The Maritime Fleet of the USA – the current status and potential for the future

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Preface

This report has been written by a team of experts from UMAS for Ocean Conservancy. This work characterises US-flagged vessels and assesses the potential for decarbonisation. The views expressed are those of the authors, not necessarily of the client.

About UMAS

UMAS undertakes research using models of the shipping system, shipping big data (including satellite automatic identification system data), and qualitative and social science analysis of the policy and commercial structure of the shipping system. Research and consultancy is centred on understanding patterns of energy demand in shipping and how this knowledge can be applied to help shipping transition to a low-carbon future. UMAS is world-leading on two key areas: using big data to understand trends and drivers of shipping energy demand or emissions; and using models to explore what-ifs for future markets and policies. For more details visit www.u-mas.co.uk.

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List of abbreviations

AIS	automatic identification system(s)	**IPCC**	Intergovernmental Panel on Climate Change
ATB	articulated tug barge	**JAF**	Jones Act fleet
BTS	Bureau of Transport Statistics	**LNG**	liquefied natural gas
CII	Carbon Intensity Index	**MARAD**	United States Maritime Administration
CO_2	carbon dioxide	**MDO**	marine diesel oil
CO_2eq	carbon dioxide equivalent	**MEPC**	Maritime Environment Protection Committee
DCS	data collection system	**NDC**	nationally determined contribution
DOT	Department of Transportation	**OGV**	ocean-going vessel
DWT	dead weight tonnage	**Ro-Pax**	roll-on and passenger (ferry)
ECA	emission control area	**Ro-Ro**	roll-on roll-off (ferry)
EEOI	Energy Efficiency Operational Indicator	**SBTi**	Science Based Targets Initiative
EEXI	Energy Efficiency Existing Ship Index	**SZEF**	scalable zero emission fuel
EU	European Union	**TEU**	twenty-foot equivalent unit
FUSE	fuel use statistics and emissions	**UK**	United Kingdom
GHG	greenhouse gas	**UNCTAD**	United Nations Conference on Trade and Development
GT	gross tonnes	**UNFCCC**	United Nations Framework Convention on Climate Change
HFO	heavy fuel oil	**US**	United States
HFOeq	heavy fuel oil equivalent	**USCG**	United States Coast Guard
IMO	International Maritime Organization	**ZEV**	zero emissions vessel

Executive summary

In order to meet the targets set by the Paris Agreement and declarations by the current United States (US) administration, an increase in energy efficiency and an urgent shifting towards scalable zero emission fuels (SZEFs) is required. The US fleet is an example of a shipping fleet that has vast untapped potential for becoming a leader in the decarbonisation of shipping.

This report takes a data-centric approach, combined with a rich understanding of the transition pathway this sector is currently on, to identify:

- Why this is now a key moment in time for the US to act decisively on decarbonising US shipping
- How the US fleet can be decarbonised[1]
- Where, around the US, the scale of opportunity lies, and what this implies for action and next steps.

The US fleet is old and under-invested, so it presents an opportunity

For reasons discussed in the report, the average age of the US-flagged fleet is higher than global averages (7.5 years older, on average) with only a few exceptions; namely, roll-on and passenger (Ro-Pax) ferries, chemical tankers, general cargo ships and refrigerated bulkers. There are many ships operating that are older than the average scrappage age of the global fleet. Tugs appear to be on average around 25 years older than those in the global fleet, which is noteworthy given the significant role that articulated tug barges have been found to play in US domestic trade. Jones Act fleet (JAF) container ships, general cargo ships and miscellaneous vessels are, on average, between 10 and 20 years older, while non-JAF bulkers and roll-on roll-off (Ro-Ro) ferries are 25–35 years older. Some particularly old examples that can be found among the ocean-going vessels (OGVs) are small container ships supplying Hawaii, Puerto Rico and the archipelagos of western Alaska, which are aged between 33 and 41 years old; while on the inland waterways it is possible to find bulkers that are 70 years old operating in the Great Lakes and service tugs over 50 years old across most of the country.

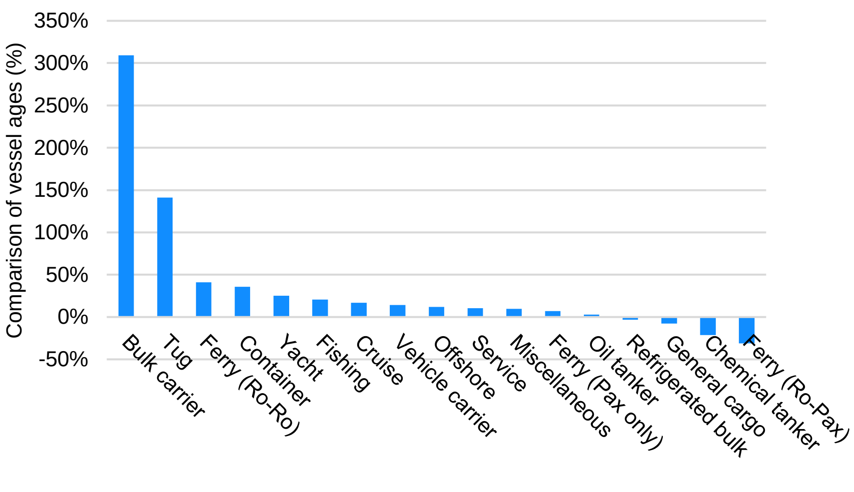


Figure 1 Comparison of median vessel age by type between US-flagged and global fleet in 2021

[1] An extensive analysis on the fuel and technology options available to the maritime industry can be found in a related report [1].

More than 40% of energy used by the US fleet could be replaced by zero emission solutions this decade

This study estimates that 17% of the current fleet's demand for energy from fossil fuels can be substituted with electrification (direct electrification when in harbour, or battery electrification for shorter voyages). A further 24% of the energy demand of the fleet represents a strong case for being early adopters of SZEFs, because the operating profiles of these vessels mean they should require minimal infrastructure investment. There are no technological barriers to both of these fuel changes being fulfilled in the current decade, and the changes could happen without premature scrappage of the existing fleet (i.e. in line with existing renewal schedules). If these changes could be combined with programmes focusing on energy efficiency, large near-term greenhouse gas reductions are possible this decade, stimulating the development of the longer-term infrastructure and solutions that will be even more crucial in the US and globally over the 2030s. Figures 2 and 3 present the clusters of ports that are best placed for decarbonisation based on the energy demand, operating of vessels and proximity of other ports.

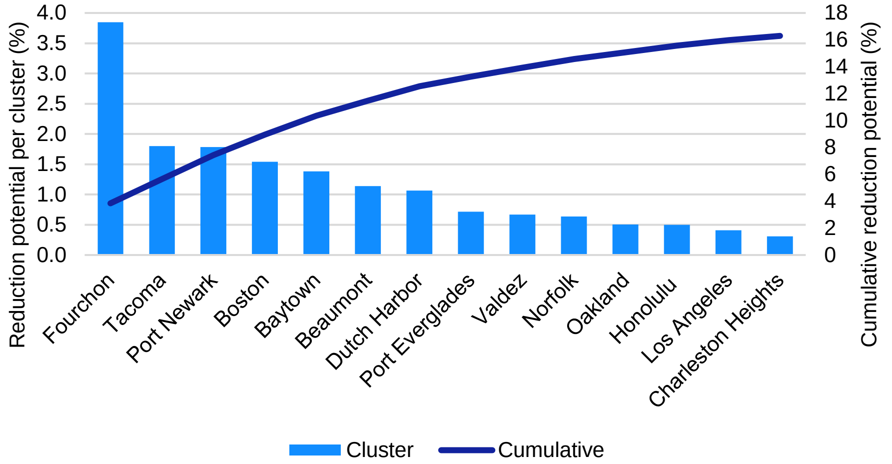


Figure 2 Top clusters for emission reduction potential – electrification

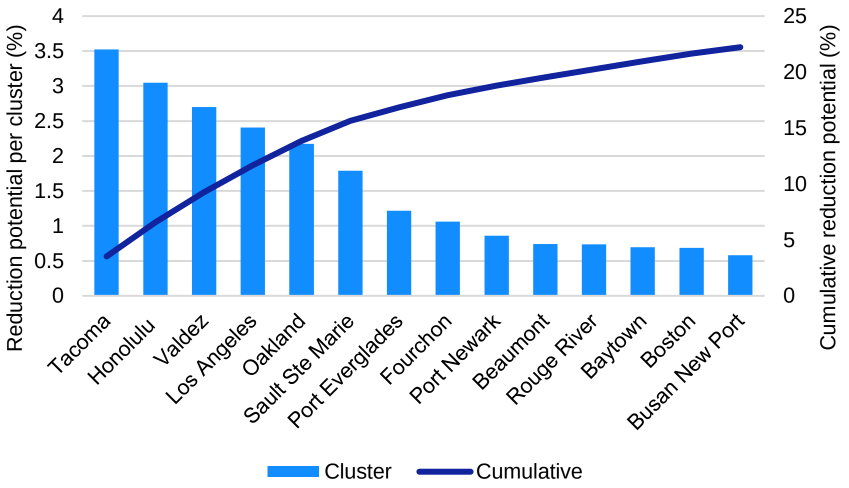


Figure 3 Top clusters for emission reduction potential – SZEF

The main condition for electrification is having small vessels operating locally with mean voyage ranges of less than 100 nautical miles (nm). It is broadly assumed that these energy demands can be met by the current state-of-the-art batteries and provision of onshore infrastructure. Vessels with a more flexible trading profile, longer range and generally larger dimensions are most suitable for SZEFs powering internal combustion or fuel cell technologies. Fuels such as hydrogen, ammonia and methanol are most suitable, given their first production step is common.

The US has significant greenhouse gas emissions from domestic shipping, which calls for urgent federal and state-led solutions

In 2018 carbon emissions from US-flagged vessels (including domestic and international shipping) amounted to around 26 million tonnes of carbon dioxide equivalent ($MtCO_2eq$), or 2.4% of global shipping emissions. Domestic voyages account for around 70% of emissions from US-flagged vessels. This presents a unique opportunity for national regulations to be used as an effective tool towards decarbonisation. In an approach similar to the regulation and enforcement of emission control areas, SZEFs could be gradually introduced as vessels operating in domestic US water are replaced by new builds or are retrofitted. Alternatively, additional conditions for JAF eligibility could be introduced that require low or zero-carbon operation for vessels operating in US cabotage.

For most countries – the US being a good example – unilateral and independent national strategies are intuitively most suitable to transition away from fossil fuels because they can be linked to the country's leading technological and political roles. The feasibility of this transition in the US is also related to the high potential to produce renewable energy and the strength of the domestic registered and operating fleet.

The Jones Act has upsides for shipping's decarbonisation

As well as contributing to the US-flagged fleet having a higher median age than the global fleet, the Jones Act means there are levels of protection around some of the shipping fleet servicing the US that can be an opportunity for the US taking a leading position on maritime decarbonisation. For example, jobs, skills development and barriers to international competition exist that ensure investment in maritime decarbonisation will stay in the US and avoid competitive disadvantage for some segments of US freight transport.

This report highlights the pivotal role that the Jones Act could have on driving decarbonisation of the maritime fleet, given that around 30% of the current fuel demand comes from domestic trade.

US leadership on the US-flagged fleet can serve US interests, while simultaneously enabling the transition of the global fleet, which the US is dependent on for trade and future economic growth

The decarbonisation of US shipping can create large numbers of jobs and employment opportunities. Shipping's decarbonisation is, to a large extent, dependent on low-carbon hydrogen-based fuel and the associated production and use technologies, so decarbonising US shipping could create opportunities for US firms to gain market share globally, both in shipping and in other areas of the rapidly emerging global hydrogen economy. Environmental benefits notwithstanding, there is a large economic prize arising from early action and the premium global positioning this can create in a future multi-trillion dollar market.

Granular data provides the information on where to target investments for greatest cost-effectiveness

A study of voyage-based activity of the US fleet was undertaken with a view to identifying the routes with the highest decarbonisation potential. This type of analysis builds an evidence base for policymakers to inform optimal onshore investment and vessel technology on the basis of current operational trends. "Cluster analysis" has been used to classify specific routes according to their decarbonisation potential based on the types and sizes of vessels and their operating profile. Two distinct types of clusters are identified: those with a strong case for electrification and others more suited to SZEF development.

SZEF “first mover” vessels covering multilateral routes that combine both domestic and international operations account for 7.4% of the total US fleet energy demand, of which 4.8% is for domestic-only shipping and 2.6% is for international voyages. This highlights the importance of the Jones Act as a driver for decarbonisation, given that around 16.7% of the current fuel demand comes from domestic trade.

The study identified the Gulf of Mexico and the Northeast and Northwest coasts as having the highest potential for an electrifiable fleet, giving a more complete picture than that suggested by observing only the contribution of the routes. The top candidates for SZEF in terms of reduction potential are on the Pacific coast, accounting for 14% of total fleet emissions, followed by nine clusters located in the Gulf, the Great Lakes and the east coast of the US, accounting for a further 8.5% between them. Combining this information with the findings on the electrifiable fleet suggests that the demand for electrification is higher in the Gulf and the Northeast of the US, while the west coast and the Great Lakes ports present a strong case for vessels switching to SZEFs (Figure 4). These findings complement the commitment that the US has made by signing the Clydebank Declaration and committing to the development of green shipping corridors.

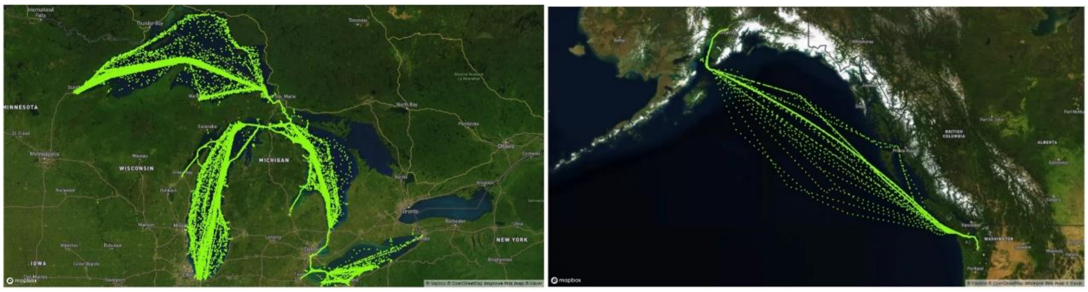


Figure 4 Routes with strong decarbonisation potential by using scalable zero emission fuels – the Great Lakes and the Northwest

When considering time at sea and at berth, the amount of energy consumed is also important because most vessels consume very little energy while at berth. However, vessels that have a lot of waiting or loading time embedded in their operating profile can have up to 12% of their energy consumption at berth. Such vessels may be ideal candidates for shoreside power to avoid their use of auxiliary generators and boilers while in port. Three of the four most energy demanding vessel types (fishing, offshore and service-tug) consume at least a quarter of their energy demand at berth.

Future work

This study, along with the related maritime fuels report [1], evaluates the potential for the US to become a leader in the transition of shipping to zero emission fuels. The next phases of discovery to be targeted to make the transition most impactful may explore the following:

- Investigating synergies between decarbonisation the US fleet (e.g. through SZEF production, electrification and infrastructure investment) and decarbonising international shipping (including non-US-flagged shipping serving the US)
- Connecting this analysis of the techno-economics with other parameters to further understand the leading candidates for early investment (including planning, overlaps with state strategy/regulation etc.)
- Spotting the opportunities for taking up multiple technologies around the US (e.g. where do already planned hydrogen/renewable electricity investments coincide with US-flagged shipping SZEF and electricity demands, and what industrial clusters may also need similar production and supply chains and can spread risks making investment cases stronger).

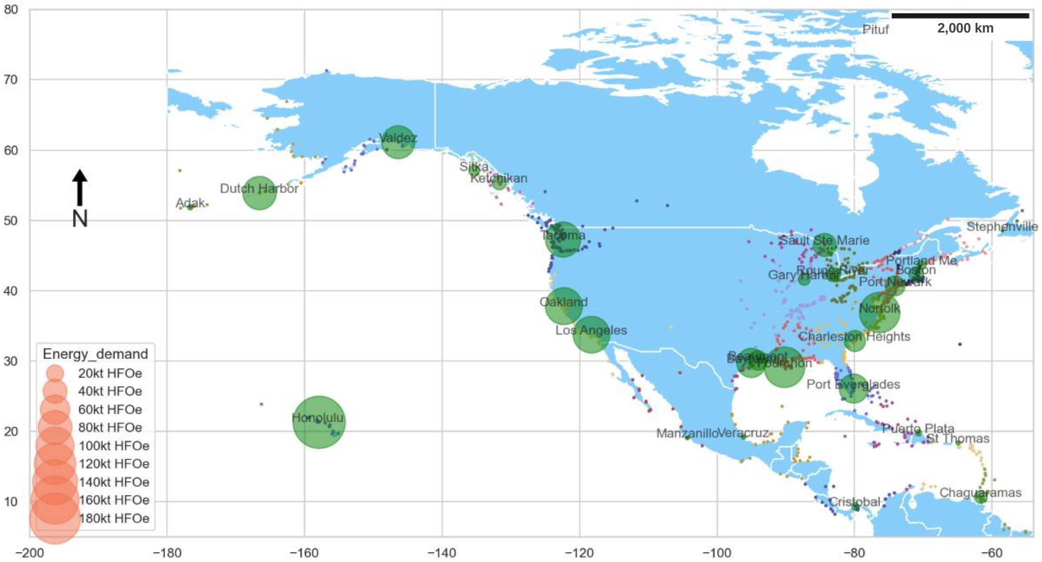
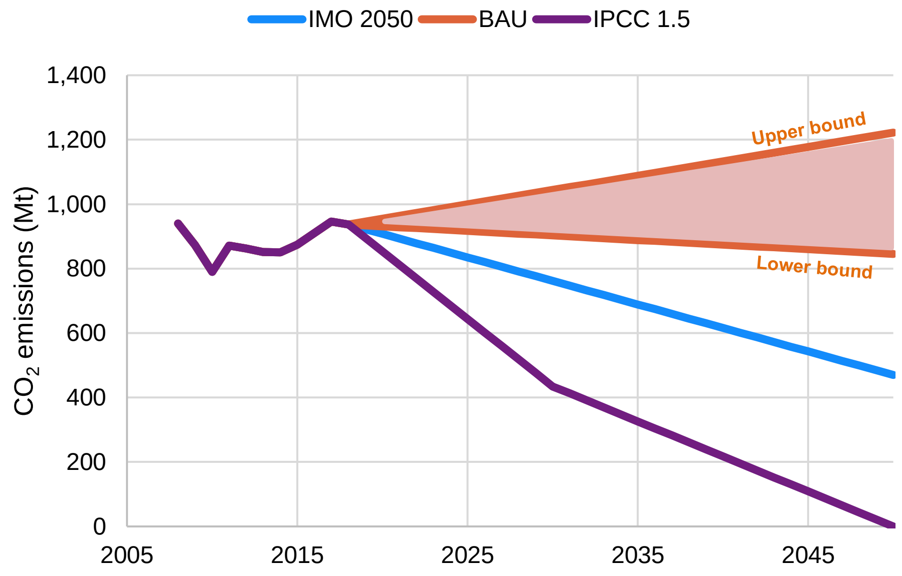


Figure note: The legend in the map indicates the amount of heavy fuel oil equivalent (HFOeq) required to meet the demand of each cluster.

Figure 5 Energy demand concentration for US fleet throughout the US

1 Introduction

Maritime shipping is a growing contributor to anthropogenic climate change, with total emissions of around 1 gigatonne of carbon dioxide equivalent ($GtCO_2eq$) in 2018 (2.89% of global emissions), which could increase to 90–130% of 2008 emissions by 2050 [2]. Following the adoption of the Paris Agreement and the stark warnings for temperature alignment coming from the Intergovernmental Panel on Climate Change (IPCC)[3], which imply the need for rapid decarbonisation, the industry is under increasing pressure to cut its carbon emissions. With such an aim in mind, in 2018 the International Maritime Organization (IMO) adopted an initial strategy to cut greenhouse gas (GHG) emissions from international shipping by at least 50% by 2050 compared with to 2008 level [4][2,3]. To reach this decarbonisation trajectory the shipping industry will have to significantly cut its emissions from the current business-as-usual case, as can be seen in Figure 1.1.



