STEERER

STRUCTURING TOWARDS ZERO EMISSION WATERBORNE TRANSPORT

D 2.1. State-of-Play of Decarbonisation of waterborne transport "technology application atlas"

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Executive Summary

This deliverable of the STEERER project is intended to provide a high level overview of the current situation regarding the transformation towards zero-emission waterborne transport by consolidating and presenting the existing findings of relevant projects and best practices, initiatives, existing decarbonisation strategies and visions for the (waterborne) transport sector. It thereby not only offers the basis for input to the update of the Strategic Research and Innovation Agenda of the Co-Programmed Partnership on Zero-Emission Waterborne Transport (cPP ZEWT) in the framework of Horizon Europe, but serves as a catalogue to promote the commitment of the broader European waterborne transport sector to deliver and implement solutions for societal challenges.

Firstly, the deliverable provides an overview of the European waterborne sector, its contributions to the EU economy, and its position both within the wider EU and international transport sectors.

The next point presented is an overview of current initiatives, both in the framework of projects co-financed by the European Union and/or national and regional administrations, as well as financed by the industry. These projects are clustered in accordance with the six areas of activities foreseen in the cPP ZEWT. For each technology identified, a first short swot analysis is included, which forms a basis for the definition of further research, development and innovation needs. In addition, a first overview of decarbonisation strategies and visions is being provided. The main results are the following:

- The Light Gas Pathway
    - Liquefied Natural Gas (LNG). It is the cleanest of the fossil fuels (minus the potential gas slips), technically can be mixed with up to 10% of clean H2, and suitable for almost all ship types. Several ships use LNG, including with dual fuel engines. However, LNG requires 2-3 times the volume of fuel-oil tanks with the same energy content and has little infrastructure facilities available worldwide. In addition, it attracts decreasing public and political support. There are a limited number of projects to improve this technology.
    - Hydrogen (internal combustion engines and fuel cells). Very little uptake in operational terms (small ships), but numerous on-going projects with rapid technological improvements for larger ships and longer distances. Presently, the technology still faces a number of challenges: high production prices, low energy density & energy efficiency; underdeveloped associated infrastructure (e.g. bunkering); high CAPEX; incomplete legal/political framework.
- The Heavy Gas and Alcohol Pathway
    - Liquefied Petroleum Gas (LPG). Fossil fuel, with a very low, but somewhat increasing market uptake. Limited supply available and missing legal framework.
    - Methanol. Promising alternative fuel, clean, available in many areas, with infrastructure similar for the conventional fuels and dual-fuel engines. Slow uptake. Some projects are further developing the dual-fuel engines. It has a low energy density and

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high retrofitting costs but can be used as a CCUS method. Incomplete legal framework as energy carrier or fuel.
    - Ammonia. A hydrogen carrier but easier to store (including in comparison with LNG or batteries), can be CO2 emission free under the right circumstances. However, no real or planned market uptake for the moment, though some of the newer engines can run on ammonia. Some projects on ammonia are being developed, including outside the EU. Weaknesses: low volumetric energy density and high fuel costs; high toxicity levels; missing legal framework (IGC code on toxic cargoes not to be used as fuel).
- The Bio:/Synthetic Fuels
    - Biofuels. Depending on the source of biomass, processing and type of energy used to convert it into a fuel, the carbon reduction or sustainability potential of each fuel will also vary. The advantage is that they can be blended at gradually higher shares as a drop-in fuel, which avoids the need for new vessels and fuel systems. No changes required for engines. However, biofuels are more expensive than most other fuels, therefore the market uptake is extremely low, with no clear improvement prospects.
    - Synthetic fuels (or Power-to-Fuel). In order for these fuels to be considered "low carbon", it is important to use hydrogen produced with zero carbon energy (such as electrolysis powered by renewables or nuclear) and CO2 that is extracted from the atmosphere. They can be used in existing infrastructures.
- Electrification. A good number of vessels, mostly hybrid, are in service; more vessels on order, the fully electric ones witnessing an increase. Mostly ferries and other types of medium or small ships. Main challenges: impractical for some vessels, in particular larger ships, due to the size and weight of necessary batteries, plus the increase in bunkering frequencies.
- A Life Cycle Performance Assessment (LCPA) of these solutions is also presented.
- Energy efficiency measures. There are numerous such solutions, each with different results in the reduction potential of emissions. Some of the solutions analysed are:
    - air lubrication: up to 10% fuel savings;
    - hull coatings;
    - waste heat recovery systems: up to 8% of main engine fuel consumption, but not applicable to slow steaming;
    - wind-assisted propulsion. Some ships already use these technology, and a few other ships are planned to use them. There is a significant number of projects looking into wind propulsion improvements. Fuel savings up to 20%, depending on ship types. The technology yields the highest efficiency gains for slow ships, but it is not suitable for all ship types. It can be a problem as higher gains require choosing windier routes.
    - optimised combustion: fuel flexibility, slow steaming, energy efficient navigation, etc. Depending on the ship type and the measure(s) implemented, the added fuel savings could reach 14% or more.
- The contribution of digital technologies was also included in the analysis.
- The role of ports for onshore power supply for all vessel types. A significant part of the overall fleet in service is equipped with a high voltage shore connection. More ships on order have this type of equipment, in particular ferries and offshore ships. The technology is generally mature, but some developments are still on-going: automatization, flexible connection points,

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mobile solutions, etc. The barriers come mostly from the variety of both ships and infrastructure, which lack not just standardisation, but also harmonisation aspects. Other barriers: no uniform TRLs; practical impossibility for some vessel types (e.g. large offshore vessels); long connection processes; trade volatility; etc.

Subsequently, a list of industry initiatives to decarbonise the waterborne sector and address the different technologies mentioned above is analysed in the deliverable.

As a next step, the STEERER project will analyse a number of possible scenarios, including the definition of emission targets for 2025, 2030 and 2050. This deliverable ends with a first overview of statistics of the various waterborne transport segments, which will form the basic input for the scenario development.

At the end of the document, an annex including the project analysed has been included. Since this deliverable is a living document, its content will be updated continuously. In case you would like to provide input to the next update of the deliverable, please contact the Waterborne Technology Platform via info@waterborne.eu.

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1. Introduction

1.1 The STEERER Project

STEERER (Structuring Towards Zero Emission Waterborne Transport) will coordinate the establishment and communication of a Strategic Research and Innovation Agenda[1] and an Implementation Plan **towards zero-emission waterborne transport, in cooperation with all key stakeholders needed to facilitate the transformation to clean waterborne transport**. In the definition of STEERER, as well as cutting greenhouse gas emissions, all harmful environmental emissions, water pollution and noise emissions have to be eliminated. STEERER's mission is to bring the various initiatives and sectors' stakeholders together to join forces for a combined effort with the maximum impact for the climate, people's health and Europe's economy.

STEERER is coordinated by the Waterborne Technology Platform (SEA EUROPE is responsible for its secretariat), counting with the participation of a total of seven partners from six EU countries.

Figure 1: STEERER's Partners

[1] The STEERER project will provide input to the Waterborne TP regarding the development and update of the Strategic Research and Innovation Agenda of the Co-Programmed Partnership on Zero-Emission Waterborne Transport in the framework of Horizon Europe (https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/european_partnership_for_zero-emission_waterborne_transport.pdf).

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In sum, STEERER aims to:

- Jointly set emission targets towards 2050 (including targets for 2025 and 2030);
- Contributing to the update of the Strategic Research and Innovation Agenda of the Co-Programmed Partnership on Zero-Emission Waterborne Transport (cPP ZEWT)[2] in the framework of Horizon Europe, to be able to reach these targets in time;
- Develop an Implementation Plan to reach the targets in due course while staying competitive and offering a valid business case;
- Developing and implementing a communication campaign, aimed at broader awareness of the waterborne transport sector and its commitment towards zero-emission transport, to become a fully sustainable mode of transport;
- Monitoring and assessing the implementation of the Strategy defined and adapting where necessary, after the project's conclusion, by the Green Shipping Expert Group.

The consortium will function as a Secretariat, where the broader expertise is involved in the **Scientific Committee (SC)** and the **Green Shipping Expert Group (GSEG)**[3] to be established by the project.

STEERER is funded by the European Commission research and innovation programme Horizon 2020, with an investment of 1,5 million euro over the course of 36 months, starting in December 2019. STEERER will play an important role in the preparation and execution of the Co-Programmed Partnership on Zero-Emission Waterborne Transport in the context of Horizon Europe.

[2] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf
[3] https://www.waterborne.eu/projects/coordination-projects/steerer/green-shipping-expert-group/member-list?view=members

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2. The European Waterborne Transport Sector

Waterborne transport moves nearly 90% of all international trade, more than 75% of external EU **trade** and **40% of internal EU trade**[4]. **Oceans, seas, inland waterways and lakes** are key to our climate, shape our environment, generate water and are becoming increasingly important as a source of raw materials, food and energy. In addition, they form an **essential transport route** for the global and intra-continental trade flows and are places for living and recreation. Although less visible, waterborne transport is essential for the functioning of modern economies. Principally the most energy-efficient and environmentally sound form of freight transportation, the quantity of goods moved by ship will not fall and is expected to increase in line with developing economies and global growth. In addition, waterborne transport is an essential means of passenger transport as well. For example, ferries are often key for local transport. Each year, more than **400 million passengers** embark and disembark at European ports[5]. It is challenging to address this global growth whilst the globe strives to decarbonise every aspect of daily life. As a matter of priority for the European Green Deal, a substantial part of freight carried by road today should shift onto waterways to boost multimodal transport and the efficiency of the entire logistics chain. The urgency to reduce emissions, the conservation of resources and the need to use resources carefully are driving the increase of energy-efficiency. Furthermore, there will be a growing demand for clean energy – not only from waterborne transport - that is expected to be more expensive and may be less available than the fossil alternatives. Increasing the energy efficiency will be a key driver for waterborne transport.

European-based maritime shipping companies control **around 36% of the global fleet**[6]. The European maritime technology sector is a **global leader** in high-technology shipbuilding (for example maritime and inland cruise ships, electric ships, offshore support) and green shipping technologies (for example battery electric, clean engines, exhaust treatment systems, green equipment and smart technology for improved efficiency and operations). European companies

[4] https://ec.europa.eu/transport/modes/maritime_en
[5] https://ec.europa.eu/transport/modes/maritime_en
[6] https://ec.europa.eu/epsc/sites/epsc/files/epsc_clean-transport-at-sea.pdf COM(2013) 918 final ' Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - a Clean Air Programme for Europe'

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supply **almost half** of global maritime equipment and have developed and designed the majority of the world's fleets' power systems. For two-stroke main engines, the market share of **EU-designed engines** was over **90% between 2015 and 2019**. For medium speed main engines, this was **around 70%**[7]. The achievement of zero-emission waterborne transport not only represents a major challenge to Europe's waterborne transport sector, it also offers an excellent opportunity to further **enhance its global competitiveness**. This means that strengthening the EU's expertise in zero-emission technologies will enable European companies to provide innovative solutions to achieve the transition towards zero-emission waterborne transport. It will also enable European companies to compete in new markets and to regain lost markets which are currently dominated by competitors from the Asian regions. A prime example is the equipment delivery for, and construction of, merchant ships such as bulkers, tankers and general cargo vessels, as well as ferries which, until recently, were mainly built in Europe.

The maritime transport sector **directly employs over 685,000** workers at sea and on shore[8]. It supports **2 million workers through indirect and induced employment**. The EU maritime shipping industry contributes a total of **€149 billion** to the EU's annual GDP[9]. EU companies own 36% of the world fleet, the largest single share in 2018[10].

Europe has **300 shipyards**, the largest of which build the most complex, innovative and technologically advanced civilian and naval ships and platforms in the world. Technologies for these ships form the basis for advanced zero-emission technologies to be further adapted for other ship types. Others maintain, convert, repair or retrofit existing (merchant) ship types. A third category builds, repairs or maintains smaller vessel types or boats. Together, these yards generate **annual production worth €42.9 billion** and **directly employ 285,000 people (EU28)**[11]**.** Moreover, for each job they create, **another six jobs** are created in the supply chain.

Almost half of marine equipment is produced by European companies, including over 70% of the world's large marine engines. The majority of the European marine equipment sector are SMEs.

[7] Internal Wärtsilä calculations based on proprietary Clarksons data.
[8] Oxford Economics, The Economic Value of the EU Shipping Industry (London, Oxford Economics, 2020)
[9] Oxford Economics, The Economic Value of the EU shipping industry, (London, Oxford Economics, 2020)
[10] https://ec.europa.eu/epsc/sites/epsc/files/epsc_clean-transport-at-sea.pdf
[11] In comparison, SEA Europe member countries generate an annual average production value of €47.1 billion and employ 313,000 people. See BALance, "European Shipbuilding Supply Chain Statistics", May 2019.

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With an annual production **of €44.5 billion**, the equipment sector produces and supplies all types of materials, equipment, systems, technologies and services. The companies can be **global, regional or local players**. Europe's maritime equipment companies are the leading providers of solutions to **combat climate change, to minimise marine pollution and to make shipping better connected, more digital, automated or even autonomous**.

Approximately 4 billion tons, representing **75% of all goods, and 415 million passengers pass through EU ports each year**. Ports are not only essential for the import and export of goods, but they also constitute energy hubs, bringing together infrastructure managers, shipping companies and energy suppliers who contribute to the uptake of electricity and clean fuels. Ports also link maritime transport with the hinterland through the different land transport modes, including inland waterways. Ports generate employment: **1.5 million workers** are employed in European ports, with the **same amount employed indirectly** across the 22 EU maritime Member States[12].

Europe has over 40,000 km of navigable inland waterways, connecting hundreds of cities and industrial regions in Europe, 250 inland ports and more than 300 TEN-T seaports. For Europe, inland waterway transport[13] is an important sustainable mode of transport for the carriage of goods and passengers, with the major share of inland waterways' freight passing through Europe's maritime ports.

[12] https://ec.europa.eu/transport/modes/maritime/ports/ports_en
[13] https://ec.europa.eu/transport/modes/inland_en

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3. Projects, Industry Initiatives, Strategies and Policy Initiatives

3.1 Approach

This deliverable provides an overview of the current situation regarding the transition to zero-emission waterborne transport. This assessment is based on the results of relevant projects, feedback from several industry initiatives, existing decarbonisation strategies and policy initiatives for the (waterborne) transport sector. This deliverable is a living document, and will be updated continuously. This analysis provides input to the regular update of the Strategic Research and Innovation Agenda[14] of the Co-Programmed Partnership on Zero-Emission Waterborne Transport[15] in the framework of Horizon Europe.

The Partnership ensures a coordinated and joint approach to develop the disruptive solutions needed to provide solutions for societal challenges. The waterborne transport sector is composed of many different stakeholders in a diversified sector (many different sub segments, different ship types, etc.). Bringing and keeping them together requires a long-term vision, strategy and programming. Business as usual will not achieve the targets, and the Partnership will be key to coordinate initiatives to avoid duplication of efforts and to speed up efforts by joining forces.

The Partnership aims to create the foundations to transform waterborne transport into a net zero-emission mode of transport, through the demonstration of deployable zero-emission solutions suitable for all main ship types and services before 2030. It will contribute to maintaining and reinforcing Europe's global leadership in innovative, green waterborne transport solutions. The Partnership's objective is to **provide and demonstrate zero-emission solutions for all main ship types and services before 2030, which will enable zero-emission waterborne transport before 2050.**

Greening the fleet will happen simultaneously on two fronts: while a certain part of the operational fleet will be converted through retrofitting, it is highly likely that another segment of the service provided by the industry will be replaced by new-builds. Close to 50,000 maritime ships and approximately 12,000 inland vessels are in operation and will need to be converted into zero-emission vessels, through retrofitting as well as replacement. At the same time, new-builds will need to be ready to become zero emission as soon as possible, meaning that they need to be compatible or adaptable so as to be used with a range of potential sustainable alternative fuels, be optimised for efficiency (including digital), potentially deploy electric and/or battery drives, as well as renewable energy assistance. Onboard fuel storage should be suitable for alternative low

[14] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf
[15] https://www.waterborne.eu/images/documents/200527_Zero-Emission_Waterborne_Transport_Proposal_Final_Version_Spread.pdf

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to zero-carbon fuels, potentially based upon modular principles to facilitate conversion to full electric or hybrid powered units.

The best most relevant solution will need to be chosen according to ship size, the type of traffic it is in, its energy demand, the required operating range, the regional energy carriers available and bunkering infrastructure, potentially emerging legislation, policies and governance. Integrated lighthouse projects will show best practice examples to be copied by early adopters. An important factor in the selection and uptake of technologies in waterborne transport, (in addition to societal factors that also include aspects of health and education) is the service a vessel provides. A lot of focus is often put on larger vessels operating a liner service on long distance routes: transport cargo from port A to port B and back, sometimes including one or more stops. However, many ships are operating on a tramp service: with a varying schedule, collecting cargo in port A and delivering it to port B, collecting cargo there for port C, etc. For liner services, ports and vessels can more easily adapt to each other; for instance, fuel choices, bunkering and recharging infrastructure can be aligned. With tramp services, a ship calls at many ports, often at short notice, meaning that the ship's next destination can change overnight and alignment within every port is not possible. If ports worldwide cannot ensure the availability of their fuels, these ships either have to be able to carry relatively large amounts of fuel or electricity or have to be equipped with multi-fuel flexible energy systems. At the same time, there are many other types of vessels, such as passenger vessels or high complex work vessels (e.g. dredging vessels, offshore construction vessels, windfarm service operation vessels). These vessel types often have a high energy demand while possibly operating worldwide as well.

The aforementioned has resulted in the development of implementation pathways for six different types of vessels (additional information is available in the Strategic Research and Innovation Agenda of the Partnership). This classification is adopted in this deliverable as well, so as to ensure that the results of the deliverable feed in the process of updating the Strategic Research and Innovation Agenda of the Partnership.

Figure 2 Types of vessels for the development of implementation pathways

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The technical content of the cPP on Zero-Emission Waterborne Transport is divided into six parallel activities. These activities are:

- Use of Sustainable Alternative Fuels[16]
- Electrification
- Energy Efficiency
- Design and Retrofitting
- Digital green
- Ports

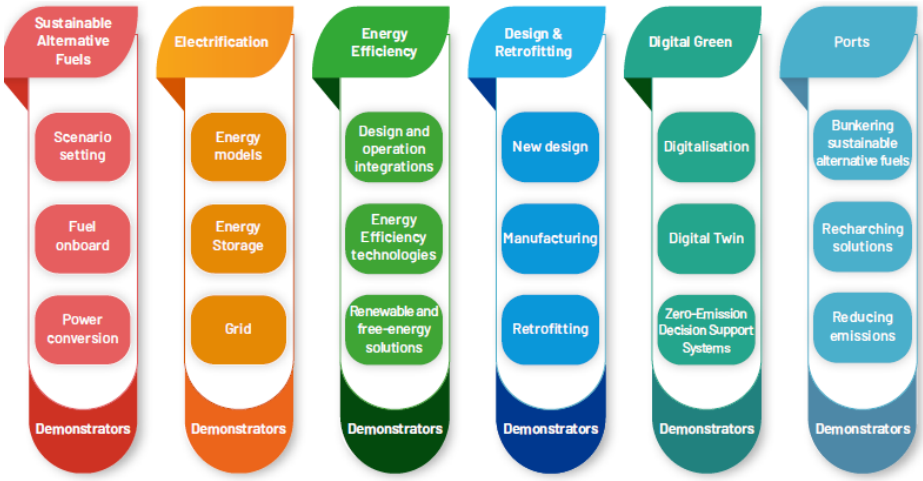

Figure 3 Activities of the Co-Programmed Partnership on Zero-Emission Waterborne Transport

[16] Wherever Alternative Fuels are mentioned in the following (e.g. charts, etc.), please note that reference is made to the use of **Sustainable Alternative Fuels**.

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3.2 Methodology

In the past couple of years, the European waterborne transport sector has initiated numerous projects and initiatives to facilitate the transition towards zero-emission waterborne transport. This deliverable serves as a "living" document and will be updated during the lifetime of the STEERER project. For this reason, the list of relevant projects will continuously be updated and all stakeholders are called to provide their input so as to have an overview as holistic as possible.

Paragraph 3.3 contains a description of the relevant projects, of which a more detailed description is available in Annex 1. For each of the relevant projects, the following items are described (for as far as information is currently publicly available):

- A general introduction regarding the technology, energy carrier and/or solution described;
- An analysis of the number of inland waterway transport vessels on order or in service with the aforementioned technology;
- An analysis of the number of sea-going vessels in service and sea-going vessels on order with the aforementioned technology, based on Clarkson's database:
    - Cut-off date used unless otherwise mentioned: 30 September 2020;
    - The Clarkson's Research World Fleet Monitor covers the World Fleet & Orderbook of Propelled Sea-going Merchant Vessels in excess of 100 Gross Tonnage. This includes the following sea-going vessel types:
        - Bulk Cargo: Oil & Product Tankers, Bulk carriers, Combined Ore/Oil or Bulk/Oil Carriers;
        - General Cargo: Fully Cellular Containership, Multi-Purpose, Ro-Ro, Other Dry Cargo;
        - Specialised: Chemical Tanker, Specialised Tanker, Gas Carrier, Pure Vehicle Carrier, Reefer;
        - Non-Cargo: Offshore, Dredgers, Tugs, Passenger Vessels;
    - Followed by a more in-depth evaluation of the projects and their feasibility. The evaluation is built around the following parameters:
        - Applicability: On what type and size of vessel is the technology being applied;
        - Geographical analysis: in which part of the world is the project being conducted, what are the nationalities of the owners choosing for the technology;
        - Technology analysis: which technology was applied, what capacity does this solution have;

Note: there might be an overlap between the projects in annex 1 and the projects following from the Clarkson's database analysis, since some vessels from projects might already be operational or the project concerns a retrofit of an existing vessel.

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3.3 Relevant Projects

3.3.1 SUSTAINABLE ALTERNATIVE FUELS

To list, explain and evaluate the current initiatives regarding the implementation of Sustainable Alternative Fuels in the waterborne transport sector, it is important to have an understanding of the different operating profiles in the waterborne transport sector in order to match applicability / feasibility of the sustainable alternative fuel concerned.

- **Long distance shipping** comprises large ocean-going ships, and a very large proportion of their energy consumption relates to propulsion of the ship at steady speed over long distances. These vessels are today driven by mechanical, direct- or geared-driven, two-stroke combustion engines. The engines are highly energy efficient for this purpose. The ships require fuel that is globally available, and the fuel energy-density is important to maximize the space available for the transport of cargo over long distances.[17]

- Vessels in the **short-sea segment** are typically smaller, with more varied operational profiles and a greater share of their time and energy is spent on purposes other than steady propulsion. For these ships, the shorter distances and highly variable power demands could make electric or hybrid-electric power and propulsion systems (including diesel/gas electric) more efficient than traditional mechanical drives. Having an electrical power distribution system allows for more efficient energy distribution over a wide range of engine load profiles. It also increases flexibility for using energy from batteries, fuel cells and waste heat as well as renewable sources (e.g. solar, wind, waves). For short-sea ships, the potential share of energy consumption to be optimized by batteries and fuel cells is higher than for deep-sea ships.

- The **Inland Waterway Transport sector** is quite diverse and consists of inland vessels, pushers and floating equipment. Inland vessels are in general smaller as compared to seagoing vessels and have less power installed on board. The vast majority of the European inland fleet sails on high speed (>1250 RPM) pre-CCR, CCRI and CCRII type approved conventional diesel (EN590) driven engines. The vessel type and its operational profile are two key elements which define the suitability of a particular greening technique/fuel. For example, small to sizeable vessels sailing short distances on canals may be suited for fully battery-electric drivetrains, whereas clean liquid fuels may be more appropriate for large vessels sailing long distances on rivers (e.g. Rotterdam-Basel);

- **Cruise ships** are a high technology, high added value product which is key for the European waterborne manufacturing industry. They have been technology leaders for the industry, in particular for green waterborne transport, since their customers demand sustainable transport beyond the standards required by authorities and the vessels operate within the

[17] DNV GL Energy Transition Outlook 2019, p35

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world's most environmentally sensitive regions. Furthermore, cruise ships are characterised by requiring high amounts of energy, including large hotel loads which are present at all times and can be larger than the propulsive load. In the shorter term, retrofitting - to enable the use of a range of potential sustainable fuels, in combination and ultimately as a single fuel - as well as electrical supplies from shore, is a logical choice. Due to their electric drive system, the extension to electric energy storage, as well as energy harvesting for their hotel load, will need to be integrated into their energy grids. For the next generation of cruisers, the most complex combinations are on the agenda; fuel cells in combination with batteries and combustion engines, energy harvesting, electricity storage and propulsion support with wind assistance are the topics which will provide manifold input for innovation transfer into other ship types. The development of smart interaction with ports for cold ironing and alternative fuel supply, for example, will deliver sustainable solutions as well as harmonisation among the ports of call for cruise ships;

- **Ferries** operate between fixed points and are the most suitable application to become fully electric with completely zero emissions. In this respect, they play a leading role when it comes to greening. Ferries operating in Europe covering a wide range of services, from urban/harbour passenger ferries with a range of a few miles, to large inter island RoPax ferries with ranges of 50 to 200 nautical miles with the longest ferry routes being as much as 500 nautical miles. For retrofitting, as well as newbuilds and ferries with a range of up to 200 nautical miles the challenge will be between full battery electric, fuel cells and ICE powered with alternative fuels, with the regional conditions and their policy priorities pushing one or the other type of solution to the forefront. Ferries with significant hotel loads will be candidates to be early adopters of fuel cells. The requirements regarding zero emissions during approach and harbour stay will push hybrid solutions with battery capacities to allow full battery electric transit for reduced noise and emissions. For the long -distance ferries, ICEs with alternative fuels will be the most competitive solution, supported by energy efficiency measures and smart power supply/buffer in port facilities;

- **Offshore vessels** are a wide category of vessels that facilitate offshore installations, operations and maintenance. Historically, this segment has focussed on oil and gas installations. But with the onset of offshore renewable energies and other Blue Growth activities, this fleet has transformed into an enabler of sustainable growth. Many of the offshore vessels are complex work vessels, such as installation vessels, dredgers and cable-laying vessels, which are capable of executing very accurate work. These types of vessels typically have a high energy consumption at peak moments. The technologies used for power generation are the same as those listed for transport vessels. As the offshore vessels are predominantly built in Europe, they are a suitable category for demonstration purposes. The variety of operating profiles, as well as the size of ships, make offshore vessels ideal candidates for innovative solutions. Their close shore activities allow for more frequent fuelling and thus low-density energy carriers can be applied. Operating close to shore also means that it is necessary to reduce SO_x and PM (particulate matter) emissions to the maximum extent possible.

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Different bunkering frequencies and limited space on board of certain vessels in combination with different energy demands implies the need for different onboard technologies.

By examining the onboard technologies in whole - engines, as well as fuel containment, storage, and supply systems - common taxonomies can be identified to simplify the decision-making process[18]. For this reason, the pathways to sustainable shipping from ABS has been chosen to categorize the different fuel options to structure this section of the document.

According to the Pathways to Sustainable Shipping report from ABS[19], the available fuel options can be categorized into three pathways that can propel the waterborne transport sector to 2030 and beyond:

I. The light gas pathway: LNG → Bio-/E-methane → Hydrogen. Generally light, small molecule fuels with high energy content, but more demanding, mainly cryogenic fuel supply systems and storage. On this pathway, if methane slip is discounted, LNG can reduce GHG emissions by approximately 20 percent; bio-methane can be carbon neutral, while hydrogen is a zero-carbon fuel in a tank-to-wake perspective.[20]

II. The heavy gas and alcohol pathway: LPG/Methanol → Bio/e-fuels → Ammonia. Generally heavier, more complex molecules, but with less demanding fuel supply and storage requirements than the light gas pathway. Methanol can reduce CO_2 emissions by approximately 10 percent, while bio-methanol can be carbon neutral, and ammonia is a zero-carbon fuel in a tank-to-wake perspective.[21]

III. The bio/synthetic fuel pathway: Bio-/Renewable Diesel → Gas-to-Liquid fuels → 2nd and 3rd generation biofuels. These fuels have similar properties to diesel oil and thus are much less demanding in terms of new infrastructure and technologies onboard and can be utilized with minimal changes to current ship designs.[22] Availability of these low carbon liquid fuels is still very limited but in June 2020 Fuels Europe published the *Clean Fuels for All,* the EU refining industry's potential pathway to enabling transport to contribute to EU's Climate neutrality ambition by 2050 where it is stated that by 2050, at the latest, every litre of liquid fuel for transport could be net climate neutral, enabling so the decarbonisation of aviation, waterborne and road transport.

The pathway chosen can differ significantly between the different types of vessels and also within the same vessel category depending on the operational profile. It is also possible that the **outlined**

[18] ABS: Patways to sustainable shipping, p. 14
[19] Here the Sustainable Alternative Fuels are being considered, however, this report includes electrification amongst others in chapters 3.3.2.
[20] https://www.offshore-energy.biz/abs-lng-and-hydrogen-lead-fuels-for-shipping-decarbonization/?utm_source=worldmaritimenews&utm_medium=email&utm_campaign=newsletter_2020-10-19
[21] https://www.offshore-energy.biz/abs-lng-and-hydrogen-lead-fuels-for-shipping-decarbonization/?utm_source=worldmaritimenews&utm_medium=email&utm_campaign=newsletter_2020-10-19
[22] https://www.offshore-energy.biz/abs-lng-and-hydrogen-lead-fuels-for-shipping-decarbonization/?utm_source=worldmaritimenews&utm_medium=email&utm_campaign=newsletter_2020-10-19

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sequence in a specific pathway is not necessarily followed in practice. For example, a specific e-fuel may be the final fuel of choice.

The pathways from ABS described above were used for further structuring the paragraph on Sustainable Alternative Fuels. It is important to highlight that this is not THE only pathway. DNV GL for example has set up different scenarios in their latest Maritime Forecast to 2050:

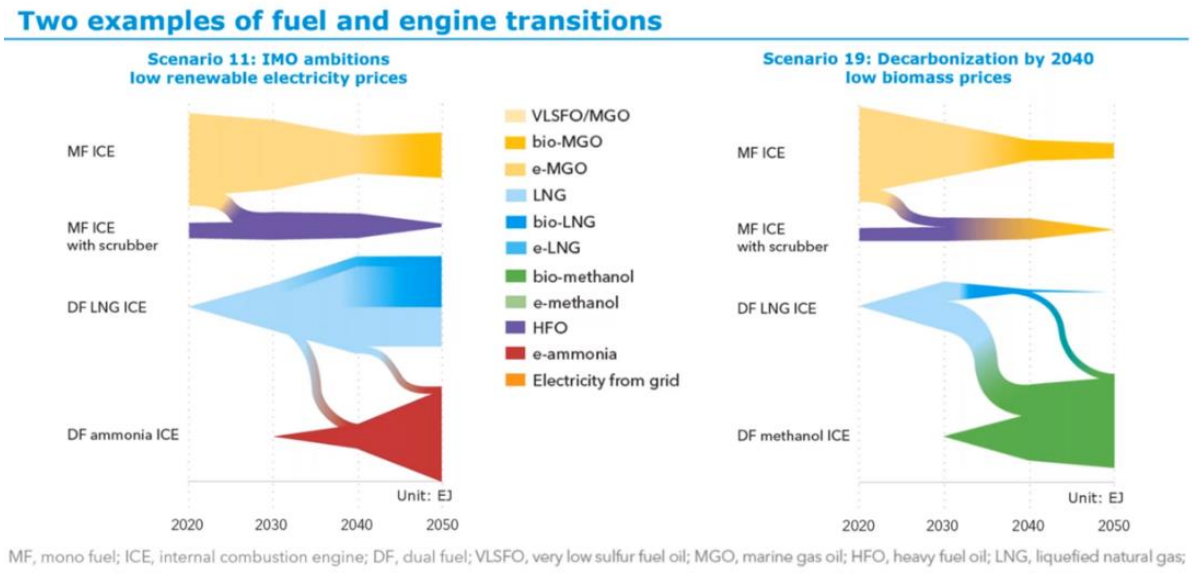

Figure 4 Examples of fuel and engine transitions, DNV GL, Maritime Forecast 2050

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3.3.1.1 THE LIGHT GAS PATHWAY

Liquefied Natural Gas (LNG)

1. Introduction of the fuel

LNG is a clear, colourless and non-toxic liquid which forms when natural gas is cooled to -162°C (-260°F). The cooling process shrinks the volume of the gas 600 times, making it more energy-dense, easier and safer to store and ship. In its liquid state, LNG will not ignite[23].

