STEERER

STRUCTURING TOWARDS ZERO EMISSION WATERBORNE TRANSPORT

D2.3 Areas of intervention and relevant actions - “implementation plan”

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Table of Contents

List of figures 5

List of abbreviations 7

1. Introduction to the deliverable 12

An overview of STEERER 12

Methodology 14

2. Intervention area 1: Sustainable alternative fuels 19

Introduction to the intervention area 19

Liquefied Natural Gas – bio and e-LNG 23

(e-)Hydrogen 26

Liquefied Petroleum Gas (LPG) 28

(e-)Methanol 29

Drop-in bio-fuels (bio-diesel and HVO) 30

(e-)Ammonia 31

3. Intervention area 2: Electrification 33

Introduction to the intervention area 33

4. Intervention area 3: Energy efficiency 36

Introduction to the intervention area 36

Wind-assisted propulsion systems (WAPS) 37

Air-lubrication systems 39

Waste-heat recovery systems 41

5. Intervention area 4: Design & retrofitting 42

Introduction to the intervention area 42

Advanced materials 43

6. Intervention area 5: Digital Green 44

Introduction to the intervention area 44

Digital twin 45

Automation 45

7. Intervention area 6: Ports 48

Introduction to the intervention area 48

Sustainable alternative fuels availability/infrastructure 49

Onshore Power Supply (OPS) 55

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

8. Conclusions 59
9. Annexes 61
Annex 1 : Fuel EU Maritime 61
Annex 2: ESSF SAPS MARIN PORTAL 65

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

List of figures

Figure 1: six areas of intervention

Figure 2: technologies and alternative fuels that are available to decarbonise international shipping

Figure 3: Overview of the defined systems and features

Figure 4: Technology readiness levels sustainable alternative fuels

Figure 5: Candidate marine fuel comparison of cost, GHG reduction potential and TRL

Figure 6: Monthly development LNG fuelled fleet

Figure 7: Vessels in service & on order with LNG as main engine fuel type

Figure 8: Vessels in service & on order with hydrogen as main engine fuel type

Figure 9: Monthly development of LPG fuelled fleet

Figure 10: Monthly development of methanol fuelled fleet

Figure 11: Vessels in service & on order with methanol as main engine fuel type

Figure 12: Possible options to store ammonia (marked in red)

Figure 13: Monthly development of fully electric fleet

Figure 14: Monthly development of hybrid fleet

Figure 15: Fully electric vessels in service & on order

Figure 16: Vessels in service & on order with WAPS per fleet type

Figure 17: Monthly development uptake air lubrication systems

Figure 18: Vessels in service & on order equipped with an air lubrication system

Figure 19: Vessels in service & on order equipped with waste heat recovery systems

Figure 20: The digital compass

Figure 21: System of Interest by Kongsberg

Figure 22: Levels of autonomy by Kongsberg

Figure 23: LNG Infrastructure in operation worldwide & in Europe by DNV GL

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Figure 25: Development of hydrogen projects worldwide by Pillsbury

Figure 26: Methanol Infrastructure in operation worldwide & in Europe by DNV GL

Figure 27: Ongoing and planned methanol projects worldwide by Methanol Institute

Figure 28: Ammonia Infrastructure in operation worldwide & in Europe by DNV GL

Figure 29: Assumed costs for refuelling infrastructure for alternative fuels

Figure 30: Vessels with high-voltage connection per fleet type

Figure 31: Visualization of shore power infrastructure worldwide

Figure 32: Visualization of shore power infrastructure in operation in Europe

Figure 33: fuels and techniques per fleet family based on an Innovative Pathway in 2035

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List of abbreviations

AFI – Alternative Fuel Insight

AI – Artificial Intelligence

CAPEX – Capital Expenditure

CCS/U – Carbon Capture Storage/Utilization

DAC – Direct Air Capture

DC – Direct Current

DME – Dimethyl Ether

E.E. - Energy Efficiency

EEDI – Energy Efficiency Design Index

EEXI – Energy Efficiency Index for Existing Vessels

EU – European Union

ETS – Emission Trading System

FAME - Fatty Acid Methyl Esters

FC - Fuel Cell

GHG – Greenhouse Gas

GSEG – Green Shipping Expert Group

GWP – Global Warming Potential

H2 - Hydrogen

ICE – Internal Combustion Engine

HFO – Heavy Fuel Oil

HVO – Hydrotreated Vegetable Oil

IEA – International Energy Agency

GT – Gross Tonnage

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HVSC – High-Voltage Shore Connection

IMO – International Maritime Organization

IWT – Inland Waterway Transport

LNG – Liquefied Natural Gas

LPG – Liquefied Petruleum Gas

MDO – Marine Diesel Oil

MeOH – Methanol

MGO – Marine Gas Oil

NH3 – Ammonia

OPS – Onshore Power Supply

RD&I – Resaerch, Development & Innovation

ROI – Return on Investment

SOFC – Solide Oxide Fuel Cell

SWOT – Strenghts, Weaknesses, Opportunities & Threats

TRL – Technology Readiness Level

TtW – Tank-to-Wake

VLGC – Very Large Gas Carriers

WAPS – Wind-Assisted Propulsion Systems

WtT – Well-to-Tank

WtW – Well-to-Wake

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Executive summary

The goal of this deliverable (D2.3) was to define key actions in order to support/fasten the development of the main technological solutions identified under each of the intervention areas from the Strategic Research and Innovation Agenda (SRIA) of the Co-Programmed Partnership on Zero-Emission Waterborne Transport (ZEWT): sustainable alternative fuels, electrification, energy efficiency, design & retrofit, digital green, ports. This work was done based on information that was gathered in the previous STEERER deliverables[1].

When starting the exercise it was clear that several key actions were applicable to all six intervention areas, so instead of repeating them each time, they have been listed in the introduction. Additionally, consolidated key actions were defined per intervention area where a SWOT analysis will be applied upon in a later stage.

Not surprisingly, the intervention area **SUSTAINABLE ALTERNATIVE FUELS** is the most extended one since it covers six sustainable alternative fuels. The chapter covers the technology-readiness level (TRL) of the onboard storage and propulsion solutions to use the sustainable alternative fuels and trends based on the number and type of vessels in service and on order using the sustainable alternative fuel concerned. Additionally, Annex I and II were added to give an overview of the well-to-wake (WtW) values of each of the sustainable alternative fuels analysed and their bio- and synthetic variants. Bunker infrastructure and fuel availability are analysed in the ports intervention area.

(e-)LNG – The TRL of onboard storage (9) and propulsion (9) is mature and there is an increasing trend of vessels in service and on order with LNG as a main engine fuel type. There is no need for further RD&I but rather stricter regulations regarding methane slip.

(e-)Hydrogen – The general TRL of onboard storage (4) and propulsion (5) still need to further mature. There are several projects ongoing that investigate the use of compressed and liquid hydrogen in both internal combustion engines (ICE) and fuel cells (FC), all applied in smaller vessels. Further RD&I in the form of demonstrators is needed to investigate the best fit regarding vessel type and operational profile for this technology.

(e-)LPG – Even though LPG is expected to play a minor role since it's a by-product in the oil production process and only applied by a very small niche (LPG carriers), it can be said that the technology is mature looking at the increasing trend of vessels in service and on order with LPG as a main engine fuel type. There is no need for further RD&I.

(e-)Methanol – is considered one of the most promising sustainable alternative fuels in the short term. The general TRL of onboard storage (8) and propulsion (7) is maturing and there is an increasing trend of a wide range of vessel types in service and on order with methanol

[1] STEERER *D2.1 State of play of decarbonisation of waterborne transport - "technology application atlas"* and *D2.2 Scenarios with quantified targets for 2025, 2030 and 2050 - "Common stakeholder target scenarios"*

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as a main engine fuel type. There is no need for further RD&I, but an urgent need for international safety standards.

Drop in bio-fuels – the general TRL of onboard storage (6) and propulsion (7) is maturing but further RD&I is needed to investigate fuel stability when (a mixture of different) bio-fuels are being stored. Additionally there is a need for stricter fuel quality standards.

(e-)Ammonia – the general low TRL of onboard storage (3) and propulsion (3) make ammonia the least advanced sustainable alternative fuel. There are no vessels yet in service or on order with ammonia as a main fuel engine type but some press releases indicate that ammonia-ready vessels are being ordered. These vessels are built in a way that once the fuel is available, the vessels can be retrofitted relatively easy.

The **ELECTRIFICATION** intervention area again gives an overview of vessels in service and on order that are either fully electric or hybrid. Here as well the trendline indicates an increase in the uptake in both. Mostly the smaller ferries opt for fully electric due to the possibility to recharge partially between stops and fully overnight and only travel shorter distances. Hybrid on the other hand can be found amongst a wide variety of vessel types. Even though uptake is increasing, there is still an RD&I need to further upscale and integrate the technology.

In the **ENERGY EFFICIENCY** chapter, several technologies are being analysed but the main focus has been put on wind-assisted propulsion systems (WAPS). The uptake of the technology is rather slow since it's not easy to compare the existing solutions and to estimate the reduction potential of the technology since this depends on several parameters. Additionally, at current fuel prices the return of investment (ROI) is rather low. Further RD&I is needed with a focus on system integration in order to fully benefit from the extra power that is generated without causing the engine to run sub-optimally.

Closely linked to the above three intervention area is the **DESIGN & RETROFIT** pillar. Even though most sustainable alternative fuels are not yet available, taking into account the average lifetime of a vessel, vessels need to be designed in a way that a retrofit is relatively feasible once the new sustainable alternative fuels are available. Additionally, new energy saving technologies (EST) and the use of battery systems require the redesigning of the vessels energy management system. Further RD&I is needed to ensure flexibility when it comes to transitioning between fuels and incorporating new EST's.

Even though **DIGITAL GREEN** is considered a very important intervention area, shipowners are generally investing more in other technologies that have a more direct impact on lowering emissions. Therefore, it might be better to consider whether the digital green pillar can be integrated in the other pillars as a horizontal pillar instead of a separate intervention area since the technology is quite mature.

The **PORTS** intervention area is closely linked to the sustainable alternative fuels and electrification areas since it investigates the bunkering infrastructure related to these pillars. Some of the sustainable alternative fuels may require more complex storage and transfer facilities than

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conventional fuels (particularly for those that are stored at high pressures and/or low temperatures, such as hydrogen and ammonia) resulting in higher CAPEX & OPEX costs.

Bunkering infrastructure – According to the DNV AFI portal, local storage facilities can be used as reload terminals with no or limited modifications to the terminal. Hydrogen infrastructure is the exception since there are currently no local storage facilities. Additionally, the bunkering of hydrogen comes with other challenges specific to its form (compressed/liquid).

Onshore Power Supply (OPS) – Even though uptake is still rather low, a rapid increase is noticeable during the course of 2021 with respect to both the vessels in service and on order. This increase is expected to grow even more rapidly in the container and passenger fleets in the coming years following the Fuel EU Maritime proposal under the Fit-for-55 package, which makes it mandatory for these fleet types to connect to OPS as from 2035. In order to fully support this trend, there is an urgent need to set a frequency standard.

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1. Introduction to the deliverable

An overview of STEERER

STEERER (Structuring Towards Zero Emission Waterborne Transport) will coordinate the establishment and communication of a Strategic Research and Innovation Agenda[2] 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 on the climate, people's health and Europe's economy.

STEERER is coordinated by SEA EUROPE, counting with the participation of a total of eight partners from six EU countries.

[2] The STEERER project will provide input to the Waterborne TP regarding the development and update of the Strategic Research and Innovation Agenda of the Candidate 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)[3] 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)[4]** 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 euros over 36 months, starting in December 2019. STEERER will play an important role in the preparation and execution of the candidate co-programmed Partnership on Zero-Emission Waterborne Transport to be established in the context of the new programme for Research and Innovation currently under negotiation: Horizon Europe.

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

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Methodology

This deliverable builds further on the previous deliverables where the state-of-play of the decarbonisation of the waterborne transport sector was described based upon information found in the Clarksons' database, public information regarding projects and expert knowledge (D2.1 State-of-Play of Decarbonisation of waterborne transport "technology application atlas"), and scenarios with quantified targets for 2025, 2030 and 2050 had been defined (D2.2 Scenarios with quantified targets for 2025, 2030 and 2050 - "Common stakeholder target scenarios"). The areas of intervention for this task are based on the six activities defined in the Co-Programmed Partnership on Zero-Emission Waterborne Transport (figure below) and hence follow the same structure as the state-of-play.

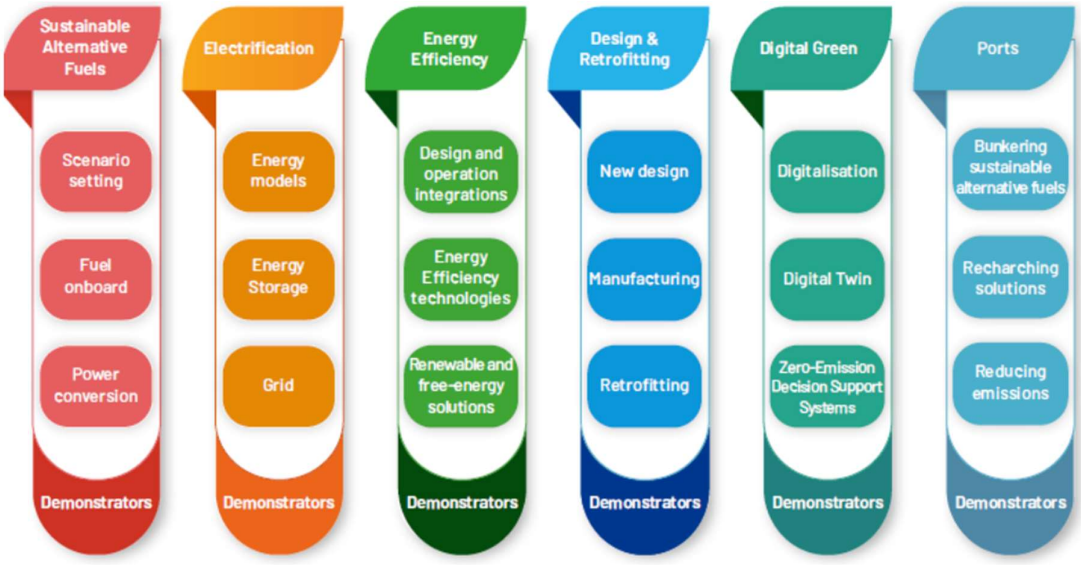

Figure 1: The six areas of intervention[5]

For each of these six intervention areas, preliminary conclusions are defined based on the information that was gathered from the other deliverables. The second part of the task is the gathering/mapping of relevant actions to be undertaken within each intervention area in order to support/fasten the further development of each of the technological solutions defined. In order to reach zero-emission waterborne transport technical actions are key, but without a legal framework and a solid business case, technologies cannot thrive. Therefore, relevant actions are listed for three themes: technical, regulatory and business.

To facilitate the generation of relevant actions, a non-exhaustive list of questions is added to the themes grouped into three categories:

[5] ZEWT cPP: SRIA

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- **Technical** (T): How can emissions be further reduced or even eliminated? What is needed to increase the TRL of the related technologies? Are there any knowledge gaps? Is the RD&I pipeline moving?
- **Regulatory** (R): How can policy support and facilitate the innovations that are needed? Are the safety measures in place? Do class guidelines need to be developed further? What existing regulations need to be updated to increase uptake?
- **Business** (B): Is it economically feasible to invest in the technology? What is the return on investment? Is retrofitting an option? What is the perception of the technology? Is there enough access to capital for RD&I, pilots & deployment? Is enough information available for the shipowner to make a decision? Do commercial agreements need to be updated?