Source: References [2] and [3]

Figure 1.1 Global CO_2 emissions trajectories for potential future scenarios

Such a rapid decarbonisation pathway will require the shipping industry to change its current development trajectory and make a significant transition away from current ways of operating. Research by Lloyd's Register and UMAS showed that, while it remains important to maximise efficiency, future increases in energy efficiency cannot sufficiently lower GHG emissions from shipping on their own to meet the ambitions of the IMO's initial strategy [5]. In order for shipping to reach such goals, scalable zero emission fuels (SZEFs) will have to become an increasingly dominant part of the shipping energy fuel mix, replacing current fossil bunker fuels such as heavy fuel oil (HFO) and distillate fuels [5]. SZEFs contribute no GHG emissions throughout their whole lifecycle (both upstream in production and downstream when in use) and have no foreseeable supply constraints or barriers to production scalability. (For an in-depth analysis of the potential for future maritime fuels in the US, please refer to the related study by UMAS [1].)

As shipping is an international industry, this process will require a concerted global effort, including most IMO member states, and will likely require significant changes in the way that bunker fuels are produced, delivered and used by ships. Even though the US is the world's largest economy, with seaborne trade responsible for 53% of US imports and 38% of exports [6], the US has so far not been

[2] This applies only to international shipping's operational emissions and omits upstream emissions.

[3] This target is referred to as "IMO 2050" in Figure 1.1 for simplicity.

active in the decarbonisation of shipping, although this seems to be changing under the current Biden administration.

1.1 Background

Even though the IMO initial strategy was adopted after the Paris Agreement was signed, the IMO Maritime Environment Protection Committee (MEPC) set shipping on a course of low ambition that did not align with the international climate change targets agreed under the United Nations Framework Convention on Climate Change (UNFCCC) . Under the IMO initial strategy, both the absolute emission reductions and the intensity of the reduction ambitions fall far short of decarbonisation within a timeframe that avoids the consequences outlined by the IPCC [3]. This lack of ambition has been reinforced by short-term measures that will not achieve the ambitions of the IMO initial strategy, such as the Carbon Intensity Index (CII) and Energy Efficiency Existing Ship Index (EEXI) [7], [8].

The gap in regulation and policy left by the IMO MEPC is slowly but surely being filled by entities that want to mitigate against delayed action on shipping emissions. The interests of financiers [9], investors [10] and charterers[4] [11] are being addressed by industry-led initiatives driving alignment and disclosure of carbon intensity. A good example is the Science Based Targets Initiative (SBTi) – designed to help companies calculate carbon intensity, assess whether their activities are aligned with global temperature goals and make climate-aligned decisions towards decarbonisation of maritime transport – which is the most ambitious trajectory-based initiative at the time of writing [12], owing to the inclusion of lifecycle carbon emissions for fuels[5] and its aim for complete decarbonisation by 2050 to satisfy the IPCC's 1.5˚C temperature goal. The SBTi and similar actions are setting a course of ambitious targets for decarbonising shipping that also create an opportunity for countries to embrace them through national action plans.

In addition to these initiatives there are calls for a carbon tax [13] and, most relevant for this study, unilateral action from countries and regions. The most prominent unilateral actions being the inclusion of shipping in the European Union (EU) Emissions Trading Scheme, and the EU's "Fit for 55" pledge, which is a policy tool adopted to cut GHG emissions by at least 55% by 2030[6] [14]. The US has been similarly ambitious, with a strong commitment to decarbonise shipping by 2050 by the current administration [15], which has been echoed by the United Kingdom (UK) [16].

The Getting to Zero Coalition[7] has published a transition strategy [17] that suggests multiple levers are needed to achieve decarbonisation of shipping, and that although IMO may be a crucial lever for the mass market transition, national and regional action become all the more important at this early stage of "learn by doing", which is less likely to be stimulated by IMO action. In addition, a strong signal has been sent by the US and 21 other countries that signed the Clydebank Declaration at the Glasgow Climate Change Conference (COP 26) committing them to setting up green shipping corridors through international cooperation [18].

The US specifically listed maritime transport as an area of focus for emission reductions in its nationally determined contribution (NDC) submitted to the UNFCCC in 2021 [19]. The NDC refers to cooperating with international bodies such as the IMO to promote decarbonisation, but domestic shipping and ports are also singled out as providing an opportunity for emission reduction. In addition to the promise of upscaling renewable energy, especially offshore [19], and the pledge to reduce methane emissions by 30% to 2030 [20], there is a significant momentum that the US can exploit to accelerate the decarbonisation of maritime transport.

[4] Charterers hire vessels on a time or per voyage basis for transporting cargo.

[5] Well-to-wake as opposed to only operational tank-to-wake emissions.

[6] This applied to all intra-EU and 50% of EU-related voyages (starting or ending in an EU country).

[7] The Getting to Zero Coalition comprises over 150 companies that are committed to getting zero carbon shipping into operation by 2030.

Decarbonising US shipping can create large numbers of jobs and employment opportunities and, because the decarbonisation depends to a large extent on low-carbon hydrogen and the associated production and use technologies, it also creates opportunities for US firms to gain market share globally, both in shipping and in other areas of the rapidly emerging global hydrogen economy. Environmental benefits notwithstanding, there is a large economic prize arising from early action and the premium global positioning this can create in a future multi-trillion dollar market [21].

1.2 Study objective

This report presents the results of a study of the current status of the US fleet and its operation, with the aim of identifying key opportunities and potential for decarbonisation, particularly using SZEFs. The report will:

- Characterise the US-registered fleet through demographics
- Discuss the Jones Act and its role in shaping the US fleet
- Analyse operational behaviours and emissions based on automatic identification system (AIS) data
- Analyse voyage-based activity to characterise geographical operations
- Identify routes and locations with the highest potential for being first movers in decarbonisation.

2 Defining the US maritime fleet

The US maritime fleet is broadly defined as the vessels that are registered under the US flag. This fleet is divided into four main categories by the US Department of Transportation (DOT): nonself-propelled vessels; self-propelled vessels; self-propelled OGVs (1,000GT and above); and recreational vessels[8]. Table 2.1 shows the size of these fleet categories, and the historical time series for changes to fleet size is shown in Figure 2.1. It is unclear where smaller fishing vessels are included in these statistics, but for the purposes of this report it is assumed that these are included in the recreational vessel category.

Table 2.1 Number of vessels in the US-flagged fleet as of 2018

Vessel category	Number of vessels	Proportion (%)
Nonself-propelled	33,266	76.9
Self-propelled	9,904	22.9
Ocean-going	182	0.4
Recreational	11,852,969	–

Source: Reference [6]

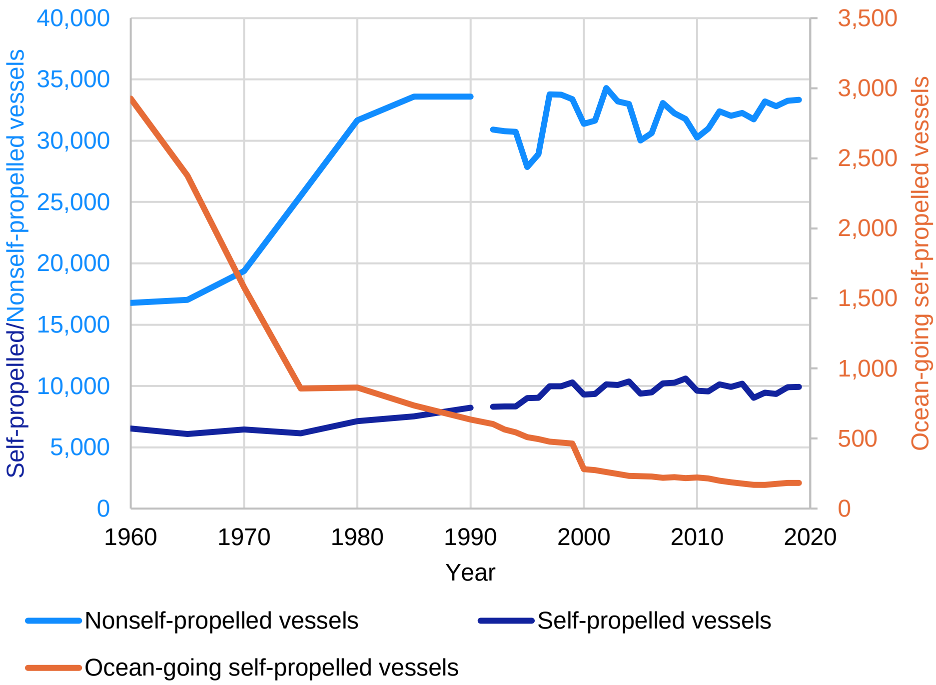


Figure note: Broken lines in early 1990s are due to missing data points.
Source: Reference [6]

Figure 2.1 US-flagged vessels in operation

Disregarding recreational vessels, the US-flagged fleet can be divided into vessels that operate domestically (self-propelled and nonself-propelled) and those that engage in international activity (ocean-going). The number of vessels in the ocean-going fleet (>1,000GT) has been declining since 1960, reaching 182 in 2019. United Nations Conference on Trade and Development (UNCTAD) places the US as the 21st largest flag (based on fleet deadweight) with 3,650 ships over 100GT at the beginning of 2020 [22]. It is not unusual for developed countries to have a small number of vessels registered under their flag, given that they usually have more onerous regulations to be followed which

[8] Nonself-propelled vessels do not have propulsion machinery on board, so need to be moved through external means such as a barge being pulled by a tug. Conversely, self-propelled vessels have the means to move independently.

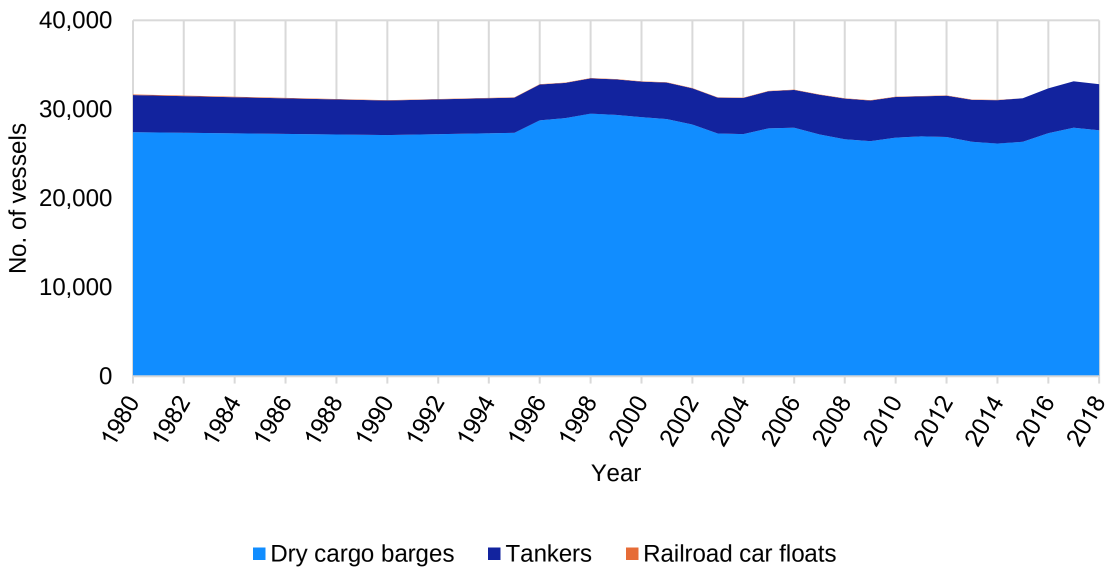
incentivises the growth of flags of convenience[9]. This fact raises questions around trade and national security for the US, which largely depends on foreign-flagged vessels for international import and export. The lack of control extends to the regulation of vessels because the IMO regulates foreign-flagged vessels and international trade, while port states, the United States Coast Guard (USCG) and the United States Maritime Administration (MARAD) have jurisdiction on US-registered vessels and activity within US territorial waters.

On the other hand, the shipping register can be used as a powerful tool towards decarbonisation, as the UK has set out to do in its Clean Maritime Plan [23], [24]. The USCG was also a leader in setting up unilateral regulation regarding ballast water treatment, which can be seen as setting a precedent for regulating vessels in US waters as well as the US-flagged fleet [25].

A distinction should be made between registration and ownership: although the US-flagged fleet is relatively small, the amount and value of vessels owned by US-based entities is significant, as the country ranks 10th and 4th respectively [22]. The Bureau of Transport Statistics (BTS) [6] provides further details on the type of vessel in each category (see Appendix A). In this report, only self-propelled vessels are considered because they are responsible for the emissions arising from merchant activity.

2.1 Historical trend of US fleet

In 1960 there were 2,926 OGVs in the US fleet, which was 16.9% of the world fleet [26], but by 2019 they accounted for only 0.34% [6]. The decline in the US-flagged OGV fleet has been sizeable and continuous over the past 50 years with 25% of US international trade being transported by US-flagged vessels in 1955, dropping to 1% in 2015 [27]. There was a sharp drop in general cargo vessel numbers in 2000 which, at the time of publication, could not be attributed to any particular event. Figure 2.2–Figure 2.5 show a time series of the fleet distribution for the three distinct categories identified[10], using data collected through BTS [6].

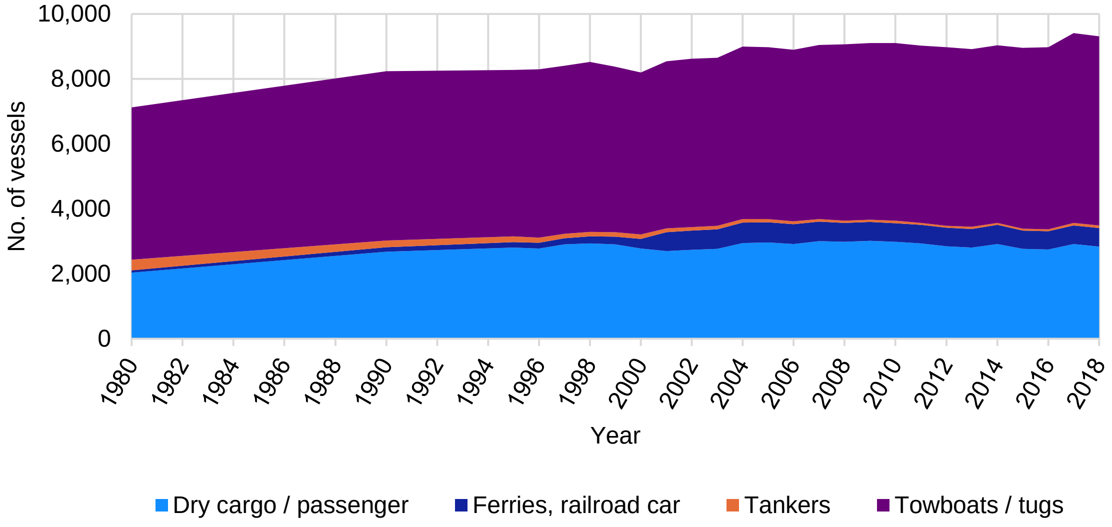


Source: Reference [6]

Figure 2.2 US-flagged nonself-propelled vessels, by type

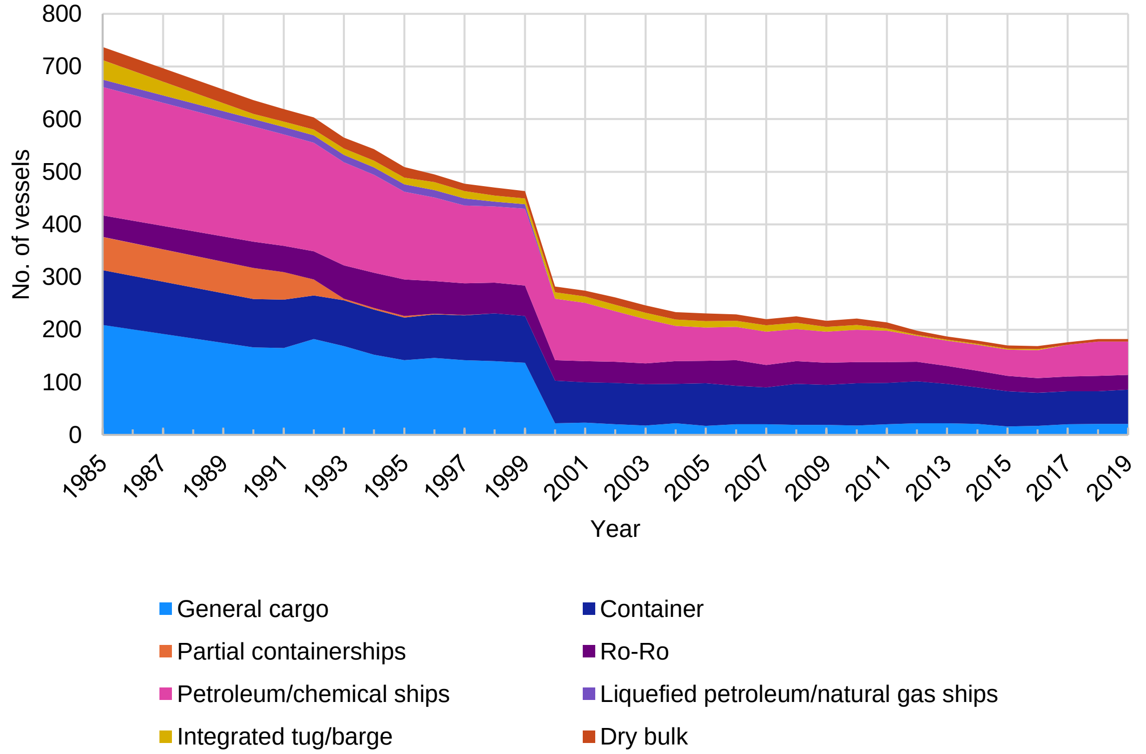
[9] The top five flags of convenience had 52% of the global fleet, by deadweight, registered under their flag in 2020 [22].

[10] Figure 2.2–Figure 2.5 show data from 1980 and not 1960 because of a change in vessel categorisation in BTS data [6]. Cargo vessels are grouped together, preventing a disaggregated view of fleet composition. A complete time series can be found in Appendix A.



