RH2INE PROGRAM: SUB-STUDY 1A: SAFETY FRAMEWORK CONDITIONS

SuAc 1.1c Hydrogen Demand Study

RH2INE Consortium

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Customer:	RH2INE Consortium	Zwolseweg 1
	Att. Havenbedrijf Rotterdam N.V.	2994 LB Barendrecht
	Postbus 6622 Port Number 1247 PB 6622	Netherlands
	3002 AP ROTTERDAM	Tel: +31 (0) 10 2922600
	Netherlands	VAT No.: NL008585635B01
Customer contact:	J.C. Boon (Port of Rotterdam)	
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Objective: this report provides a prognosis of the demand of hydrogen by inland vessels in a time frame of 20 years; including challenges or possible incentives. In addition, CO2 emission savings are quantified based on the estimated ramp-up of hydrogen demand at the cost of diesel.

Prepared by:	Verified by:	Approved by:
Dr. Jan-Henrik Hübner Global Head of Shipping Advisory	Jochum Douma Consultant	Rob van der Spek Head of Risk Management Advisory NL, digital lead region CEMEIA
Guido Carstensen Principal Consultant	Dennis van der Meulen Senior Consultant	

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ABREVIATIONS

ADN	European agreement concerning international carriage of dangerous goods by inland waterways
AIS	Automatic Identification System
ARA	Amsterdam, Rotterdam, Antwerp
BAW	Bundesanstalt für Wasserbau
BLN	Koninklijke BLN-Schuttevaer
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCNR	Central Commission for the Navigation of the Rhine (German: ZKR)
ENI	European Number of Identification
ETISplus	European Transport policy Information System
ETS	European Emissions Trading System
GHG	Greenhouse Gas
HVO	Hydrogen Vegetable Oil
IMO	International Maritime Organization
IVR	International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe
IWT	Inland waterway transport
LNG	Liquefied Natural Gas
NO_x	Nitrogen oxides
MCR	Maximum Continuous Rating of engines
MGO	Marine Gas Oil
MPA	Maritime and Port Authority of Singapore
NRMM	Non-Road Mobile Machinery Directive of the EU
OPEX	Operating Expenditure (here used incl. fuel)
PEM	Proton-Exchange Membrane fuel cell
PoR	Port of Rotterdam
RH2INE	Rhine Hydrogen Integration Network of Excellence
SCR	Selective Catalytic Reduction
STS	Ship-To-Ship

EXECUTIVE SUMMARY

Introduction

The Rhine Hydrogen Integration Network of Excellence (RH2INE) is an international programme and consists of public and private parties. Its global aim is to implement hydrogen as a fuel in the inland waterway transport (IWT). This report is the result of "sub-activity 1.1c: Demand study hydrogen bunkering of inland navigational vessels" of the tender "Sub-study 1a: Safety framework conditions" issued by the Port of Rotterdam Authority (PoR) on behalf of the RH2INE consortium.

This sub-activity report provides a prognosis of the demand of hydrogen by inland vessels in a time frame of 20 years (2020-2040); including challenges or possible incentives. It starts with setting the baseline, outlining the fleet operating on the Rhine, its trade and current fuel demand. Baselining is followed by a qualitative assessment of the market potential for hydrogen. Subsequent demand prognosis in a quantitative assessment where three specific scenarios are analysed.

In addition, CO2 emission savings are quantified based on the estimated ramp-up of hydrogen demand at the cost of diesel.

Objective

Whereas the overall sub-study 1a focusses on safety and regulations related to technical and operational aspects of hydrogen bunkering and transport, this sub-activity has two objectives:

- Qualitative assessment: Create an overview on the industry's perspective on hydrogen as fuel for inland waterway vessels in the context required emission reduction and available green fuels. Identify key drivers for adoption in ship newbuilds and existing vessels as well as potential challenges and incentives.
- Quantitative assessment: Quantify the demand for hydrogen as fuel for inland waterway vessels operating on the Rhine for the time frame 2020 to 2040 considering scenarios for regulatory and technology development. Quantify potential greenhouse gas (GHG) abatement.

Approach

Baselining: In a first step an overview on today's and potential future fleet, its operation and the resulting energy demand is being created in a desk-top approach based on a number of relevant and acknowledged data sources (reports, data bases) on fleet and trade. Operational profiles are verified by use of AIS (Automatic Identification System) data. The energy demand is modelled based on technical data and operational profiles for representative vessels clusters and scaled up to the full fleet.

Qualitative assessment: In a second step the industry perspective on alternative fuels and hydrogen has been created based on a number of semi-structured interviews with operators of larger fleets, bunker suppliers and industry associations, a workshop with more than 20 RH2INE members, DNV experience/expert knowledge and several external reports on market adoption of alternative fuels and effectiveness of related programs.

Qualitative assessment: In a third step, finally, the consumption baseline has been combined with the scenarios developed as result of the qualitative assessment in a model determining future hydrogen demand and respective GHG abatement.

Baseline

About 10.500 inland waterway vessels are operating on the Rhine with the majority of voyages between ARA ports and Ruhr area and fewer voyages towards the middle and upper Rhine up to Basel. Dry cargo vessels constitute the majority of the fleet, followed by tankers as well as push and tug boats. The average newbuilding rate is 80 vessels per year resulting in an average fleet age of 52 years with only tankers and ferries being significantly younger (average around 30 years).

