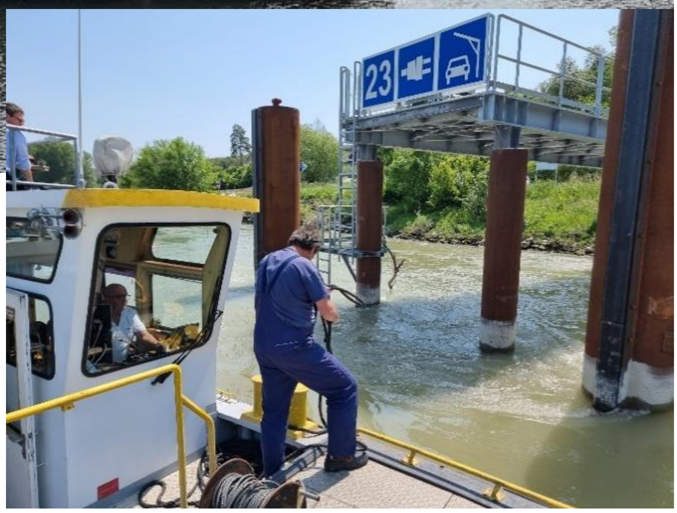
PIANC

The World Association for Waterborne Transport Infrastructure

INFRASTRUCTURE FOR THE DECARBONISATION OF INLAND WATERWAY TRANSPORT



InCom Task Group 234 – August 2023

PIANC REPORT N° 234

INLAND NAVIGATION COMMISSION

INFRASTRUCTURE FOR THE DECARBONISATION OF INLAND WATERWAY TRANSPORT

August 2023

PIANC has Technical Commissions concerned with inland waterways and ports (InCom),coastal and ocean waterways (including ports and harbours) (MarCom), environmental aspects (EnviCom) and sport and pleasure navigation (RecCom).

This report has been produced by an international Task Group convened by the Inland Navigation Commission (InCom). Members of the Task Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendations on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state-of-the-art on this particular subject. PIANC disclaims all responsibility in the event that this report should be presented as an official standard.

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1 GENERAL ASPECTS

1.1 Scope

The availability of zero-emission fuels infrastructure, including onshore electric power supply, will be key to enable greenhouse gas (GHG) zero-emission vessels and increase the competitiveness of IWT as a whole, at a time when other modes of transport are reducing their ecological footprint. To address the challenge of making inland navigation infrastructure sustainable, PIANC Task Group (TG) 234 – 'Infrastructure for the Decarbonisation of Inland Water Transport' was set up in January 2021.

1.2 Introduction

1.2.1 Terms of Reference

The Terms of Reference can be found in Appendix A of this report.

1.2.2 Objective

The objective of the TG is in line with the declaration of PIANC, namely developing approaches to decarbonise the operation of port and navigation infrastructure (i.e. move to GHG zero emissions), whilst at the same time enabling the reduction of greenhouse gas emissions from vessels by providing the necessary facilities, infrastructure and, where appropriate, incentives. For this purpose, TG 234 was tasked to identify knowledge gaps and major challenges that need to be urgently addressed and advise PIANC on further actions. The findings of TG 234 have been written down in this report that has been submitted to InCom. The report serves as a course knowledge base to guide further steps towards a rational approach to developing infrastructure for the decarbonisation of IWT.

1.2.3 Related PIANC Reports

The following PIANC reports are also relevant to the design and operation of navigation channels and fairways:

PIANC TG 3	Climate Change and Navigation – Waterborne Transport, Ports and Waterways: A Review of Climate Change Drivers, Impacts, Responses and Mitigation	2008
PIANC WG 111	Performance Indicators for Inland Waterways Transport User Guideline	2010
PIANC WG 179	Standardisation of Inland Waterways – Proposal for the Revision of the ECMT 1992 Classification	2020
PIANC WG 203	Sustainable Inland Waterways – A Guide for Waterways Managers on Social and Environmental Impacts	2023
PIANC WG 229	Guidelines for Sustainable Performance Indicators for Inland Waterways	In process

1.2.4 Members of the Task Group

A list of members is provided below:

• Mark van Koningsveld (Chair)	TU Delft Port and Waterways/Van Oord
• Gernot Pauli (Co-Chair)	Bundesministerium für Digitales und Verkehr (BMVI)
• Poonam Taneja (Support)	TU Delft Port and Waterways
• Man Jiang (Support)	TU Delft Port and Waterways
• Kai Kempmann	Central Commission for the Navigation of the Rhine (CCNR)
• Baptiste Panhaleux	Cerema
• Ulf Meinel	Viadonau
• Nathaly Tromp Dasburg	Rijkswaterstaat
• Cees Boon	Port of Rotterdam
• Turi Fiorito	European Federation of Inland Ports
• Hyumin Oh	Kanto Gakuin University
• Hugo Lopes	APDL – Port Authority of Douro
• Peng Chuansheng	China Water Transportation Construction Association

1.2.5 Meetings

Six online meetings, two progress reports to InCom, and one keynote address at PIANC-SMART Rivers were held on the following dates:

• 20/01/2022	Kick-off, getting to know each other, agreement on tasks ahead
• 02/02/2022	Progress report to InCom
• 21/04/2021	First collection of documents, identify gaps
• 21/07/2021	Looking for missing documents, discuss basic outline report
• 18/12/2021	Analyse all documents and implement in agreed report outline
• 26/01/2022	Discussion of draft, specification of tasks towards finalisation
• 01/03/2022	Finalisation of draft and preparation PIANC-SMART Rivers contribution
• 28/09/2022	Progress report to InCom
• 19/10/2022	Keynote presentation PIANC-SMART Rivers conference, feedback
• 30/05/2023	Incorporation feedback and submission of final report

1.3 Approach

The steps taken by the TG to identify knowledge gaps and challenges are listed here briefly. As suggested in the Terms of Reference (ToR dated 1 October 2020) and to provide first insights into the decarbonisation of IWT, TG 234 compiled key developments per country/organisation that participated in the TG. Similarly, main developments per energy carrier were also compiled. These compilations or briefing notes form an integral part of the report and are summarised in Chapter 2. Next, attention was given to the questions that an actor striving for decarbonisation would have. A comprehensive list of questions was drawn up in Chapter 3 and an approach was suggested over how to answer them in Chapter 4. A conclusion and a suggested course of action for InCom are provided in Chapter 5.

2 KEY DEVELOPMENTS RELATED TO DECARBONISATION OF IWT

A feasible starting point for the members of TG 234 was to create briefing notes on key developments on zero emission IWT as they observed them in their own countries/ organisations. In the following, short summaries per briefing note are included. Next to the key developments per organisation or country, briefing notes were also made of a number of promising new energy carriers. It is clear that the work done so far is not yet comprehensive at a global scale, but it provides an inspiring first step. Appendix B contains the full briefing notes of the following developments per country/organisation.

2.1 Key Developments per Country or Organisation

2.1.1 Short Report Decarbonisation IWT Europe

In 2019, the European Union presented the European Green Deal with the aim of ensuring that the EU is greenhouse gases (GHG) emission-free by 2050. In July 2021, the European Commission adopted a set of proposals (Fit for 55 package) to make the EU's climate, energy, transport and taxation policies fit for reducing net GHG emissions by at least 55 % by 2030 [European Commission, 2021a]. The initiatives include revision of Alternative Fuels Infrastructure Regulation (AFIR), the Renewable Energy Directive (RED) and the Energy Taxation Directive (ETD) [European Commission, 2021b]. AFIR supports the deployment of alternative fuels infrastructure, including refuelling points for natural gas and hydrogen and shore power. Member States are required to set up national policy frameworks to establish markets for alternative fuels and report their progress. RED deals with the promotion of energy from renewable sources and has set a binding target to produce 40 % of energy from renewable sources by 2030. The ETD aims to ensure the proper functioning of the EU internal market by ensuring that energy taxation is aligned with climate objectives.

2.1.2 Short Report Decarbonisation IWT CCNR

The Central Commission for the Navigation of the Rhine (CCNR) has drawn up a roadmap (CCNR (2022a), adopted on 9 December 2021) to lay the foundation for a common approach to the energy transition and emissions reduction by all stakeholders. This roadmap should be understood as the primary CCNR instrument for climate change mitigation and setting transition pathways for the fleet (new and existing vessels), suggesting, planning, and implementing measures directly adopted or not by the CCNR, and monitoring intermediate and final goals set by the Mannheim Declaration. In 2021, CCNR published the results of in-depth studies over financial instruments to be seen as part of a broad discussion process at Rhine, European and international level [CCNR, 2021a]. It mandated its committees to feed the study results into the PLATINA3 project, desiring an action plan for the further development of a European funding and financing instrument to be drawn up and detailed. CCNR regularly organises workshops on innovative technologies [CCNR, 2021b ; CCNR, 2021c ; CCNR, 2022b]. Besides the roadmap, CCNR also grants deviations from technical rules to allow vessels using alternative fuels to navigate to gain experience.

2.1.3 Short Report Decarbonisation IWT Austria

The current political ambitions to decarbonise IWT in Austria are higher than those on European level. The Mobility Masterplan 2030 and Government Programme 2021-2027 make concrete recommendations while also committing to endeavours such as installing shore power units. Implementation projects prepared by the Austrian waterway company, Viadonau, include the installation of shore power supply for cargo vessels at selected existing and future berths, and implementation plans for cruise vessels are underway. CCNR and Viadonau have set up an international workshop (**https://www.ccr-zkr.org/13020155-en.html**) raising awareness on the need of international harmonisation of technical standards and addressing the issue of billing systems of a future shore power system along the European waterways.

2.1.4 Short Report Decarbonisation IWT France

In order to meet the GHG emissions reduction targets in the transport sector, policies have been set up for the inland navigation sector. The 'Mobility Orientation Act' of 2019 eased the establishment of low emission zones (ZFEs) while the 'National Hydrogen Plan' of 2018 aims at achieving mass-production of green hydrogen as a fuel for mobility. A bill entitled 'Delivery of a Vessel Certificate for a Restricted Navigation', that was introduced in 2019 allowing green vessels to derogate from the EU technical regulations if they operate on a limited journey in an area of local (national) interest, has proven efficient. As a result, the French inland fleet will welcome hydrogen and GNC powered vessels in the coming years.