When LNG is used as energy carrier, it is usually turned back into a gas at regasification plants, when reaching the destination. It is then piped to private homes, businesses and industries where it is burnt for heat and electricity generation. LNG is also emerging as a cost-competitive and cleaner fuel for transport, especially for shipping and heavy-duty road transport. In addition, LNG is readily available as marine fuel, thereby an increasing number of seagoing vessels are sailing on LNG in North Western Europe (in the short-sea trades) and developments are accelerating in other parts of the world (incl. long distance shipping).

The use of LNG in dual-fuel engines and its increasing availability worldwide make LNG a trustworthy and viable intermediate fuel. LNG can enable a smoother transition towards the full use of sustainable alternative fuels, which are not available yet today in the size and scale needed by the waterborne transport sector in ports all over the globe. LNG is a cleaner fuel both in greenhouse gas emissions (-20% CO2) and local pollutants (-80% NOx, -98% SOx, -96% particle matters) compared to MGO, available today at a competitive cost. Additionally**, it is technically feasible to blend LNG with 5 to 10% of clean hydrogen without changing the properties of LNG.**

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis LNG powered vessels in service

A) Clarksons (latest retrieve 29/04/2021)

According to the Clarksons' database there are currently 652 vessels LNG capable (dual-fuel) covering 17 different flees types. From these different fleet types, 66,6% is covered by the LNG fleet followed by ferry (8,4%) and offshore (5,7%). Another 229 vessels are LNG ready (ready for future retrofit[24]) covering 10 different fleet types. From these different fleet types, 37,6% is covered by the container fleet and 28,8% by the bulker fleet.

[23] https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng.html

[24] An LNG Ready ship is a good option in situations where LNG is unlikely to be available for another few years in the vessel's intended area of operation, or if the current commercial terms are not sufficiently favourable for the required extra investment

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LNG capable

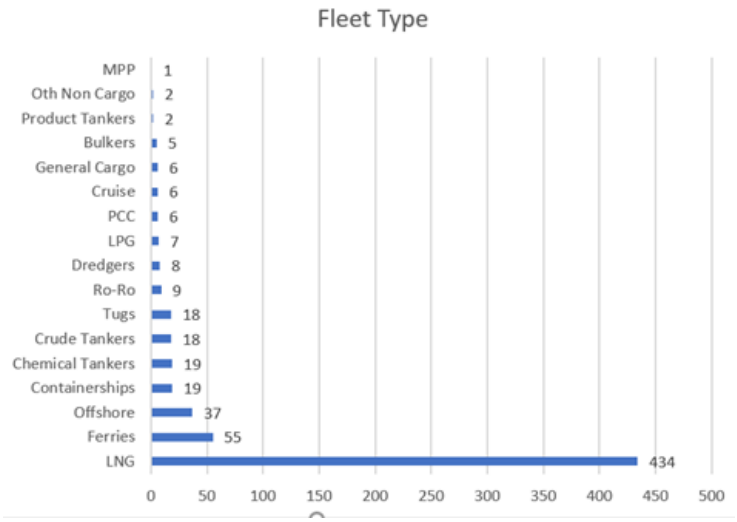

Figure 5 LNG Capable, Fleet Type, cut-off date 29 April 2021

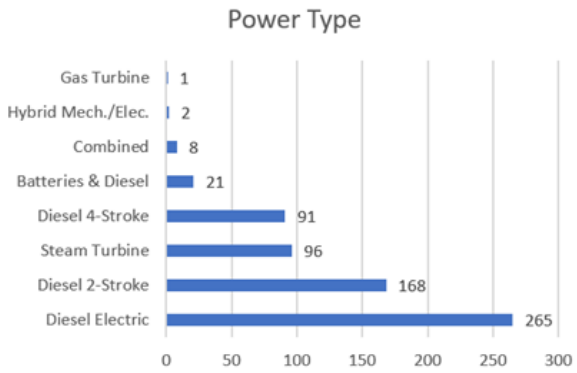

Figure 6 LNG Capable, Power Type, cut-off date 29 April 2021

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LNG Ready

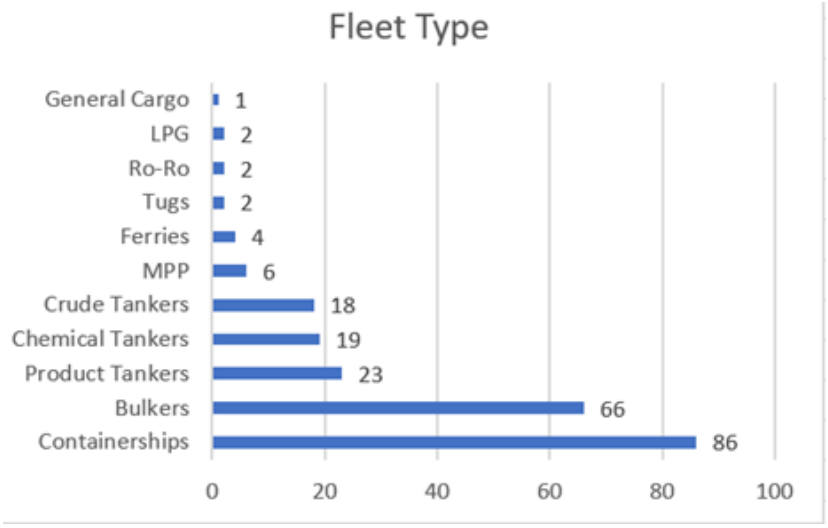

Figure 7 LNG Ready, Fleet Type, cut-off date 29 April 2021

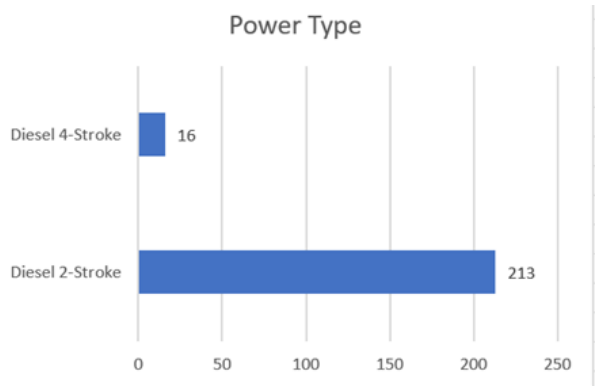

Figure 8 LNG Ready, Power Type, cut-off date 29 April 2021

B) Inland waterway vessels: expert knowledge
According to expert knowledge there are currently 12 inland waterway vessels which cover a wide variety of ship types with the exception of the smallest ones.

2.2. Analysis LNG powered vessels on order
A) Clarksons (latest retrieve 29/04/2021)
According to the Clarkson' database currently 409 vessels on order are LNG capable (dual-fuel) covering 16 different fleet types. From these different fleet types, 35,5% is covered by the LNG fleet. Another 59 vessels are LNG ready covering 7 different fleet types. From these fleet types; 25,5% is covered by the bulker fleet and 24% by container ships.

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LNG capable (dual fuel)

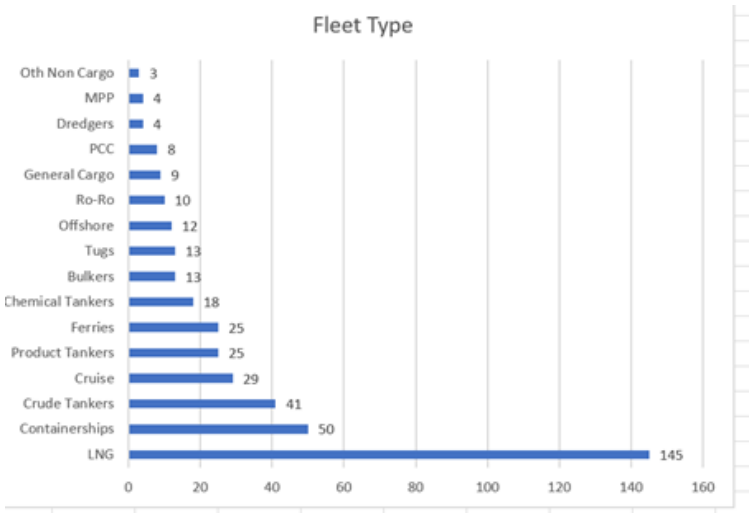

Figure 9 LNG Capable (dual fuel), Fleet Type, cut-off date 29 April 2021

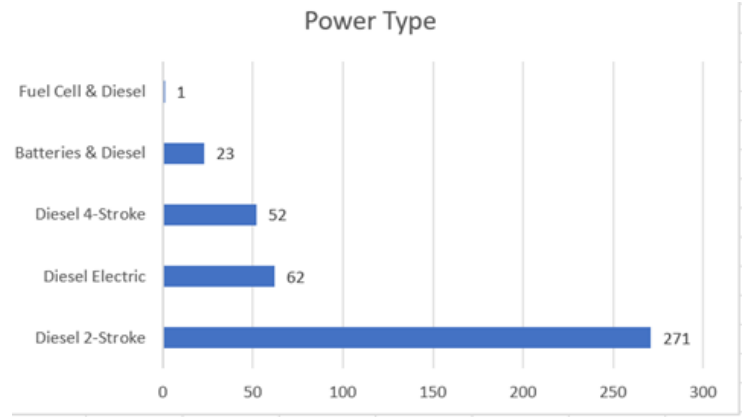

Figure 10 LNG Capable (dual fuel), Power Type, cut-off date 29 April 2021

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2.3. Analysis LNG projects annex 1

Projects included in Annex 1 regarding LNG are rather limited:

- Minerva concerns the world's first dual-fuel trailing suction hopper dredger, launched in 2017. The dual fuel engines allow the vessel to operate on either conventional liquid marine fuels or LNG. The engines can rapidly switch between fuels without loss of power and speed, enabling the vessel to operate in accordance with the regulations in emission-controlled areas, while providing the users an option to select the fuel depending upon the cost and availability. [25]
- LNGHIVE2 concerns the retrofitting of several RoPax ferries in order to create a demand for LNG as a fuel in the Spanish core ports. The project will contribute to the development of infrastructure in Spanish ports to ensure the supply of LNG to ships. The ships' current main engines will be adapted and so there will be no need to replace them with new ones.
- Nautilus (Nautical Integrated Hybrid Energy System for Long-haul Cruise Ships) aims at developing, evaluating and validating a highly efficient and dynamic integrated marine energy system fuelled by Liquefied Natural Gas (LNG) for long-haul passenger ships. This energy system, responsible to cater for all heat & power needs of a vessel, consists of a high-power density Solid Oxide Fuel Cell (SOFC) and a Li-ion battery hybrid genset. It is coupled with the existing Internal Combustion Engine (ICE) based generators.[26]

3. Technology analysis

Taking into consideration the number of vessels in service and on order that are LNG capable/ready gives an indication that the technology is maturing. For low-pressure engines, methane slip is being looked at.

The Nautilus project will develop and deliver a complete process design and digital demonstrator of a fully integrated on-board energy system of a size between 5 and 60 MW for two types of cruise ships: 1000 and 5000+ passenger vessels.

4. Potential barriers

a. Ecological
   - Upstream emissions;
   - Still a fossil fuel.

b. Economical
   - Higher CAPEX: the newbuilding cost of LNG-fuelled ships has typically been about 10–30% higher than for equivalent diesel-fuelled ships. The extra investment needs to be compensated by lower operational expenses, which will depend on oil/gas prices, maintenance cost as well as the regulatory landscape;
   - Marginal difference in OPEX between LNG and diesel. The favourable difference in the bunkering price difference between LNG and diesel diminished significantly after the

[25] https://www.ship-technology.com/projects/minerva-trailing-suction-hopper-dredger-tshd/
[26] https://www.isea.rwth-aachen.de/cms/ISEA/Forschung/Projekte/Oeffentliche-Projekte/Laufende-Projekte/~jrarg/Nautilus/lidx/1/

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oil price plunge in 2014-2016 which especially had a significant negative effect on the business case for inland vessels.

c. Technological
   - Methane slip in low pressure engines (engine technology plays an important role);
   - Possible gas leakage at high pressure;
   - LNG fuel tanks require typically two to three times the volume of fuel-oil tanks with the same energy content;
   - Lack of infrastructure and bunkering facilities for waterborne transport globally.

d. Social
   - Both public and political support for LNG has diminished significantly.

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Hydrogen

1. Introduction of the fuel

Hydrogen is a versatile energy carrier, which can help to tackle various critical energy challenges. Hydrogen can be produced from almost all energy resources, though today's use of hydrogen in oil refining and chemical production is mostly covered by hydrogen from fossil fuels, with significant associated CO2 emissions.

Clean hydrogen, being produced from renewables, nuclear or fossil fuels with CCUS, can help to decarbonise a range of sectors, including long-haul transport, chemicals, iron and steel, where it is proven difficult to reduce emissions. Hydrogen can also help to improve air quality in cities and improve energy security. In addition, hydrogen can also support the integration of variable renewables in the electricity system, being one of the very few options for storing electricity over days, weeks or months. Today hydrogen is mainly used in the refining and chemical sectors and produced from fossils, accounting for 6% of global natural gas use and 2% of coal consumption and being responsible for 830 MtCO2 of annual CO2 emissions. Scale-up will be critical to bring down the costs of technologies for producing and using clean hydrogen, such as electrolysers, fuel cells and hydrogen production with CCUS.

There are two different methods to store pure hydrogen:

- Since hydrogen is a gas at room temperature one way to store it is by compressing the hydrogen. There 5 different types of storage thanks where the pressure range varies between 200-700+ bar.
- When hydrogen is cooled down to -243 °C the molecule becomes liquid. Due to this cooling process, more energy is needed compared to compressed hydrogen.

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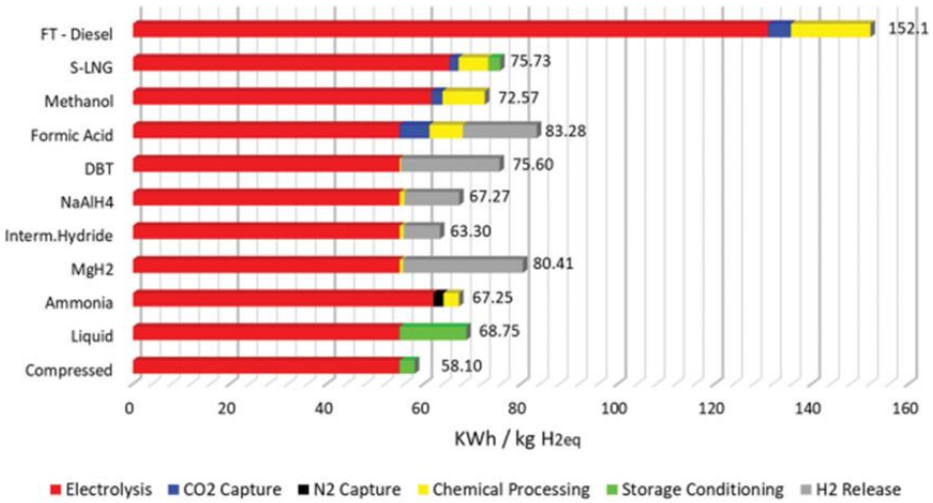

Figure 11 Energy-efficiency per alternative fuel[27]

Because of the low energy density of hydrogen, almost anything is better at storing hydrogen, than hydrogen itself.[28] For this reason, ammonia and methanol are more suitable candidates for maritime applications. These hydrogen carriers and their related projects will be analysed in the following chapters.

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis hydrogen powered vessels in service

A) Clarksons (last retrieve 21/11/2020)

According to the Clarksons' database there are currently no hydrogen powered vessels in service.

B) Inland waterway vessels: Expert knowledge

There is a small number of hydrogen-powered vessels (~5) operational in the inland waterway transport sector, either by fuel cell or internal combustion engine. Most of the vessels concern small tour boats.

[27] Energy & environmental science: Challenges in H2 Storage for Maritime Applications (https://doi.org/10.1039/D0EE01545H)

[28] Ughent presentation in MIDC (07/09/2020): METHANOL AS A VIABLE ALTERNATIVE FUEL

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2.2. Analysis hydrogen powered vessels on order

A) Clarksons (last retrieve 21/11/2020)

According to the Clarksons' database there are currently three vessels on order all due for delivery in 2021:

- 1 tug with a bollard pull of 65 metric tons. The tug has two dual fuel 4-stroke diesel engines from BeHydro with a total capacity of 4MW and a tank array of 400kg. The tug is destined to operate in the port of Antwerp (Belgium)[29];
- 1 passenger catamaran with a capacity of 84 passengers. The catamaran is being equipped with 100 kWh batteries, fuel cells and a tank array of 264kg, giving it up to 2 full days of operation (US)[30];
- 1 RoPax ferry with a capacity of 299 passengers and 80 cars. The ferry is being equipped with batteries, 2x200kW fuels cells from Ballard Power Systems and a tank array of 3,000 kg. At least 50% of the energy requirement will be covered by hydrogen (Norway)[31].

2.3. Analysis hydrogen projects annex 1

There are multiple hydrogen related projects ongoing in Europe, covering both internal combustion engines (H2-ICE) and fuel cells. Analysing the projects, most H2-ICE projects focus on passenger vessels going from 16 up to 80 passengers. In the fuel cell category, both smaller vessels can be found like water taxis and push boats as well as larger vessels such as ferries that can carry up to 640 passengers. Besides passenger vessels, there are also projects focussing on tugboats, push boats and inland cargo vessels.

One project focuses on the use of a containerized genset of 1MW to replace an auxiliary engine of a 1.900 TEU containership with the aim to upscale the capacity later on. It is estimated that the emissions of the auxiliary engine are to decline with 80%.

3. Technology analysis

The analysis of Clarkson and the projects in the annex show that most manufacturers focus on PEM fuel cells. There are several projects ongoing concerning hydrogen combustion engines but these are all linked to the same manufacturer (BeHydro). In September 2020, BeHydro launched the first hydrogen driven dual-fuel engine with a maximum capacity of 1MW. The company also announced to have the first mono-fuel hydrogen engine ready by the second quarter of 2021. When looking at the PEM FC it seems like the maximum capacity currently is limited to 200kW. The fuel cell modules can be connected to reach higher capacity. In November 2020, Havyard Hydrogen announced that they can now offer a system with 3,2MW fuel cells. This will make it possible for large vessels to sail with zero emissions over longer distances. At the same time, the

29 https://www.portofantwerp.com/en/news/hydrogen-powered-tug-world-first-port-antwerp

30 https://watergoround.com/#:~:text=WATER%2DGO%2DROUND%20PROJECT,and%20hydrogen%20fuel%20cell%20technology

31 https://www.rivieramm.com/news-content-hub/news-content-hub/norwayrsquos-first-hydrogen-powered-car-ferries-take-shape-55559

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system is scalable and can be used by both large and small vessels.[32]. The fuel cell providers partnering in the projects are Nedstack, Powercell Sweden, Ballard Power Systems and Toshiba.

4. Potential barriers
   a. Technical
      - Hydrogen production still energy-intensive;
      - Large-scale production expensive;
      - Undeveloped bunkering infrastructure;
      - Expensive to store at -253 °C;
      - Cryogenic hazard: onboard spills can cause hull damage;
      - Low energy density (onboard storage space), especially if compressed instead of liquid storage;
      - Low energy efficiency (impact on fuel cost);
      - Availability of green hydrogen;
      - Bunkering: will swappable containers filled with hydrogen be allowed safety-wise?
   b. Economical
      - CAPEX: high investment cost.
   c. Legal
      - Missing legal framework to apply it as an energy carrier or fuel on board of vessels.

[32] https://www.maritime-executive.com/article/norway-s-havyard-to-present-first-large-ship-hydrogen-system

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3.3.1.2 THE HEAVY GAS AND ALCOHOL PATHWAY

Liquefied Petroleum Gas (LPG)

1. Introduction of the fuel

LPG is recovered from "wet" natural gas (gas with condensable heavy petroleum compounds) by absorption[33]. The recovered product has a low boiling point and must be distilled to remove the lighter fractions and then be treated to remove hydrogen sulfide, carbon dioxide, and water. The finished product is transported by pipeline and by specially built seagoing tankers. Transportation by truck, rail, and barge has also developed, particularly in the United States.

LPG is mainly sourced as a by-product of either oil and natural gas production or oil refining. It can also be produced from renewable sources, for example as a by-product of renewable diesel production. A large network of LPG import and export terminals is available around the world, but the development of a bunkering infrastructure remains a barrier to its use as a maritime fuel.[34]

Propane is a gas under ambient conditions, but it has a boiling point of -42°C and hence by applying a moderate pressure it can be handled as a liquid at room temperature. At pressures above 8.4 bar at 20°C, propane is a liquid.[35] When using LPG instead of fuel oil, up to 18% of CO2 emissions reduction (T-t-W) can be reached.

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis LPG powered vessels in service

A) Clarksons (last retrieve 29/01/2021)

According to the Clarksons' database there are currently 4 vessels in service that are LPG capable (dual-fuel), all 3 are LPG carriers.

2.2. Analysis LPG powered vessels on order

A) Clarksons

According to the Clarksons' database there are currently 45 vessels on order that are LPG capable (dual-fuel), all 45 are LPG carriers.

2.3 Analysis LPG projects annex 1

No projects concerning LPG have been found. Clarkson shows an uptake in LPG as an alternative fuel when it comes to the LPG fleet.

[33] https://www.britannica.com/science/liquefied-petroleum-gas
[34] DNV GL Maritime forecast to 2050
[35] DNV GL PosPaper – LPG as a marine fuel

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3. Technology analysis

Even though the uptake of LPG as an alternative fuel has been low, the number of vessels on order with a dual fuel LPG engine is increasing rapidly indicating that the technology is (becoming) mature. MAN Energy Solutions seems to be the main manufacturer, indicating on their website to already have sold 57 of these engines.

4. Potential barriers

- Still a fossil fuel;
- Missing legal framework to apply it as an energy carrier or fuel on board of vessels;
- LPG supply limited: vessels that carry LPG as cargo show an interest in the technology.

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Methanol (CH_3OH)

1. Introduction of the fuel

Methanol is a promising alternative fuel for reducing emissions and improving the environmental performance of shipping. It contains no sulphur and because it is a clean burning alcohol, emissions of NOx and particulate matter from combustion are low[36]. It is widely available (already in 100 ports today), and storage and distribution are similar to conventional fuels. The additional CAPEX costs of installing methanol systems (e.g. ICE, fuel tanks, piping) on vessels are roughly one third of those associated with LNG systems. The cost of the fuel itself is comparable to or higher than MGO in recent years. Low-carbon methanol is expected to be more expensive. Since methanol is a liquid in normal atmospheric conditions, it can be stored in standard fuel tanks for liquid fuels, if certain modifications are made to accommodate its low-flashpoint properties. [37] Compared to HFO, the required tank volume needs to increase with 233%.

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis methanol powered vessels in service

A) Clarksons

According to the Clarksons' database there are currently 12 vessels in service that are methanol capable (dual-fuel 2-stroke engine) from which 11 are methanol carriers of around 50,000 dwt. The 12th vessel is a passenger/car ferry - the Stena Germanica - which was converted in 2015 to be capable of running on methanol. The 240-metre-long ferry, with a capacity for 1,500 passengers and 300 cars, was retrofitted with a first-of-its-kind fuel-flexible Wärtsilä 4-stroke engine that can run on methanol or traditional marine fuels.

2.2. Analysis methanol powered vessels on order

A) Clarksons

According to the Clarksons' database there are currently 11 vessels on order that are methanol capable (dual-fuel 2-stroke engine) due to be delivered within the next 3 years. The majority of interest for methanol as an alternative fuel lies again within the methanol carrier fleet. New is the interest in the chemical tankers fleet (2). All 11 vessels are around 50,000 dwt.

2.3. Analysis methanol projects annex 1

Two projects were found that are still ongoing. In the HyMethShip project methanol is reformed on board of the ship into hydrogen (which is used as fuel in an H2-ICE) and CO_2 (which is captured and stored). The technology is being applied on a ferry and the project is due by mid-2021. In the Fastwater project a harbour tug, a pilot boat and a coast guard vessel are being retrofitted to dual fuel propulsion.

[36] https://www.sspa.se/alternative-fuels/methanol-alternative-fuel-greener-shipping
[37] DNV GL Maritime outlook to 2050 – Energy transition outlook 2019

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3. Technology analysis

Even though the vessels analysed in section 2 all concern combustion engines, high temperature 200 kW PEM fuel cells in combination with a methanol reformer are also an option. Because of the reformer, there is a limitation to how fast the load points of the fuel cell can be changed dynamically so mostly when dealing with reformed systems, a battery system needs to be added to take the peak loads and the start-up loads. The start-up time of a fuel cell takes 10 minutes. The fuel cells have a modular design and can be scaled up to 5MW.[38] Fuel cells combined with alternative fuels can efficiently reduce and even eliminate emissions and noise, while energy efficiency can be increased as compared to combustion engines.[39]

Research on combustion strategies for methanol is also still ongoing.[40]

4. Potential barriers

- Low energy density;
- Retrofit can be complex, the engine needs to be retrofitted and the existing fuel tank may not be suitable (methanol is corrosive, tank needs a second internal barrier to control leakage of aerosols, as well as special coating);
- Delay of decarbonisation? Will always contain carbon but can be produced by carbon capture and usage;
- Missing legal framework to apply it as an energy carrier or fuel on board of vessels;
- Availability of green methanol.

[38] Blue World Technologies (Methanol Day)
[39] DNV GL Maritime forecast to 2050 - Energy transition outlook 2019

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Ammonia (NH3)

1. Introduction of the fuel

Ammonia is a colourless gas under ambient conditions with a lower density than air. The boiling point is -33.3°C and hence by applying a moderate pressure it can be handled as a liquid at room temperature.[41] The organic compound is already being used 100 years in the fertilizer industry, in cooling systems and as a component to control nitrogen oxides emissions (in the form of urea).

Ammonia is a hydrogen carrier that makes use of nitrogen to store the hydrogen. This process is known as the Haber-Bosch process. The energy efficiency of the of ammonia is close to the efficiency of liquid hydrogen if the ammonia is used as a fuel directly, taking into account the energy used for the electrolysis, the N2 capture and the chemical processing. If more efficient systems for ammonia combustion are used, this value can decrease.[42]

Ammonia has the key benefit of being easier to store than hydrogen, i.e. nearly identical to LPG at low pressure under ambient conditions. Hence, the cost of storage per energy unit is significantly cheaper than either hydrogen, electricity in batteries or LNG. Furthermore, ammonia does not contain carbon and processes for producing it from renewable energy are known, even though it typically is produced in industrial processes from natural gas. Therefore, it is possible to regard ammonia as an energy carrier that is more convenient than hydrogen, but still CO2 emission free under the right circumstances. [43]

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis ammonia powered vessels in service

A) Clarksons

According to the Clarksons' database there are no ammonia powered vessels in service.

2.2. Analysis ammonia powered vessels on order

A) Clarksons

According to the Clarksons' database there are no ammonia powered vessels on order.

B) Inland waterway vessels: expert knowledge

No ammonia applications/plans in IWT so far. This is currently still considered too dangerous for inland navigation, among others by the Dutch ministry (IenW) and Port of Rotterdam.

2.3. Analysis ammonia projects annex

Even though ammonia as a marine fuel is still in its infancy, several shipyards in mostly Asean countries (South-Korea, China, Japan) are working on designs for ammonia-fuelled propulsion

[41] DNV GL Ammonia as a marine fuel
[42] Energy & environmental science: Challenges in H2 Storage for Maritime Applications
[43] DNV GL Ammonia as a marine fuel

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systems together with MAN Energy Solutions. There is a wide variety of ship types for which propulsion systems are being designed: a 50,000dwt ammonia tanker, a 2,700 TEU container feeder, a 23,000 TEU container, an ammonia gas carrier and a tug boat. Most shipyards plan to commercialize their vessel by 2025. In Europe, an offshore supply vessel (Viking Energy) will be modified to run on a 2 MW direct ammonia solide oxide fuel cell (SOFC) delivered by Prototech. The system will allow the vessel to sail solely on clean fuel for up to 3,000 hours annually. The vessel is estimated to be operational by 2024.

3. Technology analysis

From the analysis in section 2 it could be deducted that the technology around ammonia fuelled propulsion is still being developed. Regarding propulsion technology, MAN has an ammonia two-stroke combustion engine that only requires a minor adaptation of an existing, mature technology, the ME-LGIM. This engine type has been in service for some time and has achieved 50,000 running hours on methanol. The LGIM concept is used as basis for the LGIP engine (which uses LPG as fuel, and is now being adapted to use ammonia as fuel). The development of the LGIM engine also dealt with some of the challenges related to ammonia such as corrosion, toxicity and low flammability. The same engine concept, already verified at sea, will constitute the core of the ammonia-combusting engine.[44] The technology group Wärtsilä announced in June that they will commence testing of ammonia as a fuel in a marine four-stroke combustion engine in the first quarter of 2021.[45]

4. Potential barriers

- IGC code to be updated: toxic cargoes not to be used as fuel. As long as the IGC code is not amended, the flag needs to decide (communicate with classification societies). Hence, there is a missing legal framework to apply it as an energy carrier or fuel on board of vessels;
- Ammonia slip (Safety/toxicity issue that need to be observed):
  - Still requires investigation (highly complex: high amounts of ammonia trigger aerosols which then trigger other components). A lot of research is being done in grain fields of the US where farmers are directly applying ammonia on the fields. For engines running on ammonia, it will depend on temperature, residence time and catalyst;
  - If you have an SCR, typically urea would be used as reaction agent. This would mean that if you have ammonia slip you can reduce the amount of reaction agent that you would be using.
    - NOx should not be a problem with current technologies (SCR);
    - N_2O to be minimized by engine manufacturers: tests still needed;
    - Operational venting: is venting ammonia acceptable? Option to recover the ammonia rather than venting?;

[44] MAN ES technical paper, Engineering the future two-stroke green-ammonia engine, November 2019

[45] 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

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- Gas freeing operations (minimum every five years): will bring a lot of smell;
- Weakness: low volumetric energy density & high fuel cost.

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3.3.1.3 THE BIO-/SYNTHETIC FUELS

Sustainable biofuels are flexible alternatives. They can be blended with conventional fuels or used as drop-in fuels fully substituting conventional fossil fuels. However, the bio-/synthetic alternatives that are mentioned in the pathways were left out in the analysis of sustainable alternative fuels since going from the fossil variant towards the bio-synthetic variant (e.g. from LNG to bio-LNG or H2 to e-H2) will have a limited impact on onboard technologies. It can rather be regarded as a drop-in fuel, which can be used directly in existing installations without significant technical modifications. For this reason, biofuels may be well suited to substitute for oil-based fuels in the existing waterborne transport fleet.

Biofuels is a very broad term covering a wide range of fuels produced from biomass. Depending on the source of biomass, processing and type of energy used to convert it into a fuel, the carbon reduction or sustainability potential of each fuel will also vary. The supply chain for each fuel can be complex and can have an impact on other environmental parameters, such as land use.[46]

The advantage of the biofuels is that they can be blended at gradually higher shares as a drop-in fuel into heavy fuel oil or diesel, which avoids the need for new vessels and fuel systems. However, this fuel category does not require any changes in the engine; as this does not influence the technology, the scope of research is consequently a more limited one.

More importantly, as noted by the IEA in its latest Renewables report, all biodiesels are more expensive than fossil marine fuels, therefore rarely used by the shipping companies, and also by the bunkering companies. Among the exceptions is the port of Rotterdam, one of the top three ports globally by bunker fuel sales, is home to a cluster of biofuel trial activity. Biofuel use is currently supported economically by a national scheme that allows renewable marine and aviation fuels to be used to meet EU RED targets. Tickets are awarded per unit of energy and have reached a value of up to EUR 0.60 per litre of biofuel, depending on fuel quality and feedstock. The scheme is currently undergoing revision[47].

Synthetic fuels, also known as e-fuels or P-t-F (Power-to-Fuel), are fuels that can be produced by combining hydrogen and CO2. The process for producing fuels in this manner is well known and, depending on demand, any type of hydrocarbons can be produced, such as e-LNG, e-methanol, e-LPG or e-MGO. In order for these fuels to be considered “low carbon”, it is important to use hydrogen produced with zero carbon energy (such as electrolysis powered by renewables or nuclear) and CO_2 that is extracted from the atmosphere. In this way, the CO_2 that is emitted when using the fuel will be balanced by the CO_2 removed from the atmosphere. One important benefit of these fuels is that they can be used in existing infrastructure. However, infrastructure for producing clean hydrogen is needed, and the technology for extracting CO_2 from the atmosphere is still expensive and energy intensive. An alternative would be to use CO_2 captured from another

46 https://www.dnvgl.com/maritime/webinars-and-videos/on-demand-webinars/access/afoc2020-faq.html?utm_campaign=MA_20Q4_WBNR_FOLLUP_Alternative%20Fuels%20Online%20Conference%20No2%20FAQs&utm_medium=email&utm_source=Eloqua

47 Renewables 2020. Analysis and forecast to 2025. IEA, revised version (nov 2020), pag. 160-166: https://iea.blob.core.windows.net/assets/1a24f1fe-c971-4c25-964a-57d0f31eb97b/Renewables_2020-PDF.pdf

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combustion process, but in this case the overall carbon balance has to be calculated taking into account that CO_2 is not completely eliminated.[48]

[48] https://www.dnvgl.com/maritime/webinars-and-videos/on-demand-webinars/access/afoc2020-faq.html?utm_campaign=MA_20Q4_WBNR_FOLLUP_Alternative%20Fuels%20Online%20Conference%20No2%20FAQs&utm_medium=email&utm_source=Eloqua

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3.3.1.4 Life Cycle Performance Assessment (LCPA)

LCPA stands for Life Cycle Performance Assessment and combines aspects of Life Cycle Assessment (LCA) and Life Cycle Costs (LCC). It is a novel and practice-oriented method for a holistic assessment of marine energy systems in the early design phase. The following charts have been produced with BAL.LCPA method and tool. The LCPA in this paragraph will serve as a starting point for other related deliverables of the STEERER project, as well as to facilitate discussions in the context of the Scientific Committee and the Green Shipping Expert Group concerning the use of Sustainable Alternative Fuels to achieve the objective of zero-emission waterborne transport.

