597
Tugboat	224	6	7,076
Workboat	1,409	8	14,001
Other	8,939	7	37,548

Source: Intelatus Global Partners

Vessels In Service

Our population of around 5,500 In Service harbor craft has an average GT of 609 tons. Exhibit 49 establishes that the average GT in all categories, with the exception of tugboats, is higher for In Service Vessels than for the whole harbor craft population.

Exhibit 49 In Service Harbor Craft by GT

Vessel Type	Average GT	Minimum GT	Maximum GT
Crew and supply	1,061	27	8,417
Ferry	302	8	10,176
Fishing	380	7	4,555
Pilot	135	57	230
Towboat	270	24	1,578
Tugboat	220	17	7,076
Workboat	1,859	14	14,001
Other	14,272	27	37,548

Source: Intelatus Global Partners

Vessels whose operational status is Unknown

The 3,100 or so vessels with Unknown operational status have a comparatively low average GT of 220 tons.

Exhibit 50 Harbor Craft with Unknown Operational Status by GT

Vessel Type	Average GT	Minimum GT	Maximum GT
Crew and supply	494	7	4,461
Ferry	115	5	4,244
Fishing	142	4	4,273
Pilot	110	39	295
Towboat	149	16	1,155
Tugboat	212	7	3,747
Workboat	566	8	5,960
Other	1,628	7	25,939

Source: Intelatus Global Partners

Idle

Our population of Idle harbor craft has an average GT of 341 tons.

Exhibit 51 Idle Harbor Craft by GT

Vessel Type	Average GT	Minimum GT	Maximum GT
Crew and supply	490	89	2,998
Ferry	266	9	2,623
Fishing	389	17	2,110
Towboat	271	22	1,161
Tugboat	236	39	1,596
Workboat	871	31	3,991
Other	196	196	196

Source: Intelatus Global Partners

Laid-up and Inactive vessels

The average GT for the Laid-up and Inactive vessels is 532 tons.

Exhibit 52 Laid-up and Inactive Harbor Craft by GT

Vessel Type	Average GT	Minimum GT	Maximum GT
Crew and supply	1,057	33	5,960
Ferry	490	8	39,012
Fishing	433	16	4,660
Towboat	196	19	1,597
Tugboat	259	6	4,918
Workboat	1,311	94	5,972
Other	5,786	97	12,724

Source: Intelatus Global Partners

6.4. Length

There are several commonly used measurements to indicate a vessel's length, including:

- Loaded waterline length or LWL: Measuring a vessel's length at the waterline.
- Length overall or LOA: maximum length of a vessel's hull parallel to the waterline.
- Length of hull or LOH: used for small boats, this measures the length of the hull without attachments.

Our database relies on the USCG data for vessel lengths which often does not specify which length category has been applied .

To give an example of the issue, we refer to McAllister Towing's A. J. McAlister, a tugboat and firefighting vessel. The vessel holds an ABS classification certificate. Exhibit 53 presents several figures for length sourced from widely used data sources.

Exhibit 53 A. J. McAllister Tugboat Length

Source	LWL	LOA	Length
McAllister	96.0	98.0	
USCG			91.4
ABS		98.0	
MarineTraffic		98.0	
Vessel Finder		95.1	

Source: Intelatus Global Partners

Exhibit 54 presents length characteristics by vessel segment.

Exhibit 54 Harbor Craft by Length (feet)

Vessel Type	Average Length	Minimum Length	Maximum Length
Crew and supply	164	36	387
Ferry	92	24	440
Fishing	83	25	362
Pilot	77	52	133
Towboat	84	26	355
Tugboat	91	26	325
Workboat	156	34	644
Other	304	32	612

Source: Intelatus Global Partners

Vessels In Service

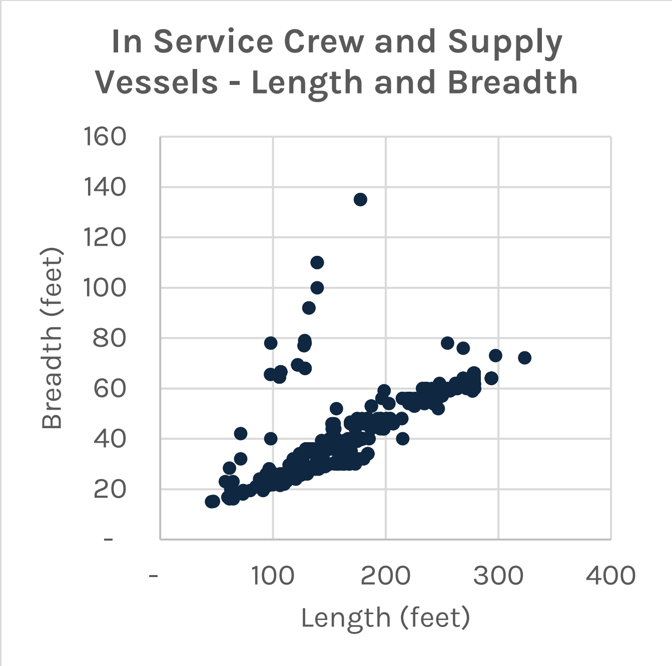
We start by looking at the length of the vessels in the crew and supply segment and compare length against breadth, gross tons and horsepower, to establish the correlation between the factors.

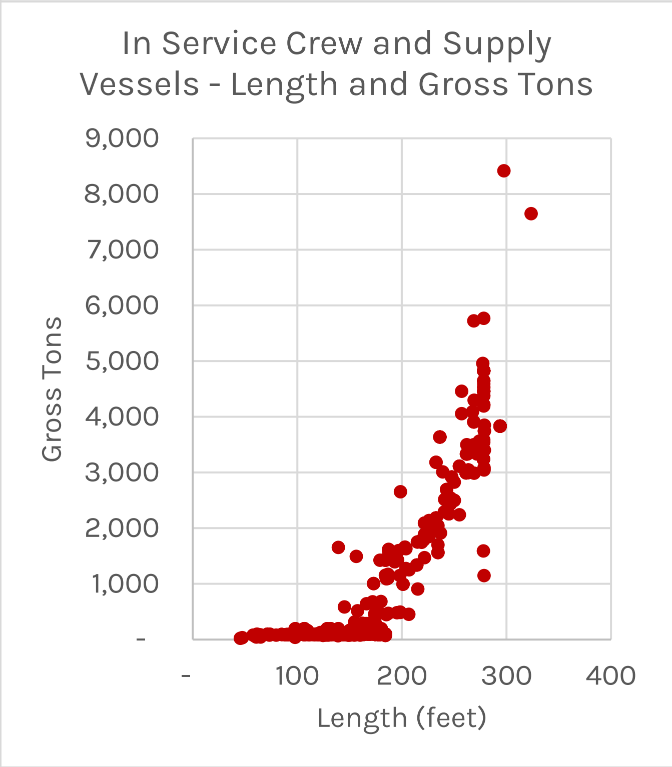
The first graph shows a comparatively linear correlation of length and breadth increase for crew and supply vessels. The average In Service crew and supply vessel length is 172 feet and breadth is 44 feet.

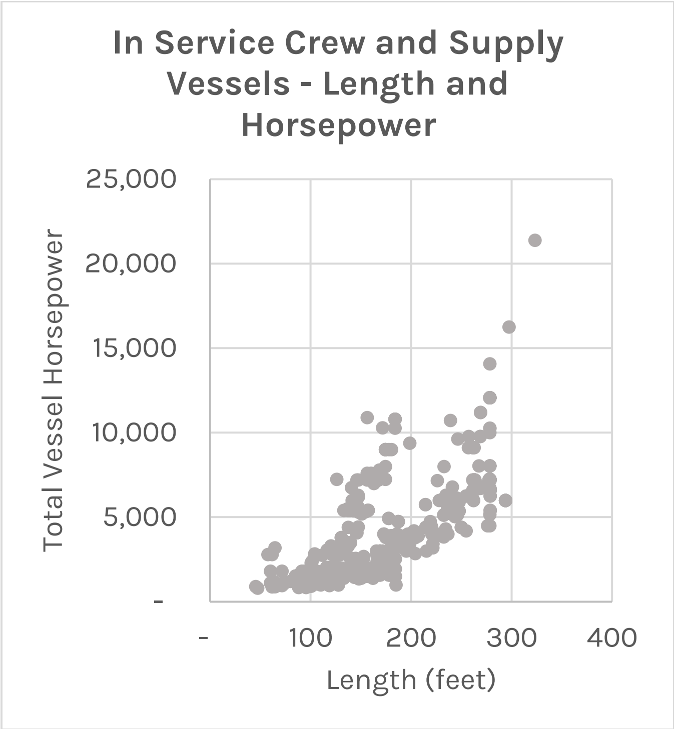
In the second graph, as vessel length increases, gross tonnage remains around the 500 tons level. However, beyond around 180 feet, gross tonnage begins to increase steadily in an almost linear fashion. The average In Service crew and supply vessel gross tonnage is 1,061 tons.

For length and horsepower, there appear to be two general relationship pathways once a vessel reaches around 140 feet – a shallower growth curve which covers a larger proportion of the vessels and a steeper curve for a group of vessels up to 200 feet in length. The average In Service crew and supply vessel length is close to 4,050 horsepower.

Exhibit 55 In Service Crew and Supply Vessels by Length, Breadth, Gross Tons and Horsepower



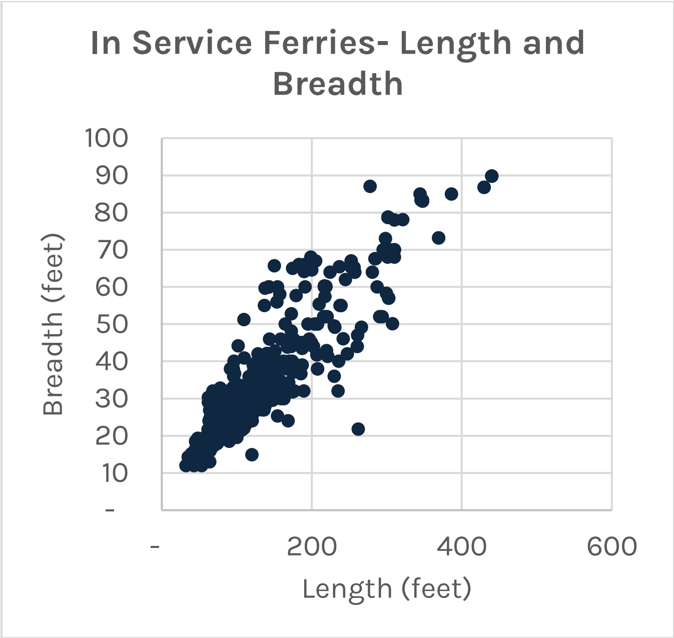


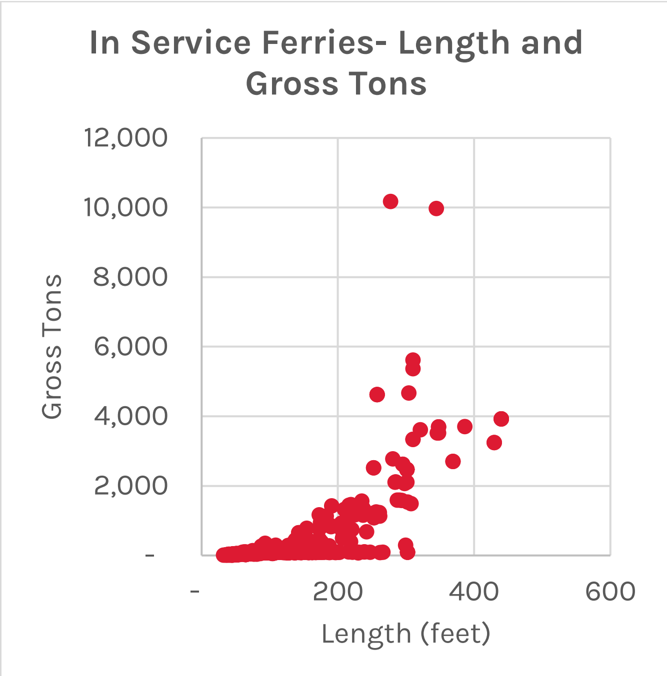


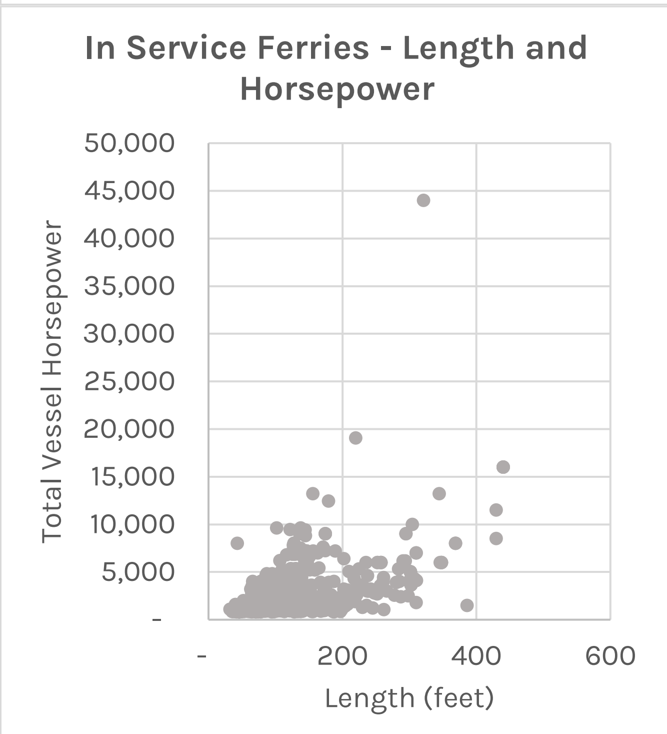
Source: Intelatus Global Partners

Looking at the Ferry segment, we note a concentration of vessels below 185 feet and different correlations between length, breadth, gross tons and horsepower than seen in the crew and supply segment.

Exhibit 56 In Service Ferries by Length, Breadth, Gross Tons and Horsepower







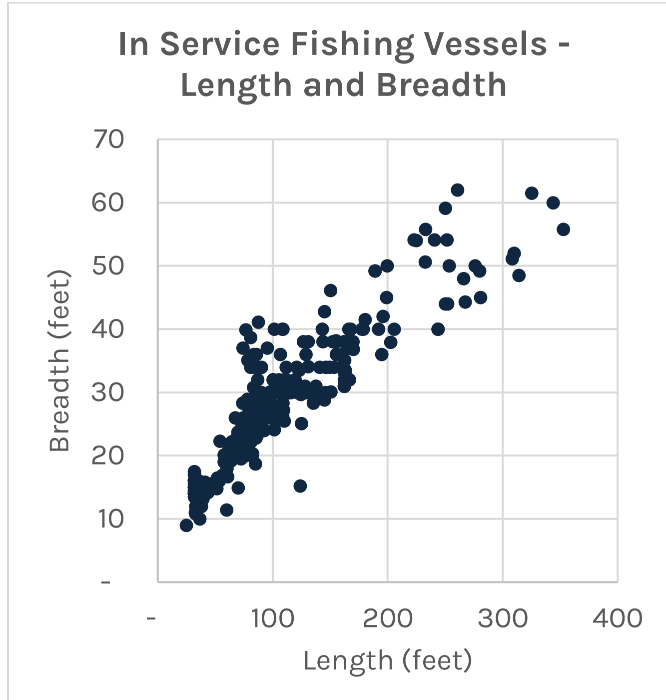
Source: Intelatus Global Partners

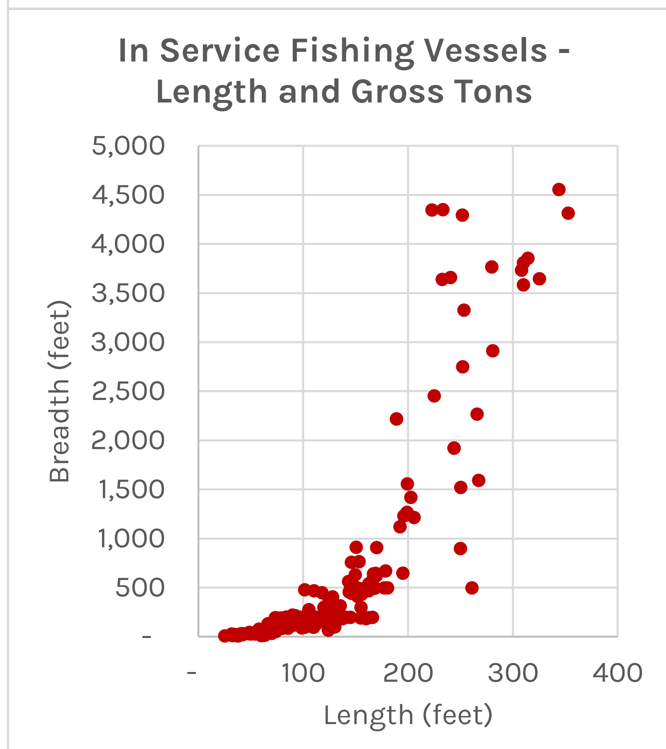
The average In Service ferry has a length of 114 feet and breadth of 30 feet. Average gross tonnage is 302 tons and horsepower 2,505.

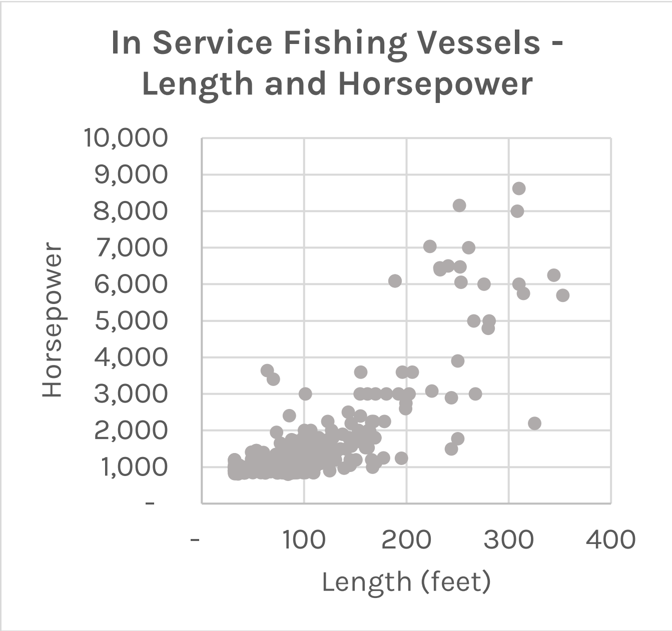
Exhibit 57 profiles the fishing fleet in the context of vessel breadth, gross tonnage and horsepower.

The average fishing vessel In Service has a length of 106 feet and breadth of 28 feet, with a gross tonnage of close to 380 tons and an average of 1,522 horsepower.

Exhibit 57 In Service Fishing Vessels by Length, Breadth, Gross Tons and Horsepower





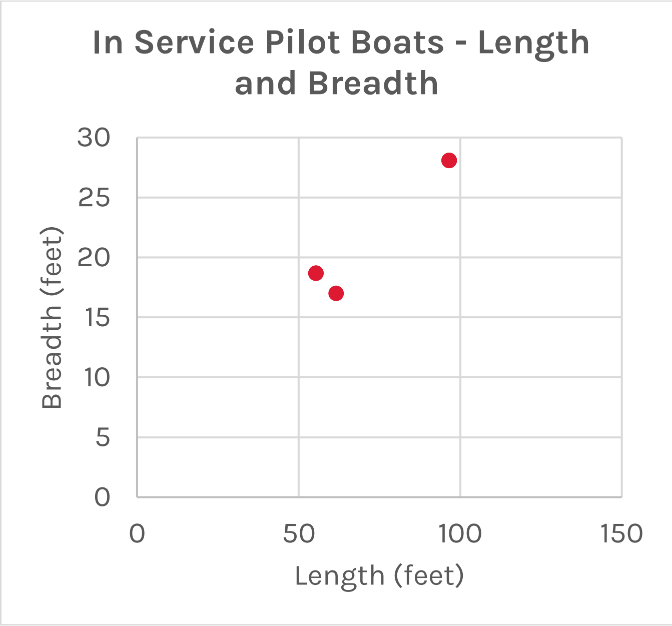


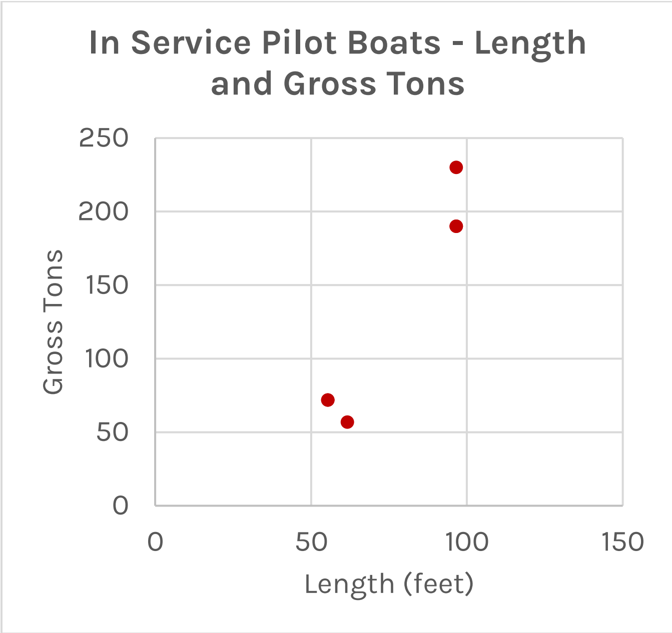
Source: Intelatus Global Partners

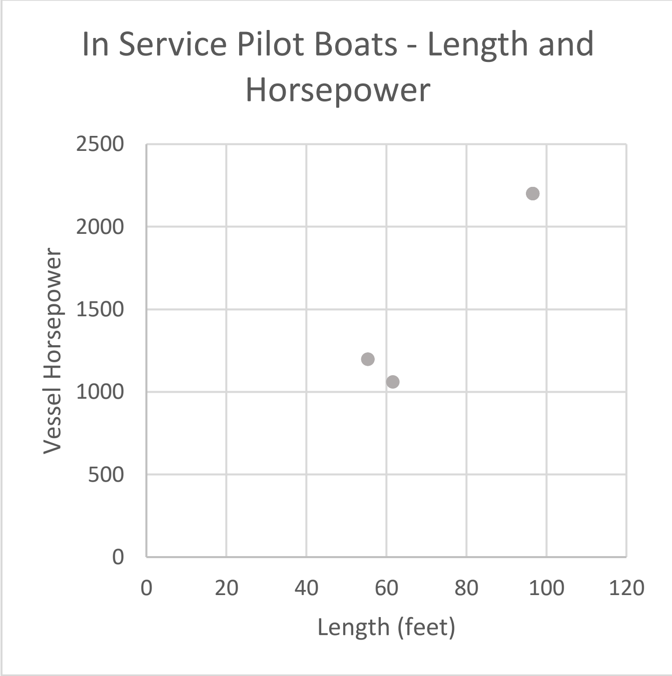
There are not so many pilot vessels above 600 kW and as such the trend data for the correlation of length, breadth, gross tonnage and horsepower is somewhat limited.

In Service pilot boats have the shortest average length of all of the vessel categories at 77 feet. Average breadth is 23 feet, gross tonnage 135 tons and 1,676 horsepower.

Exhibit 58 In Service Pilot Boats by Length, Breadth, Gross Tons and Horsepower





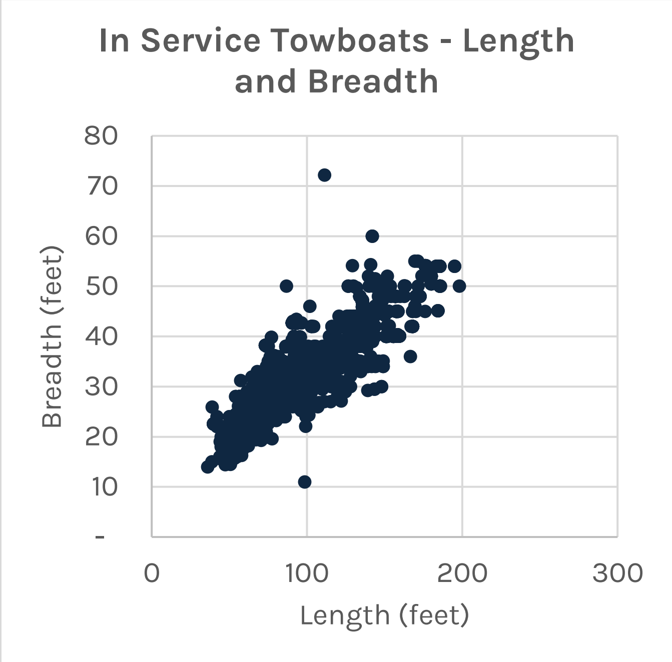


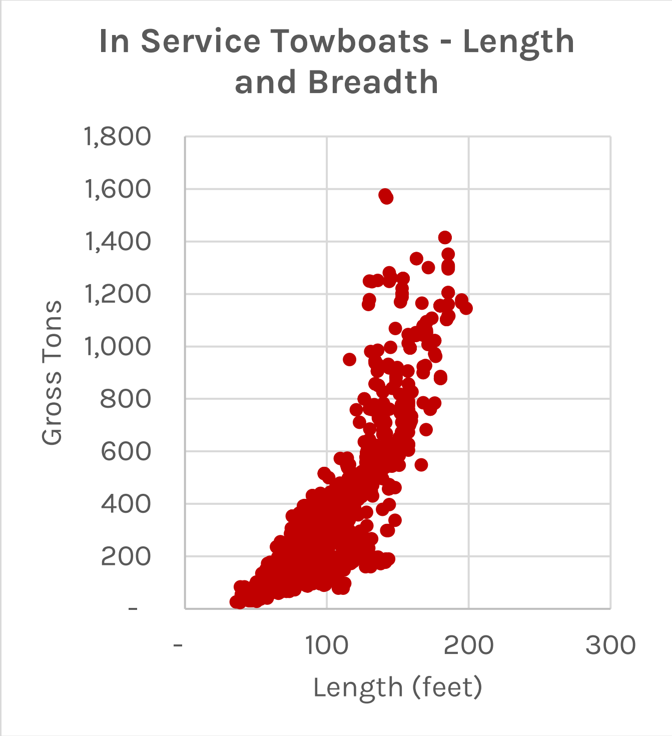
Source: Intelatus Global Partners

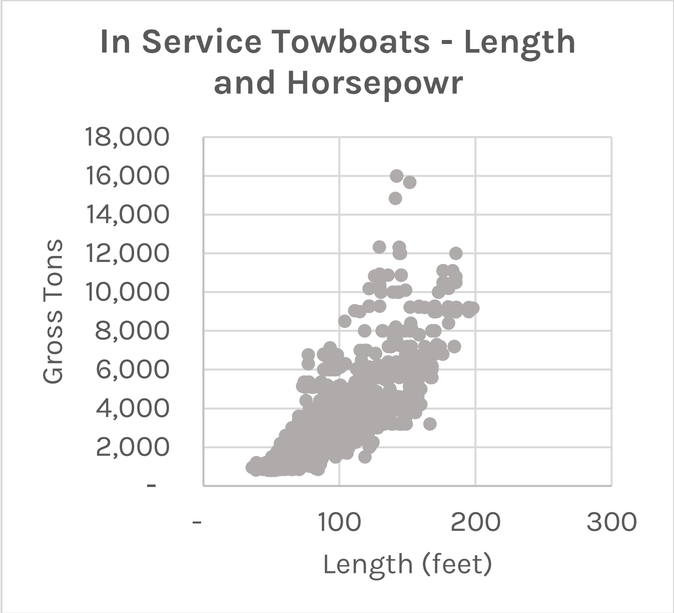
The towboat segment has a relatively close correlation of length, breadth, gross tons and horsepower as seen in Exhibit 59.

The average In Service towboat has a length of 110 feet and breadth of 36 feet. The average gross tonnage of this segment is around 443 tons and horsepower around 2,232.

Exhibit 59 In Service Towboats by Length, Breadth, Gross Tons and Horsepower





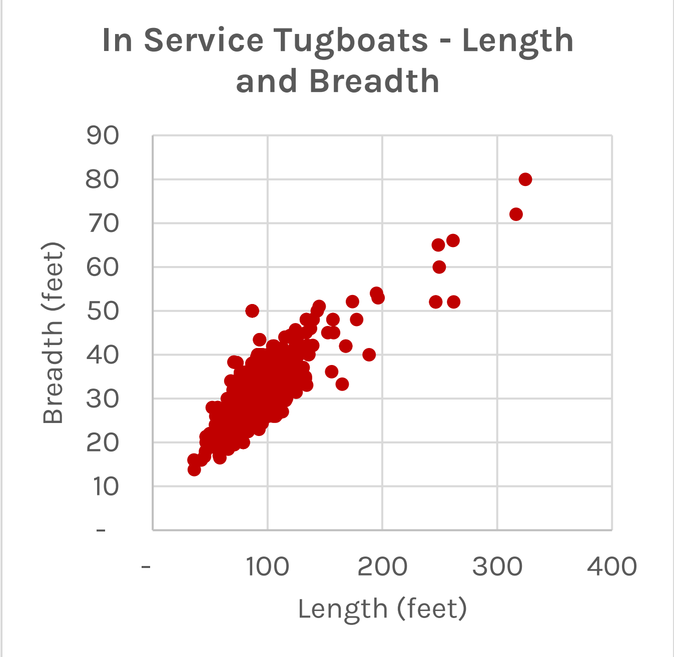


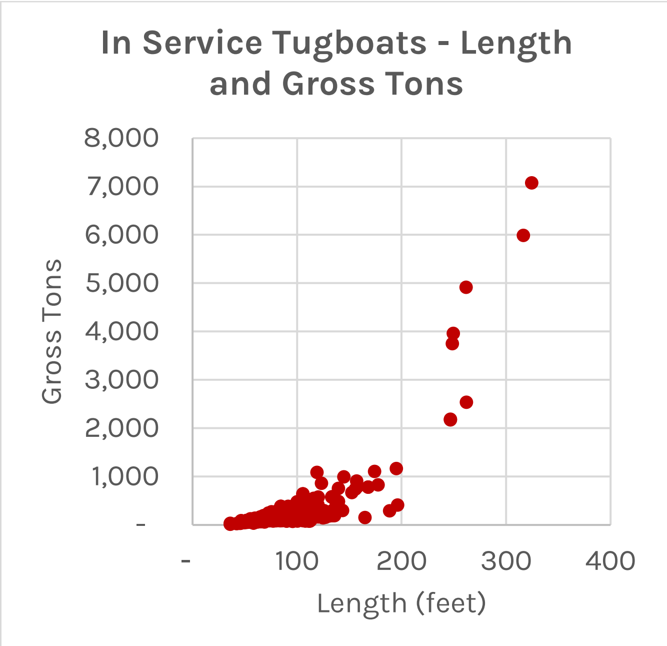
Source: Intelatus Global Partners

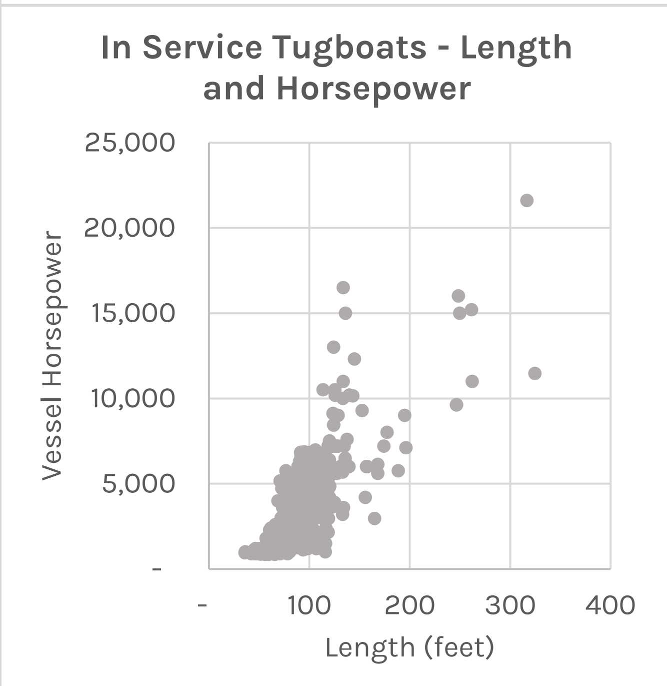
Like the towboat segment, tugboats have a relatively close correlation of length and breadth. The impact of offshore tugs can be seen in the dataset for vessels over 140 feet.