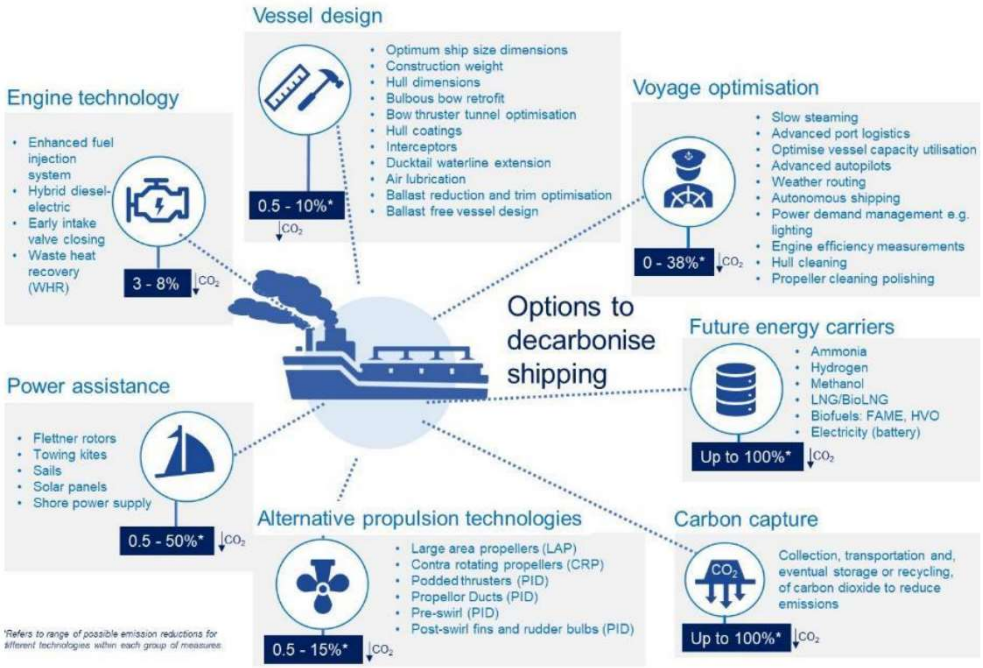

Figure 2: technologies and alternative fuels that are available to decarbonise international shipping[6]

As the image above indicates, there are different options to decarbonise shipping, but the use of sustainable alternative fuels is the most essential to reach the initial ambition by 2050. CO2, CH4 and N2O represent the greenhouse gases emitted by the waterborne transport sector. According to the IMO's 4th GHG study, CO2 remains the dominant source on a GWP-100-year basis, accounting for 98%. Regulations only dealing with well-to-tank (WtT) or tank-to-wake (TtW) emissions, or only ruling a single emission source would not be effective to incentivize the use of sustainable alternative fuels. They present the risk to displace emissions, potentially increase the overall level of emissions.

[6] Ricardo Energy & Environment: Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050 (31/01/22)

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Besides continuous developments at the technical side of the zero-emission challenge, the regulatory landscape is also undergoing significant changes. Both the IMO and the European Commission have adopted a work plan aiming to decrease emissions from waterborne transport and facilitate the uptake and use of sustainable alternative fuels.

At this stage, the main proposals on respectively the EU and IMO level are the following:

- At the EU level, the Fit-for-55-package. This is a proposal by the EU Commission to include shipping into the regional emissions trading system (ETS), implement a new regulation on Maritime Bunker Fuels (FuelEU Maritime), amend the Renewable Energy Directive (RED), revise the Energy Tax Directive and the Directive on deployment of the alternative fuels infrastructure, and to develop a greenhouse Gas Fuel Intensity standard. The Fit-for-55-package will have an impact on both maritime and IWT, to which extent is not yet certain since the scope of some of the proposals is still to be decided.
- At the IMO, work is being undertaken on the further development of measures (short, mid and long term) that allow the shipping industry to meet the goals of IMO's initial strategy and to remain in line with the Paris Agreements, such as:
    - The development of a global Carbon Intensity Standard (CII);
    - A short-term measure regarding the establishment of an International Maritime Research and Development Board (IMRB) and an International Maritime Research and Development Fund (IMRF);
    - The further development of a work plan on mid- and long-term measures, including a possible international Market Based Measure (MBM);

Before starting the more focused exercise the list below defines key actions that apply to all six intervention areas:

1. There is an enormous amount of technological knowledge available but unfortunately, it's scattered. By further developing and refining the Waterborne TP website in close collaboration with the waterborne members, the website can serve as a knowledge platform by providing a clear overview of the waterborne research projects, including potential challenges, opportunities and conclusions. The platform can serve as a means to find information faster and connect people that are working on similar technologies and it can also benefit possible future research projects that aim to further decarbonize the entire waterborne transport supply chain. Besides having one knowledge platform, it's also recommended to regularly set up knowledge sharing sessions related to the projects on the knowledge platform and physically bringing together different consortia and experts that have been working on similar topics.
2. Every sustainable alternative fuel, new power system or technology comes with different risks (toxicity, flammability, corrosivity, etc), which might be new to the waterborne transport sector. Ideally, the platform allows to include possible lessons learned from other industries. The safe and sound handling of the new alternative power systems throughout the entire maritime logistic supply chain needs to be guaranteed and possible safety risk to be minimized at any time. While the main part of the work will need to be undertaken at

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the IMO through the development of Guidelines, the platform could help to increase awareness among EU stakeholders and authorities.

3. New fuels come with a high cost, as long as there is no international price on carbon, there will be a need to incentivise the use of sustainable alternative fuels. Therefore, a dedicated waterborne fund such as the Ocean Fund proposed by MEP Peter Liese, rapporteur on the EU ETS in the European Parliament[7], would be warmly welcomed. A dedicated waterborne fund will accelerate the fuel transition by for example bridging the price gap between conventional and sustainable alternative fuels. Frameworks such as the "First movers in shipping's decarbonisation", published by Lloyd's Register 9 December 2021, can be used to identify which key ports and vessel types to target per sustainable alternative fuel initially.
4. The development of international standards or eco-labels for vessels translated into product labels could impact consumer choices on the one hand and might also incentivise cargo-owners to choose the more sustainable vessels on the other hand.
5. Ships are serious financial assets that have a life span of 20 years and more. Bringing new frontrunner technologies into the market and onboard ships therefore comes with considerable financial risks for certain stakeholders and in the first place the owner of the ship. Long term engagement from other stakeholders involved, such as charterers, cargo-owners and fuel suppliers through for example long-term chartering contracts could provide more certainty to the market and facilitate further investments in these new technologies.
6. With new technologies (i.e., sustainable alternative fuels and hardware) there is often missing technical/safety regulations and class guidelines making it not directly possible to sail on these new technologies due to lacking licenses/permits. There are possibilities for getting exceptions on the short term and adjustments to regulations on the longer term to enable the deployment of new technologies on a larger scale. However, such processes take a long time and eventual guidelines of individual classification societies are not always aligned. New initiatives (e.g., innovation projects/programs) should address the class guidelines, technical regulations and safety and environment guidelines.
7. There is a huge need for more long-term contracts. Not only between shipowners and cargo-owners but also between fuel suppliers. A long-term contract lowers uncertainty, which is needed when working with new technologies.
8. The price of new technologies can decrease due to economies of scale because costs can be spread. Enhanced cooperation between shipowners with interest in the same technologies could unify shipowners and stimulate ordering in series to reduce costs.
9. Business models need to be reviewed to make technological solutions more commercially viable such as pay-per-use, data ownership, leasing options, etc.
10. An initiative should be launched for analysing the implementation of the Fit-For-55 package. The analysis should provide clear insights into the business and economic impacts of the proposed Fit-For-55 policies which are relevant to the waterborne transport

[7] https://www.peter-liese.de/images/ETS_DRAFT_Report_13-01-2022_new.pdf

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sector. These in-depth insights are needed to raise stakeholder acceptance and support for detailed implementation plans of the proposed Fit-For-55 policies.

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2. Intervention area 1: Sustainable alternative fuels

Introduction to the intervention area

As demonstrated in the figure below, developed by the Maritime Research Institute Netherland (MARIN), the sustainable alternative fuel intervention area can cover a plethora of areas to decarbonize the waterborne transport sector. The focus of the deliverable lies on the use of sustainable alternative fuels in waterborne transport applications (such as onboard storage and energy conversion) and not on the production of the fuels (although key because the two go hand in hand). Bunker infrastructure will be covered in the sixth intervention area (Ports).

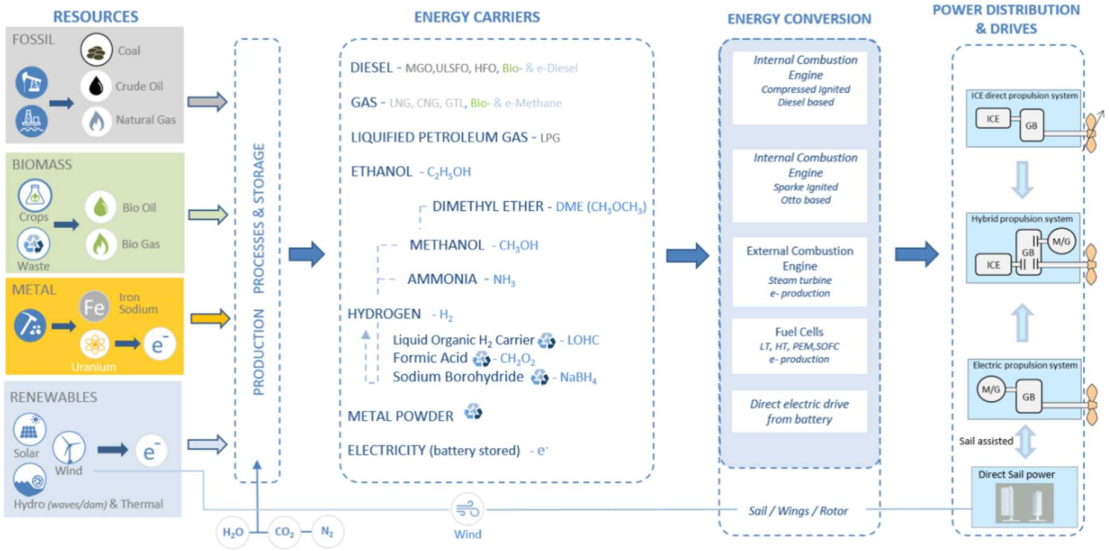

Figure 3: Overview of the defined systems and features[8]

It is expected that the legislative proposals in the Fit-For-55 package in combination with European funds that are dedicated specifically for the RD&I needed in the waterborne transport sector, such as Horizon Europe and other initiatives, will close the price gap between the conventional and sustainable alternative fuels and will push the uptake of the sustainable alternative fuels in the sector. It is also expected that sustainable alternative fuels will be evaluated on a well-to-wake basis and that all harmful air emissions are taken into account, not only greenhouse gases. As long as sustainable alternative fuels are not available in the market in the quality and quantity needed for the waterborne transport sector, intermediate solutions and technologies will remain needed to keep the sector moving globally. It will therefore be key to determine uniform rules regarding the monitoring and reporting of emissions such as methane slip for LNG, to further refine the quality

[8] ESSF SAPS MARIN Portal https://sustainablepower.application.marin.nl

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standards for biofuels and to investigate blends (LPG with DME, LNG with hydrogen, HFO with methanol, etc.).

The figures below give an indication of the technology readiness level of the onboard storage and propulsion solutions to use the sustainable alternative fuels and the costs versus GHG reduction potential compared to HFO:

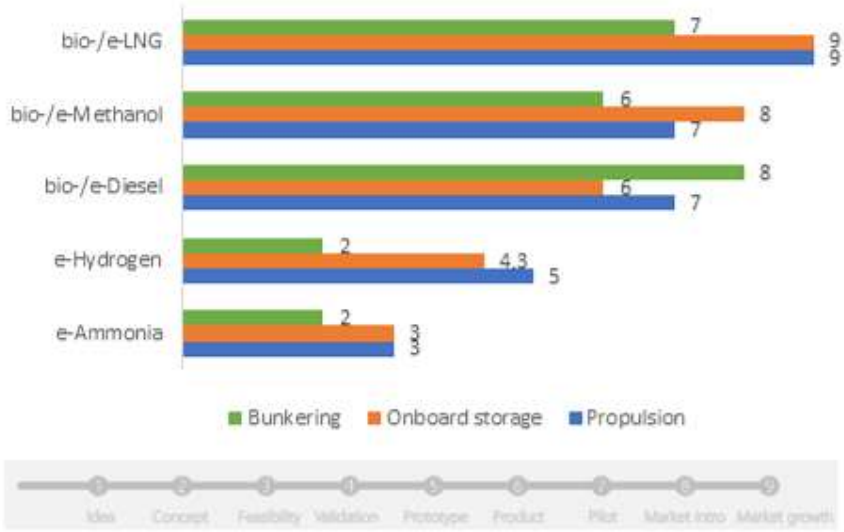

Figure 4: Technology readiness levels sustainable alternative fuels[9]

[9] Lloyd's Register Decarbonisation Hub: Zero-carbon fuel monitor – Dashboard

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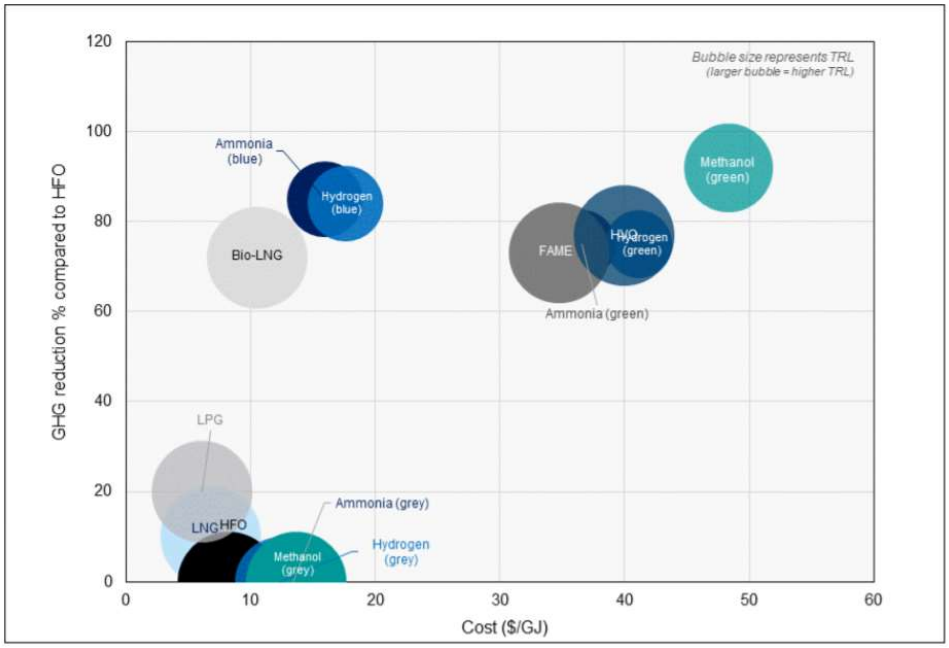

Figure 5: Candidate marine fuel comparison of cost, GHG reduction potential and TRL[10]

Before addressing each sustainable alternative fuel separately, the following key actions were defined that apply to all the sustainable alternative fuels:

Theme	Key actions
T	Development/ further optimization of **after-treatment systems** to (nearly) eliminate all types of emissions. Both transitional fuels and sustainable alternative fuels require aftertreatment systems. There is still room to further optimize existing systems or develop new (smaller) systems.
T	Further upscaling of **demonstrator projects** to identify the limits of the different fuels.
T	Setting up **field labs** to allow demonstrators to develop faster by increasing the speed of approval processes.
T	Investigate the reliability and cost of fuel cells in the waterborne transport environment (tilting, acceleration, vibrations, etc.)
T	Setting up partnerships between fuel cell manufacturers and waterborne transport stakeholders so both industries can get a better understanding of each other. The manufacturers consider marine applications as potential business opportunities but often lack the expertise of the field (regulations, specific requirements, etc).
R	Class guidelines/ES-TRIN are/is yet lacking provisions for the use of hydrogen in IWT and therefore need to be updated/adjusted where needed to facilitate the use of sustainable

[10] Concawe: Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050

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	alternative fuels. This can, e.g. be achieved by addressing the guidelines and technical regulations in current/new IA and RIA projects under Horizon Europe that are focusing on the use of sustainable alternative fuels **taking into account the different waterborne transport segments** but also follow-up on how private initiatives handle this aspect, so the work done is complementary instead of duplicated.
R	Address full **life-cycle emissions** when assessing a fuel (upstream + downstream and not only GHG but **all** harmful emissions).
R	Ensure **global uniform monitoring and reporting** of CO2, CH4, N2O in ships.
R	Fire- & safety regulations need to be developed/updated where needed to facilitate the use of sustainable alternative fuels and guarantee safety.
R	Setting up of a clear **roadmap** for the sustainable alternative fuels: when and where will which grey/blue/green fuel be available.
R	Development/ further refinement of fuel standards to **guarantee the quality** of the fuel. The purity of the fuel has a huge impact on the engine/fuel cell.
R	Review/rewrite existing regulations and guidelines to allow for more room for future innovations (**broader interpretation**).
R	Allow for flexibility in guidelines and regulations to enable adoption of new technologies for small vessels. Most technologies are developed for the maritime transport sector or for the road transport sector, the smaller vessels mainly used for inland waterway transport adopt technologies from both, but the regulatory framework takes a long time even though other sectors already have developed guidelines.
R	Setting up of a regulatory framework regarding onboard storage and propulsion related to the new fuels (the IWT case).
R	Development and implementation of regulations for operating SOFC on board of a vessel.
R	Implement measures that facilitate further research and incentivize the roll out of CCS/CCU technologies at large scale.
R	Harmonise different EU and international policies related to the use of alternative AND transitional fuels.
R	Internationally standardized WtW information on bunker notes.
B	Investigate the feasibility of large-scale deployment of technologies for CCS/CCU as a viable option for low-tech low-cost direct discharge (versus CO2 storage) technologies for ensuring the future availability of sufficient e-fuels as well.
B	Insights in the cost comparison and broader impacts between the different options for the sustainable alternative fuels as fuel and energy convertors (ICE vs FC) for different vessel types and operational profiles.
B	Insights in the availability and price trends of different fuels are needed to make sound business decisions.