2.1.5 Short Report Decarbonisation IWT Germany

The Federal Climate Protection Law (Bundes-Klimaschutzgesetz – KSG), amended by the German Federal Parliament in 2021, aims to achieve GreenHouse Gas (GHG) neutrality in Germany by 2045. The Federal Ministry for Digital and Transport (BMDV) will support climate friendly inland navigation with subsidies for decarbonisation and development of inland waterway infrastructure as well as with research and development. It has commissioned work, to be published in 2023, to develop energy efficiency indices for inland navigation together with a proposal for their practical implementation. German IWT companies are already investing in climate-neutral vessels. The report concludes that IWT in Germany has a chance to survive, when it will be innovative and when there will be adequate regulation for GHG emissions from transport, including carbon pricing, that honours the inherent energy efficiency of IWT.

2.1.6 Short Report Decarbonisation IWT Netherlands

The targets for emissions reduction in the Netherlands have been drafted in the Dutch Green Deal on Maritime and Inland Shipping and Ports (2019), signed by various governmental authorities, trade associations, ports, sector representatives and research institutes, each with a list of planned actions. Numerous initiatives have been launched e.g., investing in shore power facilities for around 500 state berths, a national ban on degassing while sailing (to be introduced step by step), examining blending biofuel obligation in inland shipping vessels. The Dutch national government has set up a supporting system for innovations such as fully emission-free powered ships for the inland shipping sector. Funding schemes have been put in place for greening of the Dutch fleet. Another initiative to stimulate the decarbonization of the fleet is a new labelling system for inland vessels' emissions performance. Attention will be given to the necessary bunkering infrastructure and the safety requirements and legal framework to facilitate the introduction of new energy carriers in the inland waterway sector in the coming year.

2.2 Key Developments per Energy Carrier

2.2.1 Short Report Hydrogen for Propulsion

Pressurised hydrogen storage is currently furthest developed for mobile applications (inland shipping) and is the most applied method in current hydrogen vessel projects. Liquified hydrogen could be an option in the overall supply chain as a mid-term solution when liquefaction plants are built and the fuel price comes down. In theory, bunkering can take place via four different configurations: truck-to-ship, ship-to-ship, bunker stations and swapping of tank-containers and depends on the physical state in which hydrogen (pressurized, liquid or hydrogen carrier) is stored on board inland navigational vessels. The most feasible scenario for the short-term is swapping pressurized hydrogen in swappable containerised containment systems (tube-containers) at container terminals. Regulations for the use of hydrogen on board of-, and bunkering of hydrogen to inland navigational vessels are still under development. On 1 January 2024, the ES TRIN 2023 will enter into force, containing rules for the use of fuel cells (**https://www.cesni.eu/wp-content/uploads/2022/11/ES_TRIN23_signed_nl.pdf**).

The availability of hydrogen as a fuel for vessels relates to hydrogen fuel production as well as to provision of bunkering infrastructure in a sufficient number of ports in the operating area. Strategic engagement of a large industrial player (gas producer, utility company, oil or energy major), who is not only aiming at supplying (moderate amounts of) green hydrogen to inland waterway vessels but also to large consumers along the Inland Waterways, is required for a breakthrough.

2.2.2 Short Report Biofuel for Propulsion

Among the synthetic fuels that are considered important for inland navigation are GTL (Gas-to-Liquid) and HVO (Hydrotreated Vegetable Oil).

GTL is produced with the Fischer-Tropsch synthesis, a process generally called XTL (X to Liquid) that was developed by Franz Fischer and Hans Tropsch in 1925. The 'X' is a variable and is replaced by an abbreviation of the original energy carrier, e.g. 'G' for gas. Within this process various liquid synthetic fuels such as GTL, lubricating oils and other paraffinic products for the chemical industry can be obtained from natural gas, other gasified fossil fuels or biomass. If biomass is used as a starting material, also the term BTL (Biomass-to-Liquid) is commonly used, replacing the 'X' by 'B'. BTL is completely derived from renewable energy.

HVO is a mixture of straight-chain and branched paraffins, the simplest form of hydrocarbon molecules under the aspect of clean and complete combustion. Typical carbon numbers are C15 ... C18. In addition to paraffins, fossil diesel fuels contain also significant amounts of aromatics and naphthenes. Aromatics impair a clean combustion. HVO, on the contrary, does not contain aromatics, and its composition is similar to that of GTL and BTL diesel fuels, produced by the Fischer-Tropsch synthesis from natural gas and gasified biomass. Having said that, it is to be emphasized that HVO is not to be mistaken with Biodiesel. Biodiesel is a chemically fatty acid methyl ester (FAME) and could cause trouble being used as a fuel substitute in a conventional engine. Increasing the blends of FAME is a greater challenge than for HVO and not covered by Assessment of Technologies in view of zero-emission IWT Report No. 2293 29 usual test fuels. The feedstock for HVO consists of renewable sources. These can be residual plant and animal fractions from the food industry or residues from vegetable oil processing.

Rapeseed methyl ester, also known as OLEO100, is a biofuel produced exclusively from rapeseed oil. It can be used in its pure form and does not need to be mixed with a fossil fuel.

It has an energy density comparable to that of diesel (slightly lower). Similar to diesel/gasoil, OLEO100 is used in internal combustion engines and can be mixed with diesel, it is therefore compatible with existing conventional propulsion systems. It is mainly used by heavy road vehicles, but it is being tested for application on inland vessels. Currently, refuelling is done either by refuelling trucks or directly by drums delivered to the refuelling station. It can be regarded as a conventional fuel when it comes to existing rules. OLEO100 is not considered harmful for human nor the environment, no specific policies are needed. Infrastructure changes required are minor and costs are therefore negligible compared to other alternative fuels. If available on location, OLEO100 refuelling specifics are comparable to those of conventional fuels; since comparable energy density and viscosity means comparable volumes and refuelling times. The main challenge is the long term availability of this fuel if it is widely adopted.

However, there are major uncertainties surrounding biofuels:

- One can speculate about the proportion of biofuels (up to 100 %) that can be incorporated in a blend (indeed the higher the remaining share of fossil diesel/gas is, the higher the emissions).
- The availability of biofuels from sustainable production is also a concern, especially given limited production capacity (for example the availability of the raw material for producing HVO is a limiting factor). It is worth noting that such uncertainties surrounding availability are also true for other alternative fuels relying on renewable electricity, such as hydrogen produced by electrolysis.
- One also needs to take account of competition with other modes of transport and other industrial sectors, in terms of the distribution and use of these biofuels. For example, most biofuels may ultimately be earmarked for the aviation or maritime sectors if no other technology is proved to be appropriate for these sectors' energy transition. In such a situation, the cost of biofuels could increase significantly. Therefore, the economic interest of the conservative transition would be considerably reduced.
- Moreover, although biofuels are deemed to be carbon neutral if the entire production chain is taken into account, burning biofuels for vessel propulsion purposes emits GHG and atmospheric pollutants, at least locally. If therefore applicable regulations were to impose zero emissions zones, as is envisaged for example in European cities, vessels running on biofuels might no longer be allowed to operate there.

2.2.3 Short Report Methanol for Propulsion

Methanol is a climate neutral fuel, when it is produced from renewable energy and can be used as fuel for combustion engines or for fuel cells. Methanol has a low energy density compared to gasoil/diesel fuel but has a higher toxicity, especially for humans. Otherwise, it is rather similar to diesel/gasoil and can be used for all applications with relatively minor interventions. Bunkering is possible from bunkering vessels, tank trucks and fixed tank stations. The required safety distances are also similar to diesel/gasoil. Safety risks during methanol transport are well understood and safety measures in place. Technical requirements and standards for methanol as fuel on inland navigation vessels are under development in Europe. Infrastructure costs are on the same level as for diesel/gasoil and low in comparison to other alternative/climate neutral fuels. More refuelling (bunkering) stops are needed because of low energy density. The main challenge is the high cost for methanol itself, when it is produced from renewable energy. Otherwise, methanol could become a standard fuel for inland navigation.

2.2.4 Short Report Battery Electric Propulsion

A battery electric propulsion system consists in general of rechargeable batteries, electric switch board and an electric propulsion system. Because of low energy density, battery electric propulsion is most suitable for ships that travel short distances (between stops). Fixed batteries require electric charging points at mooring places and exchangeable batteries require cranes, e.g. on container terminals with nearby charging point. Infrastructure costs are high as many charging points are needed and as rechargeable batteries for inland navigation vessels require a high-capacity power supply. Battery fires are rare, but hard to control. Technical requirements and standards for rechargeable batteries exist or are under development. In Europe, national and EU policies support the implementation of charging points at suitable locations of the inland waterway network. Battery costs are expected to further decrease, and energy density will increase, allowing battery electric propulsion becoming a technical and economically feasible alternative for certain inland navigation tasks. According to the latest RWS studies on the safety aspects of new energy carriers, the surrounding safety zones between the location of the battery containers and the surrounded buildings can be as low as 5 m. The most important recommendation is the location awareness for energy services. This is particularly important in case of shipping accidents.

3 RELEVANT QUESTIONS FOR WATERWAY MANAGERS

3.1 General

From Chapter 2, it can be concluded that the path to decarbonisation of IWT is different for different corridors and in different countries. While a relatively short list of potential energy carriers appears to emerge when discussing decarbonisation, which carrier (or a mix of carriers) is likely to emerge as preferred depends on a whole range of local situations. In practice, it is seen that vessels owners and bunker station operators have a strong influence on the alternative energy carriers they would like to use (bottom-up). But at the same time, the question whether a selected alternative energy carrier is going to be successful at the corridor scale can depend on a range of policy measures and subsidy schemes (top town). While momentum for change appears to be stronger bottom-up, TG 234 considered that a top-down approach could provide a stronger rational framework. So while fully aware of the bottom-up as well as the top-down perspective, TG 234 decided to take on the perspective of a waterway manager that faces the need for decarbonisation of his/her waterway. By discussing step-by-step the kind of questions that arise, a structured approach to decarbonisation emerges.