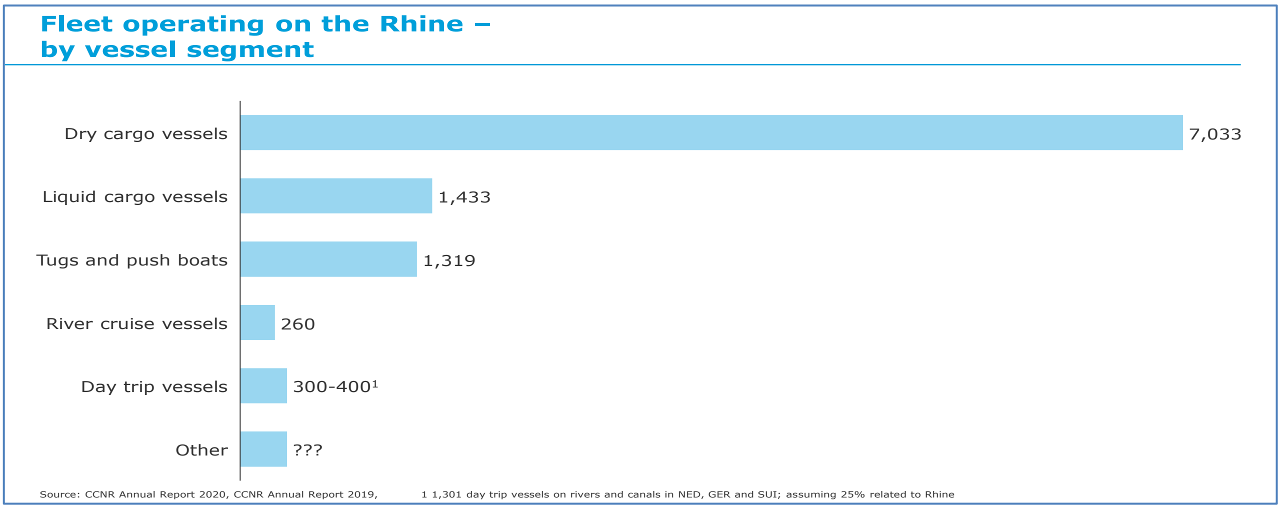

Figure 1: Fleet operating on the Rhine – by vessel segment

Based on a consumption model the total fuel (diesel) consumption of inland waterway vessels on the Rhine can be estimated to roughly 2.6 million tons, resulting in CO2 emissions of about 8.3 million tons.

Qualitative assessment

Hydrogen needs to compete with conventional diesel and a range of other alternative emission-reduced or emission free fuels. Whereas ship owners take technology and fuel decisions for newbuilds and existing vessels based on criteria as greenhouse gas (GHG) compliance, technology readiness, operability, regulation and availability, the decision is finally made based on the business case, which is (co-) influenced by the other criteria too.

Under today’s regulatory boundaries and technology status hydrogen is not favourable compared to most of the other fuels.

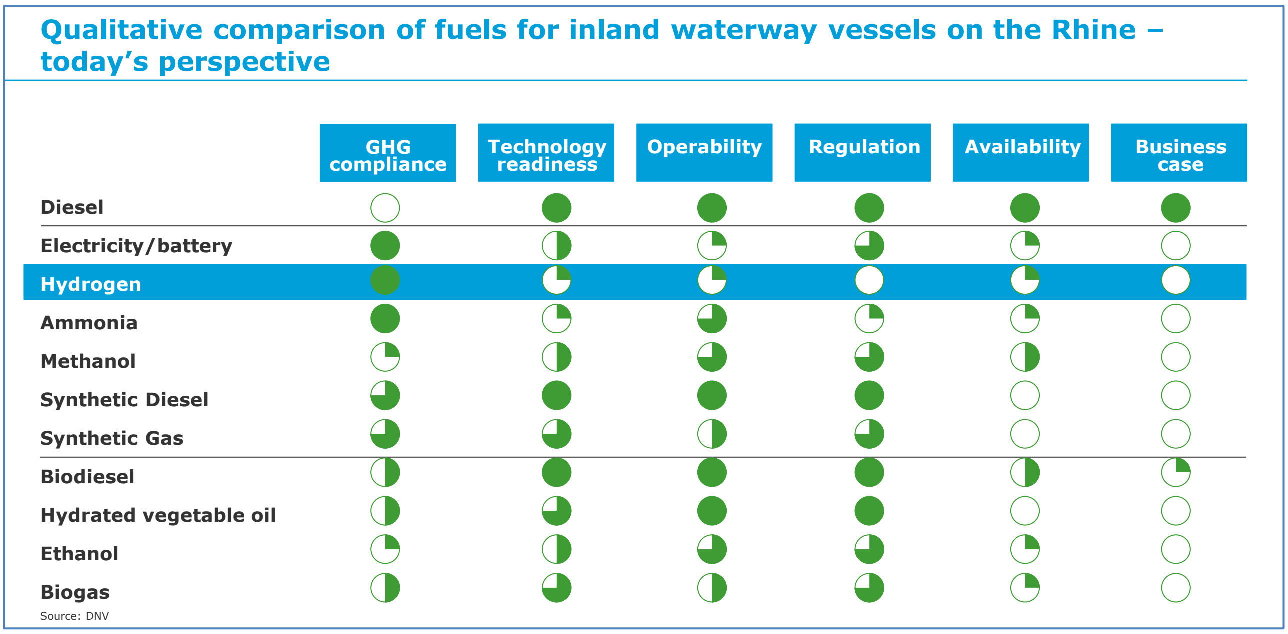

Figure 2: Qualitative assessment of fuels for inland waterway vessels – today's perspective

However, considering the regulatory and technology developments and the progressing regulation, hydrogen has good chances (depending on the scenario) to have a break-even or even favourable business case in the future.

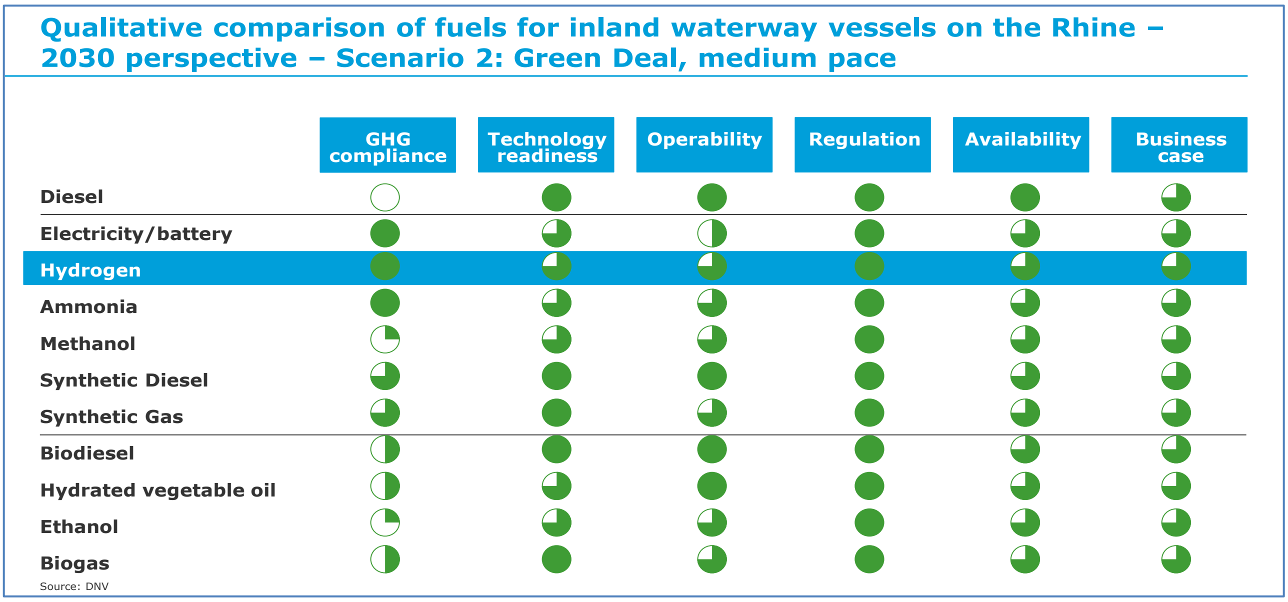

Figure 3: Qualitative assessment of fuels for inland waterway vessels – 2030, scenario 2