The average length of In Service tugboats is 90 feet and breadth 31 feet (average breadth is same as towboat segment). Average gross tonnage is 217 tons and horsepower slightly above 3,325.

Exhibit 60 In Service Tugboats by Length, Breadth, Gross Tons and Horsepower





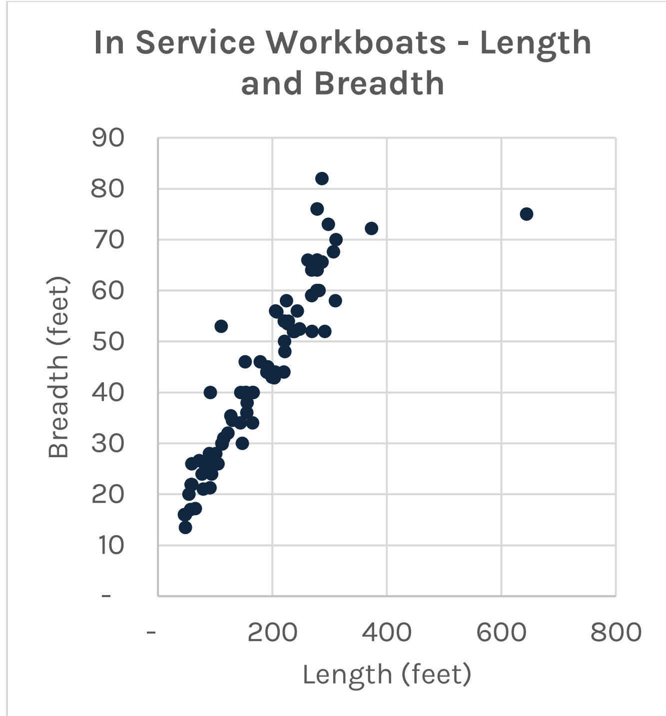


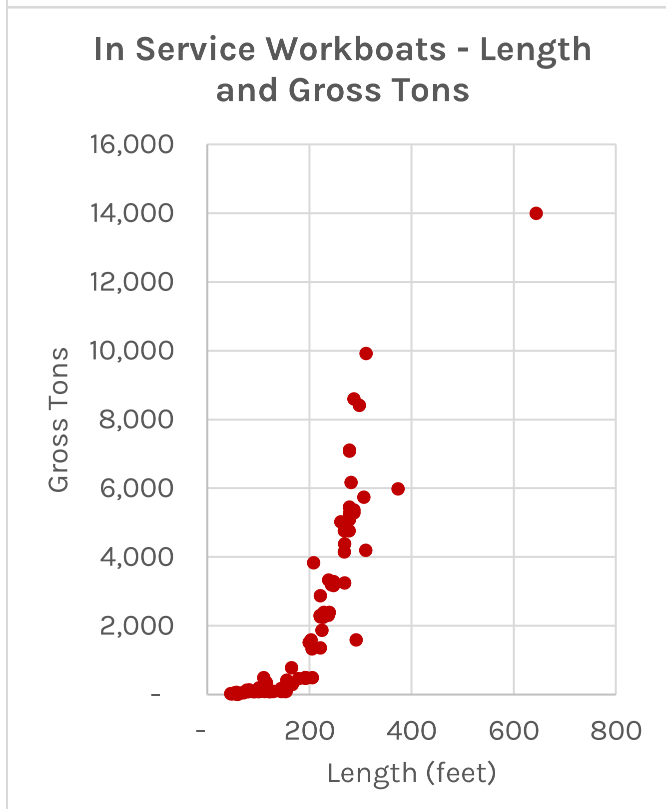
Source: Intelatus Global Partners

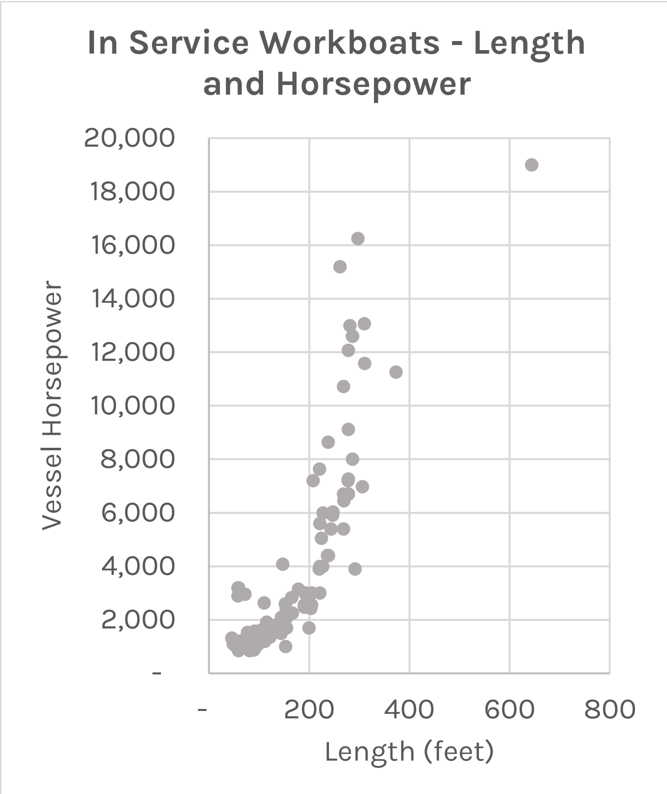
In Service workboats generally show a strong correlation for length and breadth, gross tons and horsepower, although there is one larger vessel seen in the charts – a large naval auxiliary research vessel.

In Service workboats have an average length of 181 feet and breadth of 43 feet. Average gross tonnage is 1,859 and horsepower close to 4,128.

Exhibit 61 In Service Workboats by Length, Breadth, Gross Tons and Horsepower





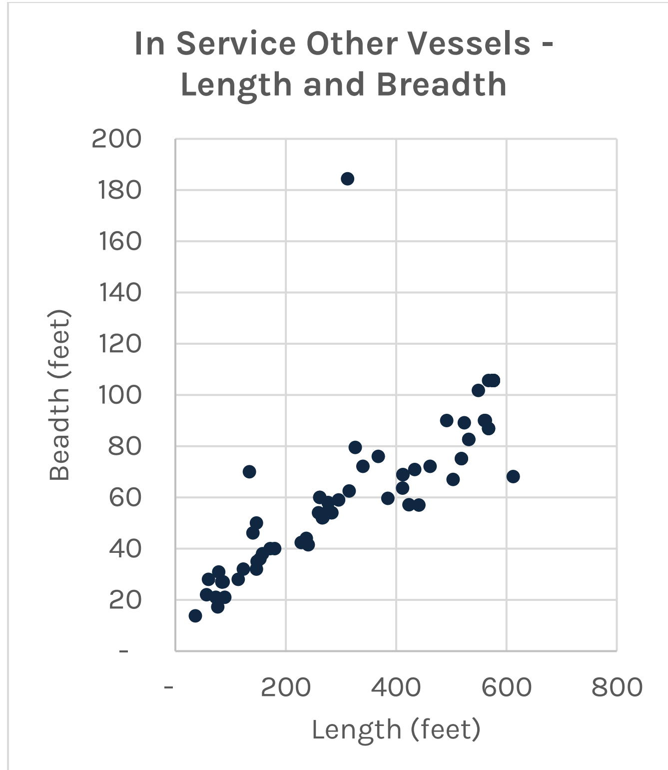


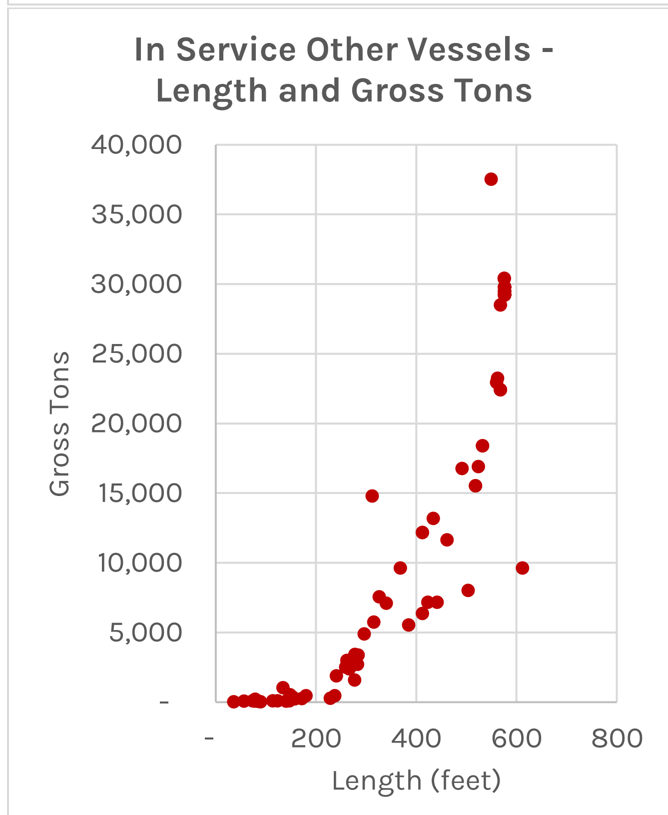
Source: Intelatus Global Partners

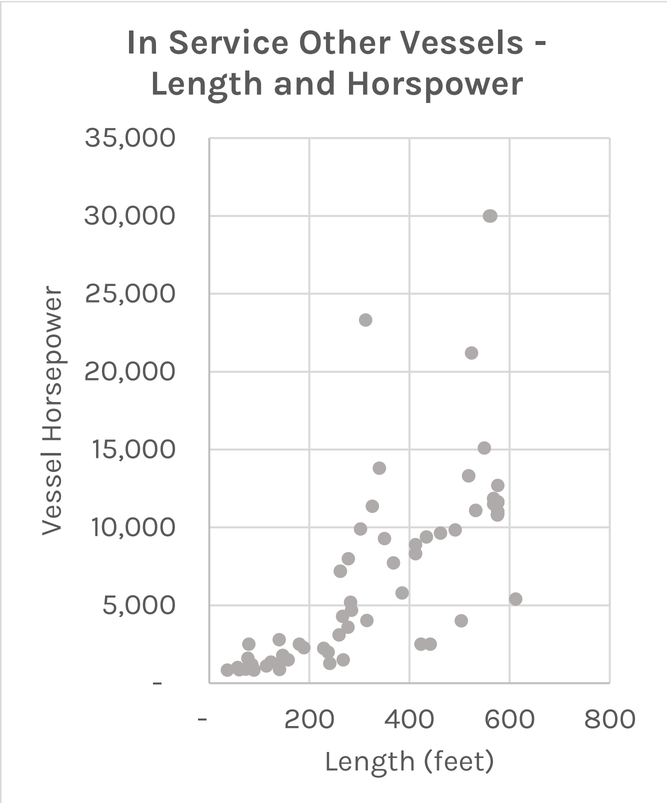
Given the variety of vessel types with the category of Other, it is surprising to see, at least for breadth and gross tons, the close correlation to length growth.

With an average In Service vessel length of 390 feet, breadth of 74 feet, 14,272 gross tons and 8,199 horsepower, it is clear that this segment features some larger oceangoing vessels that are still classed as harbor craft.

Exhibit 62 In Service Other Vessels by Length, Breadth, Gross Tons and Horsepower







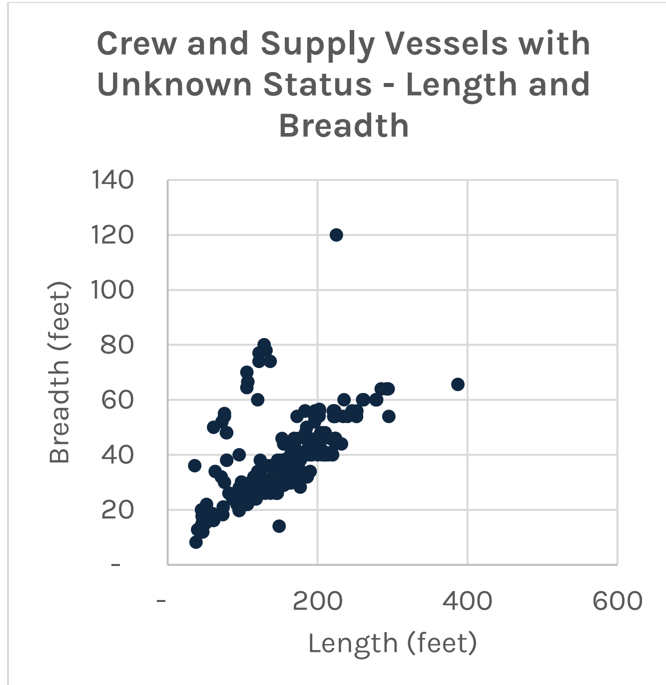
Source: Intelatus Global Partners

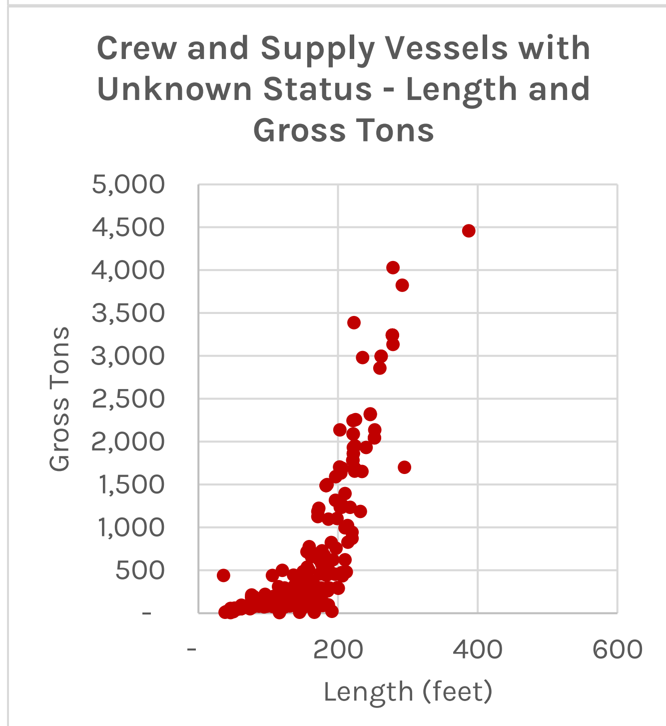
Vessels with an Unknown operational status

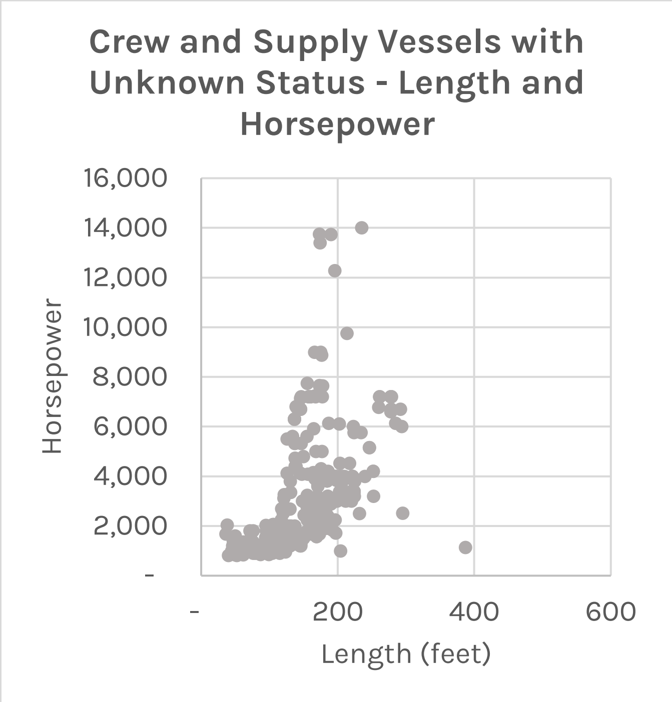
As with the In Service segment, we start our analysis with the crew and supply boats where the operational status is Unknown. The graphs in Exhibit 63 believe generally follow the same trends as seen for the In Service crew and supply boats.

Crew and supply boats with an Unknown operational status have lower average values of length (147 feet), breadth (36 feet), gross tons (494 tons) and horsepower (2,902) than the vessels that are confirmed to be In Service. This may have something to do with the older age profile of vessels in this category.

Exhibit 63 Crew and Supply Vessels with an Unknown Status by Length, Breadth, GT and Horsepower



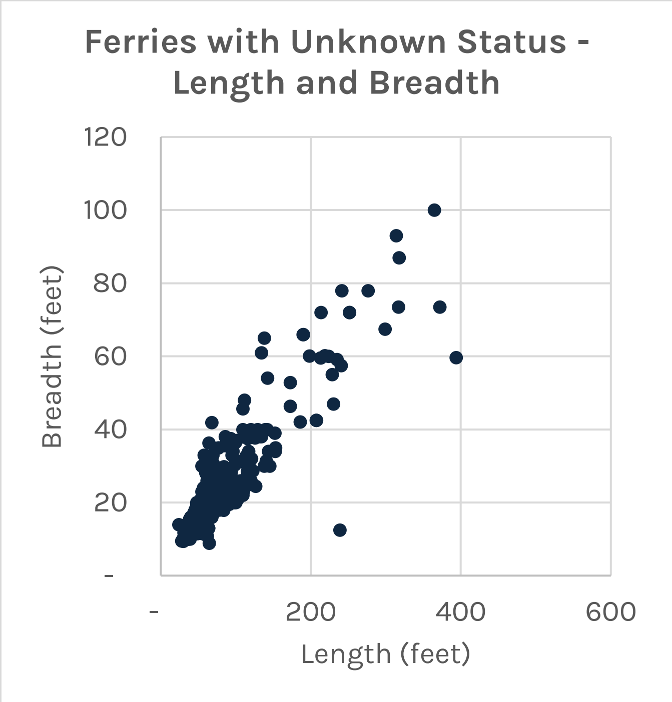


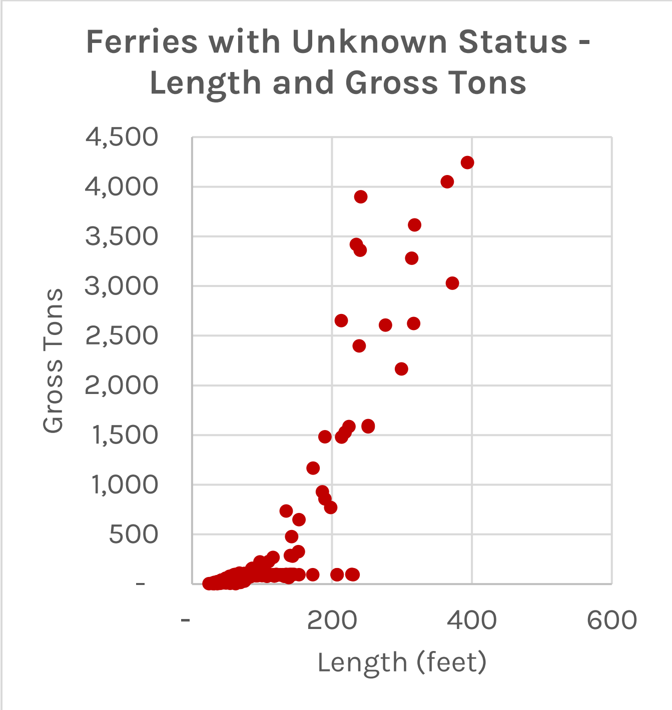


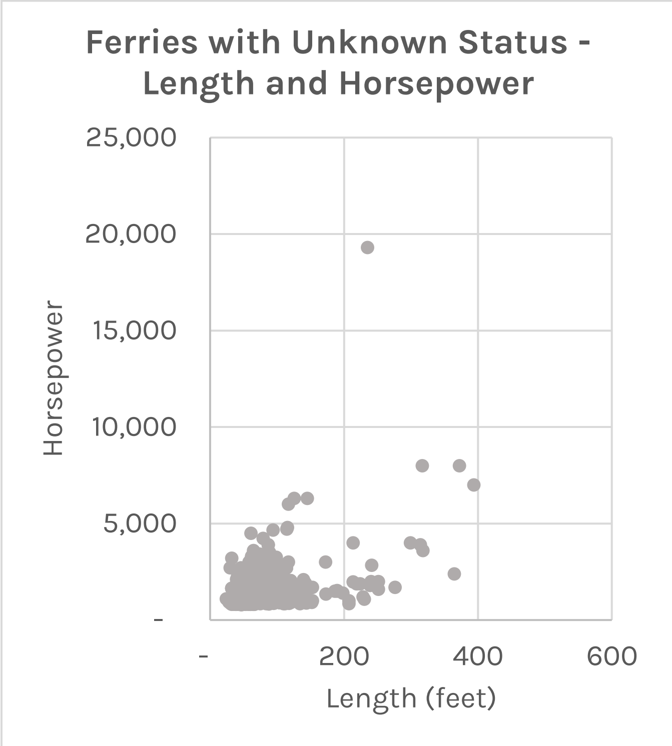
Source: Intelatus Global Partners

We see similar trends in the Unknown status Ferry segment as with the In Service vessels, although average values for length (67 feet), breadth (21 feet), gross tons (115 tons) and horsepower (1,338) are lower than the In Service Vessels.

Exhibit 64 Ferries with an Unknown status by Length, Breadth, GT and Horsepower





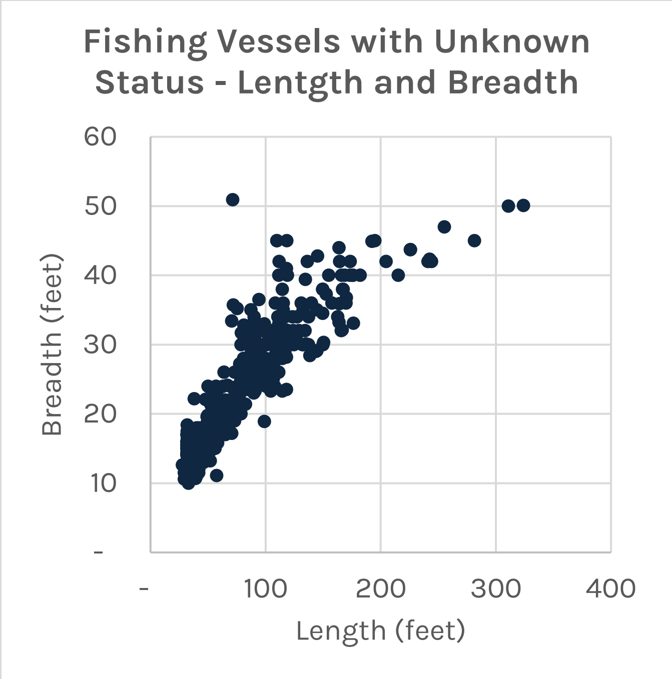


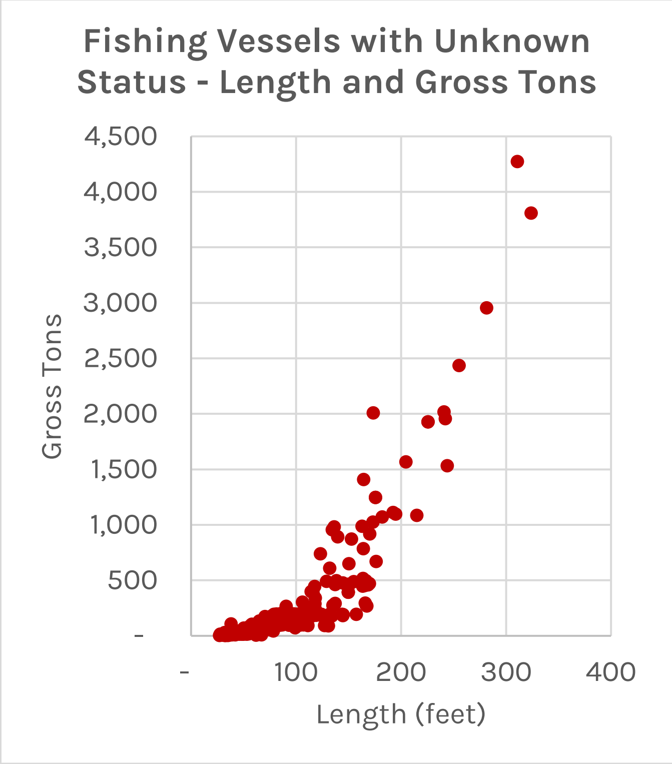
Source: Intelatus Global Partners

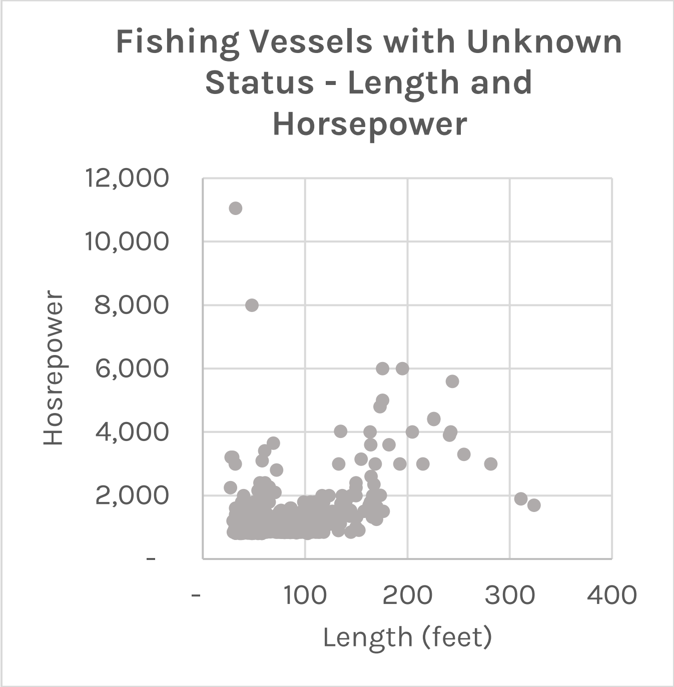
Exhibit 65 profiles the fishing fleet in the context of vessel breadth, gross tonnage and horsepower.

Average values for length (68 feet), breadth (21 feet), gross tons (142 tons) and horsepower (1,205) are lower than the In Service Vessels.

Exhibit 65 Fishing Vessels with an Unknown Status by Length, Breadth, GT and Horsepower





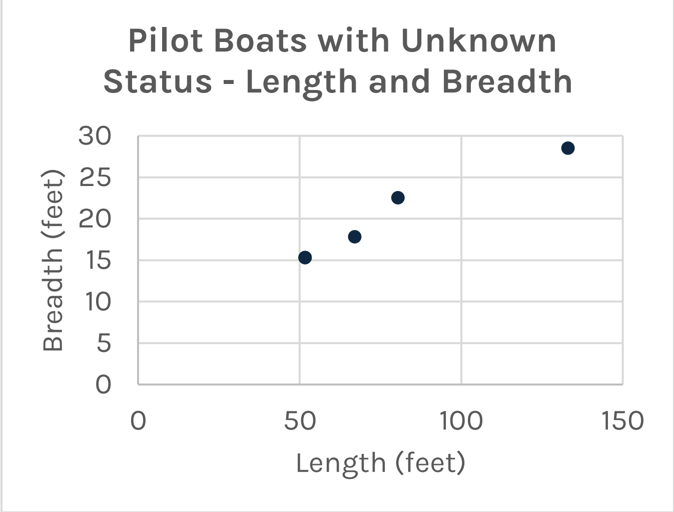


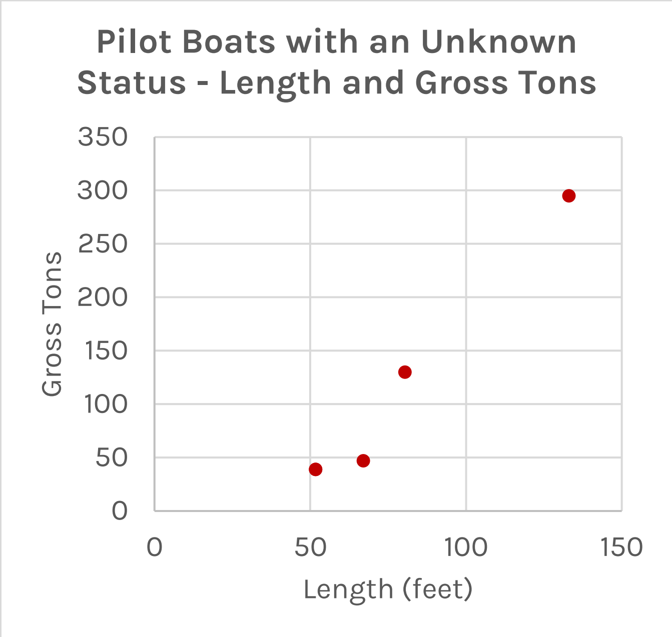
Source: Intelatus Global Partners

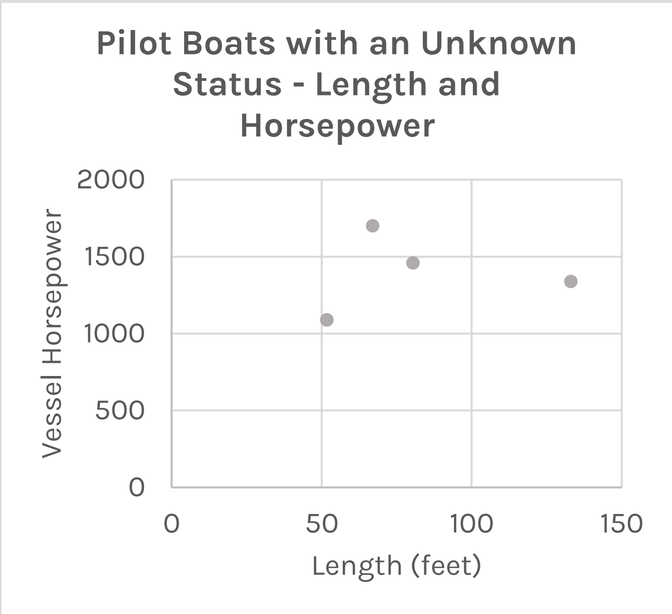
As with In Service vessels, there are not so many pilot vessels above 600 kW and as such the trend data for the correlation of length, breadth, gross tonnage and horsepower is somewhat limited.

