Decarbonisation of Scottish Maritime Transport

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Executive Summary

Background and Context

Decarbonisation of the maritime sector is of strategic importance at a UK Government level with the publication of, for example, Maritime 2050: Navigating the Future and the National Shipbuilding Strategy Refresh, both of which cover the UK as a whole, including the devolved administrations. At a Scottish Government level, there is a more general emphasis on the decarbonisation of transport as described in 'A Fairer, Greener Scotland: Programme for Government 2021-2022' and, in particular, the opportunities that have been identified as the country moves towards a "*green, sustainable and active transport system…*". Whilst the Programme for Government does not mention maritime transport specifically, clearly this is vital due to the reliance on this mode of transport for many island and rural communities, as well as for the ports and shipyards servicing the industry and its logistical importance in terms of the shipping of products. The Scottish Government has also recently published 'A Blue Economy Vision for Scotland' (March 2022), which encompasses, amongst others, the maritime sector and which sets out the long-term ambition for Scotland's blue economy to 2045.

Domestic and international shipping make significant contributions to Scotland's transport related greenhouse gas (GHG) emissions. The most recent statistics highlight that 35.58%, which equates to 14.81 $MtCO_2e$, of Scotland's net GHG emissions in 2018 were attributed to transport with shipping emissions accounting for 2.3 $MtCO_2e$ (15.5% of transport emissions). This can be further broken down to domestic shipping and international shipping, which account for 2 $MtCO_2e$ and 0.34 $MtCO_2e$ respectively. Clearly, reducing these will make a positive impact on the strategic net zero objectives set out in the Programme for Government.

Study Scope

It is within this context that this study has been undertaken, the overall aim of which was to map the academic R&D strengths and company profiles in Scotland to decarbonise maritime transport and to map these capabilities against the technology and market opportunities arising, across the world, as the industry moves toward decarbonised and zero emission operations.

This study has considered both the decarbonisation of the maritime fleet as well as of port operations, which includes the optimisation of the efficiency of current operations and the implementation of new technologies and systems. Further, it is recognised that different solutions are expected to be adopted in different sizes and types of vessel, therefore, the maritime fleet has been categorised as follows:

- Small ferries and leisure craft
- Large ferries
- Fishing boats
- Inshore service vessels
- Offshore service vessels
- Large cargo vessels

Market Drivers

One of the strongest influences on decarbonisation of the maritime transportation sector is 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 and has set concrete targets for the reduction of GHGs for 2030 and 2050. The strategy is being implemented through a package of measures that address the technical efficiency of existing ships; the operational efficiency of ships through incremental CO_2 reduction criteria; and the energy management systems onboard the vessels.

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 technologies.

These legislation and policy drivers 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.

Technology Trends

There are 3 overarching options to decarbonise maritime vessels:

Optimising Efficiency

Improving the fuel efficiency of vessels is a well-established method for optimising operational costs of maritime transport. It is also relevant, therefore, for the reduction of CO_2 emissions and there are many different options that have already been demonstrated. Some of these, such as slow steaming (where the ship is slowed to an optimum travel speed to reduce fuel burn and, therefore, CO_2 emissions), non-friction coatings and anti-fouling technologies, are well established while others, such as autonomous vessel operation and the use of supplementary power options, are emerging.

Auxiliary Power Systems and Technologies

Auxiliary power technologies, combined with existing propulsion systems and efficiency optimisation options, or with new and alternative fuels / propulsion systems (discussed below) could be utilised for further decarbonisation benefits. Two main examples of such technologies are wind assisted propulsion, such as sails and Flettner rotors, and solar-on-ship, namely arrays of photovoltaic cells that produce renewable electricity from the sun to supplement on-board power demands.

Alternative Fuels / Propulsion Systems

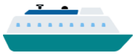
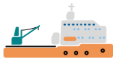
It is the use of alternative fuels and propulsion systems that is likely to have the biggest impact on the move towards low carbon and zero emissions marine transportation. There are several alternative lower carbon fuels and propulsion systems already in use, as well as new and zero emission technologies under development. These include:

- Biofuels
- Liquid natural gas (LNG)
- Hydrogen (as a direct combustion fuel and in fuel cells)
- Ammonia
- Methanol
- Hybrid electric and battery electric
- Small modular reactors (molten salt reactors)

New Technology Implementation

Whilst it is clear that the implementation of alternative fuels and propulsion systems will be key to the decarbonisation of the maritime sector and the meeting of IMO targets, analysis of the literature and stakeholder and company feedback gathered during this study clearly highlight that there is no consensus about which fuels and propulsion systems will be used. Further, the expectations are that different, and possibly multiple, solutions will be adopted for different types of vessel, depending on their size and operational requirements.

There are, however, a number of alternative fuel and propulsion technologies that have been identified as leading candidates for each type of vessel. These are summarised as follows:

	Type	Ongoing Action	Short Term (next five years)	Long Term (10 - 15 years)
	Small Ferry	Optimise efficiency	Diesel - electric hybrid / battery electric	Battery Electric
	Large Ferry	Optimise efficiency	Biofuels or Diesel - electric hybrid	Ammonia combustion
	Fishing Boat	Optimise efficiency	Biofuels	Ammonia or methanol combustion
	Inshore Service Vessel	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Battery electric / Ammonia or methanol combustion
	Offshore Service Vessel	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Electric / Ammonia or methanol combustion
	Large Cargo Vessel	Optimise efficiency	Biofuels / LNG	Ammonia combustion or fuel cell / SMR

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

Zero Carbon Ports

There is also 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.

In terms of 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 a port. To support zero carbon vessel operations, ports need to provide low / zero carbon fuels as well as provide shore to ship power facilities that allow ships to turn off auxiliary engines while berthed, reducing emissions. In Scotland, companies such as Peel Ports Group, which operates Clydeport, has committed to become a net zero port operator by 2040.

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.

The Role of Innovation

The development and adoption of low / zero carbon solutions is critically dependent on innovation and there are several innovation support programmes, at a Scottish, UK and European level, targeted at the development of decarbonisation solutions for the maritime sector. There are a number of very innovative Scottish companies and research organisations participating in RD&I projects funded via these programmes.

The achievement of decarbonised / zero emission maritime will be enabled by a wide range of existing and new technologies covering optimisation of ship efficiency; the deployment of auxiliary power systems; and the introduction of novel fuels and propulsion systems. There is, however, still significant development and demonstration required for many of these technologies, particularly new fuels, before they are ready to be commercialised in any serious way. In reality, this is unlikely to be achieved at any scale before 2030. There could, however, be a role for Scottish companies and research organisations, and particularly those that are already active in innovation, to further advance these technologies, either individually, or as part as a collaborative effort with others in Scotland and elsewhere.

Potential Market and Technology Opportunities

Based on the analysis of the evidence gathered during this study, including feedback from companies and stakeholders, a number of key opportunities for companies in the Scottish Maritime sector have been identified. Many of these opportunities are global in nature and could, therefore, result in increased levels of export. More generally, these have the potential to strengthen the existing sector as well as to attract new market entrants, either from other, parallel supply chains or through inward investment.

The main opportunities identified are:

1. The recommendations and actions set out in the UK National Shipbuilding Strategy Refresh represent a significant pipeline of business through future ferry contracts and other government owned vessels (e.g., NLB, fishery protection and naval base support vessels). There is capability across the Scottish supply chain to exploit some of the opportunities that this would offer
2. The design, development and build of battery electric powered vessels is an emerging local market with sectors including, for example, aquaculture and off-shore wind service vessels being prime targets. Furthermore, approval requirements are achievable and the option of in-field charging is considered by the sector to be a "game-changer". This also presents additional opportunities for associated products (e.g. converters, DC drives, energy management, battery management, etc)
3. The predicted growth of offshore wind capacity (estimated as a £multi-billion opportunity for the supply chain in Scotland) and the hydrogen economy (25GW production capacity target by 2045) could result in significantly increased demand for low carbon / zero emission service and operations vessels
4. Decarbonisation of the maritime sector will require ongoing investment in RD&I in many of the new and emerging technologies highlighted previously which, in turn, will support the development of innovative products and services. This includes, for example:
    - Optimisation of ship design and lightweighting
    - Optimisation of vessel operations offering opportunities for, e.g.

    - Digital twins
    - Autonomous systems
    - Digital vessel monitoring / performance optimisation
    - Sensing / digital technologies for a range of applications (e.g. optimising vessel routes, fishing boat operation, etc.)
  - Development of high value, low and zero carbon products and services in areas including advanced hull designs, hydrogen production (especially green hydrogen), storage and transportation, the production of green, alternative fuels (such as biomethanol) utilising green hydrogen and captured CO_2 as feedstocks.
5. The development of "green ports" that, as well as deploying low carbon technologies to decarbonise operations, also act as "test-beds" for innovative low/zero carbon prototype vessels. The Scottish market is relatively small but is considered a "*good controllable pilot market*"

Issues and Challenges to be Addressed

Although the maritime sector is taking steps to decarbonise, it is acknowledged in the National Shipbuilding Strategy – Refresh (National Shipbuilding Office, March 2022) that progress has been slow, and that more commitment and investment is required from the sector to enable large scale emission reduction to be achieved. There are many, potential opportunities but there are still some quite significant barriers and challenges to be overcome, some of which will require a major change in the way the maritime sector operates together with changes to existing, and the introduction of new, legislation and regulations. These issues and challenges are not, however, specific to Scotland and will impact the sector across the world.

The Scottish Maritime Transport Sector – Industrial and Academic Capabilities

The supply chain in Scotland consists of almost 200 companies, some of which actively pursue decarbonisation already (e.g., through vessel performance optimisation) and others that do not but are considered critical to achieving a reduction in emissions over time (e.g., fishing vessel owners / operators that will adopt decarbonisation technologies).

Scotland has a number of key strengths including the high profile presence of large, global players in the defence sector, as well as internationally recognised ship building and ship maintenance capabilities. It is also home to the leading European ship management cluster. To support the industry in Scotland, there is a focused and active sector association (The Scottish Maritime Cluster).

In addition, there are a number of innovative supply chain companies that are actively developing new products and processes targeted at low and zero carbon emission maritime operations and there is also a strong supply base in digital and data technologies, that will be critical to the development and deployment of operational efficiency systems, such as autonomous vessels.

From an infrastructure perspective, there are already a number of ports actively deploying technologies to decarbonise their activities and there are also available port / land assets that could be further developed to support testing and demonstration of decarbonised maritime transportation products, processes and services.

Scotland has world-leading academic maritime capability within the Naval Architecture, Ocean & Marine Engineering Centre at the University of Strathclyde. In addition, there are a number of other centres of excellence and innovation centres working in highly relevant technology areas including, for example, batteries and fuel cells, novel fuels, advanced materials and digital and data technologies.

There are, however, a number of weaknesses that, if addressed, could help to further bolster the sector in Scotland.

Most notably, the Scottish supply chain is relatively weak compared to European competitors, especially the limited number of commercial shipbuilders of scale and the lack of indigenous, major systems suppliers (e.g. Tier 1 suppliers). Coupled with a higher cost base, compared to competing shipbuilding nations, this can make Scotland an unattractive proposition.

Although there are a number of global, defence sector companies in Scotland, these are regional facilities, often with only limited levels of local control and decision making. This impacts on the ability of these companies to develop and / or implement low carbon technologies.

There are also some skills gaps in the supply chain (e.g. basic trades, electrical engineers, design engineers) and an established dependence on overseas labour. In some cases, this is limiting the ability of companies to learn, improve and innovate, as this transient labour force moves on to the next job, taking the skills and learning with it.

The lack of alternative fuel supply chains, the perceived and actual high costs of these fuels and the lack of the required transportation and storage infrastructure is also noted. This, however, is not specific to Scotland and is, in fact, a global problem that is further hampering the uptake of low carbon technologies.

Potential Options for the Development of the Maritime Sector in Scotland

Based on the evidence gathered during this study, a number of potential development options have been identified that align well with the strengths of the Scottish maritime sector, harnessing these strengths to exploit the opportunities offered by the requirement for the global maritime transport industry to decarbonise.

In the first instance, many of the companies and stakeholders contacted highlighted that the development of a Scottish Maritime Strategy, that aims to address the issues and challenges specific to Scotland and to support development of the sector should be a priority action. This should focus on the existing and emerging strengths and capabilities across industry and academia and have a particular emphasis on innovation in added-value components, systems and other technologies to support decarbonisation of maritime transportation as this is where Scotland could develop a lead and where there is potential to make the biggest impact. The creation of such a strategy, that clearly sets out the Government's direction in relation to the sector, could also help to provide clarity to companies on where, potentially, to invest their resources now and in the future.

There are also a number of specific options that could be considered within the wider context of the abovementioned Scottish Maritime Strategy. They describe some of the objectives, actions and activities that have the potential to support the growth of the sector in the future.

These are:

Development of a Maritime Innovation Centre of Excellence

Consideration could be given to a Maritime Innovation Centre of Excellence that would act as a focal point for RD&I activities and bring together innovative companies and the research community in Scotland. The aim would be to facilitate collaborative projects and bring new decarbonisation technologies to the market. This could also help to attract innovation funding into Scotland through, for example, the UK Shipping Office for Reducing Emissions (UK SHORE).

Battery Electric Vessels

There is a significant drive in the offshore renewables sector to decarbonise its operations and, coupled with the potential opportunities offered by the predicted growth of offshore wind capacity as a result of the latest ScotWind offshore wind leasing, demand for low and zero carbon support vessels is predicted to grow rapidly. There is a small but active group of companies involved in the development of battery and fuel cell technologies, as well as a world leading academic research group at the University of St Andrews that could work together to exploit the immediate opportunities. In the longer term, as demand grows, new opportunities could open up across the supply chain for existing companies as well as companies not current active in the maritime sector. Ports and other maritime facilities on the East coast of Scotland are ideally located for the building and operation of such vessels due to their proximity to offshore wind assets.

Retrofitting of Innovative Low Carbon / Zero Emission Technologies

As well as building new vessels that incorporate low and/or zero emission technologies, there will also be an increasing requirement for these technologies to be retrofitted to existing vessels. Scotland, currently, has a number of dry docking facilities and consideration could be given to their redevelopment to deliver services for the retrofitting of new technologies. Further, potential options might also include the development of technology "hubs" with each dry dock facility specialising in one specific area, e.g. electrification of vessels, conversion of vessels to run on alternative fuels, etc.

Digitisation of Vessel Operations

There is increasing interest in the digitisation of vessel operations as a means of reducing carbon emissions. Opportunities exist across the supply chain but are particularly focused on vessel operations, maintenance and the operation and management of onshore infrastructure. Scotland has a strong company base in the field of data and digital technologies as well as world-leading academic capability at, for example, the University of Edinburgh. Stakeholders contacted as part of this study indicated that many of the technologies and capabilities that already exist could be readily applied to the maritime industry with only limited modification and development required.

Design, Development and Build of Commercial Demonstrator Vessels

There is already local interest in zero carbon vessels and discussions undertaken as part of this study highlighted electrification, in particular, as a key technology that will support the achievement of this. There is, therefore, a potential opportunity for the Scottish Government and its partners, or the private sector, to consider investment in one or more high TRL demonstrator vessels, e.g. a battery or fuel cell powered ferry, that would create relatively low risk supply chain opportunities for companies already in the maritime supply chain or those seeking to diversify their customer base. As part of this, the implementation of a “green corridor” could also be considered as the location of operation of these vessels, increasing Scotland’s profile in international decarbonisation of the sector.

Net Zero Port Demonstrator(s)

There is strong interest and commitment in several Scottish ports to pursue decarbonisation. These ports could be considered as a focal point for the development and demonstration of zero carbon systems that would provide a local market for innovative Scottish companies, thus demonstrating capabilities in a real situation. Further, there is potential for selected ports to develop as clusters / hubs for particular fuels, e.g. Hydrogen in Orkney where there is already ongoing interest and activity.

Scottish Maritime Cluster Supporting Development of a Cohesive Maritime Sector

The Scottish Maritime Cluster (SMC) was highlighted by companies and stakeholders as a key strength of the Scottish sector. The SMC, as a body representing maritime companies across the supply chain and providing the link between industry and policy makers, could play a pivotal role in developing sectoral cohesion and a sectoral strategy. It could also play a key role in ensuring that any of the development options outline above progress in a way that meets the needs of industry thereby ensuring buy in and effective participation.

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1 Introduction

1.1 Study Background and Context

Decarbonisation of the maritime sector is of strategic importance at a UK Government level with the publication of, for example, Maritime 2050: Navigating the Future and the National Shipbuilding Strategy Refresh, both of which cover the UK as a whole, including the devolved administrations. At a Scottish Government level, there is a more general emphasis on the decarbonisation of transport as described in 'A Fairer, Greener Scotland: Programme for Government 2021-2022' and, in particular, the opportunities that have been identified as the country moves towards a "*green, sustainable and active transport system…*". Whilst the Programme for Government does not mention maritime transport specifically, clearly this is vital due to the reliance on this mode of transport for many island and rural communities, as well as for the ports and shipyards servicing the industry and its logistical importance in terms of the shipping of products. The Scottish Government has also recently published 'A Blue Economy Vision for Scotland' (March 2022)[1], which encompasses, amongst others, the maritime sector and which sets out the long-term ambition for Scotland's blue economy to 2045.

Domestic and international shipping make significant contributions to Scotland's transport related greenhouse gas (GHG) emissions. Transport Scotland collates and reports on statistics relating to transport in Scotland including air pollutants and GHG emissions (in this case carbon dioxide (CO_2), methane and nitrogen oxides (NO_X)). The most recent report[2] highlights that 35.58%, which equates to 14.81 $MtCO_2e$, of Scotland's net GHG emissions in 2018 were attributed to transport, with shipping emissions accounting for 2.3 $MtCO_2e$ (15.5% of transport emissions). This can be further broken down to domestic shipping and international shipping, which account for 2 $MtCO_2e$ and 0.34 $MtCO_2e$ respectively[3]. Clearly, reducing these will make a positive impact on the strategic net zero objectives set out in the Programme for Government[4].