Quantitative assessment

In order to reflect the uncertainty about the development GHG-related regulation of inland waterway transport, technical developments and market development of alternative fuels, three specific scenarios are reflected in the consumption model:

- Scenario 1: Current instruments, moderate technology development pace
- Scenario 2: Green Deal, medium technology development pace
- Scenario 3: Zero GHG emissions by 2050, rapid technology development

Depending on regulatory pathway and technology development pace between about 5,000 and 50,000 tons of hydrogen will be consumed by inland waterway vessels on the Rhine in the year 2030. While the low case scenario strongly depends on vessels newbuilds equipped for hydrogen, in both other scenarios newbuilds and retrofitted existing vessels will each contribute about half to the demand. – Until 2040 the spread between the scenarios remains constant with a range from 10,000 to little more than 100,000 tons/year. Vessels built between 2020 and 2040 will create between 60 and 80% of the demand.

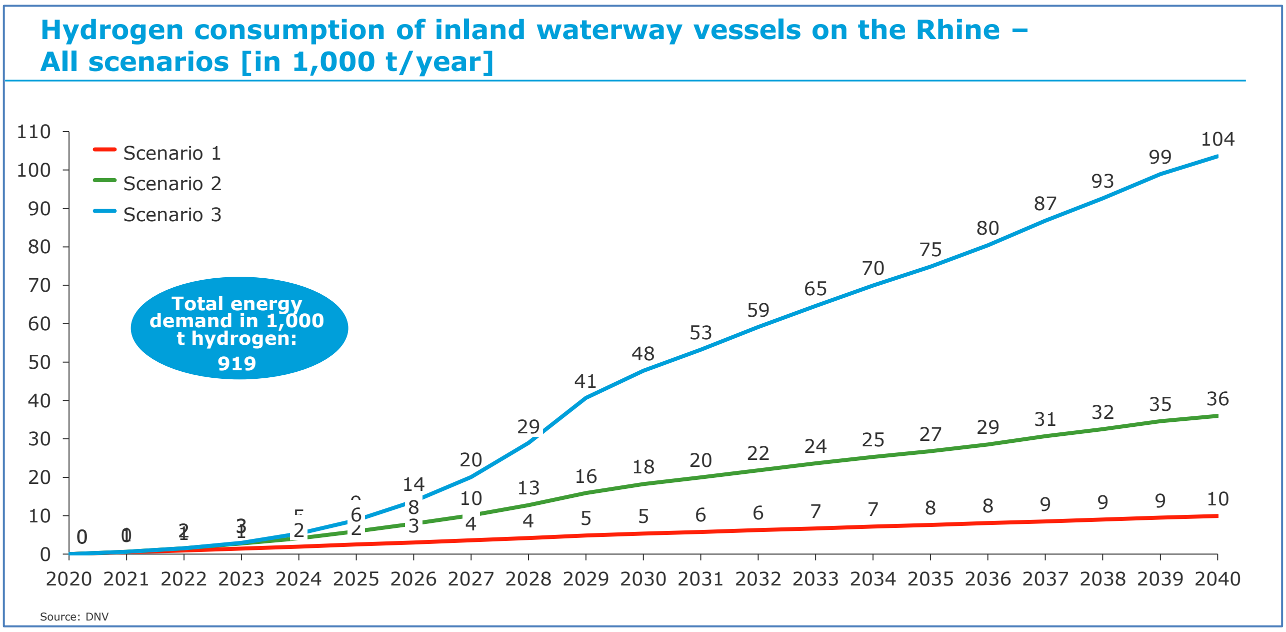

Figure 4: Hydrogen consumption of inland waterway vessels on the Rhine – all scenarios

Comparing the projections for 2040 with the total energy demand of inland waterway vessels operating on the Rhine (equivalent to about 900,000 tons/year), hydrogen will be one fuel among others with a total share between 1 and 10%. The big gap originates from the huge fleet of vessels which are already older than 20 years and will most likely rather use emission reduced or zero-emission drop in fuels with conventional combustion engines.

The CO2 abatement, which will be achieved by introduction of hydrogen as fuel for inland waterway vessels, varies for the three scenarios. In the year 2030 the abatement will be between 50,000 and 450,000 tons/year CO2 (cumulated 260,000 to 1.6 million tons). In 2040 the abatement will be between 91,000 and 950,000 tons/year (cumulated 980,000 to 8.7 million tons).

