Baselining the Skills Required for the Transition to Zero Emission Maritime Operations

Final Report

Transport Scotland/Skills Development Scotland

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J3380

Executive Summary

Transport is currently Scotland's largest sectoral emitter of greenhouse gases, responsible for 36% of emissions in 2018. Shipping accounts for 15.5% of total Scottish transport emissions with domestic shipping accounting for 2Mt CO_2e and international shipping accounting for 0.34Mt CO_2e. Since 1990, domestic shipping emissions have fallen by 41.8% and international shipping emissions have fallen by 56.1%. The Scottish Government has set targets for 30% of the ferries it owns to be low emission by 2032 and, by the same year, for low emission solutions to be widely adopted at Scottish ports.

The range of vessels operating in and around Scotland is diverse, and includes fishing boats, ferries, offshore service vessels, inshore service vessels, cargo ships and leisure vessels. Furthermore, there are multiple, potential low carbon and zero emission technologies that could support decarbonisation of the Scottish maritime sector including, for example, vessel efficiency optimisation (such as slow steaming, hull friction reduction and autonomous vessels), alternative fuels (such as ammonia, methanol and hydrogen), alternative propulsion systems (such as battery and fuel cell electrification) and auxiliary power systems (such as sails and solar panels). Scottish ports are also implementing a number of measures to reduce the carbon emissions associated with their operations including, for example, vehicle electrification, the installation of LED lighting and the installation of renewable energy generation, such as wind turbines and solar panels.

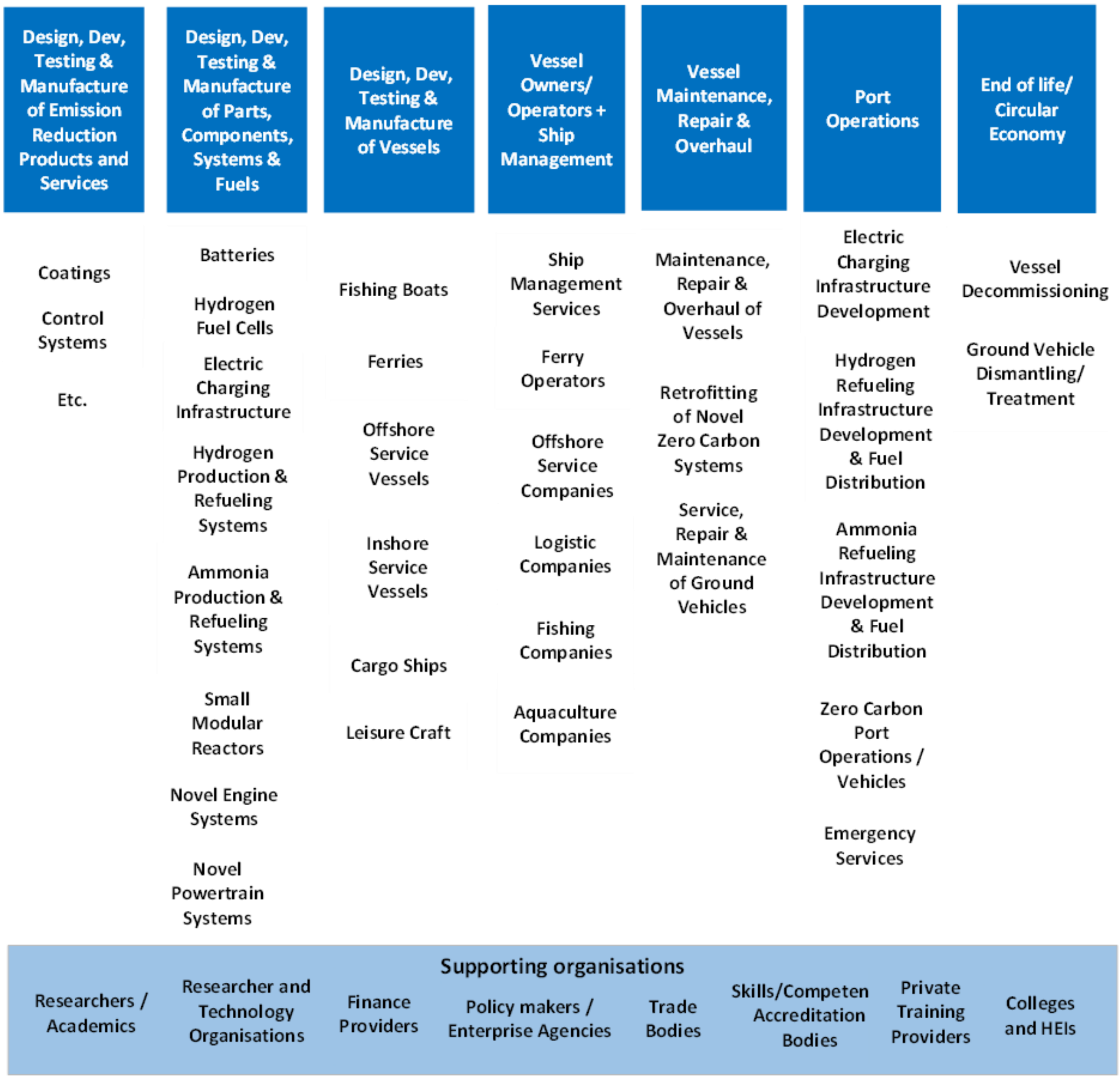
The Scottish Maritime Fleet and Low Carbon Technology Options

There is a significant (up to 15,000) but unquantifiable number of vessels operating in and around Scottish waters. Some have a permanent base in Scotland, e.g. ferries, whilst others are here on a temporary basis, e.g. off-shore service vessels and cargo vessels. The current adoption of low carbon technologies in the existing fleet is very low and a significant increase in adoption rate will have to be achieved to contribute to the net-zero target. Uptake of decarbonised and zero emission technologies is being driven the International Maritime Organisation (IMO) and its Greenhouse Gas Strategy and carbon reduction targets. In 2018, the IMO agreed to an initial strategy to reduce emissions of greenhouse gases from shipping by at least 50% by 2050 compared to 2008, with short term targets, which have been translated into legislation, for 2027 and 2030 already in place.

There are, however, significant barriers to the move towards decarbonised and zero emission maritime transportation. There is a lack of clarity within the sector on the alternative fuel and propulsion systems that will be used in different types of vessels and many of these technologies are still at a relatively low technology readiness level (TRL), requiring significant further development and demonstration before they are ready to be commercialised. Furthermore, the investment cycles in the industry are very long and it is not unusual for 20-30 year old vessels still to be in operation. This, combined with the high levels of conservativism in the sector mean that companies are slow to change.

All of these factors create uncertainty about how the level of adoption of low carbon and zero emission maritime transport will change in the short to medium term (2027) and the medium to longer term (by 2032). In turn, this impacts on when, and at what scale, skills will be required to support the uptake of many low carbon and zero emission technologies on vessels and in ports. The relationship between skills availability and levels of technology adoption is interdependent as a lack of skills in some areas can also act as a barrier to adoption. It is expected that the maritime fleet, in 2050, will still include a significant percentage of traditionally powered vessels.

The figure below summarises the different segments in maritime operations and the supply chain relating to decarbonisation in Scotland and the key stakeholder groups within each. In total, 40 stakeholders were interviewed during the research for this study. This has provided a representative sample of opinions across the maritime landscape.



It has been estimated that there are over 28,750 people employed across this maritime landscape, with the scale of demand for new or enhanced skills to support decarbonisation of the sector estimated at just over 9,000 employees up to 2032.

A range of skills will be required. These include vessel and system design, naval architecture, lightweight materials, surface technologies, sensing systems, automation technologies, battery and fuel cell chemistry and engineering, electrical and electronic engineering, high voltage systems, alternative fuel systems, alternative fuel safety, alternative fuel storage and transfer, monitoring and control, fluid and gas handling, health and safety, digital twinning, and skills relating to industry 4.0/5.0, such as data science / engineering, digitisation, software development, etc,

Skills shortages and gaps in the decarbonised and zero emission maritime landscape

A number of skills shortages and gaps have been identified across different segments of the maritime landscape including:

- Fundamental, industry wide skills shortages in several of the key disciplines, such as mechanical engineering, electrical and electronic engineering, chemical engineering software and data and digital technologies that will have a significant impact on decarbonisation of the sector, despite the high numbers of relevant university graduates and college qualifiers
- A shortage of experienced technicians, fitters and welders, with the latter being highlighted as a particular issue
- A shortage of naval architects and design engineers with experience in designing ultra efficient, low carbon components, systems and vessels
- A lack of skills relating to the understanding of lightweight materials and their application in maritime and in the use of innovative manufacturing techniques
- A lack of skills relating to the storage, handling, transportation and use of alternative maritime fuels and in the development and deployment of alternative propulsion systems, such as batteries and fuel cells
- A lack of skills to develop automated maritime navigation systems and related systems
- A lack of skills to develop relevant and appropriate safety cases for the use of alternative fuels and a lack of skills relating to the health and safety aspects of gas handling and storage was identified as a critical area in the maritime sector
- A lack of skills to understand the risks posed by the use of alternative fuel sources (such as hydrogen) amongst regulators, policy makers and planners responsible for developing new regulatory frameworks and assessing applications to develop new fuel infrastructure

It is considered that some of these shortages and gaps can be addressed by reskilling and upskilling of existing staff. This could be achieved through short courses and “on the job” learning to understand different requirements and techniques and by adapting further and higher education courses to include relevant new content for new entrants to the sector. There will also be further action required to address these skills shortages and gaps to support the uptake of low carbon and zero emission technologies in the maritime sector in Scotland which will, largely, be driven by the need for CO_2 emission regulatory compliance.

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1 Introduction

This report has been prepared by Optimat Ltd for Transport Scotland to present the results of a study into the skills required to support the decarbonisation of maritime operations and to maximise the associated economic opportunities for Scotland. It is based on research carried out over the period November 2022 to January 2023 including 40 stakeholder interviews.

1.1 Background

The Climate Change Act, passed by the Scottish Parliament, commits to reduce greenhouse gas emissions to 75% of 1990 levels by 2030, 90% by 2040 and net-zero emissions by 2045. Scotland's total greenhouse gas emissions in 2018, including international aviation and shipping, were 41.6 $MtCO_2e$.

Transport is currently Scotland's largest sectoral emitter, responsible for 36% of greenhouse gas emissions in 2018. Shipping accounts for 15.5% of total Scottish transport emissions with domestic shipping accounting for 2$MtCO_2e$ and international shipping accounting for 0.34$MtCO_2e$. Since 1990, domestic shipping emissions have fallen by 41.8% and international shipping emissions have fallen by 56.1%. The National Transport Strategy 2 identifies taking climate action as one of four key priorities, with the associated outcomes including helping deliver the net-zero target, adapting to the effects of climate change and promoting greener, cleaner choices.

The Scottish Government has set targets for 30% of the ferries it owns to be low emission by 2032 and, by the same year, for low emission solutions to be widely adopted at Scottish ports.

The Scottish Government recognises that the decarbonisation of maritime operations also has the potential to benefit the Scottish economy, through opportunities in the supply chains for new vessels propelled / powered by battery electric, ammonia combustion and fuel cell, methanol combustion, etc. To facilitate decarbonisation and secure economic benefits from this, there will be a requirement for a range of skills. There is, therefore, a need for an evidence base to be established on what these skills are and where current and future skills gaps and/or shortages may act as a barrier to decarbonising maritime.

1.2 Study Scope and Objectives

The scope of the research study includes:

- Operation of shipping craft within Scotland, including fishing boats, ferries, offshore service vessels, inshore service vessels, cargo ships and leisure vessels.
- Activities in the supply chains for the design, development, manufacture, maintenance and end of life of the above shipping craft to address Scottish and international opportunities.

The maritime landscape consists of a number of segments, including:

- Design, development, testing and manufacture of emissions reduction products and services
- Design, development, testing of parts, components, systems and fuels
- Design, development, testing and manufacture of vessels
- Vessel owners/operators and ship management
- Vessel maintenance, repair and overhaul

- Port operations
- End of life/ Circular economy
- Supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes

Skills to support the decarbonisation of maritime have been considered in the next five years (short term) and over a ten to fifteen year period (long term).

The key research objectives of this study were to:

- Understand the scale and nature of the maritime vessels currently operating in Scotland
- Understand the potential technologies and practices likely to be utilised to support decarbonisation, up to 2032
- Estimate the potential levels of adoption of decarbonisation technologies and practices in the vessels operating in Scotland
- Identify the current scale of Scottish employment in different segments of the overall maritime landscape
- Identify the scale and nature of key skills required to support decarbonisation, up to 2032
- Define the current skills provision landscape servicing the Scottish maritime landscape
- Identify key skills gaps and shortages with potential to act as a barrier to the decarbonisation of maritime operations in Scotland and the potential wider economic opportunities
- Identify the barriers to skills development
- Identify any transferrable skills and talent from other sectors

2 Research Method

The research was carried out using a combination of secondary activities (desk review of published strategies, reports, policy documents, trade press, sectoral employment statistics, etc.) and primary activities (stakeholder interviews). This provided an understanding of the scale of Scottish-based activity across the various segments of the maritime landscape. Key policies, strategies and initiatives, driving the decarbonisation of the sector were also identified. The measures being developed to achieve decarbonisation targets were defined (technical and non-technical) and investigated, along with potential barriers to implementing the measures. This secondary research provided a baseline of information to test, and build upon, during the primary research. A target database of over 80 stakeholders was developed, with representation sought over the different segments of the maritime landscape, where relevant organisations were present in Scotland. Some organisations based outside Scotland were also approached for consultation where they had a UK wide remit (e.g. trade associations and companies headquartered outside Scotland but with Scottish-based operations). Potential stakeholders were approached with an email containing briefing information about the study and intended discussion topics, which aligned with the research objectives described above. Where stakeholders expressed an interest in participating, an online meeting was arranged. In total, 40 stakeholders contributed to the study. A list of organisations contributing to the study is included in Appendix A.

Information gathered during the secondary and primary research was then analysed to address each research objective. The final findings of the study and these were incorporated into this report, a summary presentation and infographic.

3 Segmenting and Quantifying Maritime Vessels in Scotland

Maritime vessels include a wide variety of different types. Due to the wide variation in types of vessels and the applications they are used for, different low carbon technologies can be more, or less, relevant. It is, therefore, useful to segment them into groups with some common characteristics.

For the purposes of this study, we have classified vessels into six groups:

- Leisure craft – including yachts and sailing boats
- Ferries (small and large)
- Fishing boats – including small fishing boats for freshwater fishing and large commercial vessels for deep-sea fishing
- Inshore service vessels – such as tugs and towing vessels that mostly operate in harbours and inland waters and vessels that service the aquaculture industry
- Offshore service vessels – this includes service operation vessels (SOVs), specially designed ships for the logistical servicing of offshore platforms and subsea installations, and crew transfer vessels (CTVs)
- Cargo ships

3.1 Leisure Craft

According to British Marine Scotland there are approximately 14,000 to 15,000 leisure craft moored in Scotland. This comprises both small and large yachts and motorboats. It has been widely reported that the impact of the COVID-19 pandemic and the resultant restrictions on travel was a driver of growth in demand for new and second-hand leisure boats. The data shows that leisure boat sales went from a decline of 8% in in 2019 to a growth of 9% in 2020.

Regarding future decarbonisation trends for leisure craft, according to feedback from British Marine Scotland, small leisure craft are likely to transition towards electric and electric/hybrid models. This is less likely to be a viable option for larger leisure craft, due to the weight of the batteries that would be required, so these vessels are likely to transition to an alternative low carbon fuel, which are discussed later in this report.

3.2 Ferries

This category has been segmented into small and large ferries as it is expected that there will be different decarbonisation options for different sizes of vessel. The composition of the Scottish ferry fleet consists of:

- Caledonian Maritime Assets Limited's (CMAL) fleet of 37 ferries
  - 32 of these are operated by Calmac Ferries Ltd on routes in the West of Scotland. These are all roll-on/roll-off vessels that range in size, carrying passengers, vehicles and freight

- Five are operated by Serco Northlink Ferries deployed on the Northern Isles Ferry Services network. Three are roll-on/roll-off passenger/vehicle vessels and two are freight roll-on/roll-off vessels
- Orkney Ferries, operating nine small and intermediate inter-island ferries on behalf of Orkney Islands Council
- A fleet of 12 ferries providing ferry services connecting mainland Shetland with outlying islands, provided mainly by Shetland's Island Council
- Private ferry fleets consisting of:
  - Western Ferries operating four intermediate ferries (50 metre length) on the Gourock to Dunoon route
  - Pentland Ferries, operating between Caithness (Gills Bay) to Orkney (St Margaret's Hope)
  - Stena Line operating two large ferries from Cairnryan to Belfast
  - P&O Ferries operating two large ferries from Cairnryan to Larne

The Scottish Government announced investment of £580 million in ports and vessels to support and improve Scotland's ferry services over the next five years, as part of its wider Infrastructure Investment Plan, in February 2021.

Small ferries are likely to adopt diesel-battery electric hybrid technology over the next five years with an increasing shift to more pure battery electric technology use over a 10 to 15 year time period. Large ferries are likely to adopt biofuel blends or diesel-battery electric hybrids in the next five years with more reliance on ammonia combustion technology over a 10 to 15 year time period.

3.3 Fishing Boats

There were 2,082 active Scottish based fishing vessels in 2021. The fleet reduced slightly, by six vessels, since 2020. A breakdown by vessel length and fishing method is provided in the figure below.

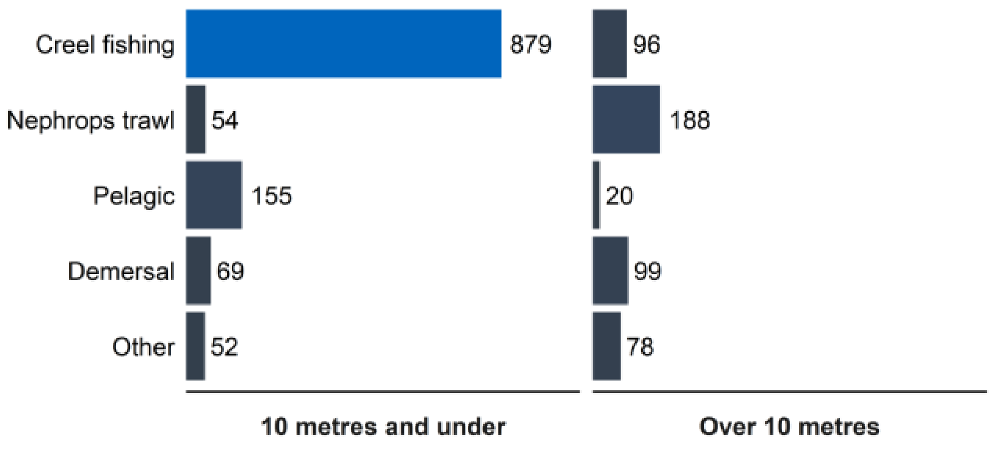


Figure 1: Number of active Scottish fishing vessels by fishing method and length, 2021

Definitions:

- *Creel fishing – baited cage-based fishing, typically using small boats close to shore. Targets lobster, crab, etc.*

- *Nephrops trawl – species of lobster, variously known as Norway lobster, langoustine, Dublin Bay prawns or scampi*
- *Pelagic – refers to fish living close to the surface, such as herring and mackerel*
- *Demersal – refers to fish living close to the seabed, such as cod, haddock and monkfish*
- *Other – various, including shellfish such as scallops not caught using creel fishing*

The fleet is dominated by small vessels that are ten metres and under in length, amounting to 1,573 vessels, which is approximately 76% of the total fleet. In Scotland, these vessels are used in inshore waters mostly for catching shellfish using creels.

The total engine power of the Scottish fishing fleet is estimated at 369 thousand kW. A segmentation of vessels by engine power is shown in the figure below.

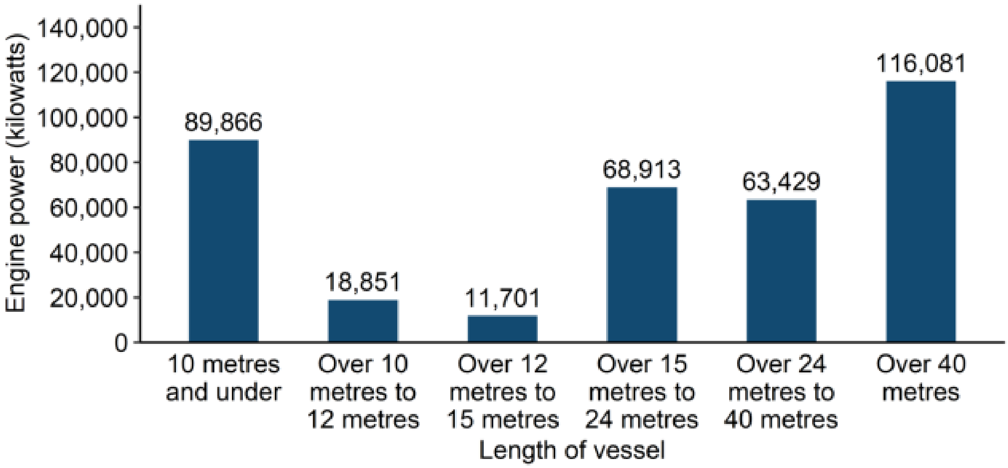


Figure 2: Engine power (kilowatts) of Scottish vessels by length, 2021

3.4 Inshore Service Vessels

These vessels are, typically, used in near-shore operations and include, for example, tugs, pilot boats and aquaculture service vessels.