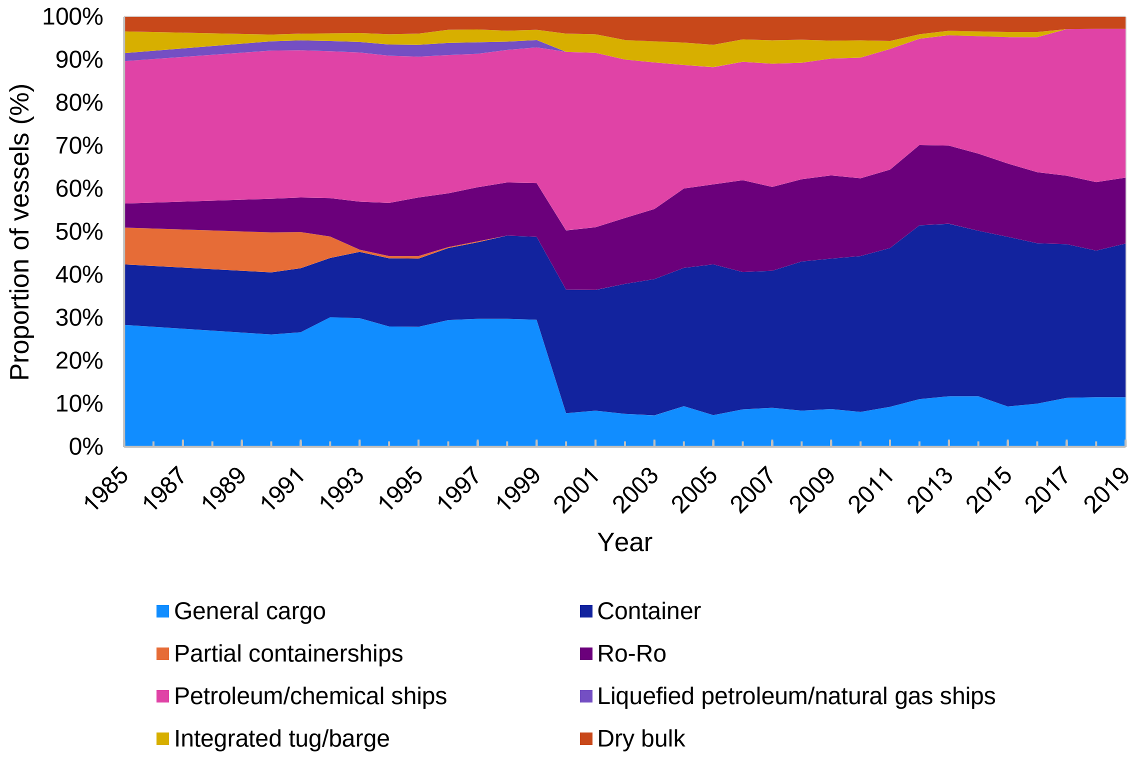
Source: Reference [6]

Figure 2.3 US-flagged self-propelled vessels, by type



Source: Reference [6]

Figure 2.4 US-flagged ocean-going vessels above 1,000GT, by type



Source: Reference [6]

Figure 2.5 US-flagged ocean-going vessels above 1,000GT, by type and proportion

2.2 The Jones Act fleet

A further distinction of shipping servicing in the US is the vessels that are part of the JAF, which is defined by Section 27 of the Merchant Marine Act of 1920 [26], as follows:

> *The Jones Act applies only to domestic waterborne shipments. It does not apply to the nation's international waterborne trade, which is almost entirely carried by foreign-flag ships. The U.S. citizen crewing requirement means that the master, all of the officers, and 75% of the remaining crew must be U.S. citizens. If the U.S. owner of a Jones Act ship is a corporation, 75% of the corporation's stock must be owned by U.S. citizens.*
>
> *Regarding U.S. territories, the U.S. Virgin Islands, US Samoa, and the Northern Mariana Islands are exempt from the Jones Act. Therefore, foreign-flag ships can transport cargo between these islands and other U.S. points. Puerto Rico is exempt for passengers but not for cargo. Vessels traveling between Guam and another U.S. point must be U.S.-owned and -crewed but need not be U.S.-built. The Jones Act is applicable to the State of Hawaii.*

The Jones Act was designed to provide protection to US shipyards, domestic carriers and sailors while also addressing concerns around national security. The Jones Act is a complex and nuanced piece of legislation that has had several conditions and exemptions added to it over the years to cater for specific conditions which have global trade ramifications [26].

Based on data from MARAD, the JAF in 2018[11] was made up of 98 eligible vessels (out of 181 total US-flagged vessels), but that only covers self-propelled OGVs (1,000GT and above) [28]. A time series of the JAF (Figure 2.6) shows how the fleet has been consistently declining in size since the 1950s, implying that those vessels currently remaining are of a significant age (see Section 2.4).

Jones Act fleet qualifiers

- Registered under the US flag
- Owned by US citizen or by corporation that has 75% of stock belonging to US citizens
- All major components of the hull and superstructure are fabricated in the US
- Master, officers and 75% of crew on board to be US citizens

No other information could be found about vessels that are part of the JAF but do not fall under the self-propelled OGV category; however, it is known that the fleet is much larger and includes [26]:

- Articulated tug barges (ATB) operating coastally and in the Great Lakes
- Bulkers operating in the Great Lakes
- Inland river fleets made up of tugs and barges (largely nonself-propelled) [29]
- Offshore supply vessels.

Thus there is a lack of clarity on how many of the US-flagged vessels (totalling over 43,000) are in the JAF. The above data describing the fleet was particularly difficult to find and required significant effort to collate, representing a barrier to access. Thus, in this study, analysis is carried out on all US-flagged vessels listed in a commercially available database [30] and treated vessels specified to be in the JAF separately.

Jones Act fleet or not?

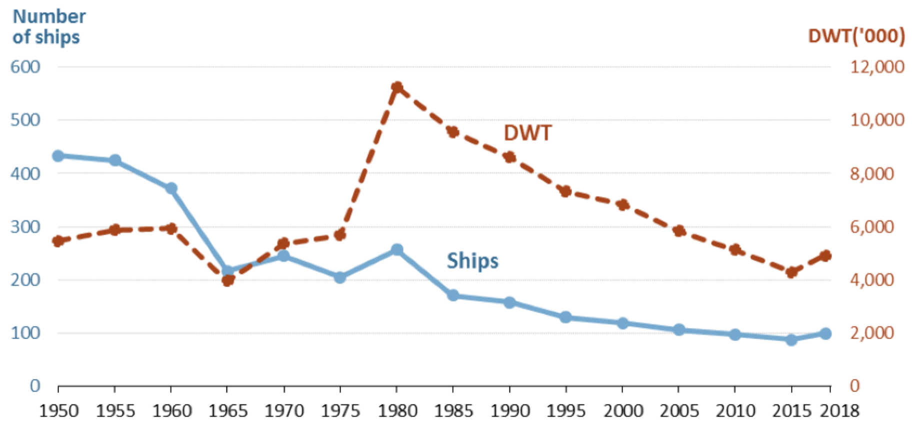
Two vessels that are very similar are not necessarily eligible to join the JAF because they must satisfy the four criteria listed above. Consider the sister ships Overseas Nikiski and Overseas Santorini. Both these vessels are tankers of a similar size and age and are registered under the US flag. They are owned by an US company; however, the Nikiski was built in the US at Philly Shipyard (formerly Aker Philadelphia Shipyard) while the Santorini was built at Hyundai MIPO in South Korea, making it ineligible to join the JAF [31], [32].

	Overseas Nikiski	**Overseas Santorini**
Flag	✓	✓
Ownership	✓	✓
Shipyard	✓	✗
Crew	?	?
JAF eligible	✓	✗

2.3 Decline in US and Jones Act fleet size

Figure 2.6 shows the decrease in the size of the fleet in the 1950s and 1960s that raised concerns around the availability of sealift capacity during the Vietnam War, leading to a temporary repeal of the Jones Act, which slowed the decrease in size of the JAF. In the late 1960s and 1970s more OGVs with larger cargo capacities joined the JAF, increasing the overall tonnage to include, for example, tankers for transporting Alaskan crude oil domestically [26].

[11] Fleet numbers up to 2020 remained similar to 2018. (This year has been chosen because of the operational data analysis in Section 3 which is based on AIS data from 2018.)



Source: Reference [26]

Figure 2.6 Time series of size of self-propelled ocean-going vessels in the Jones Act fleet

Domestic transport supply has increasingly shifted towards railroads and pipelines, with shipping losing market share despite being more fuel efficient and economical in some situations and avoiding the need to rely on the upkeep of road and rail networks. This may point towards the failure of the Jones Act to protect and strengthen the US maritime industry, with some critics arguing that it has added a barrier to trade due to higher costs and made the US fleet less competitive. One sign of this is that most of the revenue for domestic shippers comes from trade that is required by law to use US-flagged vessels [26].

The costs of keeping the Jones Act are not only evident in the increased cost of domestic shipping (due to high operating costs linked to employing US seafarers [33]) but in other aspects, including negative environmental impact and loss of domestic and foreign revenue [34]. Shifting cargo transport to other modes implies an increase in the carbon intensity of transport work, given that rail, road and air all have much higher environmental impacts. It also increases infrastructure costs because maintenance of US roads and rail tracks will subsequently increase, as will congestion, which can be translated into lost work and revenue.

The cost of building vessels in the US may be six to eight times higher than the same tonnage built in more competitive foreign shipyards [35], reducing the demand for US-built ships and hampering the shipbuilding industry and associated skilled workers. The Jones Act may therefore be essential to keeping the US shipbuilding industry from collapsing and protecting jobs that may be invaluable in times of national emergency or conflict when international cooperation would be limited. Moreover, this ship building, retrofitting and repair capacity may be fundamental in supporting the shift towards zero emissions vessels (ZEVs), making the US one of the leaders in this transition.

The additional costs related to the obligation of building and crewing vessels in the US so that they can participate in domestic trade has led to the rise of purpose-built ATBs. While this design performs better than barges, they are less reliable and efficient than ships and are at a higher risk of grounding because they operate closer to shore. ATBs carry more cargo tonnage (predominantly oil) on coastal voyages than ships [36]. Almost 90% of commercial vessels built in US shipyards since 2010 have been barges or tugboats [37].

When negotiating international trade agreements, even with the EU bloc, the US explicitly protects the JAF from free trade agreements [34]. Closer to home, US imports and exports for domestic demand are significantly affected by the limitations of the Jones Act, such as the fact that there are only two dry-bulk vessels are covered by the Act [35]. Although commodity rates are universal, transport costs are disproportionately leading to imports from other continents being cheaper than domestic ones. Some documented examples include the purchase of animal feed and fertilisers imported to Puerto Rico from afar [38]; states importing rock salt from Chile despite the US being the largest producer of this commodity [39]; and the movement of crude oil from the Gulf to the Northeast US being three times more expensive than when it is transported from Canada [35].

2.4 Age of vessels

The ageing of the US fleet is illustrated in Figure 2.7 based on data from the BTS [6]. While the dataset provided did not specify which parts of the fleet are included (e.g. container ships are omitted), it is clear that significant parts of the towboat, passenger, offshore support and dry-bulk cargo fleets were over 25 years old in 2018.

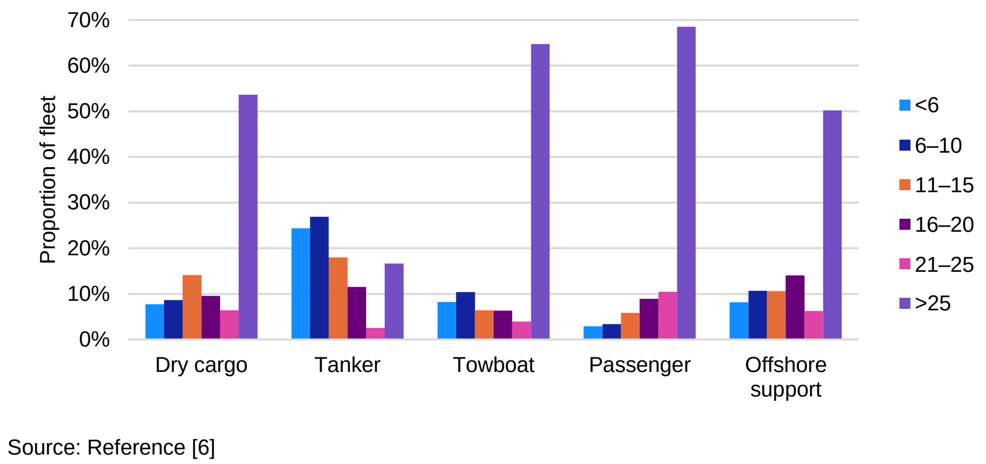


Figure 2.7 Age profile of US-flagged vessels in 2018

Comparing the US-flagged vessels to the global fleet, Figure 2.8 presents the difference in the median age of vessels of different types in operation as of 2021. Data regarding the global fleet technical specifications was obtained from the IHS Markit fleet register [30].

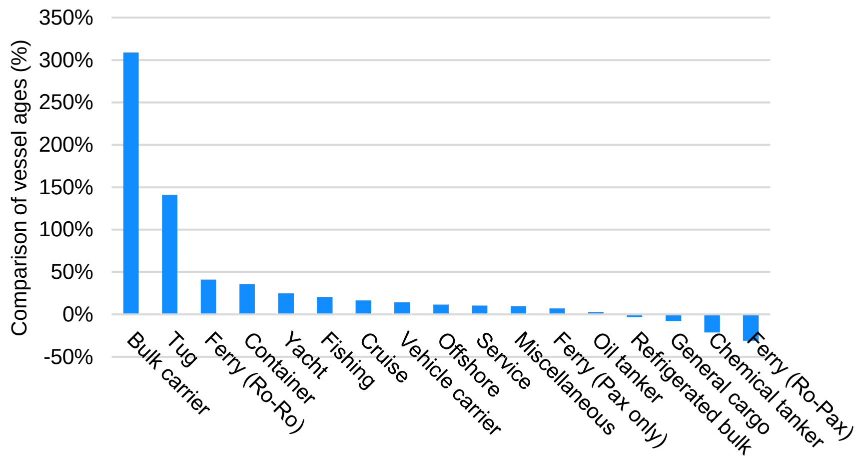


Figure 2.8 Comparison of median vessel age, by type, between the US-flagged and global fleets in 2021

As can be seen, the US fleet is older on average than the global fleet with only some exceptions in ferries (Ro-Pax), chemical tankers, general cargo and refrigerated bulkers. Tugs appear to be, on average, around 24 years older than those in the global fleet, which is noteworthy given the significant role that ATBs have been found to play in US domestic trade. Bulkers in the US fleet are on average three times older than the global fleet, at around 45 years.

Table 2.2 shows the median age of US-flagged vessels for different segments and compared with the global fleet median. Average scrapping ages for vessels (data from a couple of additional sources) are provided alongside. As can be seen, a significant number of vessels have exceeded the conventional useful lifetime, implying that these will likely have older technologies on board leading to lower efficiency. Some particularly old examples that can be found among the OGVs are small container ships supplying Hawaii, Puerto Rico and the archipelagos of western Alaska, which are aged between 33 and 41 years. On the inland waterways, there are bulkers that are 70 years old operating in the Great Lakes and service tugs over 50 years old across most of the country.

Table 2.2 Median vessel age for fleets compared with average global fleet scrapping age

Vessel type	US	Global	Global fleet average scrapping age
Bulk carrier	45	11	27
Chemical tanker	11	14	28
Container	19	14	24
Cruise	28	24	40
Ferry (Pax only)	30	28	42
Ferry (Ro-Pax)	20	29	38
Fishing	41	34	–
General cargo	24	26	32
Miscellaneous	23	21	–
Offshore	19	17	34
Oil tanker	17.5	17	24
Refrigerated bulk	31	32	–
Ferry (Ro-Ro)	24	17	31
Service	32	29	–
Tug	41	17	–
Vehicle carrier	16	14	31
Yacht	20	16	–

Source: Reference [39] and [40] for scrapping ages

Older ships have higher operating costs due to low fuel efficiency, higher maintenance costs and higher crewing levels. A statutory requirement from 1915 requires round-the-clock crew attention on machinery, and this takes at least three crew shifts per 24-hour period and prohibits mariners from working in both the deck and engine departments, discouraging the adoption of new technology [36]. When considering the top four emitting vessel types, as identified in Section 3.2, container ships and tugs tend to be older in the US fleet, which implies that the high emissions may be attributed to lower efficiency related to ageing machinery.

A clearer picture of the variation of vessel ages within the vessel types can be seen in Table 2.2, which presents the proportion of the fleet in 5-year age bands (similar to the analysis in [22]). An additional column shows the average scrapping age of vessels of the global fleet from two different sources. Although these numbers do not take the vessel size into consideration, which may also have nuanced effects on scrapping age, some vessel types in the US fleet stand out as being significantly over their useful lifetime. Most prominently, 92% of bulk carriers, 40% of containers, 37% of ferries (Ro-Pax), 42% of general cargo and 42% of Ro-Ro vessels. At the time of writing, no data specific to the scrapping of US vessels was available.

In the short term, there are various cost-effective and time-efficient emission reduction options for ship owners to consider, ranging from operational measures such as route and trim optimisation to wind-assist propulsion technologies all of which are considered essential in the pursuit of aligning shipping with international targets on GHG emissions [7], [40]. Several sources indicate that an ageing fleet is one of the consequences of the restrictive nature of the Jones Act, which has a negative impact on the US economy as a whole [37], [41]. Chapter 3 discusses how operational profiles make many US vessels optimal candidates to be first movers in decarbonisation and therefore ideal for targeted policy mechanisms.

Table 2.3 Comparison of vessel age (%) between US-flagged and global fleet, by type

Vessel type	Fleet	Vessels (%) by age group									Global fleet average scrapping age [40], [42]
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40+	
Bulk carrier	Global	6	33	31	11	8	5	3	1	3	27
	US	0	0	0	2	5	0	0	2	90	
Chemical tanker	Global	6	17	32	18	9	7	5	3	4	28
	US	11	30	45	2	4	2	0	0	6	
Container	Global	5	19	30	22	14	7	2	1	1	24
	US	0	3	20	29	9	9	6	8	17	
Cruise	Global	5	8	12	13	14	9	12	8	20	40
	US	8	4	8	12	15	12	4	27	12	
Ferry (Pax only)	Global	3	8	8	9	12	13	13	9	27	42
	US	1	11	10	21	22	11	7	3	13	
Ferry (Ro-Pax)	Global	4	10	10	10	11	11	11	7	28	38
	US	1	5	8	16	11	9	7	6	37	
Fishing	Global	1	7	3	6	9	8	15	10	39	–
	US	0	1	1	5	10	8	11	7	56	
General cargo	Global	2	9	17	10	8	11	10	10	22	32
	US	3	19	16	6	10	0	0	3	42	
Miscellaneous	Global	5	18	17	6	7	6	6	7	28	–
	US	2	10	16	13	17	6	5	15	18	
Offshore	Global	3	23	19	9	6	3	3	10	23	34
	US	2	17	19	15	15	5	3	5	19	
Oil tanker	Global	5	15	21	15	8	10	6	5	14	24
	US	0	11	0	56	28	0	0	0	6	
Refrigerated bulk	Global	1	1	3	2	13	16	22	19	24	–
	US	0	20	0	0	0	0	60	0	20	
Ro-Ro	Global	4	19	18	15	11	7	5	5	16	31
	US	0	16	5	16	16	5	0	0	42	
Service	Global	4	15	12	7	7	6	9	10	30	–
	US	1	4	3	11	19	7	8	10	37	
Tug	Global	3	20	21	11	7	6	4	6	22	–
	US	3	7	10	6	8	4	2	6	54	
Vehicle carrier	Global	4	15	36	16	15	7	4	2	1	31
	US	10	0	20	25	20	25	0	0	0	
Yacht	Global	4	16	23	17	9	6	6	4	15	–
	US	2	16	16	11	17	2	6	5	25	

Source: Reference [30]

3 Operational performance analysis

This chapter analyses the operational aspects of the US fleet based on their activity, using data from the UMAS Fuel Use Statistics and Emissions (FUSE) model that combines vessel technical specifications and AIS data to estimate fuel consumption and emissions, while also gathering operational statistics. The model has been used for several applications, including the Third and Fourth IMO GHG studies [2], [43]. The analysis in this chapter is based on transport activity in 2018.

3.1 Greenhouse gas emissions

Figure 3.1 shows the total GHG emissions for US-flagged vessels for 2018, which amount to around 26MtCO_2, or 2.4% of global shipping emissions. Of these emissions 71% relate to domestic trade, presumably by vessels in the JAF, while the remainder are from international voyages. Not all vessels are captured in the AIS data because of poor coverage in some geographical areas, incomplete datasets or smaller vessels not having AIS fitted or switched on for a long enough period.

An algorithm used in the Fourth IMO GHG Study [2] has been used to account for the GHG emissions from the vessels that are missing in the AIS database but whose technical specifications are found in the vessel database. The purpose of the algorithm is to infill the missing GHG emissions based on the average behaviour of a vessel of corresponding type and size (referred to as “infilled” emissions from here onwards). More detail about this methodology can be found in Section 2.2.4 of the Fourth IMO GHG Study [2].