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

B	Insights in the availability and price trends of different fuels are needed to make sound business decisions.

Additionally, two consolidated actions were identified that will be used for the SWOT exercise (task 2.4).

Area	Consolidated actions
SAF	Develop new propulsion systems in higher TRL levels to bring sustainable alternative fuels and propulsion systems closer to the market.
SAF	Develop high TRL cost-efficient and effective storage and bunkering systems for sustainable alternative fuels on board of vessels.

Liquefied Natural Gas – bio and e-LNG

Based on the increasing number of vessels in service in combination with the relatively high TRL levels for onboard storage (9) and propulsion (9) it can be said that the onboard technology related to liquefied natural gas (LNG) as a marine fuel is quite mature and that there is no need for further RD&I. LNG as a marine fuel has therefore not been discussed with the Green Shipping Expert Group. Vessels sailing on fossil LNG will have the possibility to switch to bio- or e-LNG when this becomes available on the bunkering market, without major retrofit or conversions needed on the ship-side. For this reason, LNG as a fuel is still taken into account in this analysis.

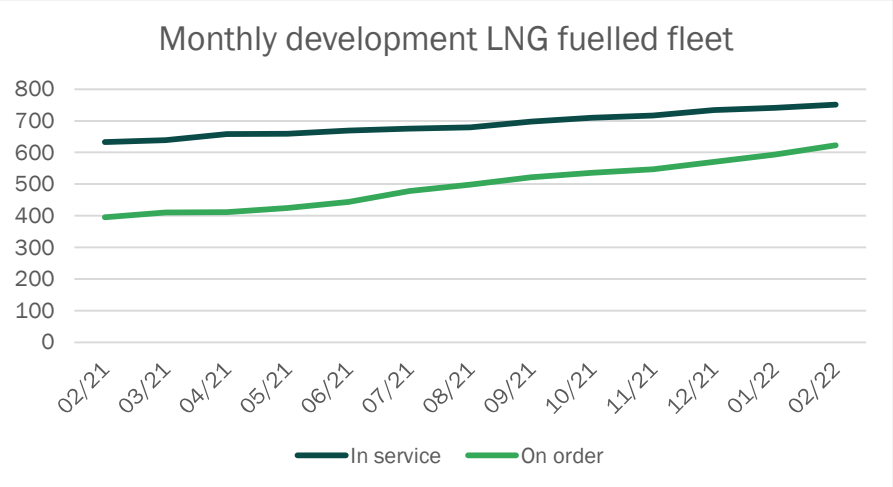

Figure 6: Monthly development LNG fuelled fleet[11]

The graph shows an accelerating increase in the uptake of LNG as a fuel for maritime vessels. Even though LNG is still predominantly chosen by LNG carriers (65,4% of the vessels is service and

[11] Clarksons' database (24/02/2022)

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30,5% of the vessels on order), the uptake amongst other ship types is also increasing. For many shipping routes, sufficient and adequate LNG bunkering infrastructure is now finally in place, as is a significant amount of operational experience (see ports intervention area). Rules and regulations have also reached a mature level, enabling a smooth newbuild or retrofit process without surprises.

The uptake of LNG for inland navigation vessels is slower. As of 2021 there are 14 LNG powered vessels in service and another 40 vessels (tankers) on order. The implementation scenarios for the usage of LNG in the European IWT sector has already been studied in the LNG Masterplan[12] and LNG Breakthrough[13] projects. There is also a strong interest for gas-electric configurations.

> The purpose of the LNG Masterplan was it to facilitate the creation of a harmonized European regulatory framework for LNG as fuel and cargo in inland navigation, including technical concepts for vessels and promotion of LNG in the sector. However, the very low diesel price in Europe made an implementation of infrastructure and a fleet change unprofitable, leading to the effect that in the Danube Region no further developments have been implemented. Nevertheless, in Western Europe the LNG Breakthrough project successfully implemented an LNG bunkering station and further created a critical mass (three LNG driven vessels) for the uptake to ensure the economic and technical viability of the bunker station.
>
> The LNG Breakthrough project, amongst others, studied innovative financing constructions (leasing tanks, hedging the price gap between LNG and Diesel), standardised LNG configurations, TCO calculations (https://tcomodel.eu/) and deployed 2 newbuild, 1 retrofitted vessel and 1 bunkering station. One of the standardised configurations concerns a gas-electric configuration tested on the pilot vessel Werkendam of Van Oord. This configuration, in more or less the same way, is now being implemented on the 40 newbuild vessels (Parsifal series) of Shell (chartered by Shell and operated by the Dutch VT Group and the Cypriot company Marlow Navigation). The configuration (dual-fuel) on the pilot vessel Somtrans LNG is now also being used in two subsequent newbuilds (Swiss LNG I and Swiss LNG II) which are also quite similar in size.

LNG can be burned in different engine types with each having an average specific engine slip factor representing methane emissions. Care must be taken though that not all low-pressure engines are treated equal and depending on their level of sophistication, deviations downwards but also upwards of the quoted values are possible. All high-pressure engines tend to have similar and extremely low methane emissions due to the physical characteristics of the combustion process.

Another way to use LNG as a fuel is through the use of fuel cells. This technology was demonstrated already in 2009 on board Viking Lady by Wärtsilä; an offshore supply vessel retrofitted with a 330kW SOFC running on LNG and successfully racking up 18.500 running hours. The NAUTILUS project is also looking into this technology under Horizon 2020, exploring integration possibilities. The concept consists of a 60 kW SOFC-battery hybrid genset. A demonstrator is expected by June

[12] http://www.lngmasterplan.eu
[13] https://lngbinnenvaart.eu/

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2024. Only SOFCs and Molten Carbonate Fuel Cells (MCFCs) make sense when using LNG. One of the SOFC advantages is its high flexibility regarding fuels, given sulphur removal and pre-reforming.

Cylindrical LNG tanks typically occupy three times the volume of an equivalent amount of energy stored in the form of fuel oil (due to the shape of the tanks and the volumetric density compared to HFO). The contained volumetric energy density of LNG is 13,17 MJ/L which results in 2,69 times more tank space required than HFO (35,5 MJ/L).[14]

In the current literature (by among others the World Bank, ICCT, SEA-LNG), different GHG emissions factors for LNG (depending on the varying methane leakage assumptions applied to LNG production pathways and its use on board vessels) reflect the fuel's uncertain benefits. The EC has calculated the different emission factors for LNG, depending on the feedstock and taking into account the overall CO2-eq (including the impact of CH4 and N2O as well).

A large-scale continuous role for LNG appears unlikely due to the uncertain GHG benefits, the additional capital expenditures, the risk of stranded assets, and most importantly the risk of a technology lock-in with a GHG emissions trajectory which would be incompatible with the EU's and IMO's 2050 climate targets.

There is however a clear need for urgent and strong policy action to regulate methane emissions both in the supply chain of LNG and in its use on board existing ships and any newbuilds. This will be important regardless of whether LNG becomes a significant bunker fuel or not. For example, although downstream methane emissions could be reduced using newer machinery with lower methane slip levels, this would still not address the risk of upstream and midstream methane emissions in the supply chain, the emissions of which are said to be much lower for bio- and e-LNG, compared to conventional LNG. These present a much more complex problem that is not strictly technological in nature, but would require regulatory changes and enforcement across the numerous jurisdictions where LNG is extracted and distributed.

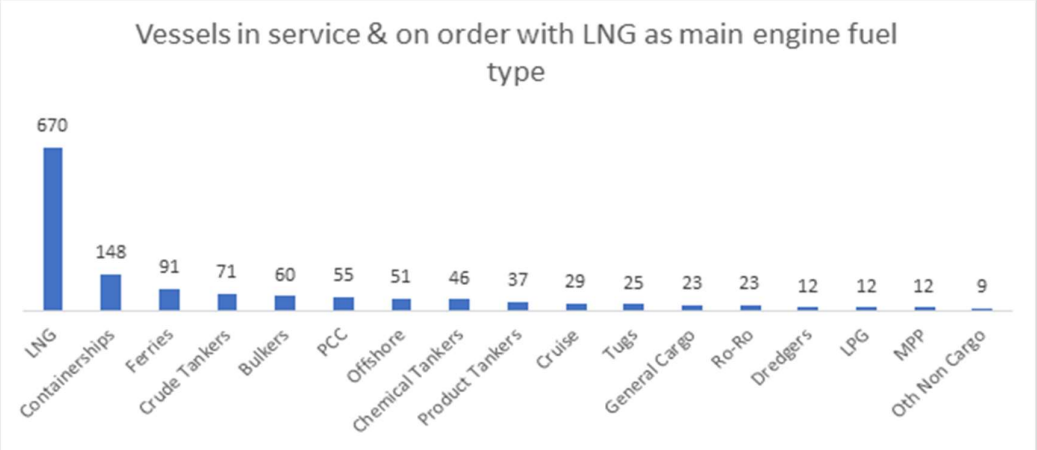

Figure 7: Vessels in service & on order with LNG as main engine fuel type[15]

[14] https://sustainablepower.application.marin.nl/energy-carriers/table
[15] Clarksons' database (24/02/2022)

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KEY ACTIONS IDENTIFIED

Theme	Key action
T	Minimize/eliminate methane slip by engine design (possibility of including after treatment systems) and proper design-for-operation.
R	Setting up stricter regulations regarding methane slip emissions and ensure global uniform monitoring and reporting (transparency).
B	Monitoring and reporting of methane slip will allow further differentiation between existing options and to incentivize the use of the better options (less methane slip). Lower slip levels are technically possible but come at a higher cost.

(e-)Hydrogen

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

Fleet Type	In service	On order	Technology
Ferries	1	2	FC
Tugs	0	1	ICE
Dredgers	0	1	FC

Figure 8: Vessels in service & on order with hydrogen as main engine fuel type[16]

Uptake of hydrogen as a fuel is currently still at its infancy in both the maritime shipping and inland waterway transport sector, and limited to mostly publicly-funded projects. Most of these projects (see annex D2.1 State-of-play) focus on the use of fuel cells as power conversion technology but hydrogen can also be burned in combustion engines. BeHydro – a joint venture between shipowner CMB and engine manufacturer ABC engines – launched the first marine dual fuel hydrogen engine in 2020. The engine can run on diesel as well as on a mixture of hydrogen and diesel. In hydrogen mode, diesel is used to ignite the hydrogen. The consumption of diesel and hydrogen depends on the load profile of the engine. At full load the engine will use 61kg of hydrogen and 45kg of diesel per hour. The efficiency at full load is around 40%.[17] In addition, BeHydro is developing a mono-fuel hydrogen engine that will be ready by the second quarter of 2022. With an efficiency range between 50% and 60% hydrogen fuel cells are more efficient than ICEs but only at low loads. From the moment the load increases the efficiency decreases a lot. In marine propulsion applications (working at average high loads) both efficiencies will be comparable. The onboard technology related to hydrogen as a marine fuel is evolving to a more mature state but one of the **biggest challenges is bunkering-related** (see ports chapter)**.**

The volumetric energy density of hydrogen as a fuel at standard temperature and pressure (STP) is approximately 3.000 times lower than diesel.[18] Compressing and liquifying hydrogen are two out

[16] Clarksons' database (28/02/2022)
[17] https://www.behydro.be/
[18] Van Hoecke L., et al., Challenges in the use of hydrogen for maritime applications. Royal society of chemistry, 2020. https://pubs.rsc.org/en/content/articlelanding/2021/EE/D0EE01545H

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of many methods to improve this low volumetric energy density. The volumetric density of **liquefied** hydrogen is only 7% that of HFO, and can require as much as 36-45%[19] of the H2 energy content in actual plants. This results in approximately five times the volume compared to the same energy stored in the form of HFO. When stored as a **compressed** gas, it's volume is roughly ten to 15 times (depending on the pressure) the volume of the same amount of energy when stored as HFO.

Hydrogen will initially be mainly a suitable option for the smaller waterborne transport segments but not for the vessels with large consumption due to its low energy density and extremely high fuel costs. This could however change in the future if a suitable liquid organic hydrogen carrier (LOHC) is found.

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Investigate the possibility to use reforming techniques to generate hydrogen onboard of the ship from different energy carriers (MeOH, NH_3, etc.).
T	Investigate the maintenance needs of different hydrogen storage systems.
T	Investigate the optimal tank type selection for different operational profiles.
T	Clarify capabilities with regards to load variation and low load operations.
T	Assess operational fit with regards to energy efficiency / density.

[19] Reuß, M., et al., Seasonal storage and alternative carriers: A flexible hydrogen supply chain model. Applied Energy, 2017. 200: p. 290-302.

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Liquefied Petroleum Gas (LPG)

Even though LPG has a role to play in the short term as a transition fuel, it is only used by a very small niche of the waterborne transport sector (LPG carriers) and availability will decrease since it's a by-product in the oil production process. For these reasons, no key actions were defined.