According to the British Tugowners Association, whose members cover ports handling 90% of Britain's sea-borne trade, there are more than 150 tugs in operation across Britain, in over 40 ports.

3.5 Offshore Service Vessels

We can consider three main areas of offshore activity, namely:

- Oil and gas exploration and extraction
- Wind farm development and operation
- Fishery protection through Marine Scotland, which is responsible for the integrated management of Scotland's seas and delivering regulatory science and compliance activities across the Scottish coastline and over 800 islands.

Many vessel types and configurations are used in the offshore oil and gas industry to deliver a wide range of services including, for example, finding and extracting energy deposits, supporting maintenance and repair of assets and the provision of hotel services for service personnel and crew. Often, vessels are customised to serve a specific function and then repurposed to serve a different function. Some vessels are hybrids and able to perform multiple functions.

Many of the vessels used in the oil and gas industry are also used in offshore wind. Again, some are custom design vessels to perform a specific function.

We consider two types of vessels:

- SOVs (Service Operation Vessels) are large vessels designed to be a support platform, operating at the offshore site for weeks at a time. They house both personnel and equipment.
- CTVs (Crew Transfer Vessels) are smaller vessels used to transfer crew and small amounts of cargo between the shore and the offshore site.

These vessels are typically owned by specialist marine service companies and are hired/leased for specific projects by energy exploration, wind energy companies, etc.

Offshore wind is expected to drive strong demand for offshore vessels. The UK is a world leader in offshore wind, with over 10 GW of operational offshore wind farms consisting of over 2,300 offshore wind turbines and plans to reach 40GW installed by 2030. Most of this capacity has been installed on the East Coast, the Irish Sea and English Channel with Scotland having around 1 GW of installed capacity.

Wind farm service vessels, mainly SOVs and CTVs, are built to serve offshore wind in both the construction and operation and maintenance phases. There is a third category, installation vessels, but these are much more highly specialised vessel that make up only a small proportion of the number of vessels used to support the offshore wind industry (and only utilising during installation phase).

Specific number of these vessels could not be identified within the scope of this study. Typically, off-shore service companies operate fleets of these specialised vessels and are contracted by OEMs and off-shore wind project developers and operators to deliver services as and when required. The duration of these contracts varies depending on the nature of the service to be delivered and, as a result, the number of vessels operating in and around Scotland changes quite regularly. There is no fixed number of vessels.

although there is evidence that there is a significant shortage of vessels that will impact offshore wind capacity development.

3.6 Cargo Ships

The main ports processing freight from cargo ships in Scotland is shown in Figure 3, below.

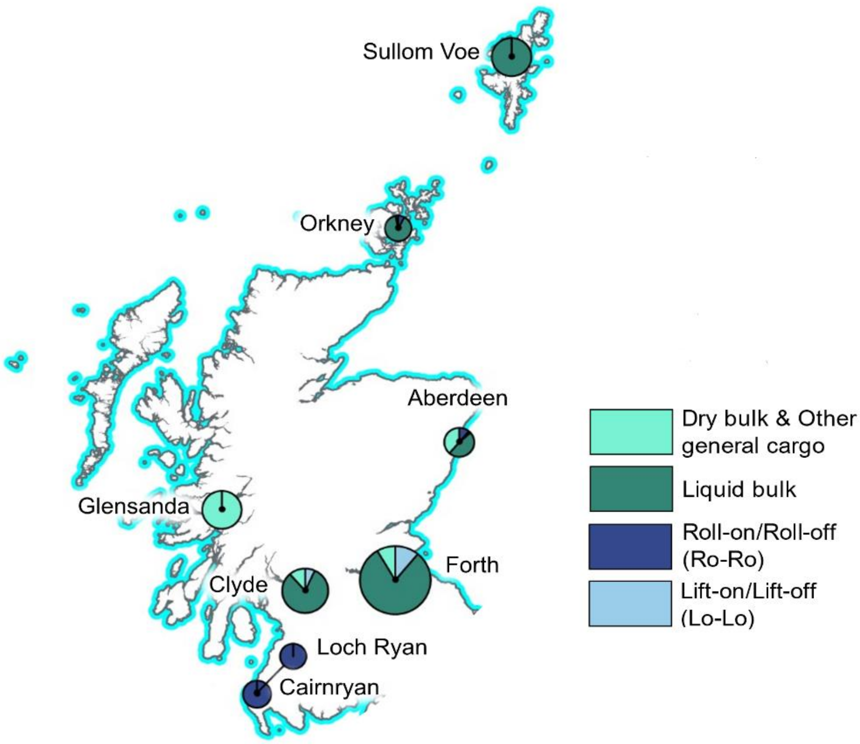


Figure 3: Map of ports in Scotland by tonnage and cargo group, for major ports over 2 deadweight million tonnes in 2021 – Table Port0304 (source: Maritime Statistics, Department for Transport: Port Freight Statistics, July 2022)

Ports on the Forth and the Clyde are the largest handlers of cargo in Scotland with Forth processing 19.8m tonnes in 2021 (15.8 million tonnes of which is liquid bulk) and Clyde processing 8.4 million tonnes in the same year (with 6.9 million being liquid bulk).

Scotland, particularly City of Glasgow College, is a major centre of training for the global maritime sector. The scale of the global cargo fleet, excluding offshore service vessels, tugs and fishing boats, can be presented as follows:

Ship type	Number and percentage of ships, by size class									
	Small GT < 500T		Medium 500T <= GT < 25,000T		Large 25,000T <= GT < 60,000T		Very Large GT >= 60,000T		Total	
General Cargo Ships	4,089	39.6%	11,814	40.8%	264	2.1%			16,167	27.6%
Specialised Cargo Ships	8	0.1%	266	0.9%	64	0.5%	7	0.1%	345	0.6%
Container Ships	19	0.2%	2,315	8.0%	1,629	12.9%	1,554	23.2%	5,517	9.4%
Ro-Ro Cargo Ships	39	0.4%	601	2.1%	549	4.3%	268	4.0%	1,457	2.5%
Bulk Carriers	286	2.8%	3,847	13.3%	6,842	54.1%	1,899	28.4%	12,874	22.0%
Oil and Chemical Tankers	1,979	19.2%	7,372	25.5%	2,773	21.9%	2,185	32.7%	14,309	24.4%
Gas Tankers	36	0.3%	1,145	4.0%	433	3.4%	591	8.8%	2,205	3.8%
Other Tankers	437	4.2%	741	2.6%	16	0.1%		0.0%	1,194	2.0%
Passenger Ships	3,435	33.3%	825	2.9%	71	0.6%	187	2.8%	4,518	7.7%
Total	**10,328**	**100.0%**	**28,926**	**100.0%**	**12,641**	**100.0%**	**6,691**	**100.0%**	**58,586**	**100.0%**

Figure 4: The Global Cargo Fleet - total number of ships by size (Source: The World Merchant Fleet in 2020, Equasis Statistics, 2021)

4 Low Carbon and Zero Emission Technology Options for Maritime Vessels

This section identifies the drivers for decarbonisation, market impact and the different low carbon technology options, before then summarising the relative future attractiveness of each technology for different vessel applications.

4.1 Drivers for Decarbonisation

The key drivers for decarbonisation can be detailed as follows.

4.1.1 The International Maritime Organisation

One of the strongest influences on the sector is the International Maritime Organisation (IMO) and its Greenhouse Gas Strategy and carbon reduction targets. The IMO is a specialised agency of the United Nations that is responsible for measures to improve the safety and security of international shipping and prevent marine pollution from shipping. The IMO sets standards for the safety and security of international shipping and it oversees every aspect of worldwide shipping regulations, including legal issues, shipbuilding, and cargo size.

In 2018, the IMO agreed to an initial strategy to reduce emissions of greenhouse gases from shipping by at least 50% by 2050 compared to 2008. The IMO has set targets for the reduction of GHGs for 2030 and 2050, with a proposed timeline for early actions to 2027 shown below:

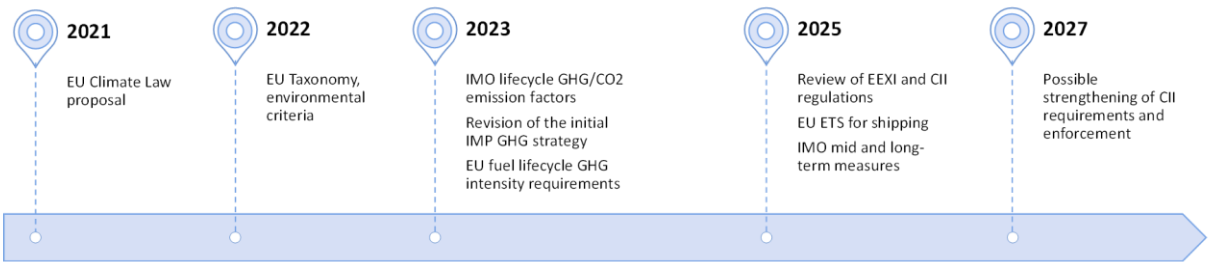


Figure 5: Timeline for the IMO Greenhouse Gas Strategy

The strategy covers cargo, roll-on/roll-off passenger and cruise vessels above 5,000 gross tonnes and trading internationally. It should be noted that the IMO deals in short term measures; in the maritime industry, 10 years is considered short term.

The strategy is being implemented through a package of measures:

- The Energy Efficiency Existing Ship Index (EEXI) addresses the technical efficiency of existing ships.
- The Carbon Intensity Indicator (CII) rating scheme addresses the operational efficiency of ships through incremental CO_2 reduction criteria.
- The enhanced Ship Energy Efficiency Management Plan (SEEMP) addresses the energy management system.

The above package is in addition to the Energy Efficiency Design Index (EEDI), which was introduced 10 years ago and is a measure of the energy efficiency of new build vessels. This is considered in terms of carbon dioxide released to atmosphere per cargo tonne mile.

The EEXI and the CII entered into force on 1st November 2022. These measures require owners of older vessels to calculate and report their carbon emissions. The CII is of particular relevance to this study as it requires mandatory carbon reduction year on year, which will drive the maritime industry to adopt new technologies that optimise vessel efficiency.

The EEDI and EEXI are both measured in terms of specific CO_2 per tonne mile, allowing a direct comparison of the efficiency of various ships of various sizes. Amongst other factors, the calculations take account of the carbon intensity (CI) for the fuel used. For example, diesel fuel has a CI of approximately 3.2, i.e. for 1kg of fuel consumed, 3.2 kg of CO_2 is released. The lower the CI value, the cleaner the fuel, thus changing the fuel mix is the primary way of reducing the environmental impact of a ship.

It is planned that the IMO Strategy will be revised in 2023 and the industry is expecting further commitments to reducing shipping emissions.

4.1.2 The Clydebank Declaration

At COP26 twenty-four countries signed the Clydebank Declaration to support the establishment of green shipping corridors, defined as "zero-emission maritime routes between two (or more) ports". A target of at least six green corridors by the mid-2020s was set, with further growth thereafter. More recently, at the COP27 event, the Green Shipping Corridor Hub was launched by the Zero Emission Shipping Mission. The Hub is being developed as an interactive platform and toolkit to support the development of green shipping corridors.

Already, over 20 green corridors initiatives are underway, covering both local and international routes.

4.1.3 National Policies and International Targets

In addition to the IMO targets for greenhouse gas reductions, several national and international targets have been defined that will drive the adoption of CO_2 mitigation options, highlighting the global importance of decarbonisation. These include, for example:

Scotland

In its Climate Change Plan, the Scottish Government has committed to reduce transport emissions by 41% in 2032, compared to emissions in 2012. The maritime sector contributes 15% of 2018 Scottish transport emissions of 14.9 million tonnes of CO_2e. Further, the Scottish Government has set a target of net zero emissions by 2045.

United Kingdom

The UK government, in the National Shipbuilding Strategy Refresh and the Clean Maritime Plan has made commitments to reduce emission from international and domestic shipping. The vision set in the strategy is as follows:

"In 2050, zero emission ships are commonplace globally. The UK has taken a proactive role in driving the transition to zero emission shipping in UK waters and is seen globally as a role model in this field, moving faster than other countries and faster than international standards. As a result, the UK has successfully captured a significant share of the economic, environmental and health benefits associated with this transition."

The specific commitments set in the Clean Maritime Plan and Strategy are:

- By 2025, all new vessels for UK waters are designed with zero emission capabilities.
- By 2035 bunkering (supply) of zero emission fuels is widely available across UK
- By 2050 the UK domestic shipping sector is net zero

Europe

The European Union (EU) is aiming to reduce emissions by at least 55% by 2030, in comparison to 1990 emission levels, and become the first climate neutral continent by 2050. Under the 2021 European Green deal, several commitments have been made, including an emissions reduction target of 90% for EU port cities by 2050. The EU has recognised that port cities are a key factor in helping to reduce overall emissions. It is estimated that over half of all maritime emission arise when ships are berthed in ports.

Rest of the World

Some other examples of national legislative programmes / targets include:

- China setting a target to be carbon-neutral by 2060
- The US aiming to reduce GHG emissions by 50% by 2030 compared to 2005 levels
- Canada aiming to reduce GHG emissions by 40–45% by 2030 compared to 2005 levels

4.2 Market Impact

The legislation and policy drivers, summarised above, define a clear requirement for decarbonisation and are already influencing sector behaviour. CO_2 emission reduction is becoming a key factor in the selection of new vessel power systems, with clear evidence of a transition to alternative, greener fuels in new ship orders.

In 2022, 98.8% of the world's ships in operation were running on conventional marine fuels with the order book suggesting that, for new ships, this will reduce to 78.9%. In terms of vessel size (measured, here, in gross tonnage) 94.5% of ships in operation were running on conventional fuel, reducing to 66.8% for ships on order. This is shown in the following figure.

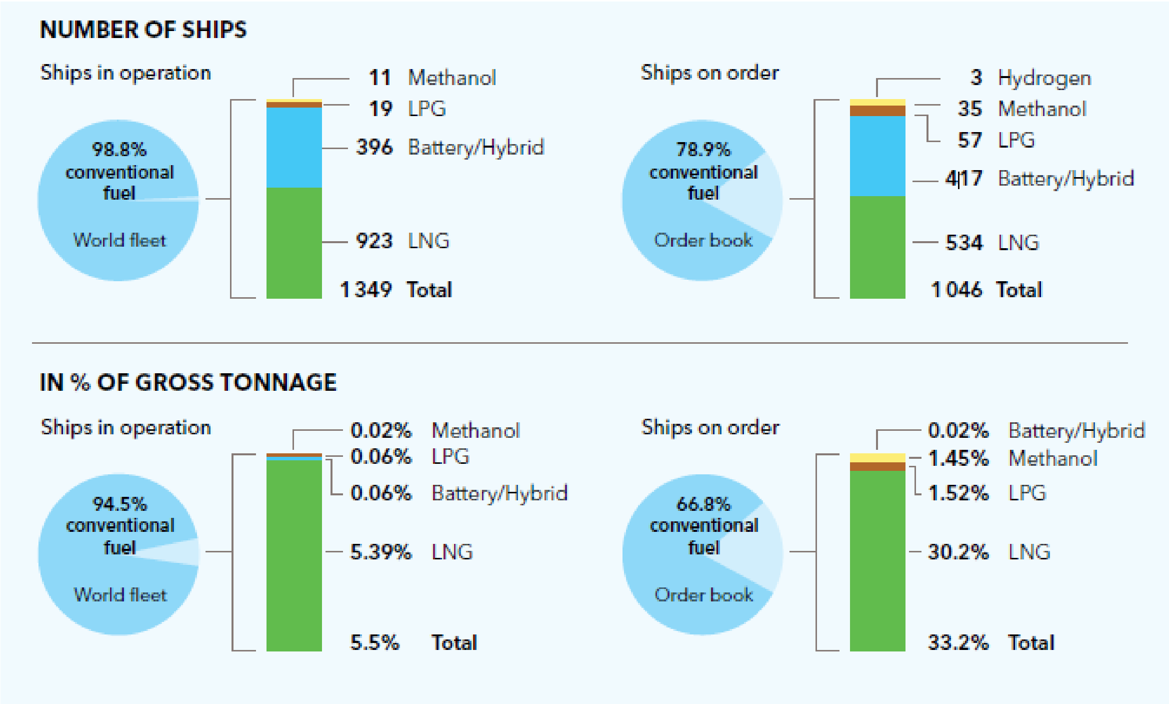


Figure 6: Trends in New Ship Fuel Types (Maritime Forecast to 2050, DNV, 2022)

Based on the above data, it is likely that liquefied natural gas (LNG) will be the dominant alternative fuel in the short term, particularly for larger vessels, with battery, methanol and hydrogen systems emerging over time as low carbon and zero emission solutions.

4.3 Decarbonisation of Maritime Vessels - Technology Trends

In this study the options to decarbonise maritime vessels has been segmented into three themes:

- Optimising efficiency
- Auxiliary power systems / technologies
- Alternative fuels / propulsion systems

The various decarbonisation technologies proposed within these three themes are summarised in the sections that follow, together with comments on their adoption.

4.3.1 Optimising Efficiency

4.3.1.1 Technology Options

Improving the fuel efficiency of vessels is a well-established method for optimising operational costs of maritime transport. Several different options have been demonstrated, as highlighted in the figure below. Some of these (e.g. slow steaming, non-friction coating and anti-fouling technologies) are well established while others, such as autonomous vessel operation, are emerging.

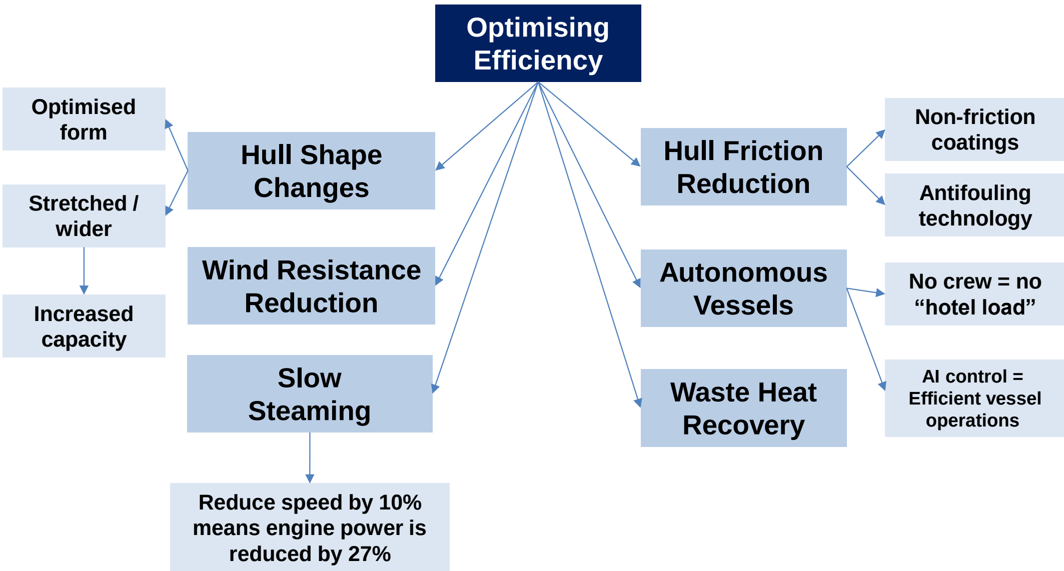


Figure 7: Efficiency Optimisation Options

In terms of recent IMO measures, optimising efficiency is of less benefit than reducing the CI value of the fuel in vessels that are in operation currently. Where the fuel cannot be changed, however, improving efficiency and reducing the fuel burn is an attractive method of reducing the environmental impact.

Hull resistance is a key contributor to high fuel consumption, due to increased power requirements to overcome water resistance on the hull. As speed increases, hull resistance increases significantly. Indicatively, when a ship increases its speed by 10%, its engine power is increased by 27%. Although this does not hold true on detailed analysis, the general rule may be taken that there is a non-linear relationship between speed and fuel consumption. The slower a ship's speed, the less fuel is required, and each hull will have an optimum speed for efficient cruise. This is known as the slow steaming effect. If a vessel uses one ton of fuel per hour at 10 knots and two tons of fuel per hour to achieve 14 knots, the extra 4 knots of speed requires twice the quantity of fuel with a significant increase in CO_2 emissions.

Maersk Group has been challenging the status quo of ship operations for almost a decade with their slow steaming and "just in time" strategy. It has reduced the design speed of many of its ships to find an optimal cruise speed. The Maersk strategy even resulted in various vessels being taken out of service for a period of time to have bulbous bows that were optimised for 13 knots removed and new, conventional bows optimised for 10 knots to be installed.

The accumulation of microorganisms, plants, algae, or animals on surfaces in contact with water, such as the hulls of ships (also known as biofouling) can reduce the efficiency of propulsion systems and increase fuel consumption, leading to increased emissions and costs. Biofouling is a significant challenge for the maritime industry, and effective prevention and control measures are necessary to reduce its impact. Modern coatings have the potential to reduce hull fouling to minimal levels. There are cases where a significantly fouled hull can cause a 10% increase in fuel burn, which is significant. These issues may, however, be easily prevented through good operational and service procedures. High performance coatings have a high cost of application and may not always return financial benefits.

There is much potential for autonomous vessels to be utilised to reduce CO_2 emissions from ships. By removing the majority, or all, of the crew, many secondary services and electrical loads may also be removed. For example, with no crew there is no requirement to maintain heated cabins, or air-conditioned spaces, the galley is no longer required and all the refrigeration plant for food can be removed. With new builds, autonomous ships incorporating artificial intelligence (AI) for navigation will not require a super structure or a traditional wheelhouse. This means that the entire vessel's design can be streamlined for minimal wind resistance. For bulk cargo and container ships the reduction or removal of the crew can reduce the power requirement by approximately 100-150 kW, which is the typical hotel load for this kind of vessel.