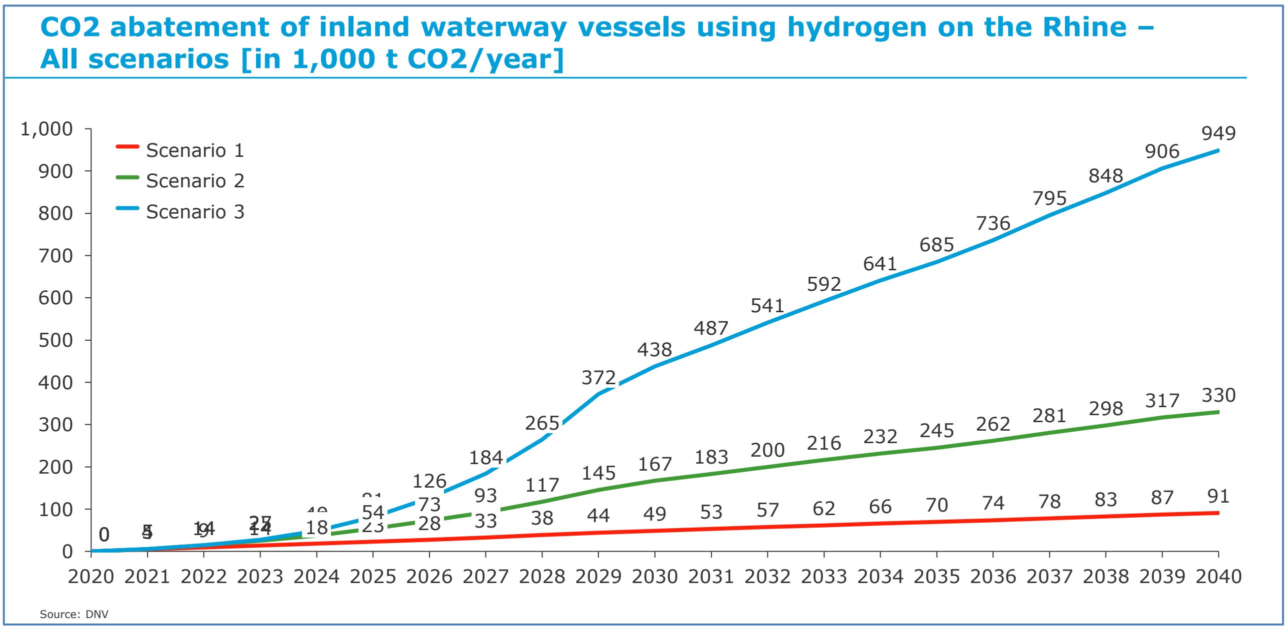

Figure 5: CO2 abatement of inland waterway vessels on the Rhine – all scenarios

Conclusion

The inland waterway industry is committed to contribute its fair share to the required reduction of greenhouse gas emissions by 2030, 2040 and beyond. – Operators have a generally positive view on green fuels and there is a general understanding that on a level playing field the overall profitability of the industry would be largely unchanged with an upside potential comparing to alternative means of transport (esp. road)

Ship owners take the choice of alternative propulsion technology and green fuels based on six decision criteria, with the specific business case being the ultimate one – GHG compliance (emission reduction credited by the regulator), technology readiness (storage system, energy converter), operability (potential adverse or positive effects compared to diesel), regulation (ship design, local permission process), availability (fuel production and bunkering infrastructure, number of suppliers) and business case (CAPEX, OPEX, revenue), influenced by the other factors

The penetration of alternative fuels in general and hydrogen in particular strongly depends on the regulatory boundaries set by EU and its member states. – CO2 pricing will have a major effect on the penetration rate of alternative fuels. Direct investment CAPEX subsidies can play an important role to accelerate the technology development and overcome technical and related operational challenges of hydrogen and other zero-emission and emission-reduced fuels. A mechanism comparable to the Norwegian NOx fund may be considered to stimulate the penetration of alternative fuels. Funds raised by pricing emissions (e.g., GHG taxation collected via the bunker suppliers) of all inland waterway vessels operating on the Rhine can be 100% recycled to the industry for direct grants for investment into clean technology.

Whereas hydrogen can be a significant part of the solution for newbuilds and younger existing vessels, additional solutions need to be found for older existing vessels. – The total energy demand of inland waterway vessels operating on the Rhine equals about 2.6 million tons/year of diesel or 920,000 tons/year of hydrogen. Depending on regulatory pathway and technology development pace between about 10,000 and 100,000 tons/year of hydrogen will be consumed in the year 2040. This equals a share of 1 to 10% of the total energy demand and saves 90,000 to 950,000 tons/year CO2 in 2040. – If all newbuilds from 2020 onwards would be fuelled with hydrogen, the total demand of these vessels would amount to about 270,000 tons/year in 2040, 29% of the total energy demand. If in addition all vessels reaching an age of 20 years would be retrofitted to hydrogen from 2020 onwards, this would contribute another 230,000 tons/year, 25% of total energy demand. About 420,000 tons/year (46% of total energy demand) would be the remaining gap caused by vessels, which are older than 20 years and appear (from a commercial perspective) not to be predestined for hydrogen retrofitting when their main engines need to be replaced in the age of 40 or older. It appears that emission-reduced or emission-free drop-in fuels will be required for these vessels.

1 INTRODUCTION

The world fleet is large with 115,000 ships and it will grow in the years to come, with more than 30% up to 2030. IMO's goal of halving CO2 emissions from shipping by 2050 will lead to a significant restructuring over the next thirty years. The IMO targets and national decarbonization policies are expected to be fundamental drivers for developing low and zero emission technologies in the shipping industry. Next to IMO's goals, the European Union formulated its goals for all sectors in the European Green Deal. It is necessary to find and integrate low-emission propulsion fuels, such as hydrogen, in every part of the transport sector. Hydrogen could significantly reduce emissions, but implementation in inland shipping is new. Hydrogen is the only available zero emission solution for longer distances and high energy needs, but it will remain expensive, especially in the short term. To bring costs down it is absolutely necessary that authorities push for hydrogen technology to be used in vessels and that safety rules & regulations are standardized, which do not exist today.

The Rhine Hydrogen Integration Network of Excellence (RH2INE) is an international programme and consists of public and private parties. Its global aim is to implement hydrogen as a fuel in the inland waterway transport (IWT). On behalf of the consortium of the RH2INE programme, the Port of Rotterdam Authority (PoR) issued an invitation to tender (sub-study 1a: Safety framework conditions) that specifically focusses on safety and regulations related to technical and operational aspects of hydrogen bunkering and transport scenarios for inland navigational vessels. The invitation to tender specifies four sub-activities:

- Sub-activity 1.1a: Identification of hydrogen containment systems for transport and propulsion on board of inland navigational vessels.
- Sub-activity 1.1b: Identification of hydrogen bunkering scenarios for inland navigational vessels.
- Sub-activity 1.1c: Demand study hydrogen bunkering of inland navigational vessels
- Sub-activity 1.1d: Identification of gaps in regulations and standards for the use of hydrogen on board of-, and the supply of hydrogen to inland navigational vessels.

This specific report focusses on sub-activity 1.1c: "Demand study hydrogen bunkering of inland navigational vessels". Whereas hydrogen in combination with fuel cells is used in silent running of submarines today and there are several applications on commercial vessels globally, experience with applications on inland vessels is very limited yet. The closest related to IWT are the hydrogen car ferries that are currently being developed to sail on the Norwegian fjords. There are a few application cases with hydrogen fuel cell technology (e.g. passenger boat "Alsterwasser" in Hamburg), but these tend to be showcases with political backing and public subsidies rather than based on economic decisions by private investors. Technical and regulatory and most important the economic cornerstones of using hydrogen as fuel for IWT are developing and are likely to be more favourable in 10 and 20 years than what they are today. Accordingly, the future hydrogen demand for IWT can hardly be extrapolated from today's market penetration.