Special care has been taken regarding the data acquisition and assessment of existing and future marine fuels. Here, a multi-criteria evaluation combining physical fuel properties, life cycle inventory data and costs is vital.

The LCPA-Tool offers a broad range of key performance indicators (KPIs):

- Energy resources (CED - cumulated energy demand);
- Ecological impact (GWP - Global Warming Potential, EP – Eutrophication Potential, AP – Acidification Potential, AFP - Aerosol Formation Potential);
- Economical impact (NPV - Net Present Value).

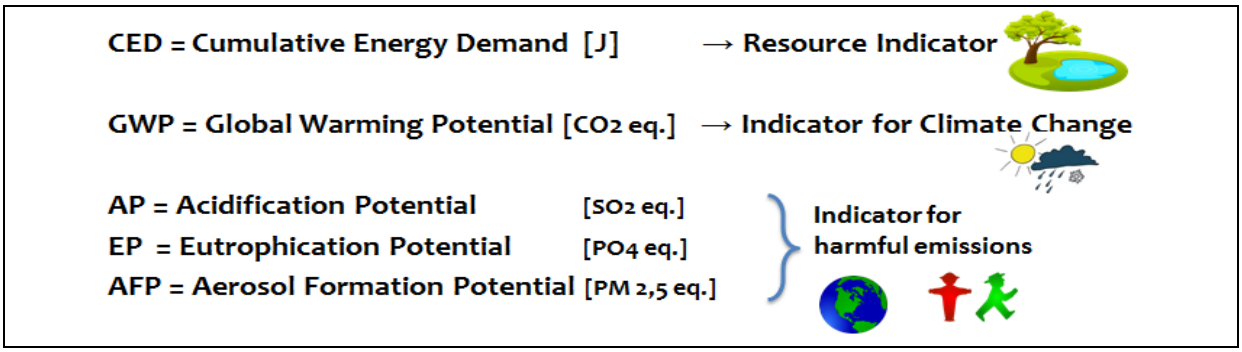

Figure 12 Environmental KPIs and their Impact Categories (source: JOULES project)

This holistic assessment is completed by taking into account external costs which is useful to evaluate the relevance of different impact categories. The external cost indicator is an additional information of the LCPA tool and is not a part of a LCA according to the ISO standards. Similar to the cost approach a 'distance-to-target' method was established to aggregate the emissions and their environmental impacts with regard to political emission targets.

The charts below result from a comparison of a 1MW energy converter with different fuels. For illustration an electric engine has been included considering the electricity production only.

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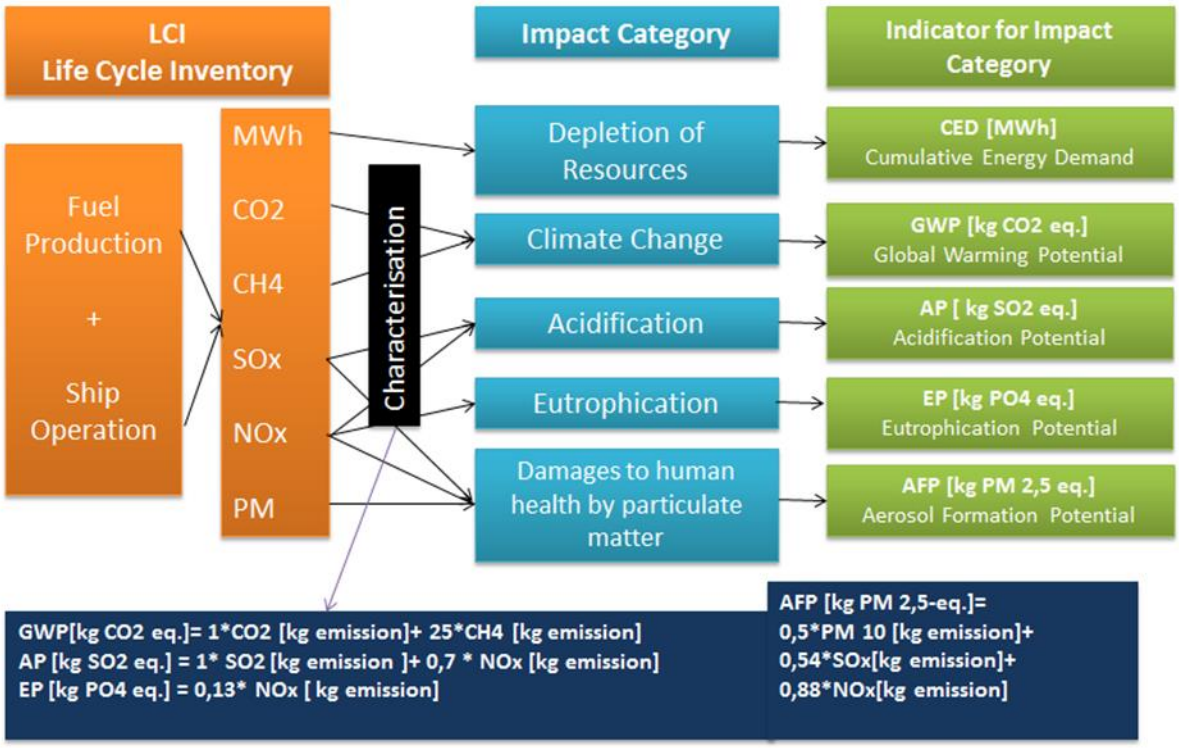

Figure 13 Indicator System for Environmental Impact Categories

The different combinations of energy carrier and energy converter perform differently in the different impact categories.

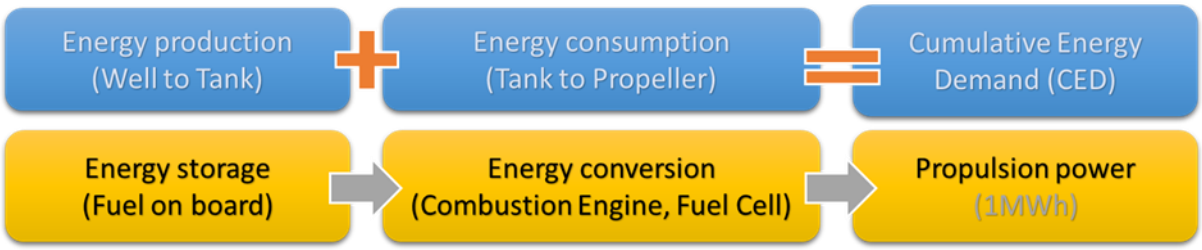

Figure 14 comparison model

All candidates deliver 1MWh propulsion power (see figure 14), but due to the energy conversion efficiency and the differences in energy density of the fuels (energy carriers) the results for e.g. depletion of resources indicated by the cumulative energy demand to produce and transport the fuel the differences are significant. As shown in figure 15 the differences in conversion efficiency are not as significant as the differences in the energy demand to produce the fuels. The figure also shows why the fossil fuels we use today are so popular and why it is difficult to replace them with cleaner alternatives as long as we have no surplus in renewable energy.

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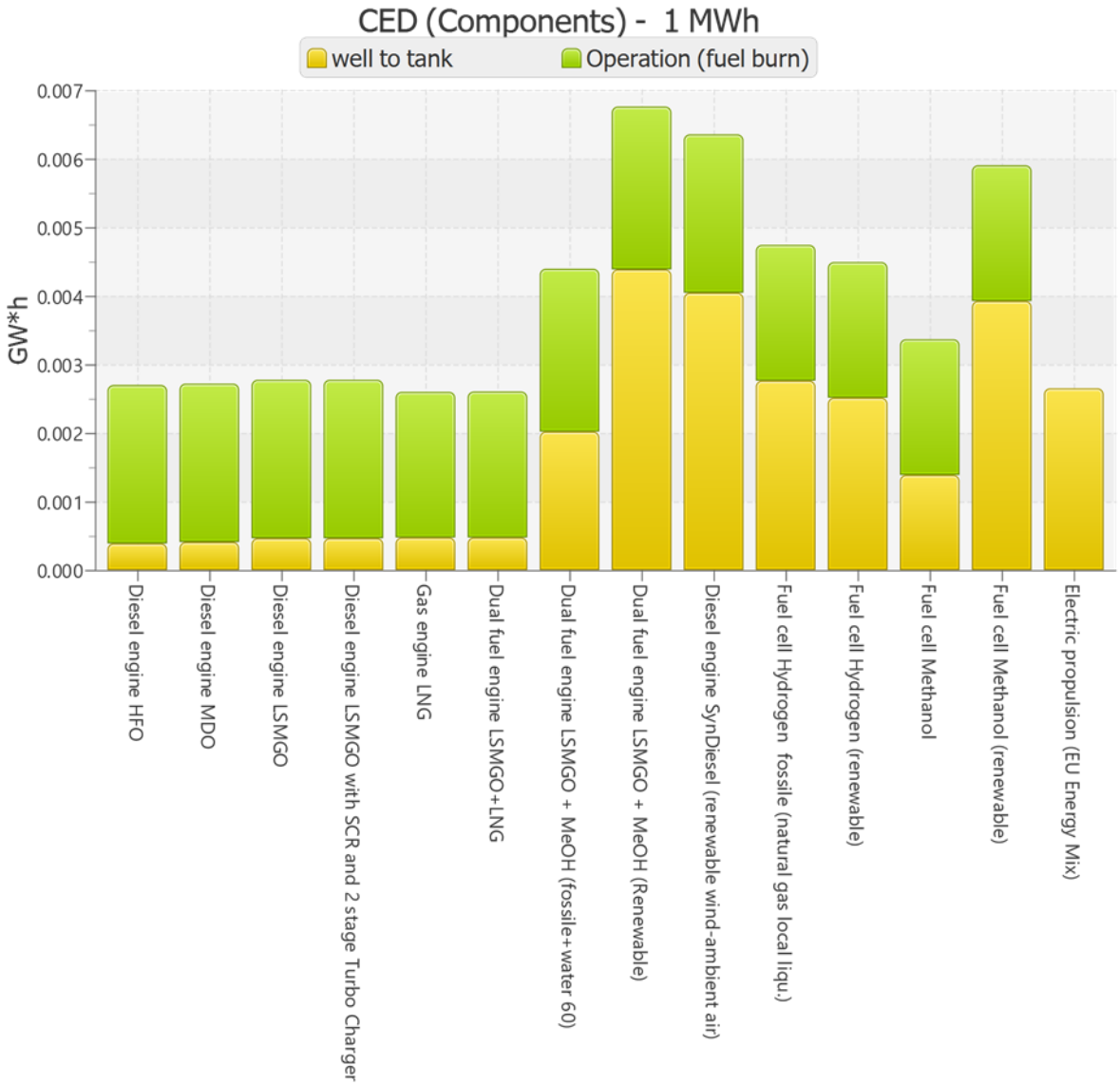

Figure 15 Cumulative Energy Demand

This picture clearly shows that clean fuels require more energy to be produced than fossil fuels. This is also reflected in the price of the fuel which is the reason why fossil fuels are used when cost of transport is the main issue. Unfortunately, the burning of fossil fuels comes with a bunch of problems for the environment as well as for human health. Repairing these damages will be possible on the cost of society. This is what we refer to as externalities.

For the analysis of the external costs we have to distinguish between the CO_2 and the NO_x, SO_x and PM 10 emissions. The impact of CO_2 emissions is globally. Meaning independent on the location of the emitting vessel. NO_x, SO_x and PM10 are regional and local emissions.

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When we consider the additional aspect of externalities the picture looks quite different. Figure 16 shows that the externalities per fuel type are significant and differ in type. HFO for instance has its most significant share in SO_x and PM10, while all diesel fuels share the same cost for CO_2.

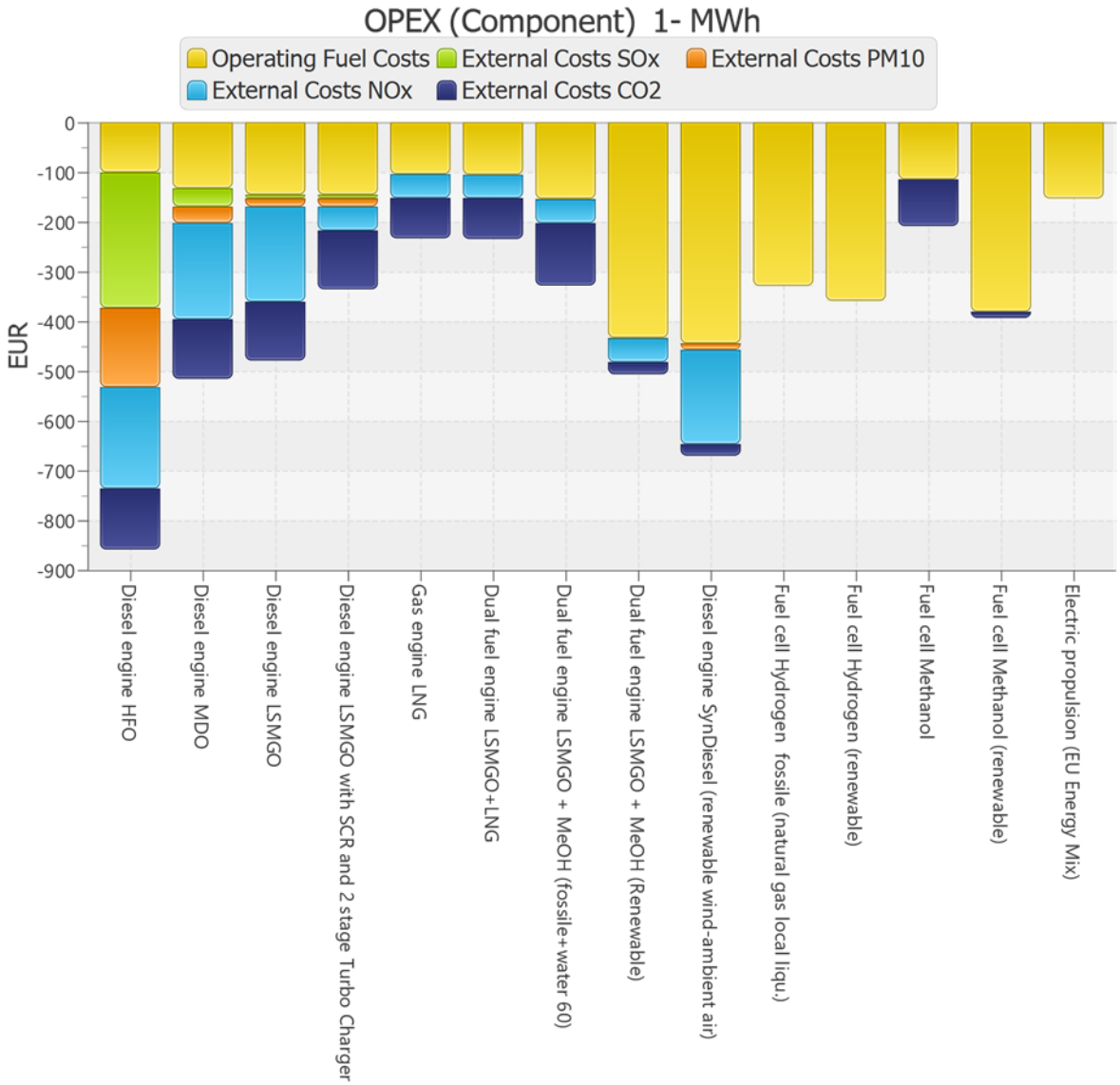

Figure 16 Operating Expenditure

To understand the reason for the high external cost it helps to look into the Global Warming Potential. The "negative" CO_2 emissions when capturing CO_2 from ambient air makes the operational balance for the Syn.Methanol and Syn.Diesel from renewable sources extremely attractive.

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Figure 17 Global Warming Potential

Also looking into the harmful emissions for humans and environment (EP, AP, AFP) it becomes immediately clear that fuels from the family of diesels are creating significantly more problems than LNG, Methanol and Hydrogen.

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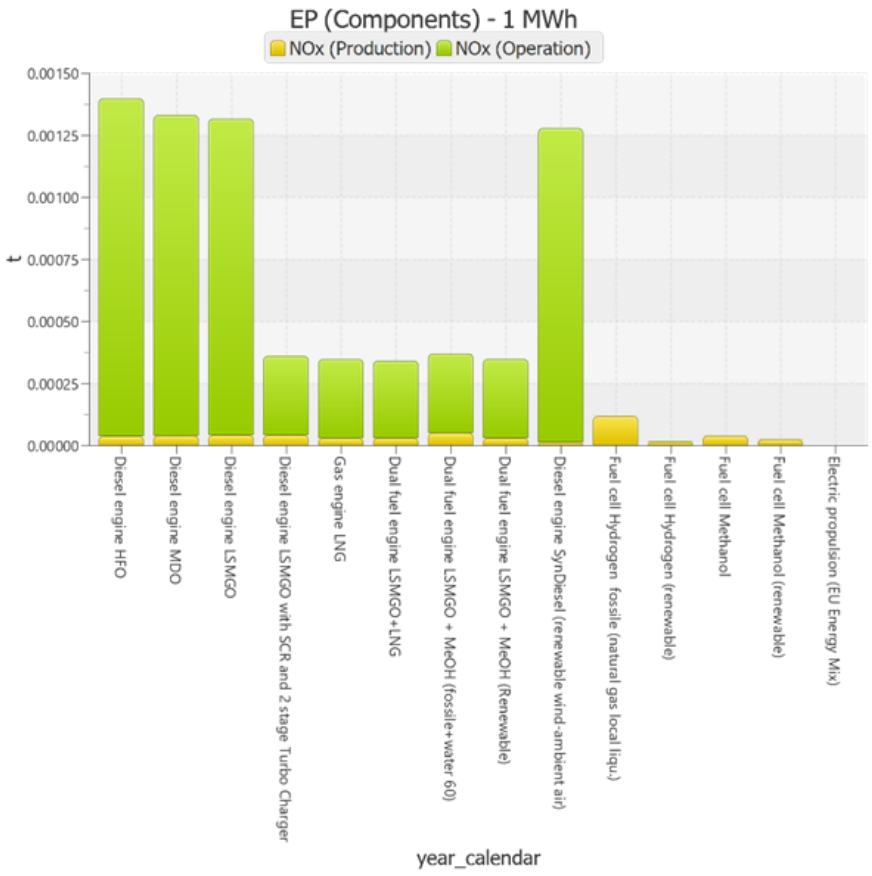

Figure 18 Eutrophication Potential

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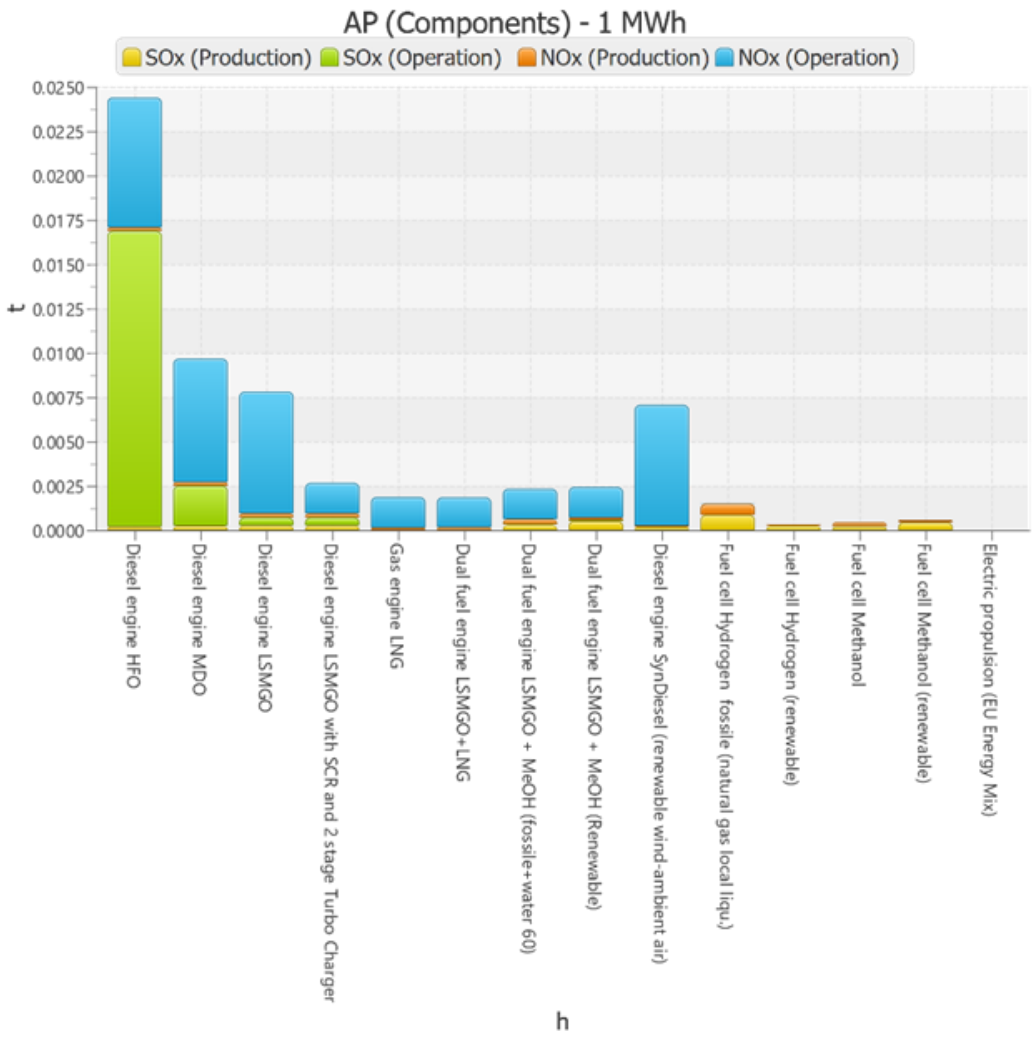

Figure 19 Acidification Potential

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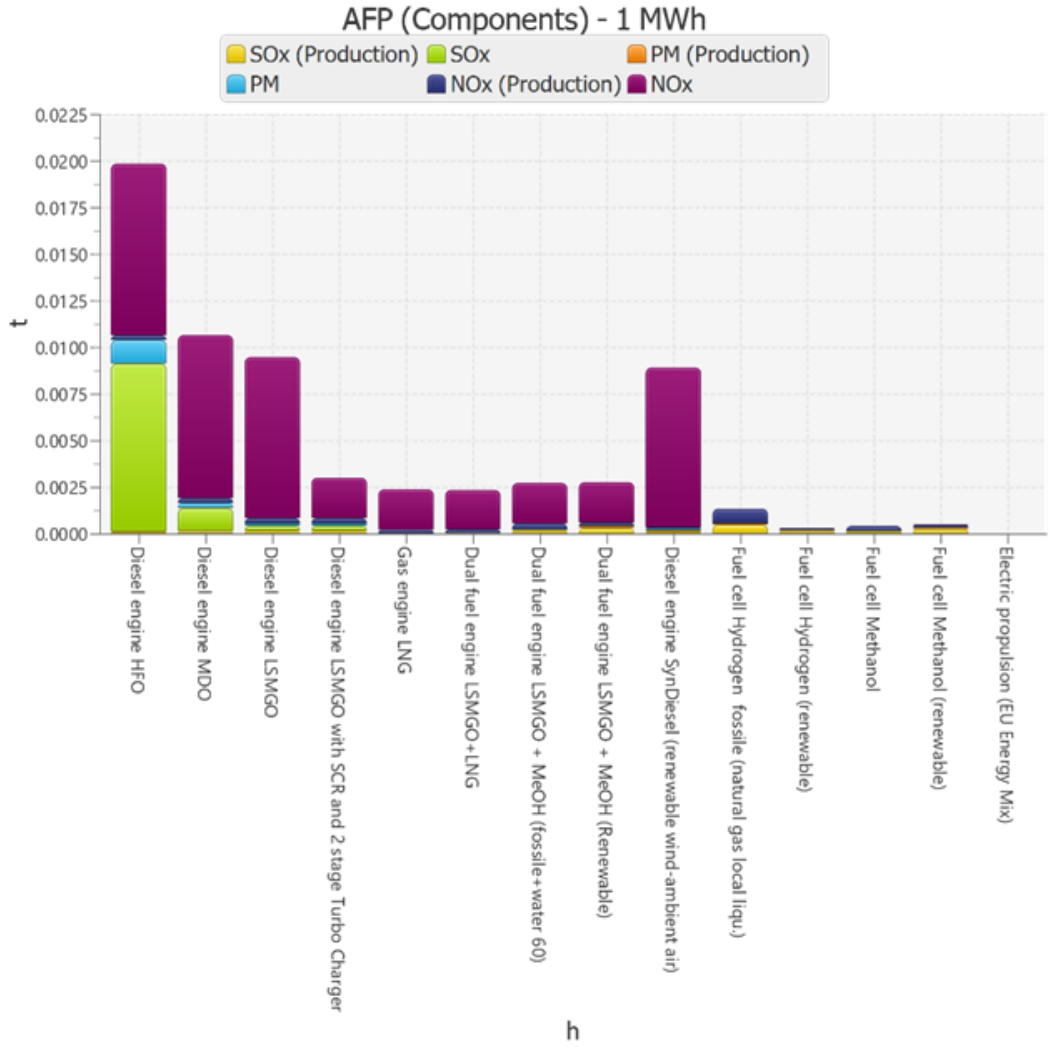

Figure 20 Aerosol Formation Potential (PM)

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3.3.2 ELECTRIFICATION

1. Introduction of the technology

A battery is an electrochemical system that can store electric power with very high responsiveness. In principle, batteries can serve all energy demands on a ship. The ship can operate on batteries alone on specific parts of the route; for example, when manoeuvring in port or during standby operations. It can also be 100%-electric for normal operation, with engines only for available backup or special circumstances. If the electricity comes from a renewable energy source, a full-electric ship may be considered to emit no CO_2, NO_x, PM and SO_x. Depending on the propulsion arrangement, it may also produce no engine noise.

2. Analysis of vessels in service, vessels on order and related projects

2.1 Analysis fully electric vessels in service

A) Clarksons (last retrieve 29/04/2021)

According to the Clarksons' database there are currently 23 fully electric vessels in service, all ferries from which 18 have the Norwegian flag.

Another 153 vessel are hybrid vessels (batteries and diesel) covering 11 different fleet types. From these fleet types, ferries cover the largest share (41,8%) followed by the platform supply vessels of the offshore fleet (36,6%).

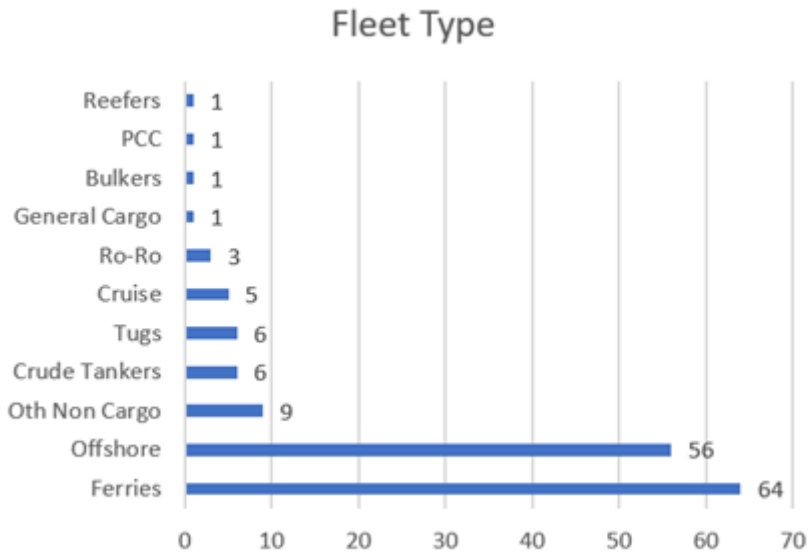

Figure 21 Hybrid Vessels (Fleet Type)

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2.2. Analysis fully electric vessels on order

A) Clarksons (last retrieve 29/04/2021)

According to the Clarksons' database there are currently 34 fully electric vessels on order due for delivery between 2020 and 2023 covering 4 different fleet types. From these fleet types ferry again covers the largest share (85,3%). Almost half of the vessels are ordered by Norwegian owners (41,2%) followed by Thai owners (35,3%).

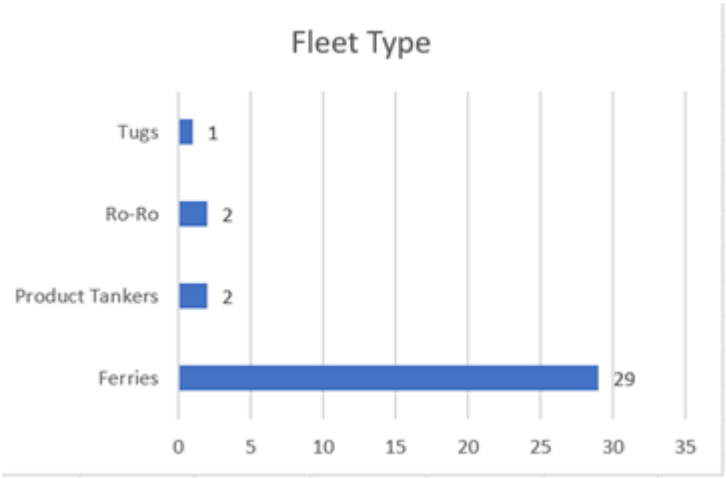

Figure 22 Fully Electric Vessels on order (cut-off date 29 April 2021)

Another 88 vessels are hybrid vessels (batteries and diesel) covering 10 different fleet types. From these fleet types, ferries again cover the largest share (30,7 %), followed by offshore (21,6%) and general cargo (13,6%). Almost half of the vessels are ordered by Norwegian owners (42%) .

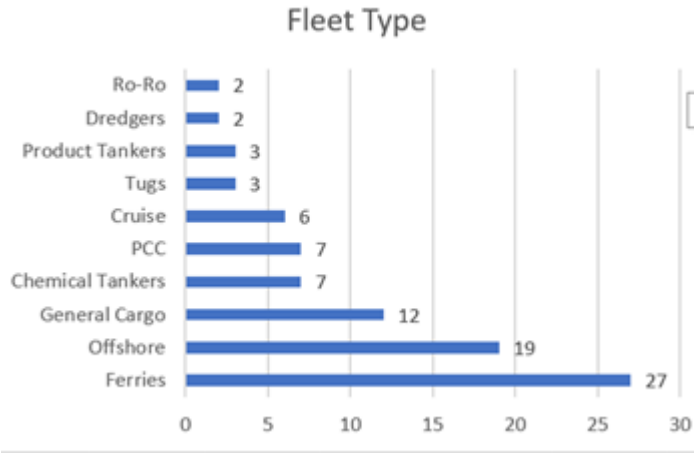

Figure 23 Hybrid Vessels on order (cut-off date 29 April 2021)

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2.3 Analysis projects annex

In service

Only a few of the projects were fully electric: Ellen (a midsized ferry of 200 pax and 30 cars), a small cargo vessel (2.000 tons carrying capacity) and an inland container vessel (104 TEU).

The larger vessels - such as a crude tanker of 130.000 dwt, ferries of 600-1500 pax and cruise vessels of 530 pax - use electrification mainly for peak shaving in a first phase. In later phases, capacity can be scaled up by adding and connecting batteries in order to cover more operations. Except for the crude tanker, the vessels are either liners or operate on inland waterways.

On order

It seems like there starts to be an uptake in the inland waterway transport sector for fully electric vessels and more specifically in for inland container vessels (Combined Cargo Terminals & Sendo Shipping, BCTN). The interest for fully electric for medium sized ferries continues. In addition, there is one project in Japan concerning an oil bunkering tanker of 1.500 dwt.

Again, the larger (liner) vessels – such as a ferry of 1500 pax and cruise of 1000-4000 pax – focus on hybrid solutions.