Other measures to optimise vessel efficiency could include, for example, the use of lighter materials to reduce vessel weight and hence fuel consumption; using air lubrication to reduce vessel friction; innovative propeller design; and enhanced energy recovery. Regarding this latter point, steam turbines can be used in ships with large amounts of waste heat available in the exhaust system. It is possible to configure a ship's exhaust with economisers to extract the heat to generate steam and, thereby, run a turbine to generate power.

4.3.1.2 Adoption of Energy Efficiency Methods

It is important to note many of the above options are already being implemented. For example, slow steaming and hull shape optimisation are well established and vessel builders and vessel retrofit / repair companies are, increasingly, using composites materials and exploring novel manufacturing methods, such as additive manufacturing, to create strong but light structures.

Stakeholders highlight that these options will continue to be implemented in the future.

4.3.2 Auxiliary Power Systems / Technologies

4.3.2.1 Technology Options

Auxiliary power technologies are wind assisted propulsion and solar-on-ship.

- Wind Assisted Propulsion
  Some large ships, such as the example shown opposite are being outfitted with a variety of wind auxiliary propulsion. Some commentators assert that wind auxiliary ships have a significant place in the decarbonising sector with fuel savings of 30% being increasingly likely to be achieved. These vessels will still require standard marine propulsion technology, either a diesel engine or a new low / zero carbon system. If new generation fuels, such as ammonia are predicted to be significantly more expensive than conventional heavy marine fuels then improved efficiency and wind assist will help reduce the annual fuel bill.

Wind ships, masts, spars, sails, foils and rotor sails as well as kites may all be used to harness wind power and there is wide range of technologies. Some of these technologies are very closely linked to traditional masts and modern sail furling systems, whilst other technologies are much more elaborate, such as Flettner rotors, which harness the aerodynamics of a large vertically mounted spinning cylinder to generate lift and forward thrust.

- Solar-On-Ship
  Photovoltaic cells can be used to satisfy on-board electricity demand. Solar panels can either be installed horizontally on deck or vertically in an arrangement with certain sail types. However, the potential of solar power to contribute to onboard power demand is expected to be very limited..

4.3.2.2 Adoption of Auxiliary Propulsion Methods

Wind assisted propulsion is an emerging solution, which has currently been implemented on around 20 commercial ships but has the potential to apply on 40-45% of global fleet. There are a number of companies developing wind assisted propulsion technologies including, for example, Yara Marine Technologies (Norway), Wallenius Marine AB (Sweden), Mitsui O.S.K. Lines, Ltd. (Japan) and Windship Technology Ltd (UK).

To date, there is a limited number of examples of solar power use on ships and one of the key issues identified is a long payback period on investment. Eco Marine Power (Japan) is one of the few companies, worldwide, that has demonstrated a solar power device to reduce emissions. Other solar powered or power assisted vessels tend to be much smaller, concept vessels used to demonstrate the technology.

The implementation of these technologies would be in addition to energy efficiency measures, described above.

4.3.3 Alternative Fuels / Propulsion Systems

As discussed earlier, changing the fuel mix to one that has a lower CI value is the primary way of reducing the environmental impact of the ship and it is the use of alternative fuels and propulsion systems that is likely to have the biggest impact on the move towards low carbon and zero emission marine transportation. There are several alternative lower carbon fuels and propulsion systems already in use as well as new and zero emission technologies under development. These include:

- Biofuels
- Liquid natural gas (LNG)
- Hydrogen
- Ammonia
- Methanol
- Hybrid electric and battery electric
- Small modular reactors (molten salt reactors)

4.3.3.1 Biofuels

Biofuels are seen as possible viable solution for relatively low demand consumers, such as small ferries, fishing vessels and harbour tugs. A biodiesel fuel could be used as a direct diesel replacement, although, in reality, this is likely to be a blend of conventional diesel and biodiesel as 100% biodiesel presents a number of challenges for conventional internal combustion engines (ICEs). Nonetheless, this could be a highly attractive option for owners with limited funds for any significant retrofit of old and small vessels. Biofuels can be derived from waste products, such as cooking oil with potential, in the future, for manufacture of biofuels from hydrogen and non-fossil carbon sources (e.g. carbon captured from industrial emissions). Biofuels are unlikely to be a viable option for international shipping because of the high volumes that would be required and concerns over large scale cultivation of land for fuels feedstocks competing against food production.

4.3.3.2 Liquid Natural Gas

Liquid natural gas (LNG) has replaced heavy fuels and diesels for some marine applications. LNG is formed when natural gas is cooled to -162°C, making it easier and safer to store. Vessels carrying LNG have been converted to use the LNG that would have been lost due to evaporation as a fuel. Due to the higher calorific value of the gas and its lower CI, a vessel operating on LNG will emit less CO_2 to atmosphere compared to the same ship on the same duty operating on heavy fuels or diesel. However, using LNG can result in the release of unburnt methane, a potent GHG, depending on the type and efficiency of the engine. Tank to wake emissions are generally accepted to be 30% lower for a ship running on gas rather than heavy oil and, as an additional benefit, a gas engine will produce a lot less particulate matter with visibly cleaner exhaust smoke. Also, LNG is commercially available in bunker quantity at a wide range of international ports making it a viable fuel for other types of ship, not just LNG carriers. Indeed, many cruise ships now use LNG, with companies such as Costa Cruises, Disney Cruise Line, P&O Cruises and Royal Caribbean introducing new LNG powered vessels to their fleets. LNG is, however, a fossil fuel and there is a view amongst some industry players that this will be considered a transition fuel as alternative, low and zero carbon alternatives are developed, proven and commercialised. According to stakeholder feedback:

"LNG (and methanol) are not long term options even though they support a reduction in CO_2 and cleaning of emissions."

4.3.3.3 Hydrogen

Hydrogen is considered as a viable option in the transition away from heavy fuel oils. Hydrogen emits zero carbon dioxide (CO_2), zero sulphur oxides (SOx) and only negligible amounts of nitrogen oxides (NOx). It can be used in several different ways: in a dual fuel mixture with conventional diesel fuels (blended fuels), as a complete replacement of heavy fuels in combustion engines or in fuel cells.

Considering, firstly hydrogen combustion. This is considered to be the most attractive option for the more powerful engines that are required for larger marine vessels, such as cargo vessels, cruise ships and larger passenger transportation vessels. For example, MAN Energy Solutions (Germany) a major developer and manufacturer of engines for a wide range of applications, is testing a single cylinder, hydrogen fired, 645 kilowatt, four stroke engine. In the first instance, this will be developed for stationary applications, but the company anticipates its first products for the marine industry will be available by 2030.

In addition Windcat, one of Europe's leading offshore personnel transfer companies has recently announced that it has placed an order for the construction of a number of hydrogen powered commissioning service operation vessels (CSOVs). These have been designed by Damen Shipyards (Netherlands) and will be built by CMB.TECH (Belgium) at a facility in Vietnam. The vessels will utilise hydrogen combustion technology but can run on dual fuel (hydrogen / diesel). CMB.TECH is aiming to position itself as a supplier of hydrogen, that will be locally produced either on or offshore, as well as a boat builder.

Hydrogen is also being explored for fuel cell systems. Several examples of prototype hydrogen fuel cell powered vessels have been developed although it is likely that fuel cells will be appropriate for certain classes of vessel (e.g. smaller passenger and vehicle ferries) rather than others. It is unlikely, that fuel cells will be able to meet the requirements of larger cargo vessels due to cost, the requirement for fuel storage as well as power requirements.

Hydrogen storage is a particular issue. The gas needs to be either compressed or stored as a liquid which requires temperatures of -250°C. There are also significant safety issues including the risk of explosion associated with hydrogen. To support the commercialisation of these technologies marine industry standards, certification and regulations also need to be develop in a timely manner. According to stakeholder feedback:

"There is still a lot of nervousness around the use of hydrogen…some of the regulators don't really understand the technology."

The overall emissions mitigation potential of hydrogen significantly improves if it is produced via a method that does not result in carbon emissions, i.e. green hydrogen. This is the manufacturing method prioritised by the Scottish Government.

4.3.3.4 Ammonia

Like hydrogen, ammonia can be used either as a direct replacement for heavy oils in combustion engines or as a hydrogen carrier in fuel cells. Furthermore, as contains no carbon atoms, ammonia emits zero CO_2. SOx emissions are also zero. There are, however, some concerns around the production of NOx, depending on the efficiency of combustion, but this can be easily dealt with through the deployment of existing NOx scrubbers, for example. There are also quite legitimate concerns about the toxicity of ammonia. Nonetheless, for larger vessels, especially, the emphasis is, increasingly, on ammonia as an alternative fuel and the marine industry seems to be relatively accepting of this and is aware that it will have to adapt accordingly. According to stakeholders:

"It is likely that ammonia will be approved for use as a marine fuel first as it is better understood."

There are a number of products under development or being demonstrated, with two of the world largest manufacturers of marine engines, MAN Energy Solutions (Germany) and Wärtsilä Corporation (Finland) developing ammonia combustion engines.

MAN Energy Solutions is developing a fuel-flexible, two stroke ammonia engine for large scale container ships, which it expects to be commercially available by as early as 2024, followed by a retrofit package for existing vessels, which will be available by 2025. The R&D is focused on the development of a complete system, from fuel tank to engine, to address issues such as the toxicity of ammonia and to avoid emitting NOx.

Wärtsilä has initiated combustion trials using ammonia, which will help the company to prepare for the use of ammonia as a fuel. As part of these tests, ammonia was injected into a combustion research unit to better understand its properties and, based on initial results, the tests will be continued on both dual-fuel and spark-ignited gas engines. These will be followed by field tests in collaboration with ship owners. Wärtsilä aims to develop a complete ammonia fuel solution comprising engines, fuel supply and storage. The company is working with ship owners, shipbuilders, classification societies and fuel suppliers to learn more about system and safety requirements, as well as fuel composition, emissions and efficiency.

Compared to hydrogen, ammonia has the advantage of being liquefied at -33°C, making it easier to store and handle.

Production of hydrogen and ammonia fuels is outside the control of the marine industry however it must follow the global trends and fuel availability. Considering ammonia, which, as already discussed, is a more attractive option for shipping; to produce ammonia and, in particular green ammonia, at a scale that would be sufficient to meet the demands of the maritime industry, would require significant growth in the production capacity of renewable electricity and green hydrogen. A study carried out on behalf of the European Maritime Safety Agency (EMSA) estimated the global supply of and demand for green ammonia as a fuel in shipping, as shown in the table below.

	Min (Mt/year)	Max (Mt/year)	Comments
Required production of 100% green ammonia for use in global maritime shipping in 2040	600	1,000	Calculated using projected global maritime fuel energy demand in 2030 and 2050 from Fourth IMO GHG Study (CE Delft & RH DHV, 2020).
Planned green ammonia capacity worldwide	5	Unknown	Minimum value derived from current production capacity developments

Figure 8: Estimated supply of and demand for green ammonia as a fuel in shipping

This demonstrates the expected levels of growth of green ammonia production that would be required over the next 10 – 15 years

4.3.3.5 Methanol

Methanol is another alternative fuel that is starting to generate interest in the marine sector due to its proven reduction in SOx (99% reduction) and NOx (60% reduction) emissions and its potential to reduce CO_2 emissions compared to traditional fuels (when used as a primary fuel this equates to around 10%). Furthermore, as methanol exists as a liquid at ambient temperatures, existing infrastructure, including engines and vessels, can be readily re-purposed / retrofitted to facilitate its use, meaning it is easier to store on vessels than gaseous alternative fuels. However, methanol has a lower energy density than both LNG and conventional fuels, which means that more fuel is required for the same energy content, making it less attractive for use in smaller vessels. In common with LNG, methanol is a fossil fuel as it is produced using natural gas as a feedstock and there is a view that this may also result in this being a transition fuel unless the technologies to produce it from renewable sources, such as biomass or renewable energy powered electrolysis, together with carbon capture and storage, can be developed and commercialised at an appropriate scale.

Both Maersk (Denmark) and Stena (Sweden) have introduced methanol powered (methanol and dual fuel combustion) vessels across their fleet, for example, ferries and bulk containers, as part of their long-term decarbonisation and sustainability strategies. It will not be considered as a transition fuel although the stipulation is that the methanol fuel should be "green", i.e. bio-methanol or methanol produced utilising green hydrogen and CO_2 from carbon capture, utilisation and storage systems.

4.3.3.6 Battery Electrification

Diesel-Electric Hybrid

There is a reasonable degree of activity in the development of diesel-electric hybrids, that combine batteries, electric motors and diesel engines combined with electric generators (the latter also known as a diesel genset), and the technology is becoming more mainstream with many of the major suppliers of traditional marine engines and gensets now offering hybrids. These include, for example, MTU Solutions (Germany), MAN (Germany), Volvo Penta (Sweden), and Yanmar Co. Ltd. (Japan) as well as smaller companies such as Hybrid Marine (UK) and Beta Marine (UK). Stakeholder input to this study indicated that:

"For new fleet, we believe that diesel-electric engines will be the way forward for power management."

These technologies are already being used successfully by the navy in aircraft carriers, for example.

To a lesser extent, hydrogen powered fuel cells are also being considered for incorporation into diesel-electric hybrid vessels but these are, mainly, still at the demonstration stage. For example, a contract was awarded for the concept design of a hydrogen fueled ferry, which could eventually operate on the Kirkwall to Shapinsay ferry route in the Orkney Islands. This contract was awarded through the HySeas III project (a European Commission H2020 funded project) by Caledonian Maritime Assets Ltd (CMAL), the aim being to demonstrate that hydrogen fuel cells can be successfully integrated with a marine hybrid electric drive system (electric propulsion, control gear, batteries, etc.) along with the associated hydrogen storage and bunkering arrangements. The actual build of this vessel would, however, require significant investment (£10s of millions) and it has not, therefore, progressed beyond the design stage.

Battery Electric

Battery electric powered boats and short journey ferries are becoming established and were the first vessels to have zero local emissions. In Scandinavia, for example, where much of the electric power from the national grid is from hydroelectric power stations, then the whole lifecycle emissions are almost as low as any sailing vessel of the 19th century. The carbon footprint for battery manufacturing and the initial carbon footprint of the ship cannot be ignored, however, operationally, the design is as near zero as can currently be achieved.

This is an area of developing activity in Scotland. Caledonian Maritime Assets Limited (CMAL) is pursuing battery electric powered ferries in their recently announced small vessel replacement programme.

In addition, Zephyrus, a recently formed joint venture (involving Aluminium Marine Consultants, MJR Power and Automation, Turbulent, Offshore Operations, Shift Energy, Ad Hoc Marine Designs, Siemens and Gamesa) is dedicated to the design, build and operation of fully electric service vessels for the off-shore industries, together with the onshore operations and charging infrastructure. The aim is to provide the world's first zero-emission offshore wind support services. The principals behind the joint venture are looking at a number of potential manufacturing locations around the UK, including in Scotland.

Small Modular Reactors

Whilst nuclear reactors have long been used for propulsion and power generation in navy surface and sub-surface vessels there is increasing interest in the use of nuclear power, especially small modular reactors, in certain classes of commercial vessel. Several companies are developing modular reactors and containerised systems, with Rolls Royce (UK) being a recognised global leader in the field. According to stakeholder input to this work:

"…there are already concept designs for shipping."

The technology will, however, need significant onshore operation and demonstration to gain sufficient knowledge, experience and data before being demonstrated at sea. The technology is still at the proof of concept stage and it is anticipated that it will take between 5-7 years to reach commercialisation. The Scottish Maritime Cluster, for example, views this as a very good option for net zero carbon shipping and although the upfront costs will be high, no refueling would be required over the lifetime of the system (up to 25 years depending on operating conditions).

However, there are significant barriers to the use of nuclear power in commercial maritime applications. Significant work will be required to guide public perception, risk and costs associated with deploying the technology. For nuclear propulsion to achieve significant uptake in commercial shipping, public and government opposition to nuclear power, and concerns related to potential misuse, must be addressed. Clearly there are implications for end of life treatment which are likely to add significantly to the while life cost of this technology option.

4.3.3.7 Summary

This section highlights that there is a range of potential fuels being developed for the maritime sector, with each being at a different level of maturity. The relative maturity of most of the above solutions is summarised in the figure below, based on technology readiness levels (TRL). This shows that further innovation activities are required for most alternative fuel options.

TRL	Bunkering			Storage onboard					Processing and conversion			Propulsion			
	Equipment	Procedures	Fuel quality standards	Structural tank	Membrane containment system	IMO type A tank	IMO type B tank	IMO type C tank	Venting system	Fuel supply system	Reformer	2-Stroke ICE	4-Stroke ICE	FC	Boiler
LSHFO ICE reference ship	9	9	9	9					9	9		9	9		9
Bio-diesel ICE	9	9	9	9					9	9		9	9		9
E-diesel ICE	9	9	9	9					9	9		9	9		9
Bio-methanol ICE	7	6	3	7					7	7		7	6		2
E-methanol ICE	7	6	3	7					7	7		7	6		2
Bio-methanol FC	7	6	3	7					7	7	3		6	7	2
E-methanol FC	7	6	3	7					7	7	3		6	7	2
Bio-LNG ICE	9	9	9		8		9	9	9	9		9	9		9
E-LNG ICE	9	9	9		8		9	9	9	9		9	9		9
Bio-LNG FC	9	9	9		8		9	9	9	9	4			7	
E-LNG FC	9	9	9		8		9	9	9	9	4			7	
E-ammonia ICE	7	2	2			7	7	7	3	7		3	2		2
NG-ammonia ICE	7	2	2			7	7	7	3	7		3	2		2
E-ammonia FC	7	2	2			7	7	7	3	7	2		2	7	2
NG-ammonia FC	7	2	2			7	7	7	3	7	2		2	7	2
E-hydrogen ICE	4	2	3				3	6	2	2		2	5		2
NG-hydrogen ICE	4	2	3				3	6	2	2		2	5		2
E-hydrogen FC	4	2	3				3	6	2	2			5	7	2
NG-hydrogen FC	4	2	3				3	6	2	2			5	7	2
Batteries	4	2	3				3	6	2	2			5	7	

Figure 9: TRL Ranking of Key Technologies (2020)

4.3.3.8 Market Development - Alternative Fuels and Propulsion Systems

Most analyses on decarbonisation of the maritime sector agree that it should be technically possible to decarbonise by 2035 but there does not seem to be any real consensus on how this will be achieved and what fuel types will dominate. Demand projections vary depending on the underlying assumptions used. For example:

- [An analysis for the Department of Transport](#) forecast expected international and domestic fuel use for zero operational GHG emissions in 2050 as follows:

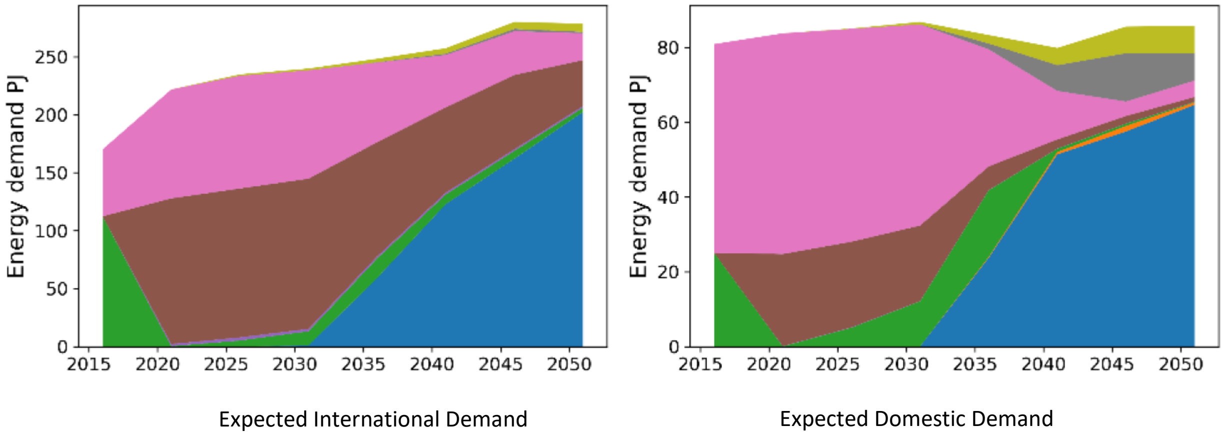
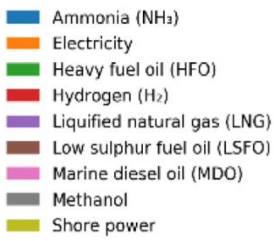


Figure 10: Expected International and Domestic 2050 Fuel Use for Zero Operational GHG Emissions



The key for Figure 10 is shown opposite.