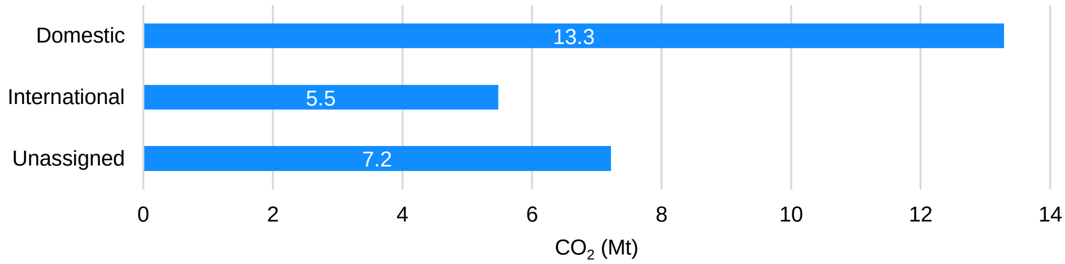


Figure note: “Unassigned” emissions are those captured in the infilled data that they cannot be specifically assigned to international or domestic trade.

Figure 3.1 US-flagged fleet international and domestic emissions in 2018

Most emissions are domestic, presenting a unique opportunity for national regulations to be used as an effective tool towards decarbonisation. An approach similar to that used for the regulation and enforcement of ECAs could be gradually introduced to reduce the prevalence of fossil fuels, as vessels operating in domestic US water are replaced by new builds or are retrofitted. Alternatively, additional conditions for JAF eligibility could be introduced that require low or zero-carbon operation for vessels operating in US cabotage.

3.2 Fleet characterisation for analysis

Following a thorough desktop research study based on federal sources of information available regarding the US maritime fleet, vessels were assigned to different types to align with the Fourth IMO GHG Study [2], which makes it possible to compare them with the global fleet and to use the existing emissions estimate and operational metrics database. Table 3.1 gathers the US fleet size information from the DOT, those specified in the vessel database [2], and those captured in the AIS dataset used for emission estimates and operating profile analysis.

Table 3.1 US fleet database comparison and emissions for 2018

Vessel type	Qty in DOT stats.	Qty in vessel database	Qty in AIS database	AIS CO_2 emissions (Mt)	Infilled CO_2 emissions (Mt)	Total CO_2 (Mt)
Bulk carrier	5	41	37	0.69	0.05	0.74
Chemical tanker	–	47	46	1.45	–	1.45
Container	62	66	63	4.72	0.18	4.90
Cruise	–	26	22	0.27	0.03	0.30
Ferry (Pax only)	2,919	135	94	0.6	0.07	0.67
Ferry (Ro-Pax)	569	100	86	0.31	0.13	0.44
Fishing	–	3,014	1,230	2.29	3.33	5.62
General cargo	21	31	18	0.24	0.05	0.29
Miscellaneous	–	103	55	0.72	0.63	1.35
Offshore		1,004	572	1.97	1.49	3.46
Oil tanker	144	18	18	0.83	–	0.83
Refrigerated bulk	–	5	5	0.05	–	0.05
Ro-Ro	29	19	11	0.47	0.04	0.51
Service	–	217	147	0.74	0.35	1.09
Tug	5,844	1,521	1,156	2.65	0.84	3.49
Vehicle	–	20	20	0.73	–	0.73
Yacht	–	83	42	0.04	0.03	0.07
Uncategorised	9,904	–	–	–	–	–
Total	10,086	6,450	3,622	18.76	7.22	25.98

Although only 56% of the US fleet is captured on AIS in terms of the number of vessels, these vessels represent 87% of the fleet by DWT. Only around half of small vessels such as fishing, offshore, yachts and others are included in AIS, so their emissions have been infilled. Overall, the infilled emissions account for 28% of the emissions, illustrating the importance of considering these vessels. A complete overview of the fleet and emissions can be found in Appendices A and C. Overall, the US fleet emitted almost 26Mt CO_2 in 2018, equivalent to 0.5% of domestic US emissions [44].

Further disaggregation of the fleet data is shown in Figure 3.2, which illustrates why upgrading the vessel types that account for the largest part of the fleet may not be the best strategy towards decarbonisation. However, tackling niche sectors (e.g. fishing, offshore vessels and tugs) could have a significant impact on emission reductions and help to focus attention on the development of appropriate propulsion and fuel technologies.

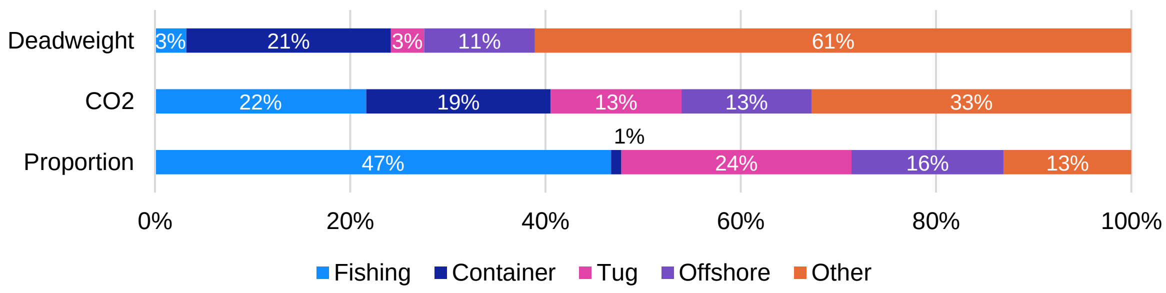


Figure 3.2 US-flagged fleet distribution, deadweight and carbon emissions by vessel type in 2018

3.3 Operating profile

Figure 3.3 shows the number of days spent at sea and at berth by different vessel types. This information shows that several vessels spend over two-thirds of their year at berth, indicating that they might be candidates for technologies such as shore power and electrification (given the time available for charging). Another consideration is that coastal communities may be disproportionately affected by pollutants because of the consumption of fuel in locations close to shore. This is increasingly becoming apparent, given the problems with port congestion seen throughout Q2, Q3 and Q4 in 2021 leading to port authority action to ease this pressure [45].

The data in Figure 3.3 shifts some of the focus slightly from the fleet to port infrastructure and operational efficiency. Measures such as virtual and just-in-time arrival[12] are relatively low capital intensive ways to reduce congestion, thus improving overall performance of vessels through operational optimisation [46], [47]. Charterers also benefit from such measures because demurrage costs can be significantly reduced or eliminated. Although it might not be suitable for all trades and some barriers are known to exist with implementation related to crew and charterer preference [48], there are significant benefits to be reaped by port authorities that invest in the infrastructure to accommodate these measures presenting a mutually beneficial situation for all parties involved.

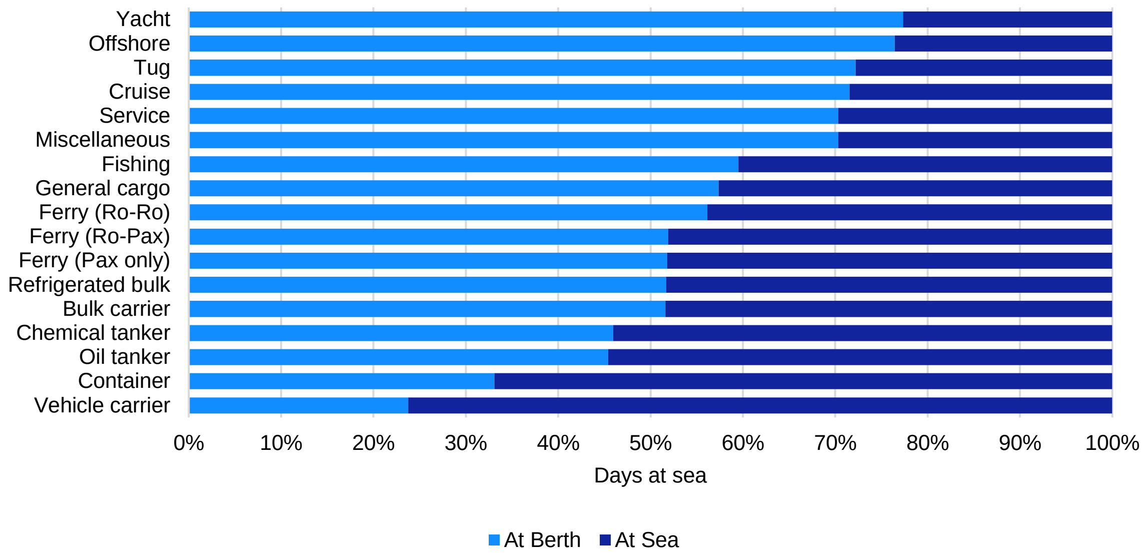


Figure 3.3 Distribution of annual days at sea and at berth for US-flagged fleet in 2018

3.3.1 Energy use

When considering time at sea and at berth, the amount of energy consumed is also important because most vessels consume very little energy while at berth. However, vessels that have a lot of waiting or loading time embedded in their operating profile can have almost 90% of their energy consumption at berth. Such vessels may be ideal candidates for shoreside power to avoid their use of auxiliary generators and boilers while in port. With this in view, Figure 3.4 displays the energy proportion at sea and at berth, while Figure 3.5 presents the cumulative energy demand for vessels in the US-flagged fleet.

[12] Virtual arrival is an operational process that involves reducing a vessel's speed on a voyage when there is a known delay at the discharge port that would result in unnecessary waiting.

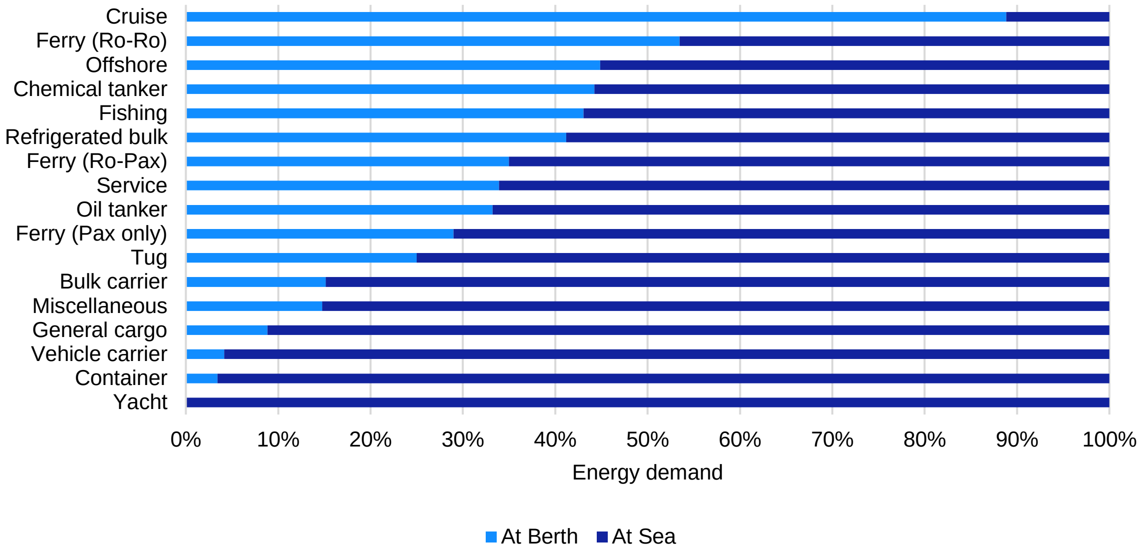


Figure 3.4 Energy proportion at berth and at sea for US-flagged fleet in 2018

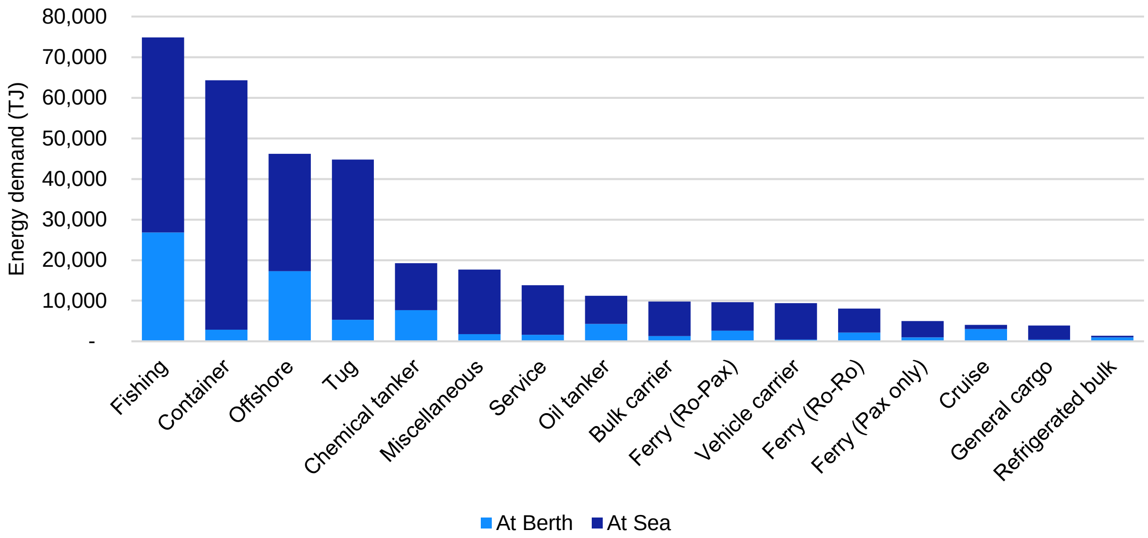


Figure note: Infilled energy demand is omitted as actual demand of consumers cannot be assumed accurately. This gives rise to the difference in proportions for the same vessel type between Figure 3.4 and Figure 3.5.

Figure 3.5 Absolute energy requirement at berth and at sea for US-flagged vessels in 2018

Figure 3.6 shows the total energy consumption of the vessel types but segmented by type of consumer – either main engine, auxiliary engine or boilers. Expressing the energy consumption proportionally at sea and at berth (as shown in Figure 3.7) shows that, for most vessel types at sea, the main engine provides almost all the energy demand. Exceptions to this are cruise, fishing and refrigerated bulk type vessels that have much greater energy demands for operational activities when at sea. For any vessel type at berth, the energy consumed by on-board equipment is entirely generated by the auxiliary engine or auxiliary engine and boiler combined.

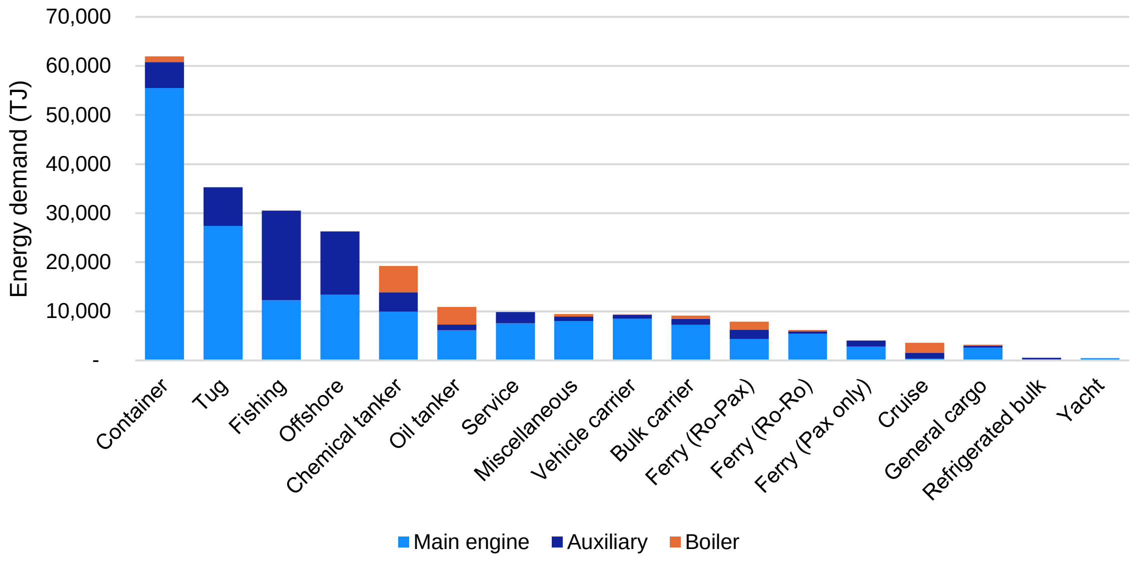


Figure note: Infilled energy demand omitted as actual demand of consumers cannot be assumed accurately. This gives rise to the difference in proportions per vessel type between Figure 3.6 and Figure 3.7.

Figure 3.6 Total on-board energy demand for US-flagged vessels in 2018

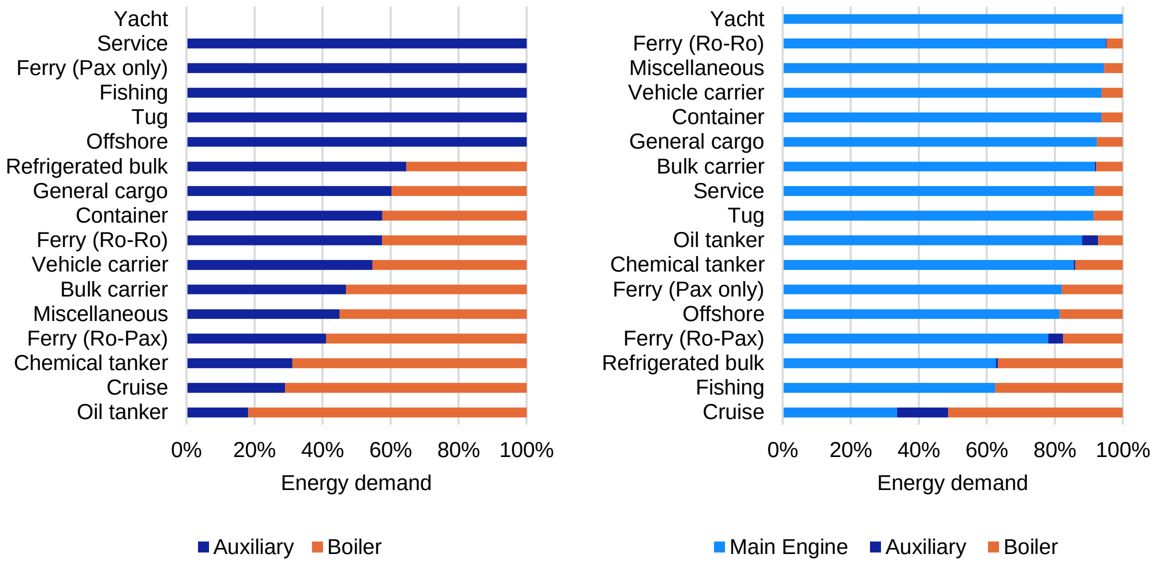


Figure 3.7 Energy demand by consumer type at berth (left) and at sea (right) for US-flagged vessels in 2018

3.3.2 Fuel mix

As with many fleets worldwide, the current on-board machinery used in US-flagged vessels does not accommodate zero-carbon fuels, meaning the fuel mix is solely dominated by fossil fuels, mainly HFO, marine diesel oil (MDO) with a small proportion of liquefied natural gas (LNG). Details of the fuel mix are shown in Table 3.2 and in Figure 3.8. As can be seen, the US fuel mix is largely represented by MDO, unlike the global fuel mix, where HFO is predominant.