Pilot boats continue the trend of other segments with an Unknown status in terms of lower average values compared to In Service vessels breadth (20 feet), gross tonnage (110 tons) and horsepower (1,336). Average length is the same (77 feet).

Exhibit 66 Pilot Boats with an Unknown Status by Length, Breadth, GT and Horsepower





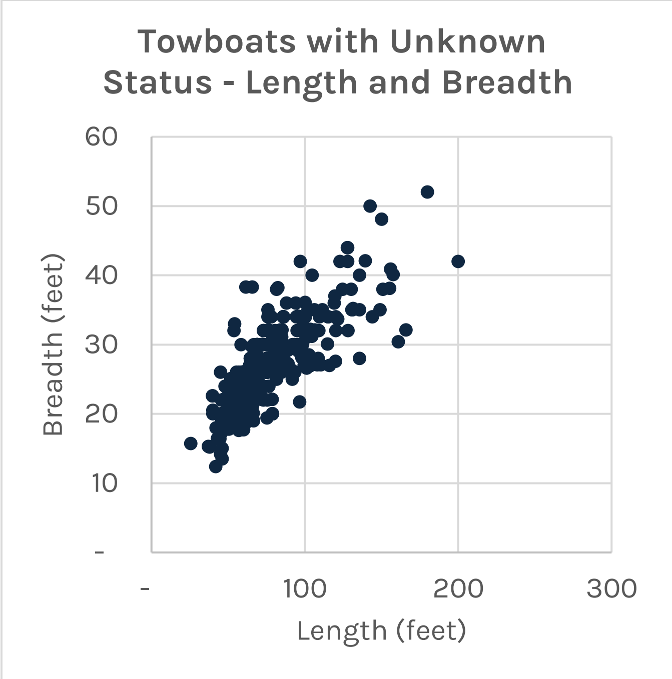


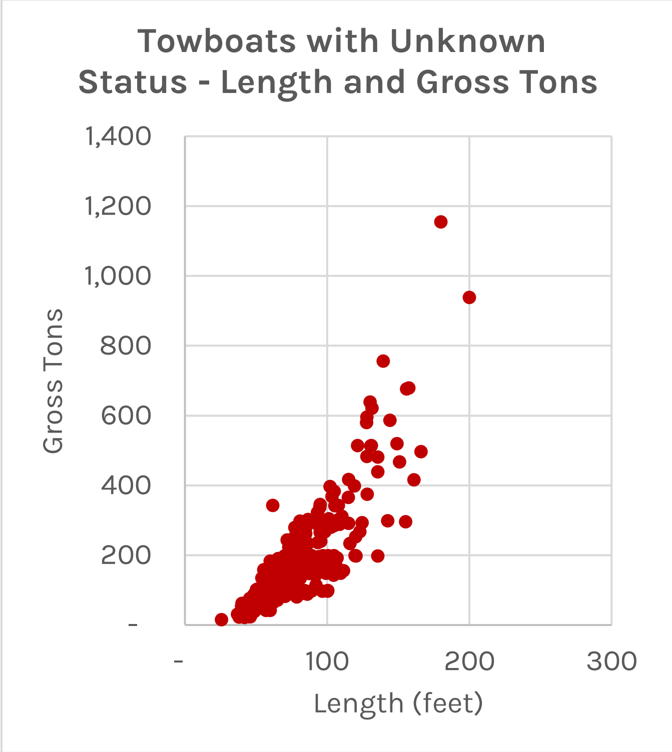
Source: Intelatus Global Partners

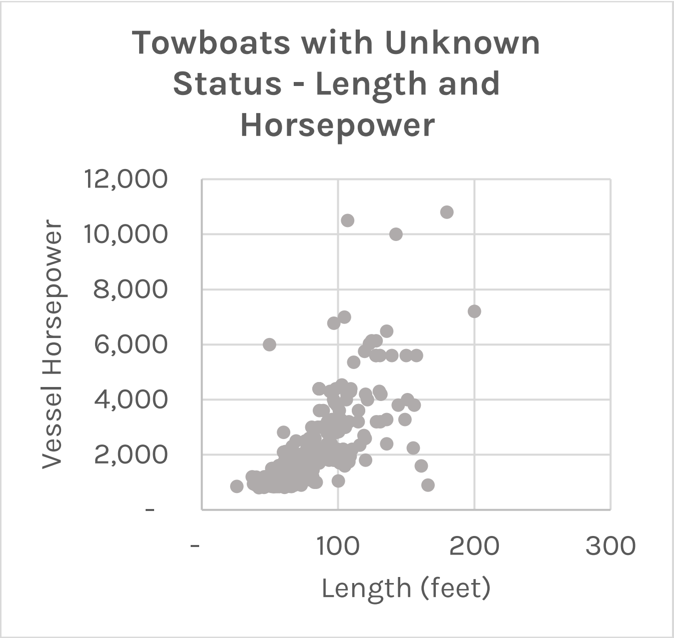
The towboat segment has a relatively close correlation of length, breadth and gross tons as seen in Exhibit 67.

As we have generally seen with all other categories of vessels where the operational status is Unknown, the average length (71 feet), breadth (26) gross tonnage (149 tons) and horsepower (1,751) are all lower than for In Service Towboats. Given that 83% of this segment is 25 years in age or older, it seems logical to conclude that the older and small vessels may be trending to longer term idle periods and even lay-up.

Exhibit 67 Towboats with an Unknown Operational Status by Length, Breadth, GT and Horsepower







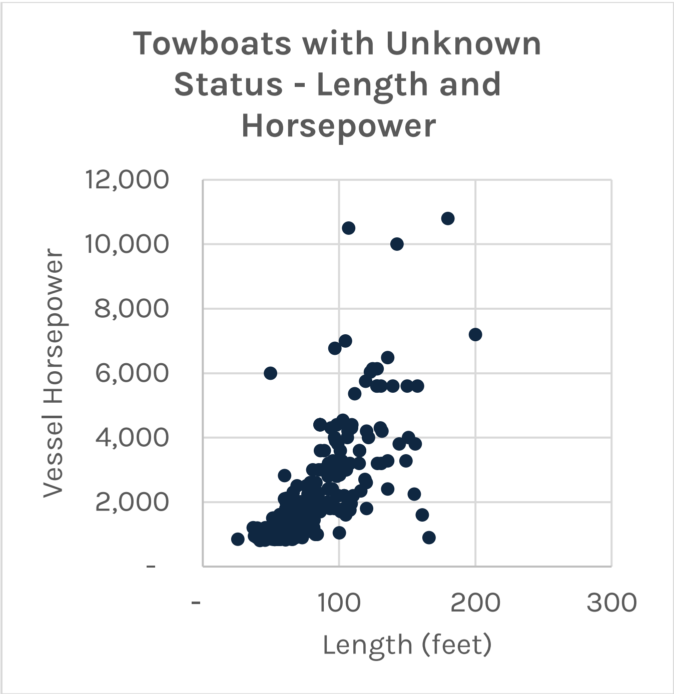
Source: Intelatus Global Partners

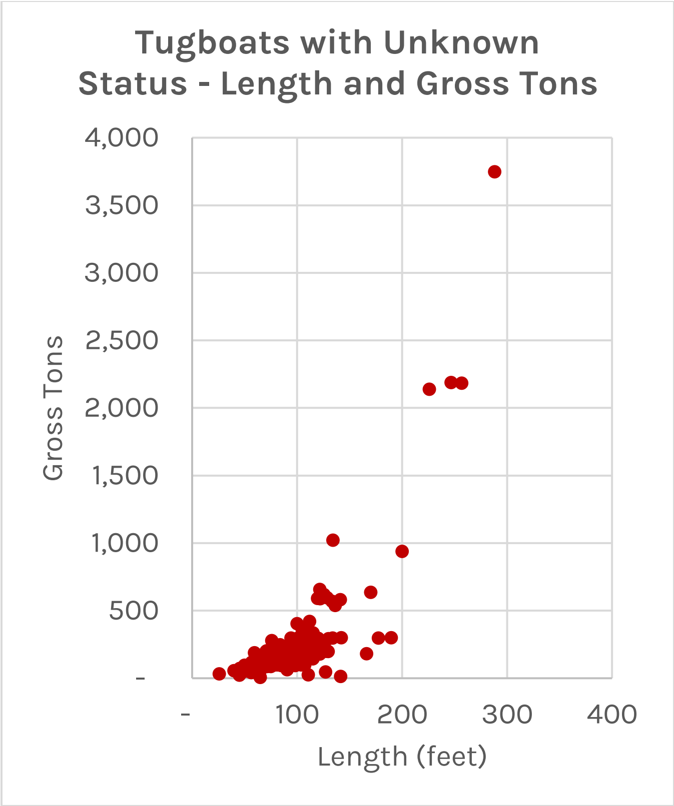
The analysis of the tugboats with an Unknown operational status closely mirrors that of the In Service vessels.

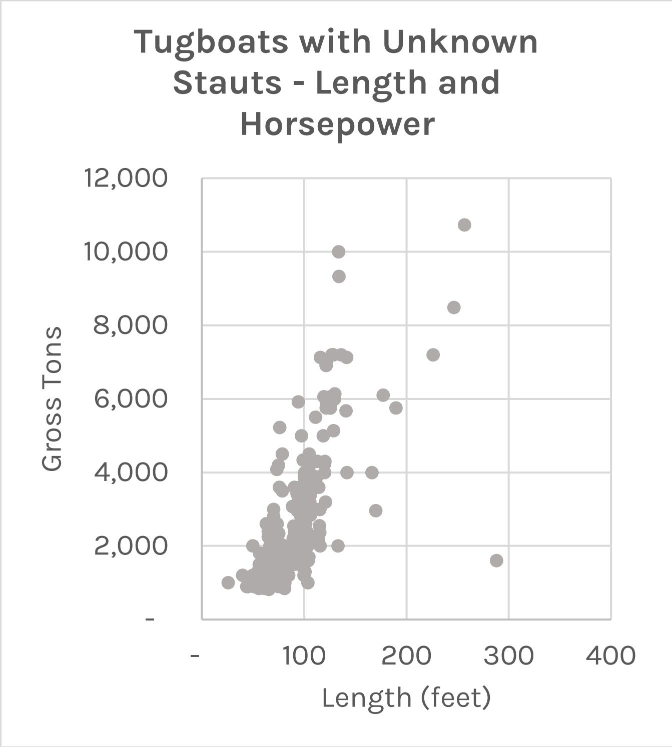
Looking at the tugboats with an Unknown operational status, we note that the average length of vessels in this category is the same (90 feet) than the average length of In Service tugboats.

All other average values are lower than the In Service Vessels. Average breadth is 28 feet, gross tonnage is 212 tons and horsepower 2,615.

Exhibit 68 Tugboats with an Unknown Operational Status by Length, Breadth, GT and Horsepower







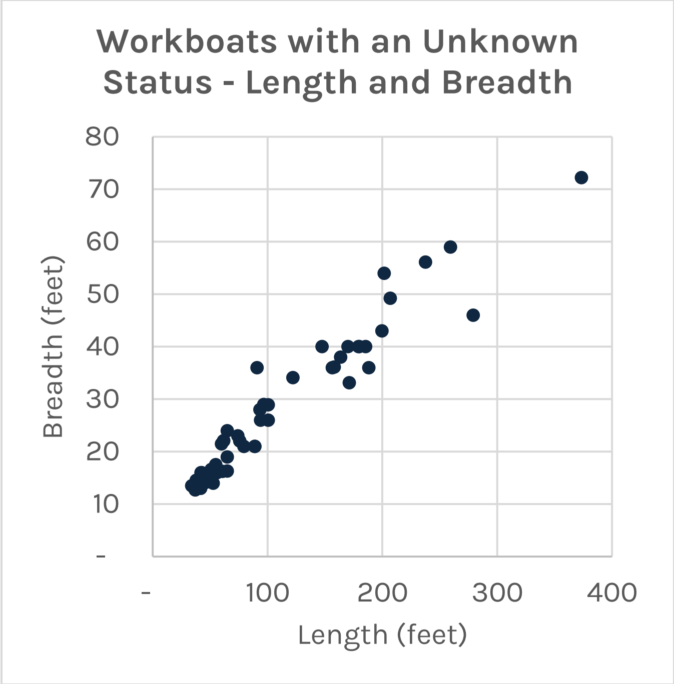
Source: Intelatus Global Partners

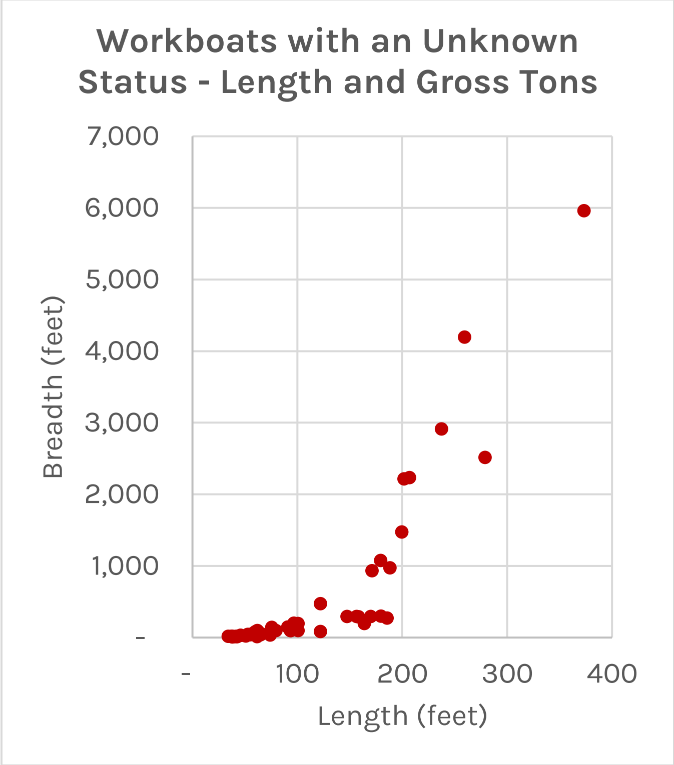
Exhibit 69 profiles the Workboats with an Unknown operational status.

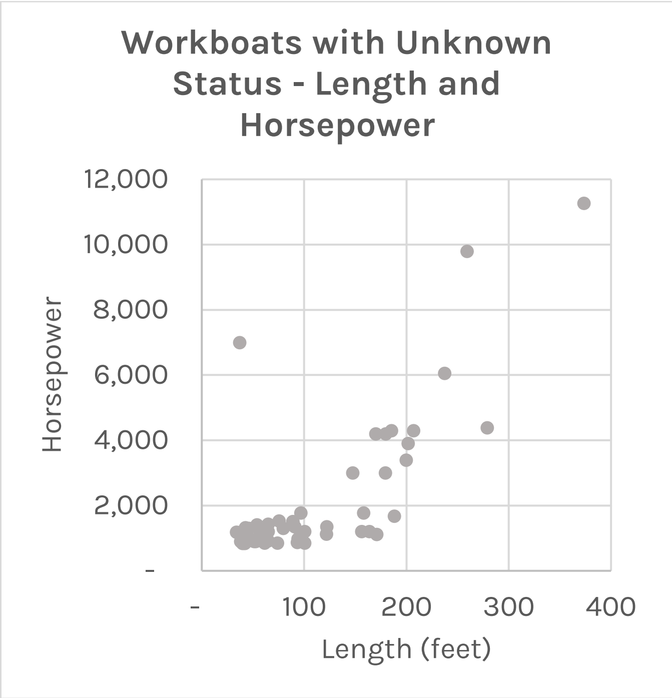
The average length (104 feet) and breadth (27 feet) of workboats with an Unknown operational status is 42% and 38% lower respectively than the values for the In Service vessels.

The average gross tonnage (566 tons) is 70% lower than the In Service workboats and horsepower 51% less.

Exhibit 69 Workboats with an Unknown Operational Status by Length, Breadth, GT and Horsepower



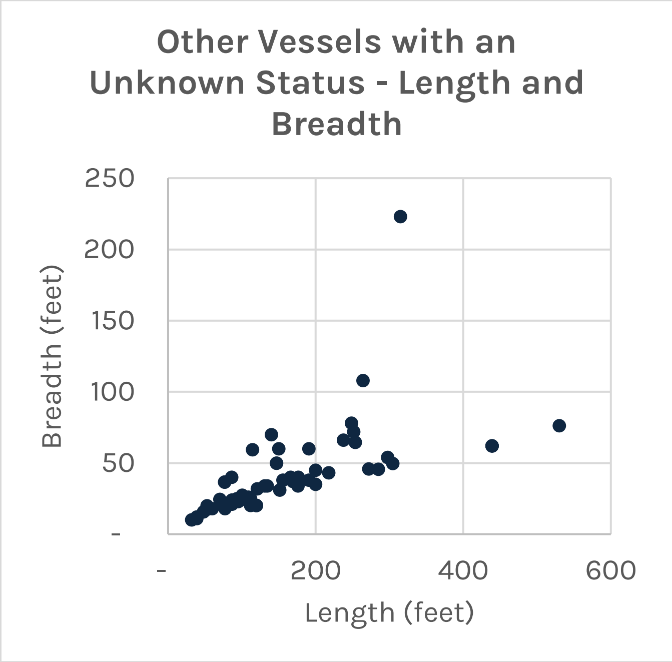


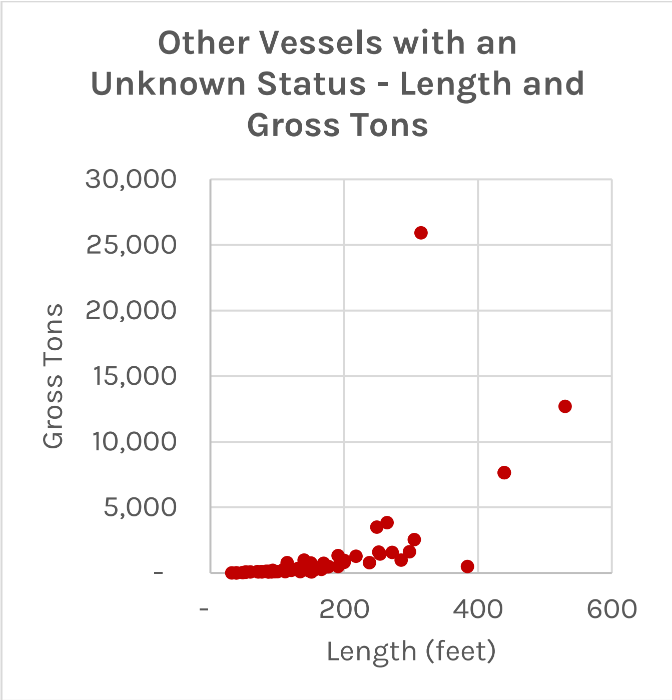


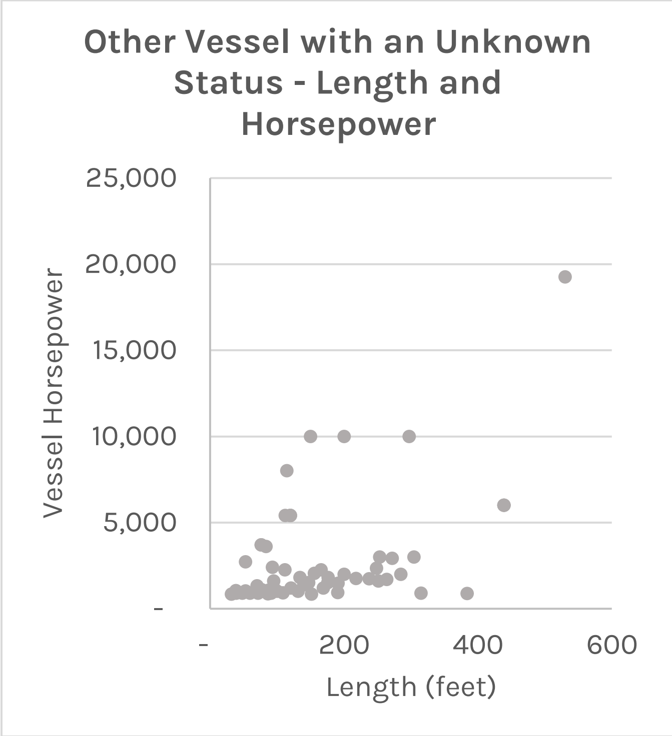
Source: Intelatus Global Partners

We finish our review of other vessels with an Unknown operational status by presenting the length analysis of Other vessels again breadth, gross tons and horsepower.

Exhibit 70 Other Vessels with an Unknown Operational Status by Length, Breadth, GT and Horsepower







Source: Intelatus Global Partners

Idle vessels

Given that there are only slightly over 200 Idle vessels, we have combined all eight categories of harbor craft into one graph for each correlation analysis in Exhibit 71.

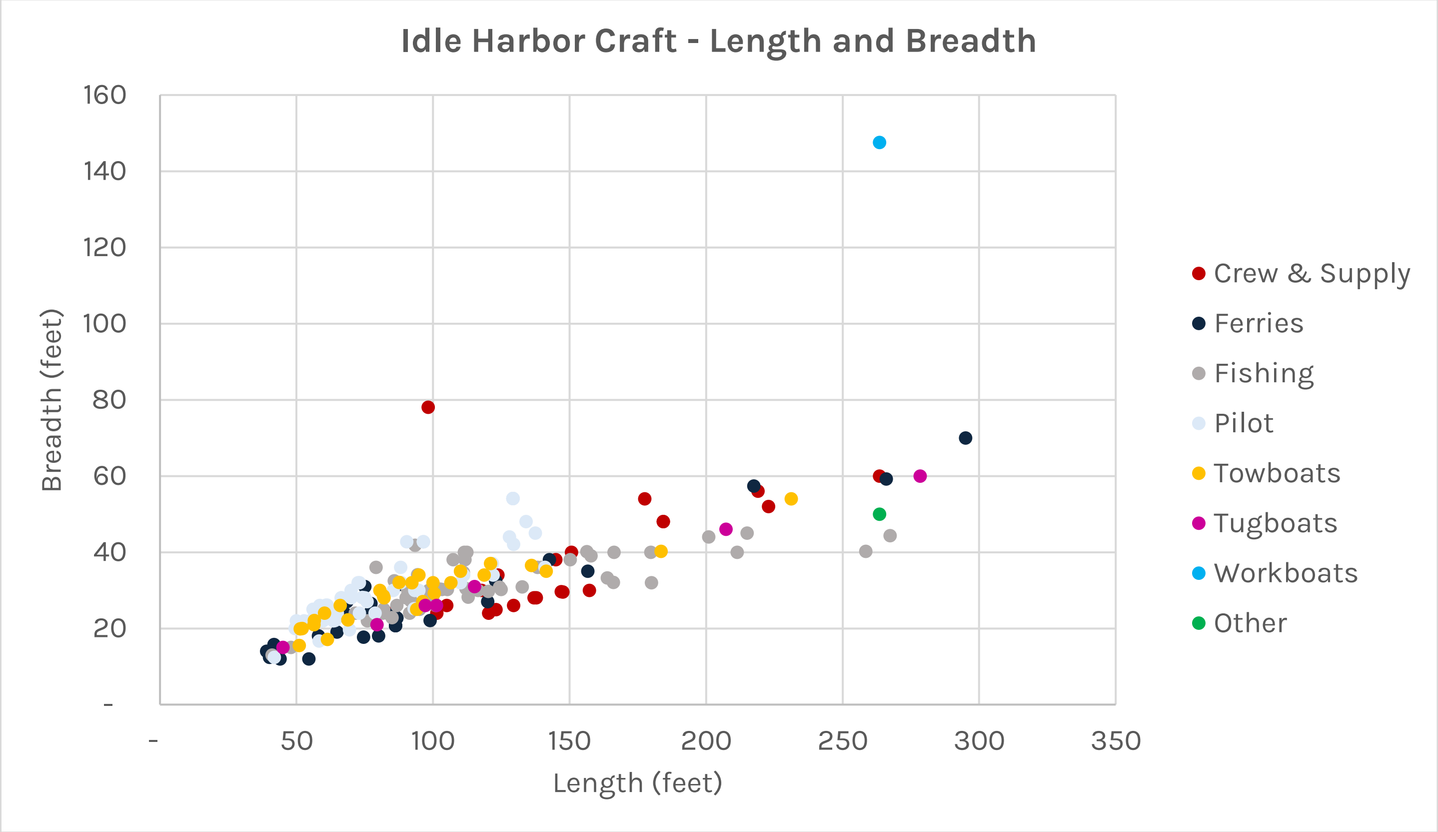
In Exhibit 71, we start with summarizing the average values for length, breadth, gross tonnage and horsepower for all the Idle vessel segments.

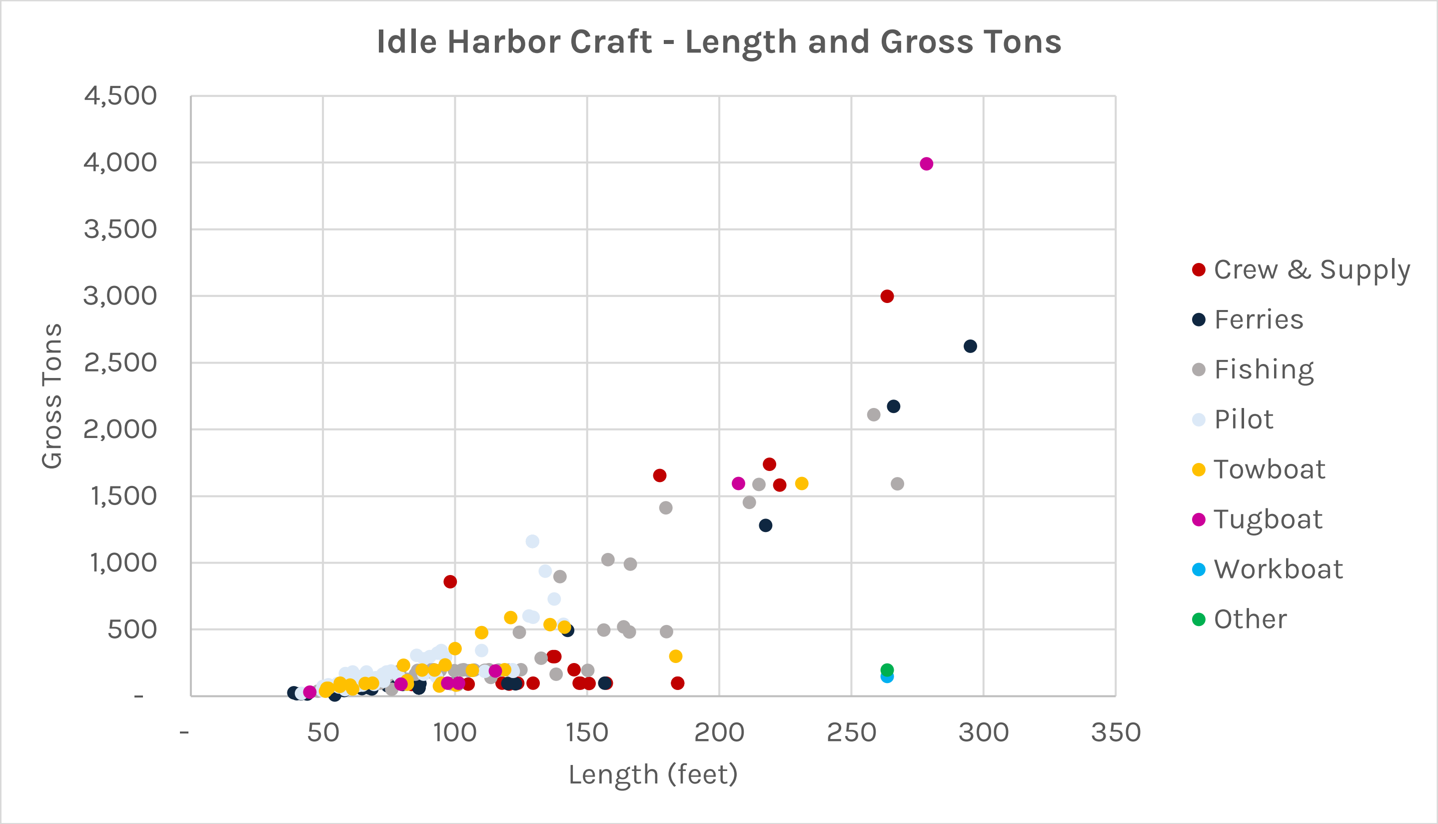
Again, it is only the tugboat segment of the Idle vessels where the category average length is slightly higher than for the In Service vessels.