3. Technology analysis

ZES-pack:

- Delivery of replaceable battery containers for new and existing inland waterway vessels. A network of open access charging points will be set up for exchanging depleted battery containers for ready-charged replacements, thereby keeping waiting time to a minimum. The network of charging stations will be gradually expanded to form a national grid of approximately 20 charge points. **An inland vessel can travel some 50 to 100 km on two charged ZES-Packs** – depending, among other factors, on the currents and the vessel's size and draught. (2,4MWh ~ 5 hours)

Containerized Battery Energy Storage System (CBESS):

- Trident Maritime Systems
  - 1MWh: installed on Stena Jutlandica. The system will be switching to battery power for bow thrusters and manoeuvring;
  - 600kWh: installed on Maersk Cape Town. The system aims to improve the vessels' performance and reliability while reducing CO_2 emissions.

ABB, Corvus Energy and Leclanché are all energy storage solution providers (ESS) that collaborate frequently as partners in the projects.

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4. Potential barriers

- Impractical for larger vessels or those on long voyages due to size of batteries needed;
- Weight: vessels like dredgers fully utilize their load capacity. Adding extra weight in the form of batteries can cause extra unnecessary trips;
- Potential loss of cargo space;
- Increase in bunker frequency.

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3.3.3 ENERGY EFFICIENCY MEASURES

Energy-efficiency is not only important in terms of reduction of emissions by making more efficient use of the current fuels, it is equally important to ensure an economically viable use of sustainable alternative fuels. Most of the sustainable alternative fuels have a higher cost than the traditional fuels, and thereby energy efficiency will be key in reducing the operational expenses of using sustainable alternative fuels. This paragraph describes a number of energy-efficiency measures which are key in reaching this efficient level of the use of (sustainable alternative) fuels.

Before analysing the different energy efficiency measures, it is important to note that each measure can have a different result in reduction potential. Table 1 below gives an indication on how the range per type of measure can vary. It is important to not only take into account the ship type and size when adopting a technology, but for some measures such as wind power it is also important to take other factors into account such as the routes of the vessel.

Type of measure	Main measures reviewed	Short description	Potentia CO_2 reductio
Hull design	Vessel size	Economy of scale, improved capacity utilization	4–83 %
	Hull shape	Dimensions & form optimization	2–30%
	Lightweight materials	High strength steel, composite	0.1–22%
	Air lubrication	Hull air cavity lubrication	1–15%
	Resistance reduction devices	Other devices/retrofit to reduce resistance	2–15%
	Ballast water reduction	Change in design to reduce size of ballast	0–10%
	Hull coating	Distinct types of coating	1–10%
Power & propulsion system	Hybrid power/ propulsion	Hybrid electric auxiliary power and propulsion (Incl. e.g. variable speed electric power generation)	2–45%
	Power system/machinery		1–35%
	Propulsion efficiency devices		1–25%
	Waste heat recovery		1–20%
	On board power demand	On board or auxiliary power demand (e.g. lighting)	0.1–3%

Type of measure	Main measures reviewed	Short description	Potential CO_2 reduction
Alternative fuels	Biofuels		25–84%
	LNG		5–30%
Alternative energy sources	Wind power	Kite, sails/wings	1–50%
	Fuel cells		2–20%
	Cold ironing	Electricity from shore	3–10%
	Solar power	Solar panels on deck	0.2–12%
Operation	Speed optimization	Operational speed, reduced speed	1–60%
	Capacity utilization	At vessel and fleet level (fleet management)	5–50%
	Voyage optimization	Advanced weather routing, route planning and voyage execution	0.1–48%
	Other operational measures	Trim/draft optimization, Energy management, Optimized maintenance	1–10%

Table 1: Measures and potential effect on energy efficiency and emissions reduction (CO2).[49]

[49] Elsevier (2017): State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review

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AIR LUBRICATION

1. Introduction to the efficiency measure

   A vessel's resistance when moving through the water is made up of multiple components, of which frictional resistance is the most dominant. Injection of air into the turbulent boundary layer (between the stationary and moving water) can reduce the frictional resistance of the hull. Air Lubrication Systems (ALS) provide a constant flow of air bubbles to lubricate the flat bottom area of a ship's hull which requires minimal structural changes[50]. Depending on the size and model of the ship, operators can experience fuel savings of between 5-10%.

2. Analysis of vessels in service, vessels on order and related projects

   2.1. Analysis air lubrication systems on vessels in service

   A) Clarksons (last retrieve 30/04/2021 2)

   According to the Clarksons' database there are currently 44 vessels in service equipped with an air lubrication system, covering 9 different fleet types and sizes (from a 3.808 dwt ferry to a 228.149 dwt container vessel).

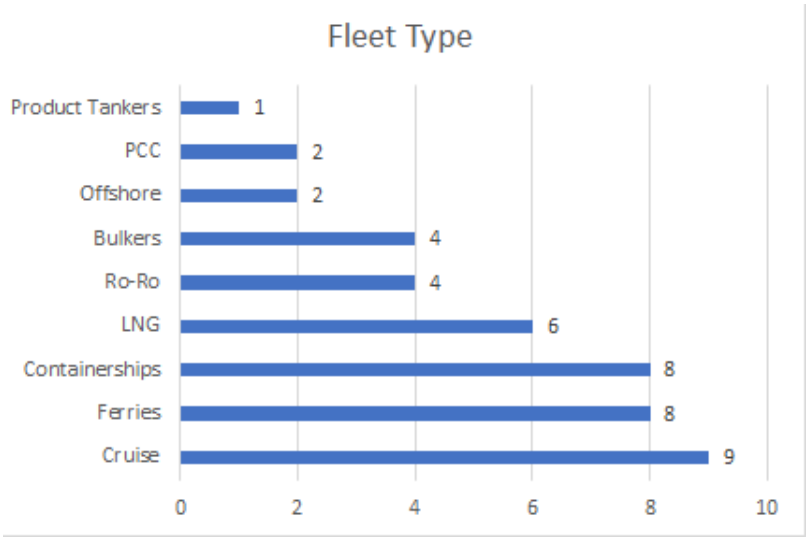

Figure 24 Air lubrication systems on vessles, fleet type (cut-off date 30 April 2021)

   2.2. Air Lubrication systems on vessels on order

   A) Clarksons (last retrieve 30/04/2021)

   According to the Clarksons' database there are currently 36 vessels on order equipped with an air lubrication system, covering 5 different fleet types from which the LNG fleet covers the biggest share (72,2%),

[50] Wartsila: Air Lubrication

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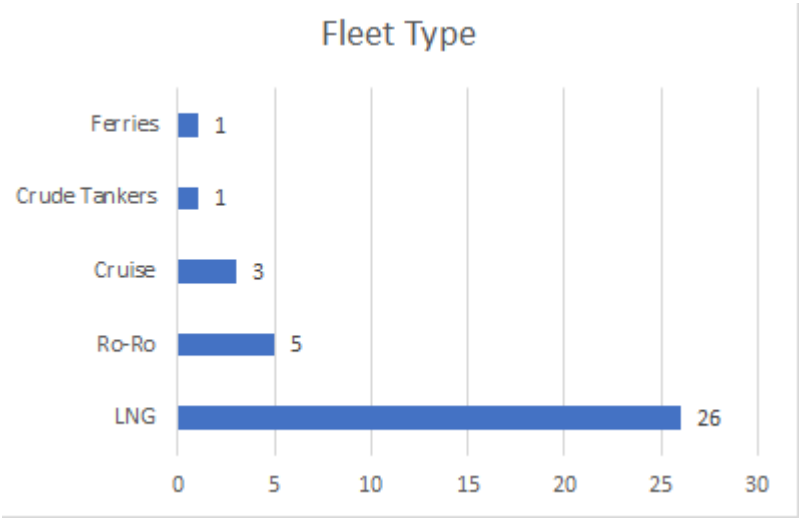

Figure 25 Air lubrication systems on vessles on order, fleet type (cut-off date 30 April 2021)

2.3. Analysis projects

Aircoat project

Passive air lubrication technology inspired by the Salvinia effect. Applying the AIRCOAT technology to ship-hull surfaces will produce a thin permanent air layer when submerged in water. This will reduce the overall frictional resistance, while acting as a physical barrier between water and the hull surface. In addition to reducing energy consumption, the air barrier will inhibit the attachment of maritime organisms (biofouling).

3. Technology analysis

Active air lubrication systems

Even though the air lubrication system was already introduced to Japan in 2010 by Mitsubishi Heavy Industries (HI), the uptake of the technology has been rather slow. But looking at the vessels on order to be equipped with an air lubrication system indicates that the interest in the technology is increasing. Where Mitsubishi HI was the main technology provider for the first vessels in service, other technology providers such as Silverstream, Hyundai Heavy Industry and Samsung have entered the market.

Passive air lubrification systems

No information was found on whether the AIRCOAT project already applied the coating to ship-hull surfaces and what the result was.

4. Potential barriers

- Compressors or blowers are required to force air out of a vessel's hull. The higher the air pressure and the more air being injected, the more power required to drive the system.

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This power must be accounted for when designing the system. If the compressor requires more power than the air injection is saving, the system isn't useful.[51]

- Efficiency gain depends on size and model of the ship: highest efficiency can be reached with the larger flat-bottomed vessels[52]

HULL COATINGS

1. Introduction to the efficiency measure[53] [54]

The steel or aluminium hulls of ships and boats need to be protected from the corrosive effects of water so that they don't rust and fall apart. At the same time, these hulls, and also non-corroding hulls such as those made of glass-reinforced plastic, are prone to accumulating biofouling – marine plants and animals which attach themselves to ship hulls as they do to any suitable underwater surface. In the case of hulls, this fouling can greatly increase resistance and prevent the ship from gliding smoothly through the water. This in turn results in a greater fuel consumption in order to get the vessel from point A to point B and that then causes excessive volumes of emissions of greenhouse gases and other atmospheric pollutants. The biofouling, when it becomes severe, can also damage the coating and the hull itself.

Hull coatings will reduce the resistance of the ship hull through water, and reduce the needed engine power, and thus reduce the fuel consumption. The savings of applying advanced hull coatings is difficult to measure, but there is no doubt a possible saving by applying high end products. In combination with good hull condition monitoring and maintenance, savings will be achieved. The benefit from this measure will come in terms of reduced fuel consumption and thus a lower fuel cost.

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis hull coatings on vessels in service

The Clarksons database does not have information on hull coatings

2.2 Analysis hull coatings on vessels on order

The Clarksons database does not have information on hull coatings

2.3 Analysis of projects

- ECOTEC-STC (2009) - Demonstration of a 100% non-toxic hull protection and anti-fouling system contribution to zero emissions to the aquatic environment and saving 3-8 % heavy fuels. The project has shown that **Ecospeed** as a Surface Treated Coating is a valuable alternative technology to the anti-foulings that are currently on the market. The greatest benefits come from its non-toxicity and long lifespan. The project conducted supervised

[51] Shipwright: Air lubrication systems
[52] Wartsila: Air lubrication
[53] Hydrex: Ship hull coating systems simplified
[54] https://glomeep.imo.org/technology/hull-coating/

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applications of the Ecospeed paint on seven vessels of various types: container vessels, general cargo vessels, an LPG tanker and a split hopper barge. The project concluded that the coating should provide anti-corrosion protection for the full lifetime of a standard ship - around 25 years.[55] Ecospeed has also received the Lloyd's Register certificate that recognizes the coating as an abrasion resistant ice coating for vessels intending to navigate in ice conditions.[56]

3. Technology analysis

Types of hull coatings currently available

- Biocidal antifouling (AF) paints: leaches copper and a number of other biocides into the water in order to kill off fouling that attaches to the ship bottom. These paints gradually release the toxic substances into the water over a period of 3-5 years, after which time they become depleted and need to be replaced;
- Fouling-release (FR) paints: a "non-stick" type of coating which works on the principle that it is difficult for fouling to stick to it. Most of the coatings currently available in this category are silicone-based;
- Hard (inert) coatings: generally, either epoxies, polyesters or vinyl esters; some are reinforced with glass flakes. These coatings are designed to protect the hull against corrosion and are intended to be used in conjunction with routine cleaning, either using high pressure washing in drydock, or underwater cleaning with the vessel still afloat. Hard coatings do not ablate or gradually dissolve as do AF paints. Nor do they leach oils or molecules of their substance as with many of the FR coatings. From an environmental standpoint they are the safest and least harmful of the coatings currently in use. By optimizing hull surface friction and using the best possible surface hydrodynamic characteristics, fuel savings over the lifetime of the ship are most often found to be in the 20-40 % range.

4. Potential barriers

- If the vessel is not moving (lay-up), the coating may deteriorate.

WASTE HEAT RECOVERY SYSTEM

1. Introduction to the efficiency measure

Waste heat recovery systems recover the thermal energy from the exhaust gas and convert it into electrical energy, while the residual heat can further be used for ship services (such as hot water and steam). The system can consist of an exhaust gas boiler (or combined with oil fired boiler), a power turbine and/or a steam turbine with alternator. Redesigning the ship layout can efficiently accommodate the boilers on the ship to better fit these systems. Waste heat recovery is well proven onboard ships, but the potential can be variable depending on the size, numbers, usage and efficiency of the engines on board.

[55] European Commission LIFE program
[56] Offshore energy: **Belgium Based Hydrex Applies Ecospeed on Two Newbuilds**

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Furthermore, these measures are usually not relevant for retrofitting, due to large costs and efforts related to redesign, steel work, extra weight, etc. The reduction potential is estimated at 3% to 8% of main engine fuel consumption.[57]

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis waste heat recovery systems on vessels in service

A) Clarksons (last retrieve 30/04/21)

According to the Clarksons' database there are currently 30 vessels in service equipped with a waste heat recovery system, covering 5 different fleet types: containerships (50%), bulkers, offshore, ferries. Except for one vessel (Japan, offshore), all vessel owners that opted for this technology are European.

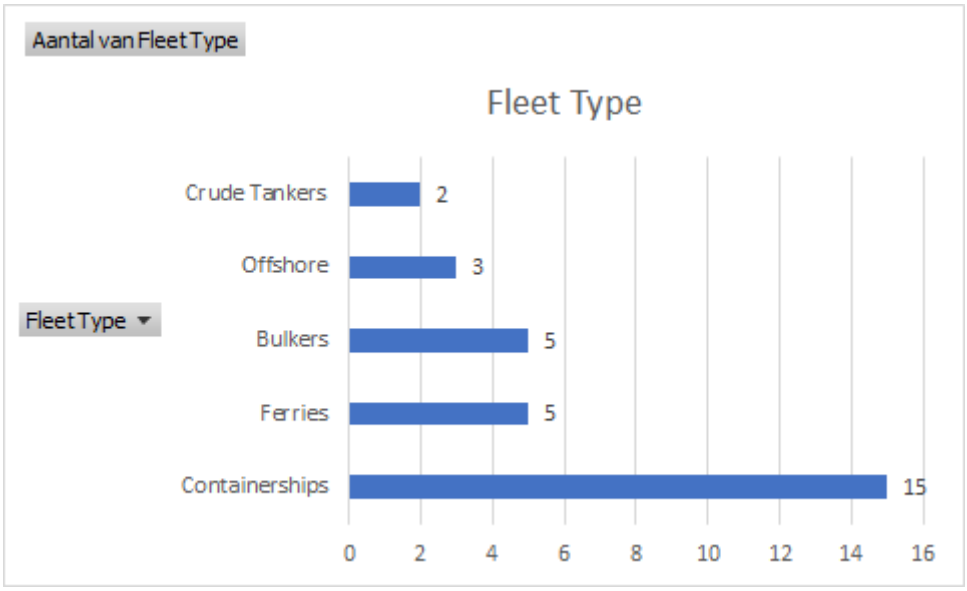

Figure 26 Waste heat recovery systems on vessles in service, fleet type (cut-off date 30 April 2021)

2.2. Analysis waste heat recovery systems on vessels on order

A) Clarksons (last retrieve 30/04/2021)

According to the Clarksons' database there are currently 12 vessels on order equipped with a waste heat recovery system, covering 4 different fleet types:

[57] https://glomeep.imo.org/technology/waste-heat-recovery-systems/

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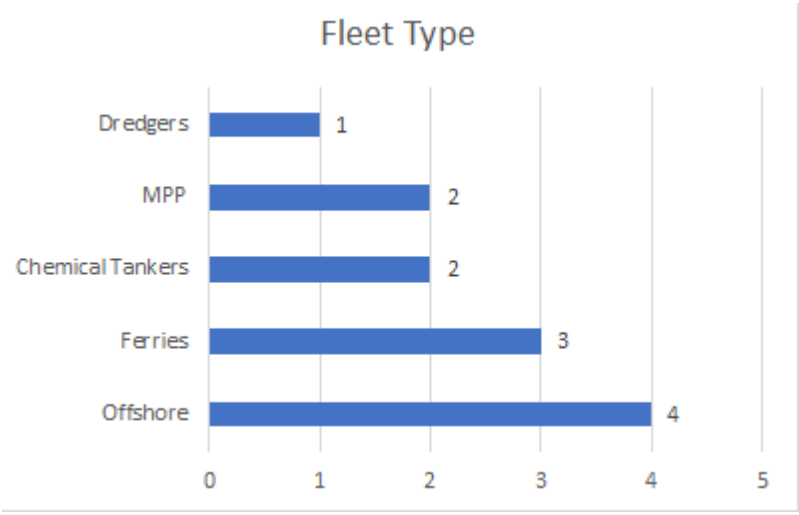

Figure 27 Waste heat recovery systems on vessles on order, fleet type (cut-off date 30 April 2021)

2.3 Analysis of projects in annex

No projects were found.

3. Technology analysis

No details on the maturity of the technology were found.

4. Potential barriers

- In reality a slow steaming vessel initially designed for e.g. 80% engine load on main engine would not be able to utilize a power turbine/steam turbine[58];
- Cost of implementation ($5-9,5 million);
- Annual maintenance needed.

WIND-ASSISTED PROPULSION

1. Introduction to the efficiency measure[59]

Wind propulsion solutions offer a near-term opportunity for significant reductions in GHG emissions. Wind propulsion systems (sails, rotors, kites etc.) can deliver between 5-20% fuel and associated emissions savings as a retrofit option (with no change in vessel operational profiles), with the potential to reach 30%. Systems integrated into optimised new builds and those used for primary propulsion will offer substantially higher savings.

1. Technologies

- Flettner rotors (rotor sails) are vertical cylinders which spin and develop lift due to the Magnus effect as the wind blows across them. When wind conditions are favourable, the Rotor Sails allow the main engines to be throttled back, saving fuel and reducing emissions

[58] GloMEEP: Waste heat recovery systems
[59] IWSA: Wind Propulsion report September 2020

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while providing the power needed to maintain speed and voyage time. A variable electric drive system, which is powered by the ship's low voltage network, is used for rotating the Rotor Sail. The optimal number and size of Rotor Sails is based on the size, speed, and operating profile of the target vessel.[60] Main technology manufacturers are Norsepower and Anemoi;

- Kite: The kite works from wind power which is transferred to the ship and results in less engine power needed to move the ship. The kite will under normal conditions generate a pulling force on the ship, which can be translated into an equivalent engine power generated.
- Suction wings: create an upward lifting force similar to the wings on airplanes. One active developer is eConowind. Its Ventfoil and eConowind unit are non-rotating wings with vents and internal fans that generate force with boundary layer suction. The former has the benefit of achieving a larger size, which translates to larger thrust, while the latter has the flexibility to be moved around. In suction wings are considered either under the category of rotors or sails[61]
- Rigid sails/wing sails: foils that could be adjusted to produce aerodynamic forces.[62]

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis wind assisted technologies used on vessels in service

A) Clarksons (last retrieve 30/04/2021)

According to the Clarksons' database there are currently 13 vessels in service equipped with a wind-assisted propulsion system covering 7 different fleet types. Most interest in the technology comes from Europe (90%). Even though there are different wind propulsion technologies (see technology analysis), 61,5% of the shipowners opted for a Flettner rotor. Ship sizes vary from a 3.638 dwt multi-purpose vessel to a 306.752 dwt tanker.

[60] Norsepower
[61] MDPI: A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology
[62] MDPI: A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology

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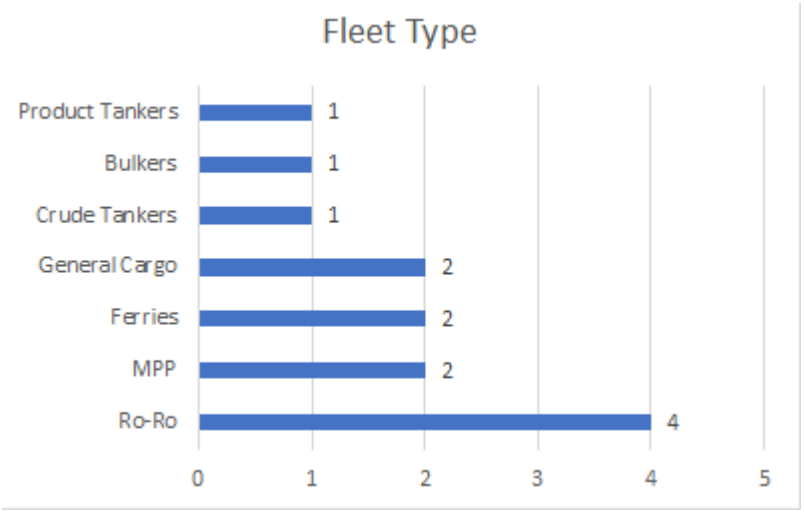

Figure 28 Wind assisted technologies on vessles in service, fleet type (cut-off date 30 April 2021)

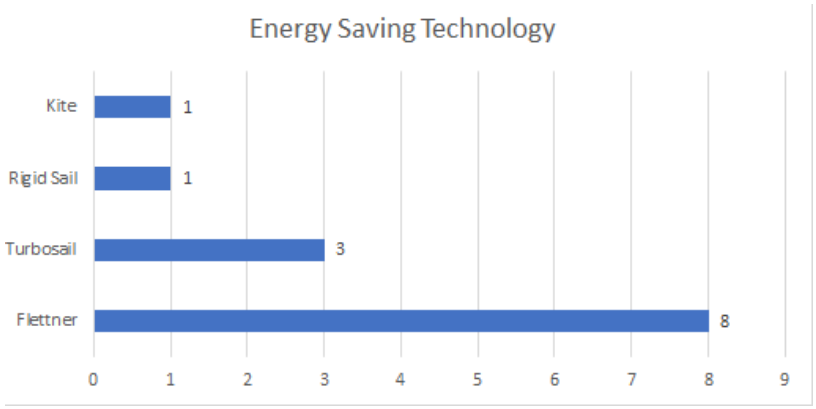

Figure 29 Wind assisted technologies on vessles in service, energy saving technolgoy (cut-off date 30 April 2021)

B) Inland waterway vessels: expert knowledge
Wind-assisted propulsion is not nearly as common in inland navigation as it is in seaborne transport.

2.2 Analysis wind assisted technologies used on vessels on order
A) Clarksons (last retrieve 30/04/2021)
According to the Clarksons' database there is currently 1 crude tanker on order equipped with rigid sails

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2.3 Analysis of projects

Five projects related to wind-assistance are available in Annex 1, notably:

- The RotorDEMO (funded by EU H2020) project was the implementation of Norsepower Rotor Sail Solution in full scale on a RoPax vessel to boost sales of the solution;
    - Viking Grace (Ro-Pax ferry, 2800 pax/450 cars): one Norsepower rotor sail. Installation year: **2018 (April)**.

- MariGreen project (funded by Interreg Deutschland/Nederland): installation of a rotor of 18 meters high and has a diameter of three meters.
    - MV Fehn Pollux (multi-purpose vessel, 4250 dwt): one Flettner rotor. Installation year: **2018 (June)**.

- The WASP-project (funded by the Interreg North Sea Region Programme) will research, trial and validate a selection of wind propulsion solutions on five vessels; Except for MV Annika Braren, all four ships are part of section 2.1)
    - MV Ankie (multi-purpose vessel, 3638 dwt): two eConowind VentiFoil wind-assisted propulsion units. Installation year: **2020** (January)
    - MV Copenhagen (ferry): one 30x5 Norsepower Rotor Sail. Installation year: **2020** (May)
    - MV Frisian Sea (general cargo vessel) (6477 dwt): two eConowind VentiFoil wind-assisted propulsion units. Installation year: **2021** (January)
    - MV Tharsis (general cargo vessel, 2364 dwt): 3 x 9m eConowind TwinFoil units. The installation year: **2021** (February)
    - MV Annika Braren (multi-purpose vessel, 5100 dwt): one wind rotor from Eco Flettner. Installation year: **2021** (April)
- The ShipCLEAN -project (funded by the Swedish Energy Agency)[63] : integrates methods and models in transport logistics and economics with energy analysis in a unique model is used in optimization of the marine transportation system to minimize fuel consumption. Based on the ship characteristics and routes, the model can calculate the optimal number of rotors and where to position them on the vessel.
- The Oceanbird (a car carrier with a capacity of 7.000 cars) will be a large, wind-powered vessel equipped with five retractable, telescopic wingsails that can rotate 360 degrees. The rigging and hull will work together as a single unit to harness the wind in the most efficient way. The sails are made of a mixture of metal and composite and will be almost 80 metres high, twice the height of those on the largest sailing vessels around today. It will be possible to 'reef' the sails, reducing their height to approx. 50 metres. The vessels will also be fitted with engines to enable them to manoeuvre in and out of port.

63 https://www.chalmers.se/en/projects/Pages/ShipCLEAN---Energy-efficient-marine-transport-through_1.aspx

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3. Technology analysis

Ship Name	Ship Type	DWT	Technology Characteristics	Ship Built Year [c]	Installation Year
Flettner-Rotor			**No. of Rotors/Diameter (m)/Height (m)**		
E-Ship 1 [a]	General Cargo/Ro-Lo	10,020	4/4/27	2010	2010
Estraden [a]	Ro-Ro	9700	2/3 [b]/18	1999	2014
Viking Grace [a]	Passenger	6107 [c]	1/4/24	2013	2018
Fehn Pollux [a]	General Cargo	4250	1/3/18	1997	2018
Maersk Pelican [a,b]	Tanker	109,647	2/5/30	2008	2018
Afros [d]	Bulk Carrier	64,000	4/-/-	2018	2018
Copenhagen [e]	Ferry	5088	1/5/30	2012	2020
Annika Braren [f]	General Cargo	5100	1/18/3	2020	Oct 2020 expected
SC Connector [g]	Ro-Ro	8843	2/35/5	1997	Q4 2020 expected
Kite			**Kite's dimension (m^2)**		
Michael A. [h]	General Cargo	4884	160	1994	2008
BBC Skysails [i]	General Cargo	9832	320 [i]	2008	2008 [i]
Theseus [i]	General Cargo	3667	160 [g]	2009	2009 [h]
Aghia Marina [i]	Bulk Carrier	28,522	320 [i]	1994	2012 [i]
Ville de Bordeaux [k,l]	Ro-Ro	5200	500	2004	Nov 2020 expected
TBA [k]	Bulk Carrier	TBA (Capesize)	1000	TBA	2021 expected
Suction Wing			**No. of wings/height (m)**		
Ankie [m]	General Cargo	3600	2/10	2007	2020
Frisian Sea [n]	General Cargo	6477	2/TBA	2013	2020
Rigid sails/wing sails			**No. of foils/height (m)/width (m)**		
MV Tharsis [o]	General Cargo	2364	2/9/3	2012	2021 expected
New Vitality [p,q]	Tanker	306,751	2/32/15	2018	2018
TBA [r]	Tanker	TBA(VLCC)	TBA	2022	2022

Table 2: Recent WASP technology adoptions[64]

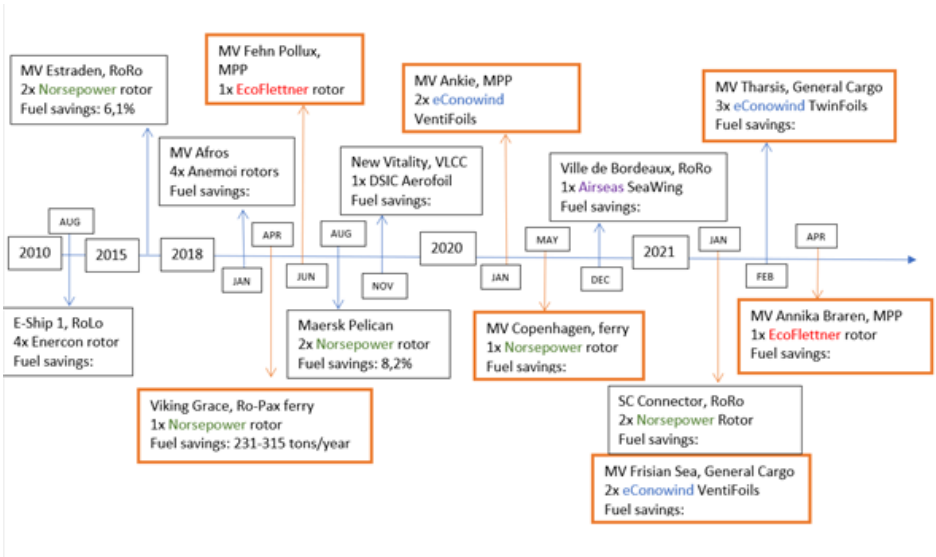

Figure 30 Timeline based on vessels in Clarckson's database: orange box = funded project

- Proven fuel savings have been publicised for a number of operational ships, including 6.1% from two rotors on the roll-on roll-off freight (RoRo) vessel, MV Estraden, 8.2% from two

[64] MDPI: A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology

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rotors on the large tanker, Maersk Pelican and up to approximately 20% the small general cargo vessel Fehn Pollux. [65]

- Rotor sails seem to be the most chosen

4. Potential barriers
    - Not suitable for all ship types: highest efficiency gain for "slow" ships like tankers and bulkers;
    - Weather routing systems need to be updated;
    - Captains can be uncomfortable by changing to windier routes.

[65] IMO. (2020). Reduction of GHG emissions from ships: wind propulsion solutions. Marine Environment Protection Committee, 1–7. London: International Maritime Organization.

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OPTIMIZED COMBUSTION

Fuel Flexibility

There are different aspects to this topic

The 'local heroes'

There are already today local hotspots for particular green fuels e.g. Södra in Sweden producing green Methanol from wood residuals currently 5000t/y (https://www.sodra.com/en/global/Bioproducts/biomethanol/) or the Biomethane plant in Amsterdam https://www.europeanbiogas.eu/netherlands-energy-biomethane-waste-water-amsterdam/producing 11Mm³/y which would favour for a similar transport challenge to decide for different solutions depending on the local champion of energy provision. Meaning that local operating shipping companies are making green and safe investments in technology which is already available for an energy source with a local advantage.

The 'Jack of all trades'

Taking advantage of the most economic fuel choice will reduce your OPEX and requires the technical possibility to convert the different energy carriers. This will require more technically advanced energy converters and thus higher CAPEX. This can be already today considered a trend since many of the currently ordered ships have a dual fuel engine in their spec. Also, the ports are preparing for this scenario e.g. Port of Antwerp has declared multi fuel approach as one of their main strategies in their green port concept.

Simplicity vs complexity or high tech to handle high risk

Direct use of electric power is by far the most energy efficient solution and a fairly simple one as well. Unfortunately, this solution does not match all transport challenges. Similar arguments hold for pure Hydrogen. As an energy carrier it is technically possible and requires at a larger scale a quite demanding setup for operation, crew training, infrastructure, safety measures, supply and investment. The next level down from the energy demand perspective are Hydrogen carriers e.g. Ammonia followed by Carbon based synthetic fuels like FT diesel or Methanol. These Syn-fuels have a lot of advantages especially when they can be handled in liquid form at ambient temperature and pressure. Disadvantages are the high energy demand to produce them. One element which sometimes gets forgotten is the combination of selected fuel and new shorter routes through the artic. The risk for the aquatic life in case of fuel spill is very much dependent on the choice of fuel.

The individual vs. global efficiency challenge

The selection of the "right " energy carrier, energy storage, and energy converter will differ depending on trade, distance and size of the ships concerned. While ship-operators aim as all other businesses to maximise their profit meaning their CAPEX and OPEX the governments are struggling to keep their climate targets. This results in an optimisation problem about: how to make the best use of the renewable energy available and how to initiate which transition path at which point in time. Monitoring both trends and CO2 emissions will deliver indicators while the market development and the (end-) customer behaviour will be the main drivers.

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Fuelsave: FS Marine +

- The stoichiometric fuel mix is optimized leading to a cleaner and more complete combustion at all load phases. Based on the specific engine and its load, the most appropriate combination of hydrogen, oxygen, methanol and water is injected into 3 different locations of the air intake;
- This provides a new level of flexibility to adjust the performance where until now engine manufacturers and operators are limited with the size of the turbocharger and he ambient air available;
- Acting directly on the combustion level is highly advantageous as this improves efficiency at its roots while other solutions (scrubbers/SCR) only attempt to cure the symptoms;
- **10% guaranteed savings on fuel consumption;**
- Applicability for 4-stroke engines and various fuel types.