The main observations from this analysis are:

- Major UK and international market share for ammonia after 2030
- Modest demand for electric power systems
- Very low / no future demand for hydrogen
- Residual demand for fuel and diesel oil continuing to 2050

- [An alternative analysis by DNV](#) also forecasts the global maritime energy demand and fuel mix over the period to 2050, as shown in the following figure

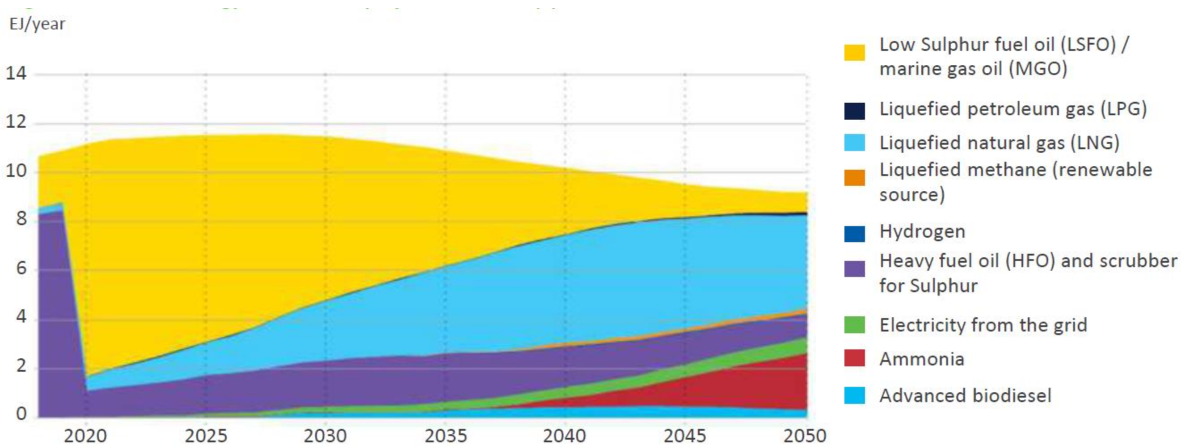


Figure 11: Forecast of the Global Maritime Energy Demand and Fuel Mix to 2050

This forecast again shows a significant market share for ammonia, a tangible demand for electric power and a large residual demand for oil and gas fuels. In a similar way to the Figure 10 above, the demand for hydrogen is negligible.

These two example analyses show that there is no real consensus on the key fuels going forward. This is discussed further, below.

4.3.3.9 Potential Adoption of Alternative Fuels and Propulsion Systems by Vessel Type

As highlighted above, the implementation of alternative fuels and propulsion systems is key to the decarbonisation of the maritime sector and meeting IMO targets. It is clear, however, from both analysis of the literature and stakeholder engagement that there is no consensus at a global level about the alternative fuels and propulsion systems that will be used and that several options are still under development (as shown in Figure 9). Further, it is also clear that the expectation is that there will be different solutions adopted for different types of vessel, depending on their size and operational requirements. We have, therefore, identified the expected alternative fuel and propulsion systems options, as shown opposite, for a range of different types of vessel, namely small ferries, large ferries, inshore service vessels, offshore service vessels, large fishing boats and large cargo vessels, to support our analysis of Scottish skills needs.

The most likely alternative fuel and propulsion systems for the different vessel types, based on our analysis, are presented below, classified in terms of the level of use that is likely over the period to 2040 and beyond. The classifications used are extensive, significant, lower or very limited/no use. For each vessel type, fuels listed opposite that are not expected to be used are not shown.

It should also be noted that this analysis covers the international maritime sector, rather than the sector in Scotland.

However, as shown in Figure 10 and Figure 11, existing fuels will continue to be used over the period to 2050. This is due, to a great extent, to existing investments in ships and fuelling infrastructure.

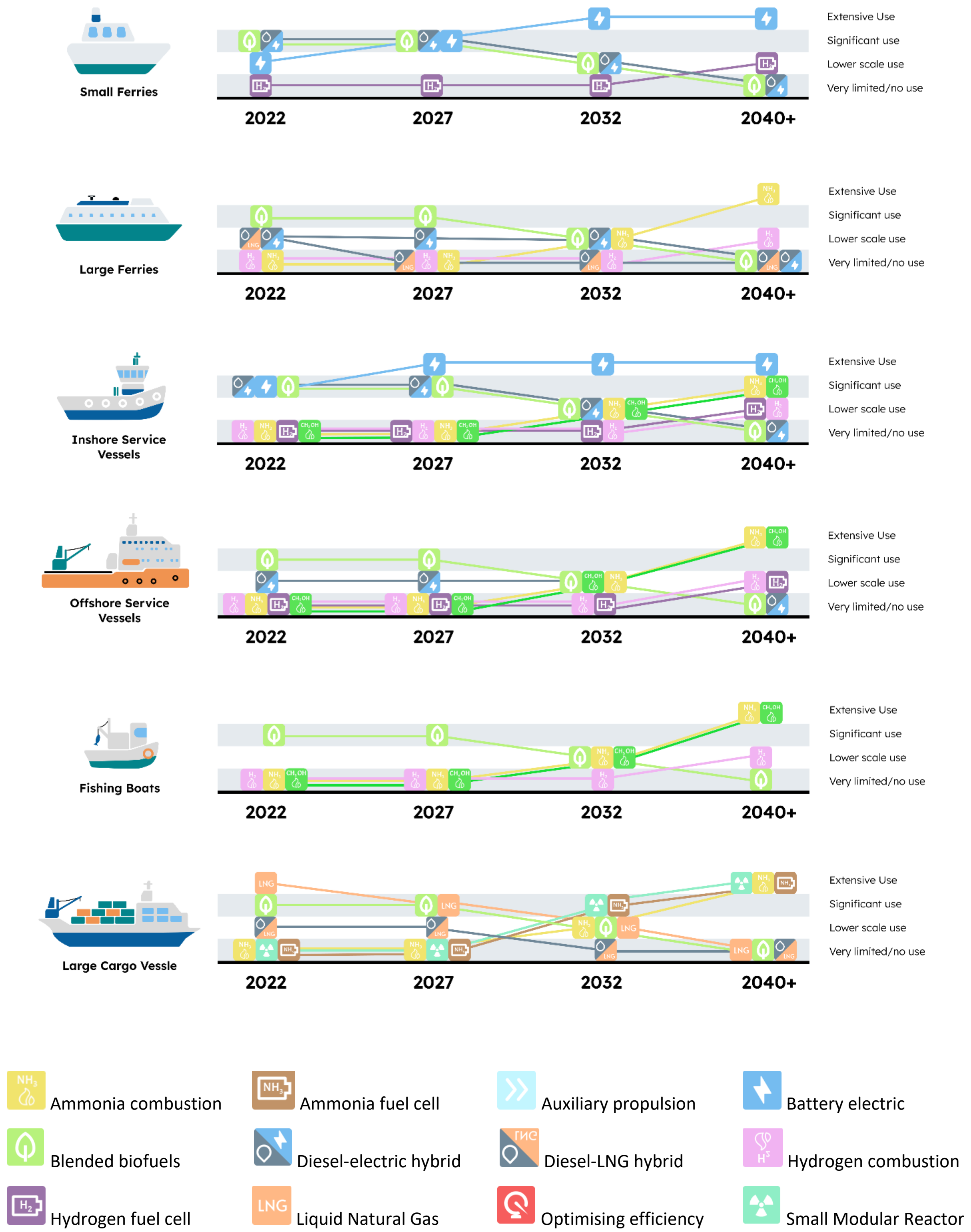


Figure 12: Expected Alternative Fuel and Propulsion Options by Vessel Type

Note: Leisure craft and small fishing boats are expected to adapt the technologies identified for small ferries

Ammonia combustion	Ammonia fuel cell	Auxiliary propulsion	Battery electric
Blended biofuels	Diesel-electric hybrid	Diesel-LNG hybrid	Hydrogen combustion
Hydrogen fuel cell	Liquid Natural Gas	Optimising efficiency	Small Modular Reactor

Figure 12 presents a complicated picture of future alternative fuel requirements. Further, as already highlighted, it is too early (*"nowhere close"* according to some stakeholders) to understand what fuel and/or propulsion system will eventually be selected for the different segments of the maritime sector.

This is highlighted by DNV in a recent report relating to maritime skills, which states

"A lack of clarity surrounding the viability and uptake of alternative fuel technologies and decarbonization trajectories, coupled with uncertainty surrounding regulatory developments and financing, is making it difficult to plan for the further training of the maritime workforce and attract investment in skills programmes compatible with the industry's future needs."

There are, however, a number of alternative fuel and propulsion technologies that have been identified as leading candidates for each type of vessel, based on the literature and stakeholder input. These are summarised in the following figure:

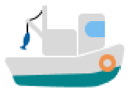
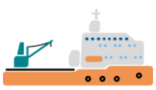
	Type	Number of Vessels	Ongoing Action	Short Term (next five years)	Long Term (10 - 15 years)
	Small Ferry	22	Optimise efficiency	Diesel - electric hybrid / battery electric	Battery Electric
	Large Ferry	43	Optimise efficiency	Biofuels or Diesel - electric hybrid	Ammonia combustion
	Fishing Boat	2,082	Optimise efficiency	Biofuels	Ammonia or methanol combustion
	Inshore Service Vessel	Information not available	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Battery electric / Ammonia or methanol combustion
	Offshore Service Vessel	Information not available	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Electric / Ammonia or methanol combustion
	Large Cargo Vessel	8,783 (arriving in Scotland in 2021)	Optimise efficiency	Biofuels / LNG	Ammonia combustion or fuel cell / SMR

Figure 13: Most Likely Decarbonisation Options by Vessel Type

It is noted here that optimising efficiency is an ongoing action that will continue across the period even with changes in fuel type.

These alternative fuels and propulsion systems are used in the assessment of skills needs for Scotland presented in Section 5, below. This is considered a reasonable way forward, based on evidence available in Scotland, for example:

- CMAL's specification of battery electric systems for its small vessel replacement programme
- Fisheries Innovation Scotland's analysis of decarbonisation options for the fishing industry, which identified methanol and ammonia combustion as optimum fuels
- Zephyrus work to develop battery electric crew transfer and offshore service vessels
- Major international engine manufacturer's work on developing methanol and ammonia combustion engines

4.4 Zero Carbon Ports

There is a significant role for ports in moving towards decarbonisation of the maritime sector. This role is two-fold: to enable decarbonisation of their own operations and to facilitate zero carbon vessel operation.

4.4.1.1 Technology Options

Focusing, initially, on port operations; transitioning to greener onshore power options, such as switching from diesel generators to solar and wind power to generate electricity, switching to electric or hydrogen powered vehicles and automating operations (smart logistics) have significant potential to reduce the carbon footprint of the port.

To support zero carbon vessel operations, ports need to provide low / zero carbon fuels as well as providing shore to ship power facilities, allowing ships to turn off auxiliary engines while berthed, reducing emissions. For example, certain vessels, such as cruise ships, demand significant amounts of energy whilst in port. A cruise ship is like a floating hotel with power required for air conditioning, space heating and heating water for showers and pools, for example.

An indicative range of options ports can implement to reduce emission and achieve net zero is shown in the figure below.

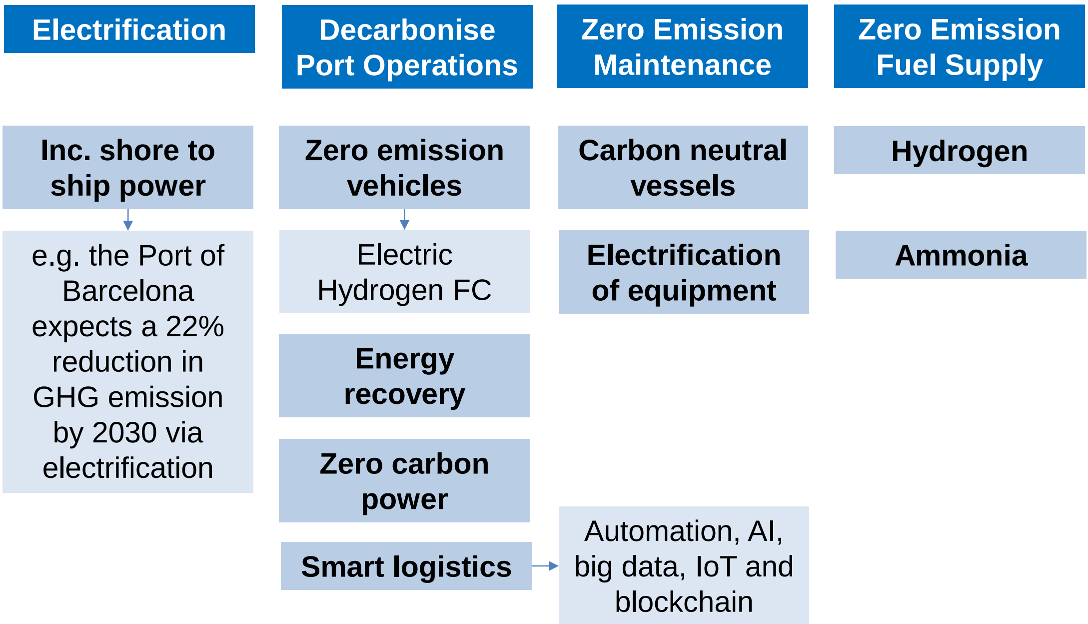


Figure 14: Examples of Decarbonisation Options for Ports

4.4.1.2 Adoption of Decarbonisation Options in Ports

The Port of Rotterdam is an example of how some ports are [taking steps to reduce their carbon footprint]() and contributing to reducing emissions within the shipping industry. The Port Authority has committed to reducing its carbon emission by 75% by 2025 and 90% by 2030 compared to emissions in 2019. Examples of projects underway at the port include the facility for ships to be 'plugged in' when they are docked to enable them to switch off their engines, and the port has committed to scaling up onshore power. It is aiming for 90% of the vessels accessing the port to be using onshore power by 2030.

"We are going to reduce our own carbon emissions as quickly as possible, while compensating in full what we still emit. So from that perspective, the Port Authority is already carbon neutral as we speak. Because our emissions will be lower and lower in the next few years, the compensation required will also decrease more and more"

The Peel Ports Group, which operates Clydeport, has committed to become a net zero port operator by 2040. The company plans to:

- Maintain effective carbon management across all its ports
- Support its customers and port user network with environmental solutions
- Procure services and goods based on reducing carbon footprint criteria

As an example of its activity, all of the vehicles used by Peel Ports are now electric and other equipment, such as lifting cranes, are being replaced by electric alternatives. Lighting is undergoing a transition to LEDs, and sensors and control systems are being installed to ensure energy is only used when required. The company is also installing green energy generation, in the form of solar panels and wind turbines whenever possible. The following figure shows what Peel Ports' "Port of the Future" could look like.

Figure 15: Peel Ports Infographic on Port of the Future

However, one of the key challenges for ports in providing zero carbon fuels is the lack of clarity as to what fuels will be required for different types of vessels. To support the development of the refuelling infrastructure required for alternatives, significant investment in bunkering facilities at ports and harbours could be required, particularly where more challenging fuels such as ammonia and, potentially, hydrogen are involved. As a result, ports are focusing on decarbonising their operations until there is clarity on future fuel demands.

5 Skills Needs and Gaps in Decarbonising the Maritime Sector

5.1 The Scale of Maritime Decarbonisation Activities in Scotland

Figure 16, below, provides an overview of the scope of maritime operations and supply chain relating to decarbonisation.

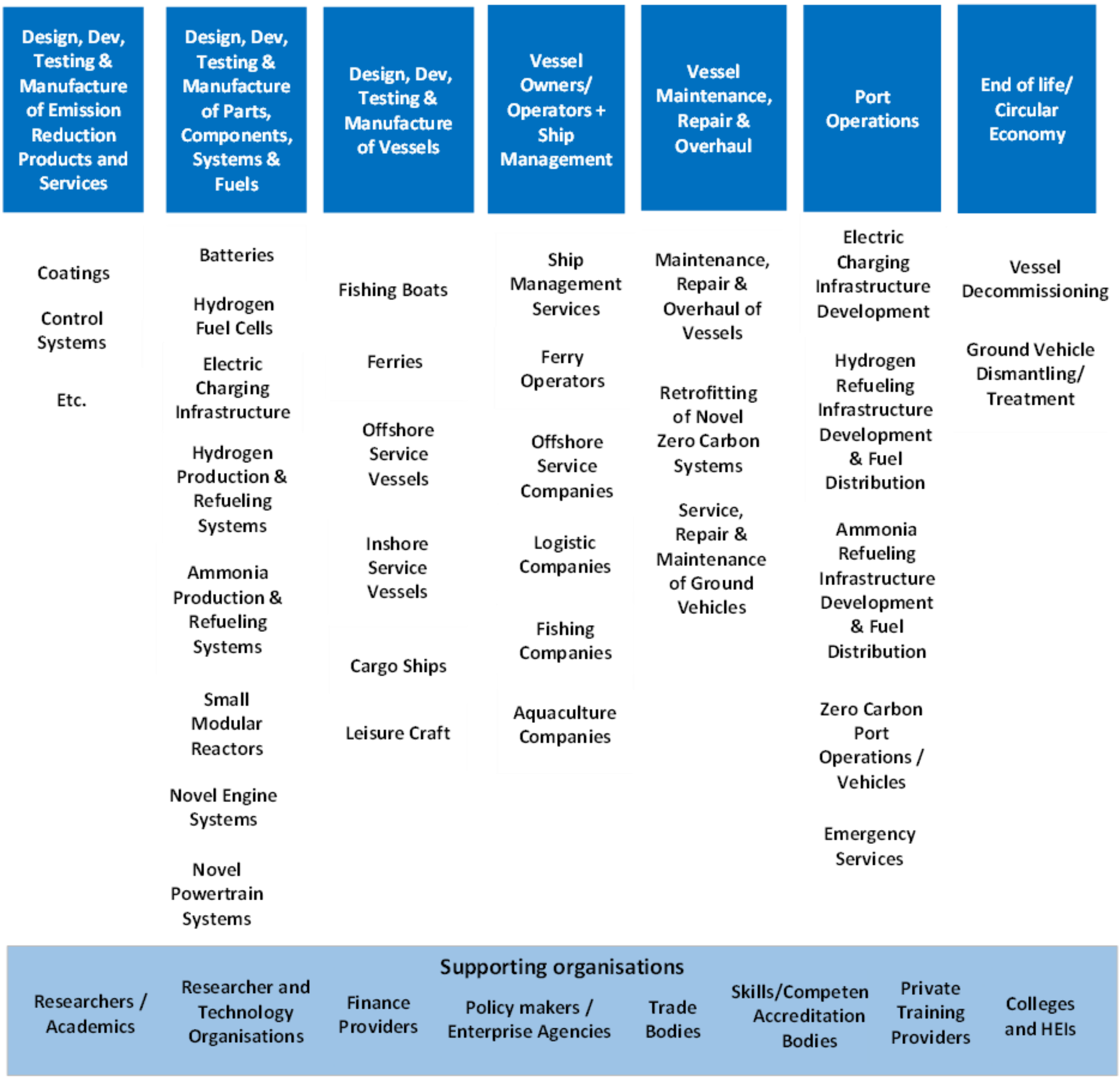


Figure 16: Scope of the Maritime Decarbonisation Supply Chain and Operational Landscape

Figure 16 illustrates the different decarbonisation options arising from the supply chain and the key elements of operation, use and end of life. It includes:

- Design, development, testing and manufacture of emissions reduction products and services
- Design, development, testing of parts, components, systems and fuels
- Design, development, testing and manufacture of vessels
- Vessel owners/operators and ship management
- Vessel maintenance, repair and overhaul
- Port operations
- End of life/ Circular economy

In addition, there are various supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes.

It is necessary to understand the scale of Scottish based activity within each segment to assess the approximate number of employees potentially requiring skills development to support the decarbonisation of maritime operations and maximise associated economic opportunities.

Appendix B contains a detailed description of the data sources used and how estimates were made for employment in the different segments of the maritime landscape.

Figure 17, below, provides indicative estimates of the scale of employment within different segments of the maritime landscape being investigated.

Maritime Segment	Indicative total employment by segment
Design, development, testing and manufacture of emissions reduction products and services	Limited data
Design, development, testing of parts, components, systems and fuels	650
Design, development, testing and manufacture of vessels	1,500
Vessel owners/operators and ship management	21,400
Vessel maintenance, repair and overhaul	900
Port operations	4,300
End of life/Circular economy	Limited data

Figure 17: Indicative number of employees in different segments of the maritime landscape in Scotland

It should be noted that, for two of the segments, 'Limited data' has been entered. This is due to the lack of alignment of the segment activities with Standard Industry Classification (SIC), Standard Occupational Classification (SOC) or other data. For the remaining segments an estimate of employment is provided. It should be also noted that the above employment estimate of 28,750 (the sum of employment in five segments, including the vessel manufacture, supply chain and various aspects of operation) is less that other estimates of the whole maritime landscape in Scotland. A 2019 report on Maritime Economics by Maritime UK estimates total direct employment in the sector of 41,000 in Scotland. As this study is focused on transport, we have not included employment numbers related to, for example, the construction of marine structures, instead focusing on vessels, which are relevant to decarbonisation.

5.2 Scale and Nature of Key Skills Required

5.2.1 Scale of Employees Likely to Require New/Enhanced Skills to Support Decarbonisation

This is a challenging analysis to carry out. For three of the categories defined in the figure above it has not been possible to define the indicative total employment by segment as discussed.

It should be further noted that many of the employees included in the 28,100 total for the other four categories will not require skills development in response to the move to decarbonisation of ships and boats. For example, of the 21,400 estimated to be involved in vessel ownership, operations and management, only those that are involved in management, operation and maintenance of the fuel and propulsion system are likely to require in-depth, additional skills development to carry out their function. At a global level this is identified as a significant number, as shown below, using three scenarios for the decarbonisation of the fleet as a basis for the analysis.