This sub-activity report provides a prognosis of the demand of hydrogen by inland vessels in a time frame of 20 years (2020-2040); including challenges or possible incentives. It starts with setting the baseline, outlining the fleet operating on the Rhine, its trade and current fuel demand. Baselining is followed by a qualitative assessment of the market potential for hydrogen. Subsequent demand prognosis in a quantitative assessment reflects uncertainty about the development GHG-related regulation, technical developments and market development in three specific scenarios:

- Scenario 1: Current instruments, moderate technology development pace
- Scenario 2: Green Deal, medium technology development pace
- Scenario 3: Zero GHG emissions by 2050, rapid technology development

In addition, CO2 emission savings are quantified based on the estimated ramp-up of hydrogen demand at the cost of diesel.

2 STUDY APPROACH

The demand study on hydrogen as potential fuel for inland waterway vessels operating on the river Rhine is based on three steps:

- Baselining – fleet, operation and fuel demand on river Rhine
- Qualitative assessment of market potential for hydrogen
- Quantitative assessment of market potential for hydrogen

These steps are detailed in the paragraphs below.

2.1 Baselining

Objective of the baselining is to create an overview on today's and potential future fleet, its operation and the resulting energy demand. This allows determining the theoretically addressable demand for hydrogen.

The fleet overview is based on a number of relevant and acknowledged data sources as:

- CCNR Annual Report 2020 "Inland Navigation in Europe – Market Observation"
- CCNR Annual Report 2019 "Inland Navigation in Europe – Market Observation"
- BAW "Driving Dynamics of Inland Vessels", 2016
- Bundesverband der Deutschen Binnenschiffahrt "Daten und Fakten 2018/2019"
- IVR "Ships Information System Database", Sept 2020
- IVR "Annual Report 2019"
- IHS Markit "Seaweb"

Trade (development) respectively ship operation data are taken from

- CCNR Annual Report 2020 "Inland Navigation in Europe – Market Observation"
- CCNR "Market Insight on Inland Navigation", April 2020
- CCNR Thematic Report "RIVER-SEA TRANSPORT IN EUROPE", January 2020
- EU Statistical Pocketbook 2019 "EU Transport in Figures"
- BAW "Driving Dynamics of Inland Vessels", 2016
- Bundesverband der Deutschen Binnenschiffahrt "Daten und Fakten 2018/2019"
- BLN-Schuttevaer Info graphic „De Nederlandse Binnenvaart"
- Stichting Projecten Binnenvaart PROMINENT report „D1.1 List of operational profiles and fleet families", 2016
- Vesseltracker AIS data

Official statistics on fuel demand of inland waterway vessels operating on the river Rhine, respectively amount of fuel bunkered in Rhine and ARA ports to inland waterway vessels are apparently not available. Instead one has to build on estimates of industry experts, i.e. bunker suppliers, operators of larger fleets and representatives of industry associations and can model consumptions based on engine and typical trade patterns per ship cluster.

2.2 Qualitative assessment

Objective of the qualitative demand assessment is to create an overview on the industry's perspective on green fuels in general and on hydrogen in particular. Key drivers as well as potential challenges and incentives need to be reflected to understand the market potential of hydrogen and derive scenarios for penetration rates in ship newbuilds and retrofits of existing vessels.

The qualitative assessment is based on:

- Semi-structured interviews with operators of larger fleets, bunker suppliers and industry associations:
    - Danser Group (Container), Ben Maelissa
    - HTS Group (Container), Henk Heuvelman
    - HGK (Dry bulk, chemical tanker, gas tanker), Tim Gödde
    - HTAG (Dry bulk), Sebastian Hasselmans
    - A-Rosa (River cruise), Matthias Lutter
    - Future Proof Shipping (zero-emissions marine transportation), Prasanna Colluru
    - A. Nobel & Zn. (Bunker supplier), H.C. Nobel sr., A. Nobel jr.
    - BLN-Schuttevaer (Industry association), Willy Kreusch

  The interview questionnaires can be found in the Appendix.

- Workshop discussion on 2020-09-30 with more than 20 RH2INE members of the following organizations
    - Air Liquide S.A.
    - Darel Consultancy B.V.
    - Covestro AG
    - Duisburger Hafen AG
    - EnergieAgentur NRW
    - Future Proof Shipping B.V.
    - HGK Häfen und Güterverkehr Köln AG (Imperial Logistics)
    - HTS Group
    - Koedood Marine Group
    - LEC GmbH
    - Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen
    - Port of Rotterdam N.V.
    - Province of Zuid Holland
    - Reederei Jaegers GmbH
    - RheinCargo GmbH & Co. KG
    - Rhenus SE & Co. KG
- DNV experience/expert knowledge on introduction of alternative fuels (e.g. hydrogen, LNG, batteries etc.) and related governmental programs (e.g. DNV as technical advisory in Norwegian NOx fund and Green Shipping Programme, partnership with MPA in Singapore etc.)
- External reports on market adoption of alternative fuels and effectiveness of related programs
    - MariGreen Feasbibility Study "Use of Hydrogen as Fuel in Inland Shipping", Oct. 2018
    - Ecorys PROMINENT report "D1.3 Analysis of barriers and facilitating factors for innovation uptake", Nov. 2015

- DUAL Ports, "Feasibility of Hydrogen Bunkering", 2019
  - EICB, "Waterstof in Binnenvaart en Short Sea", 2020
- External reports and articles on newbuild and conversion projects using hydrogen as fuel for inland waterway vessels:
  - MariGreen Feasbibility Study "Use of Hydrogen as Fuel in Inland Shipping", Oct. 2018
  - Binnenschifffahrt 2020-09 "Elektra - Vorzeige-Projekt für Wasserstoff-Technologie"
  - Future Proof Shipping "Zero Emissions Inland Container Vessel"
  - SWIM "First hydrogen fuelled water taxi being developed by Envui and partners for Rotterdam"
  - BeHydro (Anglo Belgium Corporation and CMB) "BeHydro hydrogen dual-fuel engine launched in Ghent!"
- Interviews in course of other sub-activities of RH2INE sub-study 1a (1.1a, 1.1b):
  - Eifer
  - Enviu
  - Future Proof Shipping
  - Hexagon Lincoln/HYON
  - Hydrogenious
  - H2 Fuel Systems
  - LEC
  - Nedstack fuel cell technology
  - Port of Amsterdam
  - Vattenfall
  - Voyex

Based on the synthesis of interviews, reports, articles etc. technical, regulatory, infrastructure-related and finally (positive and negative) economic drivers of the demand for hydrogen as fuel for IWT vessels on the Rhine corridor are being derived. Potential challenges hindering demand and incentives fostering demand are being identified. Different scenarios are being defined based on the drivers, with effects on penetration rates in newbuilding and retrofitting of ships with hydrogen as fuel.