Link: https://fuelsave-global.com/losungen/fs-marine/

Right-sizing

In inland waterway transport it is often found that the engines of inland vessels are oversized, i.e. the installed power is often too high given the operational profile of the vessel. Sailing profiles often show that the available power is hardly used. Hence, efficiency gains can be achieved once the vessel is equipped with the amount of power that suits the operational profile of the vessel. This could be done during a regular repowering moment of the vessel. On average, a reduction in fuel consumption of 0-10% could be realised as result of right-sizing.[66]

Energy efficient navigation

Navigating in an energy efficient way is the only greening approach that can be - at least to some extent - applied on all kinds of inland vessels with little to no additional costs. The awareness of the physical background and the parameters determining energy consumption can help the navigating staff to save fuel with the information already on board. Additional savings can be made accessible with advisory systems and applications making systematic use of sophisticated ship and waterway data. The blueprint for such systems were already made within the IDVV program[67] and in PROMINENT. CoVadem is one of the practical implementations of the IT concepts developed in IDVV and PROMINENT (see Covadem under 3.1.5).[68] The "VoortVarend besparen" program is another example, which concerns a training to create awareness and stimulate an energy efficient navigation behaviour for skippers. On average, energy efficient navigation including the systematic use of sophisticated ship and waterway data could result in a reduction of the energy consumption of around 14%.[69]

[66] https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_11_PROMINENT_D-1.2.-best-available-technologies_final.pdf
[67] http://publicaties.minienm.nl/documenten/impuls-dynamisch-verkeersmanagement-vaarwegen
[68] https://www.prominent-iwt.eu/wp-content/uploads/2018/04/17_09_04_PROMINENT_D4.4_Prototype_of_Digital_Education_and_Training_Tool.._.pdf
[69] https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_11_PROMINENT_D-1.2.-best-available-technologies_final.pdf

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Slow steaming

Reducing speed means travelling longer and burning less fuel, this equation is a function of speed, emission, and cost while fuel consumption and thus cost fall roughly by the power of two with reducing speed. Reducing speed for a given ship - designed for a specific route with a specific speed - means you are running the engines outside their operational optimum. Also, the ship`s hull is optimised for a certain speed therefore the full gain of sailing slow would be higher if your ship design would consider slow steaming from the beginning. To operate a ship safely you need to have a certain speed to keep her manoeuvrability guaranteed. It is also a good idea to have some safety margin in case of bad weather or side winds in restricted waters. Therefore, creating new ship designs for slow steaming means mainly two things, first: there is much room for improvement compared to just slow steaming with ships designed for higher speeds and second: the devil is in the details in how to find the best suited engine and propulsion arrangement to create an efficient and save vessel.

3.3.4 DIGITAL GREEN

Digitalistaion has multiple aspects. One of these aspects, is the use of optimisations measures for emission reduction. One of these measures is the principel of Just-in-time-arrival.

Just-in-time-arrival (JIT)

According to Traficom[70], the gains from a more accurate calculation of the estimated time of arrival are significant in terms of efficiency. It enables adjusting engine settings for fuel efficiency and saving fuel at optimal speeds, thereby reducing GHG emissions but still knowing that the destination will be reached at the given time. Having an accurate arrival time also enables ports to handle incoming ships more efficiently[71]. There are several studies and calculations on how much JIT-shipping could lower the GHG emissions from shipping, varying from few percentages to even a third of the total emissions[72] [73] [74].

Voyage and route optimising

Voyage optimization processes aim to improve the operational efficiency of a ship by optimizing route and speed profiles and consequently bring economic benefit to the shipping stakeholders. There are different strategies to the optimization such as finding the shortest route, avoiding bad weather and utilizing strong ocean currents to reduce fuel consumption and emissions. Most existing voyage optimization tools optimize with respect to one criterion at a time, treating other relevant criteria as constraints. Recently, also multi-objective optimization tools for optimization

70 https://www.traficom.fi/sites/default/files/media/publication/Traficom_maritime_digitalization_CO2_20190927_ABSTRACTS.pdf

71 Swedish Maritime Administration 2019. Sea Traffic Management Validation Project, Final Report.

72 Gustafsson, M. et al. 2019. Driving Emission Out of Shipping, A race against time. White Paper. Åbo Akademi, PBI Research Institute

73 Port of Rotterdam 2019. Move forward: step by step towards a digital port. White Paper

74 Johnson, H. & Styhre, L. 2015. Increased energy efficiency in short sea shipping through decreased time in port Transportation Research Part A: Policy and Practice. 71: 167-178

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of ship routes have been developed[75] [76]. There are no date available regarding the emission reduction potential of these tools.

CoVadem

Following 'Energy efficient navigation' in chapter 3.3.3, the systematic use of sophisticated ship and waterway data can result in a reduction of the energy consumption. In the IWT sector the system provided by CoVadem aims to provide this ship and waterway data on board of inland vessels. The system shares actual measurements for an optimal path of the vessel based on, a.o., current and forecast water depths and bridge clearances.

TechBinder: Smart Vessel Optimizer

Smart Vessel Optimizer is built to help maritime operations become more efficient, effective, safe and ecologically friendly. Smart Vessel optimizer is a total solution for:

- Collecting data from different onboard and onshore systems
- Compress the data
- Send data encrypted and via a secured connection
- Store data in the cloud
- Perform data analytics
- Data visualisation.

Exact data regarding the emission reduction potential are not available for all of these aspects, although the positive influence on emission reduction is recognised.

[75] Andersson, A. 2015. Multi-objective optimization of ship routes. MSc thesis. Chalmers University of Technology. 27 pp.
[76] Vettor, R. & Guedes Soares, C. 2016: Analysis of the sensitivity of a multi-objective genetic algorithm for route optimization to different settings. Maritime Technology and Engineering 3. Proceedings of MARTECH 2016

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3.3.5 PORTS

Onshore power supply (OPS)

1. Introduction to the concept

On-shore power supply is considered electrical power delivery from shore side (either from a mobile or fixed solution) to vessels. This allows vessels to turn off their (auxiliary) engines while berthed in port. Shore power can be used for all vessel types, regardless the age of the vessel.[77]

2. Analysis of vessels in service, vessels on order and related projects

2.1. Analysis high voltage shore connection on vessels in service

A) Clarksons (last retrieve 05/01/2021)

According to the Clarksons database, there are currently 642 vessels in service equipped with a high voltage shore connection. From these vessels, 35% is of fleet type container, followed by (small) offshore (31%) and bulkers (14%). Mainly the larger deep-sea container vessels are equipped (see table below) but the equipment rate varies significantly depending on sailing pattern and vessel size. Small offshore vessels have a lower power demand at berth in comparison with the operational power demand.

	TEU	OPS	NO OPS	% equipped
Small feeder	< 1000	0	1036	0%
Feeder	1001-2000	10	1232	1%
Feedermax	2001-3000	8	617	1%
Panamax	3001-5100	66	800	8%
Post-Panamax	5100-10000	281	1054	21%
Neopanamax	10000-14500	187	321	37%
ULCV	< 14501	41	89	32%

Table 3: © Port of Antwerp: Onshore Power Supply: Estimated equipment rate based on Clarksons world fleet data and own data

B) Expert knowledge

Short sea ships and smaller vessels do not need to be retrofitted to connect to onshore power. Their existing electricity infrastructure that is used to supply the ship of energy during maintenance can also be used to connect to shore. These smaller vessels are usually compatible with the grid, making use of the same frequency and voltage. Higher power demanding vessels require significant investments on both vessel and port/terminal side. Bulker and tanker vessels have a relatively low equipment rate due to trade volatility and larger power demand.

2.2. Analysis high voltage shore connection on vessels on order

A) Clarksons (last retrieve 05/01/2021)

According to the Clarksons database, 71 vessels on order are equipped with a high voltage shore connection. From these vessels, 41% is of the fleet type ferry, followed by offshore (18%). The uptake in the ferry fleet is driven by Norwegian (45%) and Thai owners (41%). Ferries have a

[77] Port of Antwerp: presentation onshore power supply

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relatively low power demand and regular trading pattern. Uptake in cruise vessels is expected to increase due to public opinion and air quality concerns.

3. Technology analysis

Shore power technology is in use since the 1980s (technology relatively mature). The minimal equipment needed for a vessel to be onshore power-ready is:

- A power distribution system;
- An electricity transformer and control panel;
- Connectors and a cable reel.

From the perspective of the port (supply side), the technology is still in further development:

- Automatization is being looked at to decrease the time of the connection process and to lower the risk of human error;
- Flexible connection points in case vessels have variable mooring points;
- Possibility to connect multiple vessels to one installation in order to cut cost;
- Mobile solutions such as barges (battery, LNG or hydrogen).

4. Potential barriers

- Every berth is unique: every ship has other power requirements and hotelling factors depending on type and size. This can for example depend on the number of cranes on the vessel (bulker), whether containers need to be cooled (container, how many cabins the vessel has (cruise), etc. Table 4 below gives an indication of the electricity take-off for different vessel types.

Vessel Type	Average Main Engine Power (kW)	Average Auxiliary Power (kW)	Auxiliary to Main Ratio	Hotelling Load Factor
Auto Carrier	10,700	2,850	0.266	24%
Bulk Carrier	8,000	1,776	0.222	22%
Container Ship	30,900	6,800	0.220	17%
Passenger Ship	39,600	11,000	0.278	64%
General Cargo	9,300	1,776	0.191	22%
Miscellaneous	6,250	1,680	0.269	22%
RORO	11,000	2,850	0.259	30%
Reefer	9,600	3,900	0.406	34%
Tanker	9,400	1,985	0.211	67%

Table 4: electricity take-off © Port of Antwerp

- Unstandardized components on vessel side: length of cable when cable on board available;
- No uniform level of technology readiness;
- Practically impossible for large offshore vessels that need to load and unload;
- Connection process can be time consuming (sometimes up to three hours);
- Frequency challenge (see figure 31 below).

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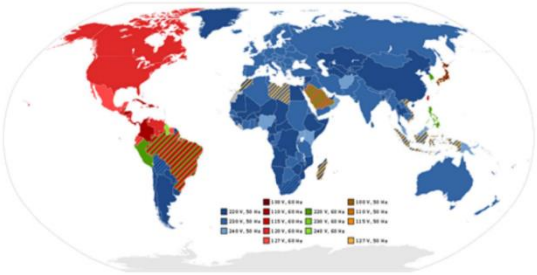

Yellow shades: 100–127 V, 50 Hz
Red shades: 100–127 V, 60 Hz
Blue shades: 220–240 V, 50 Hz
Green shades: 220–240 V, 60 Hz

Vessel Type	50 hz	60hz
Container vessel (<140m LOA)	63%	37%
Container vessel (>140m LOA)	6%	94%
Container vessels (total)	26%	74%
Roro vessels	30%	70%
Oil and product tankers	20%	80%
Cruise ships (<200m LOA)	36%	64%
Cruise ships (>200m LOA)	0%	100%
Cruise ships (total)	17%	83%

©Chalmers University

Figure 31: frequency differences for different regions and different vessel types

- Trade volatility (not every terminal is equipped)
  - Impact on the grid: vessels have different average and peak power demand

	Average Power Demand	Peak Power Demand	Peak Power Demand for 95 % of the vessels
Container vessels (< 140 m)	170 kW	1 000 kW	800 kW
Container vessels (> 140 m)	1 200 kW	8 000 kW	5 000 kW
Container vessels (total)	800 kW	8 000 kW	4 000 kW
Ro/Ro- and Vehicle vessels	1 500 kW	2 000 kW	1 800 kW
Oil- and Product tankers	1 400 kW	2 700 kW	2 500 kW
Cruise ships (< 200 m)	4 100 kW	7 300 kW	6 700 kW
Cruise ships (> 200 m)	7 500 kW	11 000 kW	9 500 kW
Cruise ships (total)	5 800 kW	11 000 kW	7 300 kW

Table 5: summary of power demand (ABB) © Port of Antwerp

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3.4 Industry initiatives

In January 2019 the **Waterborne Technology Platform** launched its vision regarding zero-emission waterborne transport in 2050[78], whilst – in addition –, an emerging number of maritime and inland **ship-owners** have set net-zero CO_2 emissions in 2050 or earlier[79] as their target[80]. The European waterborne transport sector **welcomes the European Green Deal** and is **committed to reaching its objectives**[81]. An initial group of shipowners have indicated that their fleet will be emission free in 2050, stating that RD&I will be key to reaching this objective[82]. The European maritime technology sector **annually invests 8-9% of its turnover in RD&I**[83] and is fully committed to develop the solutions needed and to invest accordingly[84].

This paragraph includes a summary of the most relevant industry initiatives of the key stakeholders of the waterborne transport sector:

- Global Maritime Forum: Getting to zero coalition[85]

  The ambition of the Coalition is to have commercially viable Zero Emission Vessels (ZEVs) operating along deep-sea trade routes by 2030, supported by the necessary infrastructure for scalable net zero-carbon energy sources including production, distribution, storage and bunkering. The coalition consists of more than 120 companies within the maritime, energy, infrastructure and finance sectors, supported by key governments and IGOs.
  Link: https://www.globalmaritimeforum.org/getting-to-zero-coalition

- Green Award

  Green Award is a voluntary quality assessment certification scheme that inspects and certifies ships in sea shipping. A Green Award certificate, which can be obtained by ships that go above and beyond the industry standards in terms of safety, quality and environmental performance, acts as a quality mark and brings benefits to its holders.
  For IWT Green Award is a quality mark for ships that demonstrate high safety and environmental standards. Green Award certificate entitles a ship to various incentives including discounts on ports dues, products and services.[86]

78 http://www.waterborne.eu/media/35860/190121-waterborne_sra_web_final.pdf
79 https://www.maersk.com/news/2018/12/04/maersk-sets-net-zero-co2-emission-target-by-2050
80 http://www.inlandnavigation.eu/media/92406/Future-proof-shipping-presentation-191016.pdf;
81 https://www.ecsa.eu/news/european-shipping-industry-welcomes-european-green-deal
82 https://worldmaritimenews.com/archives/290006/cmb-to-operate-zero-emission-fleet-by-2050/
83 SEA Europe, White Paper, Maritime Technology in Europe: A Strategic Solution Provider for Major Societal Challenges, 2019
84 http://www.seaeurope.eu/ClientData/181/658/348940/3665/4/191213%20Green_Deal_Press_Release.pdf
85 https://www.globalmaritimeforum.org/getting-to-zero-coalition/
86 https://www.greenaward.org/

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- Green Coastal Shipping Programme (DNV GL)

Through the Green Coastal Shipping Programme Norway has established a joint program between government and industry to create the world's most effective and environmentally-friendly fleet of coastal vessels. The program is aiming to revolutionise the way coastal shipping operates, converting fleets to run partly or entirely on batteries, liquified natural gas (LNG) or other green fuels. The program has now presented the first five pilot projects focusing on environmentally-friendly fuels and energy efficient design.

Link:https://www.dnvgl.com/maritime/research-and-development/futuristic-projects-transform-coastlines/index.html

- Green Marine Certificate

Green Marine is an environmental certification program for the North American and European maritime industry. It is a voluntary, transparent and inclusive initiative that addresses key environmental issues through its 13 performance indicators. Participants are shipowners, ports, terminals, seaway corporations and shipyards. To receive their certification, participants must benchmark their annual environmental performance through the program's self-evaluation guides, have their results verified by an accredited external verifier and agree to publication of their individual results.

Link: https://green-marine.org/

- Innovation Lab[87]

Innovation Lab is an ongoing program in which suppliers, knowledge institutions and inland shipping companies join forces for a sustainable and future-proof IWT sector. Policy makers, inspection services and port authorities also participate. Activities consist of knowledge sharing on three themes.

Members of the theme group "Stage V solutions" develop innovative products with which entrepreneurs can meet the new emission requirements. The "Alternative energy carriers" group explores the application of transition fuels, such as biofuels, methanol and hydrogen. Finally, the theme group "Electrification" studies ways to prepare powertrains for electric propulsion. Based on these themes, the Innovation Lab creates the right preconditions for a strong emission reduction in IWT. And thus to emission-free shipping in 2050.

- Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping[88]

Through a portfolio of research projects and activities, the Maersk-Mc-Kinney Moller Center will help create solutions and drive the transformation towards decarbonizing shipping. With our partners we will create the needed overview of opportunities for new systems of fuels and technologies across the supply chain and build confidence in the most promising solutions;

87 https://www.eicb.nl/projecten/innovation-lab/
88 https://zerocarbonshipping.com/

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while ate the same time, create the transition narrative and help drive the sector transformation in the context if climate change and the global energy transition.

Link: https://zerocarbonshipping.com/

- Maritime Campus Antwerp (MCA)

The aim of MCA is to connect entrepreneurs who develop sustainable and water-related businesses. MCA Community is broad and focuses on joining forces between the various actors in the broad maritime sector at European level.

MCA Campus accommodates organisations ranging from larger companies to start-ups, educational and research institutions to collaborate and innovate. Various facilities are made available for this purpose: ranging from co-working spaces, project spaces to various R&D halls, labs and studios.

Link: https://maritimecampusantwerp.com/about-us

- Maritime Decarbonisation Hub (Lloyd's Register)

The mission of the Maritime Decarbonisation Hub is to accelerate the sustainable decarbonisation of the maritime industry, by enabling the delivery and operation of safe, technically feasible and commercially viable zero-emission vessels by 2030. The Maritime Decarbonisation Hub will create and share evidence, insight and knowledge about the transition to a decarbonised world fleet. It will demonstrate the costs, benefits, opportunities and risks of potential pathways to decarbonise.

Link: https://www.lr.org/en-gb/marine-shipping/maritime-decarbonisation-hub/

- Maritime Battery Forum (MBF)

The Maritime Battery Forum keeps its members up to date on the developments in technology and the possibility to learn more about the technical and economic aspects of using battery technology on ships and other offshore installations. The MBF is a meeting place for exchange of knowledge based on experience from the usage of batteries within the shipping and offshore industries. MBF promotes the members' interests and ambitions to become world leading in their respective fields activity towards a sustainable maritime industry with green growth.

Link: https://www.maritimebatteryforum.com/about-us

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- Maritime Industry Decarbonisation Council (MIDC)

MIDC is a platform where all stakeholders involved can orient around steps in the decarbonisation pathway. The vision of the MIDC is to bridge the gap between shipowners, charterers, shippers, engine makers, ship builders, fuel producers, the research community, banks and classification societies to ensure the development of an evidence-based policy on GHGs that will enable the sector to reduce its GHG emissions in the most cost-effective way. The MIDC consists of approximately 20 members, originating from the broader waterborne transport sector.

Link: https://midc.be/

- NCE Maritime CleanTech

Norwegian based industry cluster NCE Maritime CleanTech represents one of the world's most complete maritime business hubs. The cluster uses the Norwegian maritime expertise, built up over generations, as a springboard for the development of new energy-efficient and environmentally friendly technologies for the ocean industries. The cluster has 120 partner companies covering every stage of the maritime value chain, including providers of renewable energy, financial institutions and research and educational institutions. Through the cluster these partners cooperate on developing innovative and competitive solutions that reduce emissions to air and sea. Many of the partners are pioneers when it comes to introducing new, green energy carriers on board vessels such as batteries, hydrogen and ammonia.

Link: https://maritimecleantech.no/

- Norwegian Hydrogen Forum

The Norwegian Hydrogen Forum (NHF) was founded in 1996 as a nonprofit members' association for conveying and promoting the advantages of hydrogen as an energy carrier in Norway. NHF represents more than 60 members from the Norwegian industry, universities, research institutes and other organizations engaged or otherwise interested in hydrogen. NHF works actively to disseminate key achievements from hydrogen research and technology commercialisation, market trends, national and international policy-making by organizing conferences, seminars and workshops, and connecting relevant international cooperation.

Link:https://www.hydrogen.no/hva-skjer/aktuelt/on-hydrogen.no-you-will-find-the-norway-overview

- RightShip

RightShip is committed to improving safety and environmental standards within the shipping industry, using its vetting platform to support the removal of sub-standard ships from the supply chain, creating a safer fleet and improving seafarer welfare. The company has developed a Greenhouse Gas Emissions Rating (GHG Rating), which is now used on one in every five vessels chartered worldwide. The GHG Rating compares the theoretical CO2 emissions of ships of a similar size and type, increasing transparency and allowing charterers

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to factor sustainability into their vessel selection process. A carbon-neutral organisation, RightShip also offers customers the ability to measure and offset the carbon emissions of their own shipping operations.
Link: https://www.rightship.com/

- Sea Cargo Charter

The Sea Cargo Charter establishes a framework for assessing and disclosing the climate alignment of ship chartering activities around the globe. It sets a benchmark for what it means to be a responsible charterer in the maritime sector and provides actionable guidance on how to achieve this. As a result, the Sea Cargo Charter will enable cargo-owners and shipowners to align their chartering activities with responsible environmental behavior and incentivize international shipping's decarbonization – to shape a better future for maritime shipping and society. The Sea Cargo Charter is applicable to bulk ship charterers: those with interest in the cargo on board; those who simply charter out the vessels they charter in; as well as the disponent owners and all charterers in the charterparty chain.

Link: https://www.seacargocharter.org/

- Smart Green Shipping Alliance

Smart Green Shipping, SGS, is an award-winning systems design house developing system solutions to contribute technically and commercially viable solutions that enable the rapid reduction of emissions from the shipping sector. It is privately owned and convenes a wider collaboration of SMEs, large corporations pioneering maritime renewables. Our purpose is to build 100% renewable powered ships. The first step is to retrofit an existing ship.

Link: https://smartgreenshipping.com/

- Sustainable shipping initiative (SSI)

The SSI is a four-stage initiative designed to help the industry make long-term plans for future success. Its members are leading companies from around the world and NGOs Forum for the Future and WWF. The cross-industry group represents ship owners and charterers, shipbuilders, engineers and service providers, banking, insurance, and classification societies.

Looking ahead the SSI strategy will focus on three activities:

a. Promoting individual leadership through nearer-term commitments and sharing individual action and performance widely.

b. Innovation platforms that seek to tackle existing barriers in partnership with others and also identify new areas that present risks and opportunities for the industry.

c. Becoming the progressive voice for the industry and scaling up the great solutions that already exist through media and communications activities

Link: http://ssi2040.org

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- The International Windship Association (IWSA)

"The International Windship Association (IWSA) facilitates and promotes wind propulsion for commercial shipping worldwide and brings together all parties in the development of a wind-ship sector to shape industry and government attitudes and policies."

- Network – create a clear sectoral approach, grouping like-minded organisations and individuals that can share ideas, skills, resources, technical and market information for the development of commercial wind-ships;
- Promote – promoting the economic value of wind propulsion to the shipping industry;
- Incubate – assist in securing funding streams, project collaboration, grant applications, research and the pooling of resources;
- Educate – act as a central information hub for the wind-ship sector, the media,NGO's, equipment producers, shipbuilders, ports, governments and the general public. Research papers, press releases etc.;
- Facilitate – initiating the establishment of common approaches/criteria for all stages of wind-propulsion projects, advise stakeholders and lobby legislative bodies on policies, activities, funding and incentives required to retrofit,upgrade and the new build of commercial wind-ships.

Link: http://wind-ship.org/en/grid-homepage/

- Zero Emission Services (ZES)

Wärtsilä, Engie, ING and Port of Rotterdam and other partners developed a Modular Energy Concept for the Inland Waterway Transport sector which was presented in 2019.[89] This was an industrial concept meant to stimulate greening in IWT towards zero-emission with containerized energy systems and an innovative financing concept (pay-per-use). The first mentioned four organizations formed a joint venture, named Zero Emission Services (ZES), to further develop the concept and to market it as a service.

Link: https://zeroemissionservices.nl/en/home-english/

- RH2INE

Rhine Hydrogen Integration Network of Excellence is a partnership and seeks to realise market-ready hydrogen applications along one of EU's oldest core network corridors. The goal is to have at least 10 inland vessels running on hydrogen by 2024 on the main trade routes between the port of Rotterdam and Cologne, on the Rhine-Alpine corridor. Three hydrogen filling stations are required along the route for this. The partnership submitted a first project for co-financing from the European Commission. This project puts the focus on how hydrogen filling stations on the corridor can be realized.

Link: https://www.rh2ine.eu/

89 https://www.eicb.nl/wp-content/uploads/2019/04/EICB-gorinchem-workshop-BK-deel-NL.pdf

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3.5 Existing decarbonisation strategies and policy initiatives

The industry initiatives are related to the strategies and initiatives at a political level and they will, together, have an impact on the decarbonisation of the waterborne transport sector. Industry initiatives can stimulate this decarbonisation process by initiating the market pull and technology push factors, whereas public measures can act as the regulatory push in this process. This paragraph includes a summary of the most relevant decarbonisation strategies and policy initiatives. Specific and detailed strategies for the waterborne transport sector and the corresponding vessel categories (i.e. deep sea and IWT), are yet to be defined and can be seen as a further elaboration of the enumeration below:

- European Green Deal (December 2019), with the objective for Europe to become the world's first climate-neutral continent by 2050, through the provision of a package of measures, which should enable European citizens and businesses to benefit from a sustainable green transition. The Green Deal sets out the Commission's commitment to tackle climate and environmental challenges. To achieve climate neutrality, the European Green Deal envisages cutting transport emissions by 90% by 2050 at the latest. In addition, it lays down the ambition to reduce GHG emissions by at least 50% by 2030[90].

- A Clean Planet for All (November 2018), A clear strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy (A Clean Planet for All). This strategy confirms Europe's commitment to lead in global climate action and to present a vision that can lead to achieving net-zero GHG by 2050 through a socially fair transition carried out in a cost-efficient manner. It defines pathways for the transition to a net-zero GHG economy and strategic priorities. Seven main strategic building blocks to achieve the objectives of this vision have been defined by the European Commission and "clean, safe and connected mobility" is one of these[91].

- European Climate Law (Proposed in March 2020), the European Commission adopted a proposal to enshrine in legislation the EU's political commitment to be climate neutral by 2050, to protect the planet and EU citizens. The European Climate Law establishes a framework for the irreversible and gradual reduction of greenhouse gas emissions and it addresses the pathway to achieve the 2050 target[92].

- Sustainable and Smart Mobility Strategy (proposed 2020)[93], part of The European Green Deal. The Commission intends to adopt a comprehensive strategy to meet this target and ensure that the EU transport sector is fit for a clean, digital and modern economy. Objectives include:

    - increasing the uptake of zero-emission vehicles;
    - making sustainable alternative solutions available to the public & businesses;
    - supporting digitalisation & automation;

90 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
91 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN
92 https://ec.europa.eu/clima/policies/eu-climate-action/law_en
93 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12438-Sustainable-and-Smart-Mobility-Strategy

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- improving connectivity & access.

- The FuelEU Maritime – Green European Maritime Space (proposed 2020), aims to accelerate achievement of low-emission, climate-neutral shipping and ports by promoting the uptake of sustainable alternative energy and power. It will focus on ramping-up the production, deployment and uptake of sustainable alternative marine fuels. It will also contribute to address the European Green Deal's ambition of regulating access of the most polluting ships to EU ports and obliging docked ships to drastically reduce their emissions, including through using shore-side electricity[94].

- A Europe that protects: Clean air for all (May 2018), provides the policy framework for the reduction of air pollutant emissions such as NOx, SOx and Particulate Matter. The 2018 Communication calls for further interventions in view of the infringements in many European countries related to limit values for air quality being exceeded[95].

- The calls from the Council of Transport Ministers (December 2018)[96], and the European Parliament February 2019)[97], upon the inland waterway transport sector to improve the sector's sustainability with a view to contributing to the Paris agreement objectives (COP21).

- The calls from the European Parliament[98] to reduce global emissions from shipping and its resolution declaring a climate and environmental emergency[99] in Europe and globally

- Mannheim Declaration (October 2018)[100], in their Declaration signed in Mannheim on 17 October 2018, the transport ministers of the Member States of the Central Commission for the Navigation of the Rhine (CCNR - Germany, Belgium, France, Netherlands, Switzerland) reasserted the objective of largely eliminating greenhouse gases and other pollutants by 2050, emphasizing the need for up-to-date, workable and harmonised environmental and safety regulations in Rhine and inland navigation. The CCNR Member States agreed to develop a roadmap in order to:

  - reduce greenhouse gas emissions by 35% compared with 2015 by 2035;
  - reduce pollutant emissions by at least 35% compared with 2015 by 2035,
  - largely eliminate greenhouse gases and other pollutants by 2050.

  This was taken up by the Inland Waterway Agenda for Europe of the Naiades II implementation EC expert group in December 2019[101].

94 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12312-FuelEU-Maritime-/public-consultation
95 https://ec.europa.eu/environment/air/index_en.htm
96 http://data.consilium.europa.eu/doc/document/ST-13745-2018-INIT/en/pdf
97 http://www.europarl.europa.eu/doceo/document/B-8-2019-0079_EN.html?redirect
98 https://www.europarl.europa.eu/news/en/press-room/20191121IPR67110/the-european-parliament-declares-climate-emergency
99 https://www.europarl.europa.eu/doceo/document/TA-9-2019-0078_EN.html
100 https://www.ccr-zkr.org/files/documents/dmannheim/Mannheimer_Erklaerung_en.pdf
101 http://www.ebu-uenf.org/wp-content/uploads/N3-Inland-Waterway-Agenda-for-Europe_final-Dec-2019-003.pdf

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- Reduction of GHG emissions from (seagoing) ships (April 2018)[102], adopted by the **IMO's Marine Environment Protection Committee (MEPC)**. It concerns an initial strategy for the reduction of GHG emissions from (seagoing) ships, setting out a vision to reduce GHG emissions from international shipping by at least 50% compared to 2008 figures by 2050 and to phase them out as early as possible this century. When the strategy will be reviewed in 2023, the level of ambition is expected to be considerably increased.

- Sustainable Development Goals of the United Nations Development Programme (UNDP) emphasize the importance of investments in infrastructure to achieve SDG 9 (Industry, Innovation and Infrastructure)[103], call for urgent action to combat climate change and its impacts SDG 13 (Climate Action)[104] and underline the need to conserve and sustainably use the oceans, seas and marine resources SDG 14 (Life Below Water)[105].

- Green Deal Netherlands on Inland Navigation, Sea Shipping and Ports (June 2019) The Dutch national government, provinces, port authorities, maritime sector organisations, shippers, transport companies, banks, and research institutes joined forces to promote sustainability in the waterborne transport sector. The parties have concluded a Green Deal with Ministry of Infrastructure and Water Management comprising dozens of measures to significantly reduce the emission of air pollutants and CO2 emissions by the inland and sea shipping sectors. The Green Deal also includes ambitions to reduce the emissions, 40% reduction in CO2 for the IWT sector by 2030 and climate neutrality by 2050. The ambition for the maritime transport sector is to reduce CO2 emission by 70% by 2050.[106]

102 http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

103 https://www.un.org/sustainabledevelopment/infrastructure-industrialization/
104 https://www.un.org/sustainabledevelopment/climate-change/
105 https://www.un.org/sustainabledevelopment/oceans/
106 https://www.government.nl/latest/news/2019/06/14/sector-and-governments-joining-forces-to-promote-clean-inland-and-sea-shipping

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4. Statistical input for scenario building

A part of the state-of-play description includes the statistics on the vessel types considered for the development of the implementation pathways (see Figure 2). This concerns information on for example tonnage, fuel consumption, kilometres travelled, operational data, age of fleet, standard refurbishment cycles and others. This information will be used in forming the basis for the development of scenarios with quantified targets for 2025, 2030 and 2050. The following paragraphs provide an overview of the results of the statistical analysis per considered vessel type.

4.1 Maritime shipping

4.1.1. Size of the fleet

In early 2020, the total world fleet amounted to 98,140 ships of 100 gross tons and above, equivalent to 2,061,944,484 dwt of capacity[107]. According to UNCTAD, in its latest Maritime Review 2020, in the 12 months prior to 1 January 2020, the global commercial shipping fleet grew by 4.1 per cent, registering the highest growth since 2014, but still below levels observed during the 2004–2012 period. The market segment that achieved the highest growth was that of gas carriers, followed by that of oil tankers, bulk carriers and container ships. Gas carriers remained the most dynamic segment, recording the highest growth throughout the 2015–2020 period. In 2019–2020, growth in the oil tankers segment was the highest observed since 2015. In comparison, for the first time in many years, the slowest-growing segment was the segment of off-shore vessels, where tonnage declined year after year, and not the segment of general cargo ships.

4.1.2. Age of the fleet

The same report indicates that at the start of 2020, the average age of the global fleet was 21.29 years in terms of number of ships, and 10.76 years in terms of carrying capacity in dwt. In terms of dead-weight tonnage, bulk carriers are the youngest vessels, with an average age of 9.28 years, followed by container ships (9.91 years) and oil tankers (10.38 years). On average, general cargo ships are the oldest vessel type (19.46 years).