Table 3.2 Energy demand (TJ) of US-flagged fleet, by fuel type, in 2018

	MDO	HFO	LNG	Methanol	Total
Total US fleet (TJ)	178	68	2	0	248
Total US fleet (%)	72	27	1	0	–
Total global fleet (%)	31	66	3	0	–

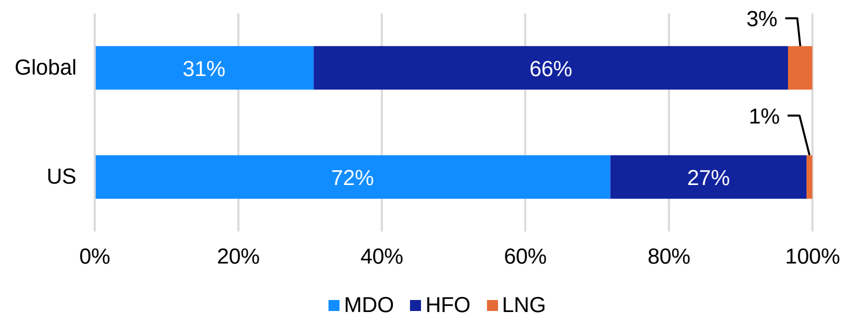


Figure 3.8 Comparison of fuel mix for global and US-flagged fleet in 2018

The difference between the global and US fuel mixes is that the US-flagged fleet is predominantly ships that operate within US waters and therefore are subject to the ECA emission regulations [25]. For ship operators to abide by such regulations, which address the level of sulphur, nitrous oxide and particulate matter, HFO must be replaced by MDO. Evidence for this can be seen in Figure 3.9, which shows that container ships (that spend most of their time in international waters away from ECAs) consume three times as much HFO as MDO.

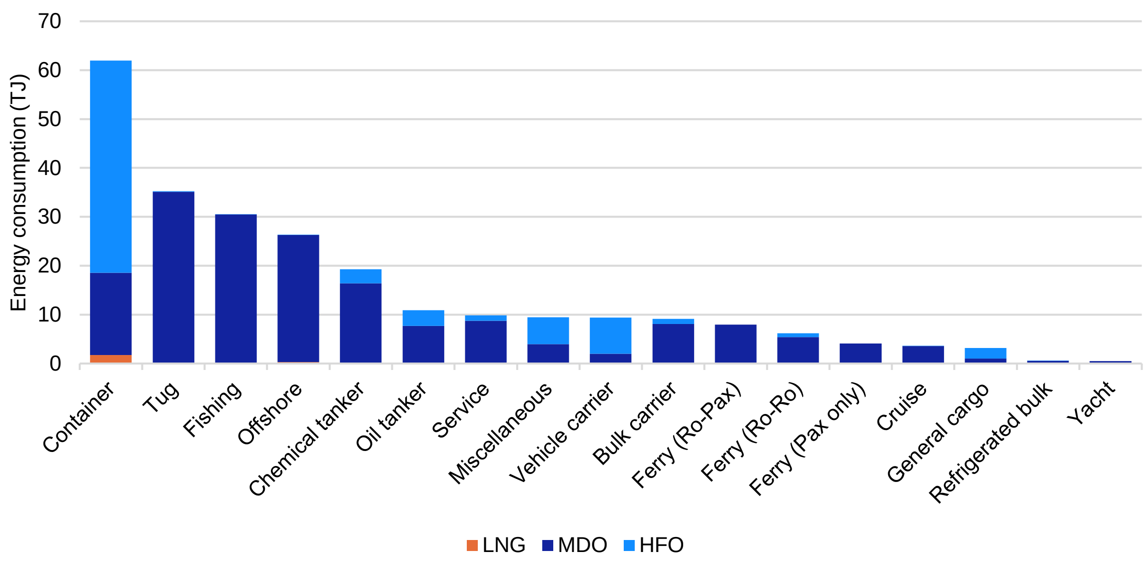


Figure 3.9 Energy consumption by fuel type (TJ) for US-flagged vessels in 2018

Figure 3.9 shows a small amount of LNG being used as a fuel for container ships: this can be attributed to vessels operating between Florida and Puerto Rico [49], which are equipped with dual fuel engines due to their operation through ecologically sensitive areas on a closed-loop route making bunkering easy. While this may be seen as a solution to reduce CO_2 emissions, LNG has been extensively shown to be ineffective at reducing overall GHG emissions for several reasons, including methane slip [50],

[51], and use of LNG presents a serious risk of stranded assets[13] if investment in bunkering infrastructure is pursued [52], [53]. The notion of LNG playing a role as a temporary or transitionary fuel is flawed, given the subsequent technology lock-in that would be a barrier to achieving zero carbon emissions. This is an increasingly important factor to be considered in the US, given the decisions being made on investing USD 1.2 trillion for the Infrastructure Investment and Jobs Act [54]. The US, having signed the methane reduction pledge to reduce emissions by 30% by 2030, will hopefully discourage further financing and investment in LNG infrastructure [20].

3.4 Carbon intensity

Carbon intensity has become an increasingly important metric for benchmarking vessel performance in recent years, with the advent of the IMO's Data Collection System and the associated calculation and reduction of the CII introduced as one of the short-term measures towards the 2050 emission reduction ambition [4]. A more meaningful metric is the Energy Efficiency Operational Index (EEOI) which is the ratio of carbon emissions to the actual transport work performed by moving cargo, measured in grams per CO_2 per tonne of transport work per nautical mile (gCO_2/t nm)[14] [55]. This is currently a voluntary metric created by the IMO MEPC; however, schemes such as the Sea Cargo Charter [11] have embraced it to benchmark against an emission reduction trajectory that aligns with the IMO's 2050 minimum 50% reduction target.

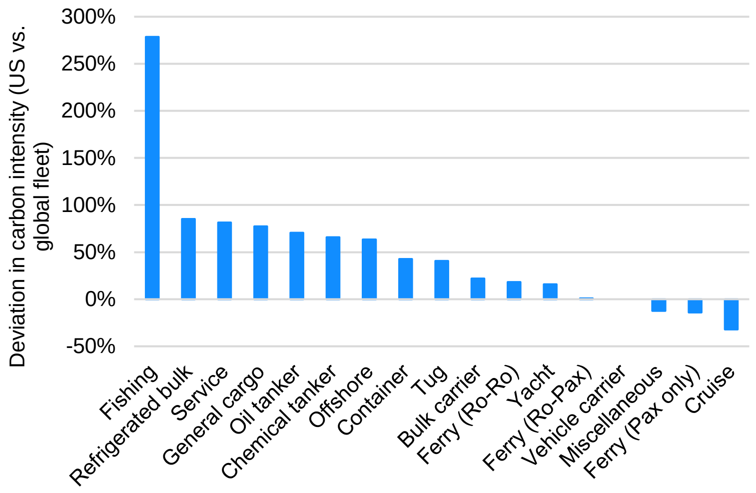


Figure 3.10 Deviation in average carbon intensity between the US-flagged and global fleets in 2018

Figure 3.10 illustrates the average difference between estimated EEOI of the US-flagged and global fleets. There is a clear trend showing higher carbon intensity for most vessel types, with the exceptions being Ro-Pax ferries and cruise vessels, which perform slightly better than the global median. A reduction in EEOI can be achieved through additional operational measures and energy efficiency technologies that may be retrofitted or become an integral part of new builds as fleet renewal takes place. Once again, ports can aid the improvement of operational efficiency by implementing measures such as better ship-to-shore communications and scheduling facilities to reduce waiting times.

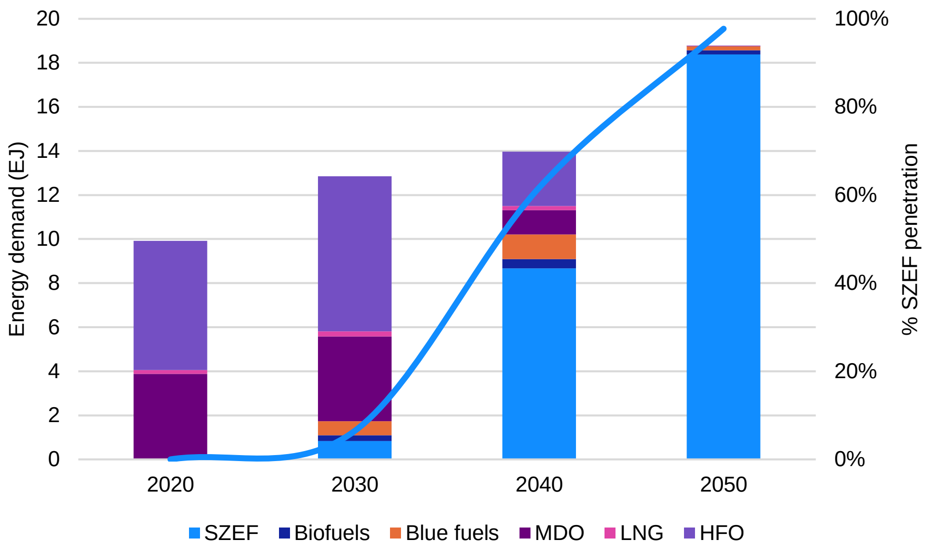
[13] Stranded assets in shipping can be defined as a vessel or infrastructure that has suffered from premature devaluation or becomes a liability.

[14] Carbon intensity is expressed in grams of CO_2 per tonne of transport work per nautical mile (gCO_2/t nm) for all vessel types with the exception of vehicle carriers, cruise vessels, and ferries (Ro-Pax and Pax only), for which carbon intensity is expressed as grams of CO_2 per GT of capacity per nautical mile (gCO_2/GT nm), because the cargo, and therefore the transport work of these vessel types, cannot be expressed in tonnes.

4 Voyage-based analysis and green corridor identification

This chapter analyses the voyage-based activities of vessels with a view of identifying routes with the highest decarbonisation potential. This type of analysis builds an evidence base for policymakers, with the aim of informing decisions on optimal onshore investment and vessel technology based on current operational trends.

The methodology used for the analysis was developed by UMAS for the Getting to Zero Coalition transition strategy [17], which is based on the assumption that to achieve full decarbonisation by 2050 a short-term goal should be set: to reach a 5% penetration of SZEF uptake by 2030. Technological transitions in other sectors have historically followed an S-shaped curve. Therefore, it is likely that the transition will be characterised by a slow introduction of SZEF followed by a phase of accelerated uptake tailing off thereafter (Figure 4.1).



Source: Adapted from [17]

Figure 4.1 Global fuel transition mix towards decarbonisation in 2050

In addition to a quantitative target, the Getting to Zero Coalition transition strategy elaborates on institutional pathways that may be followed to incentivise the actions required to reach these targets. These can be grouped as follows:

- Strong unilateral initiatives (leading countries):
  - Support SZEF production; research, design and development; shipbuilding; and retrofitting
  - Identify potential of domestic fleets and routes on which impactful incentives and regulation can be applied to minimise financial risk for the industry stakeholders
  - Commit and facilitate development in other countries and industries (i.e. shipbuilders, zero-carbon energy producers, etc.)
- Independent national spread:
  - Commitment by the government, industry and the energy sector for collaboration on a national scale aimed at reducing fuel costs in various regions
  - Support for large-scale SZEF demonstration projects
  - Identify bilateral/multilateral routes in which participant countries can deploy/agree on initiatives leading to decarbonisation
- Global actions leading to international spread:
  - IMO facilitating development of a policy regime for shipping
  - Commitment by key shipping industry actors towards zero GHG emissions by 2050

- SZEF provision becoming guaranteed at a global scale under the implementation of a worldwide institutional push. In this case, rather than evaluating 'routes', national fleets would assess regions in which their fleets operate to identify the likely timeline to fully cover its decarbonisation potential.

The strategies described above frame three contextual scenarios under which a decarbonisation transition may be deployed, most likely in parallel but at different timelines. For most countries, the US being a leading example, unilateral and independent national strategies are intuitively most suitable because they can be linked to the country's leading technological and political roles, as well as to the high potential to produce renewable energy and the strength of the domestic registered and operating fleet. A strong potential for renewable energy is an ideal indicator of the future availability of SZEF, while the operational and administrative characteristics of the US fleet (such as the Jones Act) provide the political leverage to implement impactful measures. The rest of this chapter characterises the efforts that are likely to lead to the highest emission reduction impact while minimising financial risk.

Please note that the data used for the following analysis includes AIS reporting vessels only. Therefore other vessel types, such as recreational boats or small fishing vessels, are not fully covered by the results. Given that those vessels comply with the definition criteria for electrification, they represent further capacity for decarbonisation via electrification.

4.1 Methodology

To address the questions above, routes that are most likely to kick-start the transition have been identified as first mover routes by analysing the geography of areas and ports, the vessel types and sizes, and energy demand for their decarbonisation through the steps described below. All of the analyses in this section is based on fleet activity from 2018 with supplementary data presented in Appendix E.

4.1.1 Geographical location of US fleet in terms of energy demand

To assign a geographical location to the energy demand of the US fleet, it was assumed that the fuel consumed on each voyage is provided at the departure port identified through AIS data. The resulting energy demand of all ports was then aggregated in clusters around the world to identify regions of concentrated demand. Figure 4.2 presents aggregated energy demand of the US fleet throughout the US, represented by the green circle size. The coloured dots indicate the locations of departure ports for US fleet vessels, with colours describing ports belonging to the same cluster (as defined in Section 4.1.2).

The energy demand of the US fleet is concentrated around the Gulf of Mexico, the Washington coast, and New York and New Jersey, followed by California, Alaska, Hawaii and the Great Lakes. Oakland and Long Beach are known for their major roles as ports, and the results indicate that their share of energy demand for US vessels is low when compared with other port areas in the country.

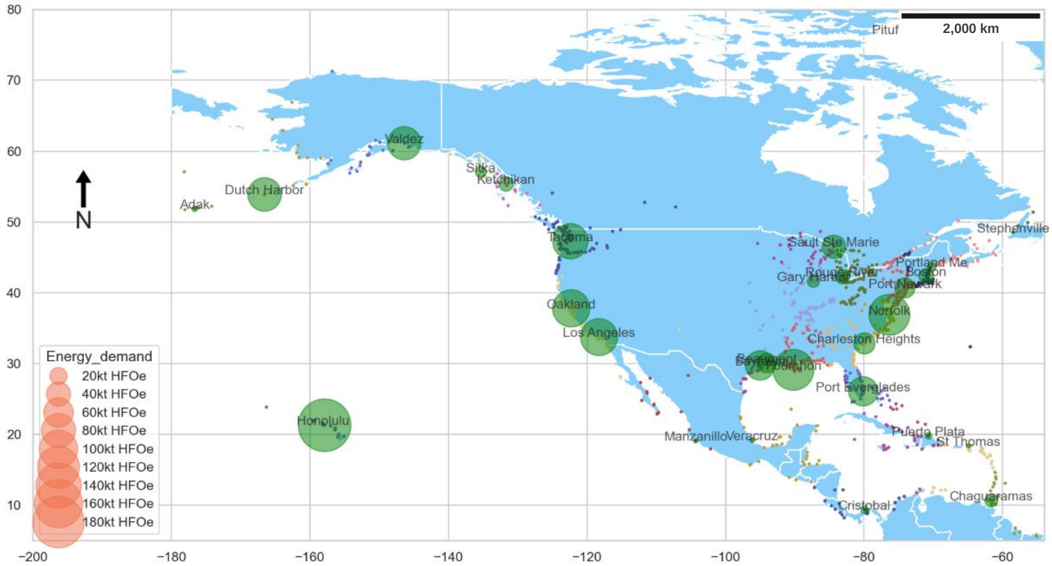


Figure note: The legend in the map indicates the amount of HFOeq required to meet the demand of each cluster.

Figure 4.2 Energy demand concentration for the US fleet throughout the US

4.1.2 Voyage-based analysis and cluster identification

The aggregated energy demand was used to define three different route types based on the voyage activity in or between clusters. Three route types are defined as follows:

Intra-cluster routes: Routes on which vessels exclusively operate inside a single cluster of ports within which all bunkering is undertaken. Figure 4.3 presents an example of this, in purple, with all the vessel activity concentrated around Hawaii. If SZEFs were provided to the ports belonging to such a cluster through localised production and distribution networks, the energy demand of these vessels would be covered, suggesting that these routes are top candidates for decarbonisation.

Bilateral routes: Routes on which vessels connect two clusters. These routes go beyond local ports, implying longer voyages usually on specific trades. These routes are represented as yellow lines on Figure 4.3, which shows an example of trade between the Hawaiian and Washington State clusters. This route type also captures long voyages between two different regions with various stops in nearby ports at either end of the route.

Multilateral routes: Routes on which vessels connect three or more clusters for which all port stops have a strong SZEF production potential. This group captures the activity of vessels covering longer distances with sporadic yet expected stops along the route. The routes in teal on Figure 4.3 show the corridor between Washington State and Dutch Harbour (Alaska) and stops in clusters along the way. The increment in clusters involved and the lesser regularity of these trading patterns indicates the next level up in the complexity of harnessing GHG reduction potential.

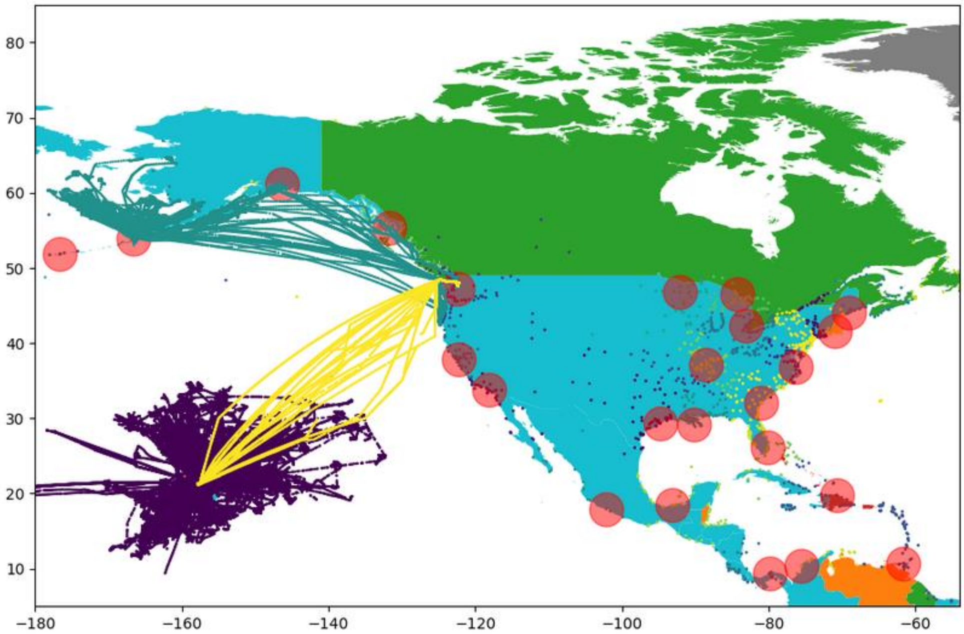


Figure 4.3 Examples of intra-cluster, bilateral and multilateral operation

4.1.3 Selecting zero emission solutions based on operational patterns and vessel characteristics

On the basis of the cluster analysis, specific routes have been classified in terms of their decarbonisation potential, depending on the type and size of vessel that operates on the routes on their operating profile. Two distinct types of clusters have been identified: those with a strong case for electrification, and others more suited to SZEF development.

The main condition for electrification is having small vessels operating locally with mean voyage ranges of less than 100nm. It is broadly assumed that these energy demands can be met by the current state-of-the-art batteries and provision of onshore infrastructure [56]. Table 4.1 lists the vessel types and sizes that are identified for electrification potential based on their activity.

Table 4.1 Vessels identified as candidates for electrification based on type and size

Ship type	Maximum size	Unit
Container	250	Twenty-foot equivalent unit (TEU)
Oil tanker	3,000	DWT
General cargo	3,000	DWT
Cruise	2,000	GT
Ro-Ro	5,000	DWT
Tug	–	GT
Offshore	–	GT
Fishing	–	GT

Vessels with a more flexible trading profile, longer range and generally bigger dimensions are most suited for using SZEFs for fuelling internal combustion or fuel cells. Fuels such as hydrogen, ammonia and methanol are most suitable, given that their first production step (synthesis of hydrogen derived from electrolysis fed by renewable electricity) is common. More details around maritime fuels can be found in the related report [1]. For the purposes of this report's analysis, all vessel types and sizes not included in Table 4.1 are considered as suitable candidates for the uptake of SZEF.