3.2 List of Questions

TG 234 foresees that a waterway manager that seeks to decarbonise his/her network encounters the questions listed below:

i. What are the most promising technologies (or energy carriers) for the decarbonisation of IWT?
ii. What is the overall transport challenge in my network (amount of cargo, number of passengers, from where to where now and in the future)?
iii. What is the state of the water transport network and of the fleet that operates on it (proportion of vessels of given type/classification, now and in the future, alternative transport modes)?

iv. What is the energy consumption that is associated with the transport challenge, given the current and future state of the network as well as of the fleet and the waterway conditions in the future considering impacts of climate change? (Emission hotspots?)
v. What type of energy carriers can replace the current ones, what quantities of fuel are needed where, and how will these fuels affect range, payload, velocity, etc.?
vi. Where should we position bunkering points or refuelling stations? What are the charging/fuelling times and the waiting times at refuelling stations?
vii. How can the estimated demand for alternative fuels (electricity, hydrogen, methanol, etc.) be supplied over the network?
viii. What are the standards or existing regulations that must be followed?

3.2.1 What Are the Most Promising Technologies (or Energy Carriers) for the Decarbonisation of IWT?

The impact on the infrastructure for the decarbonisation varies substantially with the different energy carriers. As was shown in the briefing notes of the previous chapter, biofuel for decarbonisation allows for continuous use of the existing refuelling infrastructure, whereas a switch to electric propulsion would require building a totally new infrastructure. Furthermore, none of the future energy carriers is suitable for all transport tasks. Therefore, the waterway manager is well advised to get a good understanding of the different technologies or energy carriers for the decarbonisation of IWT. This will also help him or her to efficiently consider the following questions.

3.2.2 What is the Overall Transport Challenge in My Network (Amount of Cargo, Number of Passengers, from Where to Where, Now and in the Future)?

It is important to consider what the transport challenge is in the network. The type and amount of cargo that needs to be transported, in combination with the origin and destination of this cargo, determines the demand for transport and also the location of the bunkering infrastructure of the new energy carriers. It is also important to assess whether or not there are alternative transport modes that are likely to compete with inland shipping.

3.2.3 What is the State of the Water Transport Network and of the Fleet that Operates on It (Proportion of Vessels of Given Type/Classification, Now and in the Future, Alternative Transport Modes)?

When it is clear what the transport demand is depending on future traffic flows and the vessels required to transport it, it becomes important to assess the potential for transport over water.

Looking at the state of the water transport network will reveal the vessel classes [PIANC, 2020 ; RVW, 2020] that will be able to fulfil the transport demand. The maximum vessel class that can operate on a waterway is typically restricted by a maximum available air draught (e.g. due to the presence of fixed bridges), a maximum allowable width, length and draught (e.g. due to the presence of locks) and the presence of other width and depth bottlenecks [Van Dorsser et al., 2020 ; CCNR, 2021c ; Vinke et al., 2022]. Other aspects that can come into play are traffic intensity and environmental aspects like wind and current [Huang et al., 2020]. The state of the waterway, the available water depth and the ambient current conditions influence the amount of energy that is associated with the transport function.

The waterway classification determines the maximum size of the vessels that can use it. Indeed, the energy density of the alternative fuels is lower than diesel. Therefore it will be necessary to have bigger tanks or to bunker more often. Beyond that it is important to know the composition of the fleet that is available to perform the transport function on the waterway network. Not all vessels that are part of the fleet will be of the maximum size. Smaller vessels will need more trips to transport the same amount of cargo compared to larger ships. Older vessels might still have older engines that may perform less when it comes to emissions. Also, it is important to assess the availability of alternative transport modes, e.g. road, rail, pipeline. When alternatives are available *and* capable to accommodate a significant modal shift, this will put more pressure on the inland shipping sector to adopt/convert to other energy carriers.

3.2.4 What is the Energy Consumption that is Associated with the Transport Challenge, Given the Current and Future State of the Network as well as of the Fleet and the Waterway Conditions in the Future the Considering Impacts of Climate Change? (Emission Hotspots?)

When the transport demand (volumes, origins, destinations), the state of the waterway network (e.g. water depths, currents), and the state of the fleet (composition, engine ages, etc.) are known, the associated energy demand for transport can be estimated using vessel resistance algorithms [Bolt, 2003 ; Vehmeijer, 2019 ; Segers, 2021 ; Van Koningsveld et al., 2021 ; Rijkswaterstaat, 2022a ; Rijkswaterstaat, 2022b]. Energy demand can be used to estimate the potential for GHG emissions as well as emissions of other environmental pollutants (i.e. PM_{10}, NO_x).

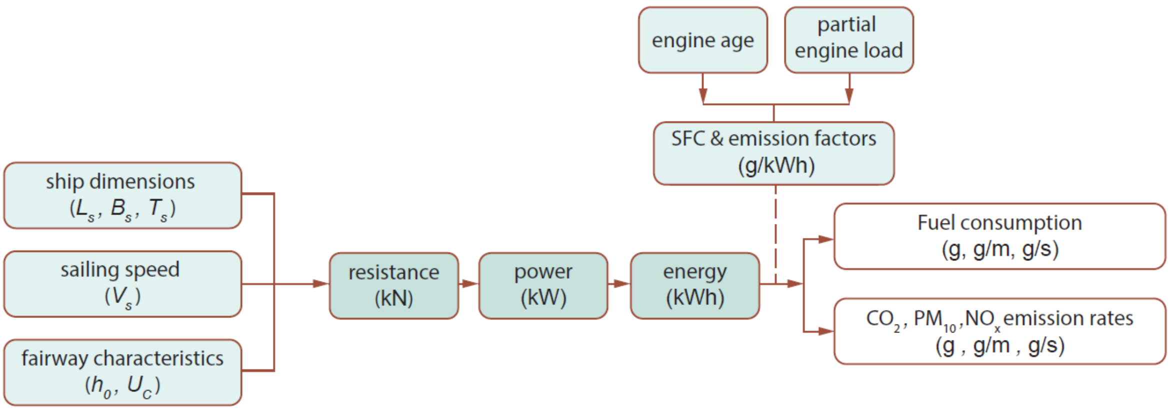

Fig. 1: Methodology for estimating emissions for IWT vessels (image modified from Segers (2021) by TU Delft Ports and Waterways is licenced under CC BY-NC-SA 4.0)

For modern waterway networks that are already actively used, the availability of Automatic Identification System (AIS) data can be an important source of input. Depending on the country of origin, digital information on the state of the waterway network may also be openly available.

AIS data, combined with waterway network data, can be utilised to provide a promising first estimate of the energy demand that is associated with the transport function. To estimate future demands, growth/shrinkage scenarios can be of use.

Construction year classes	Weight class	Fuel consumption [G/KWH]	CO_2 [G/KWH]	PM10 [G/KWH]	NO_x [G/KWH]
1900-1974	L1 – L3	235	746	0.6	10.8
1975-1979	L1 – L3	230	730	0.6	10.6
1980-1984	L1 – L3	225	714	0.6	10.4
1985-1989	L1 – L3	220	698	0.5	10.1
1990-1994	L1 – L3	220	698	0.4	10.1
1995-2002	L1 – L3	205	650	0.3	9.4
2003-2007 CCR-1	L1 – L3	200	635	0.3	9.2
2008-2018 CCR-2	L1 – L3	200	635	0.2	7
2019-2019 CCR-2	L1 – L3	200	635	0.2	7
2019-20XX STAGE V	L1	205	650	0.1	2.1
2020-20XX STAGE V	L2 and L3	190	603	0.015	1.8

Table 1: General SFC and emission factors of CO_2, PM10 and NO_x for diesel fuel and different engine construction year classes (source: Ligterink et al. (2019), and modified based on the emission standards described at DieselNet (2021)).

It is useful to take the energy consumption (kWh) as a basis for analysis, since empirical information is typically available to estimate the associated fuel consumption, via so-called Specific Fuel Consumption factors (g/kWh) (Table 1). When assumptions are made on partial engine loads and engine ages also CO_2 and environmental pollutant emissions can be estimated [Hulskotte, 2013 ; Smart Freight Centre, 2019 ; Wijaya et al., 2020].

It may be worthwhile to validate these coarse estimates with actual energy consumption, fuel use and emissions. Also, it will be useful to document the current locations and capacities of bunker facilities.

With the above method, so-called energy consumption, fuel use and emission footprints can be generated for individual vessels as they sail over the network to transport their payload. Overall patterns can be generated by aggregating the footprints of individual vessels that together represent the traffic on a corridor [Jiang et al., 2022].

Such heat maps, created from individual contributions, can be used to identify hotspots and identify root causes. This information can be used to design policies to reduce emissions [Segers, 2021]. In the long term, such policies will probably involve zero emission energy carriers, but in the years before those other measures may be necessary in an effort to reduce GHG emissions.

More coarse methods to estimate energy consumption, fuel use and emissions may also be used. Various methods are available that estimate fuel use per tonne kilometre (tkm) based on empirical data. While these methods are easier to use, especially in situations of limited data availability, they are less useful to test new situations. The most practical way forward as such is a trade-off.

3.2.5 What Type of Energy Carriers Can Replace the Current Ones, What Quantities of Fuel Are Needed Where, and How Will These Fuels Affect Range, Payload, Velocity, Etc.?

Once the total energy demand, fuel use and emissions, as well as the locations and capacities of current bunker facilities are known, it becomes possible to estimate the required volumes in case alternative energy carriers would be considered.

Alternative energy carriers will have a different energy content than more traditionally available options. Also, other energy carriers may involve alternative energy conversion systems. For each energy carrier/energy conversion combination it should be investigated what the potential influence on sailing range, payload amount and sailing velocity is. If only the sailing range is affected, an increased number of bunker stops is the main transport efficiency impact. If the range remains the same but the amount of payload is affected, the main transport efficiency impact is an increased number of trips required to transport the same amount of cargo.