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

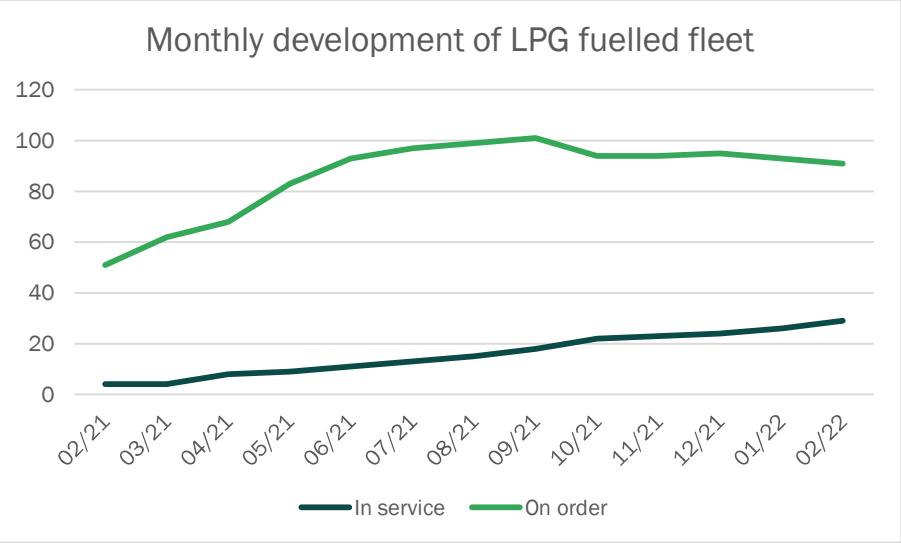

Figure 9: Monthly development of LPG fuelled fleet[20]

When looking at the vessels in service, the graph above shows a steady increase in the uptake of LPG as a fuel for maritime vessels. A more rapid increase can be expected in the following years taking into account the high number of LPG capable units. In contrast with the uptake of LNG amongst different fleet types, LPG is only used as a fuel by LPG carriers where it now is the fuel standard for VLGCs and growing across smaller vessel sizes. No LPG-related RD&I projects were found in the research undertaken to map the 'state of play'.

LPG consists of propane, but also butane, propene and some other smaller fractions. Composition differs regionally and sometimes also seasonally. Propane has the lowest boiling point, so it is deterministic for the storage behaviour. The contained volumetric energy density of LPG is 11,34 MJ/L which results in 3,13 times more tank space required than HFO (35,5 MJ/L).[21]

On a sidenote, dimethyl ether (DME) can be blended with LPG. Blends containing up to 20% volume DME generally require no modifications to equipment or distribution networks. Combustion of DME/LPG blends demonstrates reductions of 30 – 80% in CO2 emissions, and reductions of 5 – 15% in NO emissions (compared with combustion of LPG).[22]

[20] Clarksons' database (24/02/2022)
[21] https://sustainablepower.application.marin.nl/energy-carriers/table
[22] www.aboutdme.org Fact Sheet DME/LPG blending

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(e-)Methanol

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

According to the Clarksons' Fuelling transition report published in November 2020, at that moment 12 vessels were in service and 10 on order. The Fuelling Transition report of October 2019 indicated 11 in service, 1 on order. Unfortunately, no more information could be found from before that date. The interest for methanol as a fuel is the largest for methanol carrying vessels, but an increase in the orderbook was noticeable between August and September 2021 coming from Maersk ordering 7 fully cellular containers. The Sea Consortium-controlled feeder operator X-Press Feeders recently announced to have placed an order for sixteen 1,170 TEU dual-fuel newbuild containerships that can operate on regular fuel or green methanol. One vessel aside, all had a MAN ES Diesel 2-stroke engine installed but Wärtsilä recently sold 5 dual fuel engines to Van Oord.[23]

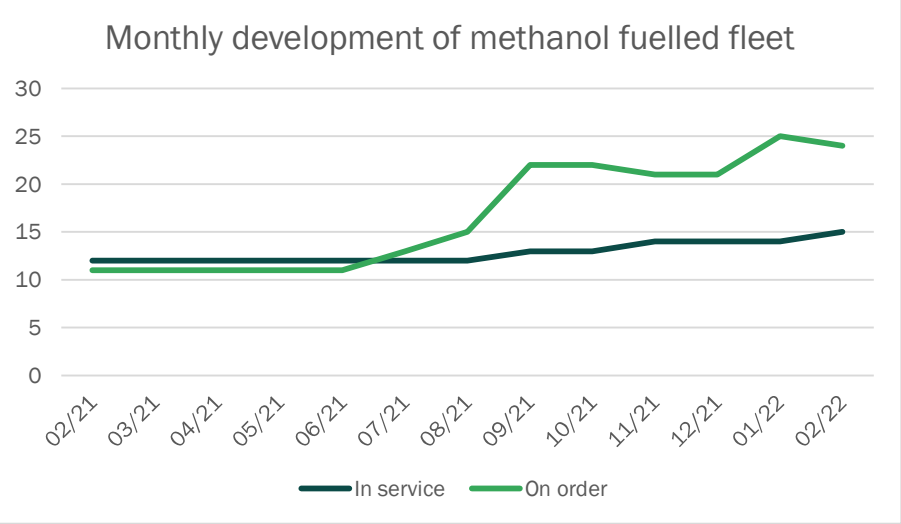

Figure 10: Monthly development of methanol fuelled fleet[24]

Even though several vessels are already using methanol as a fuel and general TRL levels for onboard storage (8) and propulsion (7) are quite ature, RD&I is still ongoing.

The FASTWATER project looks, amongst others, at the development of a methanol retrofit kit. A retrofit would involve the installation of a second barrier for the fuel tanks as well as double pipelines. Four-stroke methanol engines and retrofit kits for small and mid-sized engines with a wide range from 200kW – 4MW are in development and will be available by the end of 2022. **While new four-stroke methanol engines allow to use up to 97% of methanol, the retrofit-kits enable existing vessels to convert their diesel engine to use up to 70% of methanol.**

[23] https://www.ship-technology.com/news/wartsila-methanol-driven-engines/
[24] Clarksons' database (24/02/2022)

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As with the other fuels, methanol can also be applied in fuel cell systems in combination with a reformer. 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. Already in 2008, the EU funded METHAPU project started its trials on a prototype of a methanol based SOFC unit for auxiliary power systems for commercial vessels.

No compression, nor cryogenic storage is needed to realize tank infrastructure on board or on harbours but for safety reasons an inert gas system is. The contained volumetric energy density of methanol is 13,6 MJ/L which results in 2,61 times more tank space required than HFO (35,5 MJ/L).[25] There is some flexibility for placing integral tanks next to the side plating below the waterline or the bottom plating.

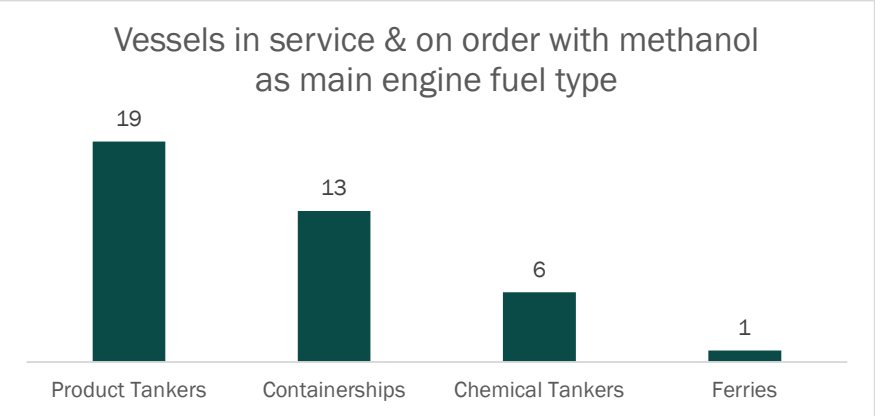

Figure 11: Vessels in service & on order with methanol as main engine fuel type[26]

KEY ACTIONS IDENTIFIED

Methanol fuel cells and engines (TRL 7-8) as well as tank systems (TRL 8) are available and demonstrated in real environments as indicated by the Clarkson's database. The reason why the TRL does not have a higher score is mostly linked to industry & safety standards that still need to be updated. On regulatory level there should also be a guarantee that the green variants of methanol are acknowledged as green fuels.

Drop-in bio-fuels (bio-diesel and HVO)

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

Virtually no low-carbon fuels are used in international shipping today. Biofuels are the only non-fossil fuel alternative that has been adopted to date, and they account for only 0.1% of final energy

[25] https://sustainablepower.application.marin.nl/energy-carriers/table
[26] Clarksons' database (28/02/2022)

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consumption. Additionally, as noted by the IEA in its latest Renewables report, bio-diesels are more expensive than fossil marine fuels, therefore rarely used by the shipping companies, and also by the bunkering companies.

According to the current policy framework, low- and zero-carbon fuels are projected to make up roughly 2% of total energy consumption in international shipping in 2030 and 5% in 2050.[27]

Biofuels are used as drop-in fuels substituting conventional fossil fuels and are compatible with existing infrastructure and engine systems. In some cases, they require modification of infrastructure and engine systems.

The contained volumetric energy density of FAME is slightly lower (34,4 MJ/L 20% FAME + 80% Diesel or 31,7 ML/L 20% FAME, 30% HVO, 50% diesel) than HFO (25,5 MJ/L) so the impact on extra tank space needed is limited.[28]

KEY ACTIONS IDENTIFIED

Theme	Key action
R	Engines need to be certified and tested for the (blends) with biofuels as alternative for the fossil diesel (e.g. Stage V engines to be certified for higher blends of FAME).
R	Fuel specifications need to be made stricter, including the measurement and enforcement due to fuel instability, corrosion, susceptibility to microbial growth, and poor cold-flow properties of certain biofuels. Also proper government measures need to be more widely known and clear to the users and fuel providers.
B	Clear information on the technical applicability and the 'good housekeeping' measures to be taken into account to be provided by the fuel suppliers.

(e-)Ammonia

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

According to the Clarkson's database there are currently no vessels on order using ammonia as a fuel but a few shipowners announced that they are ordering ammonia-ready vessels. In the inland waterway transport sector, ammonia is presently not a suitable fuel due to its toxicity and the huge external safety risks. Safety-related aspects are also concerning the use of this fuel in the maritime transport sector. Moreover, part of the ammonia emissions are made up of laughing gas which has a greenhouse gas factor of 250 times CO_2, therefore the risk of a net increase of GHG emissions is substantial.

[27] https://www.iea.org/reports/international-shipping
[28] https://sustainablepower.application.marin.nl/energy-carriers/table

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Even though there are no ammonia-ready vessels yet in the orderbook, both MAN ES and Wärtsilä are developing ammonia engines. But both engines are still in the test phase. As with the other hydrogen-based fuels, fuels cells are being looked into as well: the ShipFC project will retrofit an offshore vessel with a large 2MW direct SOFC ammonia fuel cell.

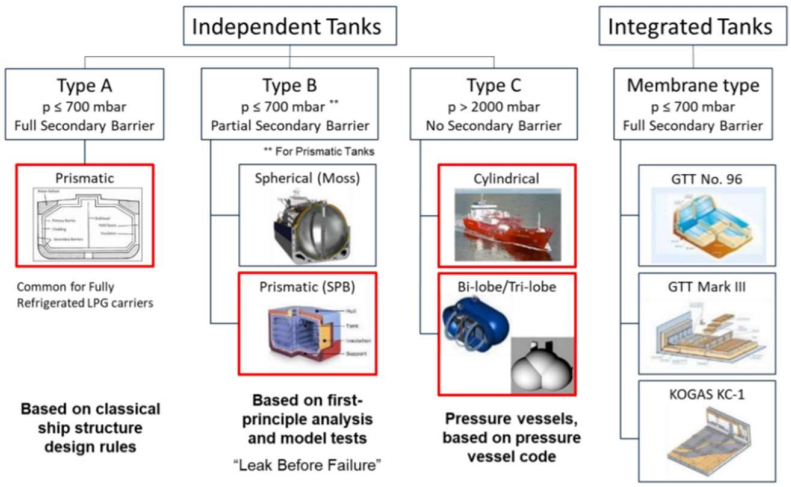

Figure 12: Possible options to store ammonia (marked in red)[29]

The contained volumetric energy density of ammonia is 10,4 MJ/L which results in 3,41 times more tank space required than HFO (35,5 MJ/L).[30]

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Further development and testing of ammonia ICE: - Determine optimal amount of pilot fuel (diesel:NH3 or H2:NH3); - Determine when and where the fuel will be mixed with the pilot fuel; - Determine effective and efficient engine management and aftertreatment (risk of ammonia slip and laughing gas).
T	Upscale ammonia fuel cell demonstrators (current limit 5 MW).
T	Further investigate optimal storage solutions.
T	Investigate the feasibility of ammonia cracking to hydrogen for reducing on-board hydrogen storage requirement/increasing vessel range.
T	Investigate alternative for operational venting (will it be acceptable to venting NH3 to atmosphere?).

[29] ABS: Alternative Maritime Fuels AMMONIA (MIDC session 30/06/2020)
[30] https://sustainablepower.application.marin.nl/energy-carriers/table

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3. Intervention area 2: Electrification

Introduction to the intervention area

Even though full electrification will only be applied in waterborne transport segments that have shorter and/or fixed/predictable routes, hybrid solutions have an important role to play in terms of more optimal energy management of certain processes on board of a vessel. New technologies might require additional energy storage systems such as batteries, gensets or supercapacitors to cover the fluctuating load variations and increase the efficiency, reliability and flexibility of the entire power system. A big advantage of full battery electric drive is the high energy efficiency as there is hardly any thermal loss of energy. This amounts to around 5-10% compared to 50-60% of energy thermal loss for internal combustion engines and fuel cells. Especially if there is a shortage of green electricity (also to make e-fuels and green hydrogen), the option of full electric propulsion using batteries charged from the grid is very attractive. Furthermore, these batteries can also be used for peak-shaving and stabilising the electricity grid, seen also the expected increase of fluctuations due to more electricity coming from wind and solar power.

One **consolidated** actions was identified that will be used for the SWOT exercise in task 2.4.

Area	Consolidated actions
ELEC 1	Fuel Cell and battery technology development and application on board of vessels, taking into account the waterborne transport segments. Both low TRL level developments focusing on the further development and demonstration of promising new battery technologies on board of vessels and high level TRL developments aiming to bring FC and battery applications closer the market.

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

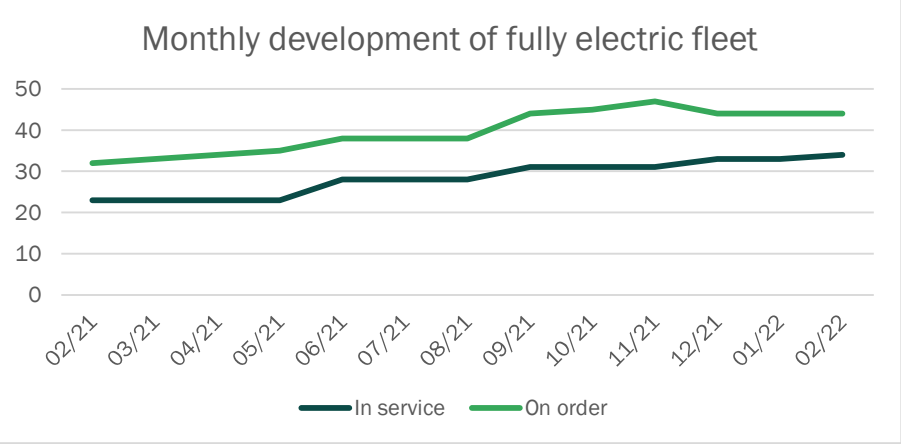

Figure 13: Monthly development of fully electric fleet[31]

[31] Clarksons' database (24/02/2022)

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The uptake of battery propulsion is rising slowly but steadily. Fully electric is predominantly chosen by the ferry fleet (smaller vessels, fixed route & timetable). The other vessels that opt for fully electric are also relatively small vessels (104 GT- 3221 GT). For IWT, fully battery electric can be a general solution for many vessels if there will be a dense network of ports and quays where batteries can be exchanged and/ or recharged. It seems less suitable for vessels with high energy consumption due to the relatively low energy density for storage of energy on board (because of the additional weight and space and loss of payload).