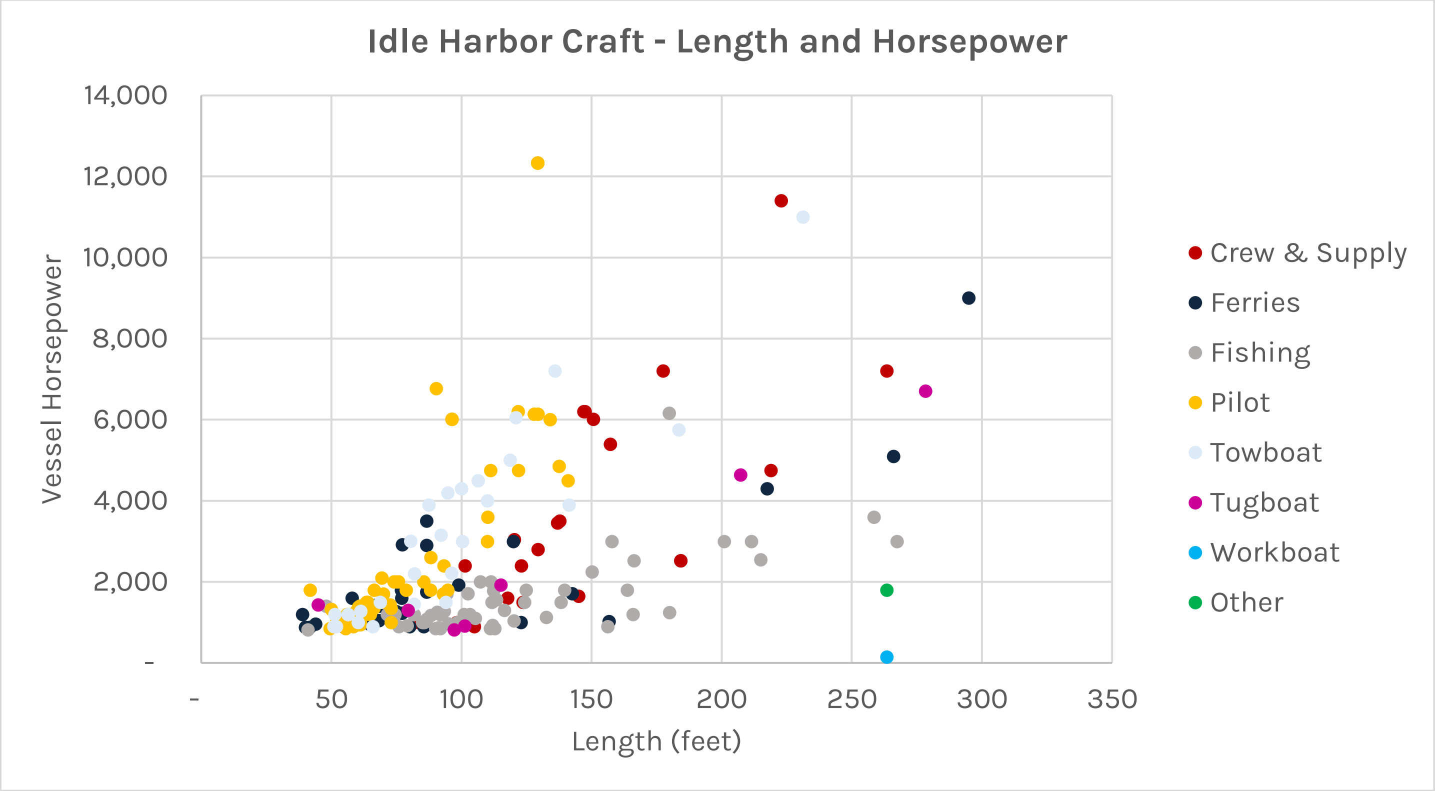
For all other parameters, the values for the In Service vessels are higher than for the Idle vessels.

Exhibit 71 Idle Vessels by Length, Breadth, GT and Horsepower

Partner	Average Length	Average Breadth	Average GT	Average Horsepower
Crew and supply	149	38	499	3,848
Ferry	97	26	266	1,917
Fishing	120	32	382	1,573
Towboat	82	30	271	3,070
Tugboat	96	29	250	3,200
Workboat	132	32	871	2,532
Other	148	50	196	1,800







Source: Intelatus Global Partners

Laid-up & Inactive Vessels

In terms of the harbor craft segment that is most suited for zero-emission solution, Laid-up and Inactive vessels do not represent the most obvious candidates as our understanding is that it is highly unlikely that these vessels will return to active service and their length characteristics are a driver to understanding the new building opportunity – we therefore provide only a simple length analysis of this category in Exhibit 72.

Exhibit 72 Laid-up and Inactive Harbor Craft by Length

Vessel Type	Average Length	Minimum Length	Maximum Length
Crew and supply	177	47	358
Ferry	103	31	434
Fishing	100	29	362
Towboat	82	37	355
Tugboat	97	39	262
Workboat	191	67	374
Other	340	113	573

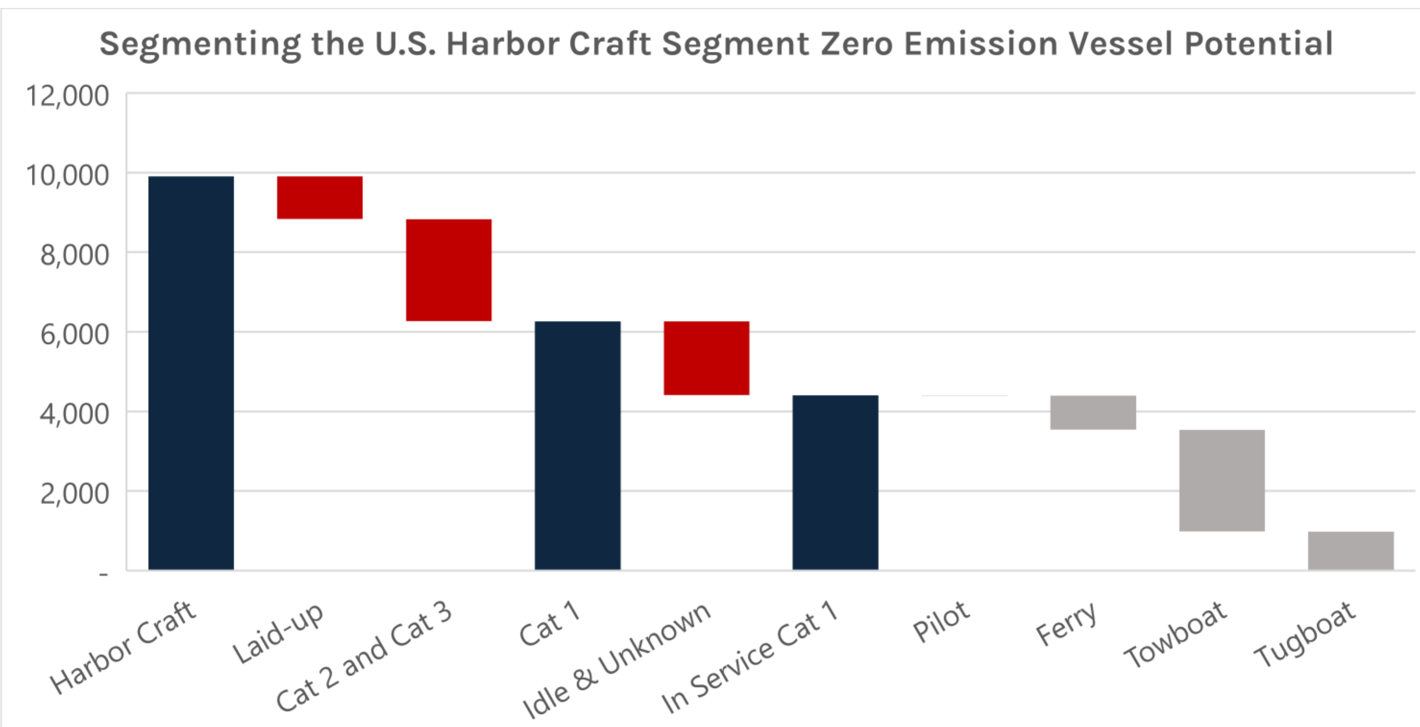
Source: Intelatus Global Partners

6.5. Summarizing the Zero-Emission Vessel Potential

We have grouped the U.S harbor craft by operational status (In Service, Idle, Unknown and Laid-up) and category reflecting suitability for zero-emission technology. This is a high-level subjective grouping and is subject to further technical review:

- Cat 1: the most suitable for zero-emission operations. This group of 4,405 vessels covers ferries, pilot boats, towboats and tugboats. These vessels are grouped as Cat 1 all operate in segments that are characterized by local operations to a fixed operation base or trade routes that can be readily supported by refueling infrastructure.
- Cat 2: medium suitability for zero-emission operations due to operational patterns or vessel architecture. This segment covers crew and supply vessels and workboats.
- Cat 3: Lower suitability for zero-emission operations and includes fishing vessels and other vessels, not categorized in the other seven core segments.

Exhibit 73 Segmenting the U.S. Harbor Craft Zero-Emission Vessel Potential



Source: Intelatus Global Partners interpretation of EPA information

Exhibit 73 identifies the 4,405 In Service ferries, pilot boats, towboats and tugboats with the highest attractiveness for zero-emission technologies such as HyZET.

The chart also presents the possibility for this group to be increased to over 6,250 vessels if Idle and Unknown vessels are also included.

Drilling down in to the 4,405 In Service Cat 1 vessels, we see that towboats account for around 58% of the vessels.

Exhibit 74 also allows us to understand that 56% of In Service Cat 1 vessels are 25 years of age or older. The 2,462 older vessels represent the lower hanging fruit in terms of suitability for replacement.

Exhibit 74 In Service CAT 1 Harbor Craft by Age Group

Age Group	Ferry	Pilot Boat	Towboat	Tugboat	Total
0-5	56	2	199	7	**264**
6-10	85		331	67	**483**
11-15	46	1	317	113	**477**
16-20	78		205	138	**421**
20-25	98	2	118	80	**298**
≥25	500	1	1,385	576	**2,462**
Total	863	6	2,555	981	**4,405**

Source: Intelatus Global Partners

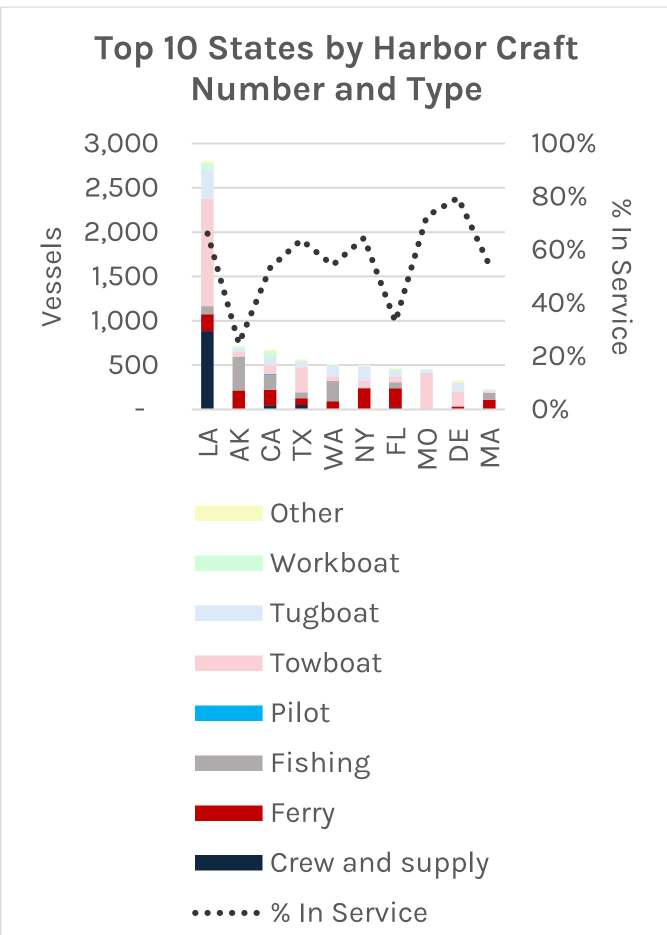
However, even though the In Service Cat 1 vessels are most suited to zero-emission operations, it is to be kept in mind that, other than hydrogen, there are several technical solutions available to achieve zero-emission operations. The options include fully electric vessels and vessels featuring other hydrogen carriers, such as methanol.

7. Segmentation of U.S. Data by Vessel State

As we discussed in Chapter 5, harbor craft serve both the coastal ports on the Atlantic, Gulf of Mexico and Pacific coasts as well as a large inland waterway system, the majority of which is deployed on the Mississippi River System. In addition to the ports and inland cargo transport, harbor craft are also present in states with fishing, oil & gas and passenger transport demand.

Exhibit 75 examines the top 10 states by total number of harbor craft (all operational statuses), which accounts for 73% of the total harbor craft population. The full list of 50 states where a harbor craft has a registered home port is shown in Appendix 4.

Exhibit 75 Top 10 States by Harbor Craft Number



Source: Intelatus Global Partners

California, the third largest state in terms of vessel home port is reviewed in depth in the next chapter.

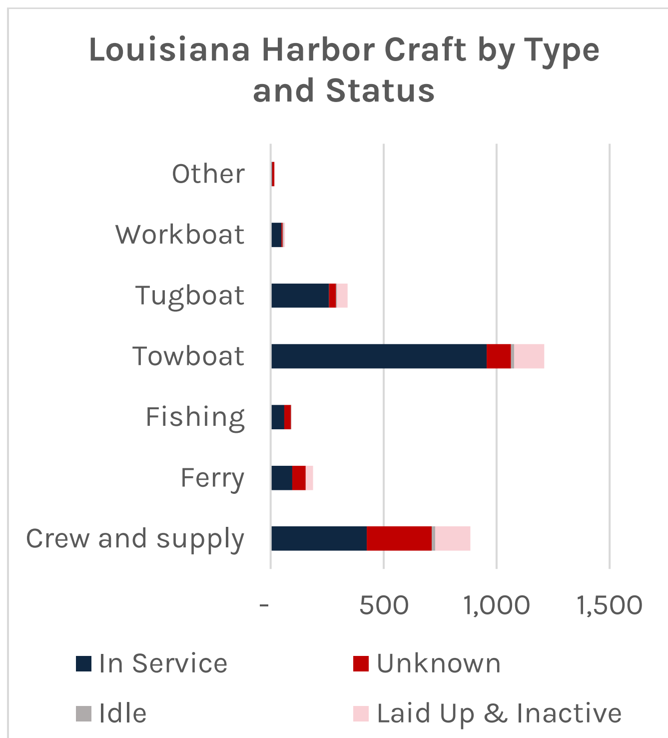
We profile the remaining Top 10 states below.

7.1. Louisiana

Exhibit 73 shows the importance of Louisiana, as 33% of all In Service harbor craft in the USA have a home port in Louisiana. In fact, the In Service harbor Craft with a home port in Louisiana account for 18% of the total U.S. harbor craft fleet.

Exhibit 76 confirms that Louisiana is an important state in the towboat segment, where Louisiana registered towboats account for a third of the U.S. registered towboats. With close to 80% of Louisiana registered towboats confirmed In Service, In Service towboats with a home port in the state account for 27% of the total U.S. towboat fleet (all statuses).

Exhibit 76 Louisiana Harbor Craft by Type and Status



Source: Intelatus Global Partners

A large proportion of Louisiana's crew and supply vessels are active in the oil & gas segment. The higher number of vessels with an Unknown status reflects those boats not needing an AIS Class A system, some deployed overseas and some that are in long-term lay-up.

Of note, according to the latest U.S. Energy Information Administration data, only 17% of Louisiana's electricity is produced from zero or very low emission sources (nuclear, hydroelectric and other renewables). However, there are several plans to produce blue and green fuels using wind and solar technology coupled with, in the case of blue fuels, carbon capture from on- and offshore sources. The state has yet to establish a Renewable Portfolio Standard to mandate a target for renewable energy generation, although the city of New Orleans has established its own standard.

Of note, the U.S. Economic Development Administration awarded the Greater New Orleans Development Foundation, a 25-partner organization, with $50 million in 2022 to "transition the regional hydrogen energy sector by closing the cost gap between green hydrogen, produced from renewable energy sources, and other forms of hydrogen used today, which rely on fossil fuels." The team plans to develop solutions to source offshore wind power, either from state or federal waters, to produce green hydrogen that supplies industrial users, including coastal and river vessels. The project also aims to develop a methanol refueling barge at the Port of South Louisiana through a public-private partnership which will supply methanol to towboats operating on the lower Mississippi River.

According to the governor of Louisiana, Arkansas, Louisiana and Oklahoma are seeking federal funding to develop a $1.25 billion clean hydrogen hub as part of a DOE administered process. The project is called Hydrogen, Arkansas, Louisiana and Oklahoma (HALO). HALO is competing with 32 other clean hydrogen hub proposals submitted to DOE.

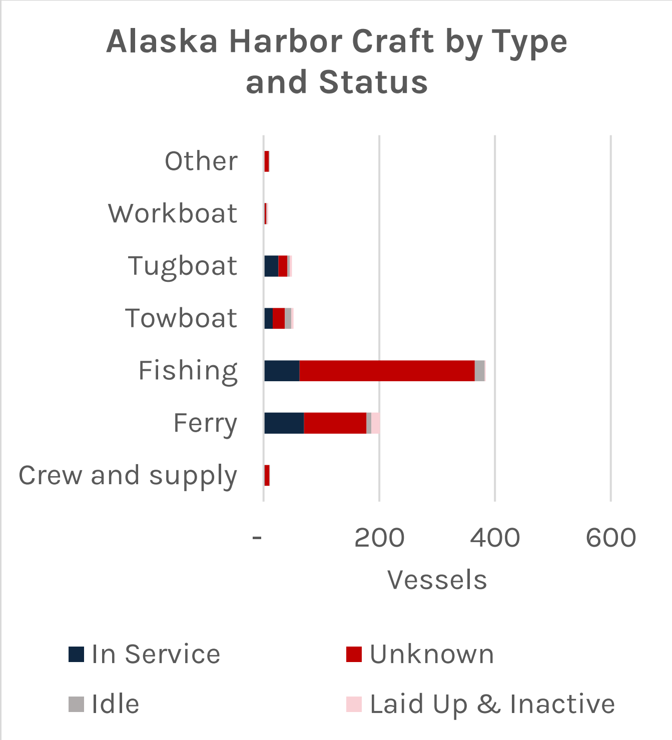
The HALO proposal envisages the production of both blue and green hydrogen for the use in petrochemical manufacturing and the production of transport fuels for both vehicles and vessels. We anticipate that, at least in the short- to mid-term, these fuels will be supplied to the international shipping segment, leaving limited locally produced zero-emission fuel supply for harbor craft. As such, zero-emission vessel harbor craft operations in Louisiana will require a significant amount of imported energy and/or a ramp-up of local clean hydrogen production capacity.

7.2. Alaska

Alaska registered harbor craft fleet is dominated by fishing vessels and ferries.

Alaska records a relatively low number for confirmed In Service vessels, which is not surprising, given the proportion of fishing vessels that are not required to feature an AIS Class A system, that facilities utilization analysis.

Exhibit 77 Alaska Harbor Craft by Type and Status



Source: Intelatus Global Partners

Further, only 35% of the states' 201 registered ferries and excursion vessels are confirmed In Service, which indicates that these vessels are generally also not equipped with AIS Type A systems.

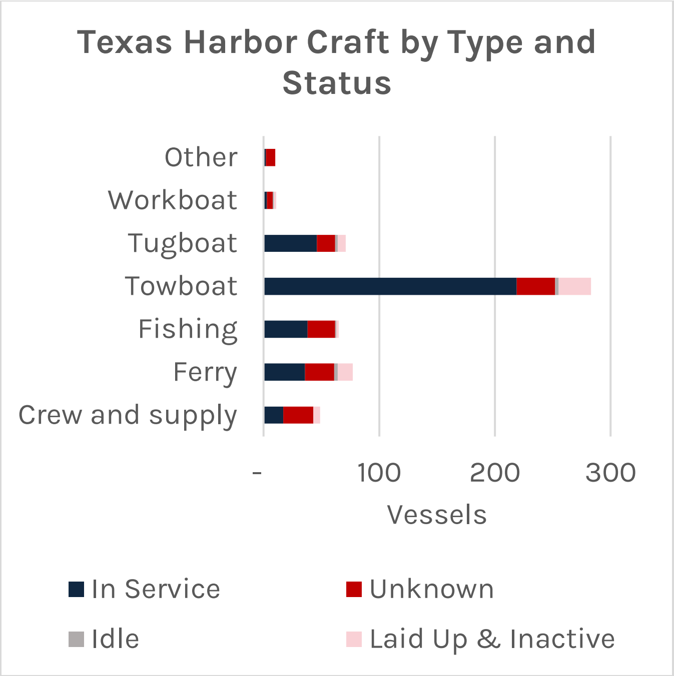
According to EIA data, around 21% of Alaska's electricity is produced from renewables. The governor has introduced a bill to establish a Renewable Portfolio Standard of 30% sustainable power by 2030 and 80% by 2040 – the bill has yet to become law.

Like many states, Alaska is seeking to secure a slice of the $7-8 billion DOE funding for clean hydrogen hubs. Alaska's project seeks to leverage carbon capture technology associated with the Alaska LNG project.

However, we see Alaska more as an exporter of blue hydrogen than a producer for its own internal demand, especially in terms of fueling fishing vessels. This results in a potentially limited short-to med-term opportunity for zero-emission vessel technology in the state.

7.3. Texas

Exhibit 78 Texas Harbor Craft by Type and Status



Source: Intelatus Global Partners

Like Louisiana and reflecting its importance in the internal transportation of petroleum products and chemicals, Texas is a leading state for registered towboats, ranked third in the USA, and like Louisiana records an In Service figure of over 75% of the category.

Towboats account for close to half of registered Texas harbor craft.

Around 44% of electricity in Texas is produced from zero-emission sources.

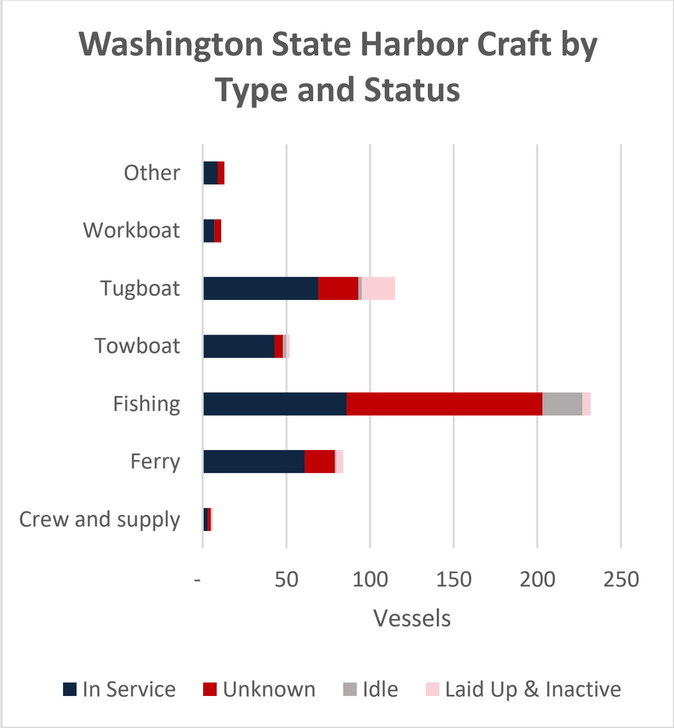
The Leading in Gulf Coast Hydrogen Transition ($LIGH_2T$) consortium is one of the 33 regional hydrogen hubs to submit final proposals to secure DOE funding in February of this year. It is understood that the hub mainly features blue hydrogen production.

If successful, $LIGH_2T$ could conceivably fuel low emission harbor craft. However, given that the fuel source will be blue hydrogen, we argue that this will be zero-emission on a well-to-wake basis.

7.4. Washington

Exhibit 78 shows that the fishing fleet is the largest harbor craft segment in terms of registered harbor craft in Washington State.

Exhibit 79 Washington State Harbor Craft by Type and Status



Source: Intelatus Global Partners

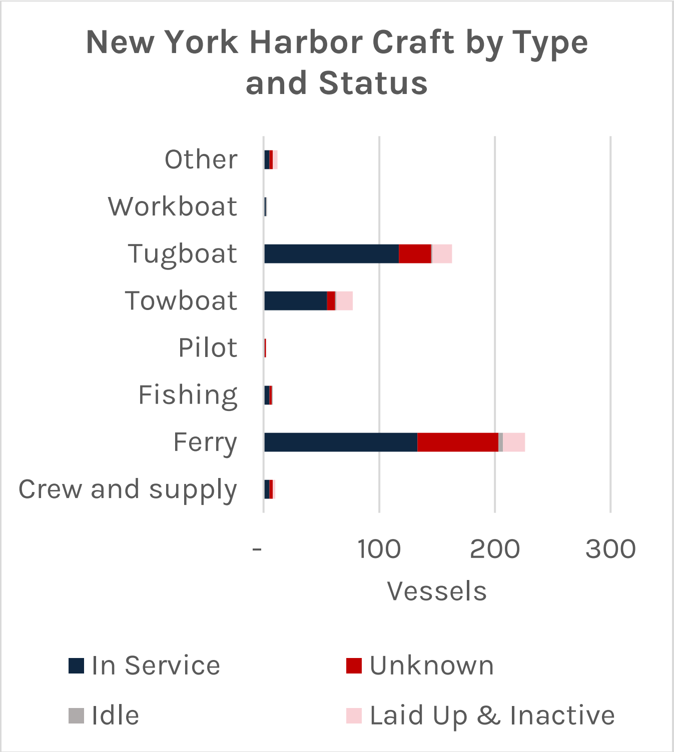
We are not surprised that only around 37% of the fishing vessel category is confirmed In Service, given that many fishing vessels do not carry AIS Type A systems.

According to the latest published figures from the U.S. Energy Information Administration, around 73% of Washington State's electricity production is classed as zero or very low carbon, with three sources dominating: hydroelectric, other renewables and nuclear. Through its Renewable Portfolio Standard, Washington targets 100% renewable power supplied from utilities by 2045.

Washington is participating the Pacific Northwest Hydrogen Association (PNWH2) along with the states of Orgon and Montana. PNWH2 aims to leverage renewable energy capacity to produce clean hydrogen.

7.5. New York

Exhibit 80 New York Harbor Craft by Type and Status



Source: Intelatus Global Partners

After fishing vessels, tugboats and ferries account for the next largest amounts of registered vessels in the state. We find this of interest, given that these two vessel segments are particularly suited to zero-emission operations, whether from electricity, hydrogen or other hydrogen carriers. New York

Given the population density close to water, it is not surprising to see that New York features 10% of the registered ferries in the U.S.

Further, given the large ports in the state, a large number of tugboats is to be expected.

New York's electricity production is around 56% from zero-emission nuclear, hydroelectric and other renewable resources, and the state seeks to boost its renewable capacity with large offshore wind farms that will come onstream in the second of this decade and during the next decade.

The state has a Renewable Portfolio Standard of 70% utility power by 2030 and 100% by 2040.

New York is one of seven states participating in the $3.62 billion Northeast Regional Clean Hydrogen Hub project that is seeking $1.25 billion of DOE funding. The other partner states are New Jersey, Maine, Rhode Island, Connecticut, Vermont and the Commonwealth of Massachusetts.

The project seeks to produce clean hydrogen for transportation, high temperature industries, district heating and hard-to-decarbonize sectors.

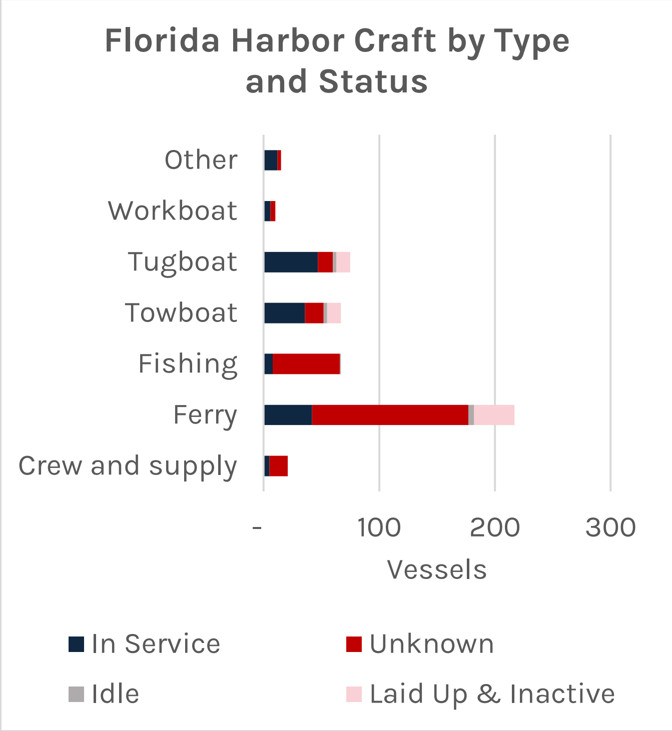
Given that the three largest harbor craft segments registered in New York are ferries, towboats and tugboats, we see New York as having significant opportunities for zero-emission harbor craft technologies.

7.6. Florida

Excursion vessels and ferries account for around 45% of Florida's registered harbor craft. Many of the vessels are not equipped with AIS Class A systems that will aid activity analysis.

Given that many of the vessels will be excursion vessels rather than ferries, we see these as lower probability candidates for short- to mid-term replacement with zero-emission vessels.

Exhibit 81 Florida Harbor Craft by Type and Status



Source: Intelatus Global Partners

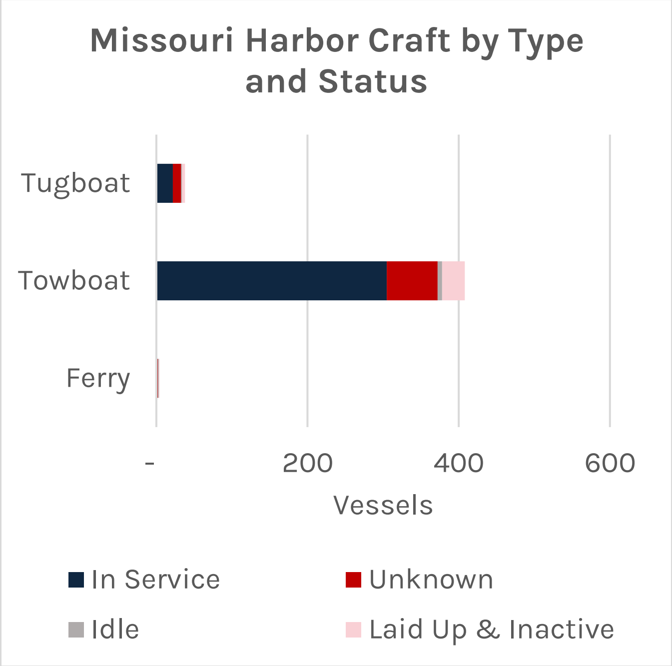
In 2020, Canaveral Pilots Association announced a plan to collaborate with Glosten and Ray Hunt Design to develop a demonstration project for the design, construction and operation of an electric pilot boat.