In addition, the report highlights that the highest average vessel sizes are found within the youngest fleet segments (zero to four years). Among this group, oil tankers have the highest average size, followed by bulk carriers and container ships. In terms of country groupings, developed and developing countries record higher average sizes fleets aged zero to nine years, whereas for countries with economies in transition, the highest average sizes are found in vessels that are between 10 and 19 years old.

[107] Unctad, Review of Maritime Transport 2020

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Table 2.1	World fleet by principal vessel type, 2019–2020 (Thousand dead-weight tons and percentage)		
Principal types	**2019**	**2020**	**Percentage change 2020 over 2019**
Bulk carriers	846 418 *43 per cent*	879 330 *43 per cent*	3.9
Oil tankers	568 244 *29 per cent*	601 163 *29 per cent*	5.8
Container ships	266 087 *13 per cent*	274 856 *13 per cent*	3.3
Other types	226 568 *11 per cent*	232 012 *11 per cent*	2.4
Other vessels	80 262 *4 per cent*	79 862 *4 per cent*	-0.5
Gas carriers	69 081 *3 per cent*	73 586 *4 per cent*	6.5
Chemical tankers	46 157 *2 per cent*	47 474 *2 per cent*	2.9
Ferries and passenger ships	7 096 *0 per cent*	7 289 *0 per cent*	2.7
Other/ not available	23 972 *1 per cent*	23 802 *1 per cent*	-0.7
General cargo ships	74 192 *4 per cent*	74 583 *4 per cent*	0.5
World total	**1 981 510**	**2 061 944**	**4.1**

Table 6: world fleet by principal vessel type, 2019 – 2021 (source UNCTAD)

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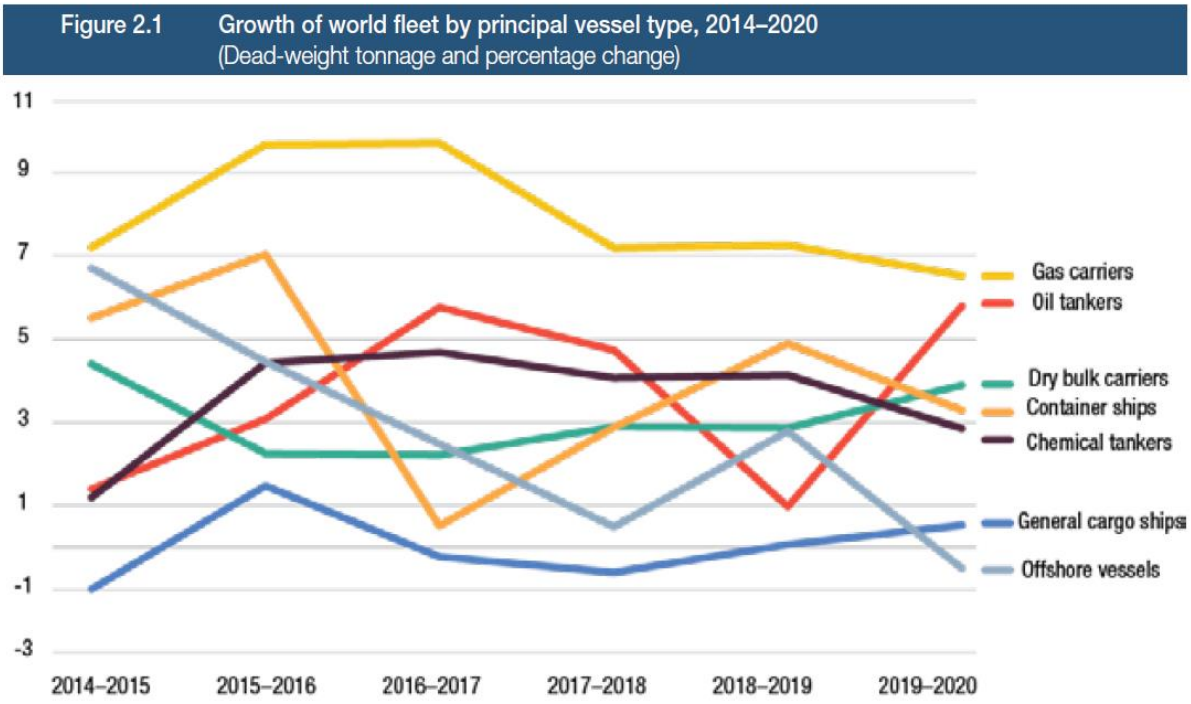

Figure 32: Growth of world fleet by principal vessel type, 2014 – 2020 (source UNCTAD)

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Table 2.2 Age distribution of world merchant fleet by vessel type, 2019–2020
(Percentage and dead-weight tonnage)

Country grouping		Years					Average age	Average age
		0–4	5–9	10–14	15–19	More than 20	2020	2020
World								
Bulk carriers	Percentage of total ships	20.22	42.17	18.70	8.99	9.93	10.18	9.69
	Percentage of dead-weight tonnage	23.30	44.86	16.73	8.22	6.89	9.28	8.87
	Average vessel size (dead-weight tonnage)	84 714	78 169	65 767	67 246	50 973		
Container ships	Percentage of total ships	15.60	20.39	32.79	14.67	16.55	12.72	12.29
	Percentage of dead-weight tonnage	24.41	29.14	28.19	11.74	6.53	9.91	9.43
	Average vessel size (dead-weight tonnage)	80 070	73 137	43 993	40 934	20 186		
General cargo ships	Percentage of total ships	4.64	12.34	15.67	7.99	59.36	26.93	26.30
	Percentage of dead-weight tonnage	8.52	23.16	19.76	9.88	38.69	19.46	18.89
	Average vessel size (dead-weight tonnage)	7 933	8 029	5 455	5 902	2 772		
Oil tankers	Percentage of total ships	14.45	18.95	20.19	11.11	35.32	19.12	18.77
	Percentage of dead-weight tonnage	24.73	24.99	26.57	17.52	6.20	10.38	10.11
	Average vessel size (dead-weight tonnage)	93 311	72 952	71 391	86 251	9 924		
Other	Percentage of total ships	11.21	18.05	15.53	8.28	46.93	23.18	22.70
	Percentage of dead-weight tonnage	21.56	16.94	22.22	10.57	28.71	15.59	15.42
	Average vessel size (dead-weight tonnage)	11 613	6 267	8 682	8 034	4 304		
All ships	Percentage of total ships	11.64	20.11	17.42	8.98	41.85	21.29	20.83
	Percentage of dead-weight tonnage	23.14	33.04	21.85	11.72	10.25	10.76	10.43
	Average vessel size (dead-weight tonnage)	47 901	40 986	30 290	32 742	6 661		
Developing economies (all ships)								
	Percentage of total ships	11.26	21.72	17.31	8.49	41.21	20.38	19.90
	Percentage of dead-weight tonnage	21.75	33.21	18.22	11.62	15.21	11.56	11.15
	Average vessel size (dead-weight tonnage)	37 438	32 440	20 900	27 950	7 544		
Developed economies (all ships)								
	Percentage of total ships	13.33	20.35	19.82	10.67	35.84	19.95	19.54
	Percentage of dead-weight tonnage	24.52	33.42	24.42	11.68	5.97	9.96	9.71
	Average vessel size (dead-weight tonnage)	61 465	52 885	40 792	38 294	7 305		
Countries with economies in transition (all ships)								
	Percentage of total ships	6.38	8.19	8.63	4.34	72.47	30.33	29.82
	Percentage of dead-weight tonnage	8.94	20.19	27.46	15.58	27.83	16.99	16.39
	Average vessel size (dead-weight tonnage)	12 644	18 987	25 905	25 880	2 724		

Source: Clarksons Research.

Table 7: Age distribution of world merchant fleet by vessel type, 2019 – 2020 (source Unctad)

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4.1.3. Fuel Consumption and emissions

The data in this paragraph are derived from the "Ship type peformance data analytics", based on the MRV-THETIS database 2019, as developed by BALance Technology Consulting. It should be noted, that the diagrams of this report are based on the MRV-Thetis Database related to the operational period 2019. This database includes data reported from 12.192 vessels that at least touched one European Union port during the defined period.

Due to considerable deviation in some of the reported data, the data set has been reduced to 10.964 records. Reasons for discarding data have been ships with more time at sea than hours one year have, ships with an average speed exceeding 25 knots or less than 5 knots. Furthermore, records showing less than 5.000 n miles sailed or including data the prevailing range have also been disregarded.

Figures 33, 34 and 35 provide data on the CO_2 emissions by ship type, fuel consumption per distance as well as the total fuel consumption.

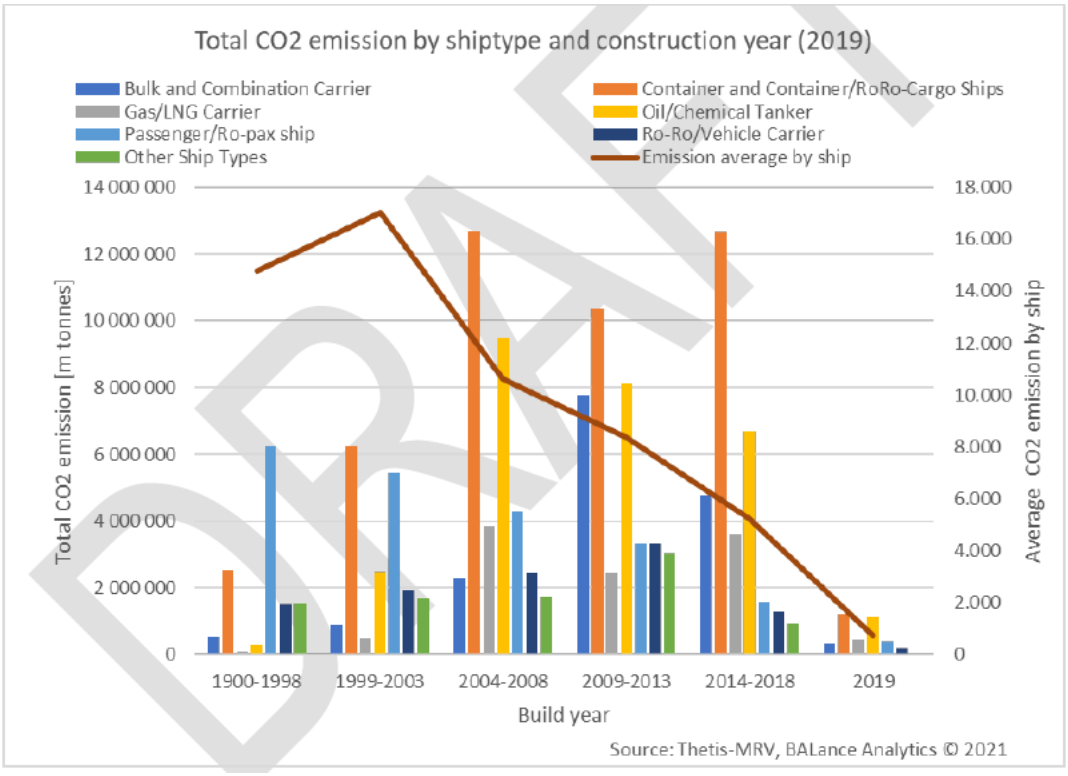

Figure 33: Total CO_2 emission by shiptype and construcdtion year (2019)

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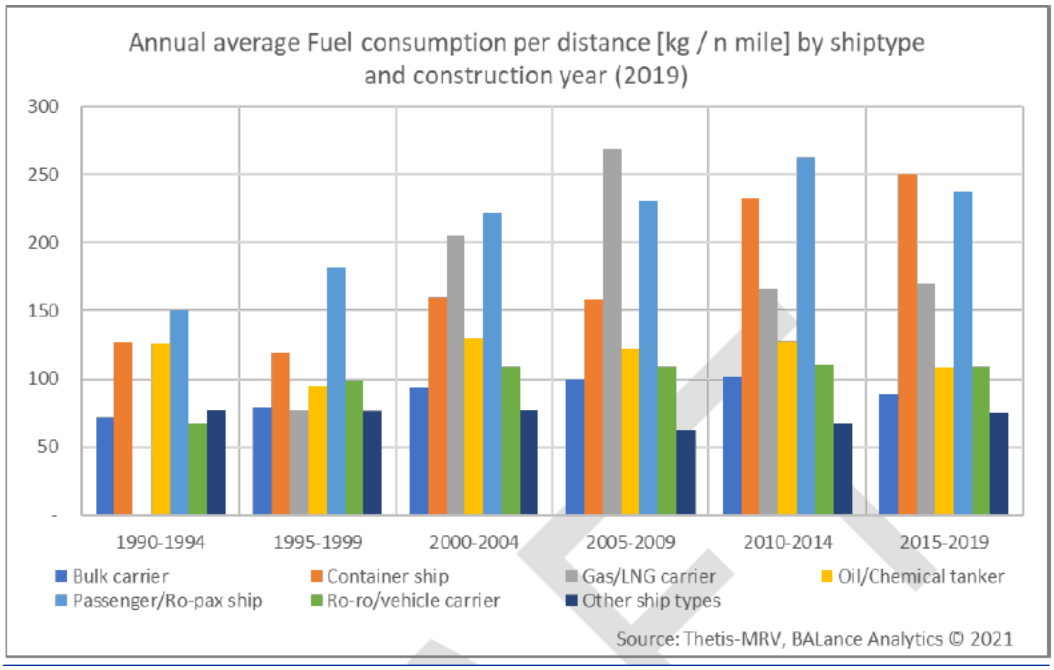

Figure 34: Annual average Fuel consumption per distance (kg/n mile) by shiptype and construction year (2019)

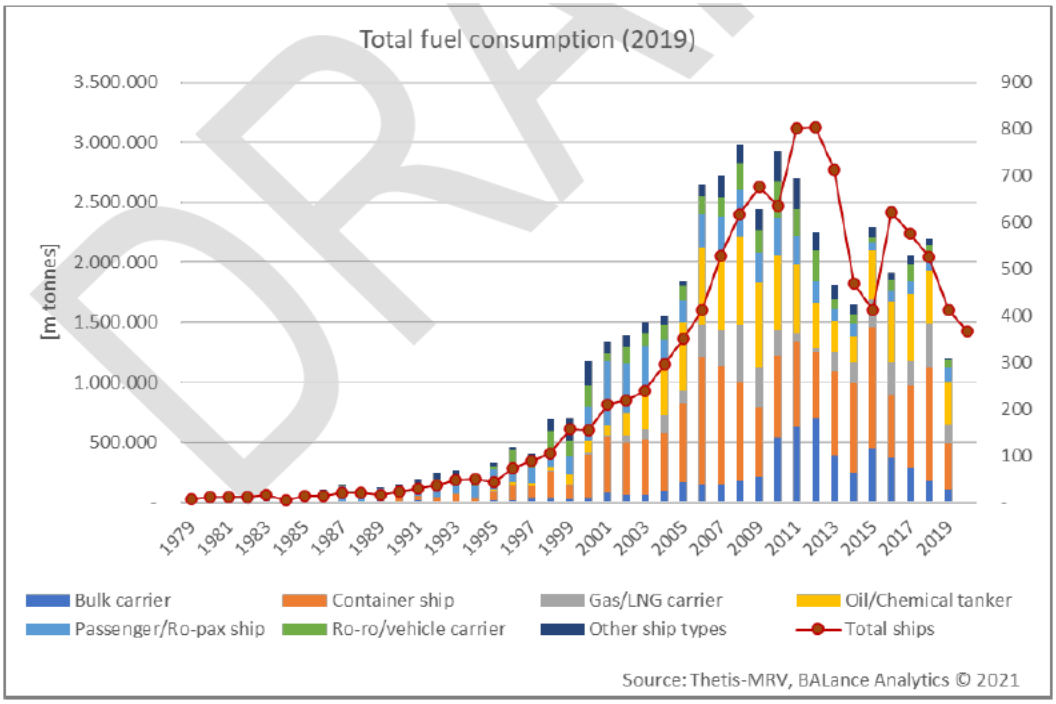

Figure 35: Total fuel consumption (2019)

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4.2. Inland Waterway Transport

4.2.1 Size of the fleet

On a European scale, The Horizon2020 project PROMINENT[108] divided the IWT market into the Rhine, Danube and 'other waterways' (i.e. Seine, Rhône/Saône, Mittelland Canal, Albert Canal, Meuse, Dortmund-Ems Canal and Elbe). For the purpose of this study a division will be made between vessels registered in the:

- Rhine and other waterway countries: Belgium, France, Germany, the Netherlands, Luxembourg, Switzerland and Czech Republic;
- Danube countries: Bulgaria, Hungary, Croatia, Moldova, Ukraine, Austria, Romania, Serbia and Slovakia.

The total IWT fleet consists of various types of vessels, however it is possible to define groups of comparable vessels, also called 'fleet families'.
The following table provides an overview of the fleet families and their indicative numbers. The indicative numbers were derived from the PROMINENT report and the study "Assessment of technologies in view of zero-emission IWT"[109].

Fleet families	Indicative number of operational vessels in Europe
Passenger vessels (hotel/cruise vessels)	346
Push boats < 500 kW (total engine power)	890
Push boats 500-2,000 kW (total engine power)	520
Push boats ≥ 2,000 kW (total engine power)	36
Motor vessels dry cargo ≥ 110 m length	610
Motor vessels liquid cargo ≥ 110 m length	602
Motor vessels dry cargo 80-109 m length	1,802
Motor vessels liquid cargo 80-109 m length	647
Motor vessels < 80 m length	4,463
Coupled convoy (mainly class Va+Europe II lighter)	140
Ferries	103
Daytrip and small hotel vessels	2207
Total	12,366

Table 8: Fleet families Inland Waterway Transport and the number of operational vessels per family

[108] https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_23_PROMINENT_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf
[109] https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition_1_Oct2020.pdf

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There is an additional relevant fleet family on which any reliable data is missing though. This concerns the fleet family 'floating equipment'. This fleet family will not be incorporated in this analysis since data is missing. However, it should be kept in mind that the market size is considerable, with a concentration in the Netherlands. The owners of such vessels are in some cases large companies active in the dredging and construction sectors. These vessels are often used for infrastructural projects. The combination of large companies as vessel owners and governmental contracts for infrastructural projects can act as an important driver for greening. An example is Van Oord that invested in LNG and HVO for some of the floating equipment (e.g. crane vessels) it operates.[110]

The following table provides an overview over the available estimated loading capacity of IWT fleet in Europe. Based on an analysis from Panteia, published in the CCNR Market Observation, the capacity utilisation rate of all fleet categories decreased but was still at a relatively high level; the analysis is based on figures from 2019 in the Rhine region and refers to a combination of higher effective available vessel and fleet capacity in combination with a lower transport demand.

	Estimated Loading capacity [1,000 tonnes]
Cargo fleet in Rhine countries	***13,600***
Dry cargo vessels	10,600
Liquid cargo vessels	3,000
Cargo fleet in Dannube countries	***3,200***
Dry cargo vessels	3,000
Liquid cargo vessels	200
Other european countries	*550*
∑	**17,350**

Table 9: Estimated Loading capacity of IWT fleet in Europe [111]

[110] Based on expert knowledge.
[111] Own figure, based on: Danube Commission "Market observation of the Danube navigation: Results 2019" (numbers from 2017) and CCNR "CCNR Market Observation - Annual report 2020" (numbers from 2019)[a]

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4.2.2. Age of the fleet

The age structure of the European inland fleet is considered separately for the Rhine and Danube fleet. In the following **Fout! Verwijzingsbron niet gevonden.**figure 36, the age structure of the Rhine fleet can be seen according to a division for dry cargo, passenger, push respectively tug boats and tank cargo vessels. It can be seen that 84% of the dry cargo fleet was built in the late 1950s and early 1960s. A significant increase of new dry cargo and specially of liquid cargo vessels can be seen in the years 2000 until 2009[112].

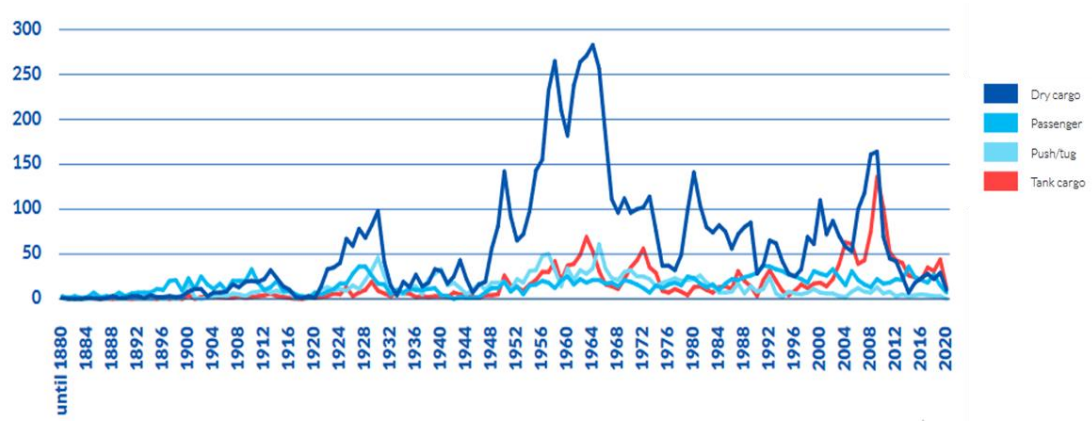

Figure 36: Commissioning activity for the Rhine fleet over time [113]

When having a view on the Danube fleet, the relative advanced age structure has to be taken into account, according to the Danube Commission´s "Market observation of the Danube navigation: Results 2019", 72 % of the push boats and 16 % of the barges are more than 40 years old, furthermore 59 % of the operational barges are more than 35 years old. [114]

The pattern to either overhaul or replace an existing engine in an inland vessel is based on the life cycle of the engine. In principle, overhaul takes place if it is still qualitatively and financially more attractive than replacing the engine. Replacement occurs when the engine is exhausted or damaged. The lifespan of an engine in years is mainly determined by the number of operating hours per year. Emission standards (CCNR I, CCNR II and NRMM Stage V) in IWT only apply to new engines and not to existing engines. Hence, overhauled engines only need to comply with the original standards that applied to the engine once it was installed in the vessel. In some cases this even concerns pre-CCNR engines, i.e. engines without an emission standard. All these factors contributed to a slow greening of the IWT fleet. Possible future developments like an emission label or the 2025 Port Bye Laws of Rotterdam can break this trend.

[112] CCNR , Annual Report Inland Navigation In Europe, Market Observation; Age Structure Of The Fleet: https://inland-navigation-market.org/chapitre/5-cargo-fleet-2/?lang=en
[113] CCNR, https://inland-navigation-market.org/wp-content/uploads/2020/09/CCNR_annual_report_EN_2020_BD.pdf
[114] Danube Commission (2020): Market observation of the Danube navigation: Results 2019 (figures based on statistics from 2017); https://www.danubecommission.org/uploads/doc/2019/Market_2019/market_observation_2019_de.pdf

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The replacement of an engine is a natural moment in which parties reorient themselves regarding the possible solutions. In general, solutions are chosen by price, technical availability and applicability in the respective vessel. In general and until now it is experienced that cleaner solutions lead to additional costs which cannot be recovered only if the (end)-customer asks for it (i.e. clean transport), pays for it (i.e. higher transport tariffs) and or wants to enter into a long-term commitment (i.e. long-term transport contract). From a technical point of perspective, an estimation can be made for the lifetime of an engine based on the average number of effective sailing hours and the maximum lifetime (in operating hours) of engines per speed class. The table below provides an overview:

Engine speed (RPM)	Engine operating hours until overhaul
Up to 750 rpm	75.000
750 – 1250 rpm	62.500
>1250 rpm	50.000

Table 10: Estimated lifetime of various types of engines for IWT

It is assumed that after an overhaul, an engine will last for another equal number of operating hours.[115]

4.2.3. Fuel consumption

The table below provides an overview of the yearly fuel consumption for most of the fleet families[116]. Unfortunately, there is no data on the fuel consumption of the fleet families 'Ferries' and 'Day trip and small hotel vessels'. The yearly fuel consumption of day trip and small hotel vessels will probably be on the low side as compared to the total average, whereas, on average, ferries will likely have a larger yearly fuel consumption as compared to day trip and small hotel vessel. The fuel consumption is already an important indication for the suitability of alternative fuels and techniques. For example, alternative fuels that are relatively cheaper than conventional diesel and lower in OPEX but more expensive in CAPEX, may be more attractive for vessels with a relatively high fuel consumption as compared to vessels with a low fuel consumption.

Fleet families	**Average fuel consumption per year (in m³)**
Passenger vessels (large hotel)	600
Push boats <500 kW	32
Push boats 500-2000 kW	158
Push boats ≥2000 kW	2070
Motorvessels dry cargo ≥110m	339
Motorvessels liquid cargo ≥110m	343

[115] https://www.europa-nu.nl/id/vk5dppqk5qyp/agenda/voortgang_van_de_implementatie_van_de?ctx=vgg6d3r5tyt4&v=1&tab=1
[116] https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_23_PROMINENT_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf as base source and https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition_1_Oct2020.pdf

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Motorvessels dry cargo 80-109m	162
Motorvessels liquid cargo 80-109m	237
Motorvessels <80 m	49
Coupled convoys	558
Ferries	69
Day trip and small hotel vessels	38

Table 11: Yearly fuel consumption per fleet family, IWT

4.2.4 Kilometres travelled

According to the latest statistics of Eurostat the total volume of goods transported on European inland waterways was **523 million tonnes** in the year 2019, which is an increase of 2.9 % compared with the previous year. The **total transport performed reached 140 billion tonne-kilometres**, which is also an increase of 6.3 % from the previous year. More than half of the transported cargo (calculated based on tonne-kilometres basis) on European inland waterways have been transported in the Netherlands (33 %) and Germany (29.2 %), followed by Romania (15 %).[117] Based on the mentioned statistics the average kilometres travelled can be calculated to 267.7 km; however, taking into account the selected representative journeys from the Prominent project (see table 7), there are more long distance trips on European level.

Region	Port A	Port B	Distance (roundtrip in km)	Number of trips per year
Rhine/ARA	Rotterdam	Duisburg	460,0	179,2
Rhine/ARA	Rotterdam	Antwerp	280,0	106,1
Rhine/ARA	Rotterdam	Karlsruhe	1340,0	58,9
Rhine/ARA	Amsterdam	Karlsruhe	1267,0	56,8
Rhine/ARA	Rotterdam	Basel	1734,0	33,6
Rhine/ARA	Antwerp	Thionville	1464,0	23,0
Rhine/ARA	Amsterdam	Antwerp	422,0	107,5
Rhine/ARA	Rotterdam	Krotzenburg	1193,4	48,9
Rhine/ARA	Amsterdam	Rotterdam	240,0	292,5
Rhine/ARA	Antwerp	Mainz	1135,0	54,1
Danube	Bor district	Constanta	1254,4	n.a.
Danube	Bor district	Constanta	1254,4	n.a.
Danube	Constanta	Dunaújváros	2692,4	n.a.
Danube	Giurgiu	Constanta	516,4	n.a.
Danube	Calafat	Constanta	1120,4	n.a.
Danube	Bratislava	Linz	534,0	n.a.
Danube	Calafat	Constanta	516,4	n.a.
Danube	Constanta	Dunaújváros	2692,4	n.a.

[117] Eurostat: Inland waterway transport statistics; https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Inland_waterway_transport_statistics

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Danube	Giurgiu	Constanta	516,4	n.a.
Danube	Giurgiu	Constanta	516,4	n.a.
Seine	Le Havre	Gennevilliers	723,2	41,9
Seine	Le Havre	Gennevilliers	723,2	95,4
Seine	Le Havre	Gennevilliers	723,2	52,7
Rhone/Saone	Fos-sur-Mer	Chalon-sur-Saone	1176,0	53,1
Rhone/Saone	Fos-sur-Mer	Lyon	714,0	41,1
Rhone/Saone	Fos-sur-Mer	Lyon	714,0	37,2
Mittellandkanal	Rotterdam	Hannover	1033,0	30,9
Mittellandkanal	Duisburg	Wolfsburg	775,0	35,5
Albertkanal	Antwerp	Meerhout	136,8	192,6
Albertkanal	Amsterdam	Liège	508,8	55,0
Albertkanal	Rotterdam	Liège	503,8	104,7
Albertkanal	Antwerpen	Liège	301,8	102,8
Maas	Amsterdam	Born	472,0	66,3
Maas	Rotterdam	Wanssum	370,0	71,0
Maas	Rotterdam	Stein	428,0	74,4
Dortmund-Ems	Rotterdam	Oldenburg	927,4	30,1
Dortmund-Ems	Rotterdam	Lingen	797,6	44,9
North South	Amsterdam	Nesle/Compiegne	973,4	21,0

Table 12: List of representative journeys; extract from Prominent D.1.1. [118]

The total transport performance of the European IWT sector amounts to around 144 bilion tkm in 2019. Around 74% of the transport crossed a country border, either in the form of export, import or transit traffic. An important share of this transport performance is clustered in Germany and the Netherlands in Western-Europe, whereas Romania has an important share in the total transport performance in Eastern-Europe. Figure 37 below provides an overview[119].

[118] PROMINENT Project, D.1.1. Annex A3: list of representative journeys
[119] https://www.ccr-zkr.org/files/documents/om/om20_II_en.pdf

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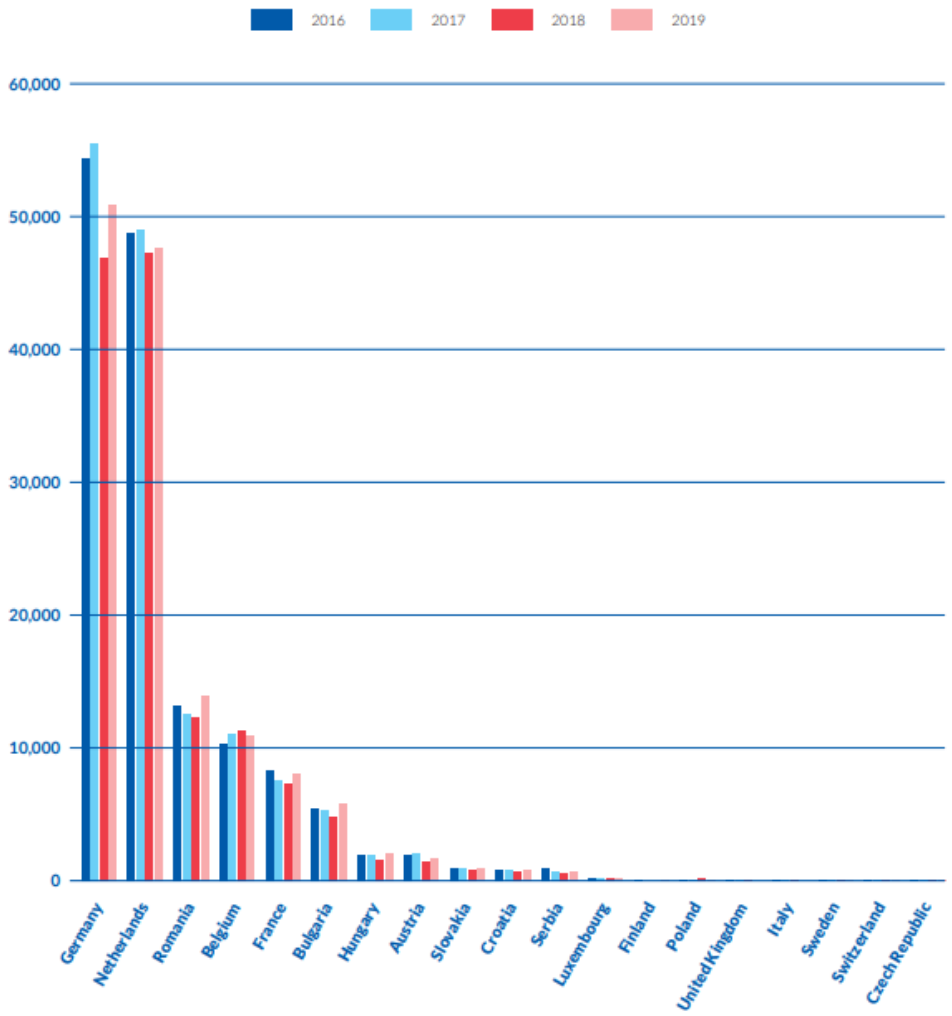

Source: https://www.ccr-zkr.org/files/documents/om/om20_II_en.pdf

Figure 37: IWT transport performance in 2016, 2017, 2018 and 2019 in main european iwt countries (transport performance in million tkm)

The figure already provides a first indication of the representative sailing areas in Europe. However, the operational data of inland vessels can be best captured in specific sailing profiles based upon representative journeys, type of vessel used and type of cargo transported. In PROMINENT, the top 96 transport journeys were identified that cover about 55% of the total transport volume in Europe. The top 5 representative sailing profiles are presented in the enumeration below:

1. Transport from Rotterdam to Duisburg
    a. 30,748 ton and 7,808 tonkm in total (mainly dry bulk)
2. Transport from Rotterdam to Antwerp
    a. 21,998 ton and 3,628 tonkm in total (mainly containers)
3. Transport from Rotterdam to Amsterdam
    a. 13,196 ton and 3,376 tonkm in total (mainly petroleum products)

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4. Transport from Le Havre to Gennevilliers
    a. 9,3790 ton and 2,462 tonkm in total (mainly crude and manufactured minerals and building materials)
5. Transport from Duisburg to Antwerp
    a. 6,159 ton and 2,251 tonkm in total (mix of a.o. petroleum products and container transport).