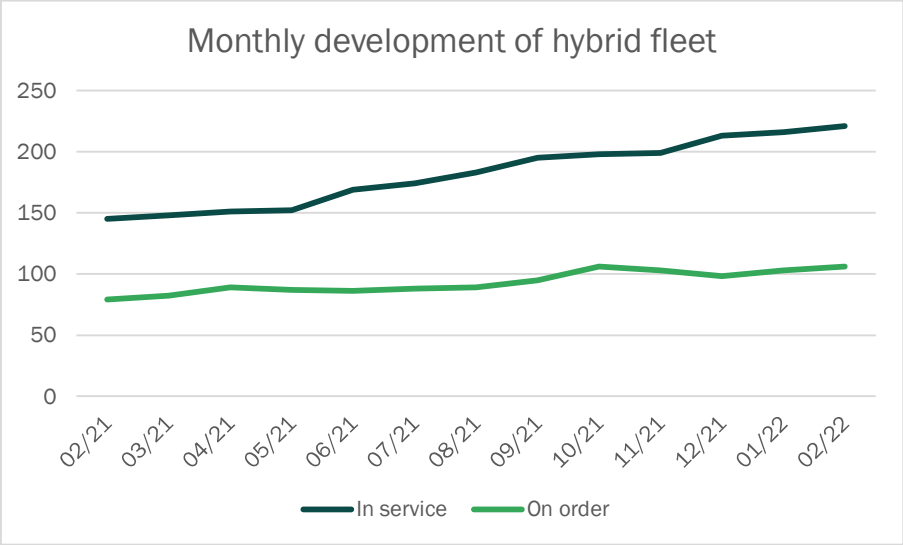

Figure 14: Monthly development of hybrid fleet[32]

As expected, the uptake of hybrid solutions is also rising steadily at a somewhat faster pace than fully electric. The ferry fleet is again the ship type that opts most for a hybrid solution together with the offshore fleet (offshore supply vessels). A rise in order is noticeable for the general cargo fleet. There are also opportunities for further deployment in IWT by the application of swappable battery containers, such as the EU-funded CURRENT DIRECT project and as applied already by ZES for a Dutch container inland barge. Earlier (September 2021), the first electric inland shipping vessel (Alphenaar) in the Netherlands sailed its maiden voyage with these swappable batteries and is now used for a daily container shuttle service between Alphen aan den Rijn and Moerdijk.

[32] Clarksons database (24/02/2022)

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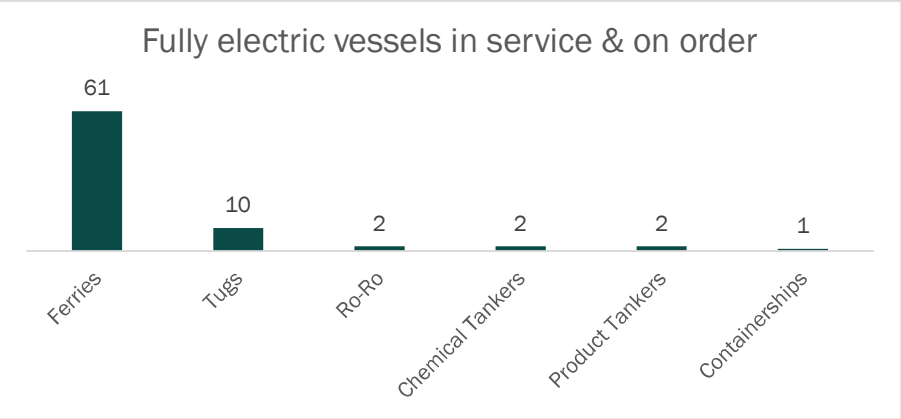

Figure 15: Fully electric vessels in service & on order[33]

The full electric option should be as much as possible developed and deployed for vessels that have the possibility to recharge frequently (short distances and/or fixed timetables). With increased technological performances in particular for the batteries and drivetrains, fully electric can also become a good option for some IWT segments on short term and on longer term depending on the land side infrastructure. Given the foreseen developments for both fully-electric and sustainable alternative fuels, the hybrid option should be avoided as a principle by these ship categories, though the ultimate decision needs to rest on an in-depth analysis of the operational necessities for that ship and the available power/fuel sources in the region. No figure was added for the different fleet types that opt for hybrid because in principle all fleet types can opt for it.

KEY ACTIONS IDENTIFIED

Theme	Key actions
T	Developing more DC components to improve efficiency.
T	Research needed to bring down the volumetric and gravimetric density of battery technology for storage onboard to make it modular and standardised and competitive with conventional fossil diesel. This could result in other types of hydrogen carriers and convertors and new types of electricity storage technology than the ones used today.
T	Demonstration of the battery design life.
R	Urgent need to set a frequency standard. The standard in the US is set at 60Hz (for deep-sea vessels) so it is highly recommended to adopt this standard internationally.
R	Regulate standards regarding the interface and procedure for plugging in modular energy containers on vessel as well as loading /refueling docks.
R	Regulate standards regarding connectors.
R	Revision of requirements with regards to endurance depending on operational area.
R	There should be sufficient consideration and safety measures in place to avoid any risk of waterborne battery fire.

[33] Clarksons' database (24/02/2022)

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4. Intervention area 3: Energy efficiency

Introduction to the intervention area

This intervention area concerns the development of ships requiring less power for operation thanks to power efficient solutions, the exploitation of renewable systems such as wind assisted navigation and the reconfiguration of (part of) the ship's architecture. The energy efficiency intervention area is key since it will lead to a reduction in fuel consumption, a very desired capability knowing the relatively low volumetric energy densities of the sustainable alternative fuels.

One of the main pitfalls here is a lack of data regarding the benefits of the energy saving technologies. Shipowners and/or developers are not always able or willing to share certain data which makes it more difficult to e.g. calculate estimates regarding possible fuel consumption reduction. It is also not clear what happens when different solutions are being combined and what the effect is on optimal engine load when for example using wind assisted propulsion systems. To get the most out of the systems, they will need to be integrated and the most ideal way to do this is on new builds.

The focus within this intervention area was put on wind-assisted propulsion systems since many technologies exist under this category but need to be demonstrated on different vessel types and operating profiles.

Before addressing individual energy efficiency measures, following key actions were defined that apply to all of them.

Theme	Key actions
T	Development of advanced energy management systems that can determine the optimal use & storage of energy for different systems onboard.
T	Investigate which E.E. measures (technical and operational) are most interesting to combine (move away from a siloed approach). For example, WAPS can reach higher potential in combination with speed reduction.
R	**Frequently update legal annexes that describe energy saving technologies (ex. Fuel EU Maritime, EU Taxonomy).**
B	Setting up an online knowledge platform where a clear overview can be found of different energy efficiency measures including the parameters that determine CO2 reduction potential, the maturity level and which vessel or operating profile would be the best fit. Dissemination and communication of objective information in a transparent way to market players such as vessel owners is needed to inform them about the possibilities for energy efficiency measures and their application for specific types of vessels and sailing profiles. This is needed to be able to convince them about the usefulness and necessity of these measures.

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Additionally, one **consolidated** action was identified that will be used for the SWOT exercise..

Area	Consolidated actions
EEF1	Identification and (further) development of the most promising and future-proof energy efficiency measures, taking into account the waterborne transport segments. The energy efficiency measures need to fit with innovations in the field of sustainable alternative fuels and electrification and support the transition towards zero-emission, including for the existing fleet.

Wind-assisted propulsion systems (WAPS)

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

Fleet Type	In service	On order	Type
RoRo	4	1	3x Flettner 1x Kite 1x Rigid Sail
MPP	3	0	1x Flettner 2x Turbosail
General Cargo	2	7	9x Turbosail
Bulkers	2	2	2x Flettner 1x Rigid Sail 1x Kite
Product Tankers	1	0	1x Flettner
Ferries	3	0	2x Flettner
Crude Tankers	1	1	2x Rigid Sail
LPG	0	2	2x Flettner

Figure 16: Vessels in service & on order with WAPS per fleet type

Most of the vessels presently equipped with wind-assisted propulsion systems (WAPS) are part of an EU-funded project. The uptake of the technology is rather slow since (1) **it's not easy to compare the existing solutions and to estimate the reduction potential of the technology since this will depend on several factors such as the type of vessel and the route where the vessel will be sailing** (which is for most maritime vessels also not fixed). Additionally (2), at current fuel prices the return of investment (ROI) is rather low.

In order to (fully) benefit from the extra power that is generated by the WAPS, a system integration is required so that the engine does not run sub-optimally. Working with supercapacitors or multiple main engines instead of one could be an option. Replacing a single 2-stroke main engine with multiple smaller medium speed engines can be done at similar or even lower CAPEX whilst bringing benefits in operational flexibility and vessel utility since smaller engines mean more cargo space.

WAPS are most suited for (1) slower sailing vessels (2) with free deck-space (3) that sail on windier routes. Due to the different parameters that impact the efficiency gains of installing WAPS, **benefits**

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should be investigated on a case-by-case basis. Another factor that should be taken into account is the robustness of the systems since some vessels might encounter sandstorms in certain regions or harm the systems during loading & unloading (e.g. ore carriers).

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Development of a **plug-and-play system** so that it's easier to swap between solutions.
T	Investigate the optimal shipping routes that could benefit from WAPS. It might be commercially interesting to provide system leases on these routes.
T	Investigate how excess wind energy can be used. For example, recharging onboard battery system or generation of e-fuels.
T	Development of digital tools that quantify the value of the wind on any ship and any route.
T	Update weather routing software to optimize wind solutions installed on the vessel.
T	Investigate means to cope with the fluctuating energy supply to avoid unfavourable loading and allow for less installed power for propulsion.
T	Demonstrate a range of wind solutions to get an idea of which solution produces the most power.
T	Create generally agreed methods to restore radar and line of sight in wind solutions.
R	Review regulations based on an **energy centric approach** instead of fuel centric. Wind should be seen as an energy source and not as an energy efficiency measure.
R	Ensure that sea trials with wind solutions are executed with windy conditions.
R	Make all energy efficiency solutions eligible for green finance. The EU Taxonomy for example currently only classify E.E. technologies as green when they lower the fuel consumption by at least 10%.
R	Develop efficiency label/index (EEDI/EEXI) for smaller vessels.
R/B	Adjustments of charter parties to allow wind-routing and allow speed changes to maximise the wind component.
B	Educate ship owners and operators on the value of wind as a short-term emission reduction solution and the impact on metrics such as EEDI.

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Air-lubrication systems

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

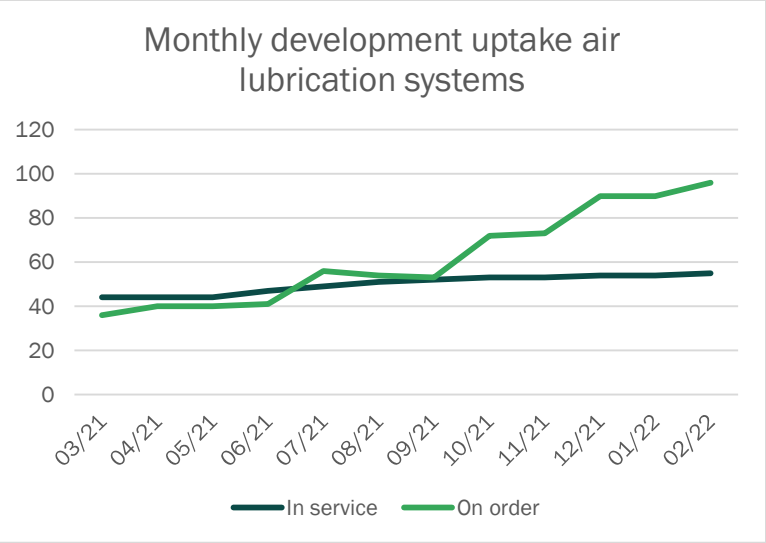

Figure 17: Monthly development uptake air lubrication systems[34]

A steady increase in the orderbook is noticeable, especially amongst the LNG fleet. The interest for this technology presently covers 9 different fleet types which is surprising since **the technology works best on flat-bottomed, slower sailing vessels**. System providers claim to be able to achieve up to 10% fuel reduction on the main engine. The reduction potential for crude and product tankers, and bulk vessels has been assessed at 7% to 10%, while for other ship segments at 3% to 5%.[35] The technology is marginally applied on inland waterway transport vessels.

[34] Clarksons' database (24/02/2022)
[35] GloMEEP: Air Cavity Lubrication

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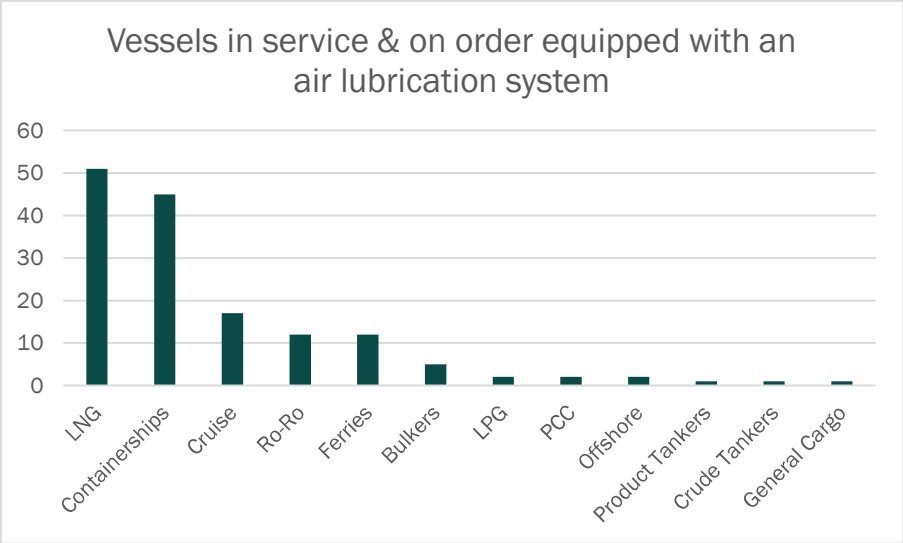

Figure 18: Vessels in service & on order equipped with an air lubrication system[36]

As mentioned above, the technology works best on flat-bottomed, slower sailing vessels. But when looking at the graph based on data from Clarkson's, surprisingly the (fully cellular) container fleet is also applying this technology.

[36] Clarksons' database (24/02/2022)

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Waste-heat recovery systems

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

The uptake of waste heat recovery systems is still rather limited: 43 vessels in service are equipped with the technology and another 20 vessels are on order. Despite the low uptake, there is a wide variety in the vessel types that choose this technology. The reduction potential is estimated at 3% to 8% of main engine fuel consumption.[37]

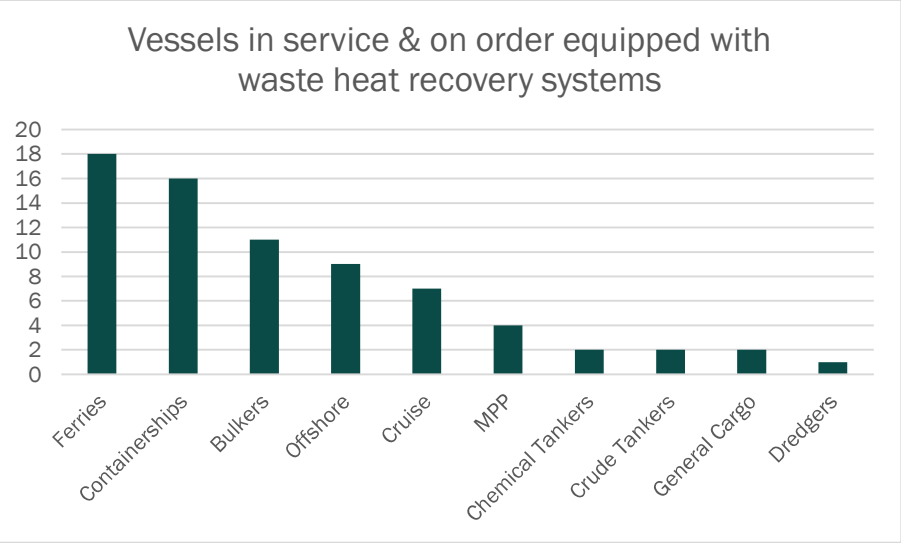

Figure 19: Vessels in service & on order equipped with waste heat recovery systems[38]

[37] https://glomeep.imo.org/technology/waste-heat-recovery-systems/
[38] Clarksons database (24/02/2022)

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

5. Intervention area 4: Design & retrofitting

Introduction to the intervention area

This intervention area covers new propulsion systems with other safety needs, new fuel storage systems taking into account the likely lower energy density linked to the new fuels, new energy efficient technologies that require revised energy management systems and investigations of effects on the engine load. All these technological evolutions require the re-thinking of the vessel design and drivetrains. Even though most sustainable alternative fuels are not yet available, taking into account the average lifetime of a vessel, **vessels need to be designed in a way that a retrofit is relatively feasible once the new sustainable alternative fuels and technologies are available**. Simulators will have a more and more important role to analyse the best fit between a certain vessel type and operational profile on the one hand and the ideal vessel design on the other hand. Additionally, it needs to be considered that every **non-standard vessel comes with additional purchasing costs so shipowners need to find a way to cooperate in order to realize economies of scale**.