Only around 19% of Florida's electricity is currently produced from zero-emission sources. Further, it does not appear that Florida is participating in a regional clean hydrogen hub currently under review by DOE. As such, to support zero-emission harbor craft, the state will either need to ramp up local clean hydrogen production and/or import clean hydrogen from other states.

7.7. Missouri

Given its position in the Mississippi River System, it is not surprising to see Missouri in the Top 10 states for harbor craft registrations and that towboats account for over 90% of Missouri's registered harbor craft.

Exhibit 82 Missouri Harbor Craft by Type and Status



Source: Intelatus Global Partners

Missouri produces around 34% of its electricity from clean energy sources, but coal still accounts for 55% of electricity generation.

Missouri is a partner in the Mid-Continent Clean Hydrogen Hub (MCH2) along with Iowa and Nebraska. If successful, MCH2 could produce zero-emission fuel suitable for towboats and this makes Missouri a state of interest for zero-emission technology development.

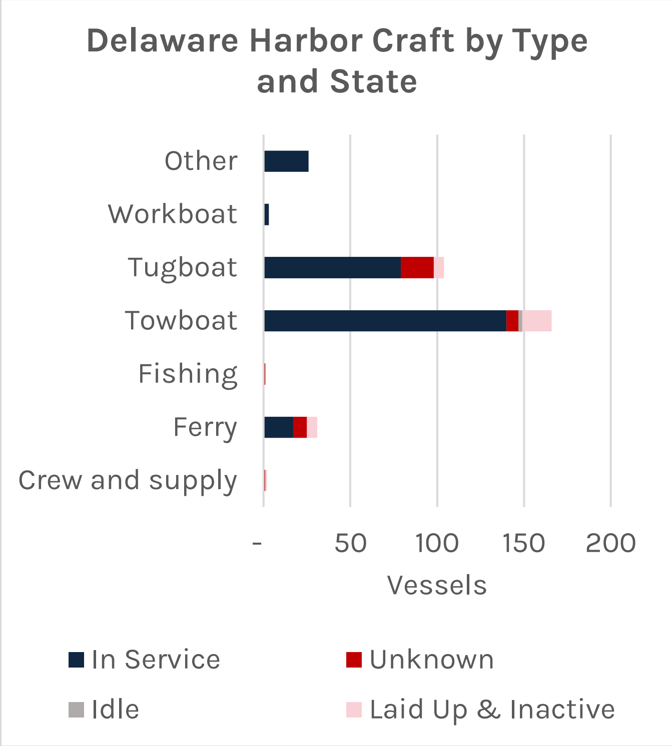
7.8. Delaware

Delaware's registered harbor craft has the highest overall proportion of In Service vessels in the USA at 80%.

81% of Delaware's 332 registered harbor craft are either towboats or tugboats and these have respective In Service status us 84% and 75%.

These segments are particularly well suited for zero-emission technologies.

Exhibit 83 Delaware Harbor Craft by Type and Status



Source: Intelatus Global Partners

Delaware's electricity production is currently predominantly fueled by natural gas, although the state has established a Renewable Portfolio Standard of 25% by 2026.

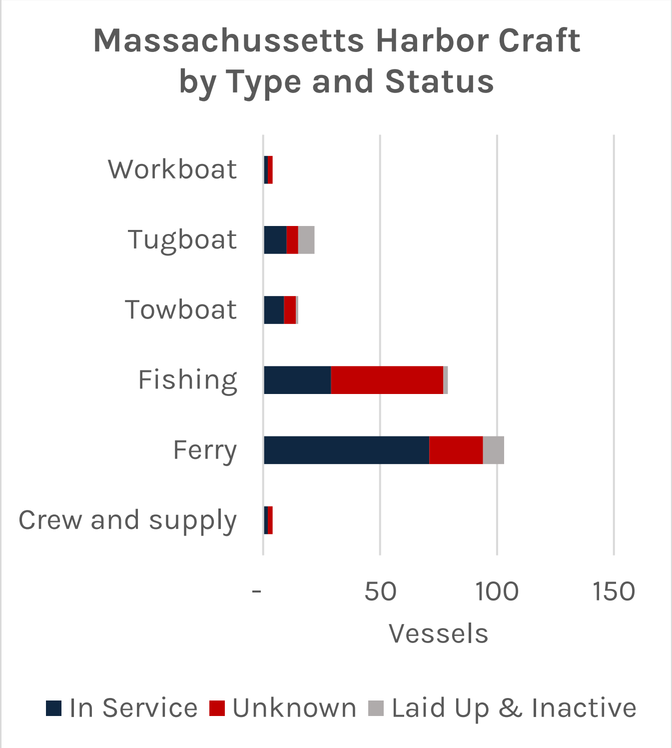
Delaware is participating in the Mid-Atlantic Clean Hydrogen Hub proposal currently under review by DOE. Partners in the proposal include Southeastern Pennsylvania and Southern New Jersey.

It appears that the hydrogen hub proposal aims to support manufacturing and transport infrastructure built around the I-95 corridor, suggesting there is limited opportunity for zero-emission harbor craft fuels.

7.9. Massachusetts

The Commonwealth of Massachusetts' harbor craft segment is dominated by ferries and fishing vessels, the former of which are generally more suited for zero-emission operations.

Exhibit 84 Massachusetts Harbor Craft by Type and Status



Source: Intelatus Global Partners

75% of electricity produced in Massachusetts is from natural gas.

Through its Renewable Portfolio Standard, Massachusetts is seeking to increase the quantity of renewables within its energy mix, where it hopes to bring offshore wind farm capacity on stream through the decade. The renewable targets for the Commonwealth are 40% by 2030 and 80% by 2050.

As we reported earlier in this chapter, Massachusetts is one of seven states participating in the $3.62 billion Northeast Regional Clean Hydrogen Hub project that is seeking $1.25 billion of DOE funding. The other partner states are New York, New Jersey, Maine, Rhode Island, Connecticut and Vermont.

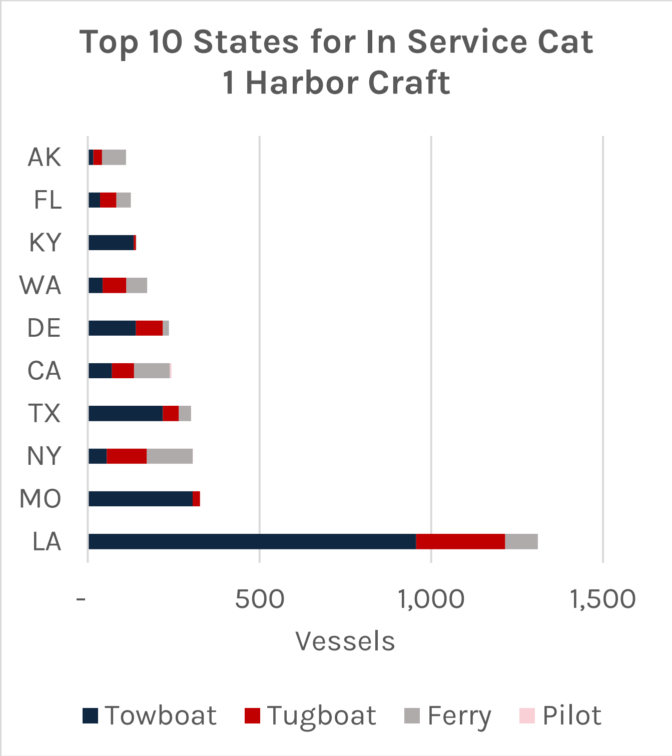
Although there is potential demand for zero-emission solutions for the 39 towboats and tugboats registered in Massachusetts, the real opportunity appears to be for the ferry segment.

7.10. The Top States for In Service Cat 1 Harbor Craft

Returning to the theme addressed in the last section of Chapter 6, there are 4,400 In Service harbor craft in the U.S. that are identified as most suited for zero-emission operations.

Three quarters of the 4,405 In Service harbor craft are active in ten states, nine of which are reviewed in this chapter and the next. The only state reviewed in this chapter that is not addressed in Exhibit 85 is Massachusetts, which has been replaced by Kentucky.

Exhibit 85 Harbor Craft by Type and Status



Source: Intelatus Global Partners

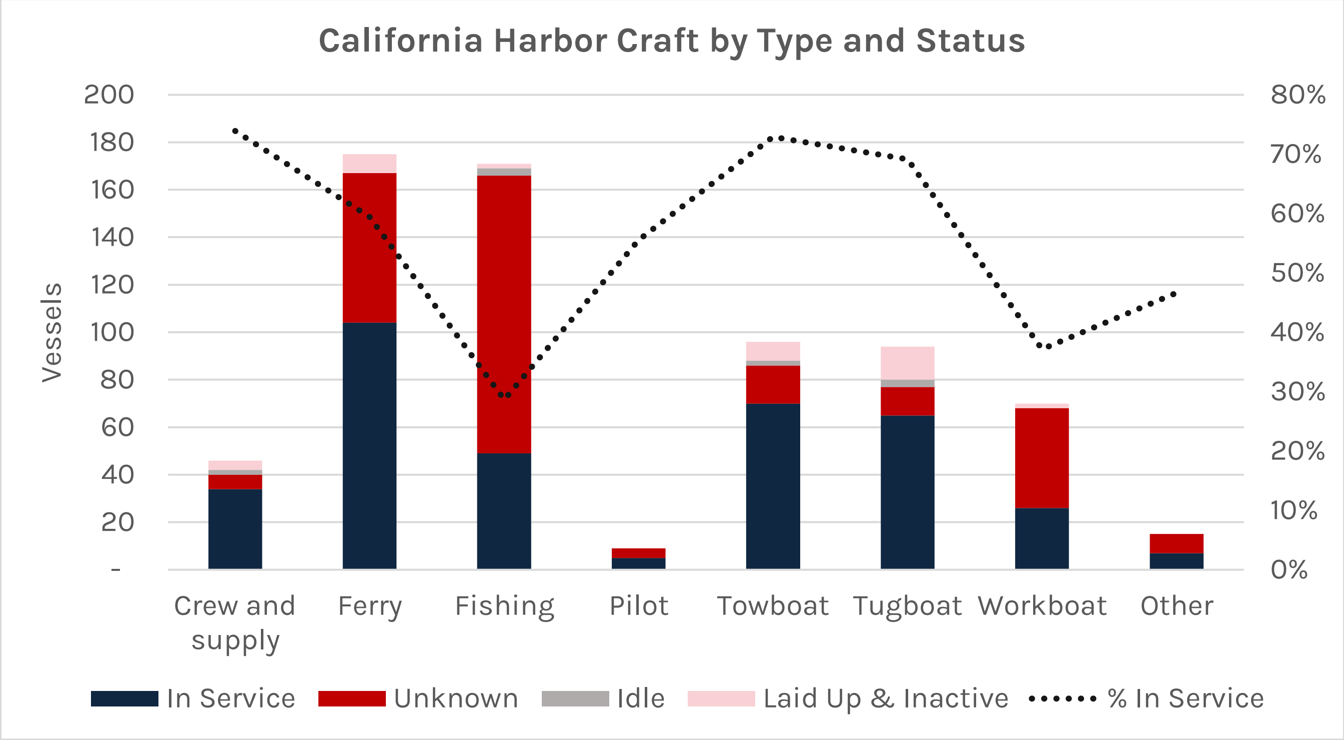
8. Segmentation of California Data by Vessel Type

In this section, we drill down to vessels that have a home port in California. As such, we do not address vessels registered in other states that trade in Californian waters and need to meet the reporting requirements of the state. However, our datasets have been supplemented by data from the Air Resources Board.

Whereas California does have comparatively small inland waterway and offshore oil & gas segments, the state is home to large international ports and large fishing and ferry/excursion segments.

Exhibit 86 presents an overview of the 676 vessels with a registered home port in California by type and status.

Exhibit 86 California Harbor Craft by Type and Status



Source: Intelatus Global Partners

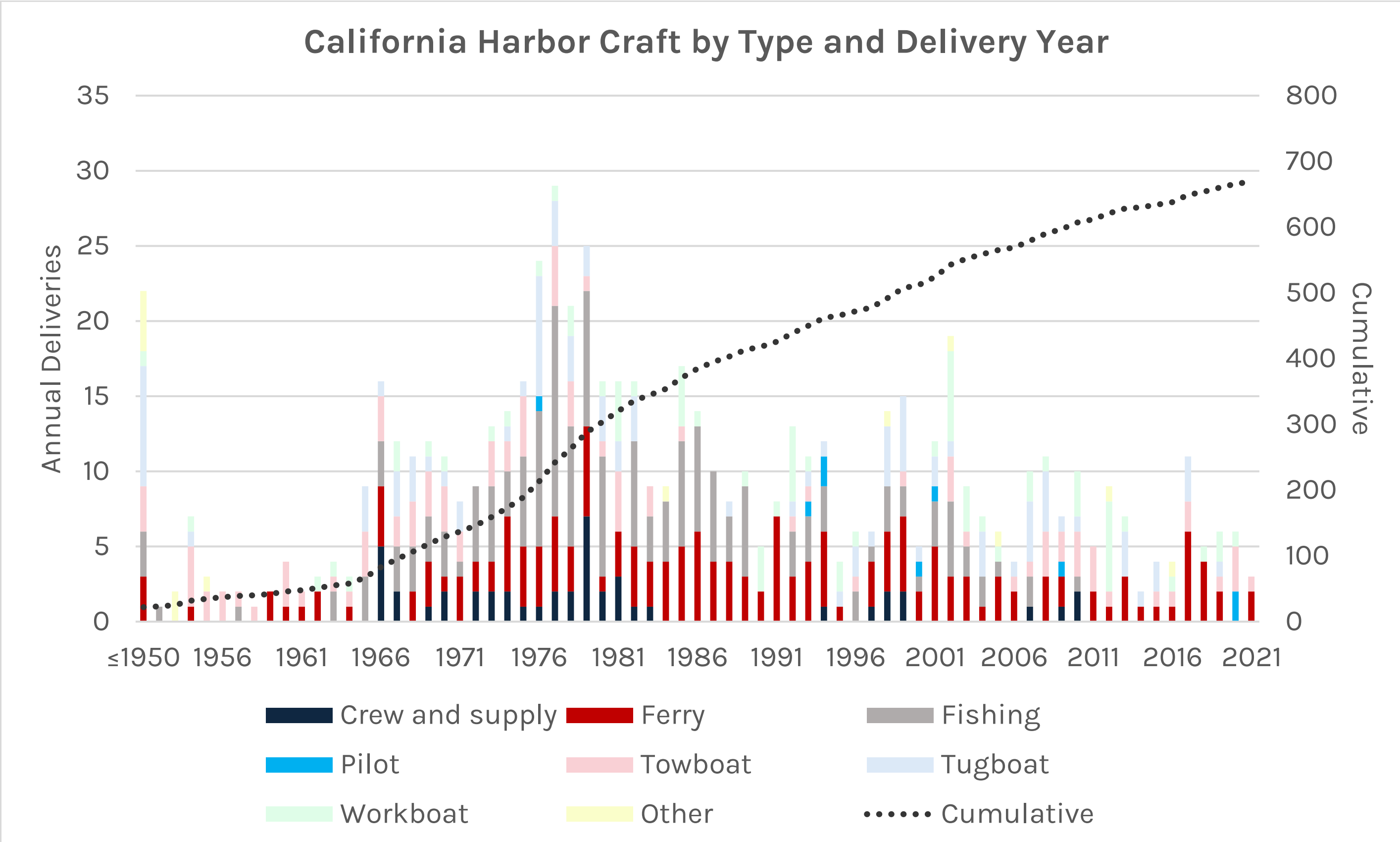
According to the latest EIA data, two thirds of net electricity generation in California is from renewable, hydroelectric and nuclear sources. Further, the state has a Renewable Portfolio Standards of 100% renewable power by 2045.

The Port of Long Beach and the Port of Los Angeles have submitted a joint proposal for federal funding to demonstrate the benefits of using hydrogen to power trucks and terminal equipment under the DOE's $7-8 billion regional clean hydrogen hub program.

One can only assume that if successful, expansion of the capabilities will only benefit the adoption of the HyZET concept and potentially support the transition to zero-emission operations of over 370 ferries, pilot boats, towboats and tugboats with a total power output of over 600 kW.

The average age of the California registered harbor craft fleet is 38 years old.

Exhibit 87 California Harbor Craft by Type and Status



Source: Intelatus Global Partners

We will now dive into each of the eight segments where vessels have a registered home port in California.

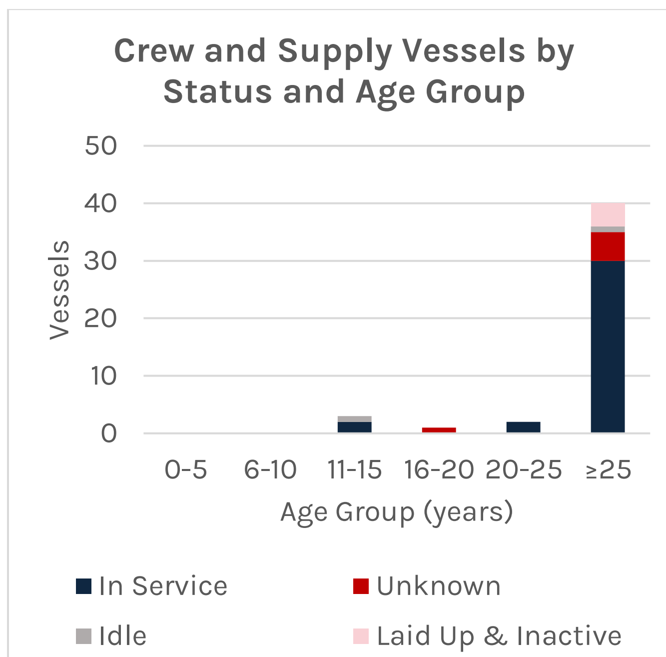
8.1. Crew and Supply Vessels

California's Commercial Harbor Craft Regulation amendments drive the potential eventual upgrade or replacement of a high proportion of the 46 crew and supply vessels with a home port in California. However, commercial drivers and technical challenges associated with the smaller vessels in the segment are likely to present a barrier to vessel upgrades in the near term.

The crew and supply segment of California registered vessels numbers 46 vessels, of which 87% are 25 years or older.

74% of the segment is confirmed as In Service and a further 13% have an Unknown operational status.

Exhibit 88 Crew and Supply Vessels by Age Group and Status

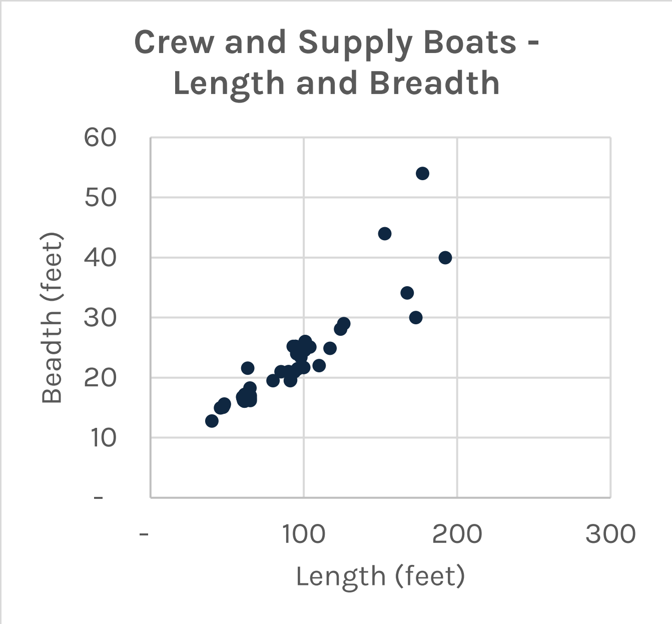


Source: Intelatus Global Partners

72% of California's registered crew and supply vessels are 65 feet or more in length, indicating a requirement to be equipped with an AIS Class A device that allows activity to be monitored. This infers that the vessels with an Unknown operational status are either trading outside of AIS range or are laid-up in place.

The crew and supply segment is concentrated below 150 feet in length, and the average length for the category is 91 feet. It should be noted that our analysis excludes one vessel from our database, picked up from CALSTART data, which we understand may have been moved from California to a demolition yard after the cut-off off date for data collection.

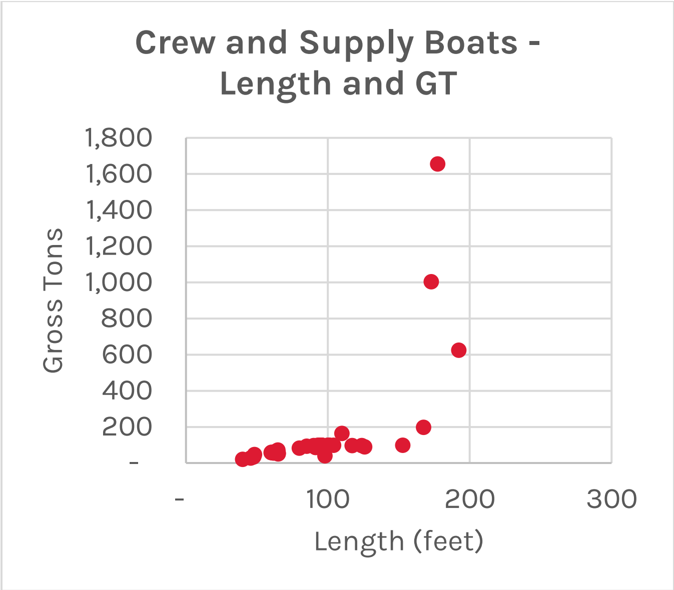
Exhibit 89 Crew and Supply Vessels by Length and Breadth



Source: Intelatus Global Partners

Vessels in this segment are generally small when measured by gross tons, with a category average of 274 tons.

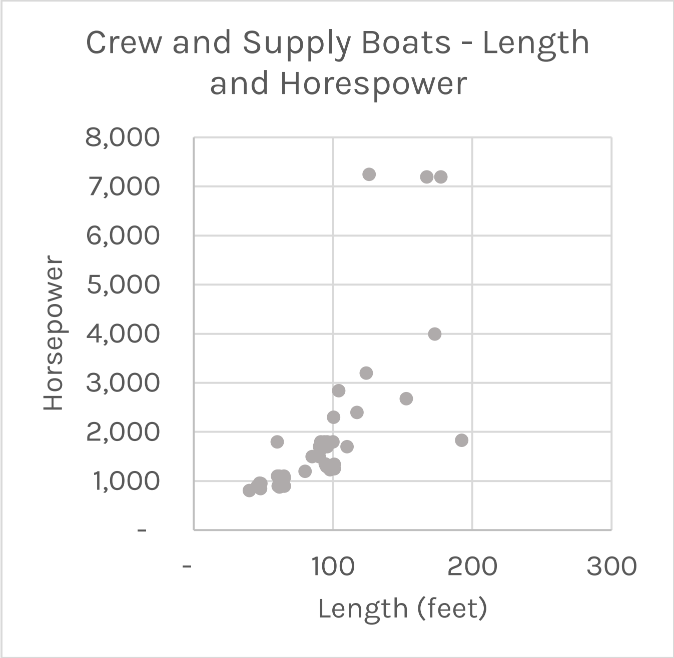
Exhibit 90 Crew and Supply Vessels by Length and GT



Source: Intelatus Global Partners

The average horsepower of vessels in the segment is slightly above 1,900.

Exhibit 91 Crew and Supply Vessels by Length and Horsepower

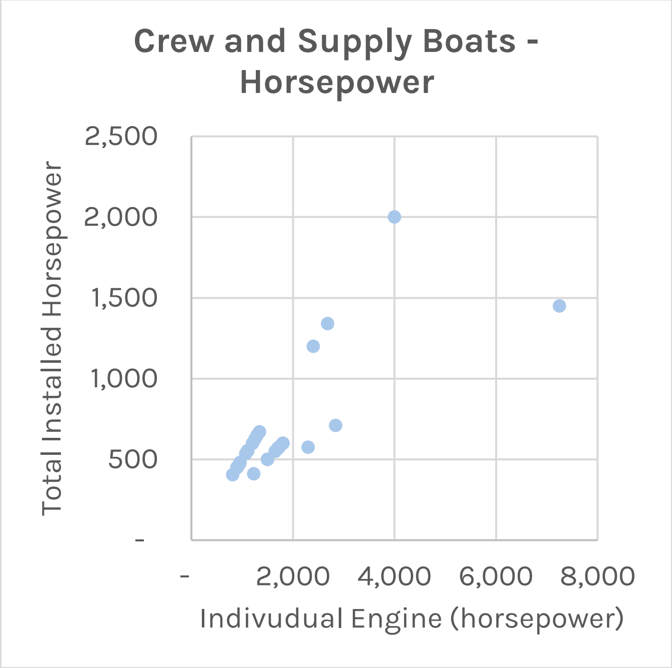


Source: Intelatus Global Partners

As we discussed earlier in this report, federal Tier 4 emission regulations for Category 1 vessels apply to new engines with a power output of 600 kW or 800 hp and above.

We have individual engine output for 51 out of the 66 crew and supply vessels in this segment. The average vessel has an average engine size of 769 horsepower. 40 (78%) of the identified vessels have individual engines of 800 horsepower or generally below federal Tier 4 requirements.

Exhibit 92 Crew and Supply Vessels by Horsepower



Source: Intelatus Global Partners

However, California's Commercial Harbor Craft Regulation amendments promote zero-emission options where feasible and Tier 3 (mainly limited to the commercial fishing and new excursion vessels) and Tier 4 engines with diesel particulate filters on all other vessels.

As a result, there is opportunity for existing older vessels to be eventually replaced by lower or zero-emission replacements.

8.2. Ferry and excursion vessels

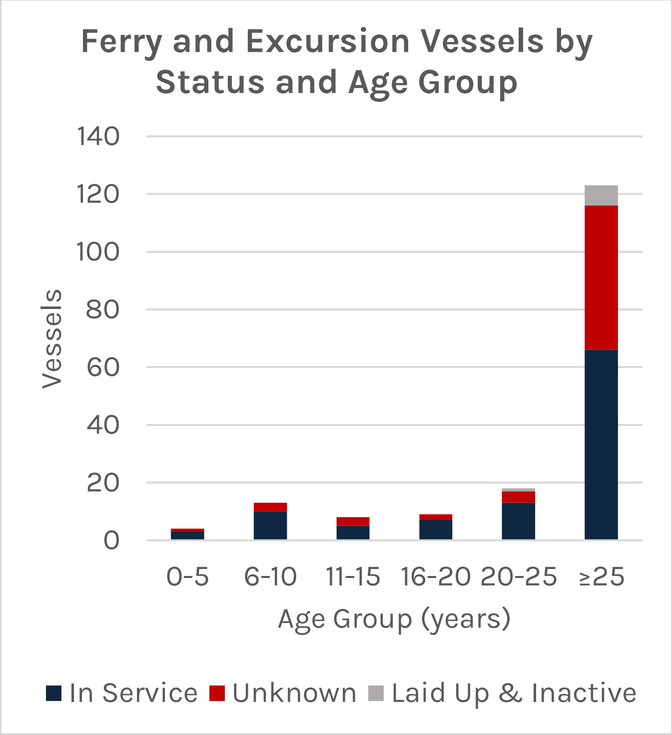
Under California's revised harbor craft regulations, short run ferries and new excursion vessels (such as those used for whale watching and dinner cruises) have specific emission compliance requirements:

- Short run ferries, including those with a single voyage of less than three nautical miles will be required to be fully-zero-emission by the end of 2025.
- New excursion vessels are required to be able to operate with a minimum of 30% zero-emission power source.

Like the crew and supply segment, the 175 ferry and excursion vessel segment features a high proportion (70%) of vessels of 25 years and older.

Close to 60% of the vessels in this category are confirmed In Service, and a further 36% have an Unknown Status. Given than the USCG allows vessels to be equipped with AIS Class B systems if they are carrying less than 150 passengers and operating below 14 knots, the high proportion of vessels with an Unknown operational status may be active but simply do not need to feature a system that allows for activity analysis.

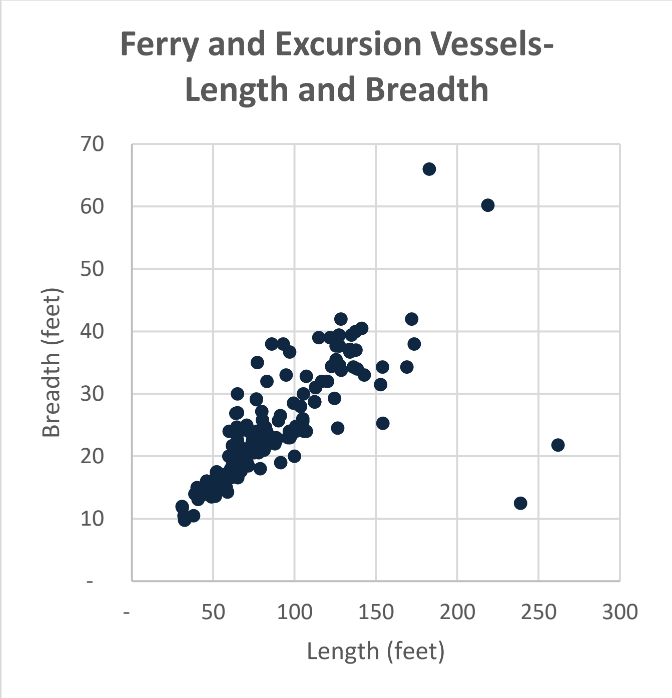
Exhibit 93 California Harbor Craft by Age Group and Status



Source: Intelatus Global Partners

The average length of ferries and excursion vessels is around 89 feet.

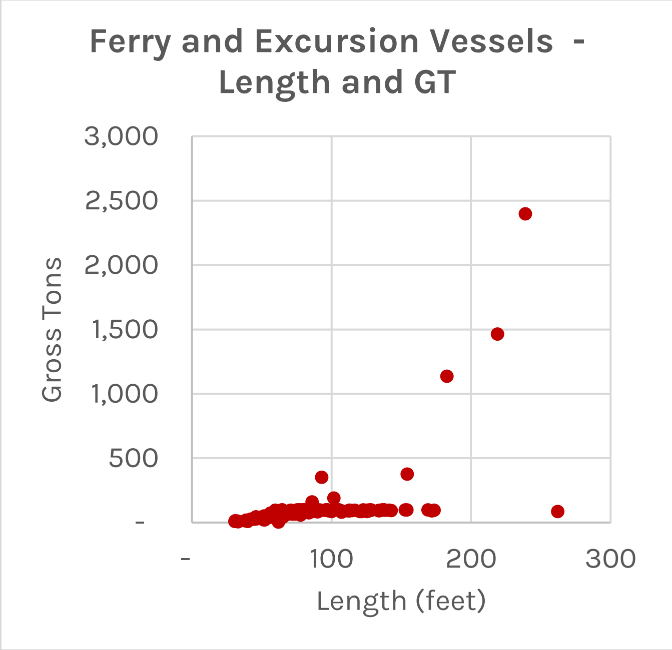
Exhibit 94 Ferry and Excursion Vessels by Length and Breadth



Source: Intelatus Global Partners

Vessels in this category average 106 gross tons.