1.2 Study Aims and Objectives

It is within this context that this study has been undertaken, the overall aim of which was to map the academic R&D strengths and company profiles in Scotland to decarbonise maritime transport. This mapping of Scotland will, in turn, dovetail with the existing work and key UK partners like the National Shipbuilding Office, BEIS and MoD, resulting in a detailed knowledge of potential project partners, funders and the concept of collaborative R&D projects or R&D calls to establish the viability of further activity.

Specific project objectives were as follows:

- Identify and benchmark Scotland's capability against global trends in decarbonising maritime transportation (what is happening where)
    - Identify the barriers to growth in decarbonisation of maritime sector

[1] https://www.gov.scot/publications/blue-economy-vision-scotland/
[2] Scottish Transport Statistics No. 39: 2020 Edition
[3] Carbon Account for Transport, No.12: 2020 Edition
[4] See https://www.gov.scot/publications/scotlands-national-strategy-economic-transformation/

    - Identify the opportunities in decarbonising maritime transport as well as considering (but not limited to):
        - Offshore wind service vessels
        - Aquaculture service vessels
        - Oil and gas services vessels
- Identify Scottish companies and universities in the maritime sector that have potential to contribute to decarbonising the sector.
    - Categorise current operational markets of each organisation (e.g. maritime, oil & gas, defence)
    - Establish a named contact within each company for future contact purposes.
    - Geographical location
- Ascertain current and future R&D and manufacturing capability in each organisation for decarbonising maritime transport.
    - Vessels: design, engineering, manufacturing, maintenance
    - Fuel / energy sources: development, production
    - Propulsion systems: design, engineering, manufacturing , maintenance and recycling
    - Port infrastructure: design, engineering, manufacturing , maintenance, operations and end of life
- Detect and note any appetite to engage in the decarbonisation of maritime sector
- Identify barriers to acceleration of decarbonisation of the maritime sector including challenges faced by Scottish tier 1 suppliers as well as gaps in Scottish capability
- Identify current activity in funding areas e.g. Clean Maritime Demonstration Competition (CMDC), KTN activity, etc.
- SWOT analysis of Scottish capabilities against sustainable maritime opportunities

1.3 Study Scope

This study has considered the decarbonisation of the maritime fleet and of port operations, covering both optimisation of the efficiency of current operations and the implementation of new technologies and systems.

Further, it is recognised that different solutions are expected to be adopted in different sizes and types of vessel, so for this analysis we have categorised the maritime fleet into the following six categories:

- Small ferries and leisure craft
- Large ferries
- Fishing boats
- Inshore service vessels
- Offshore service vessels
- Large cargo vessels

2 Global and National Trends in the Maritime Industry

2.1 Current Position

The international maritime sector is a major contributor to CO_2 emissions. Global emissions from shipping (international, domestic and fishing) were estimated at 1,076 million tonnes in 2018[5]. As shown in the figure below[5], which charts the maritime sector's annual fuel use by vessel type, large carriers dominate fuel consumption and heavy fuel oil (HFO) is the dominant fuel of choice.

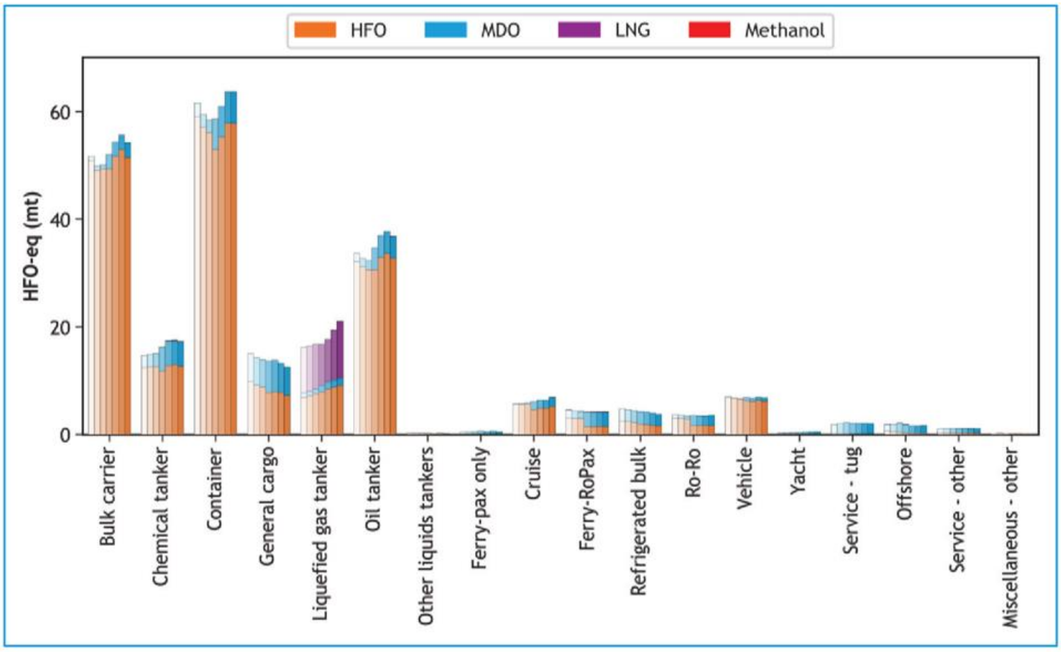

Figure 1: Maritime Sector Emissions by Vessel Type

The use of heavy fuels has been a concern for some time, because of the potential for local pollution in the form of release of particulate matter, unburned hydrocarbons and the emission of nitrogen oxides (NOx) and sulphur oxides (SOx). Although the introduction of industry regulations, such as the Nitrogen Oxide Regulations[6] and the Global Sulphur Cap[7], has reduced local pollution, the same attention has not been devoted to reducing CO_2 emission, which result from burning of hydrocarbon fuels.

Many 'greener' options have been proposed, including fuels and propulsion systems. In the sections that follow we introduce the main drivers that are encouraging the industry to consider greener options, followed by an introduction to the leading technology options and concluding with some of the barriers that will need to be overcome to facilitate the adoption of these technologies.

It should be noted that our analysis, as far as possible, encompasses opportunities that are equally applicable to the defence sector. It is our understanding that naval operations, both shoreside and

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5 Fourth IMO Greenhouse Gas Study, International Maritime Organisation, 2020

6 Implemented by the International Maritime Organisation – see https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx

7 Implemented by the International Maritime Organisation – see https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/2020%20sulphur%20limit%20FAQ%202019.pdf

vessels, will adopt decarbonisation measures developed for the commercial sector (although militarised as required).

2.2 Market Drivers and Trends

2.2.1 Key Drivers of Change

2.2.1.1 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 ships. 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[8] to reduce emissions of greenhouse gases from shipping by at least 50% by 2050 compared to 2008. The IMO has set concrete targets for the reduction of GHGs for 2030 and 2050 with a proposed timeline, to 2027, for the initial actions and measures shown below:

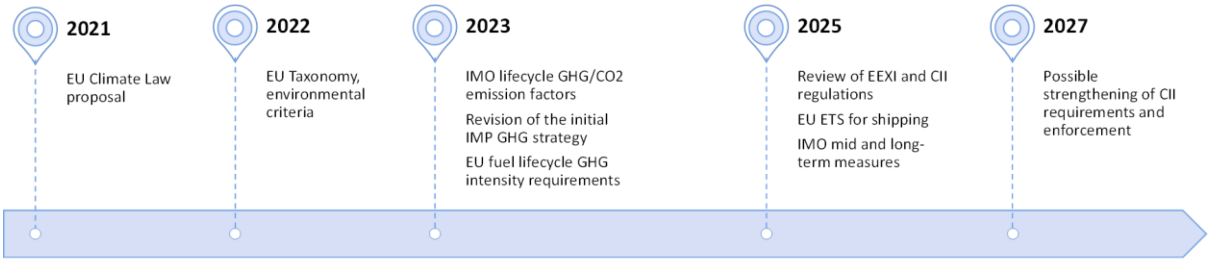

Figure 2: Timeline for the IMO Greenhouse Gas Strategy (Initial Actions and Measures)

The strategy covers cargo, roll-on/roll-off passenger and cruise vessels above 5,000 gross tonnes and trading internationally. And 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.

These are on top of 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 CO_2 released to the atmosphere per cargo tonne per mile.

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8 Initial IMO GHG Strategy, International Maritime Organisation, 2018

The EEXI and the CII entered into force very recently (1st November 2022). These measures require owners of older vessels to calculate and report their carbon emissions. The CCII, 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 different classes of vessel of various sizes. Amongst other factors, the calculations take account of the carbon intensity (CI) of 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 emission with the following high level objectives having been specified[9].

- By 2030, the initial IMO GHG strategy objective of a 40% reduction of CO_2 emissions per transport work compared to 2008 as an average across international shipping will be in place
- By 2050 the IMO initial GHG Strategy objective of 50% reduction in the total annual GHG emissions and 70% reduction of CO_2 emissions per transport work compared to 2008 will be in place. At this point companies should also be pursuing efforts towards phasing them out as part of a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals.

At this stage, however, the actions and measures that will be required to achieve these objectives have not been defined.

2.2.1.2 The Clydebank Declaration

At COP26 twenty-four countries signed the Clydebank Declaration[10] 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 a 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[11].

2.2.1.3 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. These include, for example:

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9 https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

10 https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors#signatories

11 Annual Progress Report on Green Shipping Corridors, 2022, The Getting to Zero Coalition and the Global Maritime Forum, November 2022

Scotland

In its Climate Change Plan[12], the Scottish Government has committed to reduce transport emissions by 41% in 2032, compared to emissions in 2012. The maritime sector contributes 15.5% 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[13] and the Clean Maritime Plan[14] has made commitments to reduce emissions from international and domestic shipping. The vision set in the strategy was 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 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[15] 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[16], 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[17].

Rest of the World

Some other examples of national legislative programmes / targets include:

- China setting a target to be carbon-neutral by 2060[18]
- The US aiming to reduce GHG emissions by 50% by 2030 compared to 2005 levels[19]

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12 Update to the Climate Change Plan 2018 – 2032, Scottish Government, December 2020
13 National Shipbuilding Strategy – Refresh, National Shipbuilding Office, March 2022
14 Clean Maritime Plan, UK Department for Transport, July 2019
15 EU Emissions Trading System, see https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
16 A European Green Deal, see https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
17 Port City Sustainability: A Review of Its Research Trends, Sustainability 2020, 12(20), P8355
18 China aims to cut its net carbon-dioxide emissions to zero by 2060, The Economist, September 2020
19 US Government Sets Target to Reduce Emissions 50-52% by 2030, World Resources Institute, September 2022

- Japan and Canada aiming to reduce GHG emissions by 40–45% by 2030 compared to 2005 levels[20]

2.2.1.4 Market Dynamics

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[21].

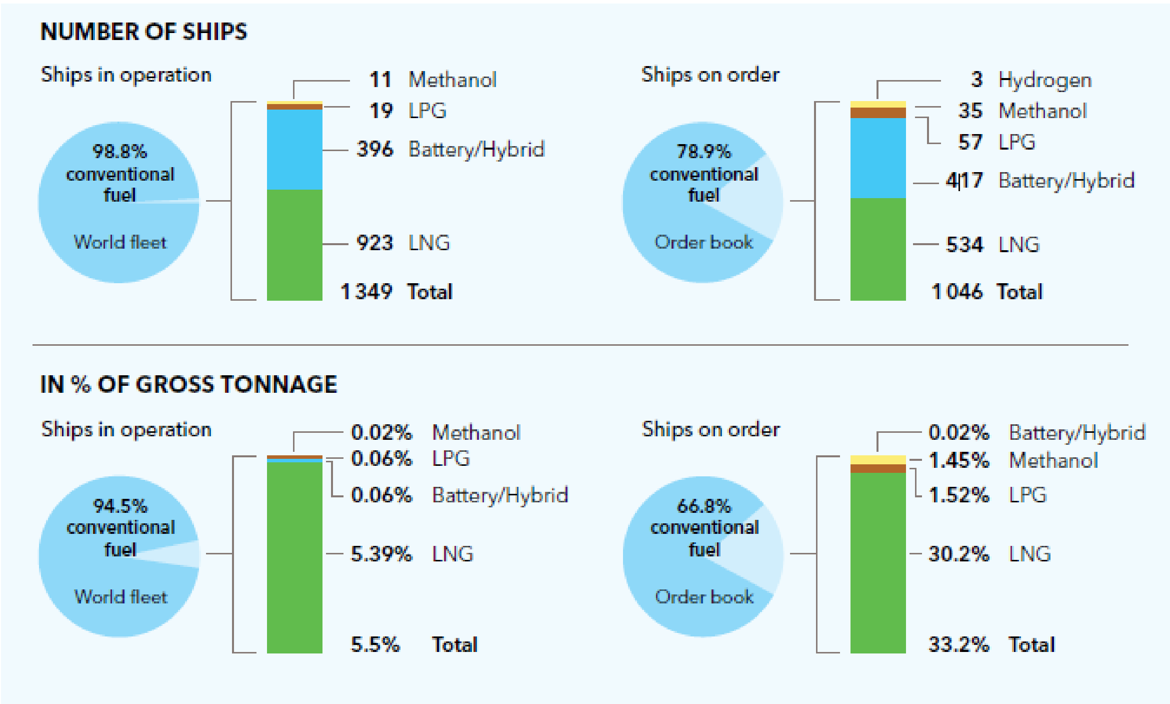

Figure 3: Trends in New Ship Fuel Types

20 Net-Zero Emissions by 2050, Government of Canada, see https://www.canada.ca /en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html and Japan Commits to Cut Climate Emissions 46-50 Percent by 2030, Natural Resources Defense Council, see https://www.nrdc.org/experts/jake-schmidt/japan-commits-cut-climate-emissions-46-50-percent-2030#:~:text=Japan%20Commits%20 to %20Cut%20Climate%20Emissions%2046%2D50%20Percent%20by%202030,-April%2022%2C%202021&text=Prime%20Minister%20Suga%20announced%20that,percent%20compared%20to%202005%20levels)

21 Maritime Forecast to 2050: Energy Transition Outlook 2022, DNV

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 as low carbon solutions.

Of course, the adoption of low /zero carbon solutions is critically dependent on innovation.

2.2.1.5 Support for Innovation

There are several programmes supporting innovation in decarbonisation solutions for the maritime sector. Selected examples of these include:

Scotland

There are a number of funding options operated by Scottish Enterprise and other public sector organisations. These include a combination of open funding programmes (e.g. SMART:SCOTLAND, that funds feasibility studies up to a value of £100,000 and Regional Selective Assistance) and funds/calls that are, typically, thematic, open for a fixed amount of time and may be competitive. The Zero Emission Mobility Innovation Fund, is currently the most relevant of these for maritime decarbonisation R&D projects.

United Kingdom

The UK Shipping Office for Reducing Emissions (UK SHORE) was established in 2022, with a budget of £206 million, to drive investment in innovation in the sector and revitalise maritime infrastructure. It has announced a package of measures including:

- Funding innovation projects through the recent second and third rounds of the Clean Maritime Demonstration Competition (CMDC)
- a £77 million Zero Emission Vessel and Infrastructure (ZEVI) competition and a £7.4 million flagship UK National Clean Maritime research hub[22]
- Exploring the development of green shipping corridors
- Investigating green shipbuilding skills
- Supporting the greening of intra-UK ferry routes through a zero emissions ferries programme
- Providing grant schemes for early research projects to be delivered by universities.

As of February 2023, a total of 55 projects[23], involving around 300 organisations across the UK, have been funded via CMDC. The aim of the CMDC is to support demonstrations and technology trials of clean maritime vessels and infrastructure. Some examples of Scottish participants in CMDC Round 1 and Round 2 projects include the University of Strathclyde, Caledonian Maritime Assets Ltd (CMAL), RAB Microfluidics, University of St Andrews, Logan Energy, Rosyth Royal Dockyard, Shetland Islands Council, Aberdeen Harbour, Aquatera, EMEC, SSE Renewables and Malin Marine Consultants.

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22 See https://www.ukri.org/news/minister-announces-investments-to-decarbonise-maritime-sector/

23 Multi-year clean maritime demonstration competition, see https://www.gov.uk/government/publications/clean-maritime-demonstration-competition-cmdc

In addition, there are plans[24] for a Centre for Smart Shipping (CSmart) that will provide a coordinating function in new and emerging technologies and will enable innovation hubs to support the development of regional clusters of expertise across the UK.

European Union

The European Union has supported a wide range of maritime decarbonisation projects, with a project portfolio in Framework 7 and Horizon 2020 valued at almost €1 billion[25]. Support is continued in Horizon Europe in, for example, the Climate, Energy and Mobility Work Programme[26].

There are some notable examples of Scottish participation in EU projects, including HyDIME (Ferguson Marine, Orkney Islands Council and EMEC), HySeas III (University of St Andrews, CMAL and Orkney Islands Council), and HIMET (EMEC, Aquatera, Orkney Islands Council)[27].

2.3 Decarbonisation of Maritime Vessels - Technology Trends

There are 3 overarching options to decarbonise maritime vessels:

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

The various decarbonisation technologies proposed within the three options are introduced in the sections that follow.

2.3.1 Optimising Efficiency

Improving the fuel efficiency of vessels is a well-established method for optimising operational costs of maritime transport. It is also relevant, therefore, for the reduction of CO_2 emissions. Several different options have been demonstrated, as highlighted in the following figure. Some of these (e.g. slow steaming, non-friction coating and anti-fouling technologies) are well established while others, such as autonomous vessel operation and the use of supplementary power options, are emerging.