Before addressing individual design and retrofitting measures, the following key actions were defined that apply to all of them.

Theme	Key actions
T	Development and implementation of new vessel designs that support multi-fuel engines.
T	Development and implementation of new vessel designs (aerodynamics) that support wind-assisted propulsion solutions.
T	Development and implementation of new vessel designs that support the variable energy supply from wind-assisted propulsion solutions.
T	Investigate the benefits of using multiple main engines to optimize engine load distribution and increasing energy management flexibility.
T	Investigate the possibility of using H2-ICE or MeOH-ICE as auxiliary engines in larger vessels.
T	Further investigate the integration of lightweight materials in the vessel design and building.
T	Further improvement of simulation tools to faster evaluate new vessel designs.
T	Investigate whether an electric drivetrain is the future best solution to guarantee flexibility when working with different energy sources.
T	Design compact exhaust cleaning systems.

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T	Optimize design for real operating conditions instead of mainly one load case and one speed.
T	Investigate how a ship design can be improved to deal with the impact of operating at different engine loads.
R	Set industry standards for different components to increase modularity of solutions.
R	Adaptation of technical and safety policies for application of new materials for ship design, modular ship designs, manufacturing with alternative processes.
R	Standardization of future proof power management.

Additionally, one **consolidated** action was identified that will be used for the SWOT exercise.

Area	Consolidated actions
DER 1	Improved ship designs and designs for retrofits, specifically related to the developments in the field of sustainable alternative fuels and electrification, covering all waterborne transport segments and hence various vessel types (modular design). Also, new initiatives should be launched by shipyards and technology suppliers to develop and demonstrate new materials and production processes to improve the production and retrofit processes, and work with sustainable materials.

Advanced materials

Developing advanced materials for ship applications will be a critical component of improving future ship performance. New features will be introduced, and multi-functional materials can be created. Amongst others, advanced materials can reduce the weight of the ship and offer a surface that improves hydrodynamic efficiency.

Lloyd's Register's Global Marine Technology Trends 2030 categorizes as advanced:

- Materials Fine-Tuned at Microscale or Nano-scale: the characteristics (strength, toughness, malleability and corrosion resistance) of metals will be enhanced by adjusting their structures;
- Thriving Composite Materials: can offer lightweight, stronger, and tougher materials that do not corrode;
- Bio-Inspired and Bio-Based Materials: to protect the surface from external challenges such as abrasion, fouling or icing;

Theme	Key actions
T	Investigate the life expectancy and performance (durability and degradation) of the new advanced materials.
T	Investigate the connection between different materials.
R	Revise fire-protection requirements.

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6. Intervention area 5: Digital Green

Introduction to the intervention area

This intervention area concerns the broadest use of digitalisation to improve efficiency and reduce emissions through making devices smart and connected. As defined in the *Path to the Digital Decade* by the European Commission there needs to be structured and close cooperation in order to boost digital capacities and capabilities around the following four cardinal points throughout the EU economy.[39]

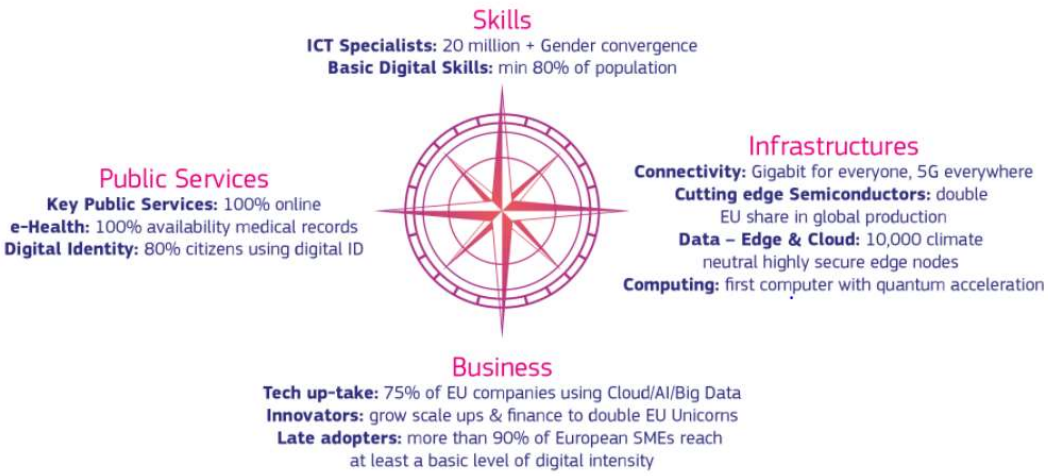

Figure 20: The digital compass

The waterborne transport sector will be dependent on this pathway when it comes to areas such as:

- Pan-European deployment of 5G corridors;
- Secure network of cybersecurity centres;
- High-tech partnerships for digital skills.

Even though digital green is considered a very important intervention area, shipowners are generally investing more in other technologies that have a more direct impact on lowering emissions. Therefore, it might **be better to consider whether the digital green pillar can be integrated in the other pillars as a horizontal pillar instead of a separate intervention area**.

The following key actions were defined that apply to all technologies in this pillar.

[39] EC: A Path to the Digital Decade: common governance and coordinated investment for the EU's digital transformation by 2030 (Factsheet 15/09/2021)

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Theme	Key action
T	Standardisation of data interfaces to facilitate modularity.
T	Setting up of waterborne transport demonstrator projects: many technologies are mature but need to be tested and further tailored for vessels.
R	Use computational fluid dynamics to approve technologies. This would be an enabler to move faster because a real world demo would no longer be needed.
R	Develop standards for modules to plug in to the digital twin.
R	Setting up of data sharing standards.
R	Investigate the increased risk related to cyber security taking into account the new fuels.
B	Data privacy and automatization issues are to be further clarified and harmonised.
B	Educate stakeholders on the advantages of solutions.

Digital twin

The **digital twin** topic has been discussed during the 3rd GSEG workshop in January 2022 where the main feedback was that digital twin is a means and not an end goal. There is a lot of mature technology in place within this intervention area but **one of the biggest hurdles is the standardization of modules**. Because standardization is a more general key action that can apply to all technologies that fall under digital green, the digital twin will not be described separately.

Automation

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

When looking at technologies such as those enabling autonomous operations, not only the technologies installed on the vessel itself but the entire system of interest should be taken into consideration: the vessel – the connectivity solution – and the remote operation centre. Each system of interest knows different technology providers and challenges that now need to work together on one integrated solution.

Figure 21: System of Interest[40]

[40] Kongsberg: MASS session 27 January 2022

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IMO defines the following four degrees of automation:

1. crewed ship with automated processes and decision support;
2. remotely controlled ship with seafarers on board;
3. remotely controlled ship without seafarers on board;
4. fully autonomous ship.

Kongsberg even went further in the classification of autonomy vs. manning taking into account the markets (vessel types) and expected timeframe.

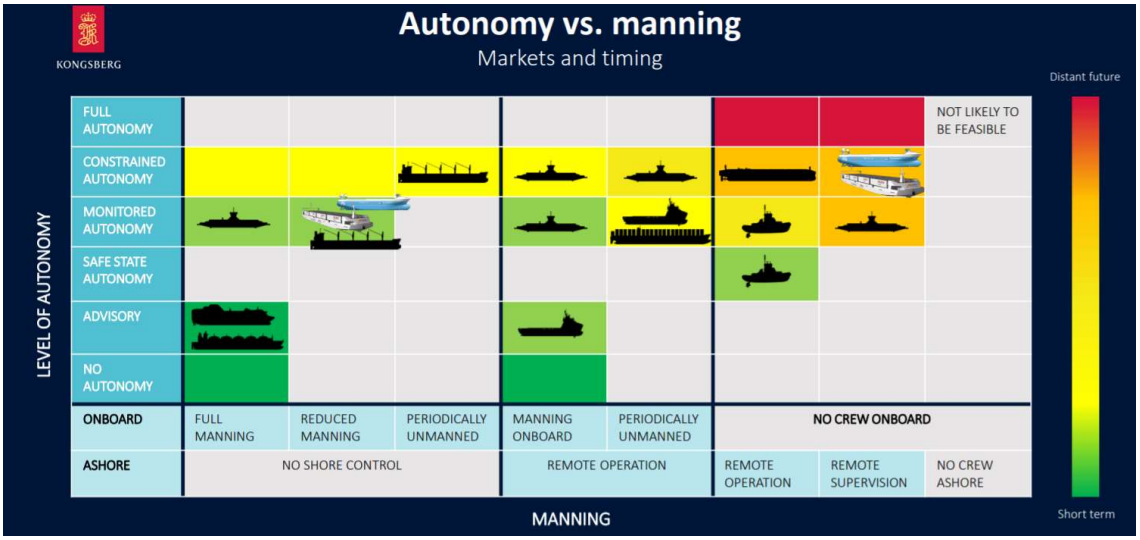

Figure 22: Levels of autonomy by Kongsberg[41]

Several inland/estuary vessels are already controlled remotely with seafarers onboard in Belgium, the Netherlands and Norway (degree 2). Through the use of sensors, AI is also already being applied for the detection and identification of objects (situational awareness), which is needed to further evolve to degree 3. Other EU-funded projects such as MOSES look at more complex operations such as AI controlled tugboats to automate mooring and docking of large vessels in order to reduce time spent on manoeuvring, reduce docking time and reduce human error.

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Investigate how connectivity issues can be handled when crossing borders.
T	Investigate how connectivity issues can be handled in area with many users (lock).
T	Investigate the best means for ship to shore communications in open sea.
R	Development of industry standards.

[41] Kongsberg: MASS session 27 January 2022

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

R	Class guidelines/ES-TRIN are/is yet lacking for the application of highly automated/autonomous sailing.
B	Cyber security risk.

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7. Intervention area 6: Ports

Introduction to the intervention area

The ports intervention area is closely linked to the sustainable alternative fuels & electrification intervention areas, since ports will be enablers by providing the necessary infrastructure to make the green transition possible.

Additionally, frameworks such as the "First movers in shipping's decarbonisation", published by Lloyd's Register (9 December 2021) will be key. The framework provides a methodology for detailed comparison of different fuel transition pathways for a shipping fleet of a given vessel type **and trade route**. This framework can help states that signed the Clydebank Declaration – an initiative that intents to support the establishment of zero-emission shipping routes between two ports with their assessment in choosing for the most suitable sustainable fuels for their ports at competitive prices.

Before addressing individual port measures, the following key actions were defined that apply to all of them.

Theme	Key action
T	Research is needed to cost-effective, widely applicable and standardised bunkering/charging solutions, considering various potential bunkering/charging locations in different ports and the different types of vessels.
R	Harmonised guidelines and permit procedures for building bunkering facilities for sustainable alternative fuels, charging and OPS connections, as well as payment models.
R	The development of bunkering infrastructure needs to be stimulated, especially along key nodes in perhaps smaller ports with less financial capacity for investments.

Additionally, one **consolidated** action was identified that will be used for the SWOT exercise.

Area	Consolidated actions
Ports	Initiatives are needed that focus on the development of cost-effective, high TRL and standardised bunkering and charging concepts, taking into account the various vessels in the different waterborne transport segments and the various geographical locations.

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Sustainable alternative fuels availability/infrastructure

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

In order to achieve zero-emission waterborne transport, a steady and safe supply of sustainable alternative fuels is crucial. Below information is retrieved from DNV's Alternative Fuel Insight (AFI) Portal: https://afi.dnv.com/Map .

LNG

For many shipping routes, sufficient and adequate LNG bunkering infrastructure is now finally in place.

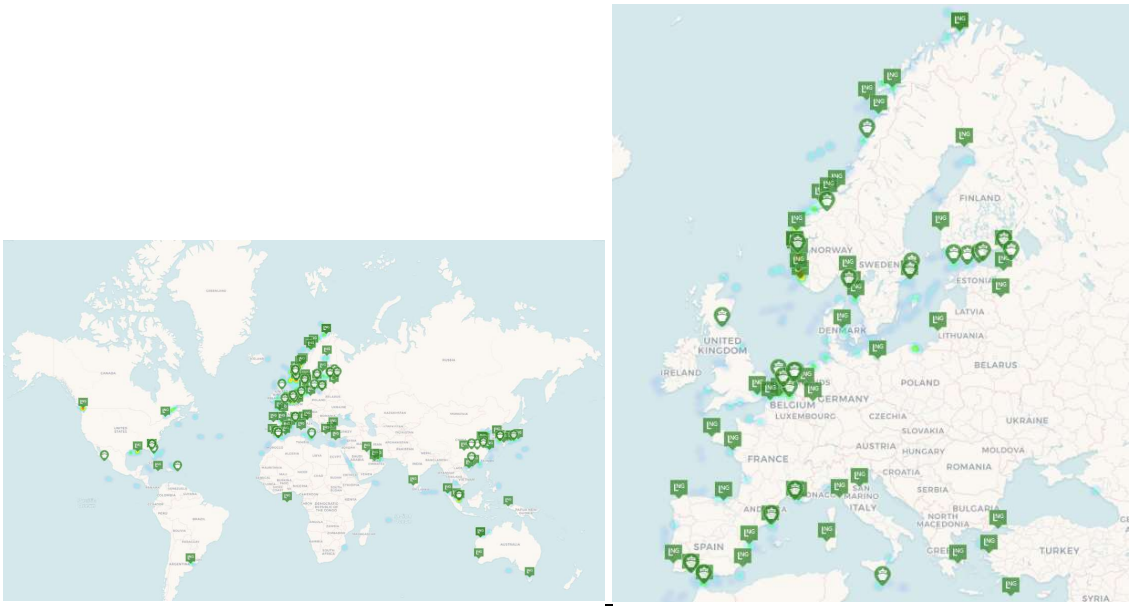

Figure 23: LNG Infrastructure in operation worldwide & in Europe by DNV GL[42]

Bunkering infrastructure	In operation	Decided	Under decision	Total
Bunker vessels	36	26	16	78
Truck loading	57	13	11	81
Bunker vessel loading	24	11	5	40
Local storage	70	27	33	130
Tank-to-ship	40	16	19	75
Other bunkering	4	6	7	17

[42] DNV AFI (06/02/2022):

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Hydrogen

Although the AFI portal shows that there is currently (06/02/22) no hydrogen bunkering infrastructure, CMB.Tech opened the world's first multimodal hydrogen refuelling station in June 2021. It is the first refuelling station in the world that produces green hydrogen, which will be used to power ships, tube trailers, cars, trucks and buses.[43]

Bunkering related challenges:

- There is no standardized connection on the vessel-side to bunker hydrogen;
- Due to the difference in pressures in onboard storage tanks (higher) and the pressure at which compressed hydrogen is supplied (lower), a compressor is needed;
- Bunkering takes a lot of time and is currently not allowed during loading and unloading of cargo;
- Swappable containers ("skits") with compressed hydrogen are expensive ($300-400k);
- Supply of liquid hydrogen is currently almost non-existent.

Pillsbury has launched the only public resource tracking the development of hydrogen projects worldwide: www.TheHydrogenMap.com. The below map gives an indicator of operational projects.