4.2 Analysis

4.2.1 Electrifiable fleet

A total of around 19% of the energy demand of the US fleet has a strong potential for electrification across different operational modes, as shown in Figure 4.4.

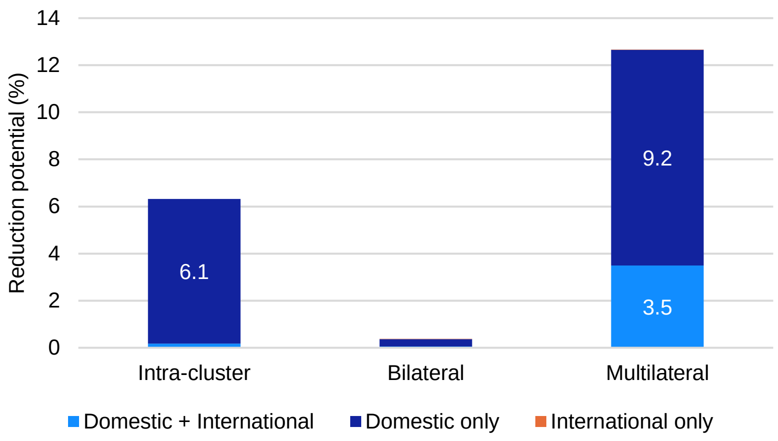


Figure 4.4 First movers potential by operational type – electrification

Of that total, 6.1% of energy demand is consumed by vessels undergoing intra-cluster domestic trade, representing one of the lowest hanging fruits for GHG emission savings because investment can focus on providing each cluster with the required renewable electricity to cover its internal shipping activities. Domestic trade visiting more than one cluster (on average 17 ports) per year (multilateral) accounts for 9.2% of the fleet fuel consumption. This could be converted to GHG emission savings if these vessels were propelled by batteries combined with a cross-national plan for electrification policies for ports. These findings highlight the pivotal role that the Jones Act could have on driving decarbonisation of the maritime fleet, given that around 15.6% of the current fuel demand comes from domestic trade.

4.2.1.1 Energy decarbonisation potential aggregation by route

Figure 4.5 shows the routes with the greatest potential for decarbonisation of which the Gulf of Mexico and Northeastern states account for a total decarbonisation potential of 7%. The Gulf leads the potential for decarbonisation of the fleet, having local/intra-cluster, bilateral and multilateral routes between Fourchon, Beaumont and Baytown that account for around 4.7% of the fleet's total energy demand. The next area of interest for electrification of the fleet is the Northeast coast clusters around Boston, Port Newark and Norfolk. The other routes, with a combined potential reduction of 2%, comprise vessels operating around Tacoma (Seattle), Honolulu, Dutch Harbour (Alaska) and Oakland and Los Angeles in California.

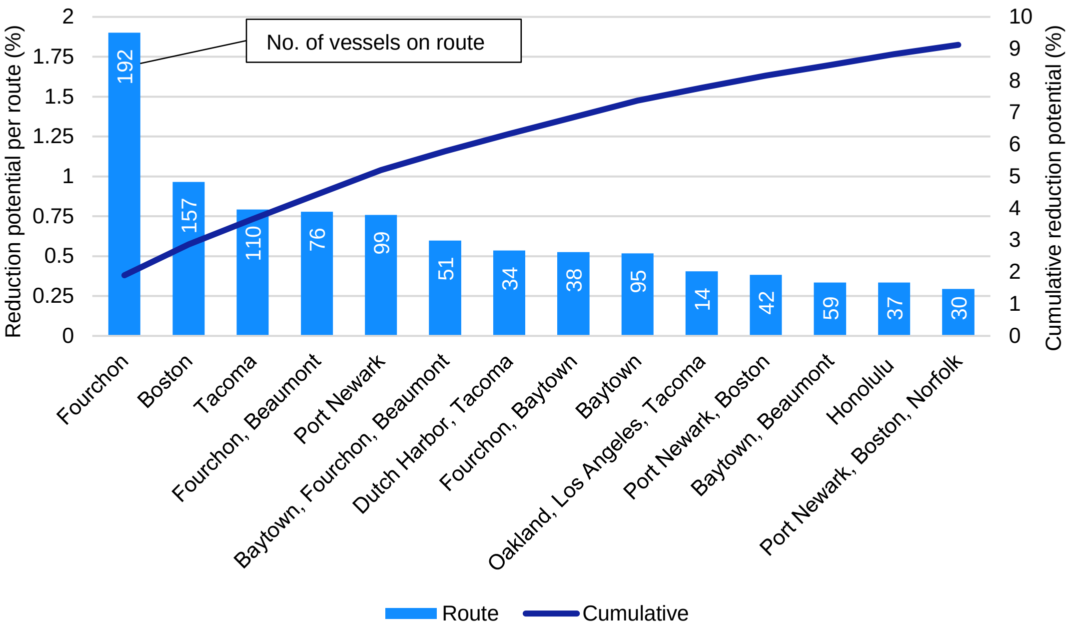


Figure 4.5 Top routes in terms of emission reduction potential – electrification

4.2.1.2 Energy decarbonisation potential aggregated by cluster

Although Figure 4.5 breaks down the reduction potential by route, some clusters are present in more than one route. This means that to estimate the total demand per cluster, the proportions of energy demand belonging to each route need to be added together. The result is a rank of clusters with their allocated reduction potential and the corresponding energy required to fully harness it. This is summarised in Figure 4.6, with the Gulf of Mexico, Northeast and Northwest coasts indicating the highest electrifiable fleet potential – giving a more complete picture than that suggested by observing the contribution of the routes alone.

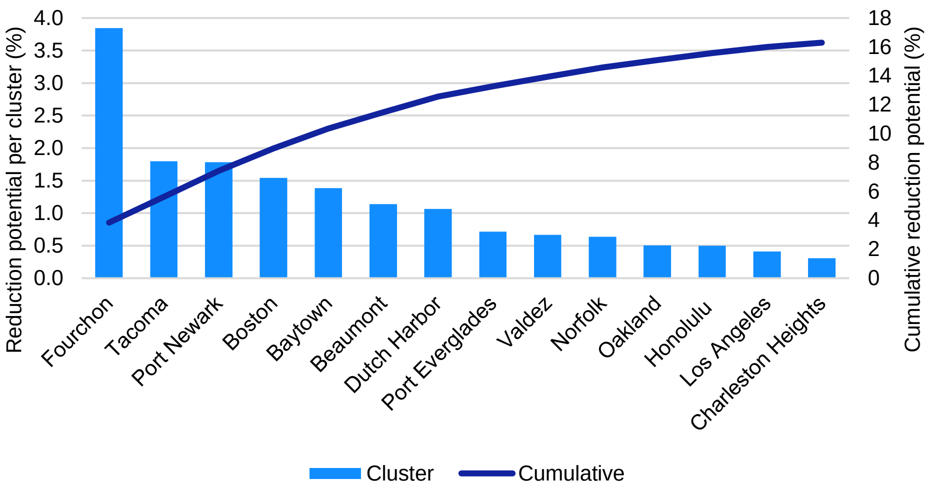


Figure 4.6 Top clusters in terms of emission reduction potential – electrification

4.2.1.3 Cluster distribution networks

While the clustering methodology works as a useful proxy to simplify the aggregations of energy demand and to establish patterns of operational regularity, this should be considered in relation to the distribution network required to cover all contributing ports within a cluster. In other words, when deciding which of two clusters with similar aggregated energy demands has the highest decarbonisation potential, the decision hinges on the capacity of the cluster to produce and distribute the sustainable fuel across its ports.

In the current analysis this has been partially addressed by making assumptions on renewable energy availability, but a space is left for the assessment of the distribution network itself. This is a parameter that will vary widely depending on factors such as existing infrastructure, local topography and governance. Figure 4.7 accounts for network issues by presenting both dimensions: the size of the red circles indicates the reduction potential of the electrifiable first movers of the cluster, while the diamonds represent the coverage radius of the cluster (i.e. the mean distance between the main port and the other ports of the cluster). Under this representation, the ideal cluster would have a big circle and a small diamond – high volumes of energy demand concentrated in a small area.

The maps for these clusters show that energy demand is both high and geographically concentrated at Fourchon (supported by Baytown and Beaumont), Boston, Port Newark and Dutch Harbour, whereas Tacoma and Valdez have great energy demand but their distribution networks are much larger to cover. Conversely Oakland, Los Angeles and Norfolk have a highly concentrated network but not a very high demand. Fourchon is not only the cluster with the highest demand (twice as much as the next cluster) but also the one that concentrates the highest number of vessels (460) with electrification potential. This is followed by Tacoma (282), Port Newark (292), Boston (326) and Baytown (319). More detailed maps can be found in Appendix E.

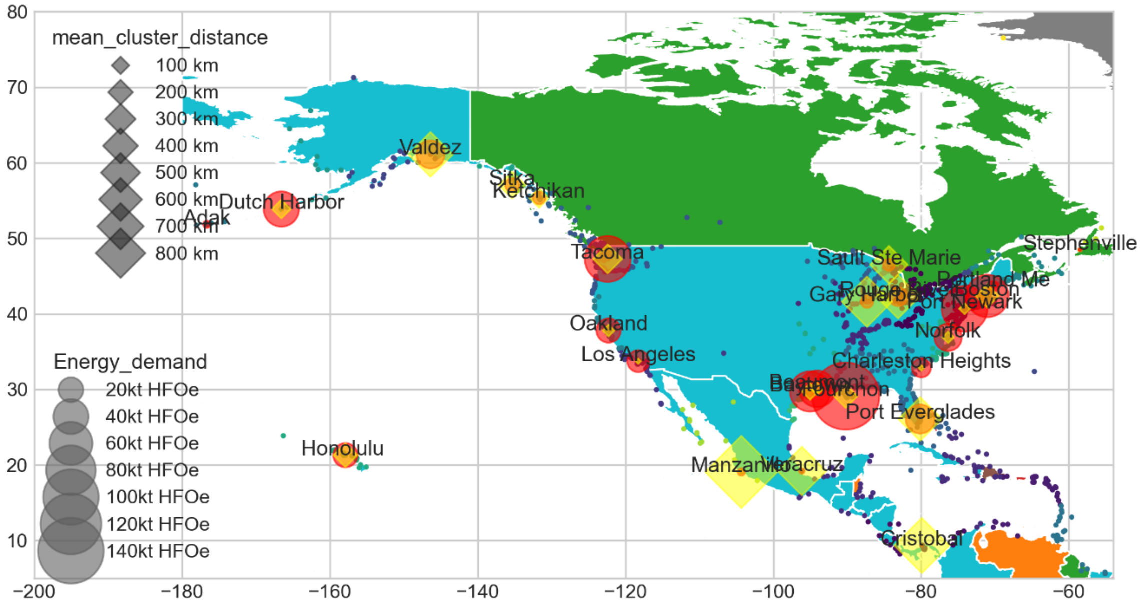


Figure 4.7 Cluster distribution network – electrification

4.2.1.4 Vessel types

An extra perspective that can be derived from the voyage analysis and the identification of first mover routes is the vessel types that represent the strong candidates for electrification (Figure 4.8).

Tugs, fishing and offshore vessels account for 8.2%, 4.8% and 3.8% of decarbonisation potential respectively. Cruise ships, Ro-Ro ferries, general cargo vessels and oil tankers combined add only an extra 0.5% of decarbonisation potential. These finding are supported by those in Section 3.3.1 (Figure 3.5), where tugs, fishing and offshore vessels are among the top four energy consumers of the US fleet, and by the fact that their operational areas coincide with the local operative assumptions used to filter electrifiable vessels (mean voyages <100 nm). An additional benefit of considering offshore and fishing vessels as suitable for electrification is that they are deployed at or close to nearshore oil-rigs (Gulf of Mexico), wind turbine foundations (shallow waters) or nearshore catch areas.

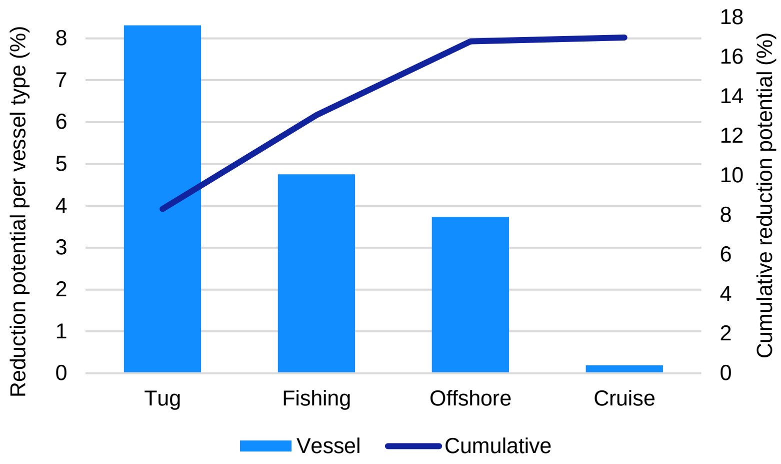


Figure 4.8 Decarbonisation potential per vessel type – electrification

4.2.2 Scalable zero emission fuels fleet

Almost a quarter (24%) of the energy demand of the US fleet has a strong potential for using SZEFs across different operational modes, as shown in Figure 4.9.

Unlike the electrifiable fleet results (Figure 4.4), the findings for the SZEF fleet are lower for the intra-cluster route, with 2.9% of the full fleet energy demand. However, the SZEF fleet has a bigger participation in bilateral routes (3.8%) and an overwhelming participation of multilateral activity, equivalent to 17.7%.

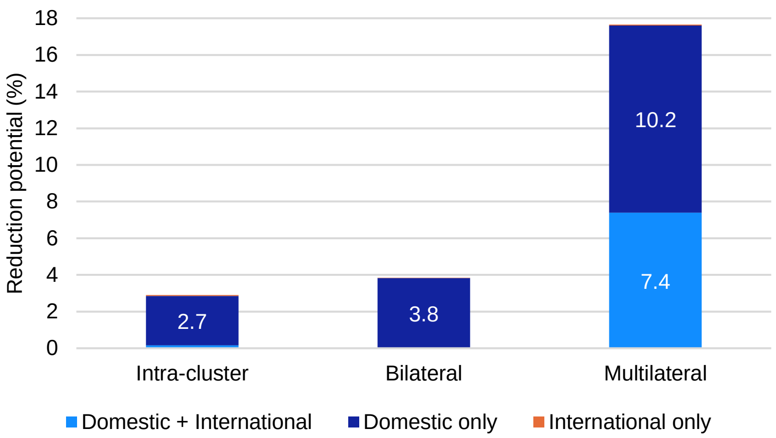


Figure 4.9 First movers potential by operational type – SZEF

This dominance in bilateral and multilateral routes indicates that the first movers potential among the SZEF fleet is linked to trading activity over larger areas, and that the transition path will have greater reliance on cooperation between the clusters involved to guarantee fuel availability.

SZEF first mover vessels covering multilateral routes that combine both domestic and international operations account for 7.4% of the total US fleet energy demand, of which 4.8% is for domestic-only shipping and 2.6% is for international voyages. As for the electrifiable fleet, the Jones Act is an important driver for decarbonisation, given that around 16.7% of the current fuel demand comes from domestic trade.

4.2.2.1 Energy decarbonisation potential aggregation by routes

Figure 4.10 shows the decarbonisation potential of each route combination of the SZEF fleet. The number inside the bars indicates the number of vessels covering the route, while the blue line describes the cumulative decarbonisation potential for the routes. The blue line illustrates how the decarbonisation of only around 100 vessels registered under the US flag would produce a 16% decarbonisation of the total GHG emissions of the fleet; well above the 5% milestone suggested by the Getting to Zero Coalition transition strategy. The following paragraphs focus on specific examples of routes that show high potential for decarbonisation through using SZEFs. More examples can be found in Appendix E.

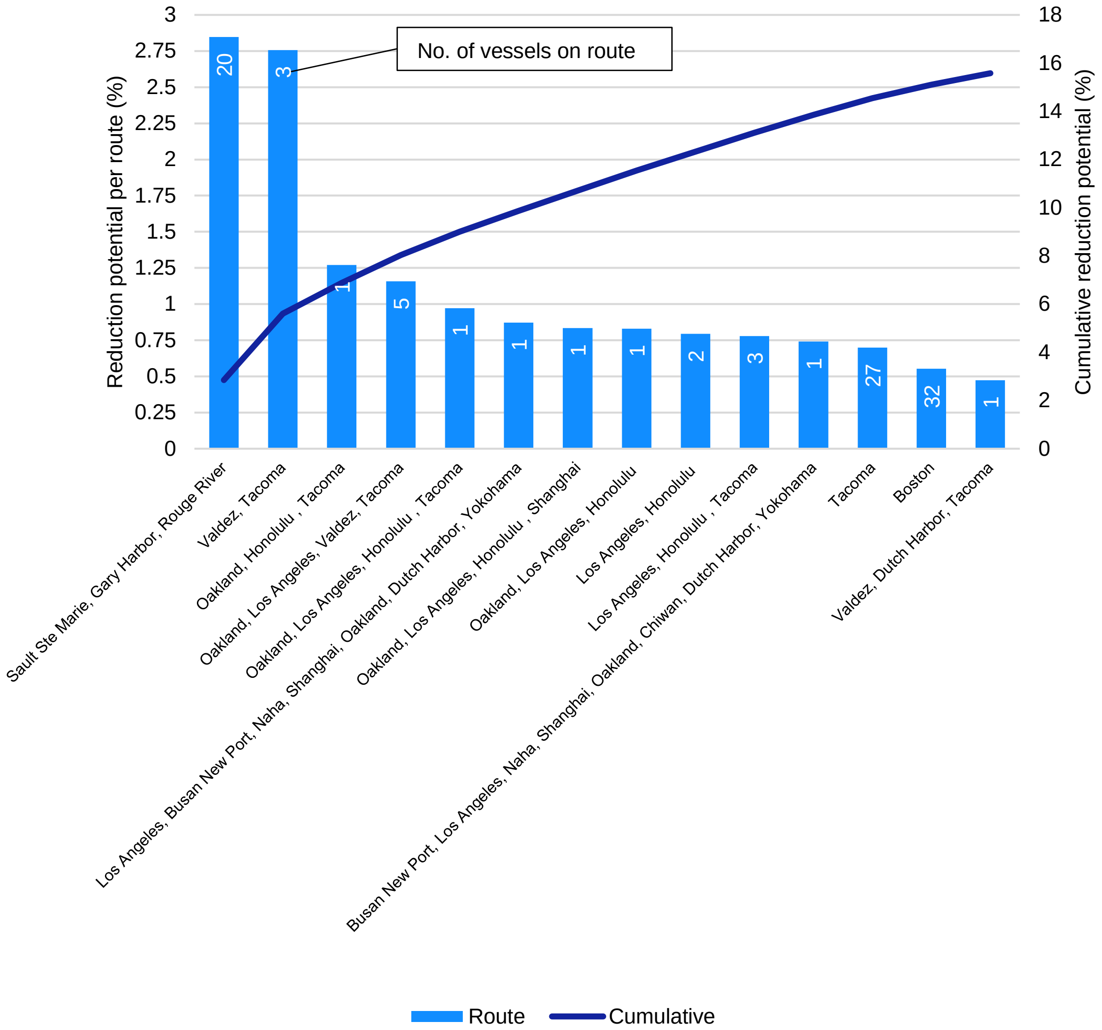


Figure 4.10 Top routes for emission reduction potential – SZEF

Under different combinations of cluster stops, a group of eight vessels cover the routes between the Pacific coast and Hawaii (Figure 4.11). Some of the vessels link the islands directly to either Washington State, Alaska, or central and south California; others shuttle between them. The aggregated energy demand relative to the overall fleet amounts to 4.6%. Notably, because all these routes have Hawaii as a common stop, should these vessels be converted to SZEFs with enough fuel available to cover the routes, the US fleet would almost reach the milestone of a 5% uptake of zero emissions from shipping activity. Two of these vessels were built in the 1980s (containers), three in the 2000s and only three are less than eleven years old. Their ages indicate that some of these vessels are prime candidates for retrofitting/replacement with zero emission technologies.