24 UK Shipping Office for Reducing Emissions, see https://www.gov.uk/government/speeches/uk-shipping-office-for-reducing-emissions

25 The Role of Research and Innovation in Europe for the Decarbonisation of Waterborne Transport, Monica Grosso et al, Sustainability, 2021, 13, 10447

26 https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2023-2024/wp-8-climate-energy-and-mobility_horizon-2023-2024_en.pdf

27 See https://www.emec.org.uk/projects/ and https://www.hyseas3.eu/

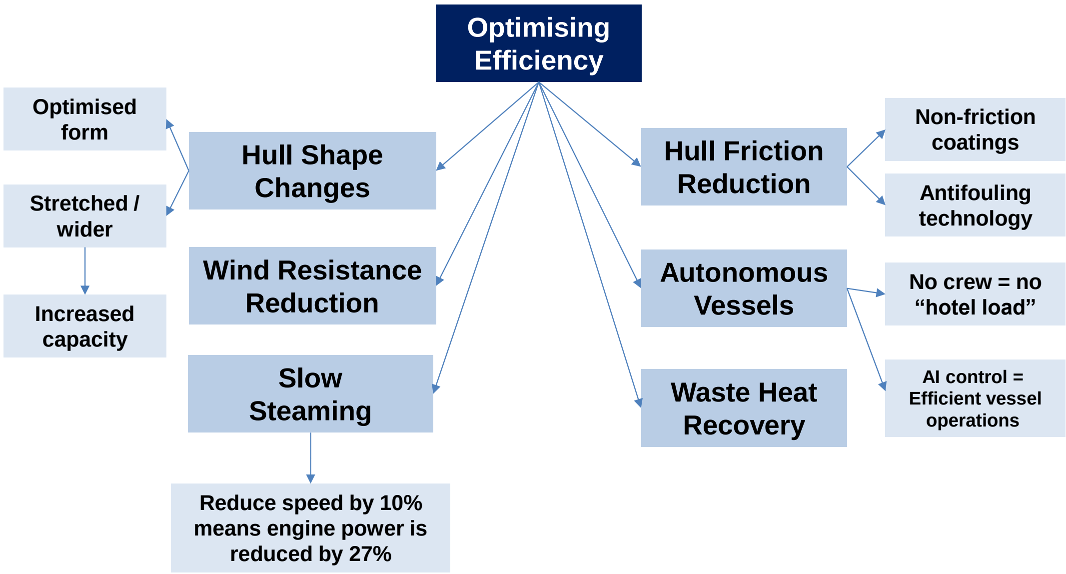

Figure 4: Efficiency Optimisation Options

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

Hull resistance is the primary cause of high fuel consumption due to increased power requirements to overcome water resistance on the hull. As speed increases, hull resistance increases significantly. As a rule of thumb, to reach the top 20% of theoretical hull speed, the fuel consumption increases by 80%. 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 tonne of fuel per hour at 10 knots and two tonnes 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 its 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 installed.

Biofouling has the potential to negatively affect the fuel burn of a ship by increasing hull resistance. Modern coatings may be able to reduce hull fouling to minimal levels but these are not a direct contribution to decarbonisation. 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 benefit.

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 refrigeration plant for food can be removed. With new build, autonomous ships incorporating artificial intelligence (AI) for navigation there will be no requirement for a super structure and 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; vessel stabilisation; 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.

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

2.3.2 Auxiliary Power Systems / Technologies

Additional auxiliary power systems and technologies can be incorporated onto vessels for further decarbonisation benefits. Two main examples of such technologies are wind assisted propulsion and solar-on-ship.

- Wind Assisted Propulsion

  

  Some large ships are being outfitted with a variety of wind auxiliary propulsion systems. The wind auxiliary ship has 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 similar to traditional sailing ships, such as masts and sails 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. This is an emerging solution, which has currently been implemented on around 20 commercial ships, with the potential to be applied to 40-45% of global fleet.

  There are a number of companies developing wind assisted propulsion technologies including, for example, Smart Green Shipping (Scotland), Yara Marine Technologies (Norway), Wallenius Marine AB (Sweden), Mitsui O.S.K. Lines, Ltd. (Japan) and Windship Technology Ltd (UK).

- 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, estimated at around 0.5% - 2% of auxiliary engine fuel consumption[28].

  To date, there are a limited number of examples of this technology 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.

Again, the implementation of these technologies would also be in addition to energy efficiency measures, such as the use of novel materials to reduce vessel weight and hull coatings to reduce friction.

2.3.3 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 a 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 emissions 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)

2.3.3.1 Biofuels

Biofuels are seen as a 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 (ICE). Nonetheless, this is a highly attractive option for owners with limited funds for any significant retrofitting 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

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[28] https://glomeep.imo.org/technology/solar-panels/

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 crops for fuels competing against food production.

2.3.3.2 Liquid Natural Gas

Liquified natural gas (LNG) has replaced heavy fuels and diesels for some marine applications. LNG is formed when natural gas is cooled to -162ºC, 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 the 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.

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

2.3.3.3 Hydrogen

Hydrogen is considered as a viable option in the transition away from heavy fuel oils. Hydrogen emits zero CO_2, zero SOx and only negligible amounts of 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 (either as a dual fuel or on its own). 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[29]. 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[30]. The vessels will utilise hydrogen combustion technology but can run on dual fuel (hydrogen / diesel). CMB.TECH is aiming to

29 https://www.man-es.com/discover/designing-the-engines-of-the-future
30 https://cmb.tech/news/windcat-offshore-and-damen-shipyards-develop-future-proof-csovs

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[31] although it is likely that fuel cells will only 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. It 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 and to support the commercialisation of these technologies, marine industry standards, certification and regulations also need to be developed in a timely manner.

"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[32].

2.3.3.4 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 it contains no carbon or sulphur atoms, ammonia emits zero CO_2 and zero SOx. There are 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.

"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[33].

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31 For example, see https://www.ballard.com/docs/default-source/default-document-library/marine-informational-paper-final.pdf?sfvrsn=c1cec080_2

32 Hydrogen Action Plan, Scottish Government, December 2022

33 'Engineering the Future Two-Stroke Green Ammonia Engine', MAN Energy Solutions Technical Paper, November 2019

Wärtsilä has initiated combustion trials using ammonia, which will help the company to prepare for its use 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[34].

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

Production of hydrogen and ammonia fuels is outside the control of the marine industry however the marine industry must follow the global trends and fuel availability. At this time the supply chain would be unable to meet the consumption demands of even a very small number of cargo vessels whilst continuing to meet the demands from existing consumers of these gases.

2.3.3.5 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[35] 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, on the downside, it 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[36]. 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 it 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)[37] and Stena (Sweden)[38] 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.

Ultimately, the methanol to be used will be "green", i.e. biomethanol or methanol produced using green hydrogen and CO_2 from carbon capture, utilisation and storage systems as feedstocks. This is a synthetic fuel opportunity that mirrors the development of synthetic aviation fuel (SAF) in the aerospace sector, although its adoption in the maritime sector is moving more slowly than the adoption of SAF.

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34 https://www.wartsila.com/media/news/30-06-2020-world-s-first-full-scale-ammonia-engine-test---an-important-step-towards-carbon-free-shipping-2737809

35 Decarbonising Maritime Transport, OECD, 2018

36 https://lloydslist.maritimeintelligence.informa.com/LL1138730/Fuelling-a-low-carbon-future-with-methanol-as-a-marine-fuel accessed 23 Feb 2022

37 https://www.maersk.com/sustainability

38 https://www.stenaline.com/affordable-and-clean-energy/

2.3.3.6 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 gensets, 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).

"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 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[39]. 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, the whole "well to wake" emission of a battery electric vessel is 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, overall, the design is as near zero as can be achieved. Unfortunately, the current battery technology on board these vessels has caused a number of issues and reports of battery fires[40], power runaway and premature battery ageing are well documented. Despite this there is still a potential for electric, plug in designs for short routes with emerging opportunities in service vessels for offshore wind, where remote charging is set-up.

This is an area of developing activity in Scotland. CMAL is pursuing battery electric powered ferries in its recently announced small vessel replacement programme[41].

In addition, a new joint venture organisation has been created that 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.

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39 https://www.orkney.gov.uk/OIC-News/OIC-Welcomes-Contract-Award-for-Design-of-Hydrogen-Fuel-Cell-Ferry.htm accessed 23rd Feb 2022

40 https://maritime-executive.com/article/newly-built-hybrid-passenger-vessel-suffers-battery-fire-under-way

41 https://www.cmassets.co.uk/project/svrp/

The organisation is looking at a number of locations around the UK but is particularly interested in locations in Scotland due to their proximity to the target markets (offshore wind in the first instance) and the access to renewable energy sources on and offshore. This would create significant opportunities across the supply chain.

2.3.3.7 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.

"…there are already concept designs for shipping."

The technology will, however, need significant onshore operation and demonstration to ensure that sufficient knowledge, experience and data is obtained 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 misuse, must be addressed.

2.3.3.8 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 5: TRL Ranking of Key Technologies (2020)[42]

2.4 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[5] 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:

[42] Techno-economic assessment of zero carbon fuels, Lloyd's Register and UMAS, March 2020

- An analysis for the Department of Transport[43] forecast expected international and domestic fuel use for zero operational GHG emissions in 2050 as follows:

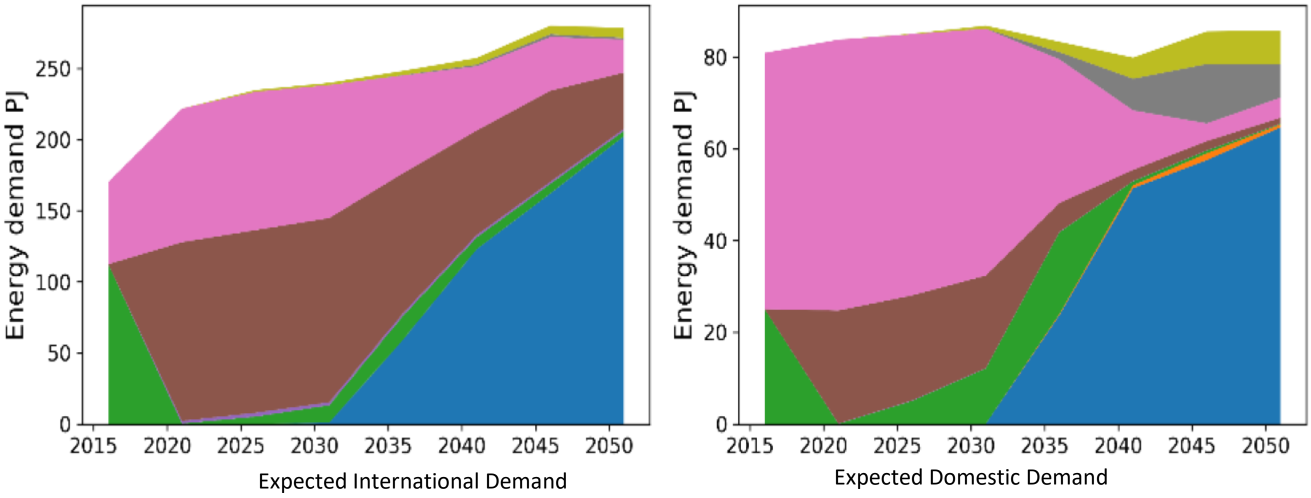
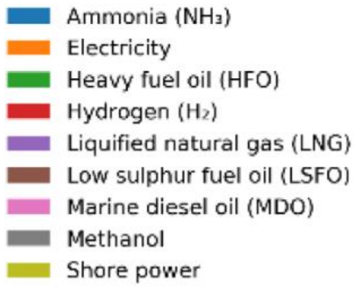


Figure 6: Expected International and Domestic 2050 Fuel Use for Zero Operational GHG Emissions

The key for figures 6 and 7 is shown opposite.



The main observations from this analysis are:

- Major UK and international market demand 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[44] also forecasts the global maritime energy demand and fuel mix over the period to 2050, as shown in the following figure.

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43 Reducing the maritime sector's contribution to climate change and air pollution, UMAS, E4Tech and Frontier Economics for the Department of Transport, July 2019

44 Ports: Green gateways to Europe - 10 Transitions to turn ports into decarbonization hubs, DNV GL, 2020

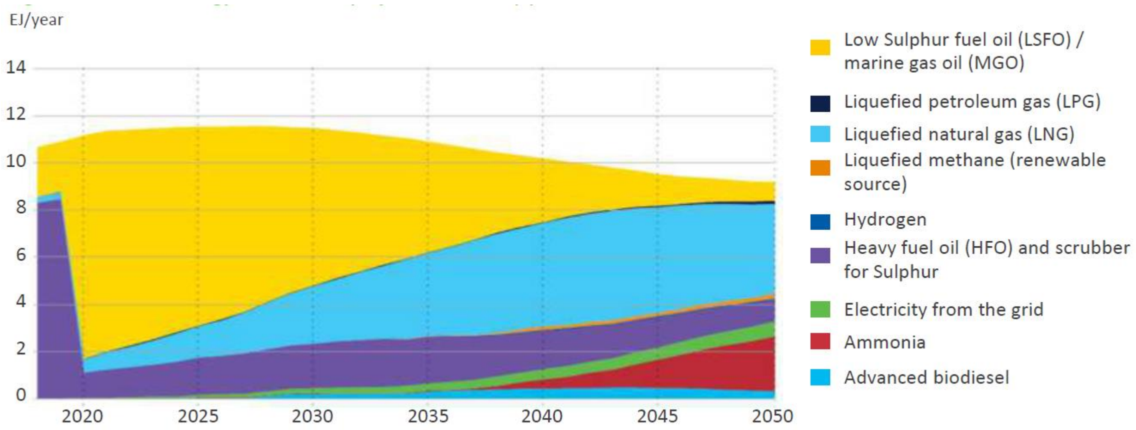


Figure 7: Forecast of the Global Maritime Energy Demand and Fuel Mix to 2050

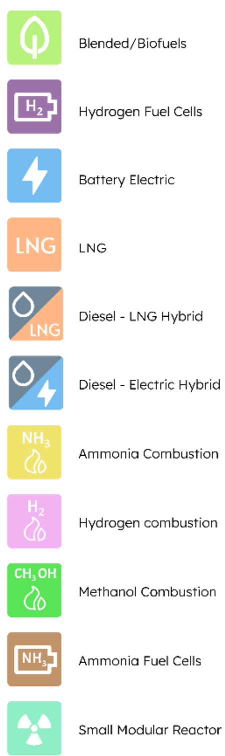
This forecast, again, shows a significant market share for ammonia, a tangible demand for electric power and a large residual demand for oil and gas fuels.

In a similar way to the Figure 6 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 in the following section.

2.5 Analysis of Alternative Fuels and Propulsion Systems by Vessel Type

As highlighted, 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 about the alternative fuels and propulsion systems that will be used and that several options are still under development (as shown in Figure 5). 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, fishing boats and large cargo vessels, to support our analysis of Scottish capability and development opportunities for Scotland.



The most likely alternative fuel and propulsion systems for the different vessel types, based on our analysis, are presented in the following figure and 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.

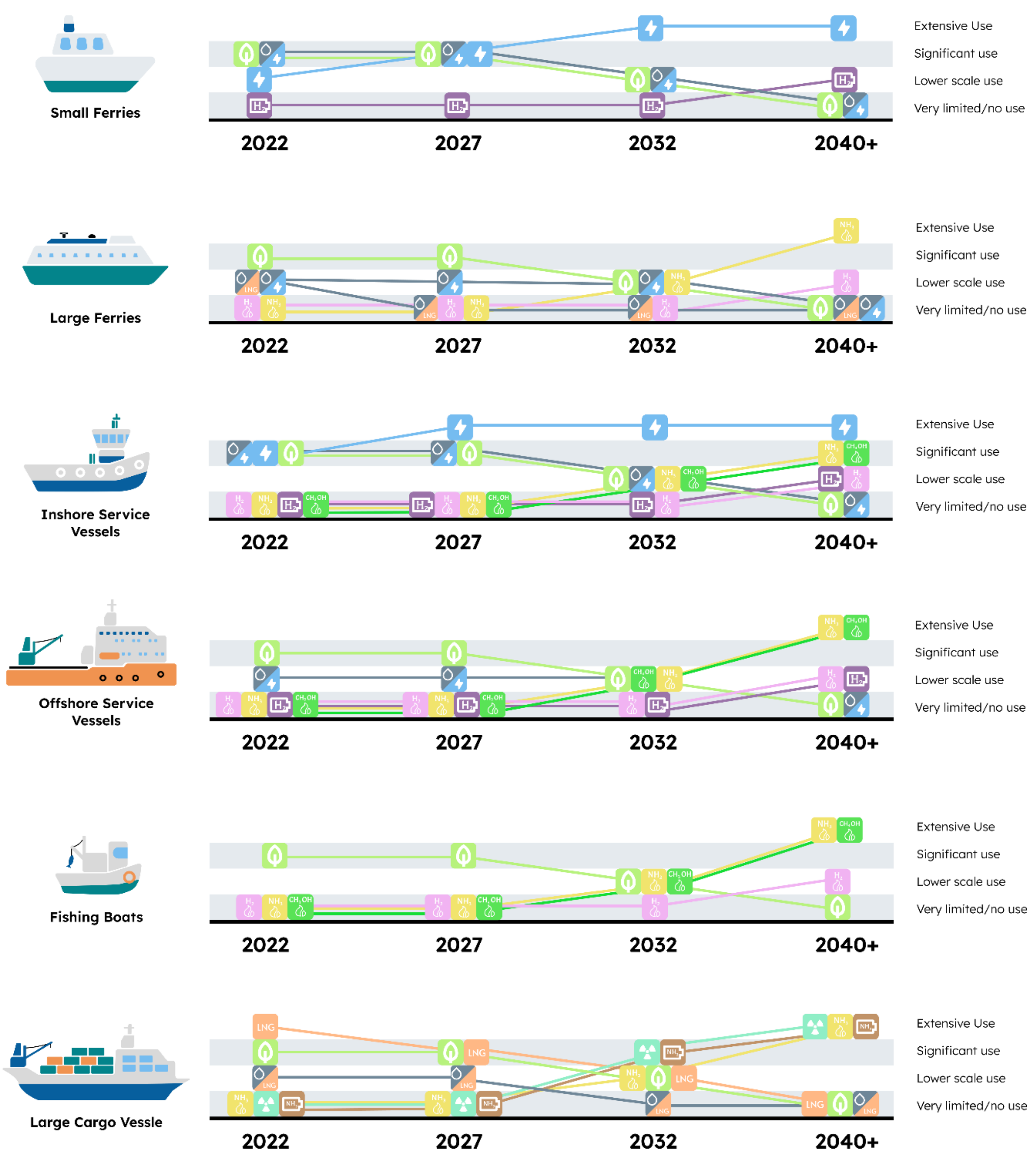


Figure 8: Expected Alternative Fuel and Propulsion Options by Vessel Type

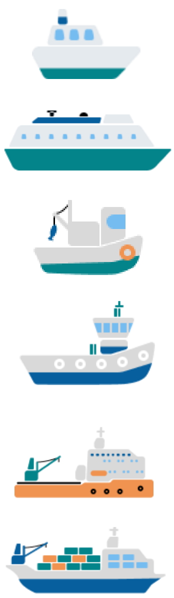
For each vessel type, fuels listed above that are not expected to be used are not shown.