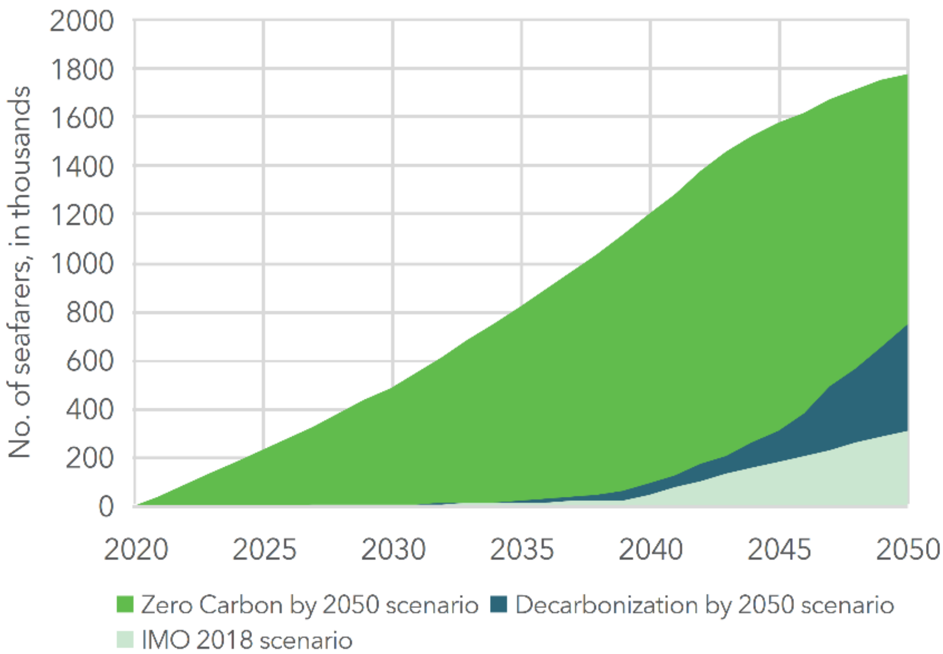


Figure 18: Estimated Number of Seafarers Working on Board Ships Equipped with

Alternative Fuel Technologies

At this stage, estimates of the scale of demand for new/enhanced skills, based on the types of activities carried out by the different supply chain segments is the best available, as presented below. Further, this figure includes estimates of when these skills are required, based on our assessment of the development and adoption of decarbonisation technologies.

Maritime Segment	Indicative total employment	% Impacted by Decarbonisation	Impacted Employment	When?
Design, development, testing of parts, components, systems and fuels	650	50%	325	Now
Design, development, testing and manufacture of vessels	1,500	75%	1,125	Now
Vessel owners/operators and ship management	21,400	25%	5,350	2-5 years
Vessel maintenance, repair and overhaul	900	25%	225	5-10 years
Port operations	4,300	50%	2,150	Now
Total	**28,750**		**9,175**	

Notes:
1) *Vessels are already being designed with hulls that optimise efficiency and novel propulsion systems are being seriously considered (e.g. CMAL Small Vessel Replacement Programme)*
2) *There will be a delay in these systems impacting on vessel owners/operators*
3) *There will be a further delay in these systems impacting the vessel repair segment*
4) *Ports are already implementing decarbonisation strategies, predominantly for their land operations*

Figure 19: Indicative Estimates of Scale of Demand for New/Enhanced Skills

5.2.2 Nature of New/Enhanced Decarbonisation Skills

The nature of the skills required to support maritime decarbonisation varies across the different segments, although it will be shown that there are some common needs. These requirements are described below for each different segment of landscape, based on the analysis of decarbonisation options presented above, as summarised in Figure 13.

It is important, however, to highlight that several stakeholders consider that it is too early to target specific alternative fuels and propulsion systems as already discussed in Section 4, above. Some of the stakeholder comments supporting this position were:

"Focus on a fundamental STEM provision – and then adapt as required"

"Develop individuals with a good education and the ability to apply their capability to different issues"

In this study, however, we have endeavoured to identify the most likely skills needs, based on our analysis of alternative fuels and propulsion systems likely to be adopted by different vessel types.

The nature of the skills required to support maritime decarbonisation varies across the different segments, although it will be shown that there are some common needs. These requirements are described below for each different segment of landscape.

5.2.2.1 Design, Development, Testing & Manufacture of Emission Reduction Products / Services

This segment, predominantly, covers the activities of companies developing products and services to optimise vessel efficiency, as summarised in Figure 7. Some of the themes are, predominantly, addressed by vessel manufacturers (e.g. hull shape changes and wind resistance reduction) and these are considered in section 5.2.2.3, below. Other topics require numerous capabilities ranging from lightweight materials, the development and applications of non-friction coatings and the development of systems to deliver autonomous ship operation. These need a diverse range of skills including product design engineering, mechanical engineering, materials engineering (especially relating to lightweight metals, composites and other lightweight materials and thin film coatings) and digital and data technologies.

Stakeholder feedback highlighted that many of the key players in this segment are established outside Scotland, but a wide range of skills needs were, nevertheless, identified by stakeholders, including:

- Lightweighting, e.g. materials, additive manufacture, etc.
- Industry 4.0 (e.g. Internet of Things) / 5.0 (e.g. humans work alongside advanced technologies and AI-powered robots)
- Data and digital skills, including artificial intelligence

These are required to enable this part of the supply landscape to optimise its capability to address the needs of a changing maritime supply chain.

Skills for the provision of auxiliary power systems (sails and solar power systems) can also be considered here. There are a small number of Scottish companies designing sail systems (e.g. SMAR Azure and Smart Green Shipping) that could be the focal point for supporting manufacturing activity. These companies require specialist design and software skills.

5.2.2.2 Design, Development, Testing & Manufacture of Parts, Components, Systems & Fuels

This segment of the supply chain landscape includes the core systems that will underpin decarbonisation, such as batteries, fuel cells, novel engine systems than can combust different fuels, electrical powertrain systems and charging and fuelling infrastructure. The companies in this segment are, therefore, having to respond to fundamental changes in their products and systems which demand new capabilities.

It is recognised that, currently, the suppliers of the major systems (e.g. engines, powertrains, etc.) are not located in Scotland and many stakeholders engaged during this study fully expect that this will continue to be the case in the future.

"All important components are sourced from overseas – this will not change. The Scottish market cannot support indigenous manufacturers"

There is, however, emerging capability in new power systems (e.g. batteries and fuel cells), high power electronics and charging and refuelling systems that have opportunities to develop further. There is also the potential for suppliers of non-core products and systems to access this changing market.

The challenge for this supply chain segment is to predict the novel technologies that will be used and to develop the capability to address needs. Key skills requirements identified by stakeholders for this supply chain segment are:

- Electrical engineering, especially relating to high voltage systems
- Design of novel fuel systems, addressing potentially corrosive materials and flammable gases, although the specifics of this are not yet clear. As indicated in Figure 13, this is likely to focus on methanol and ammonia, both of which are considered more hazardous than current fuels as follows:

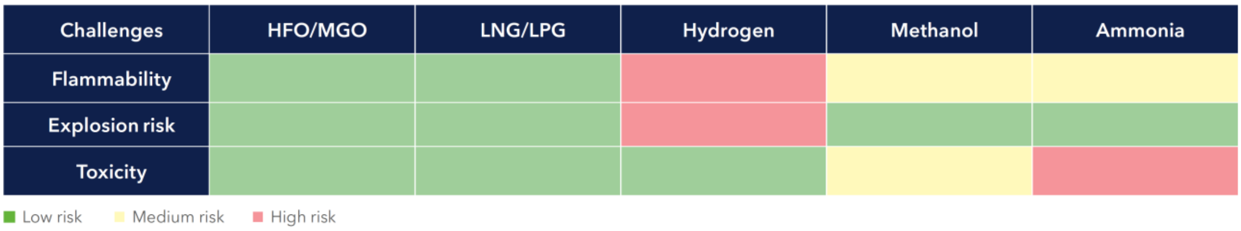


Figure 20: Comparative Safety Challenges for New Fuels

These alternative fuel options raise safety and operational issues in several parts of the supply chain.

This also highlights the safety challenges of hydrogen but it should be noted that limited demand for hydrogen as a zero-carbon maritime fuel was identified. As a result the need for capability in hydrogen systems is not currently identified as a priority

- Digital and data technologies for power management and control, including capability in the development of digital twins
- Basic trades – as discussed further in section 5.2.2.3, below

In addition, the need for Industry 4.0 / 5.0 capabilities also applies here.

This section has not addressed the manufacture of future fuels (such as methanol and ammonia) as these are considered activities of the chemical sector.

5.2.2.3 Design, Development, Testing & Manufacture of Vessels

This is a key segment of the supply chain landscape with a notable Scottish presence, particularly in the defence sector, with BAE Systems at Govan and Babcock International at Rosyth. The commercial sector also has some modest activity, namely Ferguson Marine, the Malin Group and Macduff Shipyard.

This supply chain segment has to address the challenges of optimising efficiency and accommodating zero carbon power systems. As such, these companies need to respond to fundamental changes in product design. Further, the commercial shipbuilding sector is influenced by a low-cost competitive marketplace driving the importance of innovation to gain a market position.

These companies require a wide range of skills and capabilities including, for example, marine design, product design engineering, mechanical engineering, materials engineering (especially relating to lightweight metals, composites and other lightweight materials), electrical and electronics engineering, digital and data technologies, CNC machining and welding.

Key areas of skills gaps identified by stakeholders during this study are:

- Vessel designers, that can understand efficiency optimisation designs and the needs of novel power systems
- Electrical engineering, especially relating to high voltage systems
- Design and implementation of novel fuel and power systems, as discussed above
- Digital and data technologies for power management and control, including capability in the development of digital twins

- Basic trades – well-known, fundamental problems with welders (*"we need five to ten thousand and we have around one thousand")*, scaffolders and production operators were identified by a number of stakeholders'

As above, the need for Industry 4.0 / 5.0 capabilities also applies here.

5.2.2.4 Vessel Owners / Operators and Ship Management

Companies in this segment include public sector (e.g. CMAL and Calmac) and private sector players, such as Western Ferries, Pentland Ferries, the cluster of ship management companies in Scotland, operators of onshore and offshore service vessels and fishing boat owner/operators.

These companies will need to be able to operate, monitor and maintain vessels with decarbonisation technologies and systems as well as manage and maintain these vessels and ships on behalf of private or commercial owner operators. Further, these companies will have to adapt to the increasingly digitalised and automated operation as the shipping industry implements alternative fuel technologies and the need for a new range of competences for seafarers has been identified to reflect the changing operational environment. This is summarised in Figure 21 and highlights the disciplinary nature of skills needs for decarbonised vessel operation.

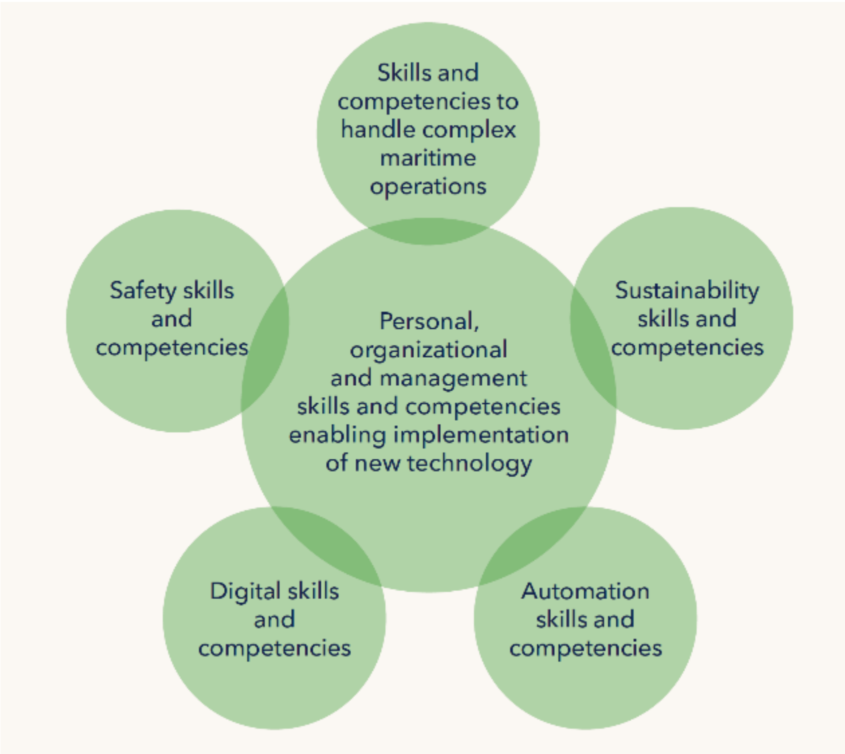


Figure 21: Skills and Competences for Decarbonisation of the Shipping Industry

A number of these skills needs were identified by stakeholders consulted during this study, including:

- Digital skills
- Automation skills

- Safety skills, especially as new fuels are introduced.

Stakeholders also highlighted the importance of skills development in a number of other areas, some of which have already been highlighted above, i.e.:

- Battery monitoring/management/services
- High voltage electronics
- Fluid and gas handling in marine environments

The specific skills needs of individual companies will, however, vary, depending of the type of vessel, its fuel and propulsion system and its operating routine.

5.2.2.5 Vessel Maintenance, Repair & Overhaul

The key challenge for companies in this segment of the supply chain landscape is to develop the capabilities for retrofitting and subsequent repair of low and zero carbon systems and to maintain low and zero carbon port vehicles and systems (e.g. static cranes).

Capabilities required for retrofitting systems are expected to be very similar to those required by vessel manufacturers, as detailed above, as retrofitting has very similar challenge to new vessel manufacturing, albeit with the constraints of the existing ship design.

Maintenance of low and zero carbon port vehicles and systems will show a number of similarities to the maintenance of battery and fuel cell powered heavy duty vehicles and it would be expected that the same companies could in time address the needs in both sectors. The recent Transport Scotland study on heavy duty vehicles highlighted the following skills required for vehicle maintenance:

- High-voltage electrical systems
- High-pressure gas systems
- Safe working at height
- IT skills relating to diagnostics

5.2.2.6 Port Operations

As indicated above, Scotland's ports have the dual challenge of decarbonising their own operation and, also, providing the facilities for fuelling berthed vessels and enabling them to operate in a zero carbon manner.

To date, the focus for ports has been on addressing their own operations which is expected to require capabilities in battery electric and, potentially, hydrogen fuel powered vehicles and static equipment, energy monitoring and management and smart logistics based on automation, IoT, blockchain, artificial intelligence and data management. To address these requirements, stakeholders identified the need for skills in:

- High voltage electrical systems
- Batteries and fuel cells powered systems
- Low energy (e.g. lighting) systems
- Digital and data technologies

They are also investing in co-located renewable energy generation (wind turbines and, possibly, solar panels) which will extend the range of skills required, although there are some overlaps with the list above.

Ports will have to extend their capabilities to support berthed vessel fuelling and power needs. They will have to develop capabilities in:

- High power electrical supply systems
- Storage and handling of alternative fuels, such as methanol and ammonia
- Managing the supply interfaces with berthed vessels

To address this future requirement, electrical engineering and digital technology specialists will be essential, together with staff with capabilities in fuel handling and associated health and safety systems and controls.

5.2.2.7 End of Life / Circular Economy

Circular economy, as a concept, is not well-understood in the maritime industry and it is reported that companies in the sector automatically focus on the recycling stage when vessels reach end of life. Based on these current practices, therefore, this is a part of the supply chain that is not likely to be impacted by low and zero carbon systems for some time, as these systems must first be adopted and used by the maritime sector. With more than 50% of the global maritime fleet being more than 15 years, it could be at least another 30 years before the recycling of these vessels at end of life is considered. When the time comes, however, it is expected that the skills required, in addition to typical decommissioning skills, such as vessel dismantling, recovery of materials, parts and components with value and management of pollutants, will focus on safe working with high voltages, high pressure gas systems and / or potentially corrosive materials and flammable gases.

The Global Maritime Forum, however, has identified the potential need for the sector to introduce circular business models to enhance the overall sustainability of the sector in the longer term. At the vessel design stage, this could require a rethink of the design approach, moving away from bespoke, custom builds to a more standardised, modular approach which would require, for example, naval architecture, design engineering and product engineering skills as well as skills in the area of digital and data technologies to enable transparency and traceability of materials across the supply chain, for example.

5.2.2.8 Summary

The key observation on the skills needs for each segment of the supply chain can be summarised as follows.

Decarbonisation Theme	Skills Need	Primary Landscape Segment							Capability
		Design, Dev, Testing & Manufacture of Emission Reduction Products / Services	Design, Dev, Testing & Manufacture of Parts, Components, Systems & Fuels	Design, Dev, Testing & Manufacture of Vessels	Vessel Owners / Operators inc Ship Management	Vessel Maintenance, Repair & Overhaul	Port Operations	End of Life / Circular Economy	
	Number of Employees	**Not known**	**650**	**1,500**	**21,400**	**900**	**4,300**	**Not known**	
Optimising Efficiency	Lightweight Materials	●	●	●		❍			Materials technologists
	Surface Technologies	●		●		●			Materials technologists
	Sensing systems	●	●	●		❍	●		Electronic Engineers
	Automation	●	●	●	●	●	●		Digital/Data Technologists
Alternative Fuels	Battery Electric		●	●	●	❍	●		Electrical Engineers
	Fuel Cell Technology		●	●	●	❍	●	❍	Chemists/Engineers
	High Voltage Systems		●	●	❍	❍	●	❍	Electrical Engineers
	Alternative Fuel Systems		●	●	●	●	●	❍	Chemical Engineers
	Alternative Fuel Safety		●	●	●	●	●	❍	Chemicals / H&S
	Alternative Fuel Storage/Transfer		❍	●	●	❍	●		Chemicals / H&S
	Monitoring and Control		●	●	●	❍	●		Electronic Engineers
	Fluid / Gas Handling			❍	●	❍	●	❍	Chemicals / H&S
	Health and Safety		●	●	●	●	●	❍	Health and Safety
Both Themes	Digital Twinning		●	●	❍	❍	●		Digital/Data Technologists
	Vessel / System Design	●	●	●		❍			Naval Engineers/Architects
	I4.0/I5.0		●	●	●	●	●		Digital/Data Technologists

Figure 22: Summary Overview of Skills Needs ***(Key: ● Significant need and ❍ Moderate need)***

This analysis is developed further in Section 5.4, below.

5.3 Skills Provision to Support Decarbonisation

A review of the Scottish maritime skills provision landscape was undertaken to identify content relating to decarbonisation. The landscape consists of universities, colleges and private skills providers and the purpose of the review was to identify courses/programmes offered. For example, courses / programmes offering modules dedicated to developing skills that support the net zero transition, with a focus on areas such as alternative fuels and propulsion systems, design / development of novel engines, and other activities associated with the maritime decarbonisation segments shown in Figure 16.

5.3.1 Specific Provision of Decarbonisation Skills

The analysis of the skills provision landscape indicates that there is limited evidence of decarbonisation content (course/programmes/modules) for the maritime sector in Scotland. There is:

- only one educational institution which provides meaningful skills development in the relevant areas, see University of Strathclyde below
- a small pool of private providers that offer some content, namely:
  - Health, safety and 'awareness' oriented (e.g. Stream Marine Training)
  - Early-stage, bespoke material that does not appear to have been rolled out across the organisation (e.g. Clyde Marine Training).
- Two UHI colleges that are delivering or developing relevant courses

Details of decarbonisation content offered by maritime skills providers can be found below.

5.3.1.1 University of Strathclyde

The university is one of the world's leading educators of marine / ocean engineering graduates. Its Department of Naval Architecture, Ocean & Marine Engineering offers eight postgraduate MSc courses, including Marine Engineering, Ship & Offshore Structures, Technical Ship Management and Sustainable Engineering: Marine Technology.

Evidence of decarbonisation content offered by the department's courses is as follows:

- MSc Marine Engineering

  Module: ***Onboard Energy Management & Marine Environment Protection***

  This module aims to provide students with the knowledge and awareness of issues in marine environmental protection, **environmentally friendly shipping** and international conventions and regulations of environmental protection and introduce the state-of-the-art technology applied in the industry and future trends. This includes **ship energy management systems** and **energy resources** including **optimisation** and **integration of machinery and power systems** in a **sustainable manner**. The module covers:

  - IMO MARPOL 73/78 Conventions on engine control
  - Marine engine emissions control: primary and secondary techniques
  - Fuel cell technology for ships, alternative fuels and energy sources
  - Issues of supply and use of low sulphur bunker fuels
  - Ballast water management
  - Overview of energy issues worldwide and necessity for energy management systems onboard
  - Major energy systems onboard and aspects of their design, manufacture and operation
  - Utilisation of waste heat energy on ships: waste heat recovery
  - Energy analysis for thermal energy system onboard

  At the end of the module, students should be able to:

  - Show an understanding of the formation and reduction technologies for marine emissions
  - Be capable of estimating energy consumption and saving for the different energy consumers on ships
  - Demonstrate an understanding of the onboard procedures and operations which minimise emissions
  - Demonstrate an understanding of energy systems design and systems integration
  - Demonstrate an understanding of how to optimise equipment in order to minimise emissions
  - Acquire the key skills for estimating energy consumption and saving

- MSc Technical Ship Management

  Module: ***Onboard Energy Management & Marine Environment Protection***

  Already described above

  Module: ***Ship Powering in Service***

  This module aims to provide students with the fundamental concept of the **energy balance** of a motorship and the major contributors to the **performance losses** of a ship in-service. These include the **resistance/power increase** due to **wind, waves, rudder actions/hull drift, hull roughness (including coating), biofouling**. Students will also be taught how to **estimate ship**

performance losses (i.e., in terms of power increase or speed loss) due to these effects. This module covers:

- Introduction to ship powering in service
- Theory of added resistance due to waves
- Numerical and experimental calculations of added resistance due to waves
- Experimental techniques for naval architects
- Towing tank experiments
- Roughness effect of biofouling – biofouling, fouling control coatings, concepts of boundary layer theory
- The effect of hull fouling on the performance of marine vehicles
- Added resistance due to wind, rudder actions/hull drift

At the end of the module, students should be able to:

- Acquire a knowledge and understanding of the technical factors which affect the performance of a ship and the machinery at sea
- Acquire a knowledge and understanding of the main causes of performance losses (in-service) associated with the hull and propulsion, and methods to estimate these losses
- Understand the techniques used for laboratory measurement of added resistance

- MSc Sustainable Engineering: Marine Technology

  Module: ***Sustainability***

  This class provides students with an understanding of the concepts of **sustainability and sustainable development**. The social, environmental and economic impact of development strategies are identified and the mitigation of negative impacts discussed.