Figure 25: Development of hydrogen projects worldwide by Pillsbury

[43] CMB.Tech: CMB.TECH opens world's first multimodal hydrogen refuelling station and presents the hydrogen truck (03/06/2021)

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LPG

The portal shows the extensive network of LPG import and export terminals in Europe. It is relatively easy to develop bunkering infrastructure at existing LPG storage locations or terminals by simply adding distribution installations. Distribution to ships can occur either from dedicated facilities or from special bunker vessels. Production has been increasing by approximately 2% annually over the last decade. It is expected that at the current production level, the demand for shipping can be safely covered until 2030, provided that demand for LPG as ship fuel will grow slowly initially and remain at a moderate level.

Methanol

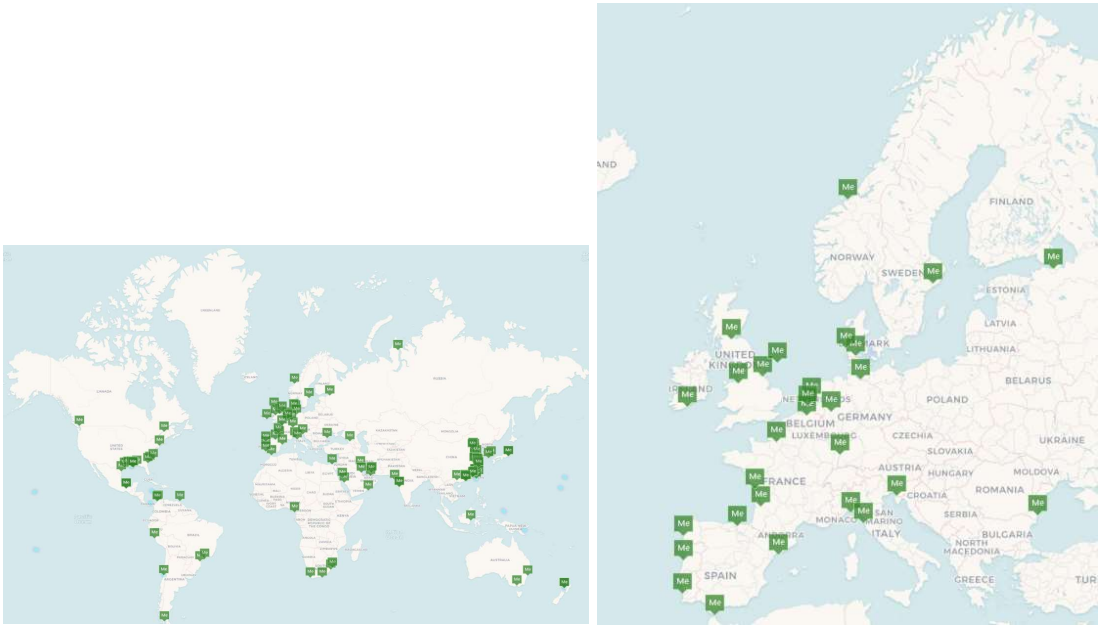

Figure 26: Methanol Infrastructure in operation worldwide & in Europe by DNV GL[44]

According to the AFI portal methanol currently counts 117 local storage facilities. On a general basis it is expected that all methanol terminals can be used as a reload terminal for a methanol bunker vessel or barge, with no or very limited modifications to the terminal. Methanol terminals are commonly also equipped with a truck loading facility for further distribution by road. The actual availability of such breakbulk services has not been validated by DNV GL specifically for each terminal. The feasibility of direct bunkering of methanol-fuelled ship at the terminals is less certain and must be assessed on a case-by-case basis.

Methanol produced from biological feedstocks or synthetic methanol produced with renewable energy is called “green methanol” and is considered as a carbon-neutral fuel. When the carbon as

[44] DNV AFI (06/02/2022)

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part of the methanol is captured by direct air capturing (DAC) or from bio-sources before its energy conversion in an internal combustion engine, the CO_2 balance is equal. On the other hand, the carbon element in methanol is responsible for a comparatively high energy density. In addition, methanol can be stored in ambient temperatures. As a result, onboard storage of methanol can use the existing tank infrastructure[1] and requires a comparatively small tank volume. The production volumes and availability of renewable and bio-methanol is growing over the last years. The International Renewable Energy Agency (IRENA) and the Methanol Institute projects that world demand for methanol may increase fivefold, to 500 million tonnes by 2050 with more than 80% from renewable sources. [45]

An overview provided by the Methanol Institute can be found of ongoing and planned Renewable (green) & Bio-methanol (orange) projects worldwide:

Figure 27: Ongoing and planned methanol projects worldwide by Methanol Institute

Biofuels

Even though global production data indicate that 32 million tonnes of biodiesel and 170 million tonnes of straight vegetable oil (SVO) are produced per year, the availability of these fuels for the maritime sector is very limited. The most promising biofuels for ships are biodiesel (HVO, BTL, FAME) and liquefied biogas. Biodiesel is most suitable for replacing MDO/MGO, Liquefied Bio Gas (LBG) is the best replacement of fossil LNG, and SVO can substitute HFO. HVO, whilst a very high-quality fuel, is quite expensive. Other options can/will come in at lower costs and may in many cases be of sufficient quality to be used on maritime applications. Storage needs to take into account "blendability", microbial growth (leading to filter clogging and all kinds of other issues).

[45] IRENA (International Renewable Energy Agency) and Methanol Institute. 2021. Innovation Outlook: Renewable Methanol. Report produced in partnership with the Methanol Institute.

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Quality/composition variation form batch to batch is also a big issue, especially for the lower quality biofuels. Existing infrastructure can be used.

Ammonia

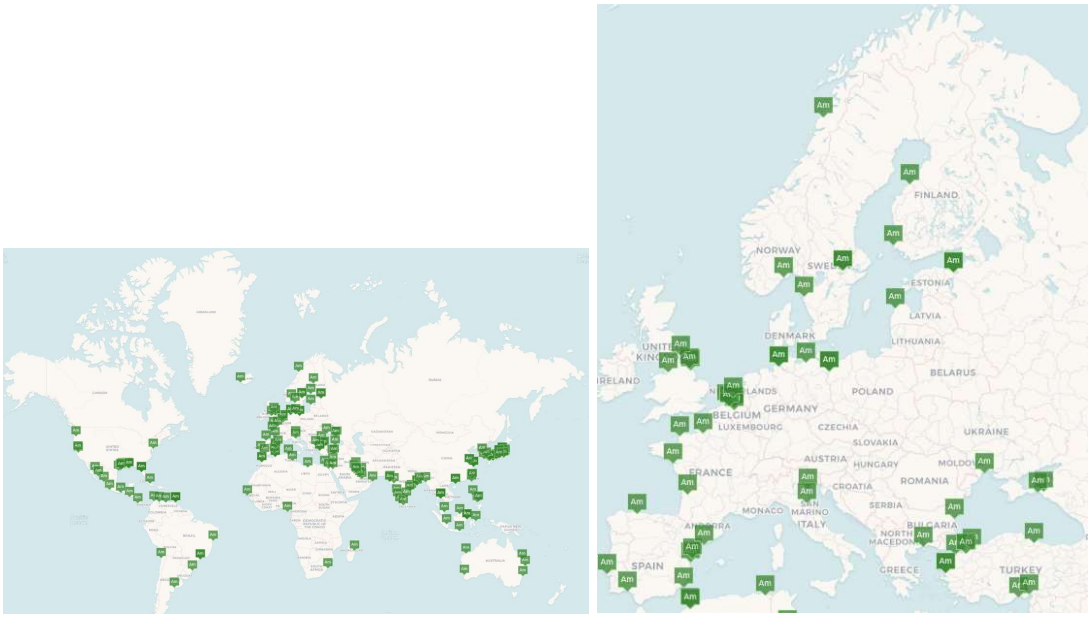

Figure 28: Ammonia Infrastructure in operation worldwide & in Europe by DNV GL[46]

According to the AFI portal, ammonia currently counts 196 local storage facilities. On a general basis it is expected that all ammonia terminals could be used as a reload terminal for an ammonia bunker vessel or barge, with no or limited modifications to the terminal. Breakbulk services may be available, but this has not been validated by DNV GL specifically for each terminal. The feasibility of direct bunkering of ammonia fuelled ships at the terminals is less certain and must be assessed on a case by case basis.

As the alternative fuels may require more complex storage and transfer facilities than for conventional fuels (particularly for those that are stored at high pressures and/or low temperatures, such as hydrogen and ammonia), the additional facilities may have significantly higher costs. The figure below gives an overview of estimated CAPEX and OPEX related to the bunkering infrastructure of the sustainable alternative fuels[47]:

[46] DNV AFI (06/02/2022)
[47] Ricardo Energy & Environment: Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050, p.95

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Fuel type	Bunker capacity (tonnes/annum)	Port facility lifetime (years)	CAPEX ($ million)	OPEX ($ million per year)	Source
HFO	1,000,000	30	10.00	0.50	No detailed data found. Estimated value to provide some balancing cost reductions.
MDO	1,000,000	30	10.00	0.50	Assumed same as HFO
LNG	1,935,000	30	53.27	5.03	LNG bunkering financing opportunities (Ocean Shipping Consultants, 2016[59])
BioLNG	1,935,000	30	53.27	5.03	Assumed same as LNG
Hydrogen	255.5	30	23.00	0.92	Feasibility of hydrogen bunkering (ITM Power, 2019[60])
Ammonia	255,500	20	41.00	1.33	A blueprint for commercial-scale zero-emission shipping pilots (Energy Transitions Commission, 2020[61])
Methanol	255,500	20	8.00	0.17	Same source as Ammonia
FAME	1,000,000	30	10.00	0.50	Assumed same as HFO
HVO	1,000,000	30	10.00	0.50	Assumed same as HFO

Figure 29: Assumed costs for refuelling infrastructure for alternative fuels[48]

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Demonstrator projects on bunkering sustainable alternative fuels at major ports.
T	Monitoring and sampling methods for fuel contamination in port.
T	Development of high durability bunker fuel pipes.
T	Demonstrator projects on bunkering at sea.
T	Availability of swappable battery containers.
T	Further development of fast charging infrastructure.
R	Development of a roadmap that sets energy and alternative fuels supply targets for ports.
R	Development of standardized connectors.

[48] Ricardo Energy & Environment: Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050, p.95

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R	Setting up of green corridors (engagement between 2 ports) and engaging in long term supply contracts with fuel suppliers.
R	Re-evaluate the safety risk for bunkering during loading and unloading. Bunkering of sustainable alternative fuels might take longer in some cases (e.g. hydrogen) and due to the energy density of some of the fuels, bunkering frequency will increase.
B	Identification of strategic bunkering hub locations in order to satisfy the need of more frequent bunkering due to lower energy densities.
B	Setting up of long-term fuel supply contracts to make it possible for fuel suppliers to invest.

Onshore Power Supply (OPS)

PRELIMINARY CONCLUSIONS STATE-OF-PLAY

Vessels equipped with a high-voltage shore connection

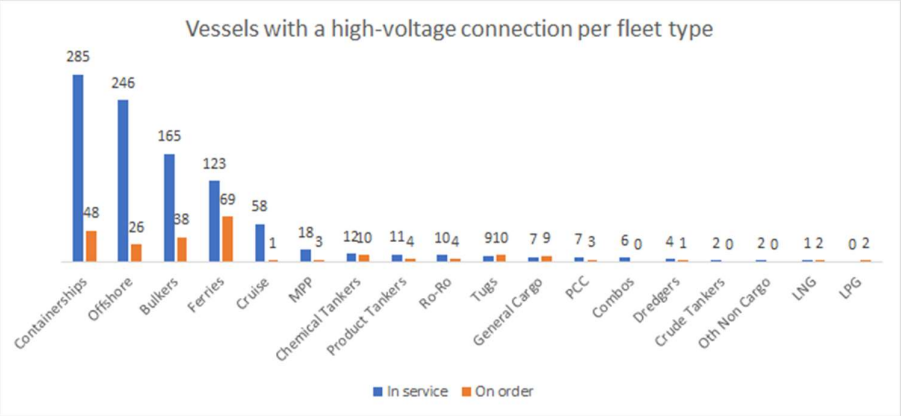

Figure 30: Vessels with high-voltage connection per fleet type[49]

The number of vessels with a high-voltage shore connection (HVSC) is rather low. The biggest uptake can be seen in the container, offshore, bulker and ferry fleet. Currently only 66 ports, scattered over 16 countries, are equipped with high voltage OPS systems for ocean going vessels, but without full coverage. This amounts to 150 berths equipped with the necessary infrastructure. Most of these OPS installations are intended to be used by cruise and RORO vessels. A few exceptions can be found in China and the US, where the Port of Long Beach made the use of OPS mandatory for container vessels. The aforementioned numbers do not include the low voltage OPS systems for inland navigation, of which there are a multitude. The port infrastructure is

[49] Clarksons database (29/11/2021)

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characterized by a high capital cost. Because of that, all OPS projects finished to date are made possible only by public support.[50]

Even though uptake is still rather low, in 2021 there was an increase of more than 51% amongst the vessels in service and a 213% increase for the vessels on order. This increase is expected to grow even more rapidly in the container and passenger fleets in the coming years following the Fuel EU Maritime proposal under the Fit-for-55 package, which makes it mandatory for these fleet types to connect to OPS as from 2035.

Ports equipped with shore power infrastructure

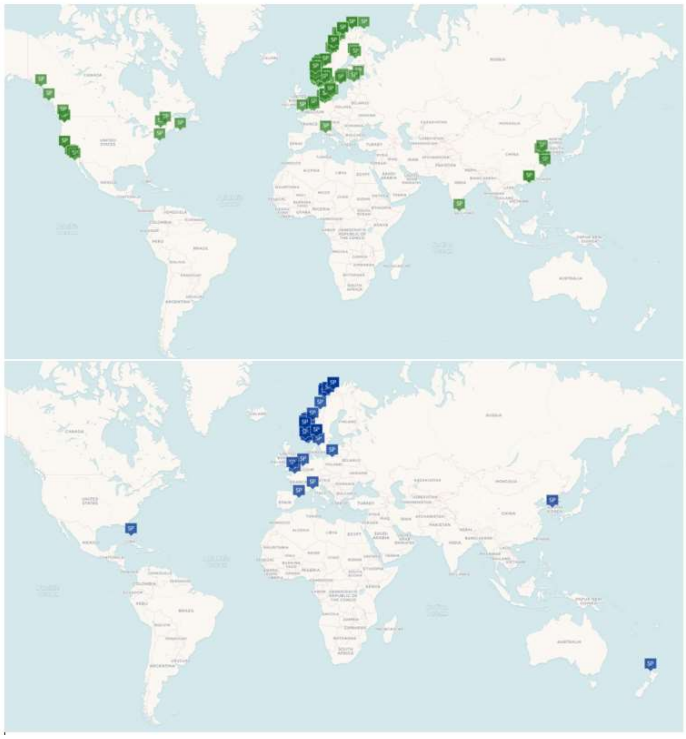

Figure 31: Visualization of shore power infrastructure worldwide (upper = in operation, lower = decided)[51]

Shore power infrastructure	In operation	Decided	Under decision	Total
High Voltage – 50 Hz	32	17	4	53
High Voltage – 60 Hz	39	18	4	61
Low Voltage – 50 Hz	73	31	0	104
Low Voltage – 60 Hz	66	25	0	91

[50] World Ports Sustainability Program 2020
[51] DNV AFI (02/12/2021)

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*Figure 32: Visualization of shore power infrastructure **in operation** in Europe (left = low voltage, right = high voltage)* [52]

KEY ACTIONS IDENTIFIED

Theme	Key action
T	Standardized components on vessel side (length of cables).
T	Connection process (can take up to 3 hours): can the process be automated to decrease time and human error.
T	Buffer impact on the grid: vessels have different average peak and power demand.
T	Connection points need to be flexible in case vessels have variable mooring points.
T	Possibility to connect multiple vessels to one installation in order to cut costs.
T	Mobile solutions (barges).
T	Development of specific compressors to fasten bunkering.
R	The number of connection points needs to be increased.
R	Uptake can further be promoted by making OPS cheaper than conventional fuels.
R	It needs to be assured that the energy taken from the grid is cleaner than the conventional fuels.
R	Allow more space within delivery schedules for additional bunkering.
R	Standardization of ship-to-shore interfaces based on current industry standards.
R	Standardization of ship-to-ship interfaces based on current industry standards.
R	Development of standards & procedures for bunkering at sea and bunkering at seaports and inland ports as well as ship-to-ship bunkering.