However, conventional marine fuels will continue to be used over the period to 2050 (as shown in Figure 6 and Figure 7) due to existing investments in ships and fuelling infrastructure. In the longer term, the

2022 2027 2032 2040+

Figure 8 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 / propulsion system will eventually be selected for the different segments of the maritime sector. This is highlighted by DNV in a recent report[46] 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. These are summarised in the following figure:



Type	Ongoing Action	Short Term (next five years)	Long Term (10 - 15 years)
Small Ferry	Optimise efficiency	Diesel - electric hybrid / battery electric	Battery Electric
Large Ferry	Optimise efficiency	Biofuels or Diesel - electric hybrid	Ammonia combustion
Fishing Boat	Optimise efficiency	Biofuels	Ammonia or methanol combustion
Inshore Service Vessel	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Battery electric / Ammonia or methanol combustion
Offshore Service Vessel	Optimise efficiency	Biofuels / Electric / Diesel - electric hybrid	Electric / Ammonia or methanol combustion
Large Cargo Vessel	Optimise efficiency	Biofuels / LNG	Ammonia combustion or fuel cell / SMR

Figure 9: 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 opportunities for Scotland, presented in Section 5 of this report.

45 The scale of investment needed to decarbonize international shipping, Global Maritime Forum, see https://www.globalmaritimeforum.org/news/the-scale-of-investment-needed-to-decarbonize-international-shipping

46 https://www.dnv.com/Publications/seafarer-training-and-skills-for-decarbonized-shipping-235124

2.6 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.

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 provide shore to ship power facilities allowing ships to turn off auxiliary engines while berthed, thereby 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 electricity required for air conditioning; and heat energy required for space heating, showers and pools.

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

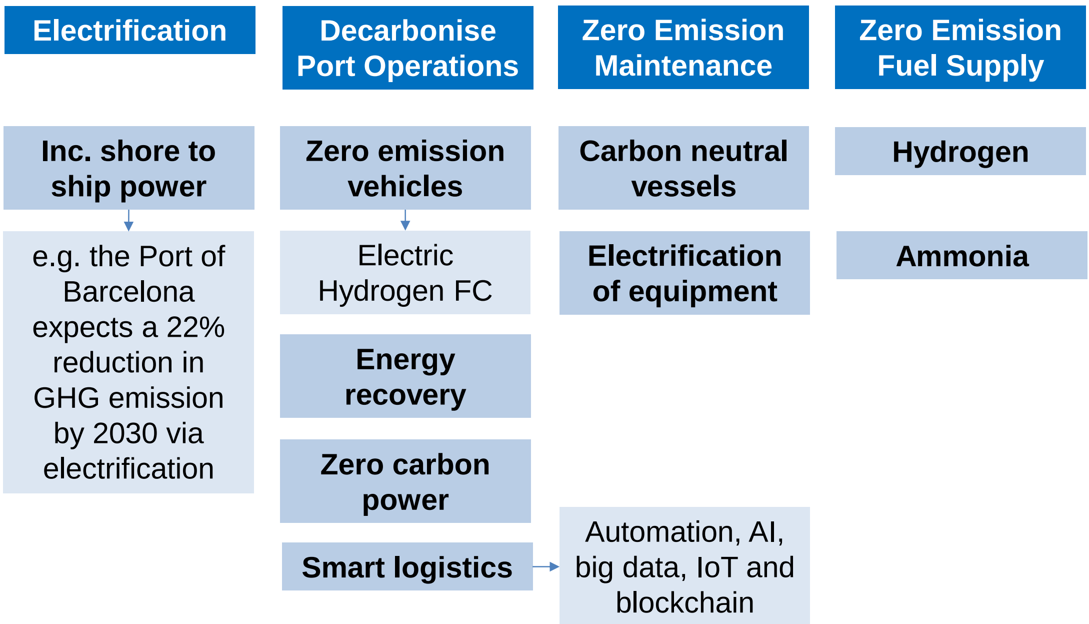


Figure 10:Examples of Decarbonisation Options for Ports

The Port of Rotterdam is an example of how some ports are taking steps to reduce their carbon footprint and contribute to reducing emissions within the shipping industry. The Port Authority has committed to reducing its carbon emissions 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"[47]

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.

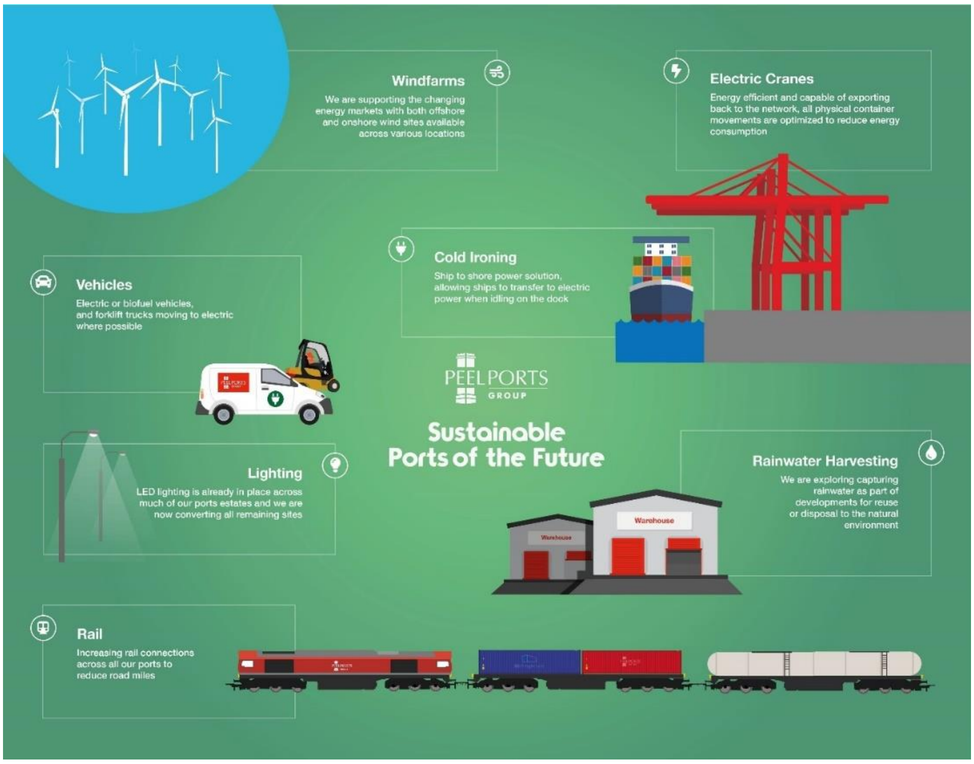


Figure 11: Peel Port Infographic on Port of the Future[48]

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,

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[47] Allard Castelein, CEO Port of Rotterdam Authority, Press Release June 2022, www.portofrotterdam.com

[48] www.peelports.com

hydrogen are involved. As a result, ports are focusing on decarbonising their operations until there is clarity on future fuel demands.

2.7 Market Barriers

Although the maritime sector is taking steps to decarbonise and, as described in previous sections, there are a number of potential opportunities for Scottish companies, is it acknowledged[13] that progress has been slow, and that more commitment and investment is required from the sector to enable large scale emission reduction to be achieved.

A number of barriers to decarbonisation have been identified, based on desk research and stakeholder engagement. These include:

- The need for international agreement on which low/no carbon fuels and propulsion systems should be developed for which applications (vessel types). Until this happens it is unlikely that anything of any substance will change and this is considered a massive challenge to address. If there is no clarity on the optimum net zero power solutions, how can opportunities be exploited as they are not fully defined?
- As a general rule, the marine industry is very conservative and slow to change. There is a lot of inertia and companies really only make changes when they are forced to do so through, for example, regulatory changes. There is also a strong focus on finances and on maximising 'the bottom line'.
- The high cost and long operating life (25 to 30 years) of existing assets. Vessel owners / operators want a return on their investment and value for money
- There is little incentive, currently, for ship owners / operators to proactively invest in fuel efficiencies or emission abatement. Many companies will wait until they have no option but to change, thus maximising the return on investment from their existing fleet.
- The lack of funding for investment in new, low carbon or zero emission vessels or retrofitting technologies onto existing vessels
- It can be very difficult to introduce new technology into the marine industry due to the requirement for it to be certified. The development of standards and certification is lagging behind technology development.
- Linked to this are the very long lead times in the marine industry. For a large ship, this can run into years from initial order to receipt of the vessel. Companies ordering new ships now will not commit to including new technologies in the build until they have been certified to appropriate standards. This can significantly extend the length of time until technology developers start to see any real commercial traction.
- There are challenges associated with the storage of alternative fuels on board vessels where space is a premium and where safety considerations are paramount. Both ammonia and hydrogen would need to be compressed or stored as a liquid and, in both cases, significantly more fuel would be required to achieve the same power outputs from an ammonia and/or hydrogen engine compared to the diesel equivalent. This would result in a larger amount of vessel space having to be allocated to fuel storage rather than to cargo, passengers, facilities, etc. (depending on the type of vessel), which would impact on its commercial operation. In addition, compressing or liquefying ammonia or hydrogen requires energy, which adds further costs on top of those already discussed.

- Ship operators have concerns about the potential lack of fuelling infrastructure, which will inhibit investment in zero emission vessels, while ports are unlikely to invest in infrastructure without demonstrated demand.
- Safety issues, potential liabilities and industry / public acceptance related to the use of less well understood and, potentially, riskier alternative fuels such as ammonia (toxicity) and hydrogen (explosion risk)
- Lack of specific international legislation, regulation and standards for the use of alternative fuels, particularly ammonia and hydrogen, and propulsion systems. Companies across the supply chain have to meet different standards and legislative requirements depending on their particular activities, e.g. equipment supplier, ship builder or ship owner / operator. The situation is being further complicated by the uncertainty around how proposed, new legislation from the IMO, focused on reducing emissions from the sector, will be implemented in reality and, therefore, what the implications of that will be for companies
- Issues around the space and cost requirements to operate dual fuel systems and the expected need for vessel recertification for alternative fuel use.
  For technologies, such as electric propulsion (battery or fuel cell), the power systems themselves tend to be sealed 'black box' systems that cannot be repaired if something goes wrong at sea. The associated demand by accreditation bodies for a back-up system to ensure "return to port" is achievable imposes additional costs and complexity.

We have used the analysis detailed in this section of the report as the basis for our assessment of Scottish capability detailed in Section 3.3.

3 Supply Chain Mapping

The objective of the supply chain mapping activity is to illustrate the strengths and weaknesses (i.e., gaps) in the Scottish maritime industry-base regarding its ability to achieve net zero.

In devising the supply chain structure (see section 3.1), research was conducted to define the industry activities that will result in the reduction of carbon emissions. This includes, for example, designing and manufacturing vessels, developing hydrogen fuel cells, owning and operating vessels, providing ship management services, maintaining and repairing vessels, providing port services, converting / re-purposing vessels, and many more activities shown in Figure 12 overleaf.

Companies were assessed against a set of criteria which determined their inclusion in the database that accompanies this report. The criteria used were:

- Company must be active in the maritime market (either primary or secondary target market)
- Company must have an active Scottish presence (e.g., Companies House registration)
- Company must offer activities that can directly contribute to a reduction in carbon emissions (e.g., developing new/novel technologies and fuels, providing designing & manufacturing services, owning/operating vessels, etc.)

Companies were further assessed against a framework for determining their strength to support decarbonisation. This is discussed further in section 4.

Note: *The supply chain mapping activity primarily consisted of desk-based research. As such, we were constrained by the availability and accuracy of information provided online via, for example, company websites and Companies House.*

3.1 Supply Chain Structure

The supply chain for maritime decarbonisation is illustrated below. It is divided into primary and secondary activities.

A company can be categorised across multiple primary (top tier) and/or secondary activities (lower/middle tier). In general, a company will not likely exceed two or three primary activities but may be active across several secondary activities.

Companies that provide support services have also been categorised, these specifically include providers of training, advisory / professional services where, for example, strategic advisory is the core offering as opposed to engineering, and skills / competence accreditation.

The database of companies mapped by capabilities has been provided as a standalone document.

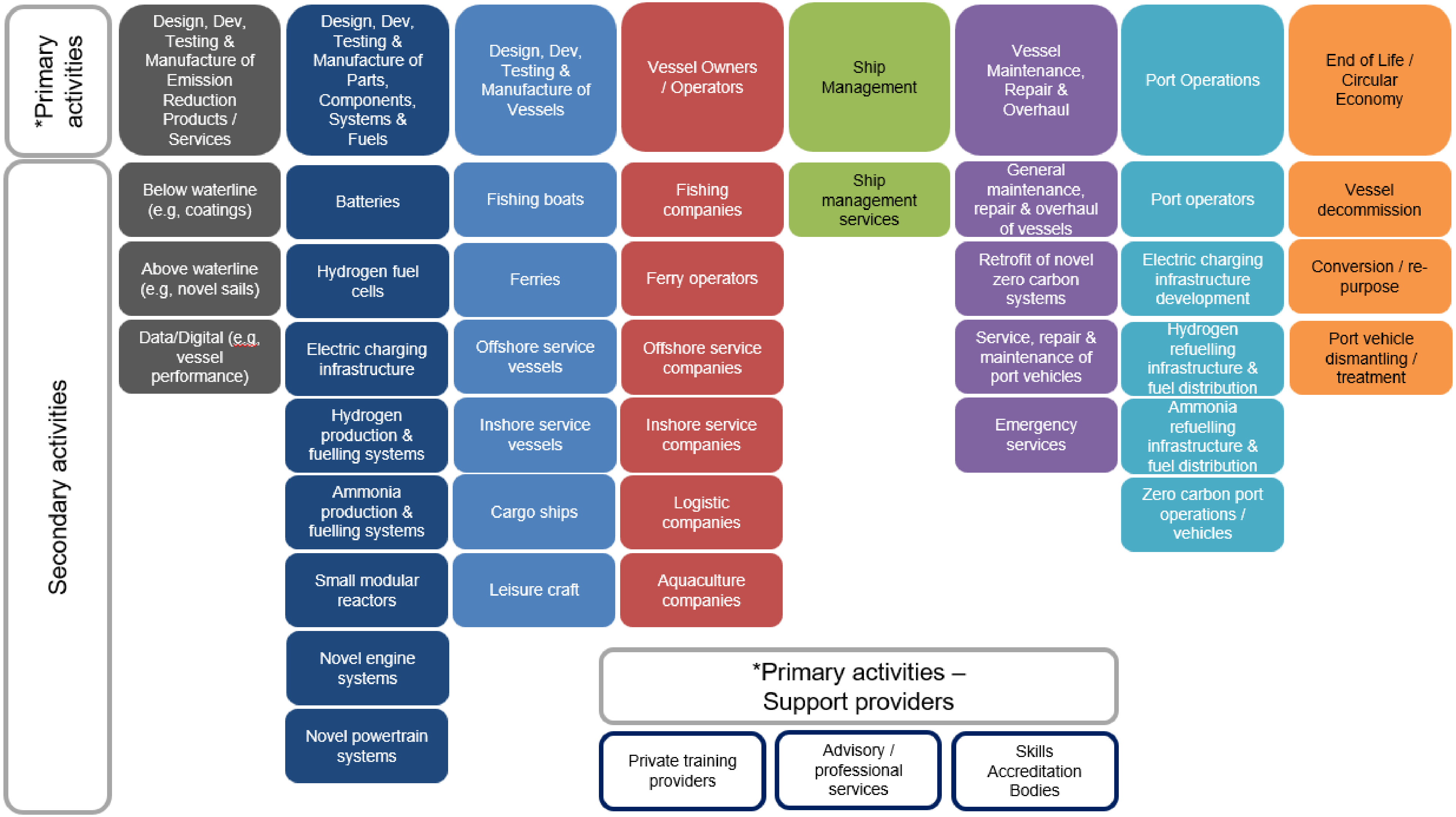

Figure 12: Decarbonising Maritime Supply Chain Structure

3.2 Characterisation of the Scottish Supply Chain

As mentioned above, the supply chain structure has been designed to reflect the Scottish maritime industry base that will directly contribute to the decarbonisation of the sector.

The supply chain consists of almost 200 companies, some of which actively pursue decarbonisation already (e.g., through vessel performance optimisation) and others that do not actively pursue decarbonisation but are considered critical to a reduction in emissions over time (e.g., fishing vessel owners/operators that will adopt decarbonisation technologies).