  Note: *No other details were available regarding this module and the content it covers.*

  Other modules in this course are expected to contribute to decarbonisation and cover, for example:

  Module: ***Advanced Marine Structures***

  - Introduction ship structures and structural design principles
  - Design of hull girder mid-ship section components

  Module: ***Design & Construction of Floating, Production, Storage & Offloading Vessels***

  - The shipbuilding process including the integration of hull construction, outfitting and painting
  - Hullform and marine system arrangements

  Module: ***Theory & Practice of Marine Computational Fluid Dynamics***

  - Introduction to fluid flow governing equations and their simplified forms
  - The solution of discretised equations

The Department is also undertaking cutting edge research into, for example, an innovative energy saving propulsor/manoeuvring device (H2020 GATERS, 2021 – 2024), green ammonia fuel cell technology (H2020 ShipFC, 2020-2025), and autonomous vessels (H2020 AUTOSHIP, 2019 – 2023).

5.3.1.2 Clyde Marine Training

This private skills/training provider is owned by the Northern Marine Group and is based in Clydebank. It provides training for the merchant navy across its cadetship programmes – Deck Officer, Marine Engineering, and Electro-Technical – and manages over 800 cadets at any one time on behalf of numerous global shipping companies.

The company has designed a 5-day training programme for battery powered vessels and methanol powered vessels to bridge the gap between heavy fuel oil and alternative fuels.

5.3.1.3 Stream Marine Training

Stream Marine Training provides training in HSE for maritime, oil and gas, renewables and the construction industry. Courses of relevance to decarbonisation of maritime include:

- Alternative Fuels and Systems Courses (17 total), including:
    - Ammonia Awareness Training
    - Liquefied Natural Gas (LNG) Awareness Training
    - Hydrogen Awareness Training
    - Methanol Awareness Training
    - Battery and Fuel Cells Awareness
    - Bunkering Operations
    - Tanker Fire Fighting

  The courses generally follow a similar structure and format, with similar content. Using the LNG Awareness Training course as an example, the training content includes the following:

    - Introduction to LNG
    - Drivers for using LNG as a fuel
    - Hazards of LNG
    - Storage solutions for ships
    - LNG bunkering
    - Management of LNG fuel tanks

5.3.1.4 UHI – Orkney College

UHI Orkney College has developed a course, approved by the Maritime and Coastguard Agency, to prepare local seafarers for working on and alongside hydrogen powered vessels.

5.3.1.5 UHI – Argyll College

UHI Argyll College is planning a new industry training centre to delivery new range of courses to workboat, leisure and ferry operators which is expected to cover a range of decarbonisation topics.

5.3.2 Wider Skills Provision

There is content relevant to maritime decarbonisation skills within a wide range of university and college courses and apprenticeships. For example:

- All electrical engineering courses will cover aspect relevant to high voltage systems, batteries and fuel cells
- City of Glasgow College, a leading global maritime training college, offers a range of courses where aspects are relevant to decarbonisation and it intends to extend this is the future.

Due to the large number of courses that could be included in this category, they have not all been listed separately. However, the number of students gaining qualifications from universities and colleges and apprenticeships in relevant subjects is presented below.

5.3.2.1 University Graduates

The following two graphs highlight the trends over the period from 2014/15 to 2020/21 for graduates in the two most relevant categories defined by HESA, namely (a) engineering and technology and (b) computer sciences.

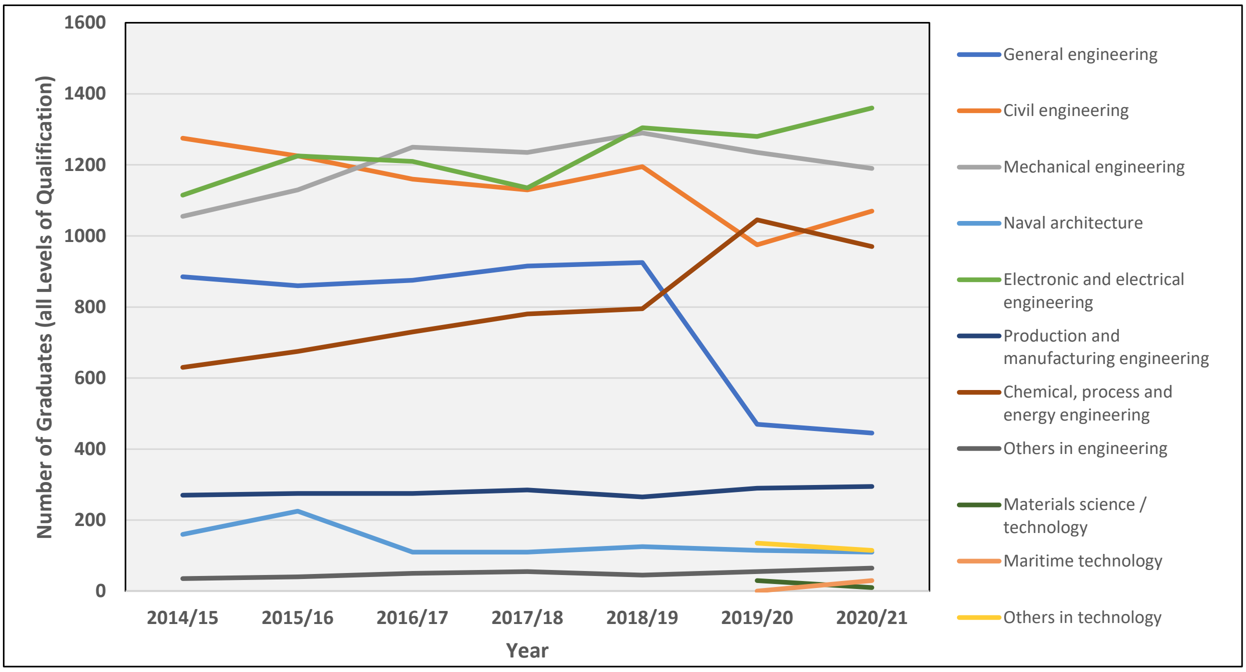


Figure 23: University Graduates in Engineering and Technology (all Qualification Levels)

Key observations here are:

- A significant decline in navel architecture graduates from 2014/15 and 2015/16
- 20% growth in electrical and electronic engineering graduates over the period from 2014/15 to 2020/21
- A significant (50%) decline in general engineering graduates over the period from 2014/15 to 2020/21

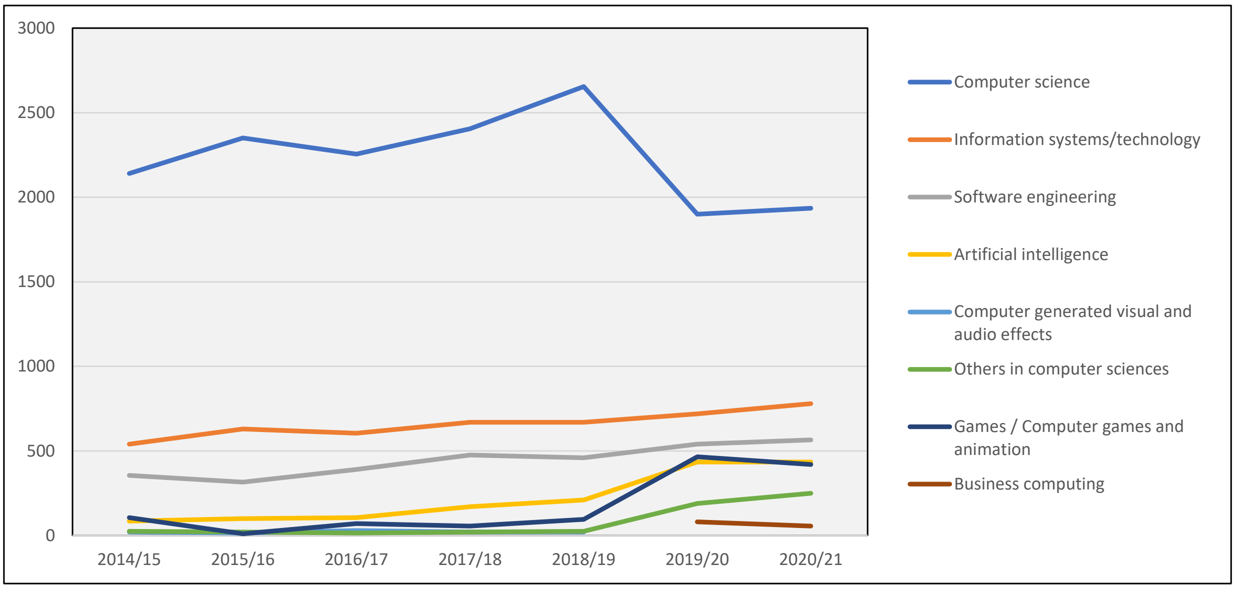


Figure 24: University Graduates in Computer Sciences (all Qualification Levels)

These figures show an overall increase of over 25% in computer sciences graduates (the total of all categories in this figure) over the period from 2014/15 to 202/21.

5.3.2.2 Qualifiers from Further Education Colleges

The figure below shows the numbers qualifying in 2020-21 from further education courses that are considered relevant to decarbonisation of the maritime sector. The majority of these qualifications are from completing non-advanced or short courses.

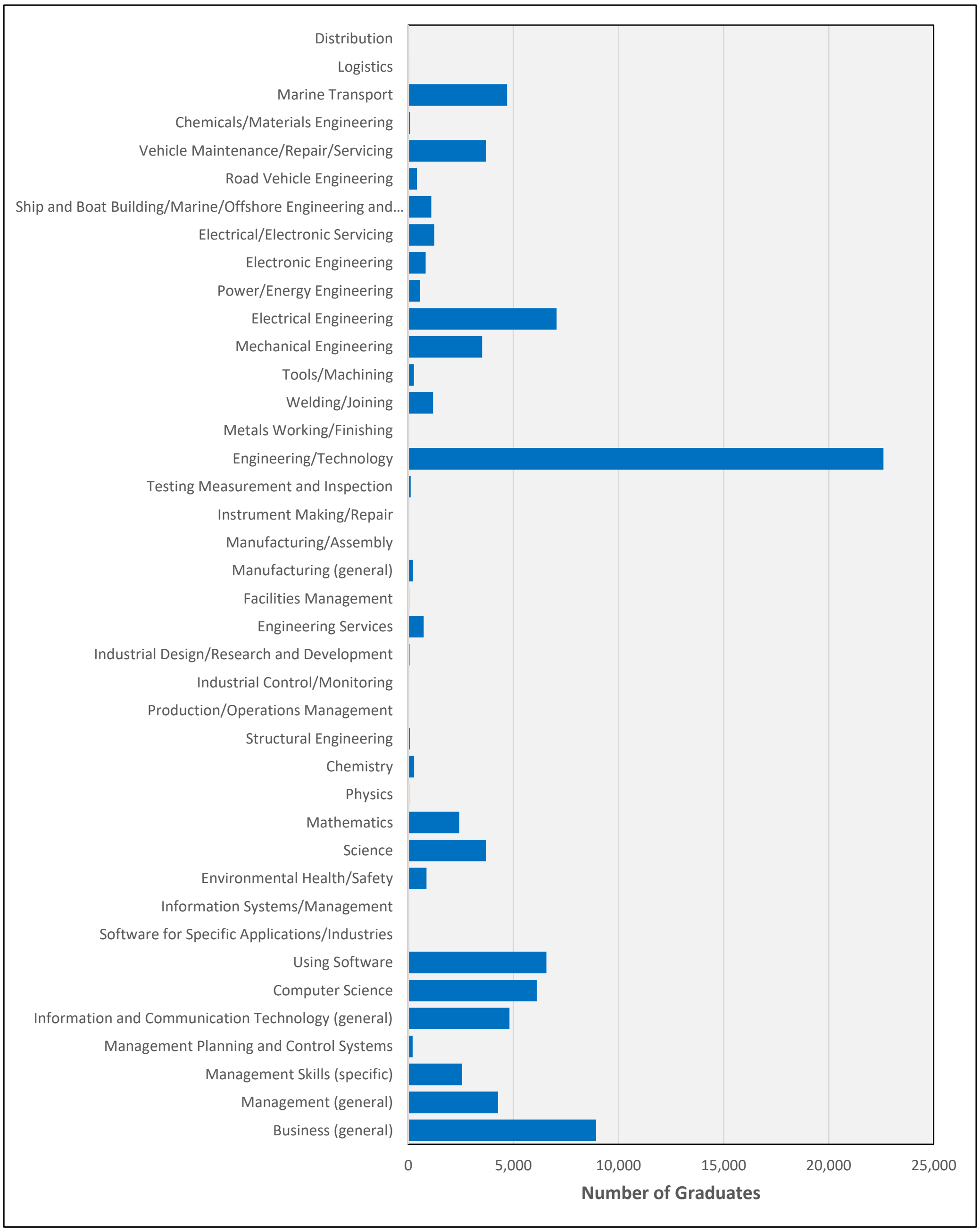


Figure 25: Qualifiers from Courses that are considered relevant to The Maritime Decarbonisation Supply Chain

5.3.2.3 Apprenticeships

The number of apprenticeships in relevant subjects for maritime decarbonisation can be summarised as follows:

Modern Apprenticeships

Over 8,000 individuals were enrolled in relevant modern apprenticeship programmes in 2022, as follows:

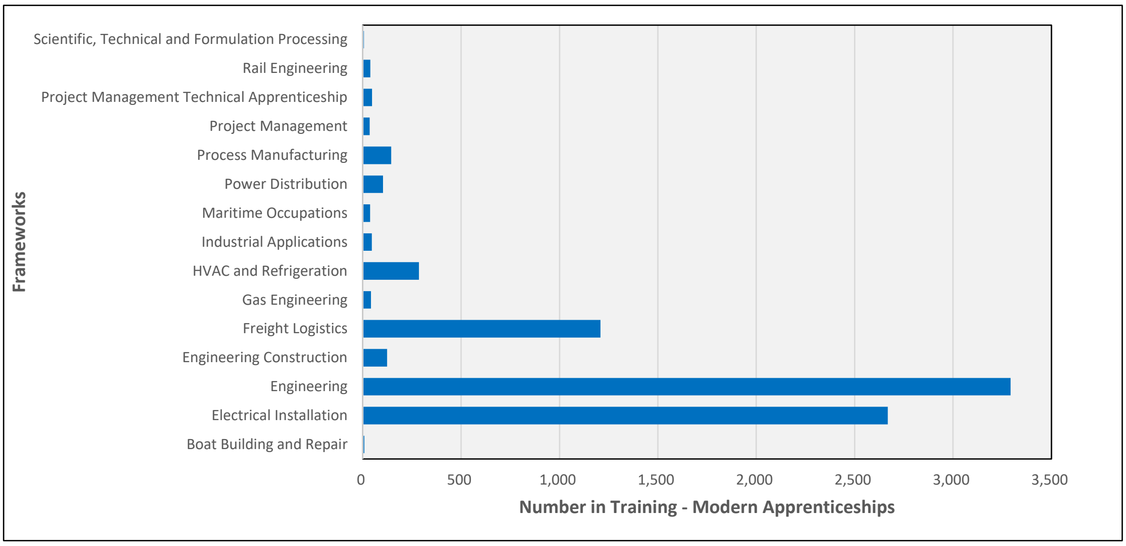


Figure 26: Modern Apprenticeships – Numbers in Training in 2022

Graduate Apprenticeships

Over 380 individuals were enrolled in relevant graduate apprenticeship programmes in 2022, as follows:

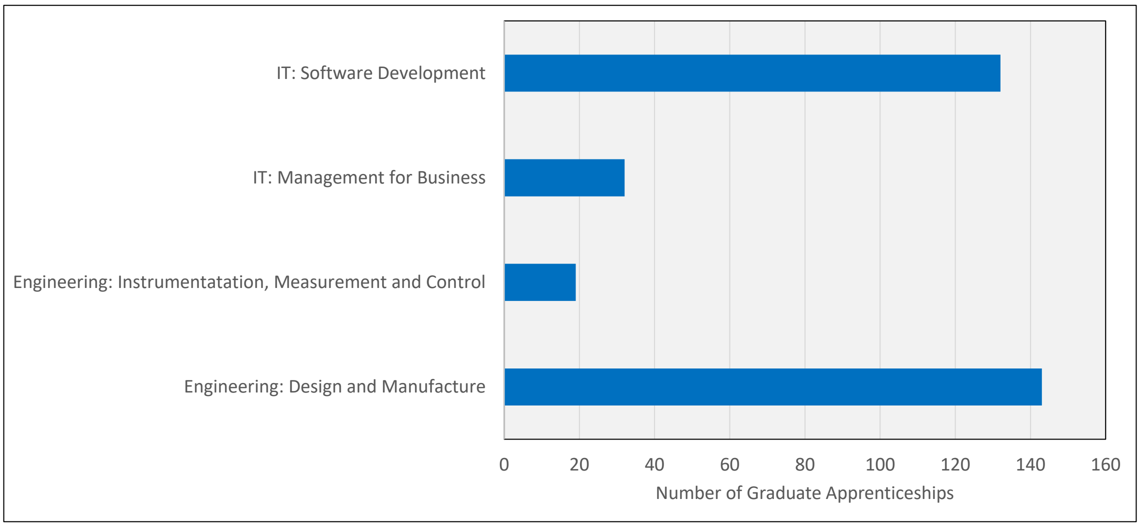


Figure 27: Graduate Apprenticeships – Numbers in Training in 2022

Foundation Apprenticeships

Over 500 individuals were enrolled in relevant foundation apprenticeships (engineering and scientific technologies) in 2020.

5.4 Key Skills Gaps and Shortages

Skills gaps and shortages for decarbonisation of the maritime sector can be summarised as follows.

Maritime Decarbonisation Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
Design, development, testing and manufacture of emissions reduction products and services *Estimated employment: not known*	• Ship and product design engineering • Materials engineering, scientists and chemists • Precision engineering of lightweight alloys and coatings • Quality inspection and control of component parts • Industry 4.0 and 5.0 • Automation technologies (digital, data and AI technologies)	In-house, further and higher education, private training providers	• Understanding of lightweight materials and innovative manufacturing techniques • Manufacturing skills • Expertise in automated maritime systems and associated technologies	General shortages noted for employees with STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue.
Design, development, testing of parts, components, systems and fuels *Estimated employment: 650*	• Ship and product design engineering • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Regulatory, standards and safety certification requirements • Detailed safety case development • Skilled trades	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems • Manufacturing skills related to alternative fuels and novel propulsion systems	General shortage of engineers and other STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue. However it should be noted that major maritime systems are not currently manufactured in Scotland.

Maritime Decarbonisation Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
Design, development, testing and manufacture of vessels *Estimated employment: 1,500*	• Ship design • Materials engineering, scientists and chemists • Precision engineering of lightweight alloys and coatings • Industry 4.0 and 5.0 • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management • Skilled trades	In-house, further and higher education and private training providers and system manufacturers	• Understanding of lightweight materials and innovative manufacturing techniques • Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems • Manufacturing skills related to alternative fuels and novel propulsion systems • Innovative ship design utilising novel fuel / propulsion systems • Safety case development for the use of alternative fuels and the development of standards and certification	General shortage of engineers and other STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue.

Maritime Decarbonisation Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
Vessel owners/operators and ship management *Estimated employment: 21,400*	• Industry 4.0 and 5.0 • Automation technologies • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management • Skilled trades	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels, including safety aspects • Monitoring and control systems linked to alternative fuel and propulsion systems	General shortages of STEM skills noted (as above) but specific skills needs will vary, depending on the type of vessel, its fuel and propulsion system and its operating routine. Digital skills to support the development of automated maritime systems, efficient route planning, etc
Vessel maintenance, repair and overhaul *Estimated employment: 900*	• High voltage system overhaul, repair and maintenance • overhaul, repair and maintenance • Overhaul, repair and maintenance of parts/components manufactured using new alloys/composites, etc. • Service, repair and maintenance of electrically powered port equipment	In-house, further and higher education and private training providers and system manufacturers	Specific skills gaps will only become apparent when new decarbonised vessels come into service. Could include skills in • Manufacturing skills • High voltage systems • Battery systems • Handling, transport and storage alternative fuels	The skills required for vessel MRO will be defined in response to what low carbon and zero emission technologies are introduced or retrofitted onto ships. It is likely that there will only be limited demand by 2032.
Port operations	• Industry 4.0 and 5.0 • Automation technologies • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in battery electric systems	Shortages around digital and data skills for energy monitoring and management and smart logistics based on automation, IoT, blockchain, artificial intelligence and data management

Maritime Decarbonisation Landscape Segment	Skills Required	Training Provision	Skills Gaps	Skills Shortages
Estimated employment: 4,300	• Skilled trades		• Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems	
End of life/ circular economy *Estimated employment: not known*	• Safe isolation and removal of high-voltage electrical systems • Valuable material identification and recovery • Second life use of batteries	Further education and private training providers	• For recycling, specific skills gaps will only become apparent when new decarbonised vessels are being dismantled • For circular economy, gaps exist around the development of innovative circular business models	Digital / data skills to support the development of innovative circular business models (e.g. material traceability across the supply chain)

Figure 28: Summary of Skills Requirements, Provision, Gaps and Shortages for Maritime Decarbonisation

It highlights that:

- There are skills gaps across a range of disciplines. It is considered that these gaps can addressed by
  - Reskilling / upskilling existing staff. This can be achieved by short courses and "on the job" learning to understand different requirements
  - Adapting further and higher education courses to include relevant new content
- There are major skills shortages that will have a significant impact on decarbonisation of the sector. There are fundamental industry wide skills shortages in several of the key disciplines, despite the high numbers of university graduates and college qualifiers highlighted above.
  "There are skills shortages across all sectors – mechanical, chemical, electrical and electronic engineers, software and data management and fitters and welders"
  DeCarb Scotland Conference, 2nd February 2023

This table has been extended to include the data in Figures 19 and 22 as shown in Appendix C.