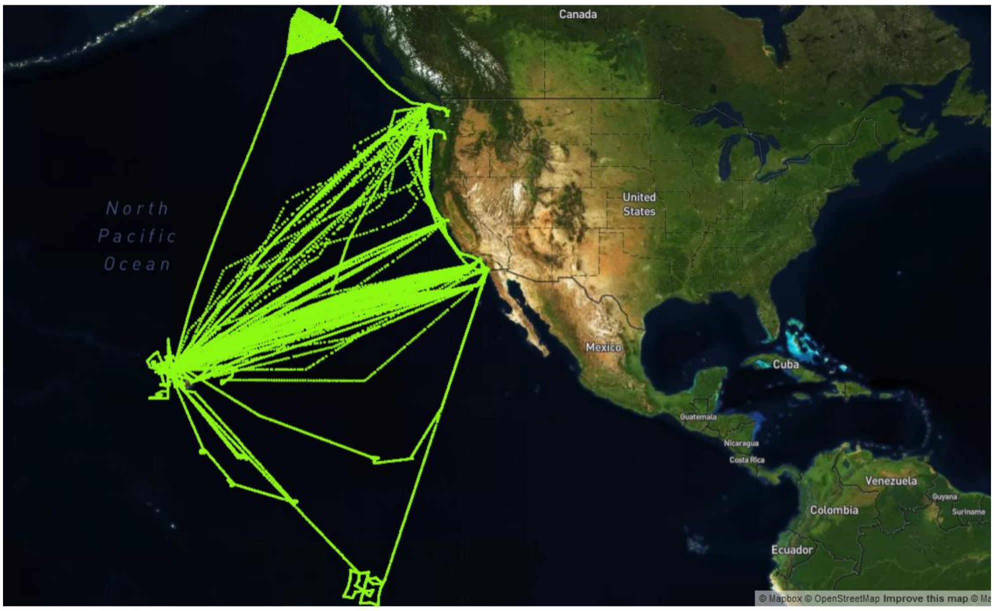


Figure 4.11 Routes with strong decarbonisation potential through SZEFs – Hawaii

Twenty vessels operating multilaterally in ports between the three clusters covering the Great Lakes have an aggregated fuel consumption of 2.8% of the US fleet total (Figure 4.12). Note that these vessels cover long routes: the filtering criteria used for the study specifies that each should have at least stopped one time throughout the year in a port belonging to each cluster in the area.

Figure 4.12 Routes with strong decarbonisation potential through SZEFs – Great Lakes

The bilateral route between Tacoma and Valdez (Washington State and Alaska) is a close second, at 2.8% of the US total from only three vessels (Figure 4.13). This is an interesting case of regular trading patterns and large fuel consumption, because these three are Ro-Ro vessels with some of the largest overall capacity >20,000DWT. Due to the scheduled nature of the work these vessels are used for, their large fuel consumption is explained not only by their size but also by their considerably higher operating speeds than other vessel types of a similar size.

Figure 4.13 Routes with strong decarbonisation potential through SZEFs – Tacoma and Valdez

4.2.2.2 Energy decarbonisation potential aggregation by cluster

Figure 4.14 shows the aggregated reduction potential for each cluster but, in this case, for vessels suitable to be converted to SZEF. The aggregations only account for the energy demand of vessels departing from the clusters. This means that, although the values are an estimate of the overall energy demanded at vessel stops, the total potential reduction in GHG emissions can only be harnessed if a route-wide approach is used for SZEF provision.

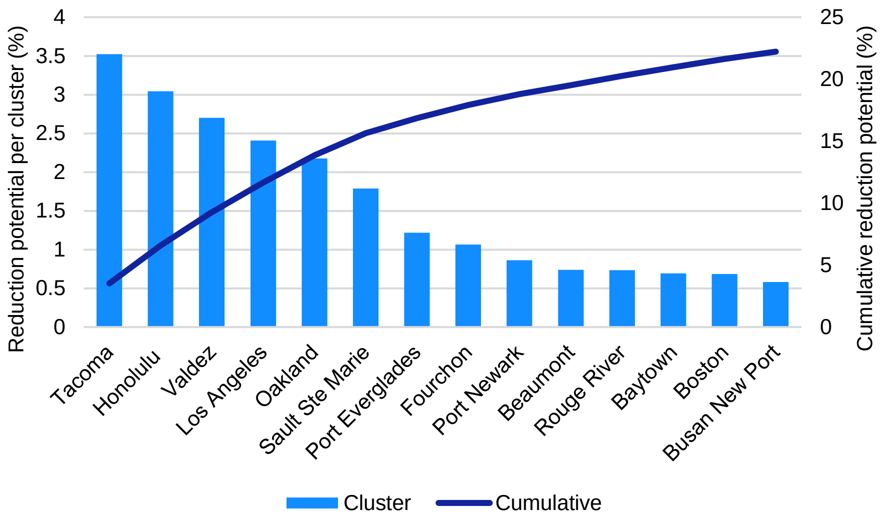


Figure 4.14 Top clusters for emission reduction potential – SZEF

Unlike the results presented in Section 4.2.1.2 for the electrifiable fleet, Figure 4.14 shows that for the SZEF fleet the top five clusters in terms of reduction potential are on the Pacific coast, together accounting for 14% of total fleet emissions. The following nine clusters in the plot are located in the Gulf, the Great Lakes and the east coast of the US and account for a further 8.5% between them.

The combination of the SZEF results and those for the electrifiable fleet suggests that the demand for electrification is higher in the Gulf and the Northeast of the US; while the west coast and the Great Lakes ports present a strong case for vessels switching to SZEFs.

4.2.2.3 Cluster distribution networks

Further corroboration on the high energy demand on the Pacific coast can be seen in Figure 4.15. However, the highest values are seen in clusters with relatively low demand densities (Tacoma, Valdez and Honolulu), which is contrasted by the still high volumes and densities of the energy demand in the Pacific clusters of Oakland and Los Angeles.

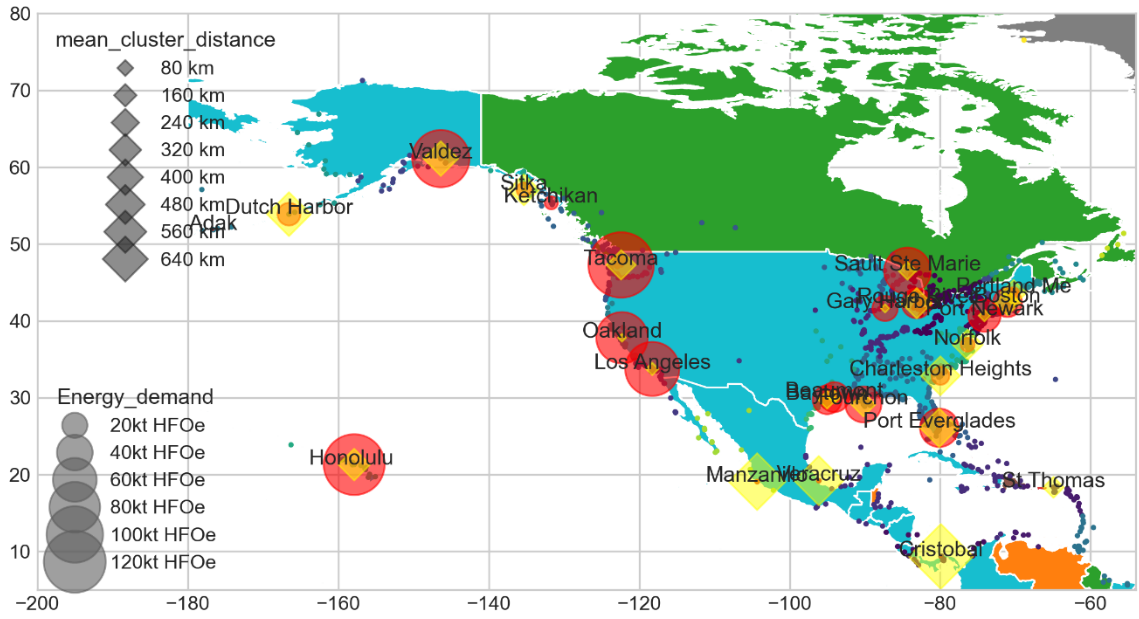


Figure 4.15 Cluster distribution network – SZEF

4.2.2.4 Vessel types

The vessel types identified as first movers likely to decarbonise via SZEFs are varied and correspond to local and regional trading activities. Containers account for 6.8% of decarbonisation potential, followed by chemical tankers (3.8%), bulk carriers (2.9%) and oil tankers (2.4%). Similarly, the accumulated potential of all ferry types (Ro-Ro, Ro-Pax and Pax only) account for 4.8%. These main seven categories represent a total decarbonisation potential of 22.5%.

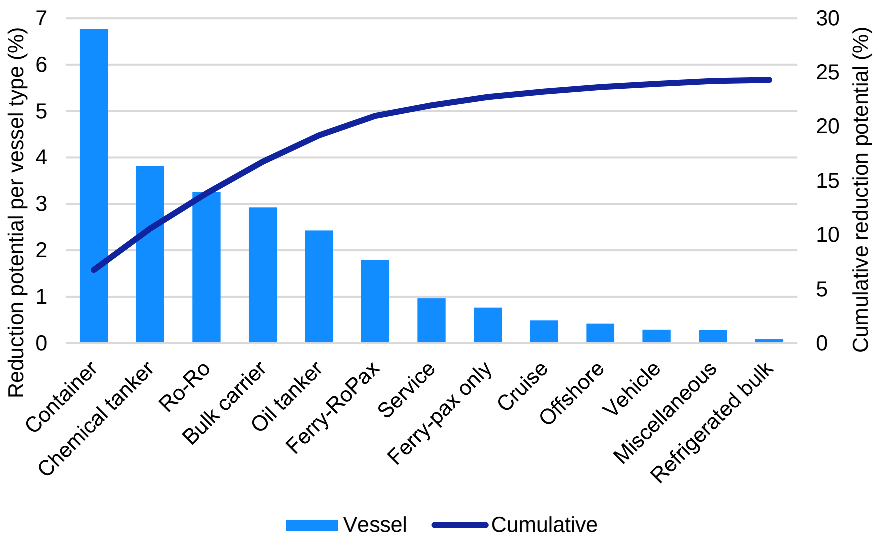


Figure 4.16 Decarbonisation potential per vessel type – SZEF

4.3 Key findings

The analysis of the geographic distribution of activity of the US shipping fleet around the country illustrates the unique opportunity that the US has as a first mover in shipping decarbonisation. The main findings are related to the clustered demand of maritime fuel and the opportunities for route decarbonisation based on activity and ship type.

- The energy demand of the US fleet is concentrated around the Gulf of Mexico, the Washington coast, and New York and New Jersey, followed by California, Alaska, Hawaii and the Great Lakes. Oakland and Long Beach are known for their major roles as ports, and the results indicate that their share of energy demand for US vessels is low when compared with other port areas in the country
- Electrification is a solution for small vessels operating locally with mean voyage ranges of less than 100nm. It is broadly assumed that these energy demands can be met by the current state-of-the-art batteries and provision of onshore infrastructure:
    - A total of 19% of US fleet energy demand has a strong potential for electrification across different operational modes, with tugs, fishing vessels and offshore supply vessels being prime candidates for decarbonisation
    - The routes with the greatest potential for decarbonisation have been identified, among which the Gulf of Mexico and the Northeastern states have a total decarbonisation potential of 7%. A further 2% of potential reduction by electrification is concentrated in Tacoma (Seattle), Honolulu, Dutch Harbour (Alaska), Oakland and Los Angeles (California)
- Vessels with a more flexible trading profile, longer range and generally bigger dimensions are most suited for using SZEFs for fuelling internal combustion or fuel cells. Fuels such as hydrogen, ammonia and methanol are most suitable:
    - A total of 24% of US fleet energy demand has a strong potential for SZEFs, with container ships, chemical tankers, Ro-Ro ferries and bulk carriers being the top candidates
    - The top five clusters in terms of reduction potential are on the Pacific coast and account for 14%. The following ten clusters, in the Gulf, the Great Lakes and the east coast of the US account for a further 8.5% between them
- The combination of these and the results seen for the electrifiable fleet therefore suggest that the demand for electrification is higher in the Gulf and the Northeast of the US, while the west coast and the Great Lakes ports present a strong case for vessels switching to SZEFs.

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Appendix A – US fleet demographics

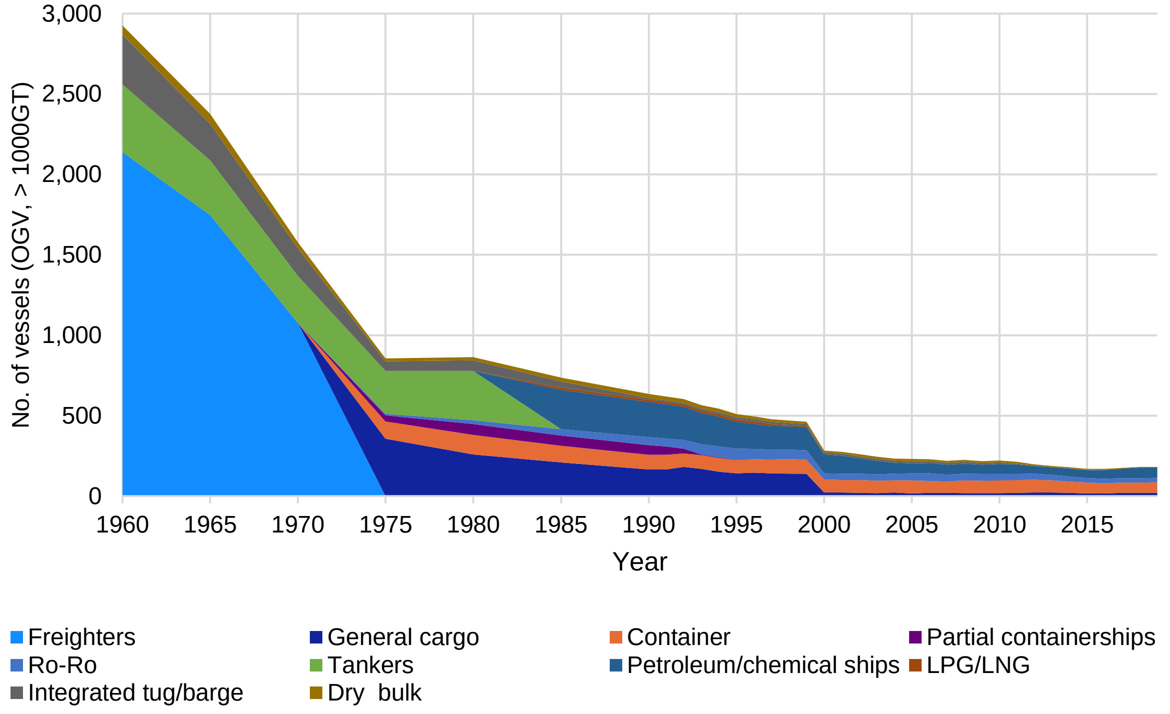
Table A.1 US-flagged vessels

Vessel type	No. vessels
Nonself-propelled vessels	33,266
Dry cargo barges	27,947
Tankers	5,181
Uncategorised	138
Self-propelled vessels	9,904
Dry cargo/passenger	2,919
Ferries, railroad car	569
Tankers	79
Towboats/tugs	5,844
Uncategorised	493
Ocean-going self-propelled vessels (1,000GT and above)	182
Tankers, total	65
Tankers, privately owned	60
Tankers	5
General cargo, privately owned	21
Container, privately owned	62
Ro-Ro, privately owned	29
Dry bulk, privately owned	5
Recreational boats	11,878,542

Source: Reference [6]

Table A.2 Vessel database, 2018

Vessel type	Size bin	No. vessels	Vessel type	Size bin	No. vessels
Bulk carrier	1	2	General cargo	1	3
	2	13		2	4
	3	10		3	7
	4	12		4	4
Chemical tanker	2	1	Fishing	1	1,230
	4	3	Miscellaneous	1	55
	5	42	Offshore	1	572
Container	1	2	Oil tanker	1	2
	2	13		4	5
	3	13		6	2
	4	16		7	9
	5	19	Refrigerated bulk	1	3
Cruise	1	17		2	2
	2	4	Ro-Ro	1	8
	4	1		4	3
Ferry (Ro-Pax)	1	42	Service	1	147
	2	28	Tug	1	1,156
	3	11	Vehicle	2	4
	4	5		3	16
Ferry (Pax only)	1	41	Yacht	1	42
	2	47	**Total**		**3,622**
	3	5			
	4	1			



Source: Reference [6]

Figure A.1 Vessel types US-flagged ocean-going vessels above 1,000GT (1960–2019)

Appendix B – Vessel type and size category definition

Table B.1 International Maritime Organization vessel type and size categorisation

Vessel type	Size bin	Capacity	Unit	Vessel type	Size bin	Capacity	Unit
Bulk carrier	1	0–9,999	DWT	Other liquids tankers	1	0–999	DWT
	2	10,000–34,999	DWT		2	1,000–+	DWT
	3	35,000–59,999	DWT	Ferry (Pax only)	1	0–299	GT
	4	60,000–99,999	DWT		2	300–999	GT
	5	100,000–199,999	DWT		3	1,000–1,999	GT
	6	200,000–+	DWT		4	2,000–+	GT
Chemical tanker	1	0–4,999	DWT	Cruise	1	0–1,999	GT
	2	5,000–9,999	DWT		2	2,000–9,999	GT
	3	10,000–19,999	DWT		3	10,000–59,999	GT
	4	20,000–39,999	DWT		4	60,000–99,999	GT
	5	40,000–+	DWT		5	100,000–149,999	GT
Container	1	0–999	TEU		6	150,000–+	GT
	2	1,000–1,999	TEU	Ferry (Ro-Pax)	1	0–1,999	GT
	3	2,000–2,999	TEU		2	2,000–4,999	GT
	4	3,000–4,999	TEU		3	5,000–9,999	GT
	5	5,000–7,999	TEU		4	10,000–19,999	GT
	6	8,000–11,999	TEU		5	20,000–+	GT
	7	12,000–14,499	TEU	Refrigerated bulk	1	0–1,999	DWT
	8	14,500–19,999	TEU		2	2,000–5,999	DWT
	9	20,000–+	TEU		3	6,000–9,999	DWT
General cargo	1	0–4,999	DWT		4	10,000–+	DWT
	2	5,000–9,999	DWT	Ro-Ro	1	0–4,999	DWT
	3	10,000–19,999	DWT		2	5,000–9,999	DWT
	4	20,000–+	DWT		3	10,000–14,999	DWT
Liquefied gas tanker	1	0–49,999	CBM		4	15,000–+	DWT
	2	50,000–99,999	CBM	Vehicle	1	0–29,999	GT
	3	100,000–199,999	CBM		2	30,000–49,999	GT
	4	200,000–+	CBM		3	50,000–+	GT
Oil tanker	1	0–4,999	DWT	Yacht	1	0–+	GT
	2	5,000–9,999	DWT	Tug	1	0–+	GT
	3	10,000–19,999	DWT	Fishing	1	0–+	GT
	4	20,000–59,999	DWT	Offshore	1	0–+	GT
	5	60,000–79,999	DWT	Service	1	0–+	GT
	6	80,000–119,999	DWT	Miscellaneous	1	0–+	GT
	7	120,000–199,999	DWT				
	8	200,000–+	DWT				

Source: Reference [2]