A breakdown of the supply chain by activities is discussed in the following sections:

3.2.1 Primary Activities

The breakdown of the primary activities of companies included in the database can be summarised as follows:

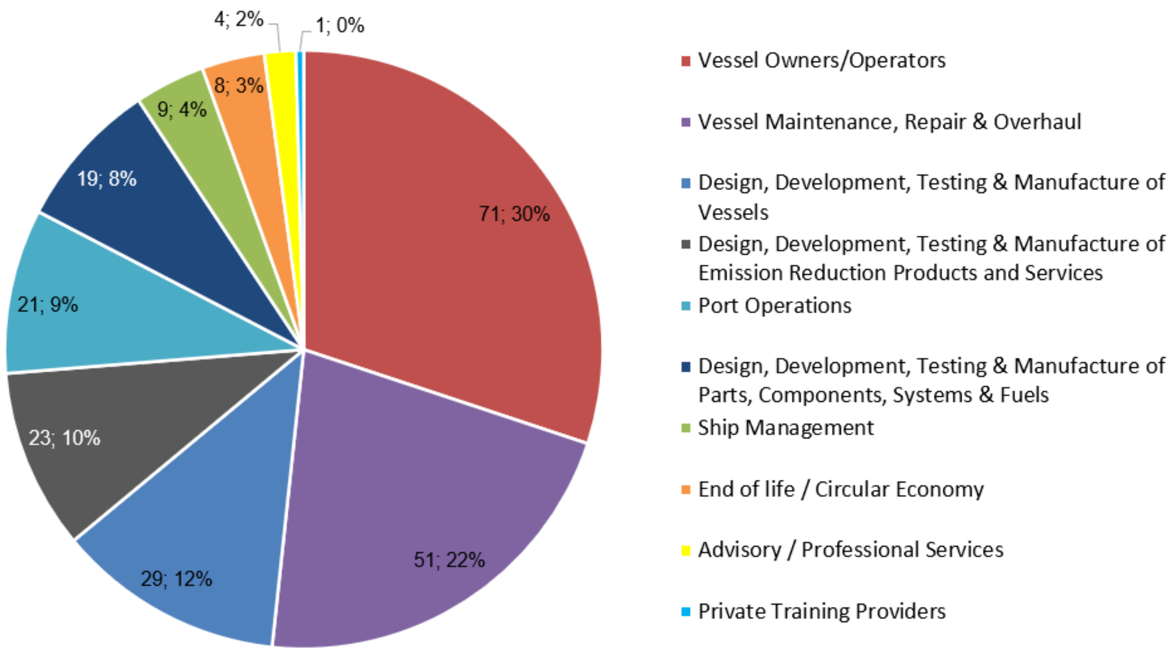

Figure 13: Segmentation by Primary Activity

As shown in the chart above, most companies are vessel owners / operators (30%), comprised largely of fishing companies. Companies engaged in vessel maintenance, repair and overhaul, similarly, represent a fairly significant proportion of the industry base (21%). The relatively low number of Scottish shipbuilding companies, albeit some of these companies are subsidiaries of major, multi-national players, directly influences the number of vessel designers, developers, testers and manufacturers (12%).

It is important to note, that while many vessel owners / operators may not be actively pursuing net zero, e.g., by investing in alternative fuels, they are a crucial component to the decarbonisation of the sector and will require support to ensure their vessels achieve net zero in the proposed timescales.

Similarly, companies engaged in vessel repairs and maintenance must be supported to develop the appropriate skills and capabilities to work with alternative fuels and novel power systems. Ship designers will also be required to explore different design techniques and practices to accommodate low carbon power solutions like hydrogen fuel cells, batteries or other novel powertrain systems; this may involve compromising on hull design, for example. Vessel manufacturers will be required to work with and integrate these new and emerging technologies and systems, which again, will require investment in skills and capabilities and a clear understanding of which fuels and systems work best for the vessel type.

3.2.2 Secondary Activities

A breakdown of the secondary activities of companies included in the database can be summarised as follows:

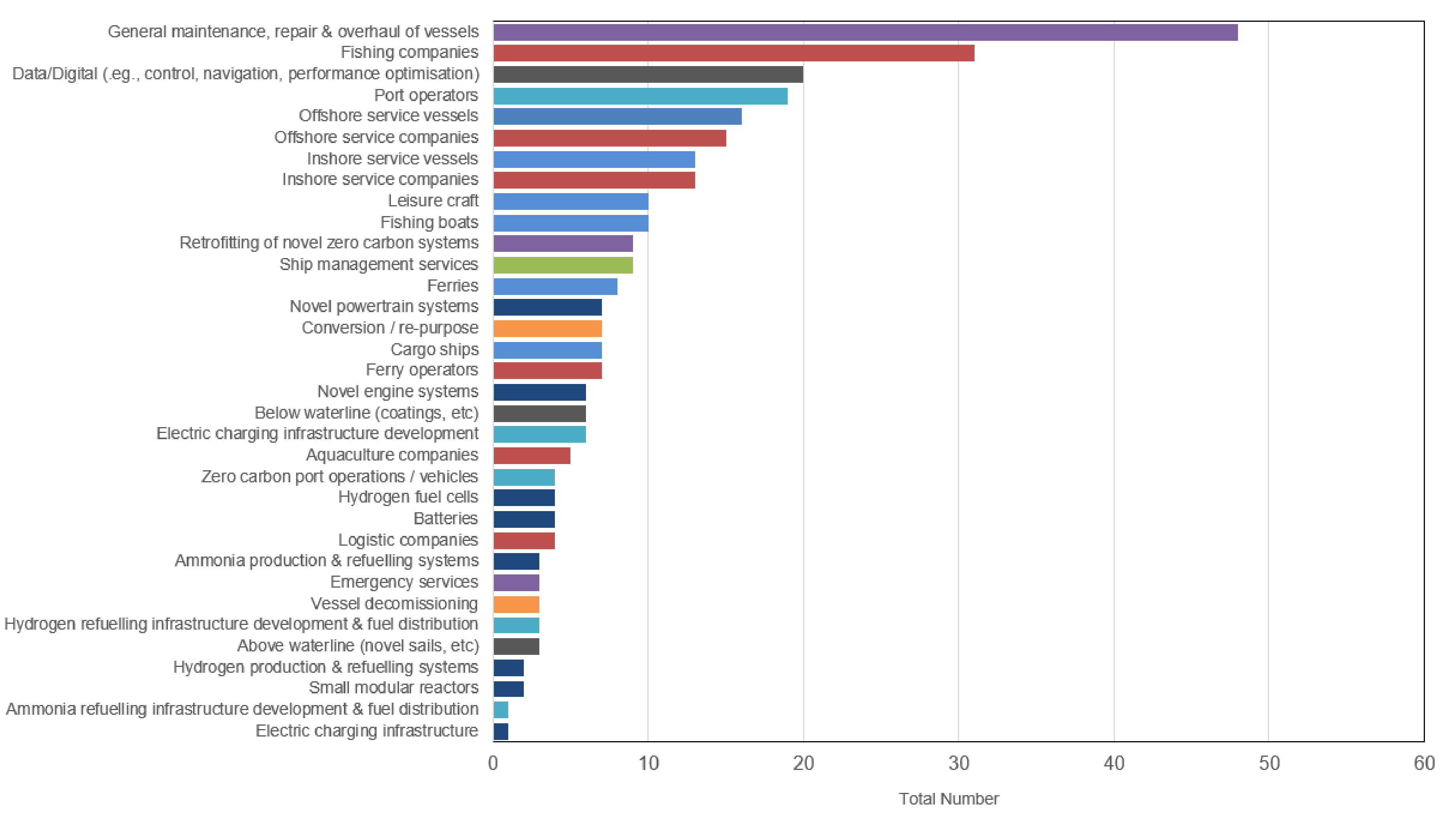

Figure 14: Segmentation by Secondary Activity

Here the colour of each bar corresponds to the primary activities shown in the supply chain structure in section 3.1. For example

- ‘General maintenance, repair & overhaul of vessels’ corresponds with the primary activity ‘Maintenance, Repair & Overhaul of Vessels’
- ‘Fishing companies’ corresponds with the primary activity ‘Vessel Owners / Operators’
- ‘Data/digital’ corresponds with ‘Design, Development, Testing & Manufacture of Emission Reduction Products / Services’
- ‘Cargo ships’ corresponds with ‘Design, Development, Testing & Manufacture of Vessels’
- and so on

The number of companies involved in ‘Data / digital’ activities relating to maritime is important to note. These include, for example, vessel and asset management tools that optimise performance and reduce energy wastage, fuel efficient hull design software, emissions monitoring solutions, artificial intelligence (AI)-enabled data analytics for ship management, and other similar data-enabled navigation and optimisation software solutions. This showcases Scotland’s strengths in data and digital product development and innovation.

3.3 Gap Analysis

Analysis of the supply chain has been conducted to identify gaps in the capabilities required to pursue the decarbonisation options explored in Section 2. This is discussed further below.

3.3.1 Optimising Efficiency

A number of measures can be taken to optimise vessel efficiency to reduce fuel consumption and, therefore, CO_2 emissions, as discussed below.

Hull Shape Changes

There are several companies in Scotland engaged in the design, development, testing and manufacture of vessels. Key players that are expected to contribute to decarbonisation through optimising the hull form/shape are as follows:

- Babcock International
- BAE Systems
- Ferguson Marine
- Houlder Offshore Engineering
- MacDuff Ship Design
- Marine Design International
- Malin Group – awarded CMDC funding to explore optimised designs[49]
- SeaTec
- Tritec Marine

[49] https://malingroup.com/2022/10/13/malin-group-partners-make-the-case-for-a-cleaner-way-to-build/

It is recognised, industry-wide, that commercial shipbuilding has declined in Scotland and vessel build contracts are being awarded to overseas shipyards[50]. While capability in optimised hull design is not considered to be lacking, there is potentially a significant gap in the capability to manufacture vessels with these optimised hull shapes/forms.

Stabilisers

Stabilisers are fins or rotors mounted on vessels below the waterline that emerge laterally from the hull. Their primary purpose is to reduce a ship's roll due to wind or waves but some modern stabilisers (in particular the various types of active fin type stabilisers) also help to improve efficiency and reduce fuel burn[51].

There is one company in Scotland active in this area, namely Kongsberg Maritime Limited based in Dalgety Bay[52]. Information in the public domain does not, however, make it clear whether manufacturing takes place at this site or if it is purely sales and support activities.

Wind Resistance Reduction

This is a design-stage consideration and involves optimising vessel design to, for example, reduce wind load and drag and, therefore, fuel consumption and carbon emissions. The vessel designers and manufacturers mentioned above may deploy design practices to reduce wind resistance.

Slow Steaming

This is a consideration for vessel owners/operators. As a method to reduce fuel consumption and emissions, slow steaming is well-established and will likely form part of a vessel owner/operator's wider efficiency programme/strategy. Examples of energy efficiency strategies/policies that may incorporate slow steaming are as follows:

- J&J Denholm – aims to reduce Group carbon footprint to net zero by 2050[53]
- Northern Marine Group – aims to uphold environmental standards by, e.g., decreasing emissions through efficient energy management[54]

Hull Friction Reduction

Examples of technologies that aim to improve the hydrodynamic flow around the hull and, therefore, aid in reducing fuel consumption and emissions include air lubrication systems and antifouling coatings.

Companies that engage in these activities in Scotland include:

- Brookes Bell – paint and coatings, and computational fluid dynamics for hull resistance and optimisation[55]
- Goltens – provides 'Environmental Retrofits' including air lubrication systems[56]

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50 https://www.marinelink.com/news/turkish-yard-starts-construction-two-502134
51 Epikhin Aleksey Ivanovich *et al 2022 IOP Conf. Ser.: Earth Environ. Sci*. **968** 012007
52 https://www.kongsberg.com/maritime/contact/our-offices/united-kingdom-dunfermline-ltd/
53 https://www.denholm-group.co.uk/media/1msdqsok/jjd-esg-strategy-may-2022.pdf
54 https://www.northern-marine.com/safety-and-quality/environment/
55 https://www.brookesbell.com/marine-services/naval-architecture/computational-fluid-dynamics-cfd/
56 https://www.goltens.com/services/green-technologies/decarbonization-solutions-eexi-retrofits/

Autonomous Vessels

Apart from industry incumbents (like BAE Systems, the defence giant that developed an advanced system for its Pacific 24 Mk IV sea boat to provide uncrewed capability) there is no clear evidence of companies investing in autonomous vessels in Scotland.

There have, however, been efforts from the sector to collaborate with and leverage Scotland's academic strengths in AI and other digital technologies to support autonomous ship development[57].

Waste Heat Recovery

Companies that offer waste heat recovery solutions in the Scottish maritime sector include:

- Howden Group – waste heat recovery system that reduces fuel consumption by up to 8%[58]
- Mowi Scotland – new aquaculture vessel fitted with heat recovery system[59]

Summary

In summary, there are a number of measures to optimise vessel efficiency. Some of these are fairly well established, e.g., optimised hull form / shape design and straightforward to implement, e.g., slow steaming. Others, such as autonomous vessels, are very much in their infancy across the sector and are, largely, being explored by large incumbents like BAE Systems (defence application). As mentioned previously, AI-enabled autonomous vessels have the potential to significantly contribute to a reduction in emissions. Scotland's academic strengths in AI, data and digitalisation could be leveraged to support the development of autonomous ships.

3.3.2 Auxiliary Power Systems / Technologies

Scottish company activity in this area is focused on the development of innovative wind assisted technologies either as the primary or auxiliary system. This includes:

- SMAR Azure – that offers software for the optimal design of sail and fibre layouts and for the design and definition of rig layouts[60]
- Smart Green Shipping – developing technical, commercially viable and digitally enabled wind powered systems for both large and small / medium vessels[61]

3.3.3 Alternative Fuels / Propulsion Systems

A number of vessel designers and vessel owners / operators are exploring alternative fuel and propulsion systems. However, there is little evidence to suggest that Scotland is producing the key fuels of the future (hydrogen, ammonia, methanol, biofuel). There is also a limited number of developers of new propulsion systems (batteries, fuel cells, hybrid conversion, etc) and little current demand from the sector.

Examples of vessel designers exploring alternative fuels and propulsions systems include:

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57 https://www.scottishmaritimecluster.com/wp-content/uploads/2020/09/Members-Area-Documents_Workshops_SMC-Workshop-Report-Digital-Autonomous-Ship-Development.pdf
58 https://www.howden.com/en-gb/products/steam-turbines
59 https://mowi.com/uk/blog/2021/11/01/camilla-eslea-is-a-welcome-addition-to-the-fleet/
60 https://smar-azure.com/wp/
61 https://smartgreenshipping.com/

- Ferguson Marine
- Houlder Offshore Engineering – design & engineering with specialism in clean technologies[62]
- MacDuff Ship Design – designs vessels with alternative fuel / propulsion systems (hybrid)[63]
- Marine Design International – designs vessels with alternative fuel / propulsion systems (hybrid and full electric)[64]
- Tritec Marine – designs vessels with alternative fuel / propulsion systems (LNG)[65]

Examples of early adopters of alternative fuels/propulsion systems include:

- CMAL – diesel-electric ferries (hybrid)[66], implementation of Small Vessel Replacement Programme for fully electric vessels, part of HySeas III consortium (hydrogen)[67], and collaborating with University of Strathclyde (zero-carbon fuels)[68]
- Inverlussa Marine Services – aquaculture workboats (hybrid)[69]
- North Star – offshore service vessels (hybrid)[70]
- Seapeak Maritime (formerly Teekay) – carrier fleet (LNG)[71]

There is a small number of hydrogen fuel cell developers, battery manufacturers and suppliers, and energy storage developers in Scotland that target (or could target) maritime applications:

- AMTE Power – batteries manufacturer
- Ecomar Propulsion – batteries and hydrogen fuel cells
- Norco Group – batteries (supplier, targets smaller scale applications, e.g., leisure boats)
- Verlume – energy storage developer (offshore vessel recharging)
- ZEM Fuel Systems – hydrogen fuel cells research and development

Similarly, exploration of ammonia as an alternative fuel is at early research level:

- Brookes Bell – fuel chemists / fuel testing, laboratory research
- ZEM Fuel Systems – ammonia fuel cells research and development

There are two hydrogen refuelling and ammonia bunkering solution providers, as follows:

- Logan Energy/H2Tec – hydrogen refuelling stations
- GAC Services (UK) – ammonia bunkering

In summary, there are no identifiable producers of alternative fuels for maritime applications in Scotland, albeit there is some evidence of research and development into novel fuels, e.g., hydrogen (in, for example, the Hyseas III project and work at EMEC) and ammonia, taking place but this appears to be largely early stage. There is some evidence of propulsion system development. Similarly, there is some

62 https://www.houlderltd.com/case-studies/lng-dual-fuel-vessel-plan-approval
63 https://www.macduffshipdesign.com/news/aqs/
64 https://www.marinedesign.co.uk/news-and-updates/the-arranmore-ferry-new-build/
65 https://www.tritec-marine.com/news/tritec-marine-to-promote-small-scale-lng-solutions-at-gastech-2022/
66 https://www.cmassets.co.uk/project/hybrid-ferries-project/
67 https://www.hyseas3.eu/
68 https://www.cmassets.co.uk/cmal-strathclyde-university-secure-30k-grant-for-clean-maritime-fuel-project/
69 https://www.inverlussa.com/our-vessels/hybrid-vessels
70 https://www.northstarshipping.co.uk/news/north-star-raises-ps140m-investment-to-build-next-wave-of-renewables-fleet
71 https://seapeak.com/site/assets/files/2533/40673_seapeak_esg_sustainability_report_lores_v8.pdf

evidence of vessel owners / operators adopting these emerging technologies (e.g., ferries, offshore service vessels, and inshore service vessels), however, these are, primarily, hybrid battery powered. There is also small number of companies engaged in refuelling (Logan Energy/H2Tec) and recharging infrastructure development (Verlume).

There is, however, a notable lack of tier 1 manufacturers of major systems in Scotland. Wartsila, for example, provides propeller repair and electrical and automation services from its UK bases (Aberdeen and Glasgow) but is pioneering alternative fuels and novel engine systems development across its other international markets: Wartsila's methanol engine (Wartsila 32) will be fitted to a wind installation vessel at a shipyard in China[72]. In addition, Rolls Royce sold its commercial marine business to Norway-based Kongsberg[73], after cutting jobs at its Dunfermline factory in 2017, further demonstrating instability in the tier 1 segment of the manufacturing base in Scotland, although Kongsberg continues to successfully operate the facility[74]. As noted previously, however, the information in the public domain[52] suggests that the activities at this site are focused on sales and services.

There is, therefore, a gap in the Scottish maritime sector regarding alternative fuel supply chains, and the base for the manufacture of propulsion systems is also limited.

3.3.4 Port Operations

As vessel owner/operators begin to adopt the alternative fuels and power systems of the future, it is crucial that port infrastructure keeps pace to ensure refuelling and recharging can take place. In addition to providing the services required to support vessels entering the port, the port operators and their operations also need to decarbonise to support the transition to net zero.

The following provides some examples of work that is being done across Scottish ports to roll out technologies to facilitate decarbonisation of port infrastructure and operations.