2.3 Quantitative assessment

Objective of the quantitative assessment is to combine theoretical or technical demand by ship cluster determined in step 1 (baselining) with assumed market penetrations in newbuilding and retrofitting developed in step 2 (qualitative assessment) to prognose the demand of hydrogen by inland navigational vessels on the Rhine corridor in a time frame 2020 to 2040.

The model prognoses energy demand by ship cluster for the time frame 2020 to 2040, considering development of cargo flows, development of ship sizes, replacement rates (newbuilding, retrofitting), etc. It combines the energy demand with penetration rates of hydrogen as ship fuel in newbuilding and retrofitting by ship cluster as developed in step 2 (qualitative assessment) for three different scenarios. Results for "high potential clusters" are being validated with experts.

CO2 emission savings from replacement of diesel to hydrogen are being quantified.

3 BASELINING – FLEET, OPERATION AND FUEL DEMAND ON RIVER RHINE

3.1 Fleet overview

This chapter provides an overview on the fleet currently operating in Western Europe in general and on the Rhine in particular. Besides an overview on vessel segments and differentiation by age, deadweight, engine size and country of registration, an overview is given in newbuilding and scrapping activity. Due to the need to use different data sources, vessel categorization partially changes between figures.

Current fleet

Some of the sources are operating area specific, looking at vessels on the Rhine only, but not providing a detailed breakdown with technical data of the fleet. The CCNR Annual Report 2020 "Inland Navigation in Europe – Market Observation" lists 9,785 cargo vessels operating on the Rhine, comprising 7,033 dry cargo vessels (propelled and non-propelled units), 1,433 liquid cargo vessels and 1,319 push and tug boats (see Figure 6).

Between 2005 and 2019 the number of dry cargo vessels in Rhine countries have decreased by about 17% (CAGR -1.3% p.a.), while the total loading capacity has increased by 15% (CAGR +1.0% p.a.). Liquid cargo vessels and transport capacity increased between 2005 and 2010. Since 2010 the number of vessels steadily decreases by 2.0% p.a., while the total loading capacity is practically unchanged.

In addition to the cargo vessels the CCNR Annual Report 2020 lists about 260 river cruise vessels operating on Rhein/Main/Danube. This is more than a doubling since 2014 (ca. 110 vessels, CAGR 5.9% p.a.).

Vessels of other types (ferry, day trip, service vessels etc.) are not explicitly listed in the CCNR Annual Report 2020. However, the CCNR Annual Report 2019 covers at least 1,301 day-trip vessels operated on rivers and canals (not the Rhine only), thereof 783 in Germany, 510 in the Netherlands and 8 in Switzerland. It can be assumed that about a quarter of them operates on the Rhine.

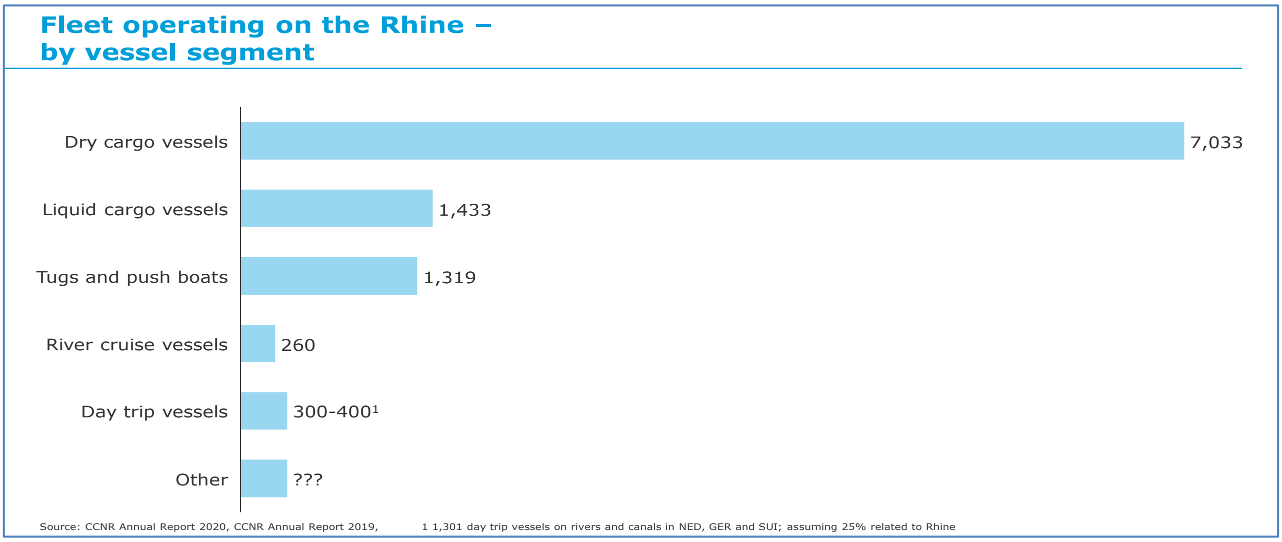

Figure 6: Fleet operating on the Rhine – by vessel segment

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Newbuilding and scrapping activity

In relation to the overall fleet size newbuilding activity is very moderate and stable since 2009 with a slightly increasing trend during the past 5 years. The IVR Annual report 2019 names 394 vessel newbuilds between 2014 and 2019, i.e. on average 79 per year (see Figure 7).