Where for the previous question AIS data could be used as a basis for quantification of the current state, testing the effectiveness of alternative policies requires simulation. A common approach for this these days is the use of agent-based meso-scale simulation models [Van Koningsveld and Den Uijl, 2020 ; Jiang et al., 2022]. With such models the effect of changes to the vessels (the agents) can be assessed beforehand.

A typical question is of course what performance indicators are most suitable. Given that a known amount of cargo needs to be transported a typical measure of transport performance is the unit of tonne kilometre (tkm), or the tons of cargo times the km of distance over which it needs to be transported. Obviously, an important indicator is the cost of transport. When we are interested in energy, fuel and emission efficiency respective units of kWh/tkm, g fuel/tkm and g emission/tkm become relevant.

It is good to realise that in the cost and emission units the efficiency of the transport chain becomes visible. Let's imagine that 3,000 tonnes of cargo need to be transported over 100 km. Then the transport performance can be expressed as 3,000 x 100 = 300,000 tkm. This performance is irrespective of vessel size. But now let's assume this cargo is transported with a vessel that has a capacity of 3,000 tonnes or a vessel that has a capacity of 1,500 tonnes. In the first case the cargo can be transported by 1 full trip to the destination and 1 empty trip back to the origin. In the second case 2 full trips and 2 empty trips are needed to transport the same amount of cargo.

Depending on local circumstances and vessel properties this will result in different emission patterns: there is good chance that the second option will have a poorer total efficiency in terms of e.g. g CO_2/tkm, at the same time the emission source in terms of g CO_2/s or g CO_2/km can be lower since the emission will be spread out over time. While for CO_2 the totals are likely to be of interest, the actual peak values may be of interest for other environmental pollutants like fine particle emissions such as PM10. It will also be interesting to see what the cost effects are when aspects like ambient current and available water depth are included. It is clear that the total performance of the IWT mode is complex. An increasingly popular approach these days is that the effects of policies are tested in simulation models or digital twins. It is necessary to do this since relying on intuition or coarse empirical data may yield unreliable results. Especially since the use of alternative energy carriers can affect things like sailing range (refuelling more often, and possibly taking longer/shorter), amount of payload that can be carried (more trips required) and perhaps the velocity profile that can be achieved.

Information on refuelling/charging times and waiting times will influence the cost competitiveness of a suggested solution.

3.2.6 Where Should We Position Bunkering Points or Refuelling Stations? What Are the Charging/Fuelling Times and the Waiting Times at Refuelling Stations?

Insight in the total energy demand over the network tells the waterway manager something about the capacity requirements of the bunker stations/charging stations on the network. Insight in the range of vessels for different energy carrier/energy converter combinations will tell the waterway managers something about the maximum inter-distance of the bunker stations/bunker vessel.

How this all works out in detail will depend on the current vessel mix, and scenarios for possible future vessel mixes as well as on scenarios for the energy carrier mix that is assumed to be used on the network.

It is good to realise that also developments in other transport modes will be of interest, as well as developments in other corridors. In the end the selected solution (or mix of solutions) must be price competitive compared to available alternatives. Unless the other transport modes lack the capacity to accommodate a modal shift, poor price competitiveness will lead to the decline of the IWT mode.

3.2.7 How Can the Estimated Demand for Alternative Fuels (Electricity, Hydrogen, Methanol, Etc.) Be Supplied Over the Network?

Insights in potential locations and capacities of alternative fuel bunker points are already an important step forward. But the availability (and cost) of alternative energy carriers may also be a deciding factor. When the supply of sufficient amounts of a given energy carrier is problematic, a preferred energy carrier, while potentially suitable, might not become the implemented solution. Availability of certain energy carriers can vary significantly from one location to the next. This is at least one of the reasons why it is not possible to point to any one energy carrier as a preferred solution that fits all.

3.2.8 What Are the Standards or Existing Regulations That Must Be Followed?

Next to demand for and the potential supply of alternative energy carriers, another important factor for likely success or failure of an energy carrier is the presence/absence of regulations. Mandatory safety margins for example, may pose inhibiting restrictions on the implementation of a given energy carrier.

4 SUGGESTED APPROACH

The questions posed in Chapter 3 are key for any waterway manager to contemplate while decarbonising the IWT mode. TG 234 suggests that these questions should be addressed first before detailed guidance can be provided on the actual dimensions of the required energy-related infrastructure components. What approach is most viable is very context dependent.

It makes a big difference if you are dealing with a very busy shipping corridor that supports a wide range of vessels and substantial cargo flows, or a much smaller waterway that caters to a limited number of vessels and only one cargo type. Or if you are dealing with a waterway system that has substantial current vs one that has more calm conditions.

Also, the governance context can play an important role in feasible ways forward. In Session 5-1 of the PIANC-SMART Rivers 2022 Conference, the chair responded to a paper on regulation for IWT decarbonisation in Europe (proceedings under publication). He indicated that China is considering to make a top-down decision on the energy carriers for the decarbonisation of inland navigation. The argument was that it would be economically counterproductive to support several energy carriers. This exchange illustrated that decarbonisation of IWT would be confronted with different challenges in a 'European context', viz. several energy carriers & market decision, than in a 'Chinese context, viz. one energy carrier & government decision.

Considering all lessons learnt, TG 234 observes that the main challenge in the decarbonisation of IWT is not so much a lack of best practices for the 'design of infrastructure' (such as dimensions and standards of bunkering stations), but rather a lack of best practices for the 'design of feasible pathways and decision making'.

5 CONCLUSIONS

TG 234 concludes that PIANC should consider setting up a WG that focuses not on infrastructure hardware, such as dimensions and standards of bunkering stations, but rather on pathways and decision making for decarbonisation of IWT, comparable with the CCNR roadmap [CCNR, 2022a]. A pathway is understood as a way to organise the transition from a fleet (existing and newbuilds) into a decarbonised fleet over a few decades. Design of the supporting infrastructure should be considered in the context of the selected pathway(s). As a matter of example we refer to the two transition pathways (conservative and innovative) that were elaborated by CCNR (2022a) to meet the reduction of emissions objectives.

From the TGs investigations it seems that once there is clarity on preferred transition pathways a wide range of reports, research programs and initiatives is available that can be used as reference material. In fact there is a huge abundance of reports and investigation on all sorts of topics relevant for IWT decarbonisation. But what is not so abundant (yet) is an integral framework that allows the comparison of different transition pathways for a given waterway or network.

It is good to know that various initiatives are ongoing that focus on the development of such a framework. One example is the Path2Zero project[1] that unites research institutes and practitioners in the Netherlands in the development of a digital twin of water transport networks, with the aim to develop and evaluate actions perspectives and sustainable business models for all parties in the inland shipping chain. Connecting a PIANC WG with this, or another similar, initiative could be a practical way forward and allow to make significant progress in a short amount of time.

In any case, significant attention should be given to sufficient international representation to ensure support for and uptake of the outcomes presented in the report.

[1] https://www.nwo.nl/en/projects/nwa143920001

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APPENDIX A: TERMS OF REFERENCE

PIANC Task Group on "Infrastructure for the decarbonisation of IWT"

Terms of Reference (1st Oct 2020)

1. Background

Global and European societal pressure is growing to keep climate change and air pollution within acceptable limits; as illustrated by

- "The European Green Deal" (December 2019[2]), to ensure that Europe will be the first climate-neutral continent, and making Europe a prosperous, modern, competitive and climate neutral economy, as envisaged in the Commission Communication "A Clean Planet for All: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy" (November 2018[3]);
- The Paris Agreement Objectives (COP21[4]);

Accordingly, political and regulatory attention has been increasingly directed towards IWT, as in many cases this transport mode's environmental and climate impact is not negligible. See for example

- The Central Commission for Navigation of the Rhine (CCNR)'s Ministerial Mannheim declaration[5] (October 2018) and the calls from the European Council[6] and European Parliament[7] to enhance the environmental track record of inland waterway transport;
- The Sustainable Development Goals (SDG) of the United Nations' Development Program (UNDP), particular SDG 9 (Industry, Innovation and Infrastructure)[8]; SDG 13 (Climate Action)[9] and SDG 14 (Life Below Water)[10].

The availability of zero-emission fuels infrastructure, including onshore electric power supply, will be key to enable zero-emission vessels and increase the competitiveness of IWT as a whole, at a time when other modes of transport are reducing their ecological footprint.

An example of zero-emission fuels can be given by the Rotterdam Port Authority which is working with various partners towards the introduction of a large-scale hydrogen network across the port complex, making Rotterdam an international hub for hydrogen production, import and transport to other countries in Northwest Europe. Providing Electric Power from shore for passenger and cargo vessels is another example. This technology is currently used to provide auxiliary power to vessels at berth. However, supplying power to vessels with fully

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[2] https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

[4] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[5] https://www.ccr-zkr.org/files/documents/dmannheim/Mannheimer_Erklaerung_en.pdf

[6] http://data.consilium.europa.eu/doc/document/ST-13745-2018-INIT/en/pdf

[7] http://www.europarl.europa.eu/doceo/document/B-8-2019-0079_EN.html?redirect

[8] https://www.un.org/sustainabledevelopment/infrastructure-industrialization/

[9] https://www.un.org/sustainabledevelopment/climate-change/

[10] https://www.un.org/sustainabledevelopment/oceans/

electric propulsion and using batteries for energy storage is a challenge still waiting for satisfactory solutions.

PIANC has declared, that the organization itself and its members "will strive to develop approaches to decarbonise the operation of port and navigation infrastructure (i.e. move to net zero emissions), whilst at the same time enabling the reduction of greenhouse gas emissions from vessels by providing the necessary facilities, infrastructure and, where appropriate, incentives".[11]

In January 2020 and considering these developments, InCom concluded that decarbonisation is of existential importance for inland navigation. Without decarbonisation, IWT will lose all its political support and will become as transport mode "non grata" for freight forwarders.