Exhibit 95 Ferry and Excursion Vessels by Length and GT

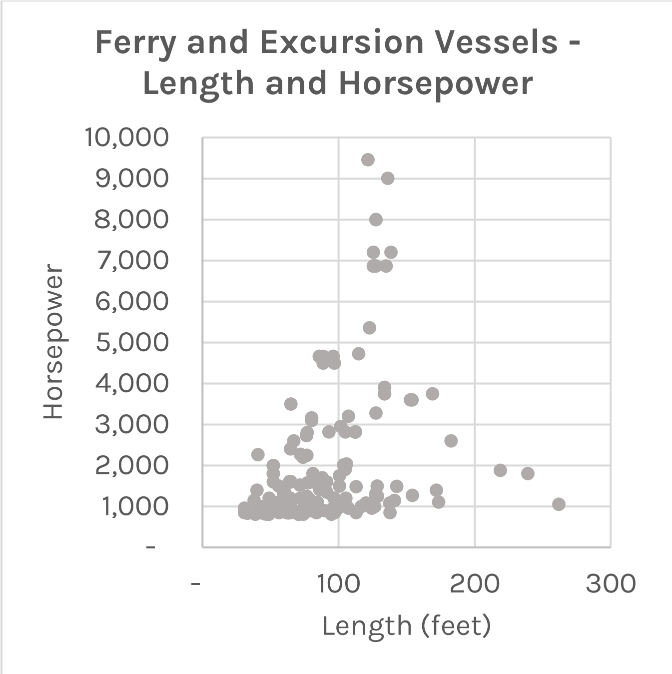


Source: Intelatus Global Partners

168 out of 175 crew and supply boats are 100 gross tons or less. There are seven larger boats, including dinner cruise vessels, included in this category.

The average vessel has an average engine size of 2,030 horsepower.

Exhibit 96 Ferry and Excursion Vessels by Length and Horsepower

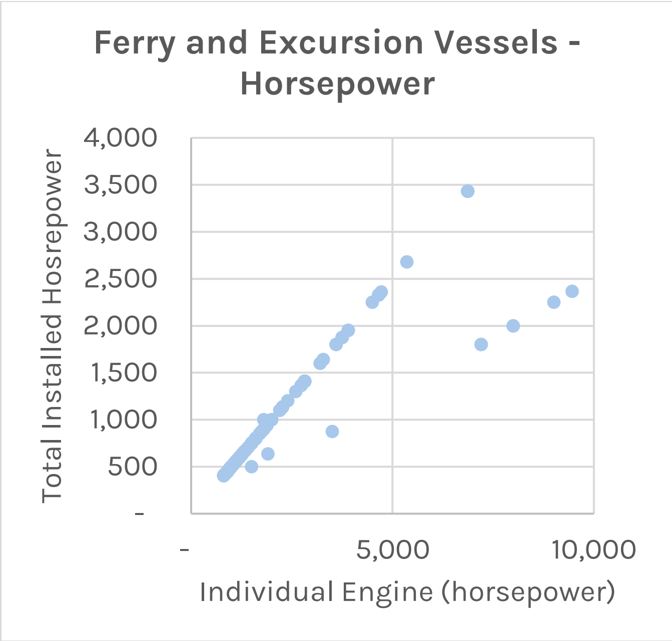


Source: Intelatus Global Partners

We have individual engine output for 118 out of the 175 ferry and excursion vessels in this segment. 67 (57%) of the identified vessels have individual engines of 800 and below horsepower and generally fall below federal Tier 4 requirements.

Despite this, and based on amended CARB regulations, this segment presents an opportunity for zero-emission technologies.

Exhibit 97 Ferry and Excursion Vessels by Horsepower



Source: Intelatus Global Partners

8.3. Fishing vessels

There are 171 registered fishing vessels in California of 600 kW and above.

89% of these vessels are 25 years or older.

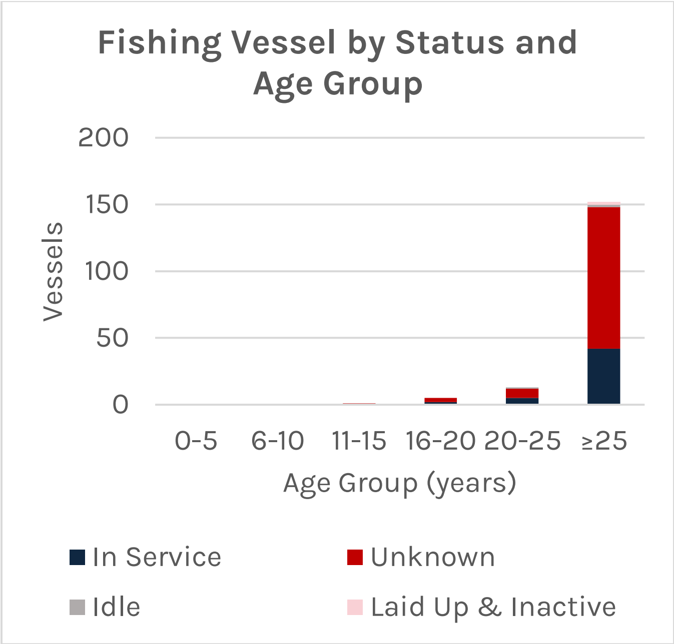
The U.S. Coast Guard allows all commercial fishing vessels to operate with a Class B system and therefore these vessels are less easy to track include. That said, 29% of the registered fishing vessels produce AIS signals that allow us to confirm their status as In Service.

It is anticipated that many of the 117 vessels with an Unknown operational status do not feature an AIS Class A system that facilitated tracking.

The operational patterns of commercial fishing vessels often make these less suited to zero-emission operations.

CARB also recognizes some of the compliance challenges for the fishing sector with the revised harbor craft regulations and, if vessels are equipped with a Tier 3 engine by the end of 2024, may grant a one-time ten-year extension option for compliance to 2035.

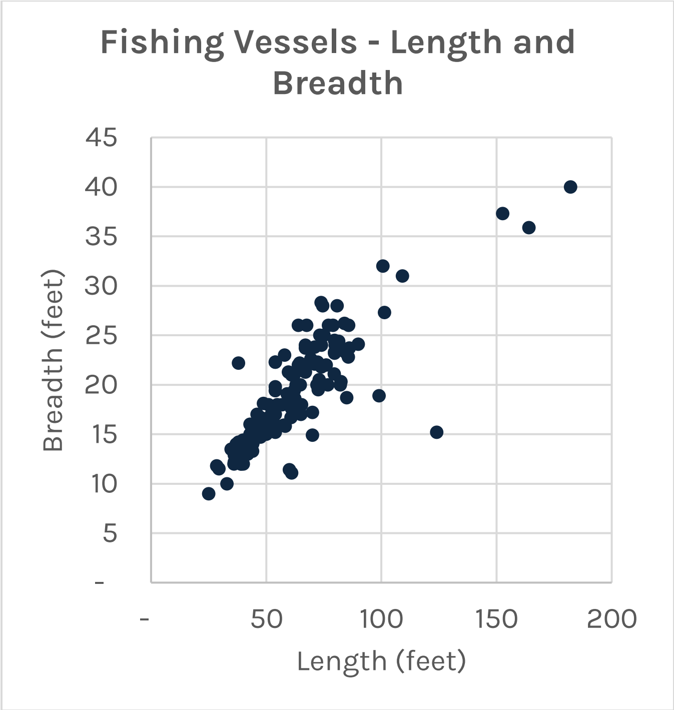
Exhibit 98 Fishing Vessels by Age Group and Status



Source: Intelatus Global Partners

The average length of fishing vessels registered in California is relatively short at 59 feet.

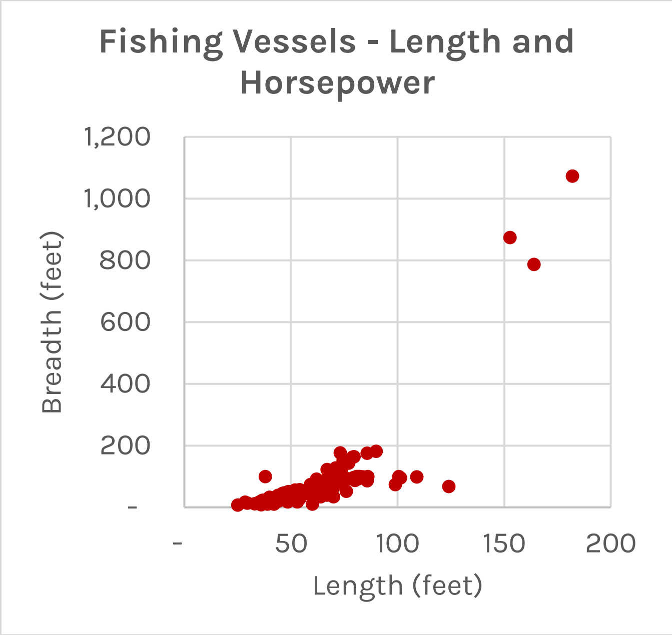
Exhibit 99 Fishing Vessels by Length and Breadth



Source: Intelatus Global Partners

The fleet average gross tonnage is 72 gross tons.

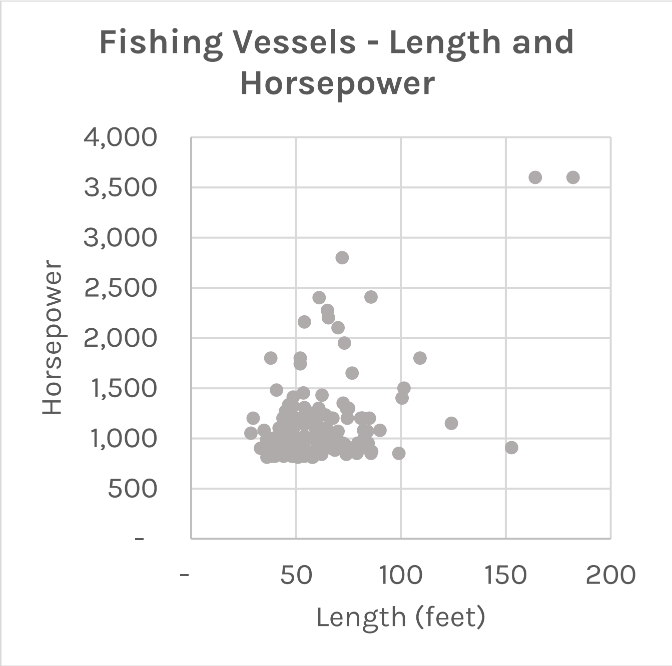
Exhibit 100 Fishing Vessels by Length and GT



Source: Intelatus Global Partners

The average fishing vessel horsepower is around 1,132.

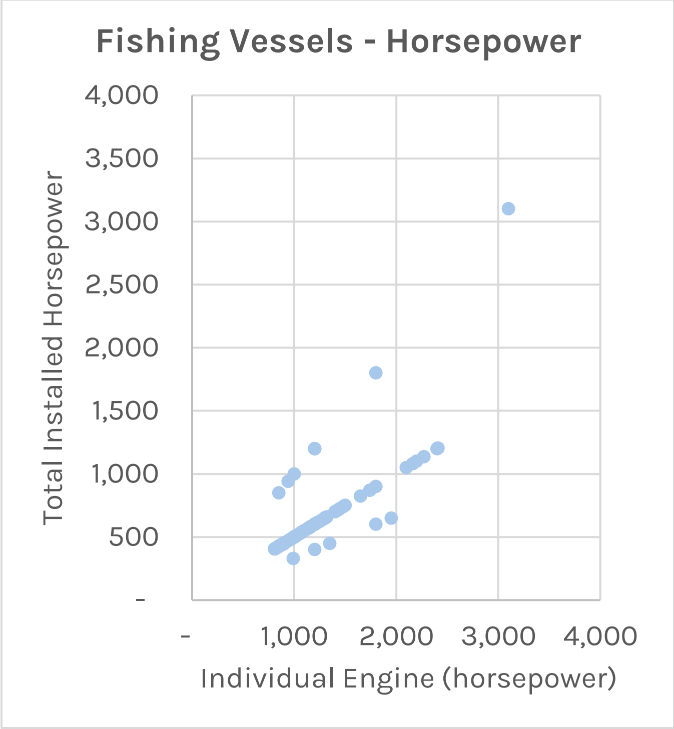
Exhibit 101 Fishing Vessels by Length and Horsepower



Source: Intelatus Global Partners

We have individual engine output for 142 out of the 171 fishing vessels in this segment. 124 (87%) of the identified vessels have individual engines of 800 horsepower.

Exhibit 102 Fishing Vessels by Horsepower



Source: Intelatus Global Partners

8.4. Pilot vessels

The are just nine pilot vessels registered in California with a total installed power of 600 kW or more.

Five of the vessels are operated by San Francisco Bar Pilots, whose operations cover San Francisco and Monterey Bays, which includes the ports of San Francisco, Oakland, Richmond, Benicia, Redwood City, Stockton and Sacramento.

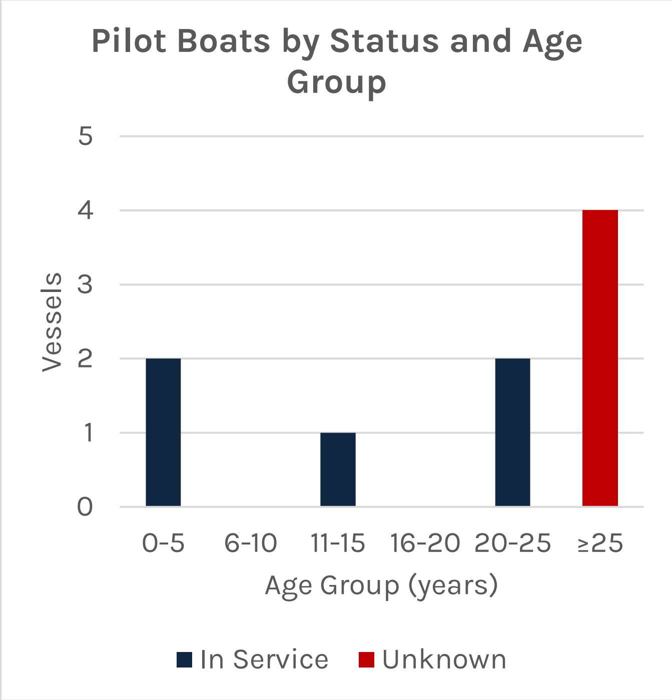
To comply with the CARB's emission requirements, San Francisco Bar Pilots and Glosten are designing new pilot boats, the first two of which are planned to be in service in 2024 and a third in 2025.

The other four pilot vessels are operated by the Port of Los Angeles.

The pilot boat segment has a comparatively young age profile when compared to crew and supply, ferry and excursion and fishing vessels. Only 44% are 25 years of age and older.

56% are confirmed In Service with the remaining 44% classed as Unknown, indicating either no AIS Class A system or the vessels are laid up.

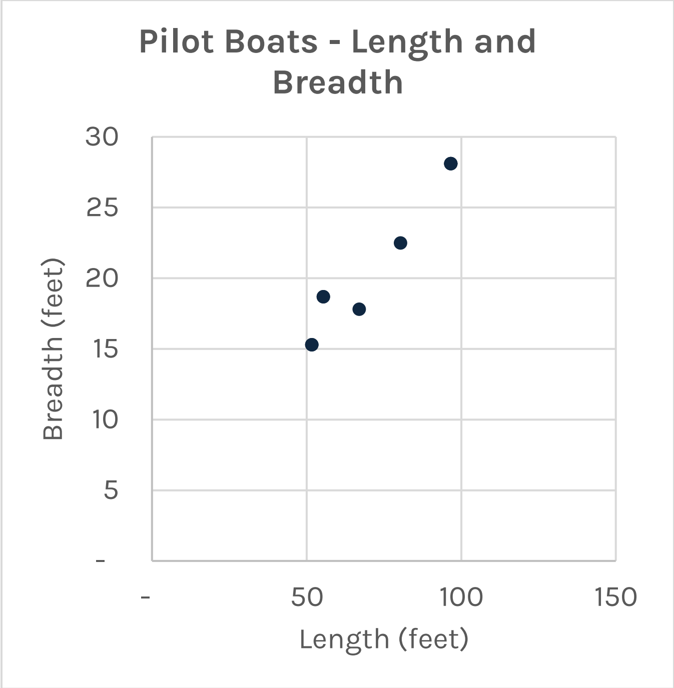
Exhibit 103 Pilot Vessels by Age Group and Status



Source: Intelatus Global Partners

The average length of pilot boats registered in California is 72 feet.

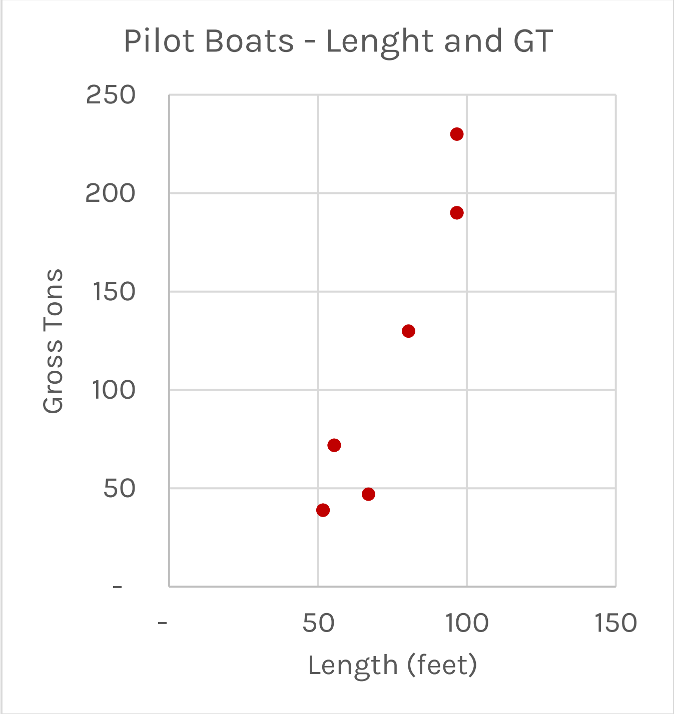
Exhibit 104 Pilot Vessels by Length and Breadth



Source: Intelatus Global Partners

The fleet average gross tonnage is 112 gross tons.

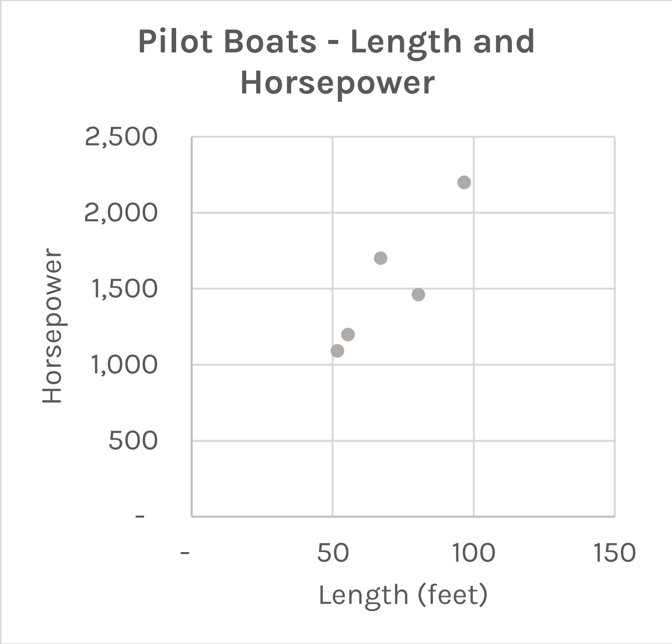
Exhibit 105 Pilot Vessels by Length and GT



Source: Intelatus Global Partners

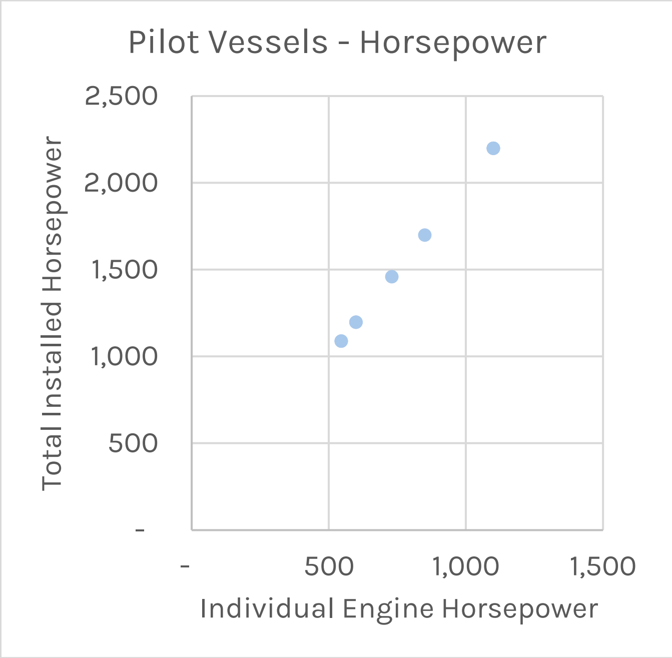
The average pilot boat horsepower is around 1,593.

Exhibit 106 Pilot Vessels by Length and Horsepower



Source: Intelatus Global Partners

Exhibit 107 Pilot Vessels by Horsepower



Source: Intelatus Global Partners

We have individual engine output for all of the pilot boats in this segment. Four of the identified vessels have individual engines of 800 horsepower or more. All vessels are equipped with two main engines.

8.5. Towboats and Pushboats

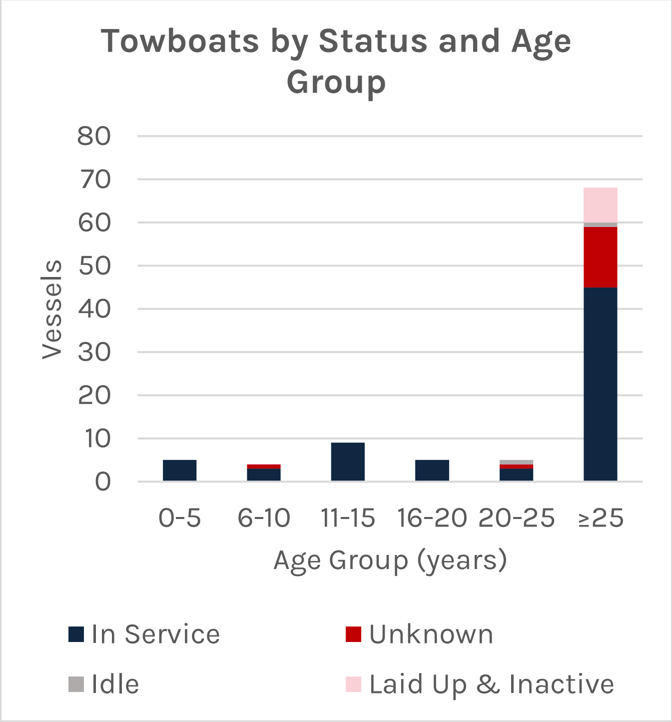
The 96 towboats registered in California feature a number of oceangoing ATBs, many of which transport petroleum products and chemicals along the West Coast.

All vessels in this segment are above 26 feet, indicating that they are required to be equipped with a Class A AIS system.

The proportion of confirmed In Service vessels is relatively high at 73% and the 17% of vessels with an Unknown status are likely either out of AIS range or laid up.

Like most of the other California segments that we review, a high proportion of tugboats are 25 years of age or older – two thirds.

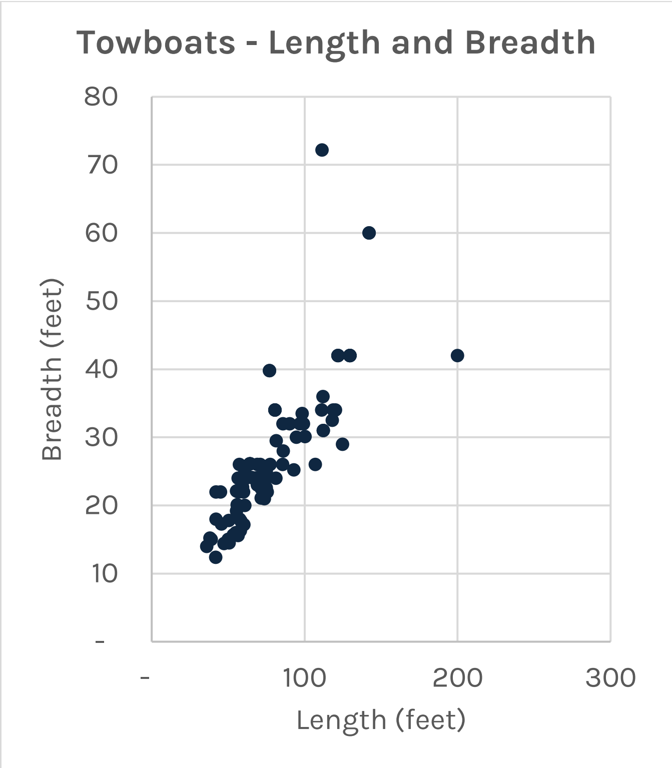
Exhibit 108 Towboats and Pushboats by Age Group and Status



Source: Intelatus Global Partners

The average length of towboats registered in California is 81 feet.

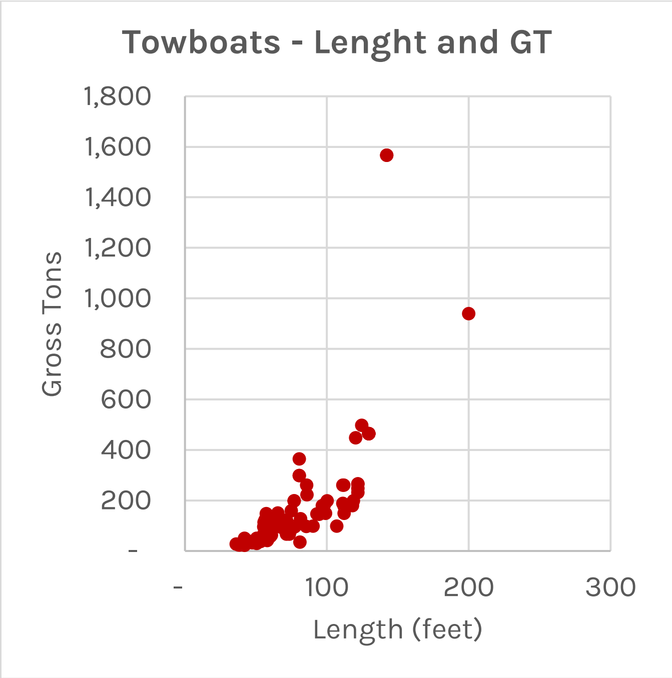
Exhibit 109 Towboats by Length and Breadth



Source: Intelatus Global Partners

The fleet average gross tonnage is 193 gross tons.

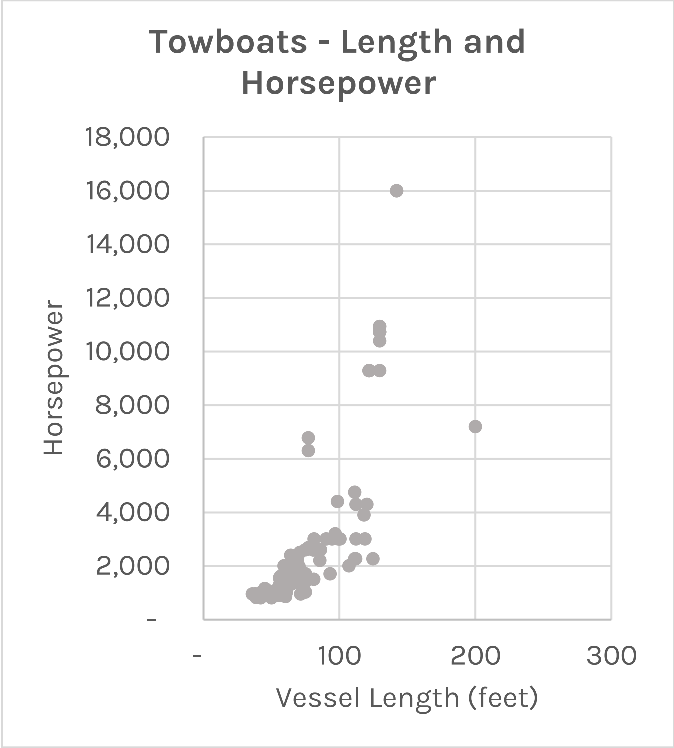
Exhibit 110 Towboats by Length and GT



Source: Intelatus Global Partners

The average towboat horsepower is around 3,240.

Exhibit 111 Towboats by Length and Horsepower



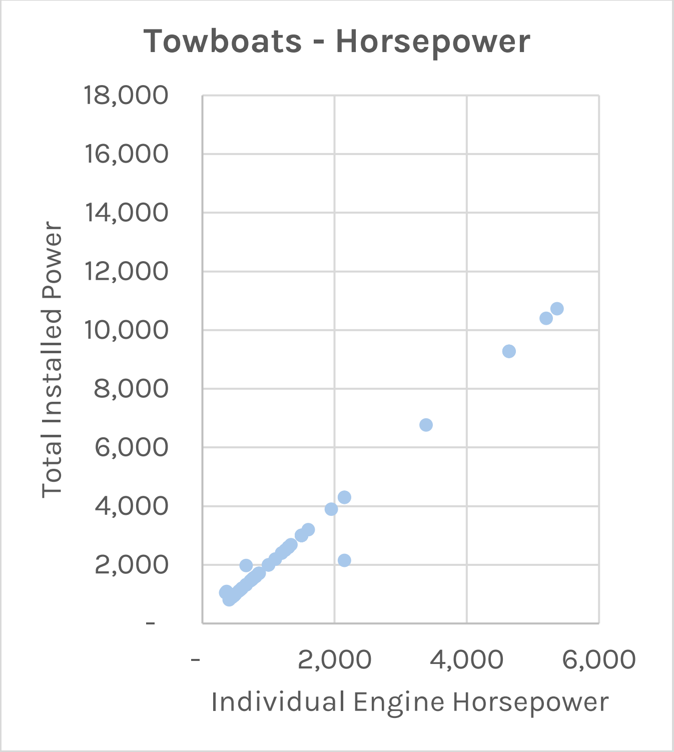
Source: Intelatus Global Partners

We have individual engine output for 71% of the vessels in this segment.