Electrification

- CMAL – shore power availability exists at some small ports and harbours (for heating, lighting, etc, plus battery charging) with expansion expected, especially as fully electric vessels are introduced to the fleet (and across the sector more broadly)[75]
- Hunterston PARC – significant grid connections and generated power provision[76]
- Forth Ports – shore power availability (first commercial port in Scotland)[77], exploring electrification as part of its successful Green Freeport[78] bid
- Port of Aberdeen – exploring net zero solutions in partnership with BP, e.g., shore power pilot project with supply of zero or low carbon power to all vessels in port over time[79]

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72 https://www.wartsila.com/media/news/24-01-2022-wartsila-hits-methanol-milestone-with-first-newbuild-engine-order-3039731

73 https://www.dunfermlinepress.com/news/national-news/16337364.rolls-royce-agrees-sell-commercial-marine-business-kongsberg/

74 For example, see https://www.kongsberg.com/maritime/about-us/news-and-media/news-archive/2022/contract-to-supply-aquarius-50-retractable-fin-stabilisers/

75 https://www.cmassets.co.uk/newsletter-new/december-newsletter-behind-the-scenes/

76 https://www.hunterstonparc.com/media/adjapjjn/pp_hunterston-brochure_sept-20211.pdf

77 https://www.forthports.co.uk/latest-news/port-of-leith-is-first-port-on-mainland-scotland-to-go-live-with-zero-emissions-shore-power-for-ships/

78 https://forthgreenfreeport.com/

79 https://www.portofaberdeen.co.uk/news/aberdeen-harbour-and-bp-to-collaborate-on-decarbonising-port-operations/

- Montrose Port offering shore power to offshore energy vessels[80].

Decarbonising Port Operations

- CMAL – electric vehicle charging points exist at a number of locations
- Hunterston PARC – renewable and low carbon energy on-site, recycling of energy assets, range of blue-green research and development opportunities
- Forth Ports – electric vehicles and plant, renewable energy on-site, exploring solar powered warehouse, automated operations, exploring decarbonisation as part of Green Freeport bid
- Peterhead Port Authority – investing in low carbon port vehicles, e.g., electric road sweepers
- Clydeport / Peel Ports Group – the Group is exploring a range of sustainability initiatives that would be rolled out to its ports, e.g., hydrogen to power lorries, LED / lighting sensors and controls[81]
- Sercel – maritime software developer that undertook a proof of concept, data-led emissions management (D-LEMA)[82] project that monitors vessel emissions in port allowing port managers to identify excessive levels of emissions

Zero Emission Maintenance

- CMAL – usage of lower maintenance materials with longer lifespans to help reduce port infrastructure maintenance
- Clydeport / Peel Ports Group – the Group is exploring a range of sustainability initiatives that would be rolled out to its ports, e.g., electric-powered forklifts and cranes

Zero Emission Fuel Supply

- Port of Cromarty Firth – leading the North of Scotland Hydrogen Programme[83] and aiming to produce, store and distribute green hydrogen at scale
- Port of Aberdeen – exploring net zero solutions in partnership with BP, e.g., hydrogen as a fuel source
- Forth Ports – exploring hydrogen and biofuels as part of Green Freeport bid
- GAC Services (UK) – provides bunker fuel services and is currently supplying LNG as well as committing to supplying methanol, ammonia and biofuel in the future

In summary, there is limited availability of shore power across Scotland with greater investment required as more vessels transition to hybrid and fully electric power. This will require engagement with power distribution network operators. Developing the re-charging infrastructure will also encourage more vessel owner/operators to invest in battery systems to power their vessels.

Larger ports are investing in sustainability and net zero strategies, some of which are bidding for Green Freeport status, which will accelerate the sector's transition to net zero as a result of the development of low carbon products, services and supply chains and the creation of thousands of jobs[84]. These ports are also taking steps to reduce carbon emissions generated from port operations through small scale trials of, e.g., electric cars, plant and equipment. The extent to which these initiatives will advance

80 https://montroseport.co.uk/2022/12/09/montrose-port-shore-power-with-plug/
81 https://www.peelports.com/news-articles/academic-tie-up-to-improve-port-innovation
82 https://www.offshore-energy.biz/ion-solution-helps-monitor-ghg-emissions-in-uk-port/
83 https://opportunitycromartyfirth.co.uk/green-hydrogen/
84 Forth Ports forecasts 50,000 "green jobs"

beyond small scale trials is not clear, which will likely impact the timescale for deployment across the wider port sector.

There is also evidence of hydrogen being explored as a zero-emission fuel of the future with, for example, the Opportunity Cromarty Firth green hydrogen project. However, the port is understood to be, initially, importing green hydrogen from Norway[85] which points to a lack of production in Scotland. Moreover, there is little evidence regarding ammonia and methanol fuelling, other than early-stage exploration, at ports which further underlines the lack of alternative fuel supply chains in Scotland. It is noted however that this is likely to change in the future (see Forth Porta and GAC Services examples above).

85 https://pocf.co.uk/2021/05/24/post-entry-a/

4 Decarbonisation Capability Assessment

4.1 Assessment of Scottish Company Capability

The companies that have been identified as most relevant to the decarbonisation of the sector, including companies pursuing decarbonisation now and companies that will be required to pursue decarbonisation in the near future, have been assessed on their level of potential to have a significant, direct impact on reducing carbon emissions.

Certain factors have been assessed to determine each company's relevance to, and impact on, decarbonisation. An assessment of their international and export potential has also been assessed. These factors are as follows (ranked Low, Medium, High):

- Decarbonisation focus
  - *Low* low/no evidence of company pursuing decarbonisation opportunities
  - *Medium* some evidence of company pursuing decarbonisation (i.e., not a key focus)
  - *High* significant evidence of company pursuing decarbonisation (i.e., a key focus)
- Industry focus
  - *Low* minor activities in maritime
  - *Medium* moderate activities in maritime
  - *High* significant activities in maritime
- Innovation potential
  - *Low* no evidence of innovation activities, e.g., investing in R&D or exploring novel technologies
  - *Medium* some evidence of innovation activities, e.g., small investment in R&D or minor adoption of novel technologies
  - *High* evidence of significant investment in R&D / adoption of novel technologies
- Export potential
  - *Low* no practical export potential and/or no obvious international sales (i.e., most clients UK)
  - *Medium* some evidence of international markets but small proportion of client base and/or there is practical export potential
  - *High* evidence of international markets representing a reasonable proportion of client-base and/or strong practical export potential

The chart below displays a breakdown of these factors across the group of companies.

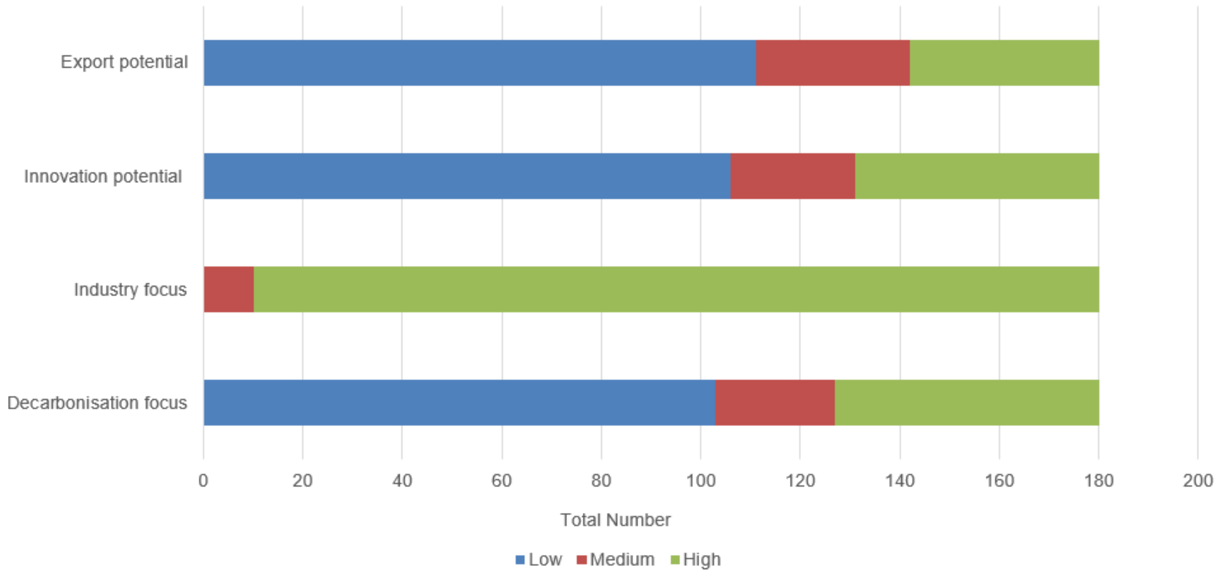

Figure 15: Assessment of Industry's Decarbonisation Potential

There are 22 companies ranked as 'high' across all four factors.

The primary category 'Design, Development, Testing & Manufacture of Emission Reduction Products and Services' has the greatest number of these companies (13), followed by 'Design, Development, Testing & Manufacture of Parts, Components, Systems and Fuels' (6) and 'Design, Development, Testing & Manufacture of Vessels (6). The category 'Ship Management' has the smallest number of companies (1).

Each of the assessment factors have also been considered, in turn.

Decarbonisation Focus

Approximately 30% of companies are ranked as having a 'high' decarbonisation focus. These companies are predominantly grouped in the primary category 'Design, Development, Testing & Manufacture of Emission Reduction Products and Services' and include, e.g., vessel optimisation software providers, large vessel designers and engineers, novel sail and wind-powered solutions providers, air lubrication systems developers, and providers of waste heat recovery systems.

A breakdown of the companies ranked as 'high' by their primary supply chain category is shown below.

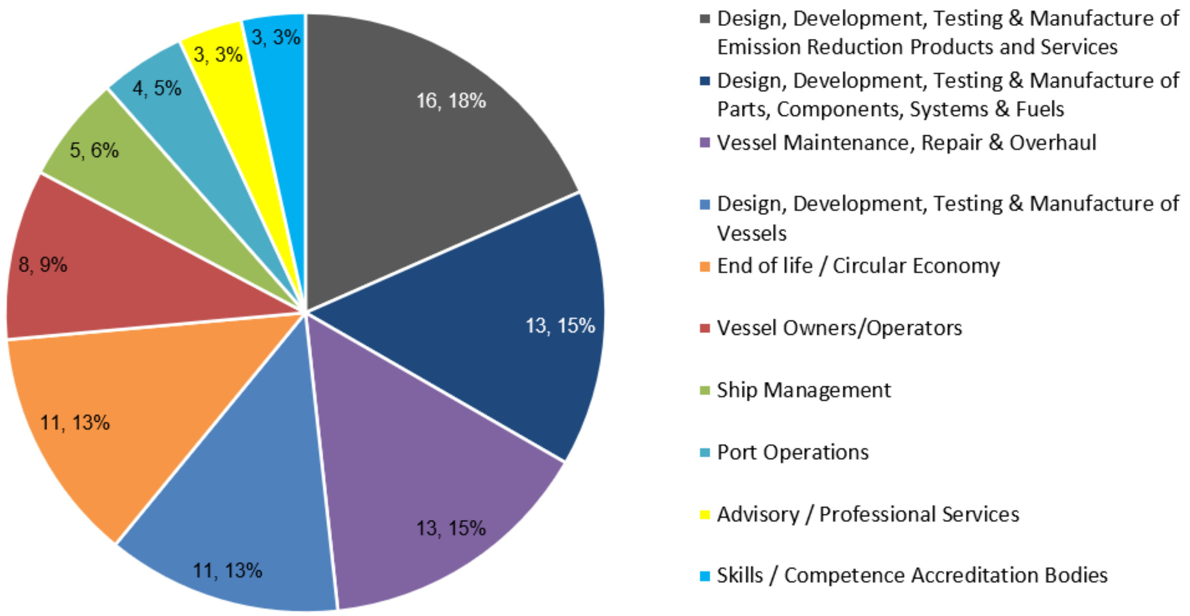

Figure 16: Supply Chain Segmentation by 'High' Decarbonisation Focus

Industry Focus

As expected, the vast majority of companies in the database have a 'high' industry focus. This means they are highly active in the maritime market, e.g., fishing vessel owner/operator, vessel designer, vessel manufacturer, digital solution developer for maritime applications, port operator, etc.

A small group of companies have been ranked as 'medium' focus because maritime is considered to be more of a secondary / minor target market. This includes, for example, companies that manufacture batteries (where the primary market is, e.g., automotive), develop hydrogen fuel cells, provide engineering services to other primary markets (e.g., aerospace and defence), and provide software tools to other primary markets.

There are no companies ranked 'low'.

Innovation Potential

As with the 'decarbonisation focus' assessment, nearly 30% of companies are considered to have a high level of innovation potential. This includes companies across the entire supply chain, but with the greatest density being in the primary category 'Design, Development, Testing & Manufacture of Emission Reduction Products and Services'; this is to be expected given the nature and focus of activities within this category.

A breakdown of the companies ranked as 'high' by their primary supply chain category is shown below.

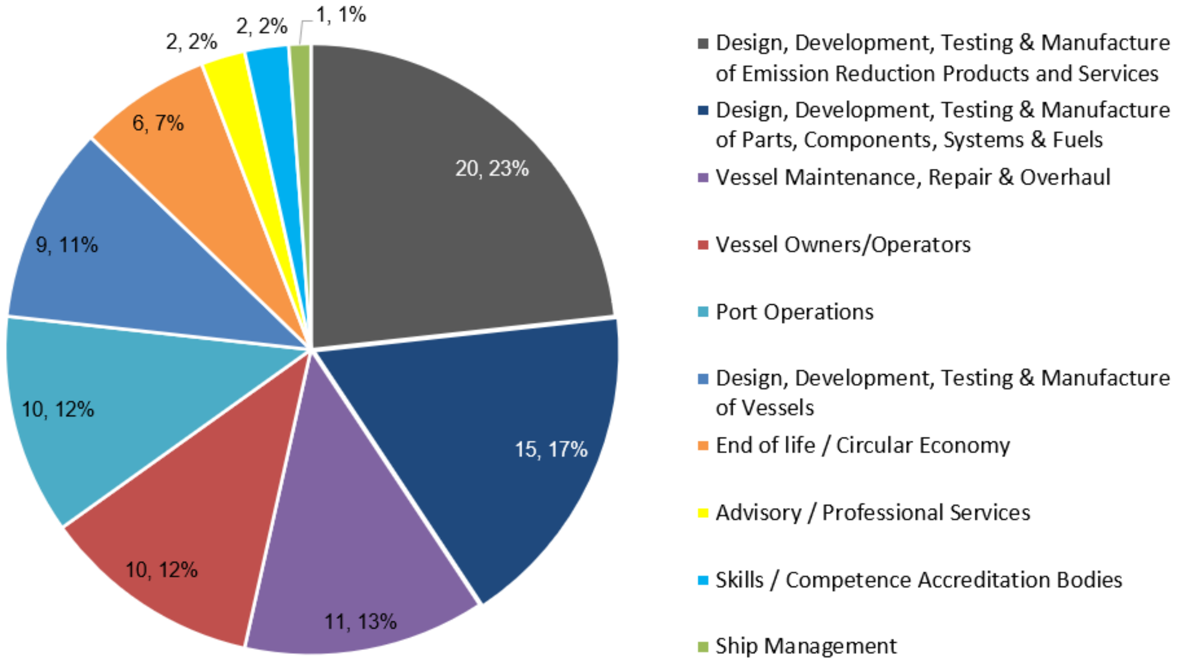

Figure 17: Supply Chain Segmentation by 'High' Innovation Potential

Examples of innovative activities taking place across the supply chain can be found in section 3.3 and in the database which has been provided separately including, for example, vessel owners/operators exploring novel fuels and propulsion systems, developers of batteries and hydrogen fuel cells, and ship managers implementing sustainability programmes, ports trialling decarbonisation initiatives, companies retrofitting of low carbon systems, ship repair and conversion / re-purposing (circular) service providers, and more.

Specific research, development and innovation (RD&I) projects across Scotland include:

- HySeas III (hydrogen fuelled ferry) and other EU projects
- Multiple CMDC funded projects, e.g., CMAL and University of Strathclyde awarded funding for clean maritime projects, plus a number of others
- Project Neptune (includes exploration of production and storage of zero carbon fuels[86])

There are also a number of companies with experience and expertise in RD&I, as evidenced by their participation in a range of Scottish, UK and EU funded projects, or by their active, self funded innovation activities.

Export Potential

As shown in Figure 15, companies with a 'high' degree of export potential are in the greatest minority of the four factors assessed, i.e., there are more companies with a 'high' degree of innovation and decarbonisation potential compared to export potential. This is because of the nature of activities undertaken by the companies in the database, including vessel owners / operators that operate in UK

86 Production and storage of non-carbon fuels for the Shetland Islands maritime sector (Ricardo, 2022)

waters, vessel designers and manufacturers that target UK vessel owners, ports operators which, for the most part, cannot practically export their services, and so on.

Companies can be categorised as 'high' if they clearly target international markets and / or if their product or service has good practical export potential, e.g., a software product.

A breakdown of the companies ranked as 'high' by their primary supply chain category is shown below.