2. Objectives

The objective of the foreseen work is in line with the declaration of PIANC, namely contributing to the reduction of greenhouse gas emissions from IWT vessels by providing the necessary facilities and infrastructure for providing low or zero-carbon fuels. Sharing globally relevant knowledge and experience will help to reach this objective.

3. Earlier reports to be reviewed

Besides the above mentioned documents, the following could be of interest for the work to be performed:

- PIANC TG3, "Climate Change and Navigation - Waterborne Transport, Ports and Waterways: A Review of Climate Change Drivers, Impacts, Responses and Mitigation", published in 2008
- PIANC WG111, "Performance Indicators for Inland Waterways Transport - User Guideline", published in 2010;
- PIANC WG203, "Sustainable Inland Waterways – A Guide for Waterways Managers on Social and Environmental Impacts ", published in 2023
- PIANC WG229, "Guidelines for Sustainable Performance Indicators for Inland Waterways" (in process)

4. Scope

The decarbonisation requires changes to inland navigation infrastructure, in particular for bunkering of alternative fuels and supply of electric energy.

5. Intended product

Decarbonisation of IWT is a topic at the same time vast and dynamic. Thus, the topic poses a double challenge: On the one side it is of existential importance, on the other side it is complex. In order to deal with this challenge, initially a **Task Group** is foreseen to monitor relevant developments in the world and report regularly back to InCom. Thus, the first product is a set of short reports to InCom.

This Task Group will, in particular, analyse the outcome of the upcoming CCNR-workshop on alternative electric propulsion for inland navigation vessels including its infrastructure needs, which will take place in the second quarter of 2021. The group may also make use of an

[11] https://www.pianc.org/

upcoming CCNR study evaluating the technologies that are or should become available for the transition of IWT to zero-emission navigation. These technologies use fuels very different than those used today, requiring very different facilities and infrastructure for their supply to the vessels. This study and similar ones from other parts of the world would allow establishing the sources and amount of greenhouse gases that need to be addressed.

After having developed a good understanding of the topic, the Task Group will provide a proposal to InCom and ExCom on the continuation of the work, including transforming the Task Group into a working group with new terms of reference. This will be the second intended product.

6. Task Group membership

In the future, inland navigation will use different fuels and electricity as well as energy input, very different from today's reliance on diesel fuel / gas oil only. Thus, the Task Group membership should ideally comprise experts with knowledge on infrastructure for the safe supply of future fuels and electricity. These experts could come from government agencies, infrastructure providers, energy utilities, fuel suppliers as well as equipment manufacturers. Also, researchers, working in the field of decarbonisation of transport, could contribute to the work.

7. Relevance to Countries in Transition

The final products are relevant for countries in transition as well as developed countries with IWT systems that significantly contribute to the countries transport emissions.

8. Climate Change

In essence, the work foreseen contributes importantly to mitigation of greenhouse gas emissions by creating a knowledge base and disseminating worldwide of the knowledge to relevant stakeholders, in particular managers of waterways and providers of alternative fuels / energy for inland navigation.

APPENDIX B: BRIEFING NOTES

KEY DEVELOPMENTS PER COUNTRY OR ORGANISATION

ix. Short Report Decarbonisation IWT Europe
x. Short Report Decarbonisation IWT CCNR
xi. Short Report Decarbonisation IWT Austria
xii. Short Report Decarbonisation IWT France
xiii. Short Report Decarbonisation IWT Germany
xiv. Short Report Decarbonisation IWT Netherlands

KEY DEVELOPMENTS PER ENERGY CARRIER

xv. Short Report Hydrogen for Propulsion
xvi. Short Report Biofuel for Propulsion
xvii. Short Report Methanol for Propulsion
xviii. Short Report Battery Electric Propulsion

PIANC TG 234
Short Report/Briefing Note

Policies and Measures for the Decarbonisation of IWT Transport in Europe

In 2019, the European Union presented the European Green Deal with the aim of ensuring that the continent is greenhouse gases (GHG) emission-free by 2050.

In December 2020, the Commission adopted the Sustainable and Smart Mobility Strategy (SSMS) communication with concrete milestones for the EU transport system to achieve the transformation towards a smart and sustainable future.

In order to deliver the Green Deal, the European Commission adopted in July 2021 a set of proposals (Fit for 55 package) to make the EU's climate, energy, transport and taxation policies fit for reducing net GHG emissions by at least 55 % by 2030, compared to 1990 levels. These proposals are all connected and complementary.

As a result of the EU's existing climate and energy legislation, the EU's GHG emissions have already fallen by 24 % compared to 1990, while the EU economy has grown by around 60 % in the same period, decoupling growth from emissions.

One of the Fit for 55 proposals is the Alternative Fuels Infrastructure Regulation (AFIR) which supports the deployment of alternative fuels infrastructure, including refuelling points for natural gas and hydrogen. The objective is to boost the uptake of zero- and low-emission vessels and of renewable and low-carbon fuels in all modes of transport. The Regulation requires that ships have access to clean electricity (onshore power) supply in major ports to reduce the presence of polluting fuels particles in the air. For inland ports specifically, all core ports will need to have an OPS installation by 2025 and all comprehensive ports by 2030. LNG no longer needs to be deployed in inland ports. At the beginning of 2021, around 50 inland and maritime ports in the EU had at least one OPS connection point. With a goal-based and axis approach, Member States should set up national policy frameworks to establish markets for alternative fuels, particularly paying attention to the TEN-T network. For inland shipping, rail and maritime in particular, this includes hydrogen and electric. Additionally, Member States will have to report their progress.

Moreover, the Renewable Energy Directive (RED) deals with the promotion of energy from renewable sources. Its revision sets an increased binding target to produce 40 % (compared to the current 32 %) of energy from renewable sources by 2030. Specific targets are proposed for renewable energy use in transport. It promotes the uptake of renewable fuels, such as hydrogen in industry and transport. The increased targets in the transport sector are a 13 % GHG intensity reduction target, a subtarget for advanced biofuels from at least 0.2 % in 2022 to 0.5 % in 2025 and 2.2 % in 2030, and a 2.6 % sub-target for renewable fuels of non-biological origin (RFNBOs). Energy from RFNBOs can only be counted towards the targets if its GHG emissions savings are at least 70 % and energy from recycled carbon fuels can only be counted towards the transport target if its GHG emissions savings are at least 70 %.

Finally, the Energy Taxation Directive (ETD) aims to ensure the proper functioning of the EU internal market. The revision of the ETD aims at ensuring that energy taxation is aligned with climate objectives, therefore ending all fuel exemptions that currently exist for fossil fuels in 2023. Sustainable biofuels and biogas, low-carbon fuels, renewable fuels of non-biological origin (RFNBOs), advanced sustainable biofuels and biogas and electricity will be taxed at zero during the transition period of 10 years, after which they will be brought to their minimum reference level. For electricity and other low carbon fuels, this will by € 0.15 per Gigajoule.

PIANC TG 234

Short Report/Briefing Note

Initiatives and Actions by the Central Commission for the Navigation of the Rhine (CCNR) on Emission Reduction

The Central Commission for the Navigation of the Rhine (CCNR) is an international organisation which has been ensuring the freedom and safety of navigation on the Rhine since 1815. It has five Member States: Belgium, France, Germany, the Netherlands and Switzerland.

Mannheim Declaration

In the **Declaration** signed in Mannheim on 17 October 2018, the inland navigation ministers of the Member States of the CCNR reasserted the objective of largely eliminating GHG and other pollutants by 2050. In addition, to further improve the environmental sustainability of navigation on the Rhine and Inland waterways, the same Mannheim Declaration tasked the CCNR to develop a roadmap for:

- reducing GHG emissions by 35 % compared with 2015 by 2035,
- reducing pollutant emissions by at least 35 % compared with 2015 by 2035,
- largely eliminating GHG and other pollutants by 2050.

CCNR study on the energy transition towards a zero-emission inland navigation sector

To achieve these core environmental objectives, the Mannheim Declaration stresses the need for new and updated financial instruments. To accomplish this task, it was decided to launch a **preparatory study**, involving many stakeholders. Building on the question 'How to finance the energy transition of the IWT sector?', the preparatory study was to identify a series of **key research question**.

On the basis of the results of the preparatory study, the CCNR decided in 2019 to launch **three in-depth studies** on:

- the 'Financing of Energy Transition Towards a Zero-Emission European Inland Navigation Sector'
- the polluter-pays principle in the IWT sector and
- the economic and technical assessment of technologies to achieve the zero-emission objective

In 2021, during its Spring plenary session, the CCNR adopted a resolution prescribing the publication of the final study results and welcomed their groundbreaking character in these considerations on the financing of the energy transition. The results of the study do not prejudge the positions of the CCNR and its member states and should be seen as part of a broad discussion process at Rhine, European and international level, which aims to:

- quantify the funding requirements for the energy transition in inland navigation
- present recommendations for the development of a European funding and financing
- and pave the way for political decisions

The CCNR also mandated its Committees to feed the study results into the PLATINA3 project, wishing that within the project, an action plan for the further development of a European funding and financing instrument is drawn up and a proposal for such an instrument is elaborated in more detail.

These study results also feed into the CCNR roadmap for the overall reduction in greenhouse gas and pollutant emissions by 2050.

CCNR roadmap for reducing inland navigation emissions

The CCNR's intention in drawing up the roadmap is to lay the foundation for a common approach to the energy transition and emissions reduction by all stakeholders. This roadmap should be understood as the primary CCNR instrument for climate change mitigation and for giving effect to the energy transition to reduce Rhine and inland navigation emissions by:

- setting transition pathways for the fleet (new and existing vessels)
- suggesting, planning, and implementing measures directly adopted or not by the CCNR
- monitoring intermediate and final goals set by the Mannheim Declaration

The roadmap was **adopted** on 9 December 2021 (**resolution 2021-II-36**) and will be published beginning of February 2022.