Slightly over 40% of the vessels in this category have individual engines of 800 horsepower or more.

Most vessels are equipped with two main engines.

Exhibit 112 Towboats by Horsepower



Source: Intelatus Global Partners

8.6. Tugboats

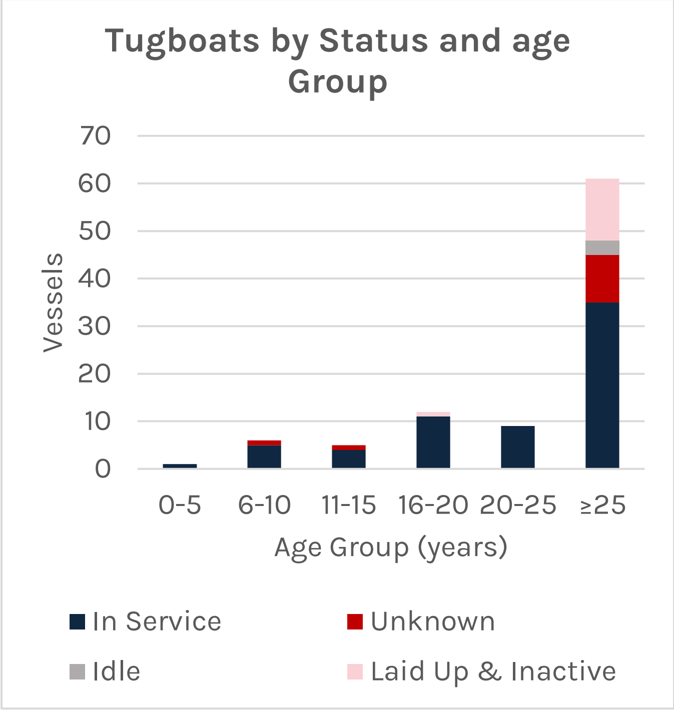
Like towboats, nearly two thirds of the vessels in the 94-strong tugboat segment are 25 years of age or older.

As with the tugboats, all vessels in this segment are above 26 feet, indicating that they are required to be equipped with a Class A AIS system.

The proportion of confirmed In Service tugboats is relatively high at 69%, and the 13% of vessels with an Unknown status are likely either out of AIS range or laid up.

The 65 In Service tugboats, and particularly the 35 vessels of 25 years of age or older, are logically the best candidates for eventual upgrade to zero-emission operations or replacement by zero-emission tugs.

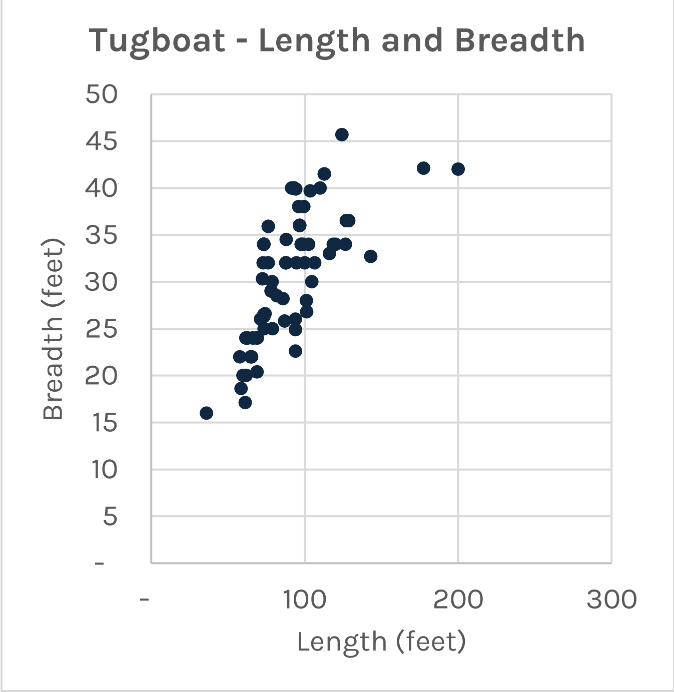
Exhibit 113 Tugboats by Age Group and Status



Source: Intelatus Global Partners

The average length of towboats registered in California is 91 feet.

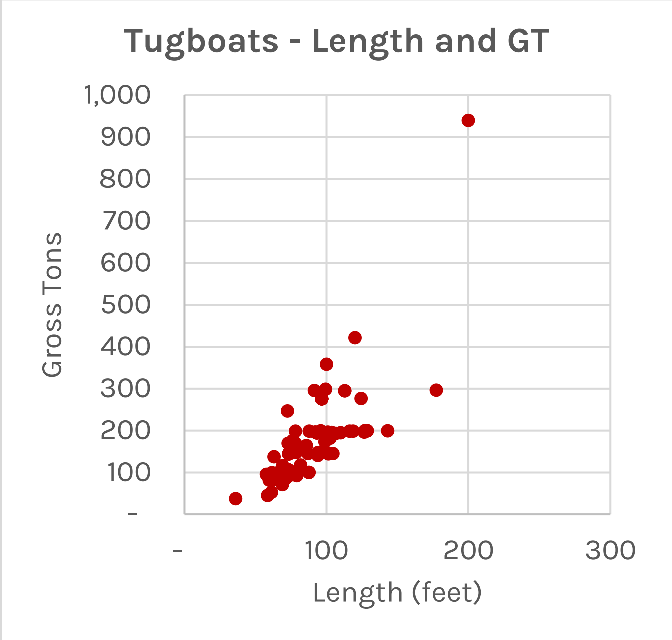
Exhibit 114 Tugboats by Length and Breadth



Source: Intelatus Global Partners

The fleet average gross tonnage is 181 gross tons.

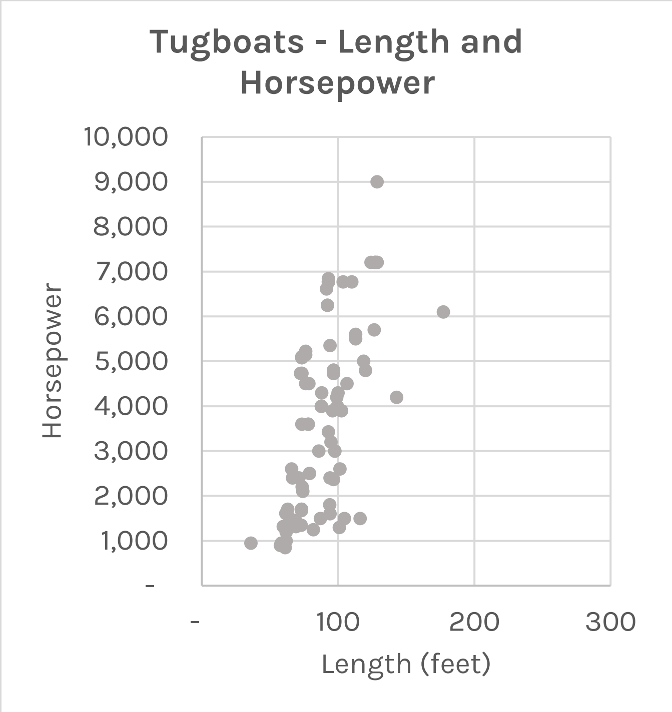
Exhibit 115 Tugboats by Length and GT



Source: Intelatus Global Partners

The average towboat horsepower is around 3,879.

Exhibit 116 Tugboats by Length and Horsepower



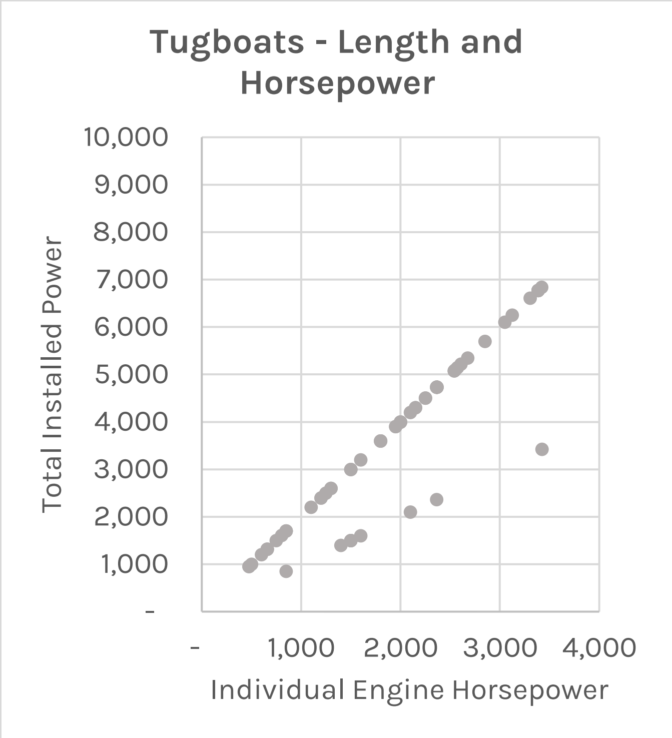
Source: Intelatus Global Partners

We have individual engine output for 73% of the vessels in this segment.

More than 88% of the vessels in this category have individual engines of 800 horsepower or more.

Many tugboats are equipped with two main engines, although some feature just one engine.

Exhibit 117 Tugboats by Horsepower



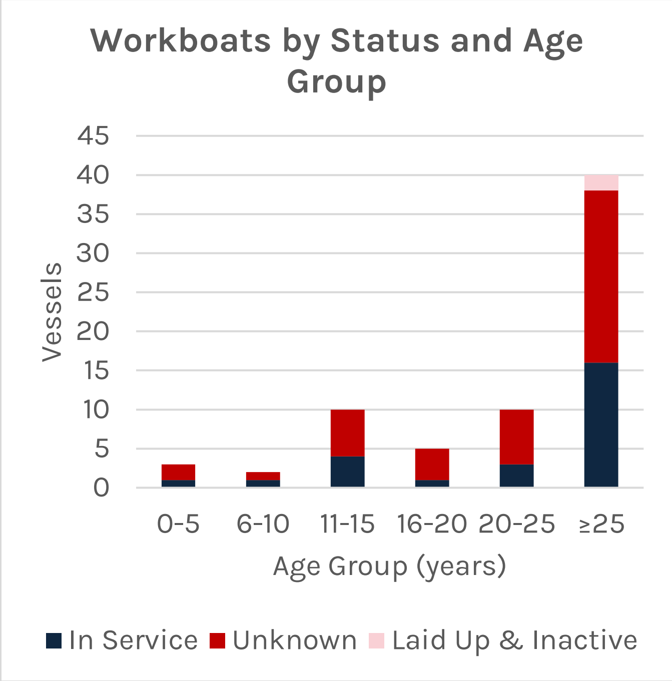
Source: Intelatus Global Partners

8.7. Workboats

Over 55% of the 70 registered Californian workboats are 25 years of age or older.

A relatively low figure of 37% of the workboats are confirmed to be In Service. The reason for 42 workboats having an Unknown operational status indicated either no AIS Class A system is fitted, or the vessels are laid up.

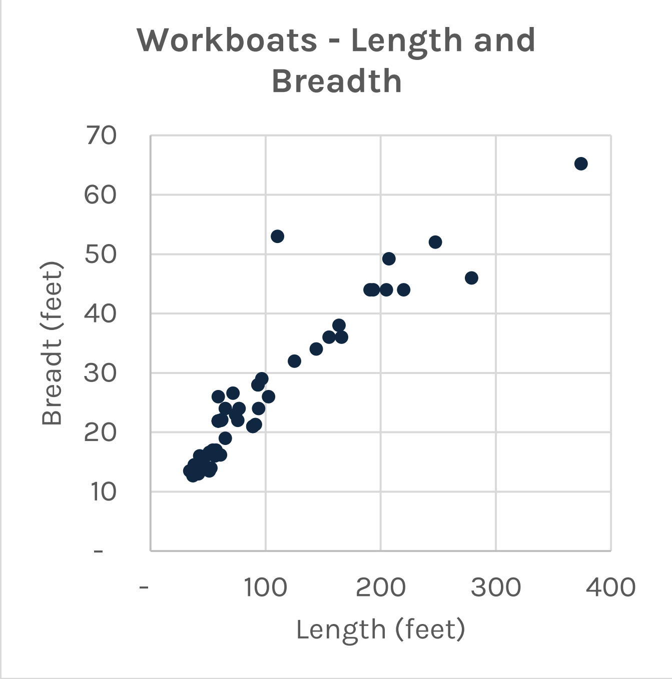
Exhibit 118 Workboats by Age Group and Status



Source: Intelatus Global Partners

The average length of towboats registered in California is 94 feet.

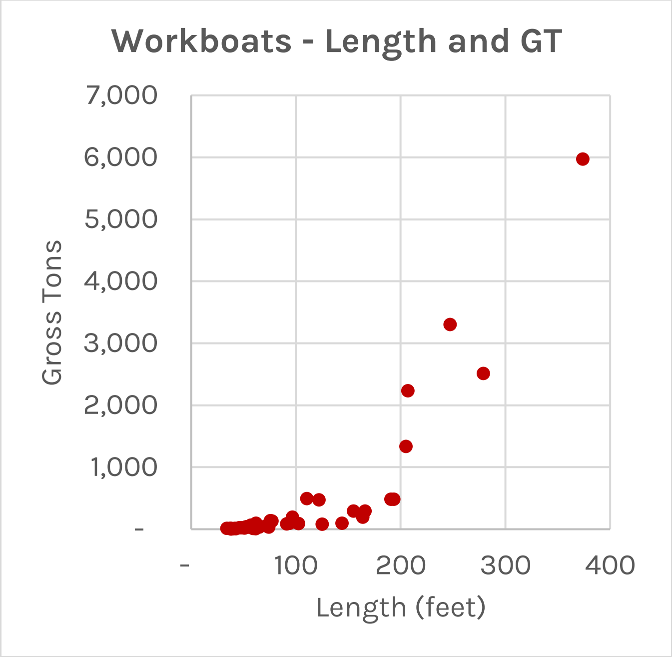
Exhibit 119 Workboats by Length and Breadth



Source: Intelatus Global Partners

The segment average gross tonnage is 402 gross tons.

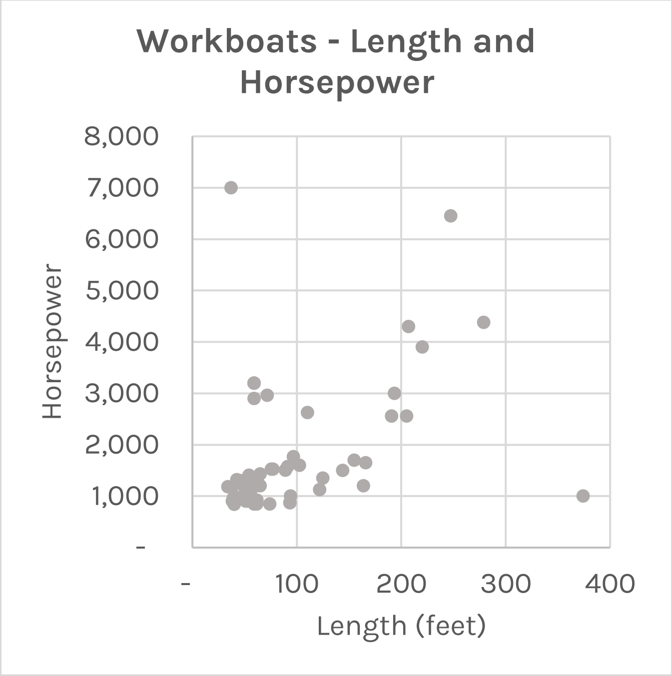
Exhibit 120 Workboats by Length and GT



Source: Intelatus Global Partners

The average towboat horsepower is around 1,748.

Exhibit 121 Workboats by Length and Horsepower



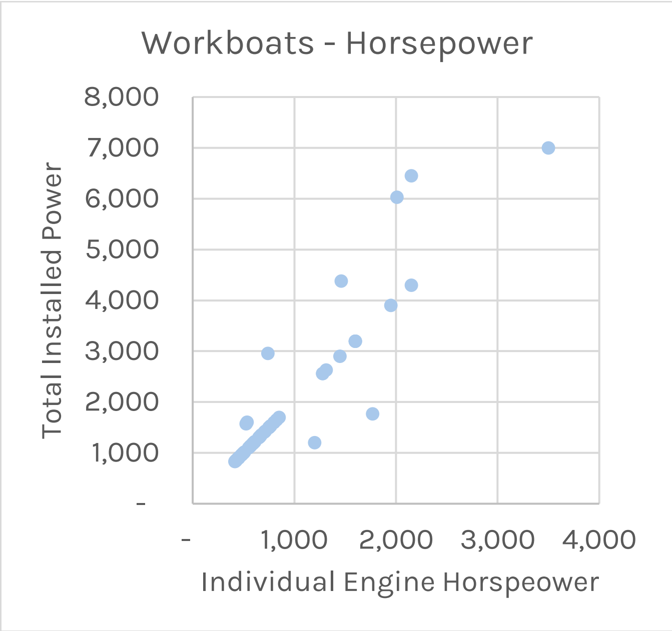
Source: Intelatus Global Partners

We have individual engine output for 97% of the vessels in this segment.

Only 24% of the vessels in this category have individual engines of 800 horsepower or more.

Most workboats are equipped with two main engines.

Exhibit 122 Workboats by Horsepower

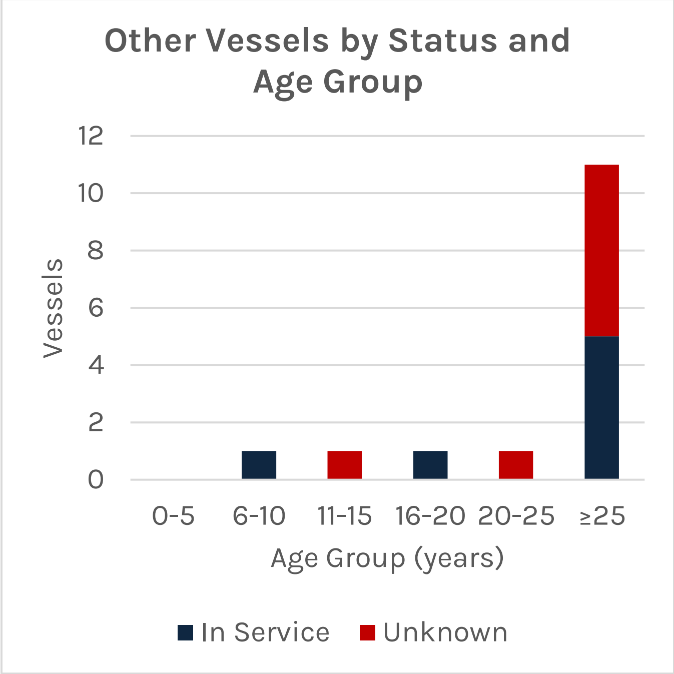


Source: Intelatus Global Partners

8.8. Other vessels

73% of the Other harbor craft of 600 kW and above 25 years of age or older. Close to 50% are In Service. The eight harbor craft with an Unknown status are likely either out of AIS range, do not feature and AIS Class A system or are laid up.

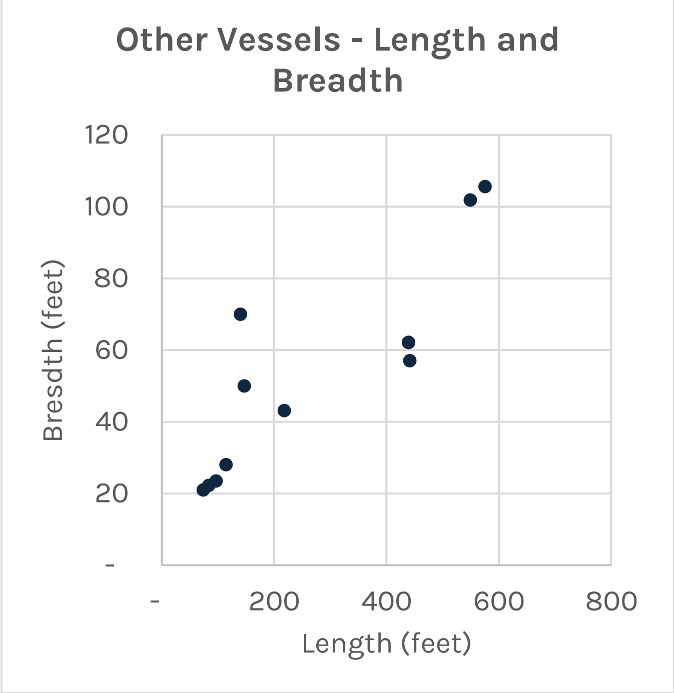
Exhibit 123 Other Harbor Craft by Age Group and Status



Source: Intelatus Global Partners

The average length of towboats registered in California is 285 feet.

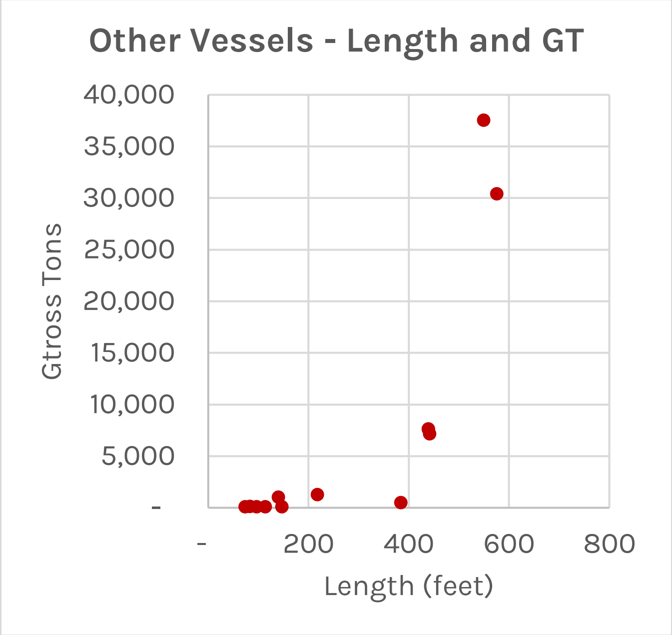
Exhibit 124 Other Vessels by Length and Breadth



Source: Intelatus Global Partners

The segment average gross tonnage is 7,212 gross tons, an average that is strongly influenced by the cargo vessels in the dataset.

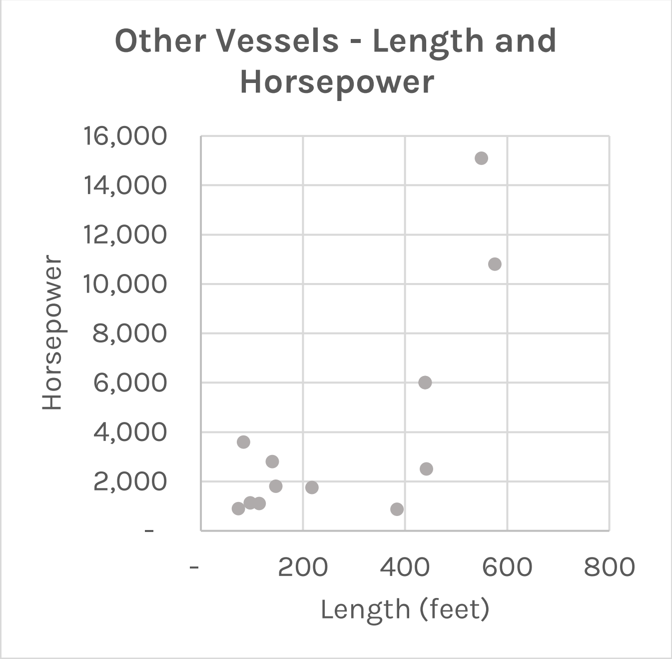
Exhibit 125 Other Vessels by Length and GT



Source: Intelatus Global Partners

The average towboat horsepower is around 3,928.

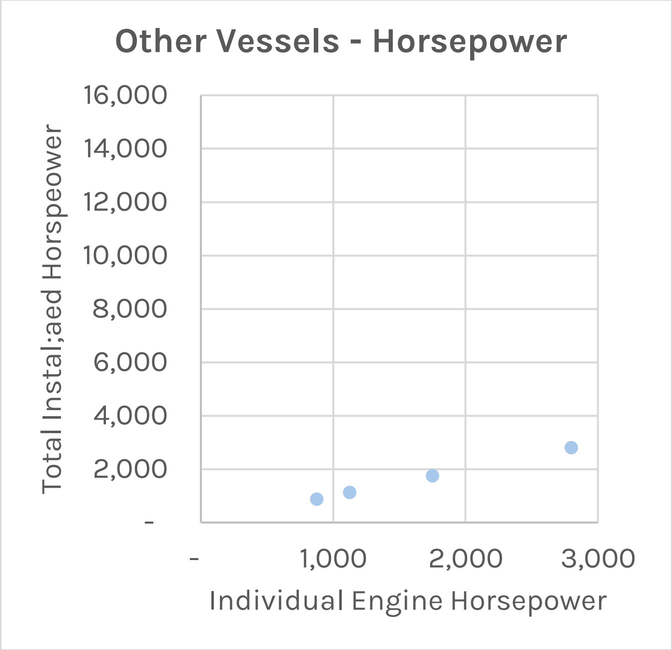
Exhibit 126 Other Vessels by Length and Horsepower



Source: Intelatus Global Partners

We have individual engine output for a quarter of the vessels in this segment. All the engines for which we have data outputs of 800 horsepower or more.

Exhibit 127 Other by Horsepower



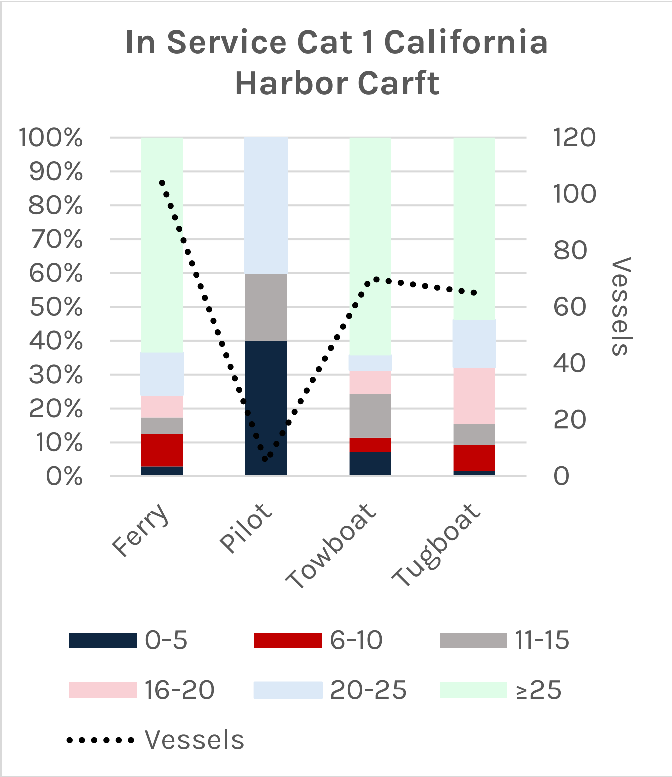
Source: Intelatus Global Partners

8.9. In Service Cat 1 Harbor Craft in California

As we have established earlier in this chapter, there are 676 registered harbor craft in California.

Of these vessels, 53% or 360 are In Service, of which two thirds are classed as Cat 1 vessels.

Exhibit 128 In Service Cat 1 California Harbor Craft



Source: Intelatus Global Partners

The 65 tugboats are the closest segment technically for the adoption of the HyZET technology.

As the towboat segment in California also features a number of oceangoing ATBs, this segment may prove less ready for the HyZET concept as, for example, towboats operating on the Mississippi River System.

The ferry and excursion vessels, especially those operating on the routine ferry routes, as well as pilot boats are generally well suited for zero-emission technologies, such as hydrogen and electricity. That said, some of the excursion vessels that venture further offshore may be less suited for short- and medium-term transition to hydrogen or fully electric technology.

8.10. A closer look at engine tiers

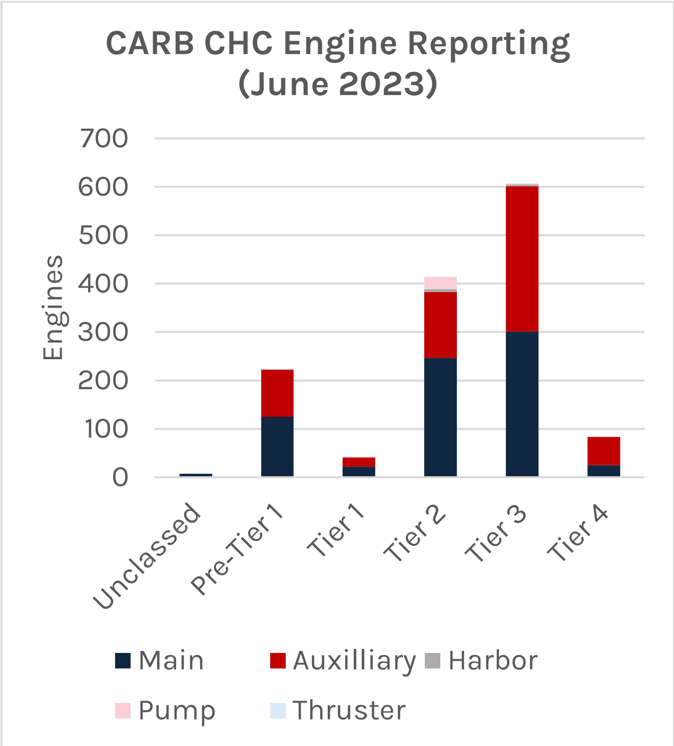
We have performed an analysis on the CHC CARB Reported Vessel Data[xvii] dated June 20, 2023, to better understand the types of engines installed on harbor craft.

We note the following major differences between the CARB dataset and our own databases used in the main analysis of this report:

- Our database groups vessels by port and state of registry and not based on where they operate.
- The CARB dataset registers vessels active withing California's waters.
- Our database examines vessels of 600 kW and above, whereas the CARD dataset also includes all vessels below 600 kW. Nearly all vessels are classed as "Active" which we infer to mean In Service.

As of June 2023, the CARD CHC vessel report included 1,379 individual engines, of which around half are below EPA Tier 3 compliance.