[52] DNV AFI (02/12/2021

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R	Urgent need to set a frequency standard. The standard in the US is set at 60Hz (for deep-sea vessels) so it is highly recommended to adopt this standard internationally.

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8. Conclusions

Linking a ship type to a sustainable alternative fuel or an energy saving technology is not a straightforward exercise since multiple parameters have to be taken into account such as the possibility to bunker frequently, the energy demand of the vessel, its operational profile (liner versus tramp) and trading routes, etc. Therefore, no further detailed suggestions will be made in this sense for the maritime transport segments apart the more general ones that have already been mentioned in the body of the text, for several of the technologies and intervention areas. For inland waterway transport, the *Study on Financing the Energy Transition towards a zero-emission European IWT Sector* made an assessment on fuels and techniques per fleet family based on an Innovative Pathway in 2035 which resulted in the figure below:

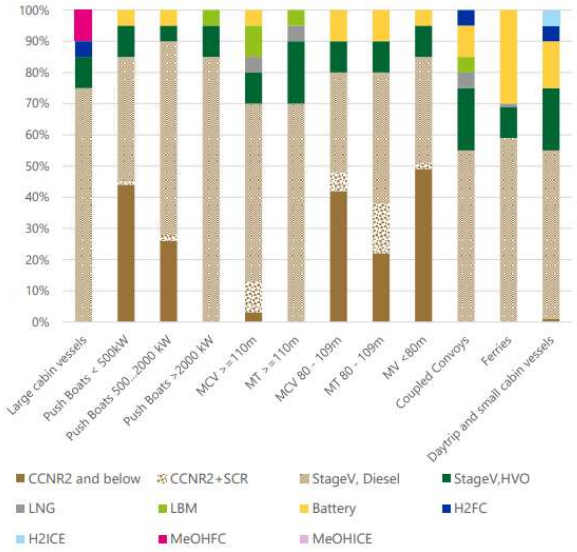

Figure 33: fuels and techniques per fleet family based on an Innovative Pathway in 2035

Even though the focus of this deliverable lies on key actions related to technology, it is important to stress that the rate of the uptake of these new technologies and sustainable alternative fuels will heavily depend on policies/regulations in place. It is expected that an **international price on carbon** will push the uptake of energy saving technologies and sustainable alternative fuels. To further accelerate the uptake of the sustainable fuels, mechanisms such as **carbon contracts for difference** (CCfDs) that bridge the price gap between the conventional and sustainable alternative fuels are needed.

Based on the maturity of the different technologies related to sustainable alternative fuels/electrification and their availability, following conclusions have been made:

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Short term (now-2030):

1. Further electrification (fully electric/hybrid) of the waterborne transport fleet should be the main focus on short term due the high energy efficiency of the solution as there is hardly any loss of energy (5-10% compared to 50-60% of energy thermal loss for internal combustion engines and fuel cells). **Therefore, a priority should be put on setting frequency standards and further advance technologies related to electrification of vessels.**
2. Promote the uptake of methanol related technologies such as the FASTWATER retrofit kit. **Current levels of bio-/e-methanol supply are still low but solutions such as the retrofit kit allow flexibility to upscale when supply increases.** More vessels installing methanol related technologies can reassure the methanol industry to increase production infrastructure. Methanol related technologies have a high-TRL level and bunkering infrastructure is also widely available. For these reasons methanol has an advantage over ammonia and hydrogen as a marine fuel in the short term.
3. There is a need for urgent and strong policy action to **regulate methane emissions** both in the supply chain of LNG and in its use on board existing ships and any newbuilds. Even though LNG is still a fossil fuel, as long as there is not enough renewable energy to supply the waterborne fleet with enough sustainable alternative fuels, LNG will have a role to play. A lock-in of the technology is not expected since vessels with the technology installed can opt for the sustainable variants once available or blend with e-hydrogen to a certain extent.
4. Even though there is not enough renewable electricity currently being produced to generate abundant synthetic fuels, it is still recommended for large ocean going vessels that do not choose for methanol to focus on ammonia and make sure the vessels are designed in a way that an ammonia retrofit is relatively easy once e-ammonia is available.
5. Even though digital green is considered a very important intervention area, shipowners are generally investing more in other technologies that have a more direct impact on lowering emissions. Therefore, it might **be better to see whether the digital green pillar can be integrated in the other pillars as a horizontal pillar instead of a separate intervention area**.

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9. Annexes

Annex 1 : Fuel EU Maritime

PART 3: ILLUSTRATION BY THE COMMISSION OF THE DIFFERENT SOURCES IN ANNEX II

Colour code:

Directive (EU) 2018/2001 in its up to date version
IMO GHG studies (1 to 4) and tech. literature for LNG
Regulation (EU) 2015/757 MRV
ESSF SAPS
5th JEC Study 2020 (values are presented along with a corresponding pathway label. The same study provides values also for other production pathways of the same fuel product).
Miscellanea: technical, literature, self-evident (to be further discussed in ESSF)

In the table:

- TBM stands for To Be Measured
- N/A stands for Not Available
- The dash means not applicable

Table 1 – Default factors

1	2	3	4	5	6	7	8	9
	WtT			TtW				
Class / Feedstock	**Pathway name**	LCV LCV [MJg]MJg	$CO_{2eq\ WtT}$ $CO2eq\ WtT$ [gCO2eqMJ]gCO2eqMJ	**Energy Converter Class**	Cf_{CO_2} $Cf\ CO2$ [gCO2gFuel]gCO2gFuel	Cf_{CH_4} $Cf\ CH4$ [gCH4 gFuel]gCH4 gFuel	Cf_{N_2O} $Cf\ N2O$ [gN2O gFuel]gN2O gFuel	C_{slip} $Cslip$ As % of the mass of the fuel used by the engine
Fossil	HFO ISO 8217 Grades RME to RMK	0,0405	13,5	ALL ICEs	3,114 MEPC245 (66) Regulation (EU) 2015/757	0,00005	0,00018	-
				Gas Turbine				
				Steam Turbines and Boilers				
				Aux Engines				
	LSFO	0,0405	13,2, crude 13,7 blend	ALL ICEs	3,151	0,00005	0,00018	-
				Gas Turbine				

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				Steam Turbines and Boilers				
				Aux Engines				
	ULSFO	0,0405	13,2	ALL ICEs	3,114	0,00005	0,00018	-
	VLSFO	0,041	13,2	ALL ICEs	3,206 MEPC245 (66) MRV Regulation	0,00005	0,00018	-
	LFO ISO 8217 Grades RMA to RMD	0,041	13,2	ALL ICEs	3,151 MEPC245 (66) Regulation (EU) 2015/757	0,00005	0,00018	-
	MDO MGO ISO 8217 Grades DMX to DMB	0,0427	14,4	ALL ICEs	3,206 MEPC245 (66) Regulation (EU) 2015/757	0,00005	0,00018	-
	LNG	0,0491	18,5	LNG Otto (dual fuel medium speed)	2,755 MEPC245 (66) Regulation (EU) 2015/757	0	0,00011	3,1
				LNG Otto (dual fuel slow speed)				1,7
				LNG Diesel (dual fuel slow speed)				0,2
				LBSI				N/A -
	LPG	0,046	7,8	All ICEs	3,03 Buthane 3,00 Propane MEPC245 (66) Regulation (EU) 2015/757	TBM	TBM	-
	H2 (natural gas)	0,12	132 JEC Study GPLHx	Fuel Cells	0	0	-	**N/A**
				ICE	0	0	TBM	
	NH3 (natural gas)	0,0186	121	No engine	0	0	TBM	-
	Methanol (natural gas)	0,0199	31,3	All ICEs	1,375 MEPC245 (66) Regulation (EU) 2015/757	TBM	TBM	-
	Ethanol ~~E100~~	0,0268	**-33.2 Calculated as**	All ICEs	1,913 MEPC245 (66)	TBM	TBM	-

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Liquid biofuels	sugar beet ethanol (no biogas from slop, natural gas as process fuel in conventional boiler)	Ref. to Directive (EU) 2018/2001 Annex III	$E - C_f{}_{CO_2}LCV$ $E - Cf\ C\ O2LCV$ **(E from Directive (EU) 2018/2001 minus (Value Column 6) / (Value Column 3))**		Regulation (EU) 2015/757			
	Bio-diesel ~~Main products / wastes / Feedstock mix~~ rape seed biodiesel	0,0372 Ref. to Directive (EU) 2018/2001 Annex III	**-26.1 Calculated as** $E - C_f{}_{CO_2}LCV$ $E - Cf\ C\ O2LCV$ **(E from Directive (EU) 2018/2001 minus (Value Column 6) / (Value Column 3))**	ALL ICEs	2,834 (calculated)	0,00005 TBM	0,00018 TBM	-
	HVO ~~Main products / wastes / Feedstock mix~~ hydrotreated vegetable oil from rape seed	0,044 Ref. to Directive (EU) 2018/2001 Annex III	**-20.7 Calculated as** $E - C_f{}_{CO_2}LCV$ $E - Cf\ C\ O2LCV$ **(E from Directive (EU) 2018/2001 minus (Value Column 6) / (Value Column 3))**	ALL ICEs	3,115 (calculated)	0,00005	0,00018	-
	Bio-LNG ~~Main products / wastes / Feedstock mix~~ Manure – Maize 60 % - 40 % Case 3 Close digestate (12 to 18)	0,05 Ref. to Directive (EU) 2018/2001 Annex III	**-38.9 Calculated as** $E - C_f{}_{CO_2}LCV$ $E - Cf\ C\ O2LCV$ **(E from Directive (EU) 2018/2001 minus (Value Column 6) / (Value Column 3))**	LNG Otto (dual fuel medium speed)	2,~~75~~5 MEPC245 (66), Regulation (EU) 2015/757	0	0,00011	3,1
				LNG Otto (dual fuel slow speed)				1,7
				LNG Diesel (dual fuels)				0.2
				LBSI				N/A
Gas biofuels	Bio-H2 Main products	0,12	N/A	Fuel Cells	0	0	~~0~~	-

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	/ wastes / Feedstock mix			ICE	0	0	TBM	
Renewable Fuels of non-Biological Origin (RFNBO) - (e-fuels)	e-diesel	0,0427	**0.9** (Ref. to JEC Study RESD1) (footnote)	ALL ICEs	3,206 MEPC245 (66) Regulation (EU) 2015/757	0,00005	0,00018	-
	e-methanol	0,0199	**1.78** (Ref. to JEC Study REME1a) (footnote)	All ICEs	1,375 MEPC245 (66) Regulation (EU) 2015/757	0,00005	0,00018	-
	e-LNG	0,0491	**6.7** (Ref. to JEC Study RELG1a) (footnote)	LNG Otto (dual fuel medium speed)	2,755 MEPC245 (66) Regulation (EU) 2015/757	0	0,00011	3.1
				LNG Otto (dual fuel slow speed)				1,7
				LNG Diesel (dual fuels)				0.2
				LBSI				N/A
	e-H2	0,12	**4.3** (Ref. to JEC Study EMEL1/LH1) (footnote)	Fuel Cells	0	0	~~0~~	-
				ICE	0	0	TBM	
	e-NH3	0,0186	0	No engine	0	N/A	TBM	N/A
	e-LPG	To be done	To be done		To be done	To be done	To be done	-
	E-DME	To be done	To be done		To be done	To be done	To be done	-
Others	Electricity	-	106,3 EU **ENERGY** MIX 2020 72 EU **ENERGY** MIX 2030 JED Study [to be further discussed]	OPS	-	-	-	-

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Annex 2: ESSF SAPS MARIN PORTAL

LNG

	GWP100			GWP20		
Solution name	**WtT**	**TtW**	**WtW**	**WtT**	**TtW**	**WtW**
Diesel (HFO) ICE 2-stroke	110,3	611,1	**721,4**	110,3	611,1	**721,4**
LNG ICE 4-stroke	144,8	573,4	**718,3**	212,3	793,9	**1006,1**
LNG ICE 2-stroke	129,7	529,8	**659,5**	190,1	756,6	**946,7**
LNG (organic waste) ICE 4-stroke	-216,5	464,9	**248,4**	-144,2	496,4	**352,2**
eLNG ICE 4-stroke high speed	-497,1	671,6	**174,6**	-497,1	855,9	**358,9**
eLNG ICE 4-stroke	-389,7	464,9	**75,2**	-389,7	496,4	**106,7**

Methanol

	GWP100			GWP20		
Solution name	**WtT**	**TtW**	**WtW**	**WtT**	**TtW**	**WtW**
Diesel (HFO) ICE 2-stroke	110,3	611,1	**721,4**	110,3	611,1	**721,4**
CH3OH ICE SI 4-stroke	248,1	539,3	**787,4**	314,8	539,3	**854,1**
eCH3OH 65% ICE DF 4-stroke	-168,9	590,8	**421,9**	-168,9	590,8	**421,9**
CH3OH (glycerin) ICE SI 4-stroke	-248	539,3	**291,3**	-248	539,3	**291,3**
CH3OH (black liquor) ICE SI 4-stroke	-256,3	539,3	**283**	-256,3	539,3	**283**
eCH3OH 95% ICE CI 2-stroke	-432,3	549,4	**117,1**	-432,3	549,4	**117,1**
eCH3OH 95% ICE DF 4-stroke	-459,8	576,8	**117**	-459,8	576,8	**117**
eCH3OH (flue gas CO2) LT PEM FC	-631,7	709,7	**77,9**	-631,7	709,7	**77,9**
eCH3OH (flue gas CO2) HT PEM FC	-579,8	651,4	**71,5**	-579,8	651,4	**71,5**
eCH3OH (flue gas CO2) ICE SI 4-stroke	-480,1	539,3	**59,2**	-480,1	539,3	**59,2**
eCH3OH (DAC CO2) ICE SI 4-stroke	-522,6	539,3	**16,7**	-522,6	539,3	**16,7**

Hydrogen

	GWP100			GWP20		
Solution name	**WtT**	**TtW**	**WtW**	**WtT**	**TtW**	**WtW**
Diesel (HFO) ICE 2-stroke	110,3	611,1	**721,4**	110,3	611,1	**721,4**
cH2 (natural gas) LT PEM FC	846,1	0	**846,1**	1254,4	0	**1254,4**
cH2 (natural gas + CCS) LT PEM FC	602	0	**602**	1105,5	0	**1105,5**
ecH2 96% ICE DF 4-stroke	25,2	131,2	**156,4**	25,2	131,2	**156,4**
eLH2 96% ICE DF 4-stroke	21,4	111,2	**132,7**	21,4	111,2	**132,7**
eLH2 LT PEM FC	0	0	**0**	0	0	**0**
ecH2 LT PEM FC	0	0	**0**	0	0	**0**

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Ammonia

	GWP100			GWP20		
Solution name	**WtT**	**TtW**	**WtW**	**WtT**	**TtW**	**WtW**
Diesel (HFO) ICE 2-stroke	110,3	611,1	**721,4**	110,3	611,1	**721,4**
NH3 (natural gas) LT PEMFC	2630,1	0	**2630,1**	2630,1	0	**2630,1**
NH3 95% ICE DF 4-stroke	1286,2	89	**1375,2**	1286,2	89	**1375,2**
NH3 95% ICE CI 2-stroke	1209,3	90,8	**1300**	1209,3	90,8	**1300**
NH3 (natural gas) SOFC	1221,8	0	**1221,8**	1221,8	0	**1221,8**
eNH3 95% ICE CI 2-stroke	17,8	90,8	**108,6**	17,8	90,8	**108,6**
eNH3 95% ICE DF 4-stroke	19	89	**107,9**	19	89	**107,9**
eNH3 LT PEMFC	0	0	**0**	0	0	**0**
eNH3 SOFC	0	0	**0**	0	0	**0**

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