Appendix C – AIS fleet size and emissions estimates by vessel type

Table C.1 Demographic and emissions details for US fleet

Vessel type	No. vessels					DWT					CO_2 emissions					
	DOT	Vessel database		AIS		Reporting ratio (AIS/IHS)	IHS		AIS		Reporting ratio (AIS/IHS)	AIS		Infilled		Total	
	No.	No.	%	No.	%	%	Mt	%	Mt	%	%	Mt	%	Mt	%	Mt	%
Bulk carrier	5	41	0.6	37	1.0	90	1.69	11.2	1.62	12.4	96	0.69	3.7	0.05	0.7	0.74	2.8
Chemical tanker		47	0.7	46	1.3	98	2.14	14.2	2.14	16.3	100	1.45	7.7	–	–	1.45	5.6
Container	62	66	1.0	63	1.7	95	3.14	20.9	3.06	23.4	97	4.72	25.2	0.18	2.5	4.9	18.9
Cruise		26	0.4	22	0.6	85	0.01	0.1	0.01	0.1	95	0.27	1.4	0.03	0.4	0.3	1.2
Ferry (Pax only)	2,919[15]	135	2.1	94	2.6	70	0.07	0.5	0.07	0.5	93	0.6	3.2	0.07	1.0	0.67	2.6
Ferry (Ro-Pax)	569	100	1.6	86	2.4	86	0.01	0.1	0.01	0.0	61	0.31	1.6	0.13	1.8	0.44	1.7
General cargo	21	31	0.5	18	0.5	58	0.48	3.2	0.39	3.0	82	0.24	1.3	0.05	0.7	0.29	1.1
Fishing		3,014	46.7	1,230	34.0	41	0.48	3.2	0.27	2.1	57	2.29	12.2	3.33	46.1	5.62	21.6
Miscellaneous		103	1.6	55	1.5	53	1.94	12.9	1.33	10.2	69	0.72	3.9	0.63	8.7	1.35	5.2
Offshore		1,004	15.6	572	15.8	57	1.71	11.4	1.04	7.9	61	1.97	10.5	1.49	20.6	3.46	13.3
Oil tanker	144	18	0.3	18	0.5	100	1.94	12.9	1.94	14.8	100	0.83	4.4	–	–	0.83	3.2
Refrigerated bulk		5	0.1	5	0.1	100	0.01	0.1	0.01	0.1	100	0.05	0.2	–	–	0.05	0.2
Ro-Ro	29	19	0.3	11	0.3	58	0.09	0.6	0.08	0.6	82	0.47	2.5	0.04	0.6	0.51	2.0
Service		217	3.4	147	4.1	68	0.34	2.3	0.31	2.3	90	0.74	4.0	0.35	4.8	1.09	4.2
Tug	5,844	1,521	23.6	1,156	31.9	76	0.51	3.4	0.39	3.0	77	2.65	14.1	0.84	11.6	3.49	13.4
Vehicle		20	0.3	20	0.6	100	0.43	2.9	0.43	3.3	100	0.73	3.9	–	–	0.73	2.8
Yacht		83	1.3	42	1.2	51	0.01	0.1	0.00	0.0	30	0.04	0.2	0.03	0.4	0.07	0.3
Uncategorised	493[16]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	**10,224**	**6,450**	**100**	**3,622**	**100**	**-**	**15.02**	**100**	**13.10**	**100**	**-**	**18.76**	**100**	**7.22**	**100**	**25.98**	**100**

Table C.2 Total carbon emissions by fleet and international/domestic designation (in Mt)

	Unassigned	International	Domestic	Total
US fleet	–	5.5	13.3	18.77
Infilled	7.2	–	–	7.22
Total	**7.2**	**5.5**	**13.3**	**25.99**

[15] Self-propelled, non-oceangoing

[16] Includes dry cargo

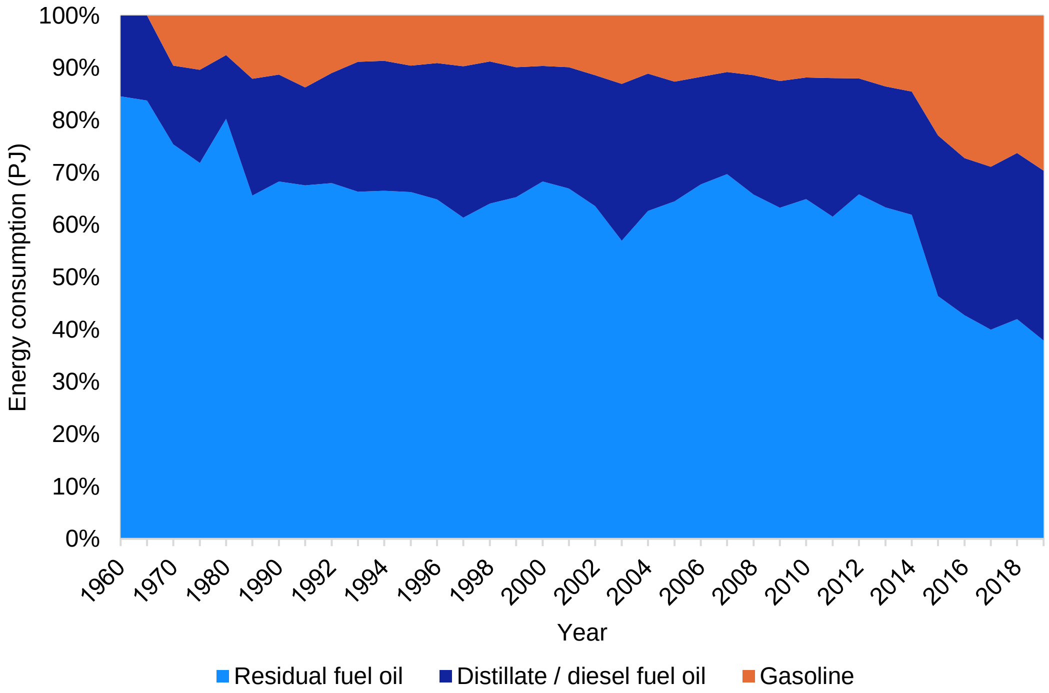
Table C.3 Complete dataset used for Figure 3.2

Vessel type	DWT (%)	CO_2 (%)	Proportion (%)
Fishing	3.22	21.63	46.73
Container	20.94	18.88	1.02
Tug	3.40	13.42	23.58
Offshore	11.36	13.31	15.57
Chemical tanker	14.22	5.59	0.73
Miscellaneous	12.93	5.21	1.60
Service	2.27	4.22	3.36
Oil tanker	12.94	3.18	0.28
Bulk carrier	11.24	2.83	0.64
Vehicle	2.88	2.79	0.31
Ferry (Ro-Pax)	0.48	2.56	1.55
Ro-Ro	0.62	1.95	0.29
Ferry (Pax only)	0.07	1.67	2.09
Cruise	0.09	1.17	0.40
General cargo	3.19	1.14	0.48
Yacht	0.10	0.27	1.29
Refrigerated bulk	0.06	0.18	0.08

Appendix D – Supplementary data

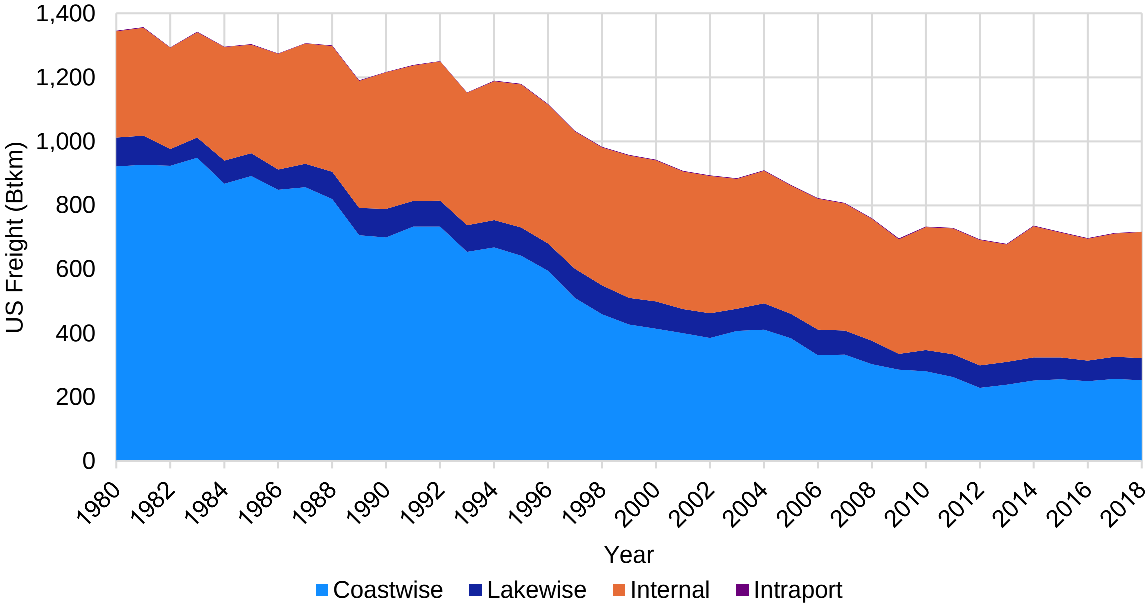
Table D.1 Energy Requirements by vessel type (TJ)

Ship type	AIS			Infilled			Total
	At berth	At sea	Total	At berth	At sea	Total	
Fishing	10,948	19,604	30,552	15,879	28,434	44,313	74,864
Container	2,718	59,231	61,949	133	2,251	2,384	64,333
Offshore	9,858	16,458	26,315	7,445	12,430	19,874	46,190
Tug	5,322	29,959	35,281		9,459	9,459	44,741
Chemical tanker	7,661	11,594	19,255	–	–	–	19,255
Miscellaneous	925	8,530	9,455	807	7,445	8,252	17,707
Service	1,614	8,240	9,854	–	3,924	3,924	13,778
Oil tanker	3,939	6,967	10,906	330		330	11,236
Bulk carrier	1,246	7,903	9,149	84	539	623	9,771
Ferry (Ro-Pax)	2,344	5,587	7,932	321	1,366	1,687	9,618
Vehicle	392	9,037	9,429	–	–	–	9,429
Yacht	–	468	468	–	457	457	924
Ro-Ro	473	5,707	6,180	1,680	229	1,909	8,089
Ferry (Pax only)	666	3,418	4,085	329	589	918	5,002
Cruise	2,630	971	3,600	398	58	455	4,056
General cargo	340	2,841	3,181	93	593	685	3,866
Refrigerated bulk	236	376	612	769	–	769	1,380
Total	51,311	196,891	248,202	28,266	67,772	96,038	344,240



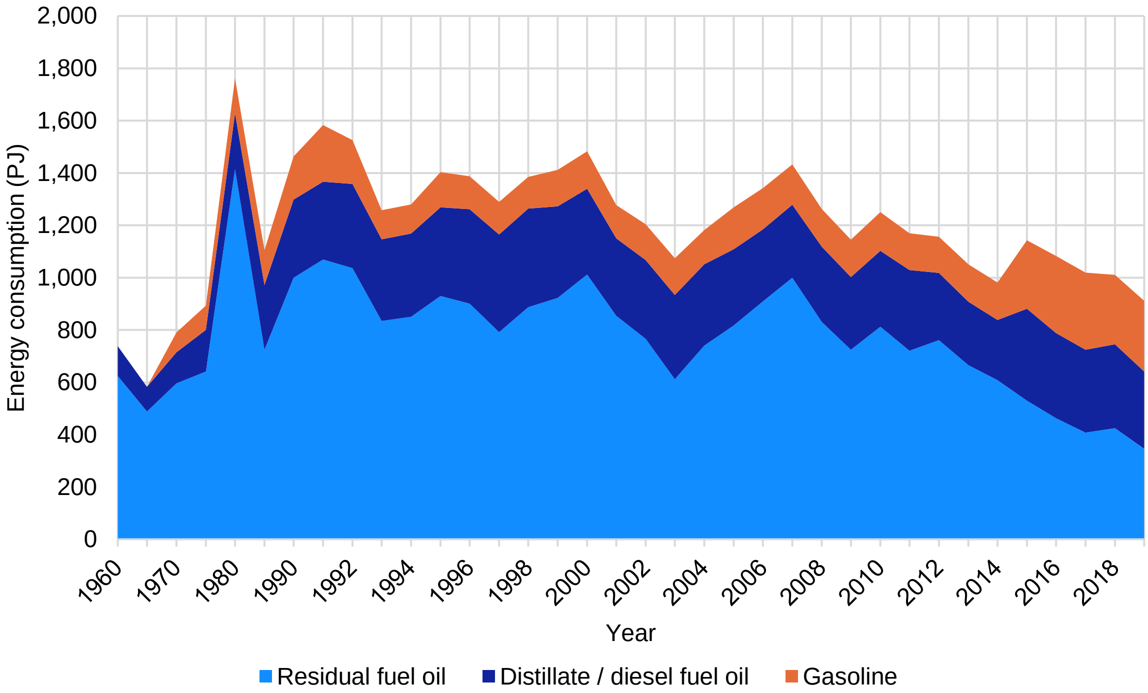
Source: Reference [6]

Figure D.1 Energy consumption (%) by fuel type, based on US sales of maritime fuels



Source: Reference [6]

Figure D.2 Distribution of US domestic waterborne trade by transport type



Source: Reference [6]

Figure D.3 Energy consumption by fuel type based on US sales of maritime fuels

Appendix E – Supplementary data for voyage-based analysis

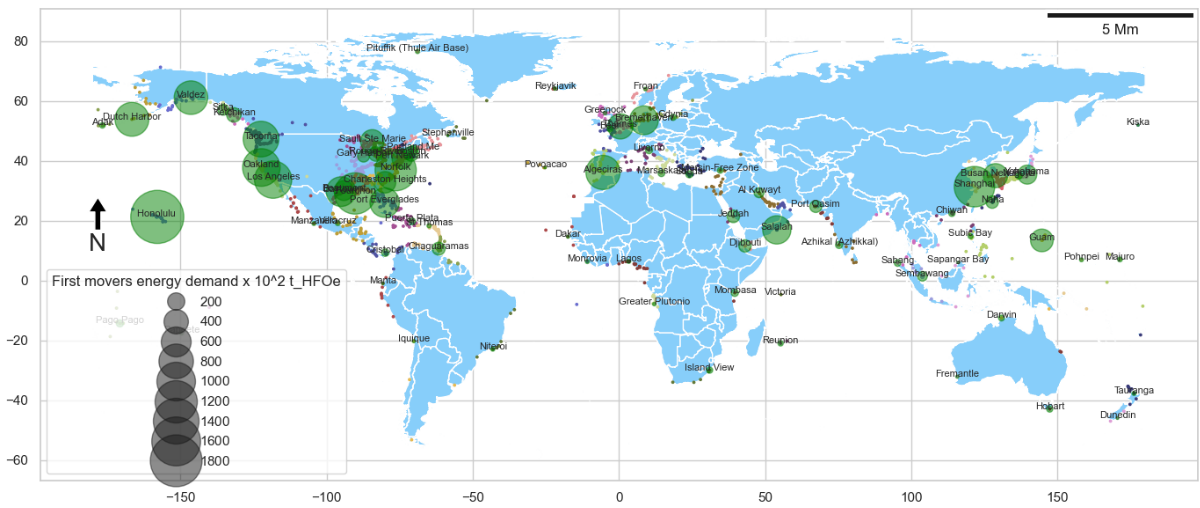


Figure E.1 Global energy demand clusters for the US fleet

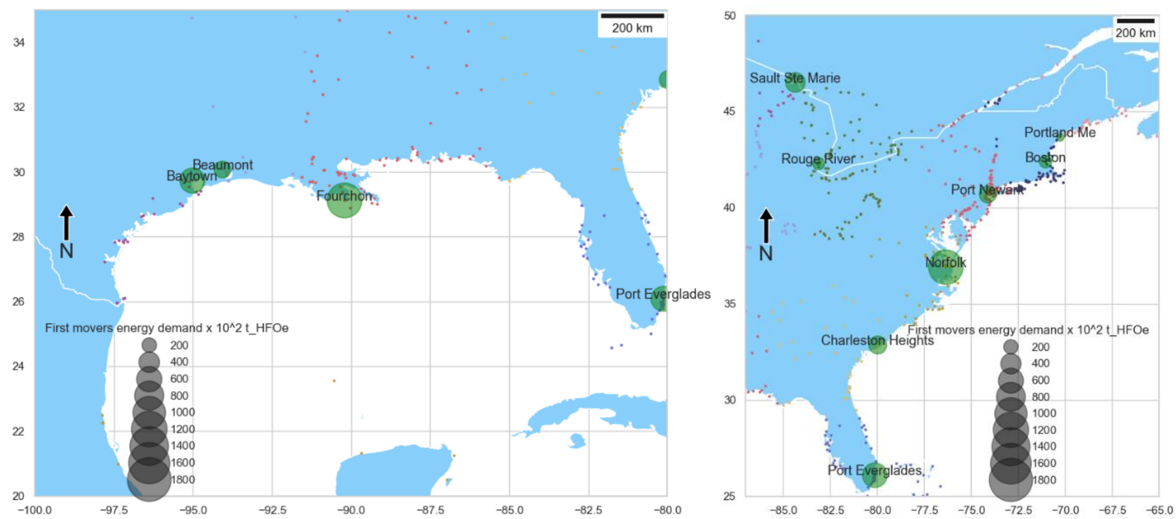


Figure E.2 Detail of energy demand clusters for the US fleet in the Gulf of Mexico and East coast

Table E.1 Fossil fuel reduction potential by operational type – SZEF

Operational type	Dom/Int split of vessels' operation	Avg. no. countries	Avg. no. port calls	Agg. HFOeq (kt)	Agg. International reduction potential (%)	Agg. Domestic reduction potential (%)	Agg. total reduction potential (%)	Total reduction Potential (%)
Intra-cluster	Dom/Int	2.00	14.34	0.05	0.02	0.16	0.18	6.32
	Dom only	1.00	7.38	1.80	0.00	6.14	6.14	
	Int only	0.00	0.00	0.00	0.00	0.00	0.00	
Bilateral	Dom/Int	1.66	3.33	0.02	0.00	0.05	0.06	0.36
	Dom only	1.00	3.11	0.08	0.00	0.30	0.30	
	Int only	2.00	2.00	0.00	0.00	0.00	0.00	
Multilateral	Dom/Int	1.99	25.93	1.02	0.30	3.18	3.49	12.65
	Dom only	1.00	17.47	2.68	0.00	9.16	9.16	
	Int only	2.00	2.00	0.00	0.00	0.00	0.00	
Sub total				5.65	0.33	18.99	19.34	19.34

Table E.2 Fossil fuel reduction potential by operational type – electrification

Operational type	Dom/Int split of vessels' operation	Avg. no. countries	Avg. no. port calls	Agg. HFOeq (Mt)	Agg. International reduction potential (%)	Agg. Domestic reduction potential (%)	Agg. total reduction potential (%)	Total reduction Potential (%)
Intra-cluster	Dom/Int	1.83	8.17	0.01	0.02	0.14	0.16	2.90
	Dom only	1.00	3.69	0.11	0.00	2.69	2.69	
	Int only	2.00	2.00	0.00	0.05	0.00	0.05	
Bilateral	Dom/Int	1.00	2.00	0.00	0.00	0.00	0.01	3.84
	Dom only	1.00	2.75	0.15	0.00	3.82	3.82	
	Int only	2.00	2.00	0.00	0.01	0.00	0.01	
Multilateral	Dom/Int	2.04	16.83	0.29	2.58	4.81	7.39	17.66
	Dom only	1.00	11.40	0.40	0.00	10.21	10.21	
	Int only	2.00	2.00	0.00	0.06	0.00	0.06	
Sub total				0.96	2.73	21.66	24.39	24.39