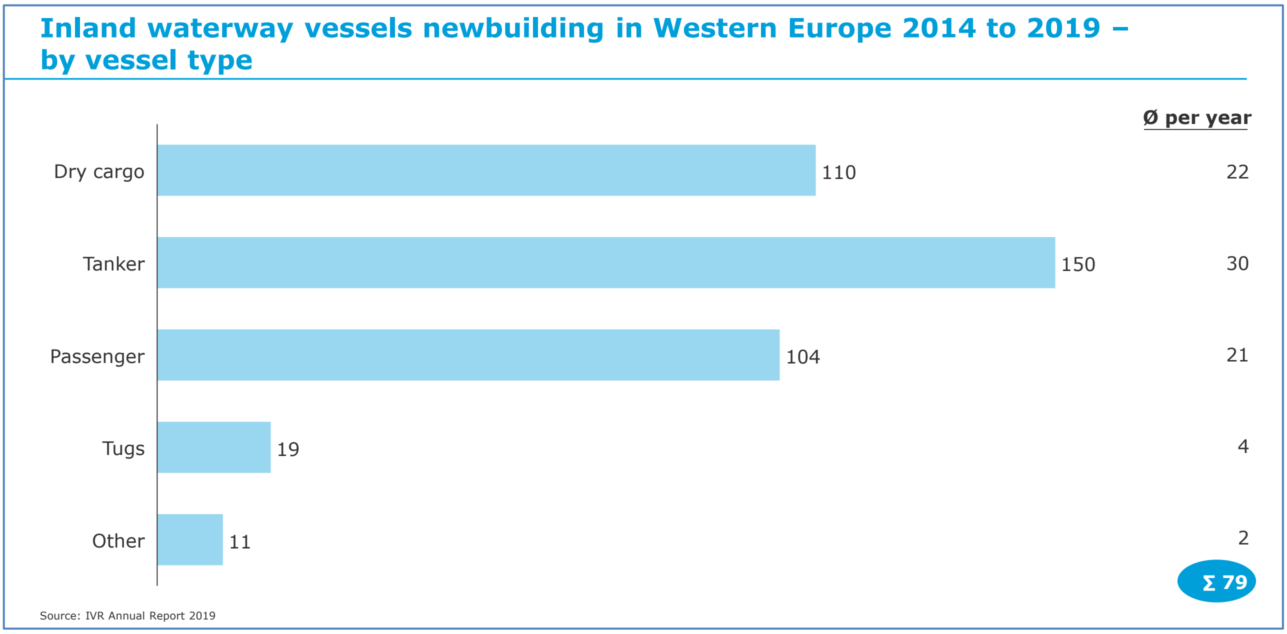


Figure 7: Inland waterway vessel newbuilding in Western Europe 2014 to 2019

According to the CCNR Annual Report 2020 20 dry cargo vessels and 40 tankers were added to the fleet in Western Europe in 2019. For dry cargo vessels this corresponds to a newbuilding rate of below 0.3%, for tankers of about 2.5%. New dry cargo vessels are typically built in deadweights of 2-4,000 t. Main owner country of newbuilds are the Netherlands followed by Belgium. New tankers are typically built in deadweights of 1,000 to 3,000 t with Netherlands and Germany being main owner countries. 19 new river cruise vessels have been delivered in Europe in 2019, 5.0% relative to the European fleet. Similar newbuild numbers have been expected for 2020 and possibly 2021.

The IVR Annual report 2019 provides the scrapping numbers for Western Europe (overall 53 in 2019 vs. 73 in 2018, see Figure 8).

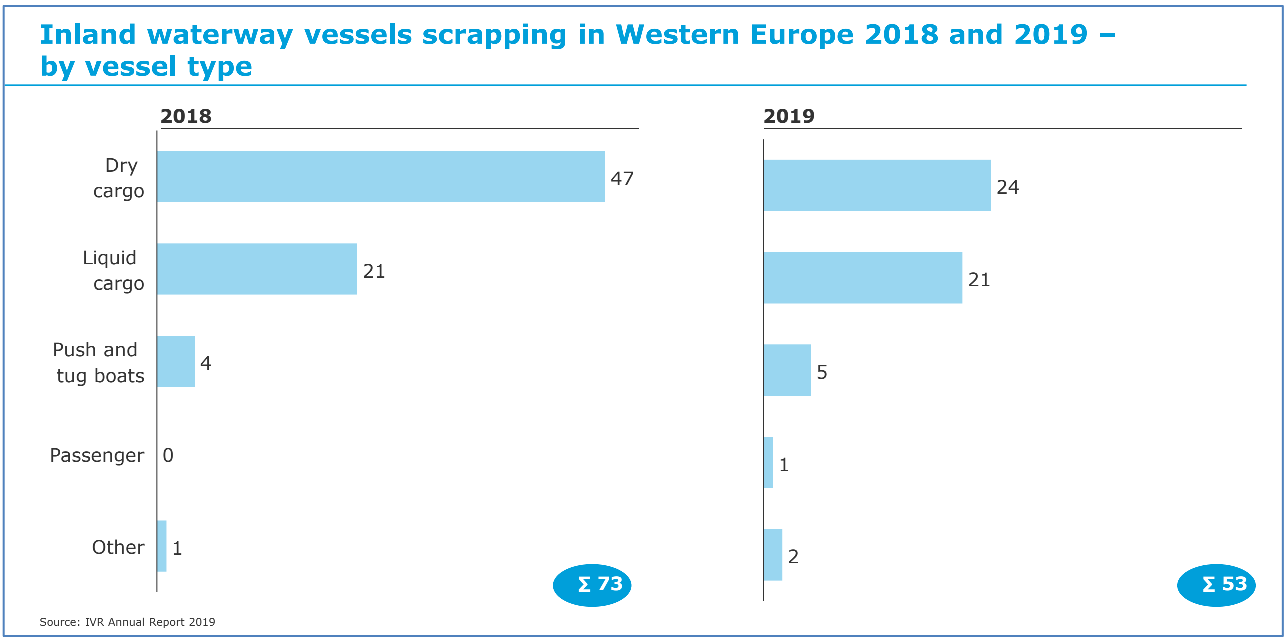


Figure 8: Inland waterway vessel scrapping in Western Europe 2018 and 2019

Country of registration

Any further breakdown of the fleet requires analyses in the IVR "Ships Information System Database", which comprises 11,643 vessels registered in the following Western European countries (Figure 9).