Past activities:

20 April 2021: workshop on 'Alternative Energy Sources for Electrical Propulsion Systems in Inland Navigation'. Objective of the workshop was to learn more about innovative technologies, as well as the technical, economic, organisational and legal challenges. One of the key conclusions was to avoid focusing on one alternative energy source only ('No one size fits all') and to remain technology neutral. Furthermore, focus should be on existing bunkering infrastructure and how this can be re-used in the future. Energy transition will also depend on the availability of alternative energy sources.

3 February 2022: **workshop** on 'Shore Power at Berths'. The workshop aspired to help solve the challenges facing the inland navigation sector in achieving zero-emission by 2050, while at the same time deriving the requirements for technical standards, management systems, the reliability and usability of the systems, and also the need to use such services from the providers' and users' perspective. The ports as well will play a particular role in this as a result of their transformation into energy hubs. A key conclusion was, that there is a need not only for standardisation of the shore power connection, but also for standardisation of the operation and payment system. The challenges must be addressed jointly and the solutions must be coordinated internationally and interdisciplinarily.

Upcoming activities:

2023: initiative (workshop or round table) to 'Improve the Safety and Ease of Navigation on the Rhine When Using Alternative Fuels' (The services that are deployed in case of incidents on the Rhine, i.e. rescue services, fire brigades and police, possibly also waterway administrations, should be enabled to successfully counter dangerous incidents with alternative fuels or large-volume electrical storage).

Links to workshops:

- **Central Commission for the Navigation of the Rhine – Workshop 'Alternative Energy Sources for Electrical Propulsion Systems in Inland Navigation' (ccr-zkr.org)**
- **Central Commission for the Navigation of the Rhine – Workshop on 'Shore Power at Berths' (ccr-zkr.org)**

PIANC TG 234
Short Report/Briefing Note

Policies, Plans and Measures for the Decarbonisation of IWT Transport in Austria

The Republic of Austria is committed to contribute to the decarbonisation of the traffic on its waterways, mainly the 351 km long section of the international waterway Danube, on a federal level as well as on the level of the federal states. As EU-member state Austria also complies with the international targets set by the EU.

Political Commitments on the National and Federal States' Level

The 'Regierungsprogramm 2020-2024' (transl. 'Government Programme 2020-2024') outlines in Chapter 3, among others, the national government's measures to decarbonise traffic also in the field of inland navigation. It enumerates "*[…] mandatory shore power connections at the public berths along the federal waterway network as well as the evaluation of a federal set of measures to promote shore power connections at private jetties on lakes and rivers*", the "*evaluation of the deployment of environmentally friendly alternative fuels*", the "*commitment of an inclusion of the shipping sector into the ETS on EU level*", the "*commitment for a fair ship diesel taxation on EU level*" and the "*maintaining of good shipping conditions and implementing shipping into logistics chains*".

The main objective of the national 'Mobilitätsmasterplan 2030' (transl. 'Mobility Masterplan 2030') is to outline strategies for climate neutral traffic by 2040. Regarding inland waterway transport, it proposes in Chapter 4.5 the usage of renewable fuels, electric drive systems primarily for small vessels and short distances and replaceable battery containers for longer distances. The 'Mobilitätsmasterplan 2030' also stresses the need for the implementation and expansion of the land infrastructure required by these alternative propulsions, such as a sufficient power supply on land for idle vessels and charging battery systems. Furthermore, hydrogen applications, liquefied biogas and synthetic methane are also proposed as possible alternatives to fossil fuels depending on the results of international research and development projects. Until a future decision about the technology of choice is made, the 'Mobilitätsmasterplan 2030' recommends a blending mandate to reduce carbon emissions in the short term in connection with a package of measures consisting of legislative specifications, infrastructure development and incentives. Finally, Austria is also campaigning for a fair taxation of ships' diesel to steer developments into a future climate neutral traffic.

The government of the federal state Upper Austria has included in Chapter 2 of its 'Regierungsprogramm 2021-2027' (transl. 'Government Programme 2021-2027') that it pursues sustainable mobility. Regarding IWT the government committed itself to install shore power units for cruise vessels in Engelhartszell and Linz.

The coalition agreement of the government of Vienna, 'Die Fortschrittskoalition für Wien' (transl. 'The Progress Coalition for Vienna'), states in Chapter 3.2 that Vienna becomes "*the first European metropolis that installs a shore power supply for inland cruise vessels in order to prevent emissions from their diesel generators*". In addition, it is written that the government of Vienna also pushes the realisation of shore power systems at additional berths along the Danube.

Accordance with EU Policy

Thus, the current political ambitions to decarbonise IWT in Austria are in line with the strategies and objectives of the EU, namely the 'European Green Deal' and the 'Proposal for a Regulation of the European Parliament and the Council on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU of the European Parliament and of the Council'. With regard to the intended transition periods the Austrian objectives regarding decarbonisation are even more ambitious than the ones on European level.

Status Quo and First Steps Towards a Decarbonisation of IWT

Currently, there are no shore power units at public berths for cargo and passenger vessels along the Austrian waterways (apart from ports).

However, implementation projects prepared by the Austrian waterway company, viadonau, which is owned by the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology include the installation of shore power supply for cargo vessels at selected existing and future berths. The first shore power units for cargo vessels are expected to be put into operation in the second half of 2022 at a public berth in Linz.

Regarding shore power supply for cruise vessels, implementation plans aim at equipping selected private berths with shore power units as quickly as possible. These implementation projects will be realised in the responsibility of the federal states of Upper Austria, Lower Austria and Vienna. Some public ports have also already realised, or have begun, to plan shore power supply for cruise vessels during their winter break.

In order to achieve a broadest possible international harmonisation of technical standards and the operational und billing systems of a future shore power system along the European waterways, the Central Commission for the Navigation of the Rhine and viadonau have recently set up an international conference, on which chances and challenges in connection with this long-term objective were discussed.

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Short Report/Briefing Note

Policies, Plans and Measures for the Decarbonisation of IWT Transport in Germany

In 2021, the German Federal Parliament amended the Federal Climate Protection Law (Bundes-Klimaschutzgesetz – KSG), it had initially adopted in 2020. The KSG is the main instrument for Germany reaching its climate goals. For the first time, it prescribes legally binding climate targets and annually decreasing emission levels for the energy, industry, building, transport, agriculture and waste management sectors. The law aims to achieve greenhouse gas (ghg) neutrality in Germany by 2045, with concrete interim targets for 2030 and 2040. The targets are subsequently achieved through targets, incentives, funding and investment programmes. The KSG establishes a fixed set of rules in case it turns out that the previous measures are not sufficient. If an emission sector exceeds the permissible annual emission quantity, the responsible federal ministry is obliged to present measures for readjustment. It is obliged to draw up an emergency programme to get its own area of responsibility back on track.

To reach the objectives of the KSG, the Federal Ministry for Digital and Transport (BMDV) will support climate friendly inland navigation among others with subsidies for decarbonisation and development of inland waterway infrastructure. The Federal Government also heavily supports research and development for the decarbonisation of inland navigation. Further subsidies are provided by some of the German 'Länder'. However, the available subsidies are largely insufficient for the transformation of the entire fleet and do not cover operating costs.

In the near future, the Federal Government will take important decisions on carbon prizing for transport. Whereas a carbon prize on fuel for road transport is already introduced, discussion on the carbon prizing of fuel for IWT just began. Decisions must be taken in a European context, as IWT in Europe is much more international than road and rail transport.

Internationally, Germany fully subscribes to the CCNR activities on decarbonisation of inland navigation. They are based on the Ministerial Declaration of 17 October 2018 in Mannheim and have most prominently led to the development for a roadmap aiming at largely eliminating greenhouse gas emissions and other air pollutants attributable to the inland navigation sector by 2050. In the framework of the European committee for drawing up standards in the field of inland navigation (CESNI), Germany has initiated and chiefly contributed to the development of technical requirements for propulsion of inland navigation vessels with alternative (meaning low carbon /climate neutral) fuels. The draft rules will be published in 2022.

Climate neutral fuels will be less available and more costly than fossil fuels. Therefore, transport – including inland navigation – must become much more energy efficient. Important studies of the Federal Government suggest that inland navigation must improve its energy efficiency by 50 % until 2045. To monitor and to support the necessary improvement of energy efficiency, the BMDV has commissioned work to develop energy efficiency indices for inland navigation, inspired by those for maritime vessels, together with a proposal for their practical implementation. The results of this work will be published 2023.

German IWT companies are already investing in climate neutral vessels. So far, the number and size of these vessels are small, but they are growing. Information on some of these vessels can be found here:

- **https://www.e4ships.de/english/inland-shipping/**
- **https://de.wikipedia.org/wiki/Sankta_Maria_II**
- **https://de.wikipedia.org/wiki/Suncat_120**

In conclusion, it can be stated that the necessary decarbonisation of German IWT will be highly challenging despite the available governmental subsidies and other support measures. Necessary investments will go far beyond the financial capacity of the sector. Consequently, many companies and even many more inland navigation vessels will disappear in the next decades. IWT in Germany will only stay a chance to survive, when it will be innovative and when there will an adequate regulation for ghg emissions from transport including carbon prizing, that honours the inherent energy efficiency of IWT.

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Policies, Plans and Measures for the Decarbonisation of IWT Transport in the Netherlands

The Netherlands is on its way to a new sustainable economy. The National Climate Agreement of the Netherlands was adopted in 2019. This Agreement includes a section on the inland shipping sector, but the specific targets for emissions reduction have been drafted in the Dutch Green Deal on Maritime and Inland Shipping and Ports (2019). The policy ambition for inland shipping is:

- **2030:** 40 %-50 % reduction of carbon emissions (relative to 2015) from the Dutch inland fleet and have at least 150 inland vessels fitted with a zero-emission power train
- **2035:** 35 %-50 % reduction of emissions of environmental pollutants (relative to 2015) from inland shipping
- **2050: virtually zero-emission and climate-neutral inland fleet**

The Dutch Green Deal was signed by various governmental authorities, trade associations, ports, sector representatives and research institutes, each indicating a set of actions planned to be taken in the coming years. For more information on these actions, see: **GD230 Green Deal on Maritime and Inland shipping and Ports.pdf (greendeals.nl).**

In 2020, the central government together with 36 municipalities and 9 provinces signed the Clean Air Agreement (SLA) containing a package of measures to improve the air quality in the Netherlands. The specific goals set for inland shipping are in line with the 2035 goals presented in the Dutch Green Deal on Maritime and Inland Shipping and Ports. Special attention is given in this agreement to the benefits of shore power facilities, cleaner engines and (new) energy carriers.