Exhibit 129 CARB CHC Engine Reporting



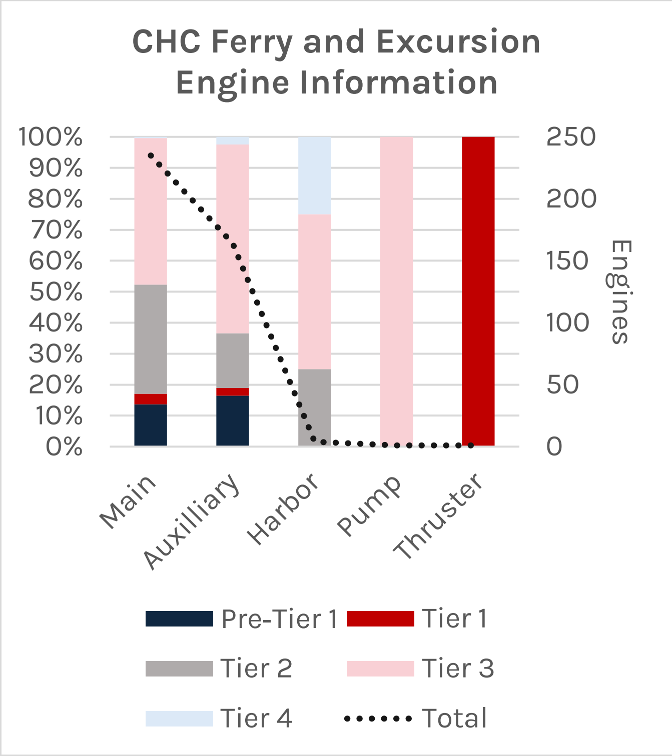
Source: Intelatus Global Partners

In Service Cat 1 Vessels

The CARB dataset includes 770 engines.

Ferries and excursion vessels account for 405 main, auxiliary, harbor, pump and thruster engines.

Exhibit 130 In Service California Ferry and Excursion Vessels – Engine Tiers

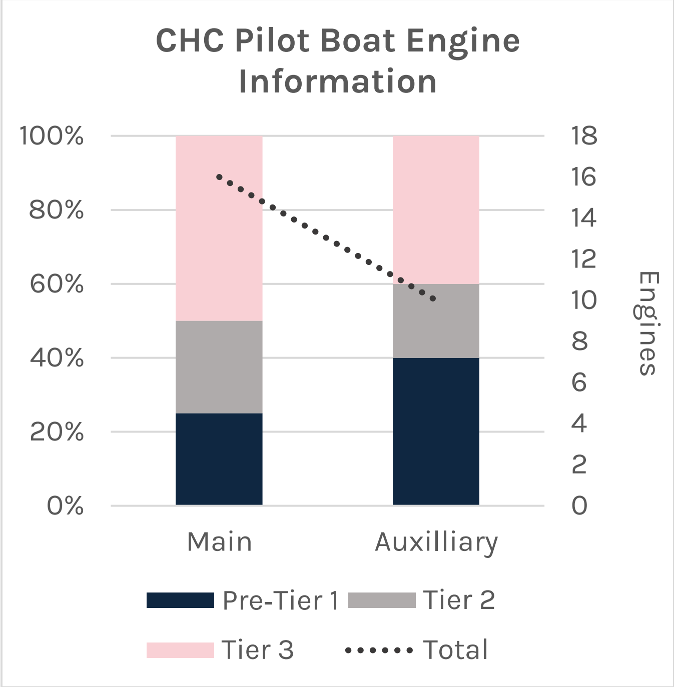


Source: Intelatus Global Partners

53% of the engines in this segment are Tier 3 and just 1% are Tier 4, indicating significant potential for emissions' reduction.

46% of the 26 engines reported for In Service pilot boats are Tier 3 compliant and there are not Tier 4 engines reported, which again confirms the potential for emissions' reduction through zero-emission technologies.

Exhibit 131 In Service California Pilot Boats – Engine Tiers



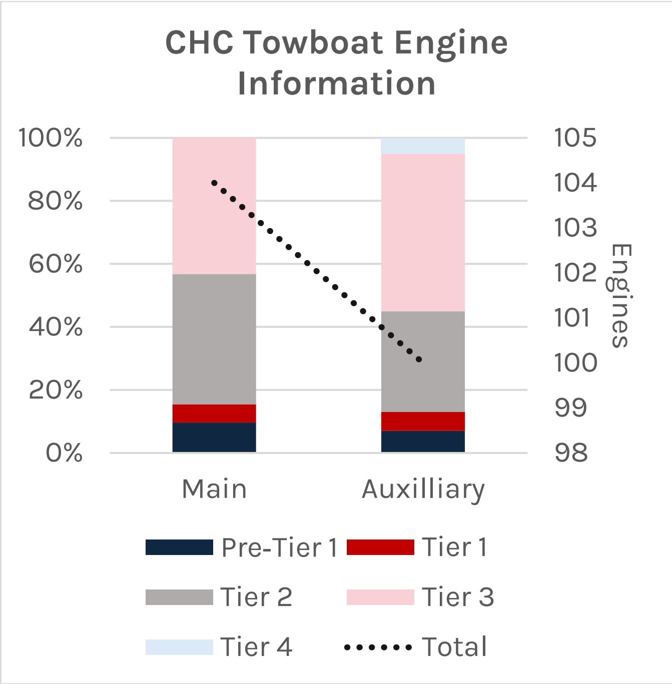
Source: Intelatus Global Partners

The towboat segment reports the second largest number of recorded engines in California, after the ferry and excursion segment with 204 engines.

More than 50% of the recorded engines are below Tier 3 compliance levels. Only 2% of the engines are Tier 4.

Given that this segment differs from the towboats active in the eastern half of the country as many are ocean going ATBs, this segment may prove less ready for the HyZET concept. However, the potential from emission reduction is evident.

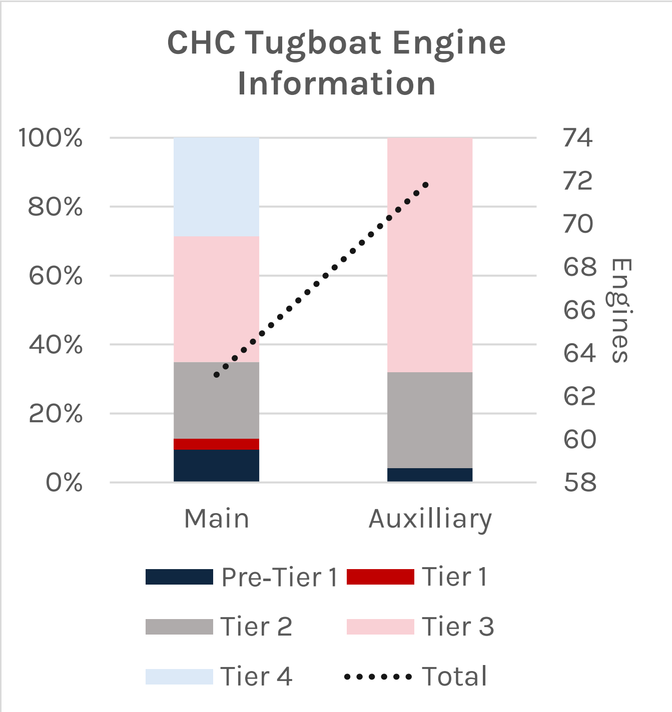
Exhibit 132 In Service California Towboats – Engine Tiers



Source: Intelatus Global Partners

There are 135 tugboat engines.

Exhibit 133 In Service California Towboats – Engine Tiers



Source: Intelatus Global Partners

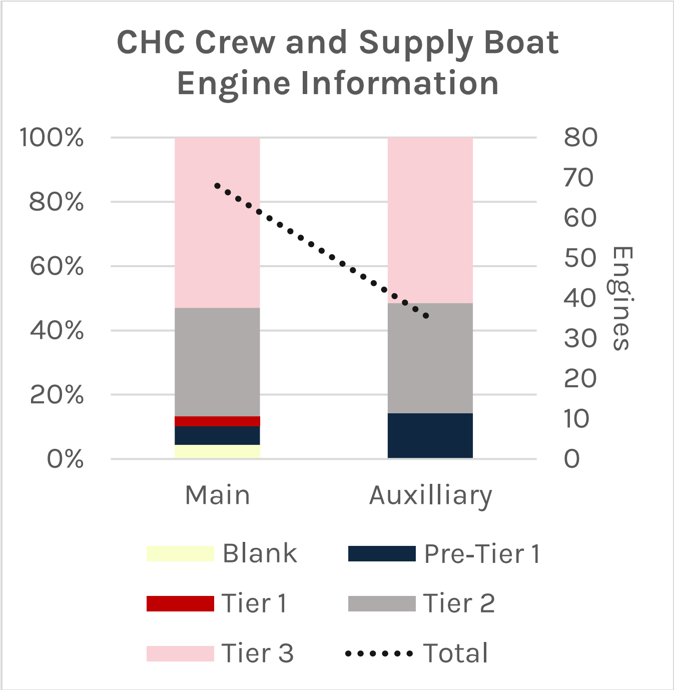
Two thirds of tugboat engines are Tier 3 or 4 compliant and once again the opportunity for transition to zero-emission technology is clear.

In Service Cat 2 Vessels

In all, there are 348 In Service Cat 2 vessel engines recorded in the CARB CHC dataset.

The Crew and Supply segment records no Tier 4 compliant engines.

Exhibit 134 In Service California Crew and Supply Boats – Engine Tiers

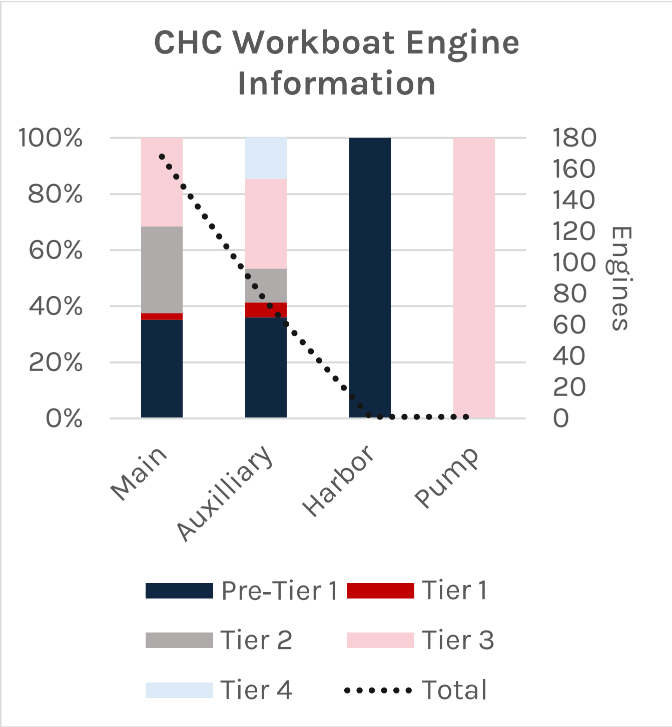


Source: Intelatus Global Partners

Two thirds of recorded workboat engines are below Tier 3 compliance.

Only 4% of workboat engines are Tier 4 compliant.

Exhibit 135 In Service California Workboats – Engine Tiers

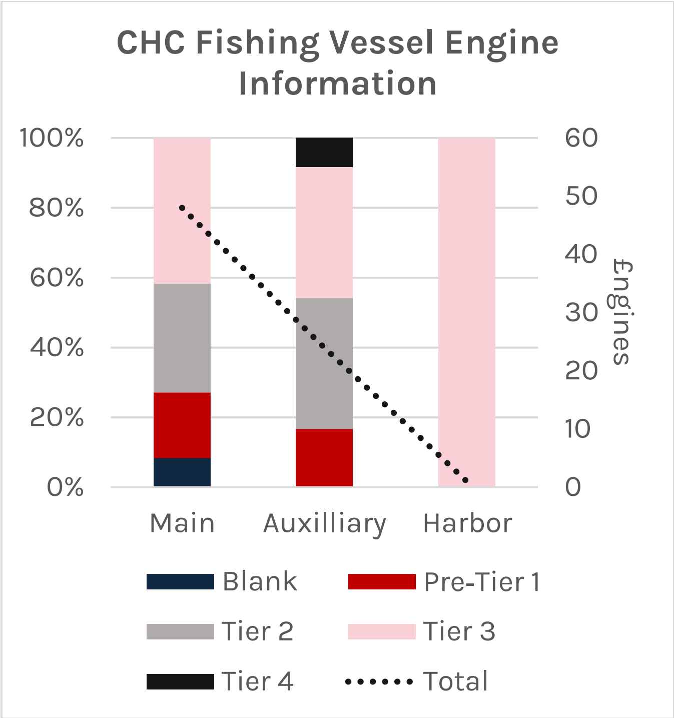


Source: Intelatus Global Partners

In Service Cat 3 Vessels

It is not surprising to see that a significant proportion of fishing vessels feature engines of Tier 3 or lower compliance.

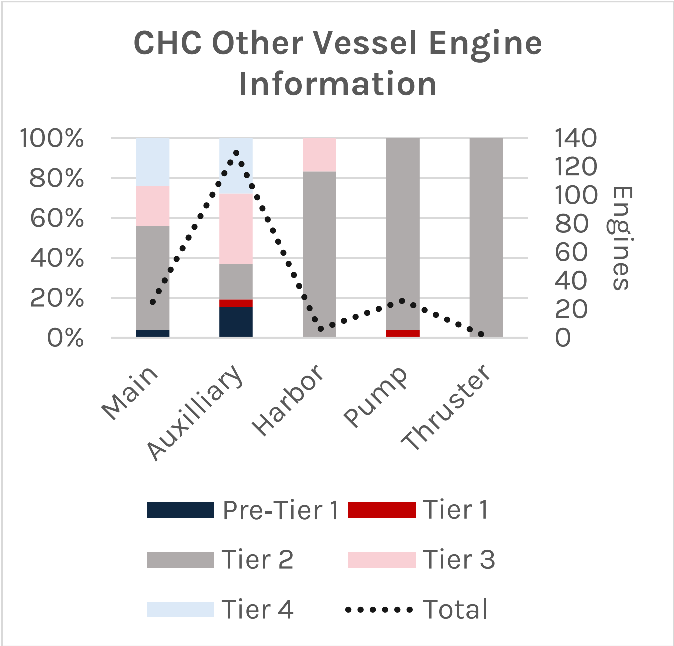
Exhibit 136 In Service California Fishing Vessels – Engine Tiers



Source: Intelatus Global Partners

We finish our analysis by looking at the vessels categorized as Other.

Exhibit 137 In Service California Other Vessels – Engine Tiers



Source: Intelatus Global Partners

9. Conclusion and Recommendations

Conclusion

This report aims to determine the size of the harbor craft sector in the United States and in California. This study found that there are approximately 10,000 harbor craft above 600 kW or 805 hp registered in the United States and 4,405 of these have been identified as highly suitable for zero-emission technology. These 4,405 vessels are ferries, pilot boats, towboats, and tugboats.

676 above 600 kW or 805 hp harbor craft are registered in California with 244 of these have been identified as highly suitable for zero-emission technology.

Ranked in descending order from largest to smallest market, Louisiana, Alaska, California, Texas, Washington, New York, Florida, Missouri, Delaware, and Massachusetts are the top 10 states for harbor craft registrations. These ten states combined represent 73% of the U.S. harbor craft population. Louisiana alone accounts for a third of all U.S. harbor craft in our survey, reflecting the importance of the Mississippi River System and the Gulf of Mexico ports. Advances in adopting zero-emission technology in these states can have a major impact on transforming the harbor craft sector.

Zero-emission harbor craft deployments will not succeed without access to electrical charging and hydrogen production and distribution infrastructure. While the top ten states have high concentrations of harbor craft, the transition to zero-emission will not happen at scale until there is sufficient charging infrastructure and hydrogen supply. Current hydrogen production levels are not sufficient to serve these vessels. Since marine vessels consume large amounts of energy, both electricity and hydrogen (and hydrogen-based energy carrier) production will need to increase to meet the future demand from these vessels.

Well-to-wake emissions are important when discussing zero-emission vessels. Vessels powered by electricity or hydrogen-based fuels can be zero-emission on a tank-to-wake basis but not zero-emission on a well-to-tank basis. Expanding the production of low or zero carbon sources of electricity and hydrogen is vital to low and zero-emission vessels, reducing greenhouse gas emissions and getting the most environmental benefit from this technology.

The global, national, and local regulatory and certification environment needs to mature further to support the wider adoption of hydrogen as a marine fuel.

Recommendations

Based on our conclusions, we recommend the following future areas of research:

- A follow-up report to assess the potential for the zero-emission technology in both the United States and specifically within California for harbor craft of below 600 kW or 805 hp.
- A road map addressing the development of certified zero-emission electricity and hydrogen-based fuel production and distribution infrastructure to support the wider uptake of zero-emission technology in, at least, Cat 1 vessels in California.
- A technical and commercial assessment of the benefits of extending zero-emission requirements to Cat 2 and Cat 3 vessels in California.
- Market research to identify specific ports throughout the United States that are willing to invest in the HyZET tug concept.

Appendix 1: Waterborne cargo for selected U.S. ports

Rank	Port	Total (tons)	Domestic (tons)	Foreign (tons)
1	Houston Port Authority, TX	266,524,394	75,862,507	190,661,887
2	South Louisiana, LA, Port of	224,695,741	115,706,421	108,989,320
3	Corpus Christi, TX	164,448,393	22,612,378	141,836,015
4	New York, NY & NJ	142,340,216	40,749,664	101,590,552
5	Port of Long Beach, CA	91,501,826	14,846,574	76,655,252
6	New Orleans, LA	89,511,808	45,254,813	44,256,995
7	Beaumont, TX	74,555,488	18,238,925	56,316,563
8	Port of Greater Baton Rouge, LA	71,222,675	44,464,034	26,758,641
9	Virginia, VA, Port of	64,518,045	5,323,046	59,194,999
10	Port of Los Angeles, CA	64,270,296	3,147,083	61,123,213
11	Plaquemines Port District, LA	52,698,083	28,556,389	24,141,694
12	Mobile, AL	50,268,633	17,453,467	32,815,166
13	Lake Charles Harbor District, LA	48,320,953	21,888,295	26,432,658
14	Port of Savannah, GA	47,656,391	839,431	46,816,960
15	Port Freeport, TX	42,243,269	4,781,243	37,462,026
16	Port Arthur, TX	40,224,061	17,265,935	22,958,126
17	Baltimore, MD	37,439,579	4,469,775	32,969,804
18	Duluth-Superior, MN and WI	32,462,993	25,934,838	6,528,155
19	Philadelphia Regional Port, PA	30,654,595	10,073,242	20,581,353
20	Northern Indiana District, IN	30,256,241	29,596,860	659,381
21	Tampa Port Authority, FL	30,034,277	18,633,724	11,400,553
22	Port of Charleston, SC	28,400,127	1,550,173	26,849,954
23	Texas City, TX	27,951,143	11,582,370	16,368,773
24	Valdez, AK	25,498,576	24,035,712	1,462,864
25	Port of Portland, OR	24,462,420	9,548,955	14,913,465
26	Southern Indiana District, IN	24,179,490	24,179,490	0
27	Port of Pascagoula, MS	23,757,927	9,724,997	14,032,930
28	Port Everglades, FL	23,745,453	11,552,604	12,192,849
29	Tacoma, WA	23,362,351	4,497,103	18,865,248
30	Seattle, WA	22,909,282	4,557,033	18,352,249
	TOTAL	**1,920,116,756**	**666,929,121**	**1,253,189,695**

Source: Intelatus Global Partners interpretation of output from the FAF5 Summary Statistics produced by the National Transportation Research Center, Oak Ridge National Laboratory

Appendix 2: Overview of California's ports (2020)

Port	Million Tons of Cargo	Highest Value Exports	Highest-Value Imports
Long Beach	79.2	Petroleum coke, wastepaper, chemicals, scrap metal	Crude oil, electronics, plastics, furniture
Los Angeles	59.5	Wastepaper, animal feeds, scrap metal, fabric, soybeans	Furniture, clothing, automobile parts, electronic products
Richmond	21.1	Vegetable oils, scrap metal, coke, coal	Autos, petroleum, minerals, vegetable oils
Oakland	19.4	Fruits and nuts, meats, machinery, wine and spirits	Machinery, electronics, furniture, plastics
Stockton	4.6	Iron ore, sulfur, coal, wheat, rice	Liquid fertilizer, molasses, bulk fertilizer, cement
San Francisco	2.2	Tallow, vegetable oil	Steel products, boats, wind turbines, aggregate
Redwood City	1.9	Iron Scrap	Aggregates, sand, gypsum
Hueneme	1.8	Autos, produce, general cargo	Autos, produce, liquid fertilizer, bulk liquid
San Diego	1.5	Machinery, metals, autos, heavy equipment	Vehicles, perishables, construction materials, heavy equipment
West Sacramento	1.2	Agricultural and industrial products	Agricultural and industrial products
Humboldt Bay	Unknown	Logs, wood chips	Logs, petroleum, wood chips
Benicia	Unknown	Petroleum coke	Automobiles

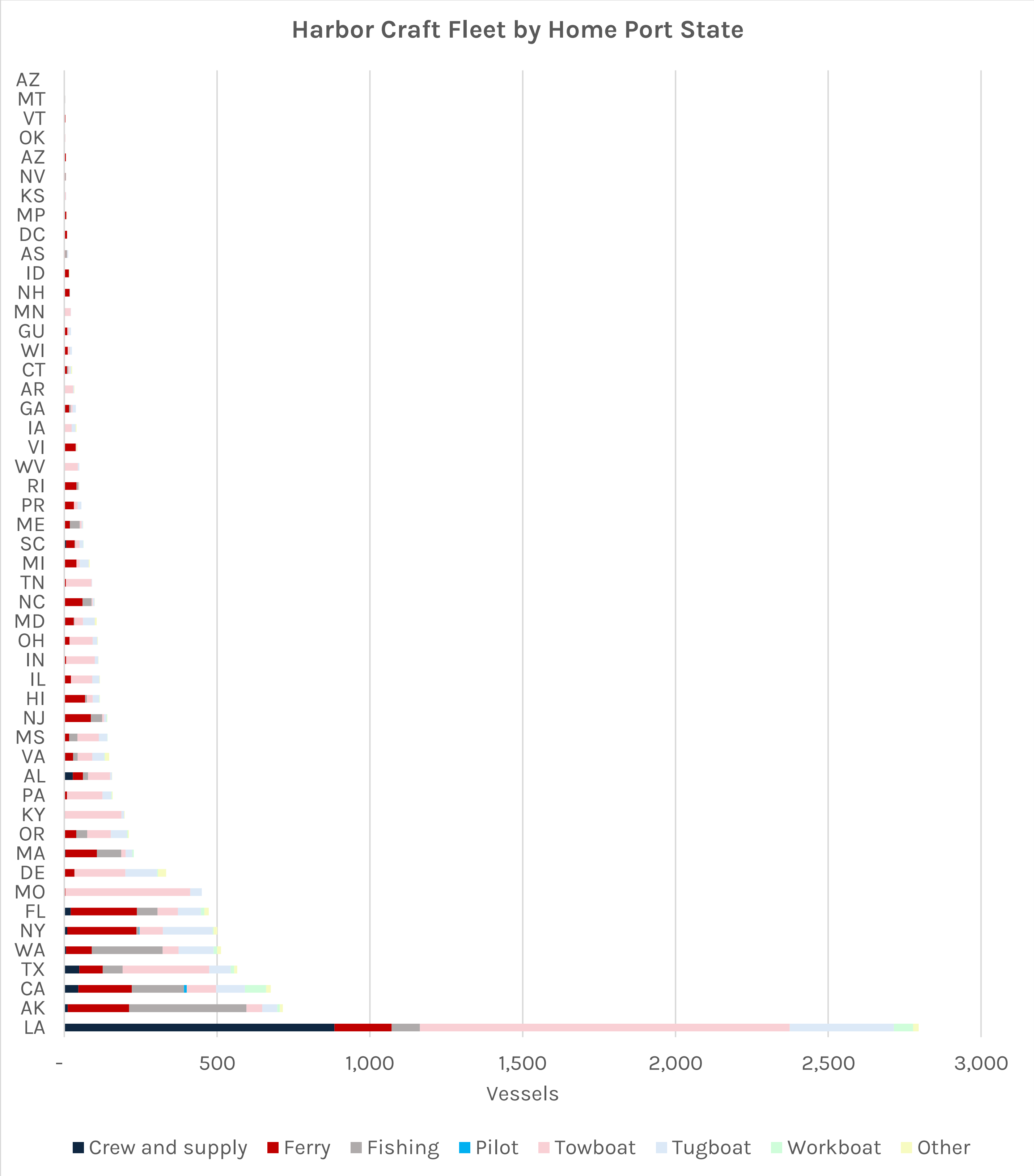
Source: Intelatus Global Partners interpretation of data from the California Legislative Office

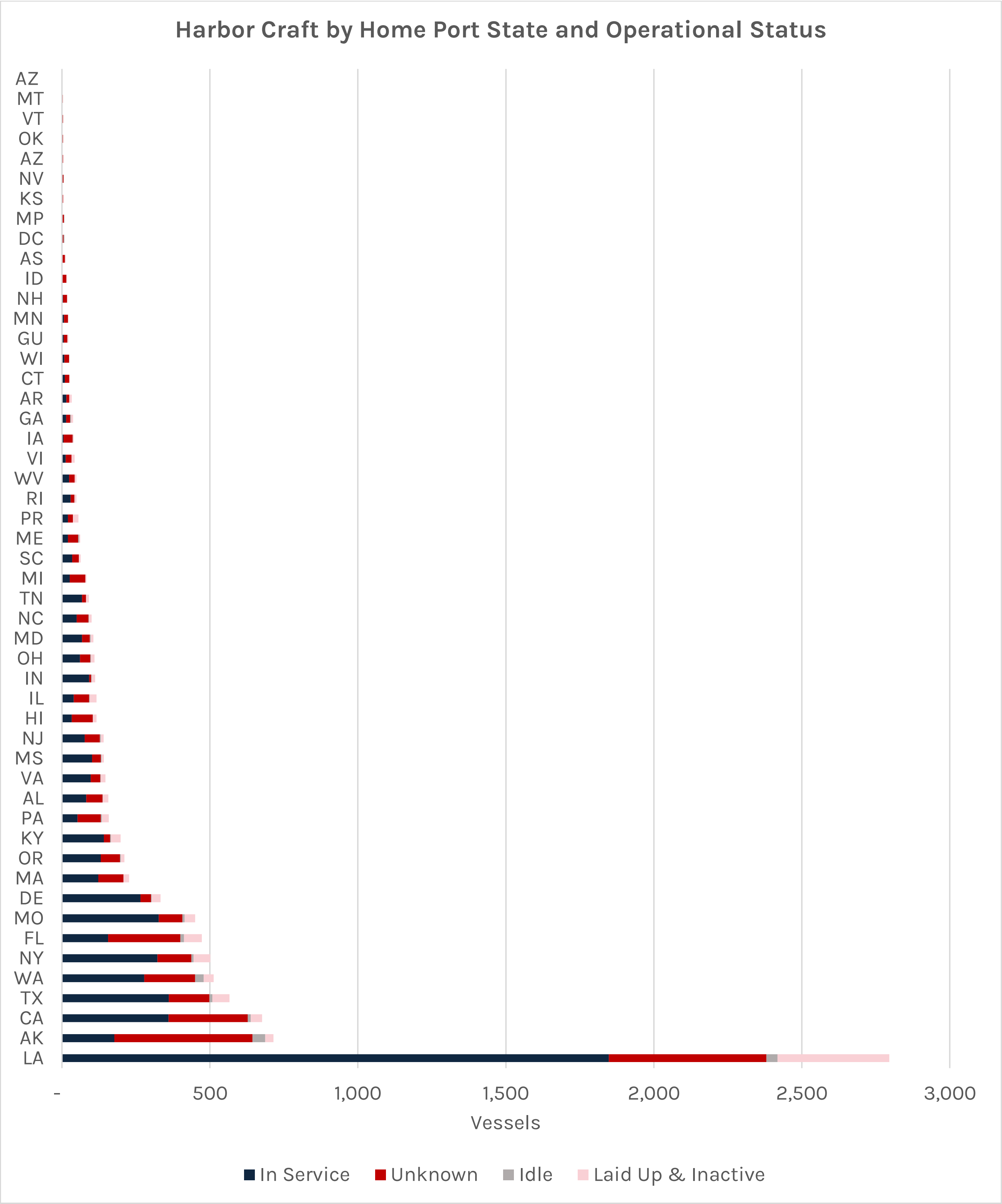
Appendix 3: Cargo transported within, from and to states by water ('000 tons)

State	2021	2030	2040	2050
Louisiana	320,659	427,999	484,374	551,204
Texas	207,531	296,745	360,864	442,742
Illinois	75,497	84,119	92,671	104,861
Michigan	40,034	42,354	46,755	58,053
California	33,070	51,539	58,370	53,053
Kentucky	42,692	41,615	39,615	42,278
Ohio	56,601	49,646	40,268	40,054
Indiana	31,771	31,102	32,057	36,901
Mississippi	23,460	31,270	32,563	35,721
Alabama	18,482	37,803	32,231	35,673
Alaska	25,173	36,914	42,711	35,039
Washington	23,084	28,965	30,159	30,983
Missouri	15,838	21,656	23,297	25,671
Minnesota	16,709	19,738	21,200	23,468
Florida	20,954	21,269	20,074	20,673
West Virginia	58,871	42,716	26,019	20,428
Pennsylvania	24,310	27,793	21,412	19,100
Tennessee	14,268	13,466	14,637	16,429
New Jersey	9,966	14,912	14,350	14,550
Iowa	6,603	8,386	10,139	12,098
New York	6,003	8,811	9,902	11,818
Oregon	6,973	8,912	10,046	11,711
Oklahoma	6,218	7,665	8,927	9,994
Hawaii	1,849	6,915	7,965	9,927
Arkansas	6,891	7,377	7,930	8,752
Virginia	6,199	7,273	7,613	8,176
Wisconsin	3,856	3,622	3,831	4,490
Connecticut	2,872	3,222	3,184	3,252
Maryland	3,509	2,991	3,047	3,190
Delaware	2,592	1,856	1,769	1,584
	1,114,556	**1,390,681**	**1,510,020**	**1,693,923**

Source: Intelatus Global Partners interpretation of output from the FAF5 Summary Statistics produced by the National Transportation Research Center, Oak Ridge National Laboratory

Appendix 4: Harbor craft fleet by home port state





Source: Intelatus Global Partners

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