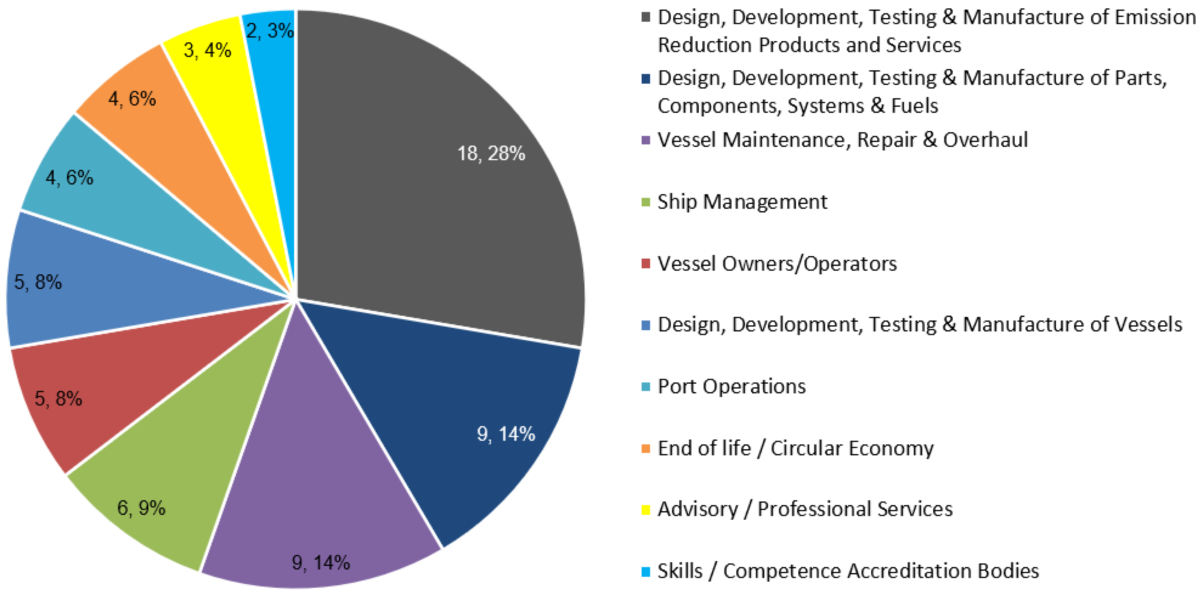

Figure 18: Supply Chain Segmentation by 'High' Export Potential

Some of these companies are large multinationals, while others are much smaller companies based in the UK.

Companies in the 'Design, Development, Testing & Manufacture of Emission Reduction Products and Services' account of the largest portion of the companies with 'high' export potential (28%). This is predominantly comprised of companies developing data / digital tools (e.g., vessel performance optimisation), as well as below the waterline solutions (e.g., air lubrication systems) and above the waterline solutions (e.g., novel sails and wind-powered solutions).

4.2 Assessment of Scottish Academic Decarbonisation Capability

In this section we present a summary of Scottish academic decarbonisation capability in areas such as innovative vessel design and operational efficiency, new propulsion technologies (including alternative fuels), and supporting infrastructure (including bunkering). Our analysis is based on a review of university websites to isolate areas of academic expertise where relevant information was available.

A total of 22 research groups were identified and were categorised into three groups:

- High relevance – research activity that is focused on maritime decarbonisation application,
- Medium relevance – research activity that has potential to be applied in maritime to support decarbonisation

- Low relevance – research activity that is more general but still relevant to maritime decarbonisation.

Academic activity that is focused on maritime decarbonisation is summarised in the table below.

Organisation	Research Group / Centre	Area of Research	Relevance (Low, Med, High)
University of Strathclyde	Naval Architecture, Ocean & Marine Engineering	Research areas include alternative fuels for shipping, autonomous ships, safety in marine fuel cells, principle investigator of Horizon 2020 funded HYSHIP project (DEMONSTRATING LIQUID HYDROGEN FOR THE MARITIME SECTOR), ShipFC project (Piloting Multi MW Ammonia Ship Fuel Cells), and AUTOSHIP (Autonomous Shipping Initiative for European Waters).	
University of Strathclyde	Naval Architecture, Ocean & Marine Engineering	Research projects include H2020 funded GATERS (GATE Rudder System as a Retrofit for the Next Generation Propulsion and Steering of Ships), and VENTuRE (Virtual and physical ExperimeNtal Towing centre for the design of eneRgy Efficient sea-faring vessels)	
University of Strathclyde	Naval Architecture, Ocean & Marine Engineering	Research focus includes energy efficiency of ships, motions and loads on ships.	
University of Strathclyde	Naval Architecture, Ocean & Marine Engineering	Research projects include H2020 funded NH3CRAFT (Safe and efficient storage of ammonia within ships), SHIPLYS (Ship Lifecycle Software Solutions); Innovate UK funded Lifecycle Energy Solutions for Clean Scotland/UK Maritime Economy, EPSRC funded CENTS (Circular Economy Network+ in Transportation Systems - Maritime)	
University of Strathclyde	Chemical and Process Engineering	Investigating novel electrochemical processes to produce hydrogen, including work SHYP BV LTD (Aberdeen) on conversion of seawater into hydrogen.	
MarRI-UK	N/A	A collaborative innovation vehicle UK industry and academia with a focus on research and innovation within mid TRL (3 – 7) levels to address the opportunities between "discovery and research" and "commercialisation" of maritime technologies and systems.	

Figure 19: Scottish Academic Capability that is Focused on Maritime Decarbonisation

The Naval Architecture, Ocean & Marine Engineering Centre at the University of Strathclyde is world leading. The Centre is rated 1st in Europe and 3rd in the world for marine and ocean engineering according to Academic Ranking of World Universities (ARWU)[87]. The centre is involved in several highly relevant maritime decarbonisation projects, including, for example, alternative low carbon fuels, new propulsion technologies, and improving the operational efficiency of vessels.

Academic activity that has the potential to be applied for maritime decarbonisation but is also applicable to many other sectors is summarised in the table overleaf.

87 Academic Ranking of World Universities, ARWU, better known as the Shanghai ranking, compiled by the Asian Agency Shanghai Ranking Consultancy

Organisation	Research Group / Centre	Area of Research	Relevance (Low, Med, High)
University of Aberdeen	Department of Chemistry	Research interests include fuel-cell processes, CO2 conversion to chemicals and artificial photosynthesis for the production of green hydrogen via solar water splitting	
University of Aberdeen	School of Engineering	Carbon dioxide hydrogenation into fuels and chemicals; Hydrogen production from biomass; Use of conventional refinery units to co-process/process biomass-derived feedstocks.	
University of Aberdeen	School of Engineering	Proton exchange membrane fuel cells; polymeric electrolytes; liquid crystals; hydrogen economies; solid oxide fuel cells; energy conversion and storage.	
University of Aberdeen	School of Engineering	Exploring the potential to generate hydrogen from organic waste	
University of Edinburgh	Artificial Intelligence Application Institute	The ONR-sponsored Naval Automation and Information Management Technology (NAIMT) project is a collaborative effort of the US Navy, (Panama City, FL), IHMC (Pensacola, FL), and the University of South Florida (USF) to integrate key technologies to meet the military's future needs for coordinating the operation of unmanned systems with greater effectiveness and affordability. AIAI is a member of the IHMC NAIMT Team inputting I-X concepts	
University of Edinburgh	Energy, Environmental and Sustainable Chemistry	Investigation of new materials for energy applications, developing novel processes for production of sustainable materials, recovery of resources and the fate of natural and pollutant chemical species in the environment. Areas of research includes synthetic fuels such as green ammonia and new materials of hydrogen production.	
University of Edinburgh	Institute for Energy Systems	Electrical Power Conversion research theme within the institute focussing on converting energy from one form into electrical energy using electrical machines and power electronics. Research areas include hybrid power systems.	
University of St Andrews	JTSI	Ceramic processing, electrochemistry, batteries, fuel cells, heterogeneous catalysis, hydrogen, materials, photochemistry and solid state ionics.	
University of Strathclyde	Advanced Forming Research Centre	Supporting metal manufacturing industries to explore the use of new material forming technologies.	
University of Strathclyde	Naval Architecture, Ocean & Marine Engineering	Research relates to ship recycling and research into the design of ship recycling yards and the optimisation of procedures using simulation, developing a ship recycling yard design and optimisation framework	
University of Strathclyde	Chemical and Process Engineering	Research focus on nanomaterials and energy conversion applications. Projects include green hydrogen production.	

Figure 20: Scottish Academic Capability that has Potential to be Applied to Maritime Decarbonisation

There are clear areas of capability, such as research into fuels cells and new types of fuels, that are applicable to maritime. Professor John Irvine's research team at the University of St. Andrews is a recognised leading group in fuel cell technology. There is also relevant fuel cell activity at University of Aberdeen, as well as research into new fuels.

In terms of academic research that is more general, but we believe has the potential to support maritime decarbonisation, such as advanced manufacturing and materials development, we have identified five research groups, as summarised in the following table. As this is a more general grouping, our list is indicative only and it could be argued that many other research groups at Scottish universities could be included.

Organisation	Research Group / Centre	Area of Research	Relevance (Low, Med, High)
University of Aberdeen	Department of Chemistry	Synthesis and characterisation of novel proton and oxide ion conductors for application in intermediate temperature ceramic fuel cells.	
University of Edinburgh	Edinburgh Centre of Climate Innovation	We create, support and work in partnership with researchers, communities, policy makers and businesses to find and implement place-based climate solutions, such as reducing emissions, building resilience and promoting equality and justice to tackle the climate emergency.	
University of Glasgow	Gregory Group	Research in the Gregory group is focused on the design and discovery of new energy materials with applications in batteries, fuel storage, gas purification/capture and thermoelectric devices among others. The energy-efficient synthesis and processing of materials is also a huge driver in the group's work.	
University of Strathclyde	Advanced Materials Research Laboratory	Laboratory and testing centre, providing full characterisation of material bulk or surface properties, covering physical, mechanical, chemical, thermal, topographical, compositional (elemental and molecular) and structural analyses	
University of Strathclyde	Design, Manufactruing and Engineering Management	Leads the Centre of Precision Manufacturing	

Figure 21: Scottish Academic Capability with Potential to Support Maritime Decarbonisation

5 Identifying Decarbonisation Opportunities

Based on the evidence in the preceding sections, our analysis of the position of the Scottish maritime sector to exploit decarbonisation opportunities is presented and discussed.

5.1 Issues and Questions

There are a number of issues that affect the analysis of potential opportunities for Scotland, in particular:

- The lack of clarity regarding alternative fuels and propulsion systems, as discussed in Section 2.7. Here, we have endeavoured to define the most likely options (see Figure 9) and have used that to underpin our analysis.
- The need to identify an international way forward. Can Scotland really pursue specific decarbonisation solutions in advance of wider international agreement?
- The need to identify a cohesive way forward. Vessel operators, ports and regulators all need to move forward together. Until they do so, individual organisations will focus on addressing opportunities over which they have control. For example, vessel operators are concentrating on optimising operational performance and ports are focusing on decarbonising their shore-based infrastructure.
- Identification of the most attractive opportunities for the maritime sector in Scotland. How should Scotland pursue commercial shipbuilding? Or is the development of high value equipment and systems more attractive? How can Scotland apply innovate designs and technologies to develop a competitive shipbuilding offering? There was some strong feedback from several stakeholders that shipbuilding is, increasingly, a very competitive, low margin activity, especially when all important vessel components are currently sourced from overseas, a situation that is not expected to change in the future

  "Scotland does not lead in any of the technology options, either development or deployment"

  Of course both shipbuilding and the development of high-tech products and systems can be pursued. The latter covers both vessel manufacture and operation, with systems relating to operation having an established and growing local market.
- The maritime sector is not seen as a developer of new technology, rather, it adapts and adopts technologies developed elsewhere.

5.2 SWOT Analysis

Based on the evidence gathered in both primary and secondary research activities and the analysis in the preceding sections we have developed a SWOT analysis of the capability of Scottish 'maritime decarbonisation ecosystem' to exploit opportunities in decarbonisation of the maritime sector, as follows:

5.2.1 Strengths

The key strengths identified are:

- Industry
    - High profile presence of large, global players in the defence sector (e.g. BAE Systems and Babcock International)
    - Internationally recognised ship building and ship maintenance capabilities (e.g. BAE Systems and Royal Navy)
    - The leading European ship management cluster[88]
    - Innovative supply chain companies
    - A strong supply base in digital and data technologies
    - Established capability in nuclear fuels, relevant to the development and operation of small modular reactors
- Infrastructure
    - Available port/land assets for development.
    - Established dry docking facilities that could be redeveloped and made available
- Research, innovation and skills development
    - World leading academic centres of excellence e.g. University of Strathclyde(naval architecture and marine engineering) and University of St Andrews (batteries and fuel cells)
    - World leading maritime training centre (i.e. City of Glasgow College)
    - Internationally recognised innovation centres (e.g. Hydrogen Accelerator Hub, Lightweight Manufacturing Centre, EMEC, etc.)
    - A strong innovative culture and high-quality industry and academic innovation facilities.
- Market / market drivers
    - A significant national maritime ecosystem
    - Large local demand and a key local customer (Scottish Government).
    - Proximity to offshore renewables and other offshore sectors
    - Strong Net Zero government policy.
- Sector cohesion
    - A focused and active sector association (The Scottish Maritime Cluster).

5.2.2 Weaknesses

The key weaknesses identified are:

- A lack of collaboration – industry, infrastructure owners and regulators need to commit to, and collaborate on, a cohesive way forward
- Industry
    - A fragmented industry with low collaborative intensity
    - A weak shipbuilding supply chain compared to European competitors, especially the lack of indigenous major systems suppliers
    - Few active commercial shipbuilders of scale

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88 For example, see https://www.insider.co.uk/special-reports/scotland-greatest-secret-seven-seas-21807795

  - A higher cost base compared to competing shipbuilding nations (e.g. Turkey, Poland, etc)
  - Lack of local control / decision making in larger companies that are, typically, subsidiaries of major multi-nationals
  - Lack of demand for decarbonised systems
  - Lack of alternative fuel supply chains and perceived high fuel costs
  - Lack of evidence of Scottish industry efforts to learn / improve / innovate, with a few notable exceptions
  - Skills gaps in the supply chain (e.g. basic trades, electrical engineers, design engineers)
  - An established dependence on overseas labour
  - Limited supply chain capabilities to understand and deal with novel technologies
  - Low attractiveness of the sector to potential employees
- Infrastructure
  - Lack of access to key port infrastructure inhibiting development opportunities
  - Some key sites are in need of development
  - The infrastructure for alternative fuels does not exist
  - The current electricity grid will not support the expected power demand from ports without further investment
- Strategy
  - Lack of a national maritime strategy for Scotland
- Market/ market drivers
  - Limited evidence of commitment to local sourcing
- Sector cohesion
  - Lack of collective, cohesive approaches that include all key companies and stakeholders
  - Lack of industry leadership in developing partnership approaches to opportunities
- External
  - Lack of direction on key decarbonisation technologies (which needs to be addressed internationally)
  - Lack of a clear strategic direction from government
  - Concerns regarding the capacity of the regulator (Maritime and Coastguard Agency (MCA)) to regulate for zero carbon ships
  - Lack of regulations, currently, for handling and safety of alternative fuels, although these are under development

5.2.3 Opportunities

The main opportunities identified are:

- Industry
  - Accessing opportunities identified in the UK National Shipbuilding Strategy Refresh[89] - a significant pipeline of business through future ferry contracts and other government owned vessels (e.g., NLB, fishery protection and naval base support vessels)
  - Supporting / building capability and capacity of existing players

89 https://www.gov.uk/government/publications/refresh-to-the-national-shipbuilding-strategy

- Offshore wind capacity growth (estimated as a multi-billion opportunity for the supply chain in Scotland[90]) and the hydrogen economy (25GW production capacity target by 2045)[91]offering opportunities for low carbon / zero emission service and operations vessels
- Exploiting predicted growth in demand for offshore service vessels
- Fabrication of large segments to support deployment of large floating wind structures
- Design for retrofitting and retrofitting existing vessels with low/zero carbon systems
- Battery electric powered ships - there is a local market and approval requirements are achievable. Further the option of in-field charging is considered by the sector to be a "game-changer"
  - Additional opportunities for associated products (e.g. converters, DC drives, energy management, battery management, etc)
- Optimisation of ship design and lightweighting
- Optimisation of vessel operations offering opportunities for, e.g.
  - Digital twins
  - Autonomous systems
  - Digital vessel monitoring / performance optimisation
  - Sensing / digital technologies for a range of applications (e.g. optimising vessel routes, fishing boat operation, etc.)
- Development of high value innovative products and services, e.g.
  - Innovative vessel designs
  - Subsea transport vessels
  - Hydrogen safety technology and systems
  - Hydrogen liquefaction facilities
  - Small modular reactors
  - Safety and emergency/crisis management
- Servicing and maintenance of ferries and other vessels
- Developing Scotland as a "test-bed" for innovative low/zero carbon prototype vessels - the Scottish market is relatively small but is considered a "good controllable pilot market"
- Development of alternative fuels supply chains (exploiting renewable energy capacity)
- Development of roadmaps for each segment of the industry (e.g. fishing, offshore service vessels, etc.) that details pathways for the sector and individuals to pursue in order to meet clear goals
- Diversification of oil and gas capabilities

- Infrastructure
  - Development of a Maritime Innovation Centre of Excellence as a focal point for innovative maritime companies
  - Additional dry dock facilities to address the current lack of capacity

90 https://www.crownestatescotland.com/news/scotwind-developers-set-out-multi-billion-pound-supply-chain-commitments
91 Hydrogen action plan, see https://www.gov.scot/publications/hydrogen-action-plan/

  - Exploitation of the recently announced freeport status of Forth Ports and the Port of Cromarty Firth
  - Development of net zero ports to support sustainable marine tourism
- Research, innovation and skills development
  - Academic-industry collaboration to commercialise emerging technologies
  - Development of low carbon power systems – linking with the needs of other transport sectors
  - Development of full-scale low carbon vessel demonstrators (i.e. higher TRL developments)
  - Support maritime technology development projects
  - Training at all levels, particularly apprenticeships
- Sector cohesion
  - Facilitate a more joined up approach and encourage stakeholders to "come together"
- Policy
  - Developing a national or international "green corridor"
  - Implement local content rules for key public sector projects (procurement) that are within trade body rules and regulations
  - Develop a Scottish sustainable maritime strategy to address the needs of and support the Scottish maritime sector

5.2.4 Threats

Key threats identified are:

- Industry
  - Loss of local commercial shipbuilding to low-cost competition in Eastern Europe and the Far East
  - International competition leading to a lack of critical mass in key segments, such as ship management, in turn leading to significant decline
  - Organisations with no local control relocate operations elsewhere
  - Challenges for companies to access the supply chain – there are no Tier 1 companies, i.e. those developing and manufacturing major systems such as engines, propulsion systems, power units, etc, in Scotland around which suppliers can coalesce
  - Safety issues, liabilities and how to de-risk, especially with ammonia and hydrogen
  - Competition for staff from other sectors
  - Workforce demographics – ageing workforce and it is difficult to attract young, talented individuals into the industry
- Infrastructure
  - Comparatively high expenditure elsewhere will mean Scotland is left behind
  - No significant alternative fuel supply and no security of supply, currently
- Research, innovation and skills development
  - Collaborations developed with overseas rather than local industries
- Sector cohesion
  - Little sector cohesion leads to independent, non-optimum decision making by industry
- Strategy / Policy

- Lack of a strong sector development strategy for Scotland (Scotland is considered a region under the UK Government's strategy for the sector[13]) meaning that there is a risk Scottish companies could lose out to companies in other UK regions on new opportunities presented by decarbonisation of maritime transport

This analysis is developed further in the following section.