To achieve the above-mentioned policy goals, different initiatives have been launched in the Netherlands. In 2020, the national government announced that all the state berths for inland shipping will be equipped with shore power facilities to reduce the emissions and noise pollution produced by vessels on shore. This means investing in shore power facilities for around 500 state berths.

A national ban on degassing while sailing is also being introduced. Inland tankers often release harmful vapours from cargo residue into the open air in order to clean the ship. This can be harmful to the environment, the crew and local residents. The ban will be introduced step by step.

Furthermore, the possibilities and obstacles for a possible obligation to blend biofuel in inland shipping vessels is also being examined. A blending obligation already applies for freight transport by road.

Techniques for fully emission-free powered ships are not yet widely applicable and are also expensive. The Dutch national government has set up a supporting system for innovations that improve the broad applicability of these techniques for the inland shipping sector. Also, as part of the Dutch Green Deal and a structural approach to reduce nitrogen emissions, a funding scheme (2021-2025) has been put in place for greening of the Dutch fleet. Around 77 M€ is available to subsidy the purchase and installation of cleaner engines as well as SCR (Selective Catalytic Reduction) systems. However, it must be noted that the available subsidies are insufficient for greening of the whole Dutch fleet. Other countries in Europe also experience this problem. The Netherlands, together with Switzerland and the CCNR investigated the possibilities of setting up a European fund for inland navigation[1].

Another initiative to stimulate the decarbonisation of the fleet is a new labelling system for inland vessels' emissions performance. The emission label shows the emission performance of vessels both in terms of pollutant and climate emissions-based on periodic measurements on board. This label could be used by e.g. banks, ports and shippers to provide benefits to cleaner vessels. The development of the emission label is part of the Dutch Green Deal[2].

Although there is still a long way to go to reach the objectives of a virtually zero-emission and climate-neutral inland fleet by 2050, many steps have already been taken. In the coming years attention will also be needed on the necessary bunkering infrastructure and the safety requirements and legal framework to facilitate the introduction of new energy carriers in the inland waterway sector.

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Hydrogen for Propulsion of Inland Navigation Vessels

Pressurized Hydrogen[1]

Pressurized hydrogen storage is currently furthest developed for mobile applications (inland shipping) and is the most applied method in current hydrogen vessel projects. The technical maturity and availability of pressurized hydrogen are clear advantages over other storage methods. The required weight of the containment system, the relatively low volumetric energy density and therefore the space required to store sizable amounts of hydrogen on-board inland navigation vessels are however disadvantages

Liquid Hydrogen

Liquid hydrogen could be an option as a mid-term solution when liquefaction plants are built and the fuel price comes down. The storage and energy density is slightly better than pressurized hydrogen and the containment system requires less space and weight. The availability and liquefaction costs are however strong disadvantages. Furthermore, storage of liquid hydrogen on-board generates boil-off gasses, requiring frequent and continuous fuel consumption to prevent losses. Relevant properties of energy carrier/fuel.

Storage Onboard

In general, bunkering can take place via four different configurations: truck-to-ship, ship-to-ship, bunker stations and swapping of tank-containers. The applicability of each configuration and the method of bunkering depends on the physical state in which hydrogen (pressurized, liquid or hydrogen carrier) is stored on board inland navigational vessels.

The most feasible scenario for the short-term is swapping pressurized hydrogen in swappable containerised containment systems (tube-containers) at container terminals.

At the moment pressurized hydrogen is more cost-efficient for inland vessels compared to liquid hydrogen. The high fuel price of liquid hydrogen is expected to improve significantly when first liquefaction plants are built. However, liquid hydrogen has a better energy density than compressed hydrogen. Bunkering of liquid hydrogen is similar to bunkering of LNG. In principle, existing technology for LNG can be modified and adapted to liquid hydrogen after extensive engineering and testing before solutions become commercially available. For these reasons liquid hydrogen is still considered as a feasible mid-term scenario for IWT.

Bunkering of liquid hydrogen to inland vessels will probably start with truck-to-ship (limited infrastructure is required). When the market is more mature, bunker barges and/or bunker stations could be developed.

Material-Based Storage

Material-based hydrogen storage (sodium borohydride, ammonia, methanol or LOHC) also requires further development, especially with regards to the hydrogen release systems. There are many advantages for material-based storage such as high storage/energy densities, relatively safe handling (comparable to diesel or even better, except for ammonia) and possible re-use of existing diesel storage and infrastructure. Methanol and LOHC are stored in the same containment systems as diesel which could potentially be a big advantage when refitting existing inland vessels. A drawback is that some material-based fuels (e.g. LOHC, NaBH4) require a return cycle meaning that additional containment systems are needed to store the spent fuel on board (taking up space). The application of these technologies and especially the required additional equipment (hydrogen release systems) are however not yet developed for the inland shipping industry or mobility in general and will most likely not be available on a large scale in the next 5-10 years.

Application (Type of Ship/Transport Task)

Looking at vessel types and trade patterns we see a differentiated picture for the future competitiveness of green hydrogen as fuel for inland waterway vessels on the Rhine:

Segments of Higher Suitability and Competitiveness of Hydrogen:

- Vessels on fixed trades, liner service or long-term freight contracts
- Vessels on shorter trades
- Vessels operating largely between ARA ports and Ruhr area
- Vessels with limited engine load volatility
- Vessels with limited impact of higher weights
- Container vessels
- Newbuilds and possibly younger vessels of 15-20 years
- Vessels owned by larger owners; incl. governmental

Segments of Lower Suitability and Competitiveness of Hydrogen:

- Vessels with irregular trading patterns operating on spot market
- Vessels with long voyages without interim stops
- Vessels with high engine load volatility
- Vessels impacted by higher weights
- River cruise vessels, dry cargo, tanker
- Old vessels, especially if above 20 years
- Vessels owned by single-ship owner

Required Refuelling Infrastructure

In general, the following main bunkering configurations can be distinguished:

1.Truck-To-Ship (TTS)

TTS bunkering requires a location where the truck(s) could be positioned at a quay, directly next to the vessel that will be bunkered. Possible locations are normally selected by the authorities. Along the Rhine such a location could in principal be located in a port or along the river. Because of safety reasons, the location would need to facilitate safe mooring of the vessel.

2. Ship-To-Ship (STS)

STS bunkering is also a flexible solution as it could be conducted in different parts of the port (if not restricted by port regulations) and it could accommodate all volume-ranges.

The bunker barges and vessels will need to be supplied with hydrogen, which ideally requires the presence of an (intermediary) hydrogen production or storage site in or within a certain distance of the port.

3. Bunker Station (On Shore or on a Pontoon or Vessel)

A third option for hydrogen bunkering is establishing a bunker station, where vessels moor at a jetty or pontoon and are supplied with hydrogen from a storage tank by means of a pipeline. The bunker station can be supplied by ship, truck, train or pipeline. At a bunker station, hydrogen is transferred from a fixed storage tank (usually placed on land) through a cryogenic pipeline with a flexible hose at the end to a vessel moored at a quay, jetty or floating pontoon.

4. Mobile Hydrogen Tanks (Swapping of Containers)

This solution may offer advantages of simplified distribution at start-up and lower delivered costs as no expensive land-based infrastructure is required. Also, the 'bunker' time could be significantly shorter than for the other configurations and the operation could take place at the same location as the (un)loading operations, which makes this solution attractive for vessels utilising cranes and similar port infrastructure such as container ships. The tank-containers could be handled as standard dangerous goods (DG) containers, for which procedures and regulations are widely established. Alternatively, if the hydrogen fueled vessel is fitted with an onboard crane, it would (in theory) also be possible to load the tanks directly from another vessel or truck while moored at the quay.

Safety Risks Regarding Refuelling

The external safety distances[2] for swapping H2 containers at container terminals are relatively small (39 m) when containers are directly loaded from trailer onto the receiving vessel.

- However, in the future case when demand grows and storage of containers in the stack might be needed (to create a buffer stock), the external safety distance could increase with about a factor 3. This should normally not be a problem for container terminals because of their layout and location, which provides sufficient stand-off distance to vulnerable objects.
- Bunkering of gaseous hydrogen via hose results in relatively small distances (approx. 40 m) when bunkering takes place directly from a (tube)-trailer. The distance for bunker stations could go up to approximately 100 m.
- For truck-to-ship (TTS) bunkering of liquid hydrogen result in safety distances of approximately 80 m.

Existing Rules, Standards, Policies for Infrastructure

Regulations for the use of hydrogen on board of-, and bunkering of hydrogen to inland navigational vessels are still lacking. Currently, hydrogen-fueled vessels are only allowed to operate on inland waterways based on an exemption given by national authorities or the CCNR. However, ES-TRIN is currently being updated with technical requirements and rules for inland navigational vessels with fuel cell systems.

Infrastructure Costs

Cargo owners do not have an increased price willingness for greener transports, as long as a cheaper conventional alternative exists. In turn, higher costs affecting the entire industry can most likely be passed on to customers. For energy containment system swapping existing infrastructure of container terminals can be used.

A breakthrough of hydrogen supply to inland waterway ships will most likely require strategic engagement of a large industrial player (gas producer, utility company, oil or energy major), who is not only aiming at supplying (moderate amounts) of green hydrogen to inland waterway vessels but also to large consumers along the Inland Waterways. First ports with hydrogen bunkering infrastructure (for the time being swappable containers moved by container bridges) will be most likely one of the ARA ports, followed possibly by ports with container terminals alongside inland waterways.

Implementation (Pilots, Country/Region)

Containerised pressurized hydrogen for propulsion is already leaving pilot implementations behind.