These skills shortages impact the potential of the maritime sector to attract staff as stakeholder input suggests that companies in other sectors are offering higher salaries and other sectors (e.g. software, renewables, utilities) are considered more attractive to work in. Further, it highlights the ongoing challenge of attracting more school leavers into STEM subjects so that skills shortages can be addressed.

In addition, the need for multi-disciplinary staff has been highlighted by numerous stakeholders and in the literature (Figure 21). This need covers technical disciplines (e.g. combined mechanical and electrical engineering capabilities, which is already being addressed with some colleges and universities now offering mechatronics courses) and combinations of technical, digital and management skills.

5.5 Barriers to Skills Development

Several barriers to skills development were identified, including:

- The lack of clarity in the sector on the alternative fuel and propulsion systems that will be used in different types of vessels. Until there are decisions on future fuels and propulsion systems it is unlikely that there will be significant progress on decarbonisation. There is a similar lack of clarity from government on preferred fuels. As a result companies are reluctant to make decisions to invest in required skills development for fear of pursuing the wrong option.
- The promotion of each decarbonisation technology by key developers, which tend to provide conflicting views of the relative merits of different technologies
- Investment cycles in the maritime sector. Vessels typically have a 25 to 30 year lifetime and as shown in Figure 6 the vast majority of vessels on order at the moment are designed to use traditional fuels. As a result the composition of the fleet, and the need for decarbonisation skills will change very slowly.
- The conservative, slow to change nature of the sector
- Health, safety and liability concerns (for example, see Figure 20) when using alternative fuels
- The capabilities and capacity of the Maritime and Coastguard Agency (MCA) to regulate the changing nature of the sector, as highlighted by several stakeholders
- The timescales for accreditation of new or revised courses to address the changing needs of the sector
- The wide-ranging skills shortages, as detailed above

5.6 Transferable Skills and Talent

A number of different skills to enable decarbonisation of the maritime sector have been identified. There are several opportunities for transfer of skills between different sectors, including:

- Electrical engineers required for high voltage power systems can be accessed from the power and rail sectors, although it is recognised that voltage used will be lower in maritime
- Electrical engineers with battery electric and hydrogen fuel cell capabilities can be accessed from the heavy duty vehicles sector and, possibly, the aviation sector

- Gas handling and safety skills can be transferred from the process industry, particularly the chemical sector, where a number of these alternative fuels are already processed or used in chemical manufacturing
- Digital and data technologists to support automation in the maritime sector can be accessed from a range of sectors, although it is recognised that such individuals are highly sought after and may pursue opportunities in other sectors that they consider more attractive
- Manufacturing skills, for example welders and associated job roles, can be accessed from a range of sectors, although the regularly highlighted shortage of these skills will make this challenging

6 Conclusions and Recommendations

6.1 Conclusions

The main conclusions from this study are:

Technology Drivers Trends and Barriers

- There is a clear recognition by the sector of the need for decarbonisation and key global sectoral organisations are taking the lead in imposing decarbonisation targets and measures
- Decarbonisation will be achieved through a combination on efficiency optimisation, the use of alternative fuels and propulsion systems and the implementation of auxiliary power systems
- There are a number of strategies to optimise the efficiency of all types of vessels and several of these have been in place for some time. It is expected that these will continue to be developed and implemented in parallel with other interventions
- A number of alternative fuel and propulsion systems have been identified but there is no clarity on those that will be adopted and implemented by the maritime sector
- Auxiliary power systems are under development to reduce fuel use, but these have not been widely adopted by the sector
- The lack of clarity within the sector on the alternative fuel and propulsion systems that will be used in different types of vessels is a major barrier to adoption and the subsequent need for skills development
- The investment cycles in the sector and its conservative, slow to change nature, are other major barriers to change.
- As a result, individual organisations are focusing on implementing change that they have control of rather than taking a comprehensive approach to decarbonisation
- There is a reluctance within key stakeholders to commit to specific skills development before alternative fuels and propulsion systems are identified for widespread implementation
- Further, it is expected that the maritime fleet in 2050 will still include a significant percentage of traditionally powered vessels

Skills Shortages and Gaps

These have been identified, based on our assessment of implementation of the most likely alternative fuels and propulsion systems:

- A range of skills are required to enable decarbonisation of the maritime sector. These include skills in lightweight materials, surface technologies, sensing systems, automation technologies, battery electric technologies, fuel cell technology, high voltage systems, alternative fuel systems, alternative fuel safety, alternative fuel storage and transfer, monitoring and control, fluid and gas handling, health and safety, digital twinning, vessel and system design and industry 4.0/5.0
- Health and safety aspects of gas handling and storage was identified as a critical area for skills development
- Awareness and understanding of risks posed by the use of alternative fuel sources (such as hydrogen) amongst regulators, policy makers and planners responsible for developing new regulatory frameworks and assessing applications to develop new fuel infrastructure
- A need for interdisciplinary skills to deliver a decarbonised maritime sector was identified
- It is considered that these gaps can be addressed by reskilling and upskilling of existing staff through short courses and "on the job" learning to understand different requirements and techniques and by adapting further and higher education courses to include relevant new content for new entrants to the sector
- There are fundamental industry wide skills shortages in several of the key disciplines that will have a significant impact on decarbonisation of the sector, despite the high numbers of relevant university graduates and college qualifiers.
- These skills shortages impact the potential of the maritime sector to attract the range of staff required to support decarbonisation

Skills Provision

- A small number of courses with specific decarbonisation content were identified
- There are a wide range of university and college courses that include content that will provide a basic knowledge and understanding to support decarbonisation. Adaption of these courses to include more specific decarbonisation content would be a beneficial change.
- There are several opportunities for transfer of skills between different sectors, covering technical, manufacturing and digital skills

6.2 Recommendations

Based on the work carried out in this study we would make the following recommendations:

1. Decarbonisation drivers and trends should be regularly monitored to identify when key decisions are made regarding the alternative fuels and propulsion systems selected for different types of vessel and when they will be implemented
2. Skills development provision should focus on the skills gaps identified in this work, which are based on analysis of the most likely decarbonisation options identified for different types of vessel
3. Skills providers should be encouraged to adapt and extend relevant courses to include specific content relevant to maritime decarbonisation
4. A portfolio of short courses should be developed for staff at all levels to support the reskilling / upskilling of the current workforce on relevant decarbonisation technologies

5. Development of these new and revised courses should be overseen by representatives of industry, regulation and accreditation bodies to ensure easy adoption and uptake
6. These skills gaps and skills development provision should be regularly reviewed and revised when the evidence base on preferred alternative fuels and propulsion systems changes
7. Options for cross sectoral skills development, in areas such as high-power electronics, battery technologies, fuel cell technologies and gas and fluid handling should be investigated
8. Strategies to attract individuals into the maritime industry should be developed to minimise the impact of the identified industry wide skills shortages

Appendices

Appendix A: Contributors to the Study

Stakeholders from the following organisations kindly provided input to the study. Opinions provided reflect individual's views and are not necessarily the views of their organisations.

1 Aquatera
2 Babcock International
3 British Marine Scotland
4 Caledonian Maritime Assets Ltd
5 City of Glasgow College
6 Clyde Marine Training
7 Clyde Port Authority / Peel Ports
8 Core Power (UK) Ltd
9 Cromarty Firth Port Authority
10 Douglas Lang (SMC and ex-Anglo Eastern)
11 EMEC
12 ESP
13 Eyemouth Marine
14 Ferguson Marine
15 Fisheries Innovation Scotland
16 Forth Ports Scotland
17 Forth Valley College
18 H2 Green Ltd
19 Houlder Offshore Engineering Limited
20 Macduff Ship Design
21 Malin Group
22 Maritime Skills Alliance
23 Michelin Sustainable Innovation Park
24 National Manufacturing Institute Scotland (NMIS)
25 NESCOL - Scottish Maritime Academy
26 Northern Lighthouse Board
27 Peterhead Port
28 Robert Gordon University
29 Royal Navy
30 Scottish Hydrogen and Fuel Cell Association
31 Scottish Maritime Cluster
32 UHI Argyll
33 UHI Orkney College
34 University of St Andrews – Hydrogen Accelerator
35 University of St Andrews – School of Chemistry
36 University of Strathclyde – Driving the Electric Revolution, Industrialisation Centre
37 University of Strathclyde – Department of Naval Architecture
38 University of Strathclyde – Department of Naval Architecture
39 University of Strathclyde – Power Networks Demonstration Centre
40 Zephyrus

Appendix B Characterising the Maritime Decarbonisation Landscape in Scotland

To set the context for research and analysis into the skills required for maritime decarbonisation, the scope of the different parts of the relevant supply chain and operations need to be defined. Figure 29, below, summarises the overall scope of this study.

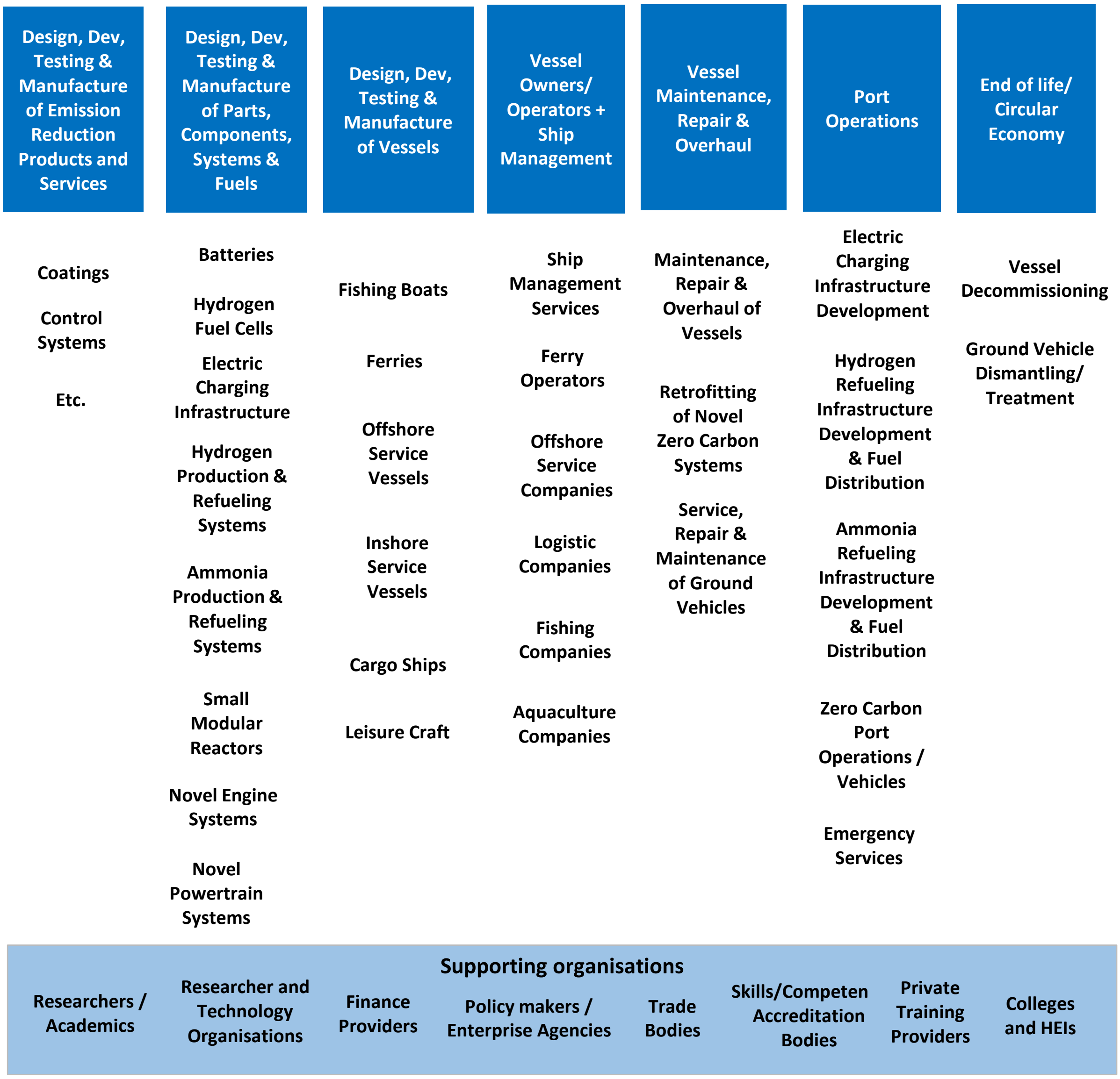


Figure 29: Scope of the Maritime Decarbonisation Supply Chain and Operational Landscape

Figure 29 illustrates the different decarbonisation options arising from the supply chain and the key elements of operation, use and end of life. It includes:

- Design, development, testing and manufacture of emissions reduction products and services
- Design, development, testing of parts, components, systems and fuels
- Design, development, testing and manufacture of vessels
- Vessel owners/operators and ship management

- Vessel maintenance, repair and overhaul
- Port operations
- End of life/ Circular economy

In addition, there are various supporting organisations including researchers/academics, research and technology organisations, finance providers, policy makers/enterprise agencies, trade bodies, skills/competence accreditation bodies, private training providers and colleges/higher education institutes.

It is necessary to understand the scale of Scottish based activity within each segment to assess the approximate number of employees potentially requiring skills development to support the decarbonisation of maritime operations and maximise associated economic opportunities.

The analysis below uses data sourced from the Office for National Statistics service, nomis. Specifically, the databases used were:

- UK Business Counts – enterprises by industry and employment size band (accessed 3/11/22, latest data 2022)
- Business Register and Employment Survey – data based on 'Employment' numbers (accessed 3/11/22, latest data 2021)

Where possible, the scale of each of the segments is quantified in terms of number of enterprises operating in Scotland and employment within these segments. The quantification is based on the following methods:

- Search of several databases accessible via the Office for National Statistics, Nomis website for official labour market statistics (as defined above). Both sources enable searching for Scottish level data within industries defined at the 5-digit Standard Industrial Classification (SIC) Code level. Whilst this is the most disaggregated level of SIC Code data available, there are still limitations with using this approach due to potential lack of alignment between the supply chain/market segments defined in Figure 29 and the activities included in the most relevant 5-digit SIC Codes. Notwithstanding these limitations, this approach can provide a reasonable indication of scale of activity present in Scotland. It should be noted that when data from nomis is presented in figures later in this section, all figures are rounded to avoid disclosure. In some cases the values may be rounded down to zero. However, all zeros are not necessarily true zeros.
- Due to the potential limitations with the SIC Code approach, described above, it is also useful to use other sources of data such as company databases (e.g. FAME), trade body directories, general internet searching, etc.
- Where SIC Code data does not have a good fit with the types of organisations, defined for maritime operations and the supply chain, it can be useful to identify whether Standard Occupational Classification (SOC) data for Scotland has an occupation category(s) that fits with the segment definition. The database used, in this instance, is the Annual Population Survey – regional employment by occupation (available via the Nomis website). It is assessed that 2021 SOC data should not be used due to the impact of miscoding data in ONS surveys as detailed on the ONS website. This is connected to an error in coding of four digit SOC data when the ONS moved from using SOC 2010 to SOC 2020 in January 2021. As a result of this, the SOC data

used in this report is based on the last set of annual data published by ONS before the miscoding started, i.e. January 2020 to Dec 2020.
- Where none of the above sources can provide a robust point value for number of organisations or employees present in Scotland then a range estimate may made which will, necessarily, include an element of subjectivity. If no range estimate is possible then 'no data' is displayed

Each of the main segments is described and quantified below.

Design, Development, Testing & Manufacture of Emission Reduction Products and Services

Activities included in the scope of this segment are:

- Coatings
- Control systems

The SIC Codes that have some alignment with these activities are:

- 25610 : Treatment and coating of metals (which includes non-metallic coating of metals: plasticising, enamelling, lacquering etc.). However, this SIC Code also includes non-relevant activities such as plating, anodising etc. of metals, heat treatment of metals, deburring, sandblasting, tumbling, cleaning of metals, colouring, engraving, of metals and hardening, buffing of metals
- 26511 : Manufacture of electronic instruments and appliances for measuring, testing and navigation (except industrial process control equipment)

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
25610	Treatment and coating of metals	65	900	Low
26511	Manufacture of electronic instruments and appliances for measuring, testing and navigation (except industrial process control equipment)	85	4,500	Low

Figure 30 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering design, development, testing of emission reduction products and services (Scottish data)

Based on SIC data, there are 170 enterprises employing 5,475 people in the defined categories. However, the alignment of these SIC categories with the types of companies involved in the segment is assessed as low. Whilst the SIC codes are likely to be used by companies producing maritime coatings and control systems, the extent to which companies having these SIC codes service the marine market is unclear. Therefore, the overall number of both enterprises and employment is almost certainly overstated.

It is assessed that there is insufficient data to quantify this segment of the landscape.

Design, Development, Testing & Manufacture of Parts, Components, Systems & Fuels

Activities included in the scope of this segment are:

- Batteries
- Hydrogen Fuel Cells
- Electric Charging Infrastructure
- Hydrogen Production & Refuelling Systems
- Ammonia Production & Refuelling Systems
- Small Modular Reactors
- Novel Engine Systems
- Novel Powertrain Systems

The SIC Codes that have some alignment with these activities are:

- 20110 : Manufacture of industrial gases (which includes manufacture of liquefied or compressed inorganic industrial or medical gases, including elemental gases such as hydrogen). However, this SIC Code also includes non-relevant activities such as manufacture of other industrial gases such as liquid/compressed air, refrigerant gases etc.
- 20150 : Manufacture of fertilizers and nitrogen compounds (which includes manufacture of ammonia). However, this SIC Code also includes non-relevant activities such as manufacture of straight or complex nitrogenous, phosphatic or potassic fertilisers, urea, crude natural phosphates and crude natural potassium salts, manufacture of associated nitrogen products including nitric and sulphonitric acids, ammonium chloride, ammonium carbonate, nitrites and nitrates of potassium, manufacture of potting soil with peat as main constituent, manufacture of potting soil mixtures of natural soil, sand, clays and minerals.
- 27120 : Manufacture of electricity distribution and control apparatus (which includes manufacture of power circuit breakers, control panels for electric power distribution, surge suppressors (for distribution level voltage), electrical relays, duct for electrical switchboard apparatus, electric fuses, power switching equipment and electric power switches (except pushbutton, snap, solenoid, tumbler). However, this SIC Code also includes non-relevant activities such as prime mover generator sets.
- 27200 : Manufacture of batteries and accumulators (which includes manufacture of primary cells and batteries containing lithium). However, this SIC Code also includes non-relevant activities such as the manufacture of non-rechargeable batteries and lead acid batteries.
- 27900 : Manufacture of other electrical equipment (which includes manufacture of battery chargers and manufacture of fuel cells). However, this SIC Code also includes a significant number of non-relevant activities such as electrical signs, electrical welding/soldering equipment, etc.
- 28110 : Manufacture of engines and turbines, except aircraft, vehicle and cycle engines (which includes manufacture of marine engines, manufacture of pistons, piston rings, carburettors and such for all internal combustion engines, diesel engines etc, manufacture of inlet and exhaust valves of internal combustion engines, manufacture of turbines and parts thereof). However, this SIC Code also includes non-relevant activities such as manufacture of railway engines, steam turbines and other vapour turbines, hydraulic turbines, waterwheels and regulators thereof, wind turbines, gas turbines, except turbojets or turbo propellers for aircraft propulsion, manufacture of boiler-turbine sets, manufacture of turbine-generator sets and manufacture of engines for industrial applications
- 28150 : Manufacture of bearings, gears, gearing and driving elements (which includes manufacture of mechanical power transmission equipment, transmission shafts and cranks:

camshafts, crankshafts, cranks etc., bearing housings and plain shaft bearings, manufacture of gears, gearing and gear boxes and other speed changers and manufacture of power transmission chain). However, this SIC Code also includes non-relevant activities such as manufacture of clutches and shaft couplings, manufacture of flywheels and pulleys, manufacture of articulated link chain and manufacture of ball and roller bearings and parts thereof.

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
20110	Manufacture of industrial gases	5	125	Med
20150	Manufacture of other fertilizers and nitrogen compounds	5	75	Med
27120	Manufacture of electricity distribution and control apparatus	30	500	Low
27200	Manufacture of batteries and accumulators	5	100	Med
27900	Manufacture of other electrical equipment	30	300	Low
28110	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	35	175	Low
28150	Manufacture of bearings, gears, gearing and driving elements	10	350	Med

Figure 31 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering design, development, testing and manufacture of parts, components, systems and fuels (Scottish data)

Based on SIC data, there are 120 enterprises employing 1,625 people in the defined categories. However, the alignment of a number of these SIC categories with the types of companies involved in the segment is assessed as low. Taking only those SIC codes assessed as having a medium level of fit with the defined activities the employment is 650. This is likely to overstate the actual level of employment in this segment as a number of the SIC activities are likely to have applications in sectors other than maritime. However, it does present an indicative estimate of the scale of this segment.