5.3 Development of a Scottish Maritime Sector Strategy

Earlier in this report (section 2.7) a number of barriers to the development and commercialisation of low and zero carbon technologies were identified. Many of these will require significant changes to, for example, legislation and regulations as well as rely on some major changes to the way the industry operates currently. It is not clear, at this stage, what, if any, role Scotland's maritime industry can play in facilitating these changes.

There are, however, a number of issues, identified in the 'weaknesses' above, that are within the control and remit of the Scottish Government and its partners that could be addressed and, thereby, further support the development of decarbonised maritime transportation in Scotland.

Decarbonisation of the maritime sector is of strategic importance at a UK Government level with the publication of, for example, Maritime 2050: Navigating the Future and the National Shipbuilding Strategy Refresh, both of which cover the UK as a whole, including the devolved administrations. At a Scottish Government level, there is a more general emphasis on the decarbonisation of transport as described in 'A Fairer, Greener Scotland: Programme for Government 2021-2022' and, in particular, the opportunities that have been identified as the country moves towards a "*green, sustainable and active transport system…*". Whilst the Programme for Government does not mention maritime transport specifically, clearly this is vital due to the reliance on this mode of transport for many island and rural communities, as well as for the ports and shipyards servicing the industry and its logistical importance in terms of the shipping of products.

Whilst the UK Government, as part of the implementation of its maritime strategies has, for example, set out plans for a Centre for Smart Shipping (CSmart) that will provide a coordinating function in new and emerging technologies and will enable innovation hubs to support the development of regional clusters of expertise across the UK, it is unknown, at this stage, where these hubs will be located. The development of a Scottish Maritime Strategy, that aims to address the issues and challenges specific to Scotland and to support development of the sector could be beneficial in helping Scotland to attract one of the UK Government funded innovation hubs. It was suggested by many of the companies and stakeholders contacted during this study that this should be a priority action, focusing on the existing and emerging strengths and capabilities across industry and academia and having a particular emphasis on innovation in added-value components, systems and other technologies to support decarbonisation of maritime transportation. This is where Scotland could develop a lead and where there is potential to make the biggest impact.

One of Scotland's strengths, as highlighted previously, is the SMC, which is very active across the sector and should, therefore, have a key role in the development of this strategy. This should ensure that it is aligned with the needs and ambitions of the industry in Scotland, recognising that maritime is a global industry, and also aligns with the direction of Government at a Scottish and UK level.

The creation of a Scottish Maritime Strategy should also help to address an issue highlighted by a number of organisations interviewed during this study, namely, that they are unaware of the strategic direction of either the Scottish government (through Transport Scotland) or UK government on how the maritime sector will be decarbonised. This lack of clarity means that many companies across the supply chain are unwilling to invest in innovation or in new technologies until it is clear where government strategy, policy and, potentially, funding will be focused. The creation of a relevant and evidence driven national strategy, and effective communication of its aims and objectives, could, therefore, provide the clarity that companies need.

5.4 Identifying Attractive Opportunities (Recommendations)

Based on the evidence gathered during this study, together with an analysis of the outputs of the SWOT, a small number of opportunities have been identified that align well with the strengths of the Scottish maritime sector. These have a particular emphasis on innovation in added value components, systems and other technologies to support decarbonisation of maritime transportation as this is considered to be an area where Scotland could develop a lead and where there is potential to make the biggest impact, rather than, for example, in developing cost driven commercial ship building capability, where Scotland is deemed to be relatively weak compared to other regions in Europe and the rest of the world, such as Turkey, Poland, China and Singapore. These development options should be considered within the wider context of the abovementioned Scottish Maritime Strategy and are key objectives, actions and activities that have the potential to support the growth of the sector in the future.

These development options are:

5.4.1 Development of Innovative Technologies and a Maritime Innovation Centre of Excellence

Strength

- Innovative supply chain companies
- World leading academic centres of excellence
- Internationally recognised innovation centres

Opportunity

- Development of high value innovative products and services
- Development of a Maritime Innovation Centre of Excellence as a focal point for innovate maritime companies

Participants

- Technology Park lead organisation (public or private sector or academic organisation)
- Key companies in the supply chain focused on innovation
- Academic groups / innovation centres

The analysis carried out in section 4.1 indicates that there is a number of innovative companies across the maritime supply chain that are actively involved in the development of products and services that are directly relevant to the decarbonisation of maritime transport. A number of these companies are undertaking these activities through funded R&D projects (such as the IUK CMDC funding mechanism) or through their own, internal R&D programmes. Furthermore, Scotland has a number of world-leading academic centres of excellence and innovation centres that are developing technologies with potential to translate into commercial application or that have capabilities to support companies with their R&D and innovation activities. At the moment, however, there is little or no focus for these activities and collaborations seem to happen on an ad hoc basis.

The creation of a Maritime Innovation Centre of Excellence would provide a focal point for these companies and, once established, help to support other companies to invest in innovation or attract them into the maritime supply chain. The aim would be to facilitate more strategic business-to-business and business-to-academic collaboration with the aim of commercialising technology developments. It could also go some way to addressing some of the weaknesses and threats highlighted, specifically:

- A fragmented industry with low collaborative intensity
- Lack of direction on key decarbonisation technologies (which needs to be addressed internationally)
- Lack of evidence of Scottish industry efforts to learn/improve/innovate
- Limited supply chain capabilities to understand and deal with novel technologies
- Low attractiveness of the sector to potential employees

This Centre of Excellence could be virtual or physical but would be a focal point for innovation. It should also recognise and link into the innovation activity already ongoing in the sector in Scotland, both within companies and across universities and innovation centres, as well as recognise some of the other infrastructure development projects in the sector such as the Malin Group's proposed Scottish Marine Technology Park[92] and the development of Hunterston PARC[93], to avoid any overlap, duplication or confusion with regards to the role each of these facilities will play. Any new Maritime Innovation Centre of Excellence could, therefore, be a hub for innovation, linking into and being complimentary to existing and proposed developments.

5.4.2 Battery Electric Vessels

Strength	Opportunity	Participants
• Innovative supply chain companies • World leading academic centres of excellence • Internationally recognised innovation centres	• Developing and building capability and capacity of existing and new players in the design, build and operation of electric vessels (battery / fuel cell) • Development of off-shore recharging or refuelling (green hydrogen) infrastructure	• Companies / organisations in the supply chain developing relevant tech • Key customers such as CMAL • Key academic centres such as University of St Andrews • Offshore renewable operators and their suppliers

It is highlighted that CMAL has a strategic commitment to the electrification of at least part of its fleet vessels through the use of batteries and/or fuel cells. Furthermore, a new joint venture set up with the aim of building and operating a fleet of battery electric offshore service vessels, and the associated onshore infrastructure, is considering sites in Scotland in which to base its operations. More generally, there is a significant drive in the offshore renewables sector to decarbonise its operations and, coupled with the potential opportunities offered by the predicted growth of offshore wind capacity as a result of the latest ScotWind offshore wind leasing, demand for low carbon and zero emissions support vessels

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92 https://malingroup.com/scottish-marine-technology-park/
93 https://www.hunterstonparc.com/

will grow accordingly. In addition, the analysis of Scottish company capability highlighted a small but active group of companies involved in the development of battery and fuel cell technologies as well as a world leading academic research group at the University of St Andrews. The tangible, commercial opportunities that could be provided by CMAL and others would, in turn, create opportunities across the supply chain for existing companies as well as companies not currently active in the maritime sector.

5.4.3 Retrofitting of Innovative Low Carbon / Zero Emission Technologies

Strength	Opportunity	Participants
• Existing dry docking facilities that have the potential to be redeveloped • Scotland's leading ship management capability	• Design for retrofitting and retrofitting existing vessels with low/zero carbon systems	• Dry dock owner operators • Ship managers (with fleets to be converted) • Supply chain companies maintaining, repairing and overhauling vessels

As well as building new vessels that incorporate low and/or zero emission technologies, there will also be an increasing requirement for these technologies to be retrofitted to existing vessels. Scotland, currently, has a number of dry docking facilities that could be redeveloped to deliver services for the retrofitting of new technologies. This includes, for example, harnessing the existing skills and capabilities of Scotland's world leading ship management industry, that includes a strong focus on naval architecture and vessel design. Potential options include the development of technology specific "hubs" with each dry dock facility specialising in one specific area, e.g. electrification of vessels, conversion of vessels to run on alternative fuels, etc.

5.4.4 Digitisation of Vessel Operations

Strength	Opportunity	Participants
• A strong industry base in digital and data technologies • Leading academic / research centres of excellence • Internationally recognised innovation centres	• Optimisation of vessel operations and the operation and management of onshore infrastructure	• Leading vessel operators (public and / or private sector) • Port operators • Digital and data technology developers • Academic groups (e.g. Edinburgh University) and Innovation Centres (e.g. The Data Lab)

There is increasing interest in the digitisation of vessel operations as a means of reducing carbon emissions. Opportunities exist across the supply chain but are particularly focused on vessel operations, maintenance and the operation and management of onshore infrastructure. Scotland has a strong company base in the field of data and digital technologies as well as world-leading academic capability at, for example, the University of Edinburgh. Stakeholders contacted as part of this study indicated that many of the technologies and capabilities that already exist could be readily applied to the maritime industry with only limited modification and development required. Potential opportunities would, however, need to be clearly articulated as there is a perception that the maritime industry is not particularly innovative and is slow to adopt new technologies. Furthermore, in common with many other industries trying to attract employees with relevant digital and data skills, competition is fierce resulting in ever increasing salaries and difficulties in attracting and retaining staff.

5.4.5 Design, Development and Build of Commercial Demonstrator Vessels

Strength	Opportunity	Participants
• Large local demand and a key local customer	• Development of full-scale, low carbon vessel demonstrators (high TRL developments) • Implement local content rules for key public sector projects (procurement) • Establish a Green Corridor as a "test-bed" for innovative, zero carbon technologies	• Project sponsor (public or private sector or public-private partnership • Companies in the maritime supply chain

There is already local interest in zero carbon vessels. One specific example is the Scottish Government, through CMAL, committing to decarbonisation of its ferry fleet across Scotland and electrification, in particular, is highlighted as a key technology that will support the achievement of this goal. There are other examples of potential investment in zero carbon vessels. There is, therefore, a potential opportunity for the Scottish Government and its partners, or the private sector, to invest in a small number of high TRL demonstrator vessels, e.g. a battery or fuel cell powered ferry, that would create relatively low risk supply chain opportunities for companies already in the maritime supply chain or those seeking to diversify their customer base. Where possible, the aim would be to maximise local content, within trade body rules and regulations, which would help to support Scottish companies to exploit opportunities. This would also go some way to help address an identified weakness, namely the limited evidence of commitment to local sourcing.

A "green corridor" could be implemented as the location of operation of these vessels, increasing Scotland's profile in international decarbonisation of the sector.

5.4.6 Net Zero Port Demonstrator(s)

Strength	Opportunity	Participants
• Key ports with a commitment to decarbonisation	• Exploitation of the recently announced freeport status of Forth Ports and the Port of Cromarty Firth • Development of net zero ports to support sustainable marine tourism	• Forth Ports and the Port of Cromarty Firth, for example • Supply chain companies developing low / no carbon systems

We understand there is strong interest and commitment in several Scottish ports to pursue decarbonisation. These ports could be the focal point for the development and demonstration of zero carbon systems that would provide a local market for innovative Scottish companies, thus demonstrating capabilities in a real situation. Further, there is the potential for selected ports to develop as clusters / hubs for particular fuels, e.g. Hydrogen in Orkney.

5.4.7 Scottish Maritime Cluster Supporting Development of a Cohesive Maritime Sector

Strength	Opportunity	Participants
• The Scottish Maritime Cluster	• Development of a cohesive sector	• The Scottish Maritime Cluster • Companies across the maritime sector and enabling sectors (e.g. digital) • Key academic groups and research organisations

Scottish Maritime Cluster (SMC) is a key strength of the Scottish sector. The aim of this active and focused organisation is to *"…bring together Scotland's world-class shipping, ports, shipbuilding, equipment, education, training and maritime service enterprises to drive economic growth in the global maritime market. We do this through building cooperation among our globally recognised experts, promoting the sector and influencing economic policy makers."*

The SMC, as a body representing maritime companies across the supply chain and providing the link between industry and policy makers, could play a pivotal role in developing sectoral cohesion and the Scottish Maritime Strategy. It can also play a key role in ensuring that any of the development options outlined above progress in a way that meets the needs of industry thereby ensuring buy in and effective participation. This could, however, require additional support to SMC, whether that is through funding or additional human resources.

6 Conclusions

Based on the evidence gathered during primary and secondary research activities and the analysis of this evidence we can draw the following conclusions:

- The international maritime sector is a major contributor to carbon dioxide emissions. Global emissions from shipping (international, domestic and fishing) were estimated at 1,076 million tonnes in 2018 The international maritime sector is a major contributor to CO_2 emissions. Global emissions from shipping (international, domestic and fishing) were estimated at 1,076 million tonnes in 2018.
- One of the strongest influences on decarbonisation of the maritime transportation sector is 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. The IMO has set concrete targets for the reduction of GHGs for 2030 and 2050
    - 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.
- 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 technologies
- These legislation and policy drivers 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.
- The development and adoption of low / zero carbon solutions is critically dependent on innovation and there are several innovation support programmes, at a Scottish, UK and European level, targeted at the development of decarbonisation solutions for the maritime sector. There are a number of Scottish organisations participating in RD&I projects funded via these programmes.
- The achievement of decarbonised / zero emission maritime will be enabled by a wide range of existing and new technologies covering optimisation of ship efficiency; the deployment of auxiliary power systems; and the introduction of novel fuels and propulsion systems.
- There is still significant development and demonstration required for many of these technologies, particularly new fuels, before they are ready to be commercialised in any serious way which, in reality, is unlikely at any scale before 2030.
- 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. There are several ports in Scotland that are already developing and implementing decarbonisation plans and others that have potential to do more.

- Although the maritime sector is taking steps to decarbonise is it acknowledged[13] that progress has been slow, and that more commitment and investment is required from the sector to enable large scale emission reduction to be achieved. There are still some quite significant barriers and challenges to be overcome, some of which will require a major change in the way the maritime sector operates.
- The Scottish maritime sector is made up of over 200 companies across the supply chain, of which 22 have been assessed as being particularly relevant in terms of their decarbonisation capabilities (assessment criteria – decarbonisation potential, industry focus, innovation potential and export potential). In addition, there are a number of other companies that are active in the sector and that have potential to make a strong impact on decarbonisation.
- Scotland also has world-leading academic maritime capability within the Naval Architecture, Ocean & Marine Engineering Centre at the University of Strathclyde. There are a number of other centres of excellence and innovation centres working in highly relevant technology areas including, for example, batteries and fuel cells, novel fuels, advanced materials and digital and data technologies.
- The creation of a Scottish Maritime Strategy, that clearly sets out the Government's direction in relation to the sector should be a priority and would help to provide clarity to companies on where, potentially, to invest their resources. This, in turn, would support growth of the industry in the future.
- There are many existing and emerging opportunities that align well with Scottish strengths in the maritime sector. A small number of development opportunities have been identified have a particular emphasis on innovation in added value components, systems and other technologies to support decarbonisation of maritime transportation. This is considered to be an area where Scotland could develop a lead and where there is potential to make the biggest impact, rather than, for example, in developing cost driven commercial ship building capability, where Scotland is deemed to be relatively weak compared to other regions in Europe and the rest of the world. These development options should be considered within the wider context of the abovementioned Scottish Maritime Strategy and are key objectives, actions and activities that have the potential to support the growth of the sector in the future. These are:
    - Development of a Maritime Innovation Centre of Excellence
    - Battery Electric Vessels
    - Retrofitting of Innovative Low Carbon / Zero Emission Technologies
    - Digitisation of Vessel Operations
    - Design, Development and Build of Commercial Demonstrator Vessels
    - Net Zero Port Demonstrator(s)
    - Scottish Maritime Cluster Supporting Development of a Cohesive Maritime Sector
- These development options could also go some to way to addressing some of the identified weaknesses in the maritime sector in Scotland.

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Appendices

Appendix A – Stakeholders Consulted

The following stakeholders were consulted during this study. We acknowledge and thank them for their contribution.

Altrad Babcock
AFC Energy
Aquatera
Babcock International
British Marine Scotland
City of Glasgow College
Clyde Marine Training
Clyde Port Authority / Peel Ports
CMAL
Core Power (UK) Ltd
Cromarty Firth Port Authority
EMEC
Anglo Eastern (ex-CEO)
Eyemouth Marine
Ferguson Marine
Fisheries Innovation Scotland
Forth Ports Scotland
H2 Green Ltd
Houlder Offshore Engineering Limited
Lloyds Register
Macduff Ship Design
Malin Group
Marine Design International
MSIP
National Manufacturing Institute Scotland (NMIS)
Northern Lighthouse Board
Peterhead Port
Robert Gordon University
Royal Navy
Scottish Hydrogen and Fuel Cell Association
Scottish Maritime Cluster
University of St Andrews – Hydrogen Accelerator
University of St Andrews – School of Chemistry
University of Strathclyde – DER
University of Strathclyde – Naval Arch.
University of Strathclyde – Naval Arch.
University of Strathclyde – PNDC
Wood Group
Zephyrus

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