See for example: **Future Proof Shipping – Creating a zero-emissions shipping world.**

Main Challenges, Technology Barriers

The availability of hydrogen as a fuel for vessels relates to hydrogen fuel production as well as to provision of bunkering infrastructure in a sufficient number of ports in the operating area.

Even though it appears likely that hydrogen bunkering infrastructure will be available in an ARA port and at least in the Ruhr area within the next few years, ship owners would face a limited number of potential suppliers and thereby a supply and a price risk.

Further Information

See for example **RH2INE » RH2INE Kickstart Study**.

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'OLEO-100' Biofuel for Propulsion of Inland Navigation Vessels

Rapeseed methyl ester, also known as OLEO100, is a biofuel produced exclusively from rapeseed oil. It is a B100 biofuel, meaning that it can be used in its pure form and does not need to be mixed with a fossil fuel. OLEO100 returns 3,7 times more energy than it is required to produce it. When used instead of conventional diesel, it reduces GHG emissions by up to 60 % and PM by almost 80 %.

Relevant Properties of Energy Carrier/Fuel

OLEO100 has an energy density comparable to that of diesel (slightly lower).

Storage Onboard

Similar to diesel/gasoil; OLEO100 is used in internal combustion engines and can be mixed with diesel, it is therefore compatible with existing conventional propulsion systems. OLEO100 is stored at ambient temperature and atmospheric pressure. Storage does not induce release of toxic or flammable vapours. However, OLEO100 has detergent properties that can scrape off residues, it is therefore recommended to clean the fuel system beforehand to avoid any clogging of sensible parts (filters, fuel valves, etc.)

Application (Type of Ship/Transport Task)

Similar to diesel/gasoil; nowadays, this biofuel is mainly used by heavy road vehicles. But it is being tested for application on inland vessels. This fuel could be used by any kind of heavy mobility (trucks, heavy duty vehicles, inland vessels, etc.) regardless of operation specificities and cargo transported.

Required Refuelling Infrastructure

Similar to diesel/gasoil; no additional precautionary measure has to be taken. Currently, as this fuel is still emerging, refuelling is done either by refuelling trucks or directly by drums delivered to the refuelling station.

Safety Risks Regarding Refuelling

OLEO100 is biodegradable and not toxic, it does not pose a threat to human health nor the environment. Furthermore, its flashpoint is 101°C compared to 75°C for conventional low sulphur diesel making it even safer to handle.

Existing Rules, Standards, Policies for Infrastructure

OLEO100 can be regarded as a conventional fuel when it comes to existing rules. From the vessel perspective, the European standard for technical requirements for inland navigation vessels (ES-TRIN) foresees additional requirements only for fuels with a flashpoint lower than 55°C, which is not the case for OLEO100. Engines that are CCNR 2 compliant can run on both diesel and B100, hence on OLEO100. As regards to NRMM regulation, the engine must hold a B100 type approval to run on OLEO100.

Furthermore, as OLEO100 is not considered harmful for human nor the environment, no specific policies related to infrastructure are needed.

Infrastructure Costs

Changes required for OLEO100 are minor (installation of fixed dedicated tanks at foreseen refuelling stations). Costs are therefore negligible compared to other alternative fuels.

Supply Chain Specifics: Waiting/Charging/Refuelling Times, Etc.

If available on location, OLEO100 refuelling specifics are comparable to those of conventional fuels. Comparable energy density and viscosity means comparable volumes and refuelling times.

Implementation (Pilots, Country/Region)

In France, there is one pilot project led by CFT-SOGESTRAN. CFT has partially converted one vessel (1 main engine out of 2) to OLEO100 in 2021 for a 6 months test period. The vessel is operated on the river Seine. So far, the experiment is rather positive, no major change has been observed regarding manoeuvring capabilities of the vessel and the engine shows no sign of premature wear. However, due to the increased flashpoint, combustion occurs at a higher temperature and produces more NOx.

Main Challenges, Technology Barriers

There is no technology barrier.

The main challenge is the long-term availability of this fuel if it is widely adopted. Rapeseed is primarily grown to feed cattle and produce vegetable oil. OLEO100 is only a by-product, and its production rate could not equal the current demand for fossil fuel. Therefore, OLEO100 is an interesting substitute for fossil fuel but can only be considered as a transition fuel for the time being.

Further Information

More information on the pilot project of CFT in France here:

https://www.saipol.com/en/news/la-filiale-cft-compagnie-fluviale-de-transport-du-groupe-sogestran-est-le-premier-transporteur-fluvial-a-naviguer-avec-oleo100-une-energie-100-colza-francais/.

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Methanol for Propulsion of Inland Navigation Vessels

Methanol is a climate neutral fuel, when it is produced from renewable energy. 2 to 3 MJ energy (input) is needed for 1 MJ of fuel (output). Methanol can be used as fuel for combustion engines or for fuel cells. When used with a combustion engine, the arrangements in the vessel are basically identical to those of conventional vessels. When used with a fuel cell, the arrangement is widely different and will consist basically of the fuel tank, the fuel reformer, the fuel cell and an electric propulsion system consisting of rechargeable batteries (mostly as back-up and for peak power needs), an electric switch board, control systems and electric motors.

Relevant Properties of Energy Carrier/Fuel

Methanol has a low energy density compared to gasoil/diesel fuel (factor 3), but higher than other alternative fuels. Otherwise, it is rather similar to diesel/gasoil.

Storage Onboard

Fixed (inbuilt) tanks, similar to those for diesel/gasoil, but most likely double walled or inerted with nitrogen.

Application (Type of Ship/Transport Task)

Methanol can be used for all applications.

Required Refuelling Infrastructure

Similar to diesel/gasoil; bunkering possible from bunkering vessels, tank trucks and fixed tank stations. No specific spatial planning issues as required safety distances similar to diesel/gasoil.

Safety Risks Regarding Refuelling

Safety risks similar to diesel/gasoil; lower flashpoint; toxic vapours: less toxic to aquatic environment. Because methanol is transported by inland tank vessels in large quantities, safety risks well understood and safety measures in place.

Existing Rules, Standards, Policies for Infrastructure

Technical requirements and standards for methanol as fuel on inland navigation vessels are under development in Europe as part of Chapter 30 and Annex 8 of the European Standard for Technical Requirements for Inland Navigation Vessels (ES-TRIN). No specific policies for infrastructure needed.

Infrastructure Costs

Infrastructure costs are on the same level as for diesel/gasoil and low in comparison to other alternative/climate neutral fuels.

Supply Chain Specifics: Waiting/Charging/Refuelling Times, Etc.

Similar to diesel/gasoil; because of low energy density more refuelling (bunkering) stops needed.

Implementation (Pilots, Country/Region)

In Europe, very small number of pilot applications have been approved.

Main Challenges, Technology Barriers

There are no significant technological barriers. The main challenge is the high cost for methanol itself, when it is produced from renewable energy. Otherwise, methanol could become a standard fuel for inland navigation.

Further Information

See for example:

- **https://marine-offshore.bureauveritas.com/inside-look-methanol-fuel**
- **https://www.interreg-danube.eu/uploads/media/approved_project_public/0001/39/c510e9deb4535f5d155ca9bf03d2db786a443a8f.pdf.**
- **https://www.e4ships.de/english/maritime-shipping/**

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Battery Electric Propulsion for Inland Navigation Vessels

A battery electric propulsion system consists in general of rechargeable batteries, electric switch board and an electric propulsion system.

Relevant Properties of Energy Carrier/Fuel

Electricity stored in rechargeable batteries has a low energy density compared to gasoil/diesel fuel (factor 10 … 100).

Storage Onboard

Fixed (inbuilt) or exchangeable (containerised) rechargeable batteries, possibly recharged during operation by solar panels.

Application (Type of Ship/Transport Task)

Because of low energy density, battery electric propulsion most suitable for ships that travel short distances (between stops). Ferries, day trip passenger vessels, etc. can use stops for recharging of fixed batteries. Exchangeable (containerised) batteries can be employed by container vessels, serving terminals with a distance in between of ca. 100 km.

Required Refuelling Infrastructure

For fixed batteries, electric charging points at mooring places; for exchangeable batteries, cranes, f.e. on container terminals with nearby charging point.

Safety Risks Regarding Refuelling

Similar safety risks as known from electric cars. Battery fires are rare, but hard to control.

Existing Rules, Standards, Policies for Infrastructure

Technical requirements and standards for rechargeable batteries exist, also when installed on vessels, such as Chapters 10 and 11 of the European Standard for Technical Requirements for Inland Navigation Vessels (ES-TRIN), or are under development, such as EN Standards for electrical, high-power ship-shore connections. In Europe, national and EU policies support the implementation of charging points at suitable locations of the inland waterway network.

Infrastructure Costs

Infrastructure costs are high as many charging points are needed and as rechargeable batteries for inland navigation vessels require a high-capacity power supply. In Europe, the large number of existing ship-shore connections at mooring places intended to supply electric energy for vessels stopping overnight are insufficient.

Supply Chain Specifics: Waiting/Charging/Refuelling Times, Etc.

Rechargeable batteries for propulsion of ships have charging times of several hours. Fixed batteries can be recharged overnight, in the case of ferries also topped up during intermediate stops. Exchangeable batteries can be swiftly replaced during stops at container terminals.

Implementation (Pilots, Country/Region)

Battery electric propulsion is already leaving pilot implementations behind.

See for example:

- **https://de.wikipedia.org/wiki/Sankta_Maria_II,**
- **https://solarcircleline.com/**
- **https://zeroemissionservices.nl/en/homepage/.**

Main Challenges, Technology Barriers

The technology is well developed and even in inland navigation more and more often applied. The technology is also rather simple compared to technologies for other alternative fuels/energy carriers. Infrastructure costs are high with little economy of scale. Battery costs will further decrease, and energy density will increase, allowing battery electric propulsion becoming a technical and economically feasible alternative for certain inland navigation tasks.

Further Information

See for example **https://www.interreg-danube.eu/uploads/media/approved_project_public/0001/39/709e196ec09e54cfcf0dd20dd8b54cdf456dfe4b.pdf**.

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