4.2.5. Emissions

Relevant other information to state concerns the emission profile of the IWT sector. The table below provides an estimation of the existing emissions of the European IWT fleet.

Engine year	NOx (g/kWh)	PM (g/kWh)	Fuel consumption (g/kWh)	Comment
<1975	10,8	0,6	235	
1975-1979	10,6	0,6	230	
1980-1984	10,4	0,6	225	
1985-1989	10,1	0,5	220	
1990-1994	10,1	0,4	210	
1995-2002	9,4	0,3	205	
2003-2007	9,2	0,3	200	CCR I
>2007	6,0	0,2	200	CCR II

Table 13: estimation emissions of European IWT fleet Source: Prominent[120]

This is a relatively old estimation based on data from 2012. The table clearly shows though how the emissions significantly declined as result of the emission standards CCRI and CCRII, this especially applies to the NOx emissions. As of 2019 en 2020 the new emission standards are in place, for respectively engines with an installed power of <300kW and >300kW. The new standards are as follows for each power group:

Power	**CO**	**HC**	**NOx**	**PM**	**PN**
kW	g/kWh	g/kWh	g/kWh	g/kWh	#/kWh
19≤P<75	5	(HC+NOx≤4,70)		0,3	–
75≤P<130	5	(HC+NOx≤5,40)		0,14	–
130≤P<300	3,5	1	2,1	0,1	–
P≥300	3,5	0,19	1,8	0,015	1×10^{12}

Table 14: NRMM Stage V limits

[120] https://www.prominent-iwt.eu/wp-content/uploads/2018/07/2018_04_30_PROMINENT_D6.3_D6.5_Combined_Deliverable.pdf

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However, as of November 2020 there are no NRMM Stage V type approved engines yet in the category >300kW. On average, the largest share of the fleet still sails on pre-CCR and CCRI type approved engines.[121]

[121] https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_23_PROMINENT_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf

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5. Conclusion

Deliverable 2.1. provides a first broad overview of the state-of-play regarding the transition towards zero-emission waterborne transport. The deliverable provides a clear overview of the current state-of-play regarding technologies developed for and by the European waterborne transport sector, their applicability to certain ship types, as well as the potential barriers and areas for improvement. It however also reveals that not all information needed is publicly available.

In addition, it shows the commitment of both international, European, national and regional governments and authorities to achieve the elimination of emissions towards 2050. Equally important, the number of arising industry initiatives to achieve a carbon-neutral economy as soon as possible, is clearly highlighting the commitment of the waterborne transport sector.

The final part of the report provides the first statistical data which will be of use in the next steps of the STEERER project concerning the development of scenarios with quantified targets for 2025, 2030 and 2050. In addition, it reveals the diversified waterborne transport sector. Not only concerning the different ship types and trades, but also concerning the age of the fleet of certain segments, as well as other characteristics which clearly need to be taken into account when defining the roadmaps to be able to transform the waterborne transport sector to a zero-emission mode of transport.

Furthermore, this deliverable is not “cast in stone”. On a frequent basis, its content will be updated, so as to align with the increasing number of relevant initiatives. In addition, it will be used to start-off a communication campaign regarding the commitment of the waterborne transport sector to develop and deploy solutions for societal challenges.

Finally, this deliverable is a starting point for discussions with experts in both the Scientific Committee and the Green Shipping Expert Group with a view to update the SRIA of the cPP on Zero-Emission Waterborne Transport.

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6. Annex 1

This Annex primarily contains a non-exhaustive list of projects which demonstrate application of innovative techniques/fuels fitting into the zero-emission pathway. Furthermore, the annex also contains an overview of the number of vessels sailing on more mature greening technologies/fuels which perhaps do not directly result in a zero-emission performance, but fit into the pathway towards reaching it. I.e. techniques/fuels as a diesel-electric powertrain and LNG can be a transitional technique/fuel towards, respectively, a fully electric powertrain and bio-LNG.

6.1 Sustainable Alternative Fuels

6.1.1 The light gas pathway

LNG

Project Name	NAUTILUS
Project Description	The project aims to develop, evaluate and validate an integrated marine energy system, with the core consisting of a highly efficient Solid Oxide **Fuel Cell** (SOFC) coupled with a battery, referred to as a genset, using LNG as fuel is proposed for passenger ships and achieved through: a) Virtual Process Design Concept of On-Board Energy System b) Physical Proof of Concept and Genset Demonstrator
Applicability	Passenger ships
Partners	Deutsches Zentrum für Luft –und Raumfahrt (DLR), Chantiers de l'Atlantique, Carnival Maritime GmbH, Ecole Polytechnique Fédérale de Lausanne, GRANT Garant, Lloyd's Register EMEA, MAN Energy Solutions, Meyer Werft PAPENBURG, Royal Caribbean Cruise Line, Rheinisch-Westfälische Technische Hochschule Aachen, SOLIDPower, Technische Universiteit Delft, Lunds Universitet, Teknologian tutkimuskeskus VTT
Delivery Date	Demonstrator by June 2024
Status	Ongoing
Link	https://www.isea.rwth-aachen.de/cms/ISEA/Forschung/Projekte/Oeffentliche-Projekte/Laufende-Projekte/~jrarg/Nautilus/lidx/1/V
Funded?	Overall budget of €7.89M over 4 years with 100% grant from EU.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Minerva - LNG Hopper Dredger
Project Description	Development, production and commissioning of the worlds' first LNG fuelled Trailing Suction Hopper Dredgers. It is the first application of LNG on complex work vessels. This project demonstrated and proved that LNG is a clean and feasible solution and that Duel Fuel LNG engines are able to handle intense load variations.
Applicability	Complex work vessels, like dredging vessels, service operation vessels, offshore vessels
Partners	Royal IHC, DEME
Delivery Date	September 2017
Status	Finished
Link	https://www.royalihc.com/en/news/worlds-first-lng-powered-hopper-dredger-launched
Funded?	No

Project Name	GAINN4SHIP INNOVATION – LNG technologies and innovation for the maritime transport for the promotion of sustainability, multimodality and the efficiency of the network
Project Description	GAINN4SHIP INNOVATION proposed a pilot action on alternatives and retrofitting of an HSC (High Speed Craft) ro-pax ferry to run on LNG. Although the retrofit of the Bencomo Express unfortunately could not be completed because of the lack of a competitive LNG distribution chain in the Canary Islands, the project partners demonstrated that the technology for high-speed LNG ships is ready for use and available on the market.
Applicability	RoPax ferry
Partners	Fundación Valenciaport; Fred Olsen S.A.; Dirección General de la Marina Mercante; Centre Internacional de mètodes numèrics en enginyeria; Autoridad Portuaria de Valencia
Delivery Date	May 2018
Status	Finalised – not executed
Link	http://www.gainnprojects.eu/
Funded?	Budget around € 6.2 million, of which 50% was funded by CEF Programme

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	LNGHIVE2 VESSELS DEMAND: Green and smart links – LNG solutions for smart maritime links in Spanish core ports
Project Description	The project includes the retrofitting of five ro-pax vessels belonging to the shipping company Baleària, to run on LNG.
Applicability	RoPax Ferry
Partners	Baleària Eurolíneas Marítimas, Fundación Valenciaport, Gas Natural Comercializadora, Port Authority of Gijón and Scale Gas Solutions.
Delivery Date	July 2021
Status	Ongoing
Link	https://www.fundacion.valenciaport.com/en/project/lnghive2-vessels-demand-green-and-smart-links-lng-solutions-for-smart-maritime-links-in-spanish-core-ports-2/
Funded?	Budget around € 59 million, of which 20% is funded by CEF Programme.

Project Name	LNGHIVE2 VESSELS DEMAND: Green and smart links – LNG solutions for smart maritime links in Spanish core ports
Project Description	The project aims at retrofitting the ropax vessel Hedy Lamarr to be fuelled with LNG.
Applicability	Ro-Pax
Partners	Baleària Eurolíneas Marítimas
Delivery Date	December 2021
Status	Ongoing
Link	
Funded?	Budget around € 12.7 million, of which 15% is funded by CEF Programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Technique	LNG
Technique Description	Liquified Natural Gas is a fossil transitional fuel which is cleaner as compared to diesel fuel (EN590) used in IWT. Based on average operational profiles, savings could be realized up to 70% on NOx and 95% on PM compared to CCNR-2 emission limits, and 10% on CO2 equivalent emissions.
Applicability	In general most types of inland vessels. There may be restrictions for the smallest vessels due to the required space for the installation (e.g. cryogenic tank and tank connection space).
Number of operational vessels	12 (mostly 110m inland tanker vessels)
Funded	More than half of the LNG driven inland vessels received funding under various European (e.g. CEF) and national funding programmes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Hydrogen

Passenger vessels/ferries

Internal combustion engines

Project Name	Hydroville
Project Description	World's first accredited passenger vessel powered partially by hydrogen in a diesel engine (H2ICE, 441kW). At 19kts in dual fuel mode (55% H2), the engine saves: • 58% CO2 compared to diesel mode • 65% NOx compared to diesel mode • 13% increase in thermal efficiency In the first year of operation, saved over 4000kg CO2 based on H2 consumed
Applicability	16 pax shuttle
Partners	CMB Technologies
Delivery Date	11/2017
Status	In service
Link	https://www.ship-technology.com/projects/hydroville-passenger-ferry/
Funded?	No

Project Name	HydroBingo
Project Description	World's first passenger ferry powered by a dual fuel hydrogen-diesel internal combustion main engine. Powered with 2x 485kW hydrogen diesel combustion engines.
Applicability	80 pax shuttle
Partners	CMB Technologies, Tsuneishi Facilities & Craft
Delivery Date	Q1 2021
Status	
Link	https://www.mynewsdesk.com/tsuneishi-holdings-corporation/pressreleases/tsuneishi-facilities-and-craft-aims-to-build-the-worlds-first-hydrogen-powered-passenger-ferry-2920262
Funded?	No

Project Name	HydroCat
Project Description	The hydrogen CTV will be able to transport 24 service engineers at a cruise speed of 25kn, propelled by 2x1000 horsepower and will consume 170 kg of hydrogen per day
Applicability	Crew Transfer Vessel (24 pax)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Partners	CMB Technologies, Windcat Workboats, Vattenfall
Delivery Date	Q2 2021
Status	
Link	https://fuelcellsworks.com/news/cmb-technologies-and-windcat-to-develop-hydrogen-crew-transfer-vesselsctvs-project/
Funded?	No

Project Name	ZeFF – Zero Emission Fast Ferry
Project Description	The power to propulsion is designed with **fuel cells** fuelled by hydrogen and batteries. The vessel will have approximately 45% less energy consumption than current vessels per passenger-km, and can be made with varying size and capacity, from 100 to 300 passengers. The vessel will utilise foils that lift the vessel out of the water and will have cruise speed between 25 and 45 knots.
Applicability	Ferry (100-300 pax)
Partners	NCE Maritime CleanTech, Norled, Selfa Arctic, LMG Marin, Hyon and Servogear.
Delivery Date	2021
Status	Concept
Link	https://bein.no/en/zeff-zero-emission-fast-ferry-2/
Funded?	Awarded NOK 10.5 million from the public support scheme PILOT-E.

Project Name	FlagShips
Project Description	The FLAGSHIPS project contributes in building two new build vessels: • a hydrogen push-boat (19 operating hours a day) • a passenger and car ferry where at least 50% of the energy requirement is covered by hydrogen. The ferry has 3×200 kW PEM **fuel cell** modules and hydrogen tanks for storage of 600kg hydrogen (compressed) allowing the vessel to sail 140 nautical miles.
Applicability	Push boat RoPax Ferry (199 pax & 60 cars) - MF Hidle
Partners	Norled, Compagnie Fluvial de Transport, LMG Marin, Ballard Europe, maritime OEM ABB
Delivery Date	2022 Q1
Status	
Link	https://flagships.eu/2020/08/11/flagships-ferry-taking-shape-in-turkey/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Funded?	€5 million awarded by the EU's Horizon 2020 research and innovation fund

Project Name	MF Hydra
Project Description	Passenger ferry, powered by two FCwave™ 200 kW fuel cell modules. The ferry will be the first of its kind to run on liquid hydrogen. Compared to compressed hydrogen, liquid hydrogen takes up four times less space, which allows more energy onboard and extends a ship's range. Initially, the liquid hydrogen will be imported, and the plan is to build a local, renewable hydrogen supply chain in the future.
Applicability	Ropax Ferry (299 pax, 80 cars)
Partners	Norled, Westcon, Ballard Europe
Delivery Date	2021 Q2
Status	On order
Link	http://www.publicnow.com/view/1C0C4601E3EA18B8A531CBD8DAD3A24876E5FDF0?1601596068
Funded?	No

Project Name	HySeas III
Project Description	First sea-going ropax ferry that will be fuelled by hydrogen produced from local renewable energy sources. HySeas III aims to demonstrate that fuel cells may be successfully integrated with a proven marine hybrid electric drive system (Ballard HD100 100 kW **PEMFC** and Leclanché batteries), along with the associated hydrogen storage and bunkering arrangements.
Applicability	Ropax ferry (100 pax)
Partners	Ferguson Marine Engineering, Ballard Power Systems, Kongsberg Maritime AS,…
Delivery Date	31/12/2021
Status	
Link	https://www.hyseas3.eu/
Funded?	Expected costs around €12.6 million of which € 9.3million awarded by the EU's Horizon 2020 research and innovation fund.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	ISHY
Project Description	Development, testing and validation of technical tools and socio-economic models (business cases) for the implementation of hybrid and hydrogen **fuel cell** technologies in vessels and ports, and realising the development and the demonstration of the feasibility of these technologies. The ISHY Project consists of 5 Pilots: • The hybrid hydrogen diesel retrofit of the Inland Waterway Breakbulk Barge, the Vera Cruz • The new to be build hydrogen propelled passenger ship, the Z9 (350pax) • The new to be build hybrid hydrogen diesel crew transfer vessel • The to be retrofitted hybrid battery electric-diesel inland waterway inspection vessel of the UK • The multi-fuel and power bunkering facility in the harbour of Ostend
Applicability	Small inspection craft, crew transfer vessel, inland vessel (freight), passenger transport vessel.
Partners	NV Economische Impuls Zeeland, WaterstofNet, TU Delft, GEO Aqua, Hybrid Marine Ltd, Llyod's Register EMEA, Vera Cruz Shipping, Solent University, Rondvaartbedrijf Zilvermeeuw, Université Polytechnique Hauts-de-France, Yerseke Engine Services, zepp.solutions, Katholieke Hogeschool Vives Zuid, Parkwind
Delivery Date	30/06/2022
Status	Ongoing
Link	https://www.gceocean.no/media/2662/1-hybridisation-of-inland-waterway-and-coastal-ships-nico-cf-bolleman.pdf https://www.maritiemnederland.com/artikelen/techniek-innovatie/varen-op-waterstof-als-de-eindgebruiker-daar-om-vraagt
Funded?	The project receives €9,206,068 co-financing from the Interreg 2 Seas programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Havila Kystruten
Project Description	The system will be based on several 200kW **fuel cell** system modules that will be connected in parallel to produce a total power of 3.2MW, 3.5 t LH2 Tank
Applicability	RoPax Ferry (640 pax)
Partners	Havyard Group, PowerCell Sweden
Delivery Date	End of 2022
Status	Pilot
Link	https://shipsmonthly.com/news/havila-kystruten-to-test-fuel-cells/
Funded?	Awarded NOK 104 million from the public support scheme PILOT-E

Project Name	SWIM
Project Description	Development of a H2 **Fuel Cell** propelled water taxi.
Applicability	Water taxi
Partners	Enviu, Watertaxi Rotterdam, Flying Fish and ZEPP.solutions
Delivery Date	2023
Status	Ongoing
Link	https://www.enviu.org/2020/02/12/first-hydrogen-fueled-water-taxi-being-developed-by-enviu-and-partners/
Funded?	Co-financing from the Municipality of Rotterdam, the Dutch Ministry of Infrastructure and Water Management and the Gieskes Strijbis Fund.

Project Name	Hydrogen Powered Ferry
Project Description	A Japanese consortium plans to develop and deploy a 100-passenger tour boat powered by electric batteries and hydrogen **fuel cells**. The project will entail the development of new shipboard technology, including the fuel supply system and an energy management system to combine power from the battery with power from the fuel cell.
Applicability	Ferry (100 pax)
Partners	NYK Line, Toshiba, Kawasaki Heavy Industries, Class NK, ENEOS Corporation
Delivery Date	2024
Status	Demonstration
Link	https://www.offshore-energy.biz/japanese-firms-partner-up-on-commercialisation-of-high-power-fuel-cell-vessels/
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Fuel cell boat - Nemo H2
Project Description	The project delivered a newbuild **fuel cell** boat for the canal cruise on the Amsterdam canals. The boat is equipped with FC's and batteries. The hydrogen is stored under pressure (350 bar).
Applicability	Small tour boat
Partners	Alewijnse, Integal, Linde Gas, Lovers, MSN
Delivery Date	2010
Status	Finished – not operational
Link	https://www.rvo.nl/sites/default/files/rvo_website_content/EOS/DEM006005.pdf
Funded?	Co-financed by the Dutch programmes EOS and IAE.

Project Name	GKP7H2
Project Description	The pilot project GKP7H2 is part of DNV GL Green Coastal Shipping Program. Brødrene Aa has has designed a 30-meter-long high-speed vessel with hydrogen propulsion as part of the project. The 150 pax vessel will have 1,2 MW installed **fuel cells** and hydrogen tanks for storage of 450 kg hydrogen allowing the vessel to sail 120 nautical miles at 28 knots speed without refuelling.
Applicability	Ferry (High-speed vessel)
Partners	Hub for Ocean
Delivery Date	2021
Status	Finished
Link	https://www.oceanhywaycluster.no/projectlist/project-1
Funded?	Mobility Zero Emission Energy System (MoZEES)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Jules Vernes 2
Project Description	Deployment of a hydrogen fuelled electric powered catamaran. The vessel runs on two **fuel cells** of 5kW each, both equipped with electrochemical batteries powered by hydrogen
Applicability	Small river shuttle
Partners	Public Transport Joint Corporation of the Agglomeration of Nantes (Semitan), Symbio
Delivery Date	2019
Status	In service
Link	https://www.themayor.eu/en/hydrogen-powered-shuttle-to-transport-passengers-in-nantes https://www.symbio.one/en/navibus/ https://www.energy-observer.org/innovations/jules-verne-2-navibus-nantes-hydrogen-propulsion
Funded?	The project received €678,000 from The Métropole of Nantes and the French Environment and Energy Management Agency (Ademe) and the Region.

Project Name	First hydrogen fuel cell powered tugboat
Project Description	Develop a concept design for a 65 tonnes bollard pull harbour tug, fully electric driven. The electric power for the propulsion motors is generated onboard by hydrogen **fuel cells**. Hydrogen in 20 ft ISO containers will allow 2 to 4 days autonomy. 45-50t and 75-80t concepts are in design.
Applicability	Tugboat
Partners	Nedstack, OSD-IMT
Delivery Date	
Status	
Link	https://nedstack.com/en/news/osd-imt-and-nedstack-join-forces-hydrogen-fuel-cell-powered-tug
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	HydroTug
Project Description	ultra-low emission tugboat: 'dual fuel' technology with a particle filter and catalytic converter. (2 x 2 MW **dual-fuel engines**). Tests show that up to 85% of the engine power can be delivered by hydrogen.
Applicability	Tugboat
Partners	CMB Technologies, Port of Antwerp, ABC Engines
Delivery Date	Q1 2022
Status	On order
Link	https://www.co2logic.com/en/news/world-first-port-antwerp-gets-first-%E2%80%9Chydrotug%E2%80%9D
Funded?	No

Project Name	Zero-emission multi-purpose support vessel
Project Description	The ULSTEIN SX190 Zero Emission DP2 construction support vessel is Ulstein's first hydrogen powered offshore vessel, featuring a Nedstack fuel cell power system. Total installed power of 7,5 MW, of which 2 MW is generated by a **fuel cell** power system
Applicability	Support vessel
Partners	Ulstein, Nedstack
Delivery Date	2022
Status	Concept
Link	https://www.4coffshore.com/news/ulstein-unveils-zero-emission-ship-design-nid14454.html
Funded?	No

Project Name	BeHydro genset
Project Description	Containerized genset of 1MW to replace 1 auxiliary engine of a 1,900 TEU containership (can be scaled-up). Can be applied on all ships where there is place for containers on deck. Expected efficiency gain: decline of emissions from auxiliary engine with 80%.
Applicability	Containership (1,900 TEU)
Partners	CMB.Tech, CMB
Delivery Date	
Status	approval in principle expected by end of 2020
Link	
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	SeaShuttle Hydrogen Fuel Cell Container Ship project
Project Description	Short-sea container ship powered by hydrogen **fuel cells**. For the moment, the project envisages zero emissions during 20% of a round trip between Poland and the Oslo Fjord.
Applicability	Container (200 TEU)
Partners	Samskip, Kongsberg, Hyon, Massterly
Delivery Date	
Status	
Link	https://fuelcellsworks.com/news/samskip-leads-way-in-norway-with-seashuttle-hydrogen-fuel-cell-container-sh/
Funded?	Awarded NOK 6 million from the public support scheme PILOT-E

Project Name	Ark Germania
Project Description	The project will upgrade a freight-vessels with an electrical infrastructure that makes it easy and cheap for fuel cell manufacturers to test up to 1 MW of **fuel cells** in real maritime environments. Manufacturers install their gear in a container that will be placed on the weather deck of ARK GERMANIA and connected to the ship's electrical grid. The fuel for the different types of fuel cells being tested will be placed in tank containers next to the fuel cells.
Applicability	RoRo freight vessel (342 TEU, 180 cars)
Partners	DFDS
Delivery Date	
Status	
Link	https://www.dfds-news.com/ships/fuel-cell-testing-moves-forward-on-ark-germania/?pdf=13983
Funded?	Danish Maritime Fund

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	HyShip - Topeka
Project Description	Construction of a new ro-ro demonstration vessel running on liquid green hydrogen (LH2). The good ship will run on a 1,000-kWh battery and a 3 MW PEM hydrogen **fuel cell**
Applicability	Ro-Ro vessel
Partners	Wilhelmsen, Kongsberg Maritime LMG Marin, Equinor, Norled, PersEE, Diana Shipping, Stolt-Nielsen Inland Tanker Service BV, Air Liquide, NCE Maritime CleanTech, DNV GL
Delivery Date	2024
Status	
Link	https://www.euractiv.com/section/shipping/news/norways-green-hydrogen-ship-granted-e8m-in-eu-funding/
Funded?	€8 million from the EU's Research and Innovation programme Horizon 2020 under the Fuel Cells and Hydrogen Joint Undertaking

Inland

Project Name	WEVA-project
Project Description	Feasibility study for the vessel MS Antonie to sail on 100% green hydrogen, which is produced locally by Nouryon using renewable electricity.
Applicability	
Partners	Nouryon and NPRC
Delivery Date	
Status	Ongoing
Link	https://www.nouryon.com/news-and-events/news-overview/2019/partners-cast-off-for-study-on-zero-emissions-hydrogen-shipping/
Funded?	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	RiverCell/ELEKTRA
Project Description	Development of an emission-free hybrid/electrically driven experimental vessel for use in the Berlin-Brandenburg region and for commercial operation between Berlin and Hamburg. The vessel will have a H2 capacity of 750kg stored in a compressed way (500bar). **Fuel cell** power will be 3*100kW and battery capacity of 2*1250kWh.
Applicability	Inland push boat
Partners	ANLEG GmbH, Berliner Hafen und Lagerhausgesellschaft mbH, BALLARD Power Systems Inc., EST-Floattech B.V., Imperial Logistics International B.V. & Co. KG, Schiffswerft Hermann Barthel GmbH, SER Schiffselektronik Rostock GmbH
Delivery Date	2025
Status	Ongoing
Link	https://www.marsys.tu-berlin.de/menue/forschung/elektra_2/ https://www.oceanhywaycluster.no/member-area-hydrogen-vessels/elektra
Funded?	Funding from the Bundesministerium für Verkehr und digitale Infrastruktur

Project Name	H2 power module for IWT
Project Description	Feasibility study to determine promising options, conditions, questions and goals for R&D of the application of a H2-power module for an inland vessel. The vessel should be used for container transport on the Rotterdam/Terneuzen - Paris route. Aspects that are taken into account are: • Improve performance and reduce costs for storage of H2. • H2 infrastructure. • Safety on ship, waterways and surroundings. • Changes in ship design for integration of H2 Power Module. • Laws and regulations. • Business case inland shipping.
Applicability	Small inland vessel
Partners	Aqua Navis, Conoship International, Mobiele Stroom
Delivery Date	
Status	
Link	https://projecten.topsectorenergie.nl/projecten/h2-power-module-voor-de-binnenvaart-00031865
Funded?	€50,000 from the Dutch Topsector Energie programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	ZEM/SHIPS
Project Description	The Zero emissions ships project aimed to develop and realise the first hydrogen-powered inland passenger ship (capacity > 100 persons), power-assisted by a 300-600 kW electric motor that gets its electricity from a **fuel cell**. The vessel combines 2 fuel cell systems (48 kW) with a 560 V gel battery and 50 kg of hydrogen stored at 650 bar.
Applicability	Inland passenger ship
Partners	The State Ministry of Urban development and the Environment, HHA Hamburger Hochbahn Aktiengesellschaft, Germany Alster Touristik GmbH, Germany Proton Motor Fuel Cell GmbH, Germany Linde AG, Germany Germanische Lloyd AG, Germany Hochschule für Angewandte Wissenschaften, Germany Nuclear Research Institute plc, Czech Republic ETC-Consulting Group Ltd
Delivery Date	2010
Status	Finished
Link	https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3081 http://www.hydroville.be/waterstof/7-roy/
Funded?	€2,384,424 by the European LIFE programme.

Project Name	Zero-emission IWT
Project Description	The aim of the project is to retrofit an existing inland container vessel and equip it with H2 **Fuel Cells** and batteries.
Applicability	inland container vessel (110m)
Partners	Future Proof Shipping
Delivery Date	2022
Status	Ongoing
Link	
Funded?	The project receives co-financing from the Dutch programme Schone binnenvaart en duurzame logistiek in Rotterdam

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	"Marinization" and integration of hydrogen technology for inland shipping and shortsea applications
Project Description	Developing and 'marinizing' a hydrogen fuel cell-based propulsion configuration for regional shipping. The configuration shall be suitable for class type approval: • Defining all relevant critical user requirements. • Preparing system (components) for certification by class societies for use in a maritime environment. • Achieving a generic hydrogen ship propulsion system design based on a 'systems engineering approach', in which the fuel cell plays an integral role in a ship propulsion system. • Testing and researching the integrated system for use in shipping. • The physical demonstration and thus the introduction of a 40kW system for those directly within the test environment.
Applicability	inland container vessel (110m)
Partners	Damen Shipyards Gorinchem, Future Proof Shipping B.V., Holland Ship Electric B.V., Marin, MSN B.V., Nedstack Fuel Cell Technology B.V.
Delivery Date	2020
Status	Finalised
Link	https://projecten.topsectorenergie.nl/projecten/marinisering-en-integratie-van-waterstoftechniek-voor-binnenvaart-en-short-sea-toepassingen-00031425
Funded?	€ 492,164 from the Dutch Topsector Energie programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	HYNOVAR
Project Description	HYNOVAR was created from the joint initiative of HySeas Energy, the CCI of the Var and ENGIE Cofely H2 France to develop a hydrogen maritime shuttle powered by a land-based refueling station. The proposed vessel is projected to be 26 meters in length and have a capacity of 200 passengers. The 260 kg of compressed hydrogen gas will give 10 hours at 12 knots.
Applicability	Inland passenger vessel
Partners	CCI du Var, ENGIE COFELY, Circuit Paul Ricard, Bateliers de la Côte d'Azur and HYSEAS Energy
Delivery Date	
Status	Ongoing
Link	https://mediterraneedufutur.com/en/projects/hynovar/ https://fathom.world/france-wants-to-lead-europes-hydrogen-society-shipping-is-part-of-the-plan/
Funded?	Around €7 million co-financing by French public bodies.

Project Name	Marigreen
Project Description	Through a consortium of 59 German and Dutch maritime companies and research institutions, a total of 12 innovation projects will be realized as part of the broader MariGreen Project. One of the projects is about the development and application of a Plug and Play Energypack. The training vessel Emeli is equipped in a pilot with a direct drive E-motor of 200 kW on the axle and an H2 **fuel cell** (30 kW) in combination with a battery pack. H2 is stored under pressure (200 bar), with storage capacity of 12kg.
Applicability	Inland training vessel
Partners	Mariko, FME, Martieme Academie Harlingen, ABH, Frisia, Ahlers&Vogel, Alert, Damen, DNV GL, DST, and partners.
Delivery Date	2019
Status	Finished
Link	http://nl.marigreen.eu/projects/plug-and-play-energypack-for-inland-shipping-and-short-sea/
Funded?	The project received co-financed from the INTERREG program Germany-Netherlands.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Maranda
Project Description	Emission-free hydrogen fuelled PEMFC based hybrid powertrain system is developed for marine applications and validated both in test benches and on board the research vessel Aranda. The 165 kW (2x 82.5kW AC) **fuel cell** powertrain (hybridized with a battery) will provide power to the vessel's electrical equipment as well as the dynamic positioning during measurements, free from vibration, noise and air pollution.
Applicability	Research vessel
Partners	Powercell Sweden
Delivery Date	March 2021
Status	
Link	https://www.fch.europa.eu/sites/default/files/4.%20Laurence%20Grand-Cl%C3%A9ment%20-%20MARANDA.pdf
Funded?	Expected costs around €3.7 million of which € 2.9million awarded by the EU's Horizon 2020 research and innovation fund.