Design, Dev, Testing & Manufacture of Vessels

Activities included in the scope of this segment are:

- Fishing Boats
- Ferries
- Offshore Service Vessels
- Inshore Service Vessels
- Cargo Ships
- Leisure Craft

The SIC Codes that have some alignment with these activities are:

- 30110 : Building of ships and floating structures (which includes building of commercial vessels such as passenger vessels, ferry-boats, cargo ships, tankers, tugs etc., building of warships, building of fishing boats and fish-processing factory vessels and building of hovercraft (except recreation-type hovercraft)). However, this SIC Code also includes non-relevant activities such as construction of drilling platforms, floating or submersible, construction of floating structures such as floating docks, pontoons, coffer-dams, floating landing stages, buoys, floating tanks, barges, lighters, floating cranes and construction of non-recreational inflatable rafts etc.

- 30120 : Building of pleasure and sporting boats (which includes manufacture of inflatable boats and rafts, building of sailboats with or without auxiliary motor, building of motor boats, building of recreation-type hovercraft, manufacture of personal watercraft and manufacture of other pleasure and sporting boats). However, this SIC Code also includes non-relevant activities such as canoes, kayaks, rowing boats, skiffs, etc.

The number of enterprises and level of employment in each of the above SIC Codes, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
30110	Building of ships and floating structures	65	7,000	Med
30120	Building of pleasure and sporting boats	20	100	High

Figure 32 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering design, development, testing and manufacture of vessels (Scottish data)

Based on SIC data, there are 85 enterprises employing 7,100 people in the defined categories. The alignment of the 30110 SIC category with the types of companies involved in the segment is assessed as medium, due to the inclusion of non-motorised structures. Data can also be sourced from Standard Occupational Classification statistics. SOC Code 5236, (Boat and ship builders and repairers) shows employment in this occupation of 1,500. This is significantly less than the employment estimate of 7,000 from the SIC data for 'Building of ships and floating structures' and this implies building of floating structures, such as drilling rigs, accounts for the majority of employment in this SIC Code. It should also be noted that the SOC Code employment figure of 1,500 includes those involved in boat and ship repairers as well as builders, although there will clearly be employees involved in both new build and repair. It should be noted that the SOC Code 5236 will not include employment in the design, development and testing of the ships and boats being constructed.

The fit of SIC Code 30120 is assessed as high. However, this employment will be included in the SOC code data.

It is assessed that SOC data is a more accurate estimate of numbers of people active in building and repair of boats and ships, as this does not include the construction of floating structures which do not require to be decarbonised. An estimate of 1,500 employees is used for this segment of the maritime landscape. The later segment focusing on maintenance, repair and overhaul will clearly duplicate the number of employees present in this segment.

Vessel owners/operators and ship management

Activities included in the scope of this segment are:

- Fishing Companies
- Ferries
- Offshore Service Companies

- Logistics Companies
- Aquaculture Companies
- Ship Management Companies

The SIC Codes that has some alignment with these activities are:

- 03110 : Marine fishing (which includes fishing on a commercial basis in ocean and coastal waters, taking of marine crustaceans and molluscs, whale catching, taking of marine aquatic animals: turtles, sea squirts, tunicates, sea urchins etc., activities of vessels engaged both in marine fishing, and in processing and preserving of fish and gathering of other marine organisms and materials: natural pearls, sponges, coral and algae)
- 03210 : Marine aquaculture (which includes fish farming in sea water including farming of marine ornamental fish, production of bivalve spat (oyster mussel etc.), lobsterlings, shrimp post-larvae, fish fry and fingerlings, growing of laver and other edible seaweeds, culture of crustaceans, bivalves, other molluscs and other aquatic animals in sea water
- 09100 : Support activities for petroleum and natural gas extraction (which includes exploration services in connection with petroleum or gas extraction, e.g. traditional prospecting methods, such as making geological observations at prospective sites. Directional drilling and redrilling; "spudding in"; derrick erection in situ, repairing and dismantling; cementing oil and gas well casings; pumping of wells; plugging and abandoning wells etc., liquefaction and regasification of natural gas for purpose of transport, done at the mine site, draining and pumping services, on a fee or contract basis, test drilling in connection with petroleum or gas extraction, oil and gas field fire fighting services)
- 46140 : Agents involved in the sale of machinery, industrial equipment, ships and aircraft (which includes machinery, including office machinery and computers, industrial equipment, ships and aircraft)
- 50100 : Sea and coastal passenger water transport (which includes transport of passengers overseas and coastal waters, whether scheduled or not, operation of excursion, cruise or sightseeing boats, operation of ferries, water taxis etc., renting of pleasure boats with crew for sea and coastal water transport (e.g. for fishing cruises)
- 50200 : Sea and coastal freight water transport (which includes transport of freight overseas and coastal waters, whether scheduled or not, transport by towing or pushing of barges, oil rigs etc., renting of vessels with crew for sea and coastal freight water transport)
- 50300 : Inland passenger water transport (which includes transport of passengers via rivers, canals, lakes and other inland waterways, including inside harbours and ports, renting of pleasure boats with crew for inland water transport)
- 50400 : Inland freight water transport (which includes transport of freight via rivers, canals, lakes and other inland waterways, including inside harbours and ports, renting of vessels with crew for inland freight water transport)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
03110	Marine fishing	1,840	4,500	High
03210	Marine aquaculture	120	2,250	High

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
09100	Support activities for petroleum and natural gas extraction	85	13,000	High
46140	Agents involved in the sale of machinery, industrial equipment, ships and aircraft	155	175	Med
50100	Sea and coastal passenger water transport	85	1,000	High
50200	Sea and coastal freight water transport	60	400	High
50300	Inland passenger water transport	20	75	High
50400	Inland freight water transport	5	0	High

Figure 33 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering vessel owners/operators and ship management (Scottish data)

Based on this SIC Code data there are 2,370 enterprises and 21,400 employees in the defined categories. The fit between SIC Codes and definition of this maritime segment is assessed as high in all cases except for SIC 46140, 'agents involved in the sale of machinery, industrial equipment, ships and aircraft', which is assessed as having medium alignment. It should be noted that only a proportion of the employees are likely to require different skills as a result of operating on a decarbonised vessel.

Employment data was sourced for SOC 3513, 'Ship and hovercraft officers' (2,500 employees), SOC 8232, 'Marine and waterways transport operatives' (1,400 employees) and SOC 9119, 'Fishing and other elementary agricultural occupations' (4,600 employees).

The employment figure of 21,400, sourced from SIC data, is assessed as being the most reasonable option to describe the scale of this segment.

Vessel Maintenance, Repair & Overhaul

Activities included in the scope of this segment are:

- Maintenance, Repair and Overhaul of Vessels
- Retrofitting Novel Zero Carbon Systems

The SIC Codes that have some alignment with these activities are:

- 33150 : Repair and maintenance of ships and boats (which includes repair and routine maintenance of ships and repair and maintenance of pleasure boats)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
33150	Repair and maintenance of ships and boats	85	900	High

Figure 34 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering vessel maintenance, repair and overhaul (Scottish data)

SIC Code 33150 (repair and maintenance of ships and boats) has a high level of fit with the activities included in this segment. This suggests a total of 85 enterprises and 900 employees.

Data can also be sourced from Standard Occupational Classification statistics. SOC Code 5236, (Boat and ship builders and repairers) shows employment in this occupation of 1,400. However, this includes employment in new build boats and ships as well as repair and maintenance. The figure of 900 employees, from SIC data, is assessed as more accurate for this sector.

Port Operations

Activities included in the scope of this segment are:

- Electric Charging Infrastructure Development
- Hydrogen Refuelling Infrastructure Development & Fuel Distribution
- Ammonia Refuelling Infrastructure Development & Fuel Distribution
- Zero Carbon Port Vehicles
- Emergency Services

The SIC Codes that has some alignment with these activities are:

- 33200 : Installation of industrial machinery and equipment (which includes installation of industrial machinery in industrial plant) However, this SIC Code also includes non-relevant activities such as assembling of industrial process control equipment, installation of other industrial equipment, e.g.: communications equipment, mainframe and similar computers, irradiation and electromedical equipment etc., dismantling large-scale machinery and equipment, activities of millwrights, machine rigging, installation of bowling alley equipment
- 42210 : Construction of utility projects for fluids (which includes the construction of distribution lines for transportation of fluids and related buildings and structures that are an integral part of these systems). However, this SIC Code also includes non-relevant activities such as construction of civil engineering constructions for long-distance and urban pipelines, water main and line construction, irrigation systems (canals), reservoirs construction of, sewer systems, including repair sewage disposal plants, pumping stations and water well drilling
- 42990 : Construction of other civil engineering projects nec (which includes construction of industrial facilities, except buildings, such as refineries, chemical plants and construction work, other than buildings, such as outdoor sports facilities)
- 43210 : Electrical installation (which includes the installation of electrical systems in all kinds of buildings and civil engineering structures of electrical systems. This class includes installation of, electrical wiring and fittings). However, this SIC Code includes non-relevant activities such as telecommunications wiring, computer network and cable television wiring, including fibre optic, satellite dishes, lighting systems, fire alarms, burglar alarm systems, street lighting and electrical signals, airport runway lighting, electric solar energy collectors and connecting of electric appliances and household equipment, including baseboard heating)
- 52101 : Operation of warehousing and storage facilities for water transport activities of division 50 (which includes operation of storage and warehouse facilities for all kind of goods including operation of grain silos, general merchandise warehouses, refrigerated warehouses, storage tanks etc., storage of goods in foreign trade zones and blast freezing
- 52220 : Service activities incidental to water transportation (which includes activities related to water transport of passengers, animals or freight including operation of terminal facilities such as harbours and piers, operation of waterway locks etc., navigation, pilotage and berthing activities, lighterage, salvage activities and lighthouse activities)

- 52241 : Cargo handling for water transport activities of division 50 (which includes loading and unloading of goods or passengers' luggage travelling via water transport and stevedoring

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
33200	Installation of industrial machinery and equipment	155	1,250	Low
42210	Construction of utility projects for fluids	40	500	Low
42990	Construction of other civil engineering projects nec	850	10,000	Low
43210	Electrical installation	2,785	26,000	Low
52101	Operation of warehousing and storage facilities for water transport activities of division 50	5	0	High
52220	Service activities incidental to water transportation	145	4,000	High
52241	Cargo handling for water transport activities of division 50	10	300	High

Figure 35 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering port operations (Scottish data)

SIC Code data for this segment totals 3,830 enterprises and 37,750 employees. However, the degree of alignment between some SIC Codes and segment activities is assessed as low due to the significant level of non-relevant activities included in each of the SIC Codes marked as 'Low'. The SIC Codes relevant to services incidental to water transportation (SIC 52220) and cargo handling for water transportation activities (SIC 52241) are assessed as having a high degree of fit with the segment definition. Overall, these SIC Codes have employment of 4,300.

A report on Organisational Statistics (2021-2022) from the Scottish Fire and Rescue Service identifies 5,600 staff scheduled to crew appliances. Firefighters in coastal areas may be called on to attend incidents at port facilities, with a risk of this involving battery electric powered or hydrogen fuelled vessels in future, for example.

The scale of this sector can be estimated by using the employment data for those SIC Codes with a high degree of alignment with segment activities. It is assessed, therefore, that the segment contains at least 4,300 employees. This excludes firefighters that may require skills development on how to address incidents involving decarbonised vessels and associated port refuelling/recharging infrastructure.

End of life/ Circular Economy

Activities included in the scope of this segment are:

- Re-lifing / reusing, repurpose with modifications and downcycling
- Vessel Decommissioning
- Port Vehicle Dismantling/ Treatment

The SIC Codes that has some alignment with these activities are:

- 33150 : Repair and maintenance of ships and boats (which includes repair and routine maintenance of ships and repair and maintenance of pleasure boats)

- 38210 : Treatment and disposal of non:hazardous waste (which includes the disposal and treatment prior to disposal of solid or non-solid non-hazardous waste including operation of landfills for the disposal of non-hazardous waste, disposal of non-hazardous waste by combustion or incineration or other methods, with or without the resulting production of electricity or steam, compost, substitute fuels, biogas, ashes or other by-products for further use etc., treatment of organic waste for disposal)
- 38220 : Treatment and disposal of hazardous waste (which includes the disposal and treatment prior to disposal of solid or non-solid hazardous waste, including waste that is explosive, oxidising, flammable, toxic, irritant, carcinogenic, corrosive, infectious and other substances and preparations harmful to human health and the environment. This class includes operation of facilities for treatment of hazardous waste, treatment and disposal of toxic live or dead animals and other contaminated waste, incineration of hazardous waste, disposal of used goods such as refrigerators to eliminate harmful waste, treatment, disposal and storage of radioactive nuclear waste including treatment and disposal of transition radioactive waste, i.e. decaying within the period of transport, from hospitals and encapsulation, preparation and other treatment of nuclear waste for storage)
- 38310 : Dismantling of wrecks (which includes dismantling of wrecks of any type (automobiles, ships, computers, televisions and other equipment) for materials recovery. This class excludes disposal of used goods such as refrigerators to eliminate harmful waste and dismantling of automobiles, ships, computers, televisions and other equipment to obtain re-sell usable parts)
- 38320 : Recovery of sorted materials (which includes the processing of metal and non-metal waste and scrap and other articles into secondary raw materials, usually involving a mechanical or chemical transformation process. Also included is the recovery of materials from waste streams in the form of (1) separating and sorting recoverable materials from non-hazardous waste streams (i.e. garbage) or (2) the separating and sorting of mixed recoverable materials, such as paper, plastics, used beverage cans and metals, into distinct categories)

The number of enterprises and level of employment in the above SIC Code, in Scotland, is summarised below.

SIC Code	SIC Description	No. of Enterprises	Employment	Fit of SIC definition to Maritime activities in segment
33150	Repair and maintenance of ships and boats	85	900	High
38210	Treatment and disposal of non:hazardous waste	60	3,500	Low
38220	Treatment and disposal of hazardous waste	10	2,000	Low
38310	Dismantling of wrecks	5	30	Med
38320	Recovery of sorted materials	105	2,000	Low

Figure 36 - Number of enterprises and employment data by relevant SIC Code and degree of fit between SIC definition and maritime activities covering end of life/circular economy

Based on the SIC Codes, there are 265 enterprises and 8,470 employees in this segment. However, several of the segments have a low alignment between the SIC Code coverage and the maritime activities being investigated. Only the SIC Code 33150, repair and maintenance of ships and boats, is assessed as having a high level of alignment, with 85 enterprises and 900 employees. It should be noted that there is duplication of SIC Code 33150, which is also used in the assessment of the maintenance, repair and overhaul segment. It is assessed that there is insufficient data to define an estimate of the number of employees in this segment.

Summary of employment in the Scottish Maritime landscape

Figure 37, below provides a summary of the indicative levels of employment in the different Maritime segments in that are likely to require some additional skills when decarbonising.

Maritime Segment	Indicative total employment by segment
Design, development, testing and manufacture of emissions reduction products and services	Limited data
Design, development, testing of parts, components, systems and fuels	650
Design, development, testing and manufacture of vessels	1,500
Vessel owners/operators and ship management	21,400
Vessel maintenance, repair and overhaul	900
Port operations	4,300
End of life/Circular economy	Limited data

Figure 37 - Indicative number of employees in different segments of the maritime landscape in Scotland

Note that the above employment data does not cover all maritime industries, only those relevant to transport decarbonisation. For example, employment related to construction of drilling rigs has not been included. Instead, the focus has been on motorised ships and boats which require decarbonisation to reduce transport greenhouse gas emissions.

In some cases, the alignment between the maritime segment definition and SIC/SOC code data was low. In these circumstances no indicative estimates were able to be identified and therefore 'Limited data' was registered.

It should be noted that not all employees will require skills development as a result of the shift to decarbonisation. For example, of the 21,400 employees involved in vessel operation and management, only a minority will need significant levels of skills development. Many of these employees will not interact with the vessel's propulsion system and require no additional skills of competencies to carry out their job function in a decarbonised vessel.

Appendix C: Combining Employee Numbers, Roles and Skills Requirement Data

Maritime Decarbonisation Landscape Segment	Skills Required	Roles	Training Provision	Skills Gaps	Skills Shortages
Design, development, testing and manufacture of emissions reduction products and services *Estimated employment: not known*	• Ship and product design engineering • Materials engineering, scientists and chemists • Precision engineering of lightweight alloys and coatings • Quality inspection and control of component parts • Industry 4.0 and 5.0 • Automation technologies (digital, data and AI technologies)	• Naval engineers / architects • Materials technologists • Electronic engineers • Digital/data technologists	In-house, further and higher education, private training providers	• Understanding of lightweight materials and innovative manufacturing techniques • Manufacturing skills • Expertise in automated maritime systems and associated technologies	General shortages noted for employees with STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue.
Design, development, testing of parts, components, systems and fuels *Estimated employment: 650*	• Ship and product design engineering • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Regulatory, standards and safety certification requirements • Detailed safety case development • Basic trades	• Naval engineers / architects • Materials technologists • Electronic engineers • Digital/data technologists • Electrical engineers • Chemical engineers • Chemists • Engineers • H&S	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems • Manufacturing skills related to alternative fuels and novel propulsion systems	General shortage of engineers and other STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue. However it should be noted that major maritime systems are not currently manufactured in Scotland.

Maritime Decarbonisation Landscape Segment	Skills Required	Roles	Training Provision	Skills Gaps	Skills Shortages
Design, development, testing and manufacture of vessels *Estimated employment: 1,500*	• Ship design • Materials engineering, scientists and chemists • Precision engineering of lightweight alloys and coatings • Industry 4.0 and 5.0 • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management • Basic trades	• Naval engineers / architects • Materials technologists • Electronic engineers • Digital/data technologists • Electrical engineers • Chemical engineers • Chemists • Engineers • H&S	In-house, further and higher education and private training providers and system manufacturers	• Understanding of lightweight materials and innovative manufacturing techniques • Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems • Manufacturing skills related to alternative fuels and novel propulsion systems • Innovative ship design utilising novel fuel / propulsion systems • Safety case development for the use of alternative fuels and the development of standards and certification	General shortage of engineers and other STEM skills. Skills shortages highlighted across all industry sectors for mechanical, chemical, electrical and electronic engineers, software and data management experts and fitters and welders The lack of welders has been identified as a specific issue.

Maritime Decarbonisation Landscape Segment	Skills Required	Roles	Training Provision	Skills Gaps	Skills Shortages
Vessel owners/operators and ship management *Estimated employment: 21,400*	• Industry 4.0 and 5.0 • Automation technologies • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management • Basic trades	• Digital/data technologists • Electrical engineers • Chemists • Chemical engineers • Engineers • H&S	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels, including safety aspects • Monitoring and control systems linked to alternative fuel and propulsion systems	General shortages of STEM skills noted (as above) but specific skills needs will vary, depending on the type of vessel, its fuel and propulsion system and its operating routine. Digital skills to support the development of automated maritime systems, efficient route planning, etc
Vessel maintenance, repair and overhaul *Estimated employment: 900*	• High voltage system overhaul, repair and maintenance • overhaul, repair and maintenance • Overhaul, repair and maintenance of parts/components manufactured using new alloys/composites, etc. • Service, repair and maintenance of electrically powered port equipment	• Naval engineers / architects • Materials technologists • Electronic engineers • Digital/data technologists • Electrical engineers • Chemical engineers • Chemists • Engineers • H&S	In-house, further and higher education and private training providers and system manufacturers	Specific skills gaps will only become apparent when new decarbonised vessels come into service. Could include skills in • Manufacturing skills • High voltage systems • Battery systems • Handling, transport and storage alternative fuels	The skills required for vessel MRO will be defined in response to what low carbon and zero emission technologies are introduced or retrofitted onto ships. It is likely that there will only be limited demand by 2032.

Maritime Decarbonisation Landscape Segment	Skills Required	Roles	Training Provision	Skills Gaps	Skills Shortages
Port operations *Estimated employment: 4,300*	• Industry 4.0 and 5.0 • Automation technologies • High-voltage electrical systems • Battery electric systems • Alternative fuel systems • Systems integration • Project management • Basic trades	• Electronic engineers • Digital/data technologists • Electrical engineers • Chemical engineers • Chemists • Engineers • H&S	In-house, further and higher education and private training providers and system manufacturers	• Understanding of alternative fuels • Expertise in automated maritime systems and associated technologies • Expertise in battery electric systems • Expertise in novel propulsion and high voltage power systems • Expertise in handling, transport and storage alternative fuels • Monitoring and control systems linked to alternative fuel and propulsion systems	Shortages around digital and data skills for energy monitoring and management and smart logistics based on automation, IoT, blockchain, artificial intelligence and data management
End of life/ circular economy *Estimated employment: not known*	• Safe isolation and removal of high-voltage electrical systems • Valuable material identification and recovery • Second life use of batteries	• Electrical engineers • Chemical engineers • Chemists • Engineers • H&S	Further education and private training providers	• For recycling, specific skills gaps will only become apparent when new decarbonised vessels are being dismantled • For circular economy, gaps exist around the development of innovative circular business models	Digital / data skills to support the development of innovative circular business models (e.g. material traceability across the supply chain)

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