Project Name	H2SHIPS
Project Description	The H2SHIPS will demonstrate the technical and economic feasibility of hydrogen bunkering and propulsion for shipping and will identify the conditions for successful market entry for the technology. Two pilot projects will be implemented as part of H2SHIPS: • Hydrogen powered port vessel • H2 refuelling system suitable for open sea operation will be developed and tested. A further major output will be an action plan for the implementation of an H2SHIPS pilot on the river Seine in Paris in 2022. H2SHIPS will demonstrate the added-value of H2 for water transport and develop a blueprint for its adoption across North-West Europe, avoiding considerable GHG-emissions.
Applicability	Port vessel
Partners	Hynamics, University of Birmingham, Amsterdam Port Authority, Delft University of Technology, Navalu, SYCTOM, HAROPA, Port of Ostend, Steinbeis 2i GmbH, HYDROGEN EUROPE, Transport & Environment, Tata Steel Europe
Delivery Date	2022
Status	Ongoing
Link	https://www.nweurope.eu/projects/project-search/h2ships-system-based-solutions-for-h2-fuelled-water-transport-in-north-west-europe/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Funded?	€3,47 million co-financing from the Interreg NWE program

Project Name	H2Watt
Project Description	H2Watt is a platform for realising a range of innovation projects that aim to implement hydrogen. The focus lies on processes and systems for introducing hydrogen as a fuel, which can be used in the areas of production, storage, mobility and heating systems. The initial projects include a hydrogen-fuelled residential quarter, the Borkum Island railway and a water taxi. The first pilot project of Ameland concerns the equipment of a water taxi with a **fuel cell** powered by hydrogen.
Applicability	Water taxi
Partners	ABH, Borkumer Kleinbahn, FME, Municipality Ameland, Hochschule Emden-Leer, Hygro, Mariko, Resato, Royal Wagenborg, Borkum Nordseeheilbad GMBH
Delivery Date	2021
Status	Ongoing
Link	https://h2watt.eu/en
Funded?	Co-financed within the framework of the INTERREG program Germany-Netherlands with funds from the European Regional Development Fund (ERDF), the State of Lower Saxony (Lower Saxony Ministry for Federal and European Affairs and Regional Development) and the provinces of Drenthe, Friesland and Groningen.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Living Lab: H2 in the Port of Den Helder
Project Description	The aim of the project is the technical and commercial validation of innovative hydrogen technology for vessels in a realistic operating environment. Validation of the business cases of the supply chain partners to stimulate investments in hydrogen refuelling infrastructure and hydrogen vehicles. The project includes the setting up of a testing ground for hydrogen around the port of Den Helder, which consists of the realization of a public hydrogen refuelling facility and the development of an electric-hydrogen-powered vessel. One of the activities concerns the experimental development of an electrically powered vessel with a hydrogen range extender, executed by Damen Shipyards.
Applicability	
Partners	Damen Shipyards, Pitpoint, Port of Den Helder, ENGIE, T U Delft, New Energy Coalition, Bureau Veritas
Delivery Date	
Status	Ongoing
Link	https://www.rvo.nl/initiatieven/dkti-tenders/proeftuin-h2-de-haven-van-den-helder
Funded?	DKTI transport

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

6.1.2 The heavy gas pathway

LPG and Methanol

Project Name	Stena Germanica
Project Description	The 240-metre long ferry was retrofitted with a first-of-its-kind fuel-flexible Wärtsilä 4-stroke engine that can run on methanol or traditional marine fuels.
Applicability	Ferry (1300 pax, 300 cars)
Partners	Wärtsilä, Stena, Methanex Corporation, Remontowa Shipyard
Delivery Date	2015
Status	In service
Link	https://ec.europa.eu/inea/en/ten-t/ten-t-projects/projects-by-country/multi-country/2012-eu-21017-s
Funded?	Total project cost: €22,502,000 EU contribution (TEN-T): €11,251,000

Project Name	GreenPilot
Project Description	Swedish pilot boat was converted for methanol operation on one of two engines. The conversion work had two main components: 1) Conversion of an engine to methanol operation 2) Adaptation of on-board systems, primarily fuel supply and safety
Applicability	Pilot boat
Partners	Swedish Maritime Technology Forum, ScandiNAOS, SSPA Sweden, Swedish Transport Administration, Swedish Maritime Administration
Delivery Date	2018
Status	Not in service (demonstration project)
Link	https://smtf.se/wp-content/uploads/2019/02/D8.3-Final-Report-ver20181128-with-appendices2.pdf
Funded?	Co-funded by the Swedish Transport Administration, Swedish Maritime Administration, and the Methanol Institute.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	HyMethShip
Project Description	The HyMethShip system innovatively combines a membrane reactor, a CO2 capture system, a storage system for CO2 and methanol, as well as a hydrogen-fuelled combustion engine into one system. The new concept allows for a closed CO2 loop ship propulsion system while maintaining the reliability of well-established marine engine technology. The system will be demonstrated onshore at full scale.
Applicability	Ferry
Partners	Meyer Werft, LLoyds Register, Exmar,...
Delivery Date	July 2021
Status	Ongoing
Link	https://www.hymethship.com/consortium/
Funded?	Total cost: €9,288,310, EU contribution: €8,438,110 (Horizon 2020)

Project Name	Fastwater
Project Description	Retrofitting of a harbour tug, pilot boat and coast guard vessel to dual fuel methanol/diesel propulsion/**Develop universal, scalable retrofit kits/**Commercialize medium speed and high-speed methanol engines/Demonstrate reduced pollutant and CO2 emissions/Demonstrate the reliable operation of 3 vessels /Develop a training program for crew /Demonstrate the complete supply chain from renewable methanol producers to ship bunkering/Develop rules and regulations (including a methanol fuel standard)/Elaborate business plans
Applicability	Tugs with 2 x 1,9 MW medium speed engines for 55t bollard pull Pilot Boat 300 kW high speed MD95 engine Coast guard vessels with high speed diesel engines (Mercury 4.2 L, 235 kW) River cruiser (4*315 kW main engines + 2*340kW thruster) Engine retrofit kits will become commercially available, to convert engines in the 200 kW – 4 MW range to dual-fuel operation on methanol (engine supplier and retrofit company HZM)
Partners	Lund University, BALance Technology Consulting, ABC, Heinzmann, Port of Antwerp, Ghent University, Scandinaos, SSPA, Meyer Werft, LLoyd's Register, National Technical Universitiy of Athen, Supertoys, Methanex, Swedish Maritime Administration.
Delivery Date	Test and trials of the Tug (55 t bollard pull) are finalised in 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

	Pilot Boat testing will end in 2023 Coast guard vessel will be tested until the end of 2023 River cruiser concept will be available early 2023
Status	Ongoing
Link	https://www.fastwater.eu
Funded?	Overall budget of €6.35M over 4 years with a grant of €4.99M from EU.

Ammonia

Project Name	Design for 50,000 dwt ammonia tanker
Project Description	MAN ES was responsible for the development and specifications of the dual-fuel ammonia engine, HMD focused on the basic design of the ammonia-fuelled propulsion system. HMD plans to commercialise an NH3-fuelled vessel from 2025.
Applicability	Medium Range Tanker
Partners	Hyundai Mipo Dockyard (HMD), MAN Energy Solutions, Lloyd's Register
Delivery Date	2025
Status	Approval in Principle (AiP)
Link	https://www.offshore-energy.biz/hyundai-mipo-dockyard-wins-lr-approval-for-ammonia-powered-ship/
Funded?	No

Project Name	Design for ammonia-fuelled container feeder
Project Description	SDARI will develop the ship design and engineering, which will utilize MAN's dual fuel technology and ABS will assess safety-related issues and contribute to the development of rules and standards in relation to ammonia as a fuel.
Applicability	2,700 TEU Container
Partners	MAN Energy Solutions, ABS, SDARI
Delivery Date	
Status	
Link	https://www.maritime-executive.com/corporate/abs-man-and-sdari-develop-design-for-ammonia-fueled-container-feeder
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	C-Future
Project Description	The project aims to develop designs for an ammonia-fuelled 23,000 TEU ULCS
Applicability	23,000 TEU container
Partners	Dalian Shipbuilding Industry Co. (DSIC), MAN Energy Solutions, Lloyds Register
Delivery Date	
Status	Approval in Principle (AiP)
Link	https://www.offshore-energy.biz/ammonia-fuelled-23000-teu-boxship-design-gets-aip/
Funded?	No

Project Name	Nordic Green Ammonia Powered Ships (NoGAPS)
Project Description	As a first step, the project will develop a proof of concept on how the barriers to the adoption of ammonia as a zero-emission maritime fuel can be overcome, focusing on safety and efficiency, sustainable and steady fuel supply chains, as well as commercial viability. Based on the findings of the proof concept, the project partners will explore the potential for continuing the work on the first demonstration of a green ammonia powered ship with the goal of having it in operation by 2025.
Applicability	Deap-sea
Partners	MAN Energy Solutions, DNV GL, Yara International, Wartsila, Orsted, …
Delivery Date	2025
Status	
Link	https://www.nordicinnovation.org/programs/nordic-green-ammonia-powered-ships-nogaps
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Ship FC - Viking Energy
Project Description	The project will see an offshore vessel, Viking Energy (owned and operated by Eidesvik and on contract to energy Equinor), have a large 2MW ammonia fuel cell retrofitted, allowing it to sail solely on the clean fuel for up to 3,000 hours annually. The ammonia used in the energy system will be produced by electrolysis. Ammonia is an abundant energy source and can easily be made from renewable resources making it one of the fuels that will likely meet part of shipping's future energy demand. The goal of the project is also to ensure that a large fuel cell can deliver total electric power to shipboards systems safely and effectively. A significant part of the project will be the scale up of a 100-kilowatt fuel cell to 2 MW.
Applicability	Offshore supply vessel
Partners	Eidesvik, Equinor, Yara, Wärtsilä, Nel, NCE Maritime CleanTech,...
Delivery Date	31/12/2026
Status	Pilot
Link	https://www.ammoniaenergy.org/articles/viking-energy-to-be-retrofit-for-ammonia-fuel-in-2024/
Funded?	The project has a budget of 230 million NOK, of which €10 million is being funded by the EU's Fuel Cells and Hydrogen Joint Undertaking (FCH JU), through its Horizon 2020 program.

Project Name	Joint R&D agreement Tugboat
Project Description	For the remainder of 2020, they will focus on elements including the technological development for the hull, engines, and fuel supply systems, as well as the development of safe and secure navigation methods. After that, based on the evaluation of their results, they anticipate starting the study for the construction of the ammonia fuel tugboat.
Applicability	Tugboat
Partners	NYK Line, Class NK, IHI Power Systems
Delivery Date	
Status	
Link	https://maritime-executive.com/article/r-d-project-to-design-world-s-first-ammonia-fueled-commercial-tugboat
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Joint R&D Agreement Ammonia Gas Carrier
Project Description	Joint R&D agreement for the commercialization of an ammonia-fuelled ammonia gas carrier (AFAGC) that would use ammonia as the main fuel, in addition to an ammonia floating storage and regasification barge (A-FSRB). The project is expected to stabilise the ammonia fuel supply by using barges rather than land facilities such as storage tanks and regasification facilities, which contribute to the early introduction of ammonia fuel.
Applicability	Gas Carrier
Partners	NYK Line, Japan Marine United Corporation (JMU), ClassNK
Delivery Date	
Status	
Link	https://www.ship-technology.com/news/japanese-companies-ammonia-gas-carrier/
Funded?	No

Project Name	Feasibility study of ammonia fuel cell propulsion river cruise ship
Project Description	STG Rivercruise Company wants to distinguish itself in the market with a sustainable cruise concept, with ships that are specifically designed for this purpose and equipped with the most modern and sustainable technology. The ships which are currently under development will therefore be propelled by means of a hybrid (diesel / electric) drive. STG Rivercruise Company wants to gain insight into the technical and economic feasibility of the ammonia fuel cell propulsion to be developed for river cruise ships.
Applicability	River cruise vessel
Partners	STG Rivercruise Company BV
Delivery Date	2018
Status	Study finalised
Link	https://www.rvo.nl/subsidies-regelingen/projecten/haalbaarheidsonderzoek-ammoniak-brandstofcelaandrijving-river-cruise-schip
Funded?	€25,000 grant provided by the RVO/MIT programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

LNG

LNG in IWT

Technique	LNG
Technique Description	Liquified Natural Gas is a fossil transitional fuel which is cleaner as compared to diesel fuel (EN590) used in IWT. Based on average operational profiles, savings could be realized up to 70% on NOx and 95% on PM compared to CCNR-2 emission limits, and 10% on CO2 equivalent emissions.
Applicability	In general most types of inland vessels. There may be restrictions for the smallest vessels due to the required space for the installation (e.g. cryogenic tank and tank connection space).
Number of operational vessels	12 (mostly 110m inland tanker vessels)
Funded	More than half of the LNG driven inland vessels received funding under various European (e.g. CEF) and national funding programmes.

Biodiesel

Biodiesel in IWT

Fuel	Biodiesel
Fuel description	A drop-in renewable fuel, in IWT generally divided into two types: HVO and FAME. The fuel can be blended with fossil diesel fuel or can fully replace diesel fuel. A 100% use of biodiesel in combination with an aftertreatment system will make it possible to realise a zero-emission performance TTW.
Applicability	In general all types of inland vessels. However, some small precautions need to be taken (fuel tank cleaning, placing fuel water separator filters, etc).
Number of operational vessels	Around 12 inland vessels are sailing on HVO, most with a blended fuel of 30% HVO and 70% fossil diesel and a small number on 100% HVO. Even more vessels are sailing on a blend of FAME and fossil diesel.
Funded	The fuel is mature, no funding is being provided nowadays in IWT.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

6.1.3 Electrification

Fully electric

Long distance

No projects found

Off-shore

No projects were found

Short-sea

Project Name	Project e5 –3,5 MWh
Project Description	The vessel is a pure battery tanker powered by large-capacity lithium-ion batteries
Applicability	Oil bunkering tanker (1,500 dwt)
Partners	Yamamizu, MOL, Asahi Tanker, Mitsubishi Corporation
Delivery Date	March 2022
Status	On order
Link	https://www.marinelog.com/technology/video-japanese-consortium-moves-ahead-on-all-electric-tanker-project/
Funded?	No

Project Name	E-ferry project: Ellen – 4,3 MWh (Denmark)
Project Description	A fully electric, medium sized car and passenger ferry, run only on power from batteries charged in harbour. E-ferry has the world's largest battery, which allows it to travel longer distances than existing electric ferries (up to 21.4 nautical miles or nearly 38 km) before it needs to be recharged
Applicability	Ferry (200pax, 30 cars) - liner
Partners	Ærø Kommune, Danfoss Editron, Dansk Brand og Sikringsteknisk Institut, Hellenic Institute of Transport, Leclanché, Rådgivende Skibsingeniører Jens Kristensen ApS, Søby Shipyard, Danish Maritime Authority, Tuco Marine Group
Delivery Date	2019
Status	In service: After 10 months in service, the electric ferry has met or exceeded all expectations. In addition, it has proven that electric propulsion costs less than diesel power.
Link	https://www.xn--el-frgeprojekt-3ib.dk/nyheder/e-ferry-ellen-crosses-the-finish-line-and-delivers-great-results
Funded?	Partially funded by Horizon 2020, €16M (~ 75%)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	All-electric ferries Amsterdam
Project Description	The construction of five new all-electric ferries being built by Holland Shipyards Group for Amsterdam's municipal public transport provider, GVB. The ferries will operate on three of the North Sea Canal routes. Each ferry is 41 meters in length, is 13,9 meters wide, holds 20 cars, four trucks, or 400 passengers. The ferries will be equipped with air-cooled Corvus Orca Energy ESS that will supply electrical power to the ferry's all-electric power and propulsion system.
Applicability	Ferry
Partners	GVB, Holland Shipyards Group, Holland Ship Electric, Corvus Energy
Delivery Date	First ferry in 2021. After that, one will arrive every six months, until 2023.
Status	Ongoing
Link	https://corvusenergy.com/corvus-energy-awarded-contract-for-five-new-ferries-to-be-built-at-holland-shipyard-group-for-gvb-in-amsterdam/
Funded?	

Project Name	Transport: Advanced & Modular (TrAM)
Project Description	The aim of the TrAM project is to develop a zero emission fast going passenger vessel through advanced modular production.
Applicability	Ferry (147 pax)
Partners	Wartsila, Fjellstrand, NCE Maritime CleanTech, Kolombus…
Delivery Date	September 2022
Status	
Link	https://tramproject.eu/about/
Funded?	Partially funded by Horizon 2020

Project Name	Guangzhou cargo ship – 2,400kWh
Project Description	the 70m-long and 14m-wide cargo ship has a battery system made up of more than 1,000 lithium-ion batteries and supercapacitors, giving the vessel the autonomy to travel up to 80km.
Applicability	Electric cargo ship (>2000 tons carrying capacity)
Partners	Guangzhou Shipyard
Delivery Date	2018
Status	In service

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Link	http://www.chinadaily.com.cn/business/2017-11/14/content_34511312.htm
Funded?	No

Project Name	Gouwenaar 2.0 and Alphenaar
Project Description	Construction and deployment of two diesel-electric inland container vessels which will on the short-term be equipped with batteries. The intention is to convert these hybrid vessels to fully electric vessels.
Applicability	Inland container vessels (90m)
Partners	Nedcargo
Delivery Date	Alphenaar built in 2019 and Gouwenaar 2.0 built in 2017 (hybridisation date yet to be determined)
Status	Ongoing
Link	https://binnenvaartkrant.nl/alphenaar-elektrisch-en-emissieloos-over-gouwe-en-ijssel
Funded?	

Hybrid

Long distance

Project Name	Maersk Cape Town
Project Description	A containerized 600 kWh marine battery system will be installed in a trial on board the Maersk Cape Town in December 2019 to improve vessel performance and reliability while reducing CO2 emissions.
Applicability	Container (4,496 TEU)
Partners	Maersk, Trident Maritime Systems
Delivery Date	Q2 2020
Status	In service
Link	https://tridentllc.com/news/#:~:text=The%20containerized%20600%20kWh%20marine,manufactured%20by%20Trident%20Maritime%20Systems.
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Short Sea

Project Name	E-Shuttle Aurora Spirit
Project Description	The E-Shuttle has battery packs for flexible power distribution and blackout prevention. According to the company, it reduces bunkering requirement and CO2 emissions by approx. 50%' instead of 'annual emission reduction potential is estimated at up to 42%, with fuel consumption reduced by up to 22% compared to traditional shuttle tankers.
Applicability	Crude tanker (130 000dwt)
Partners	Teekay, Samsung Heavy Industries (SHI), Corvus Energy
Delivery Date	2020
Status	In service
Link	https://www.teekay.com/blog/2019/03/25/launching-of-the-e-shuttle-aurora-spirit/
Funded?	No

Ferry

Project Name	Stena Jutlandica – 50 MWh (Sweden)
Project Description	The project began in 2018 and is made up of three phases: Step 1 • Battery power on bow thrusters and manoeuvring when berthing in port. • Optimises power usage during operation (Peak Shaving) • Battery capacity 1 MWh Step 2 • Battery operation in port and in the archipelago up to around 10 nautical miles • Battery capacity about 20 MWh Step 3 • Full battery power up to about 50 nautical miles • Battery capacity about 50 MWh
Applicability	Ferry (1500pax, 550 cars)
Partners	Stena Teknik, Callenberg Technology Group, Corvus Energy, Trident Maritime Systems
Delivery Date	?
Status	Step 1 operational
Link	https://www.offshore-energy.biz/stena-lines-battery-hybrid-ship-completes-1st-month-of-operation/
Funded?	Half of the funding for the project coming from the Swedish Transport Administration and the EU.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Tõll: Hybrid electric ferry (Norway)
Project Description	the batteries are expected to reduce the vessel's diesel consumption by 20%, thus also cutting CO2 emissions by 1,600 tons per year. In addition to emissions, underwater noise and vibration levels are also reduced.
Applicability	Ferry (600 pax)
Partners	Baltic Workboats, Corvus Energy, LMG Marin, Norwegian Electric Systems, TS LAevad
Delivery Date	March 2020
Status	In service
Link	https://www.offshore-energy.biz/estonias-first-hybrid-ferry-toll-starts-service/
Funded?	

Project Name	Washington State Ferries
Project Description	Washington State Ferries' fleet to be equipped with a hybrid drive and energy storage systems. According to the manufacturer, the new ferries can run entirely on battery power and, if necessary, in hybrid mode
Applicability	Ferry (1500 pax, 144 cars)
Partners	Vigor Fab, ABB, Washington State Ferries
Delivery Date	2024
Status	
Link	https://www.electrive.com/2020/06/08/abb-to-supply-drives-for-washington-state-ferry-fleet/
Funded?	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Cruise

Project Name	Battery storage systems on AIDAperla – 10 MWh (lithium ion)
Project Description	The battery systems can be charged with shore power and during sea operation (peak load shaving). In addition to pure battery operation, the systems may also contribute for an extended period of time, e.g. during port mooring or during ship manoeuvres. Thanks to the use of this technology, the consumption of fossil fuel will be reduced further and the efficiency of ship operations will be increased significantly.
Applicability	Cruise
Partners	Aida Cruises, Corvus Energy
Delivery Date	End of 2020
Status	Still to be retrofitted (< Clarksons)
Link	https://www.maritime-executive.com/article/aidaperla-to-get-battery-system-in-2020
Funded?	No

Project Name	Battery powered cruise ships
Project Description	While the engines run mainly on marine gasoil, the ship's battery pack enables it to run solely on batteries for around 45 to 60 minutes under ideal conditions. The hybrid propulsion will reduce CO2 emissions by more than 20%, compared to other ships of the same size.
Applicability	Cruise (500 pax)
Partners	Hurtigruten
Delivery Date	Summer 2019
Status	In service
Link	https://www.hurtigruten.com/about-hurtigruten/hurtigruten-news/first-ever-cruise-ship-sails-on-battery-power/
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Six hybrid cruise ships from Genting Hong Kong
Project Description	Each of the 286-metre-long vessels will be powered by twin units of ABB's Azipod electric propulsion system with a total capacity of 30 MW. The electric drive motor is in a submerged pod outside the ship hull and can rotate 360 degrees to increase manoeuvrability and operating efficiency. Since the electricity for the electric motors onboard is generated from fossil fuels, they are hybrid ships despite the electric drive. However, the generators onboard the cruise ships just ordered will not be powered by ship diesel, but by liquid gas. ABB states that the Azipod system can save up to 20 per cent fuel compared to conventional shaft drives.
Applicability	Cruise (1000-4000 pax)
Partners	ABB, Genting Hong Kong, MV Werften
Delivery Date	2023 and 2024
Status	
Link	
Funded?	

Inland

Project Name	Invotis IX
Project Description	A hybrid (diesel-electric powertrain with a battery pack (136KwH Lithium NMC) inland waste collector ship (45m) deployed by Bek en Verburg. The engine can operate electrically for one hour in a row and then needs another hour to recharge. In between, the ship sails on GTL.
Applicability	Inland
Partners	Bek en Verburg
Delivery Date	2017
Status	In service
Link	https://www.portofrotterdam.com/nl/nieuws-en-persberichten/nieuw-hybride-vaartuig-van-bek-verburg https://vlootschouw.nl/schepen/schip/invotis-ix/
Funded?	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Sendoliner
Project Description	First commercial inland freight vessel (110m) to sail zero-emission on charged batteries (up to 3h). The vessel has a hybrid configuration (diesel-electric powertrain with a battery pack of 500kWh). The vessel has a modular platform allowing change to different technique.
Applicability	Inland - Container
Partners	Sendo Shipping
Delivery Date	2019
Status	In service
Link	https://sendo-shipping.nl/de-sendo-liner/
Funded?	The vessel received co-financing from the Dutch IDB programme for the energy-efficient design of the vessel.

Project Name	Invotis X
Project Description	A hybrid (diesel-electric powertrain with a battery pack) inland waste collector ship deployed by Bek en Verburg.
Applicability	Inland
Partners	Ben en Verburg
Delivery Date	2020
Status	In service
Link	https://binnenvaartkrant.nl/invotis-x-overtreffende-trap-van-duurzaam
Funded?	

Project Name	Sendo Mare and Sendo Nave
Project Description	The construction of 2 'zero-emission' ready inland container vessels (122m). Both vessels have a diesel-electric propulsion system and a modular design. The intention is to equip both vessels with batteries on the short-term.
Applicability	Inland - Container
Partners	Sendo Shipping
Delivery Date	2020
Status	In service
Link	https://www.schuttevaer.nl/nieuws/dossiers/groen_ondernemen/2020/01/27/sendo-mare-haalt-green-deal-doelstellingen-nu-al/
Funded?	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Den Bosch Max
Project Description	Construction and deployment of two diesel-electric inland container vessels of the new Den Bosch Max type. Both vessels will on the short-term be equipped with batteries. The intention is to convert these hybrid vessels to fully electric vessels. As of 2020 the vessels are under construction.
Applicability	Inland – Container (140 TEU)
Partners	BCTN, Concordia Damen, Veth Propulsion
Delivery Date	June 2020
Status	In service
Link	https://bctn.nl/bctn-elektrische-barges/
Funded?	

Project Name	Nijmegen Max
Project Description	Construction and deployment of one diesel-electric inland container vessels of the new Nijmegen Max type. The vessel will on the short-term be equipped with batteries. The intention is to convert the vessel to a fully electric propulsion system.
Applicability	Inland container vessels (120m)
Partners	Nedcargo, BCTN, Concordia Damen
Delivery Date	2020 (hybridisation date yet to be determined)
Status	Ongoing
Link	https://www.schuttevaer.nl/nieuws/actueel/2020/06/23/cascos-den-bosch-max-klaar-voor-transport/ https://www.schuttevaer.nl/nieuws/schip-en-bedrijf/2020/07/01/nijmegen-max-als-basis-voor-innovated-shipping/
Funded?	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Project Name	Citybarge
Project Description	The construction and deployment of a small fully electric inland barge for the transport of goods (waste, construction materials and retail products) via the canals of historic cities (e.g. Amsterdam, Delft, Utrecht, etc.).
Applicability	Small inland barge
Partners	Citybarge, Kotug, Skoon, Province South-Holland
Delivery Date	2020
Status	First barge commissioned. Possibly more will follow on the short and medium term.
Link	https://binnenvaartkrant.nl/delft-krijgt-primeur-met-elektrische-duwboot-op-de-grachten
Funded?	Co-financing from the Dutch regional programme 'Investeren om te vernieuwen'

Project Name	Diesel-electric propulsion for "MS Johanna"
Project Description	Elaboration of a system concept (mechanical and electrical aspects) for low emission EU Stage V engines on board of motorships on the Danube.
Applicability	Inland Motor Vessel
Partners	FLUVIUS
Delivery Date	2020
Status	Concept
Link	http://www.fluvius.hu/
Funded?	INTERREG Programme (Danube Transnational Programme)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Miscellaneous

Project Name	Hybrid-electric rescue vessel (China)
Project Description	The vessel features Azipod electric propulsion, energy storage system and automation and control solutions that are expected to optimise operational efficiencies. The vessel can operate with batteries for up to three hours, which is necessary to carry out safe rescue operations in areas affected by dangerous gas. The system controls three sets of diesel generators and two sets of lithium batteries, which have 1680kWh total capacity.
Applicability	Rescue vessel
Partners	ABB, Huangpu Wenchong Shipbuilding
Delivery Date	2020
Status	In service
Link	https://www.ship-technology.com/news/abb-technology-hybrid-electric-rescue-vessel-china/
Funded?	No

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

6.1.4 Diesel-electric powertrains

Diesel-electric

Technique	Diesel-electric powertrains
Technique Description	A diesel-electric powertrains consists of one or more generators and an electric motor. This set-up enables to sail in an efficient manner in an operational profile which is suited for it (e.g. on canals). Furthermore, the technique can be seen as a transitional technique towards hybridisation (adding batteries) and fully electric powertrains (e.g. removing diesel generators and adding larger batteries or fuel cells).
Applicability	In general all types of inland vessels.
Number of operational vessels	200 to 300 inland vessels.
Funded	The technique is mature and no funding is being provide nowadays.

Energy-efficiency measures

Project Name	Improved hull design for "MS Ulm"
Project Description	Improvement of hydrodynamics and efficiency enhancement for motor ships on the river Danube via a new vessel hull design.
Applicability	Inland Motor Vessel
Partners	FLUVIUS
Delivery Date	2020
Status	Concept
Link	http://www.fluvius.hu/
Funded?	INTERREG Programme (Danube Transnational Programme)

Project Name	MariGreen MV Fehn Pollux
Project Description	In initial pilot projects, the basic suitability of wind-supported ship propulsion systems was demonstrated and a prototype of a Flettner rotor was developed and built. Based on measurement data, potential savings were estimated for the test ships. In order to test and evaluate the technology of the Flettner rotor in practice, the Eco-Flettner rotor was installed on the MV Fehn Pollux of the shipping company Fehn Ship Management.
Applicability	MPP

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Partners	EcoFlettner GmbH, Abh-emden, ankerbeer, BOMA MASCHINENBAU, Dirks elektrotechnik, DNV GL, Fehn Ship Management, Hochschule Emden-Leer, Lais Nord GBR, MFH, Ralf Oltmanns, Privattreuhand, SEC, Jens Werner – Coaster services
Delivery Date	June 2018
Status	In service
Link	http://nl.marigreen.eu/projects/wind-windship-engineering-and-design/
Funded?	€1.065.060 from Interreg Deutschland / Nederland

WASP: Wind Assisted Ship Propulsion

The project brings together universities, wind-assist technology providers with ship owners to research, trial and validate the operational performance of a selection of wind propulsion solutions on five vessels thus enabling wind propulsion technology market penetration and contributing to a greener North Sea transport system through harvesting the regions abundant wind potential.

- 01/2020: Installation of a fixed two wing 'Ventifoil' system on the 3,600-dwt general cargo ship
- 05/2020: Installation of the large 30m tall Rotor Sail on a ferry

Link:https://vb.northsearegion.eu/public/files/repository/20200612142300_WASP-NewsletterJune2020.pdf

Oceanbird: Wind-Powered Car Carrier Ship

- The vessel will use five 80-foot-tall wings, similar in shape to airplane wings, for propulsion
- Those huge wings will be able to collapse down like a telescope to 45 feet in order to slip under bridges or when encountering rough seas.
- The vessel will be capable of transporting 7,000 cars across the Atlantic in 12 days, a trip that with current internal combustion engines takes seven or eight days.
- The ship will also be equipped with a small motor, probably electric, for navigating harbours and tricky areas.
- 90% lower emissions than a vessel with a diesel engine
- the concept won't be ready for launch until probably 2025

Link: https://www.oceanbirdwallenius.com/
w.linkedin.com/pulse/how-predict-potential-fuel-savings-from-wind-assisted-fabian-tillig/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

6.1.5 Miscellaneous

Project Name	Conceptual design of a new LNG propelled pusher
Project Description	Identification of existing specific LNG engines and analysis of operational requirements in the navigation area of the Danube river. Definition of ship main characteristics and basic design.
Applicability	Danube Pusher; > 4000 HP
Partners	SHIP DESIGN GROUP (SDG) and NAVROM
Delivery Date	2020
Status	Concept
Link	https://www.shipdesigngroup.eu/ / https://www.navrom.ro/index.php/en/
Funded?	INTERREG Programme (Danube Transnational Programme)

Project Name	Renewable Electricity on board of Motor Ships (e.g. "MS **Melanie-H**")
Project Description	Installation of solar panels incl. optimising electric system of vessels for cooling, heating and further use on board. (Replacement of one auxiliary engine)
Applicability	Inland Motor Vessel
Partners	FLUVIUS
Delivery Date	2020
Status	Concept
Link	http://www.fluvius.hu/
Funded?	INTERREG Programme (Danube Transnational Programme)

Project Name	On-Board Sewage Treatment
Project Description	Installation of sustainable on-board sewage treatment of wastewater on a river cruise vessel.
Applicability	River cruise vessels
Partners	Cergol Engineering and Danubia Kreuzfahrten
Delivery Date	2020
Status	Concept
Link	http://cergolengineering.com/ / https://danubia-kreuzfahrten.com/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285

Funded?	INTERREG Programme (Danube Transnational Programme)

Aftertreatment system

Technique	Aftertreatment system (SCR+DPF)
Technique Description	The application of an aftertreatment system consisting of a Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF) on existing engines in IWT is done since 2010. This technique makes it possible to practically nullify PM and NOx emissions. It can also be seen as a transitional technique towards reaching the zero-emission objective. An aftertreatment systems in combination with biofuels like, for example, HVO, will make it possible to realise a zero-emission performance TTW.
Applicability	In general all types of inland vessels.
Number of operational vessels	Around 100 inland vessels.
Funded	The technique is mature, however a funding programme of €79 million has been announced in the Netherlands for investments in SCR's.

Ports

Project Name	**EALING – EUROPEAN FLAGSHIP ACTION FOR COLD IRONING IN PORTS**
Project Description	EALING is a studies project that expresses the need to accelerate the deployment of On-shore Power Supply (OPS) solutions in EU ports, and aims at: - Ensuring that a common harmonised and interoperable framework is brought forward to facilitate the implementation phase of OPS infrastructure, in accordance with the EU technical, legal and regulatory framework; - Ensuring the port to vessel compatibility in the TEN-T Maritime Network, for the vessels calling at the ports of the consortium; - Leading all the necessary technical, financial, legal and environmental studies to prepare and accelerate the effective launch of cold ironing and electric bunkering equipment in the ports.
Applicability	Onshore power supply
Partners	Fundación Valenciaport; Circle; Ocean Finance; Port Autorities of Valencia, Barcelona, Huelva, Gijón, Venice&Chioggia,

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	Trieste&Monfalcone, Ancona, Piraeus, Koper, Rafina, Leixoes and Açores; Bulgarian Ports Infrastructure Company; National Company Maritime Ports Administration SA Constanta; Marine Institute; Symbios Funding & Consuting; Protasis; Hydrus Engineering; Fincantieri SI.
Delivery Date	June 2023
Status	Ongoing
Link	Not available yet.
Funded?	Yes. Budget around € 7 million, of which 50% is funded by CEF Programme.

Project Name	**EALINGWORKS VALENCIAPORT: PREPARATION OF THE ELECTRICAL GRID OF THE PORT OF VALENCIA FOR ONSHORE POWER SUPPLY**
Project Description	EALINGWorks Valenciaport aims to prepare the port's electrical network for the supply of OPS to container ships, ferries and cruise ships in the new terminals of the Port of Valencia (new container terminal and new passenger terminal). To this end, a new electrical substation (type GIS - Gas-Insulated Switchgear) with an initial capacity of 60MW (extendable to 90MW in the future) will be built during the project. The Action also includes the installation works of the underground electric line that will connect the substation to the general network. Both interventions will enable the supply of OPS in the port of Valencia in situations of high demand.
Applicability	Onshore power supply (OPS)
Partners	Fundación Valenciaport, Port Authority of Valencia.
Delivery Date	June 2023
Status	Ongoing
Link	Not available yet.
Funded?	Yes. Budget around €8.6 million, of which around 20% is funded by CEF Programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.875285