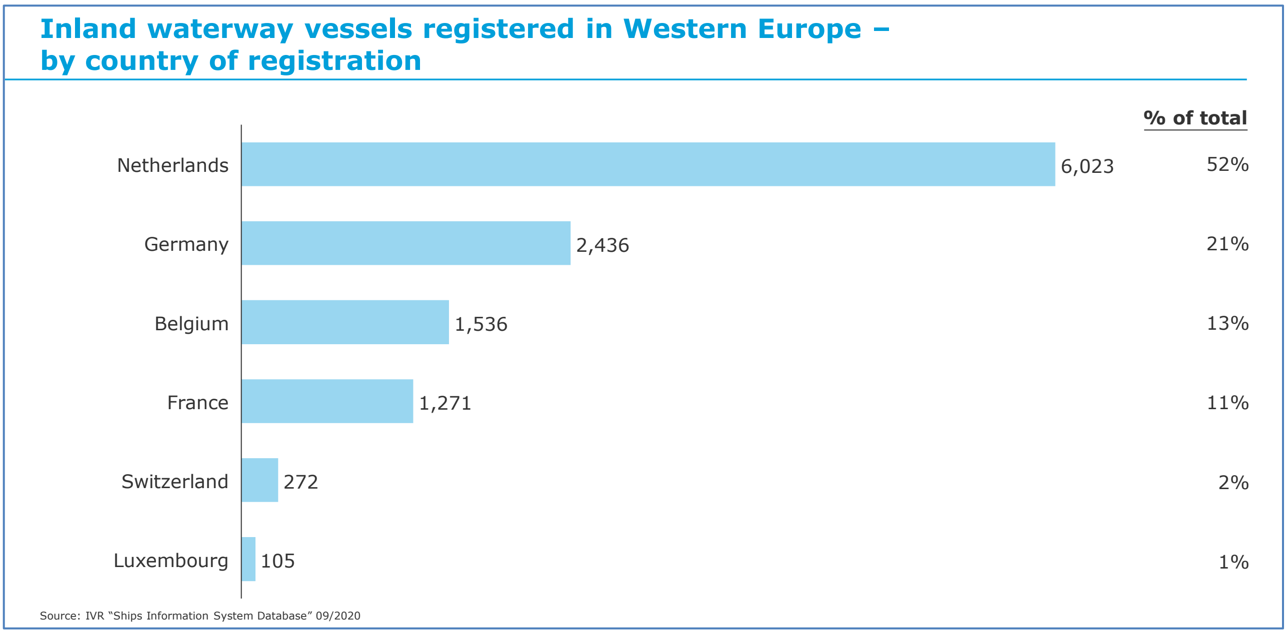


Figure 9: Inland waterway vessels registered in Western Europe – by country of registration

Whereas for only 2,323 of these 11,643 vessels an "Area of Navigation" is listed and 95% of the 2,323 have a certificate to sail on the Rhine, it can be assumed that the full list of more than eleven thousand vessels comprises about 1,000 vessels which are not operating on the Rhine (e.g. in northern France or canals only). A further check combining the technical data from the IVR "Ships Information System Database" via the ENI with position data from the Automatic

Identification System (AIS), which all vessels operating on the Rhine need to send, could not be made, as the available AIS dataset for 2019 did not contain ENIs but only IMO numbers (for just about 1,000 vessels, as the other vessels don't seem to have an IMO number).

However, assuming that the fleet composition of 11,643 vessels in the IVR database for Western Europe is largely representative for the about 10,500 vessels which sailed on the Rhine in 2019, we see the following composition of the Rhine fleet (Figure 10):

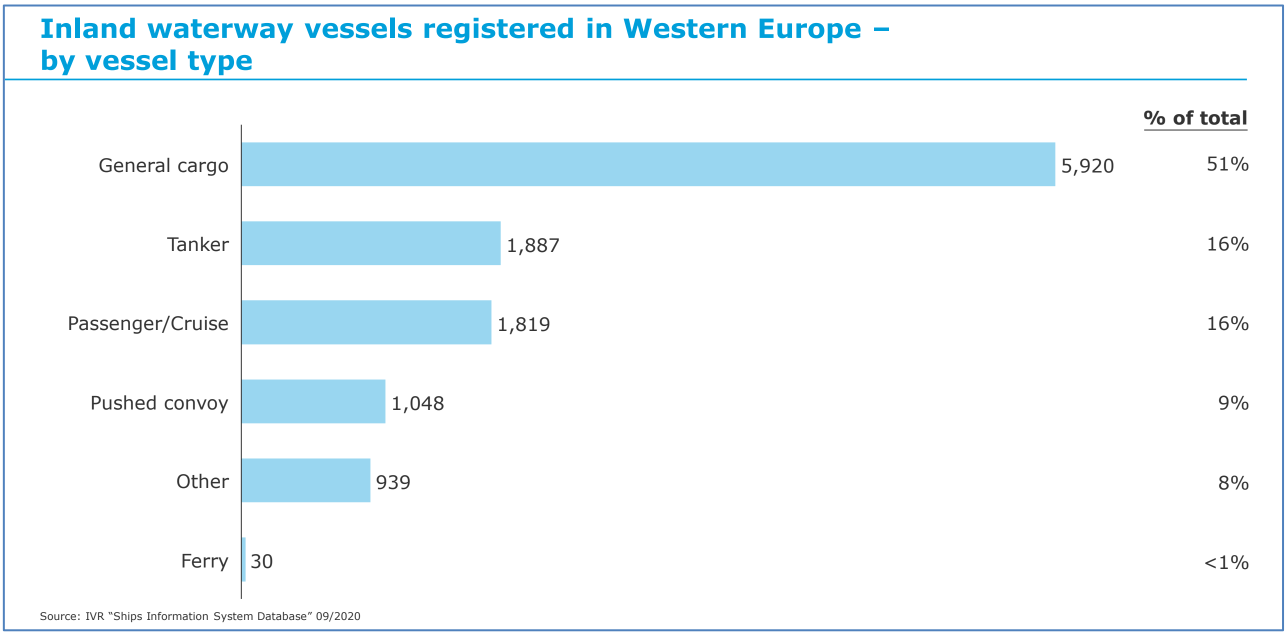


Figure 10: Inland waterway vessels registered in Western Europe – by vessel type

With 5,920 vessels about half of the fleet operating on the Rhine consists general cargo vessels, a term which IVR uses for both dry bulk vessels and container vessels. Only 271 (5%) out of the 5,920 vessels are characterized as "freight barge" whereas there is no meaningful differentiation provided for the others. For 2,318 (39%) of the general cargo vessels there is no engine power given in the IVR database. However, it may not be concluded that all of them are non-propelled, as for 426 of them a main engine construction year is given.

Besides the general cargo vessels, tanker and passenger/cruise vessels are the next biggest vessel segments. Out of the 1,819 passenger/cruise vessels 1,158 are characterized as day cruise ships, 438 as cruise ships, 128 as ferry and 95 fall under other sub-segments.

Vessel age

The average fleet age is 52 years, whereas general cargo ships, pushed convoys and other vessels are on average even older, while ferries and tanker have comparably young average fleet ages of 26 respectively 32 years. With 47 years passenger vessels are near the average.

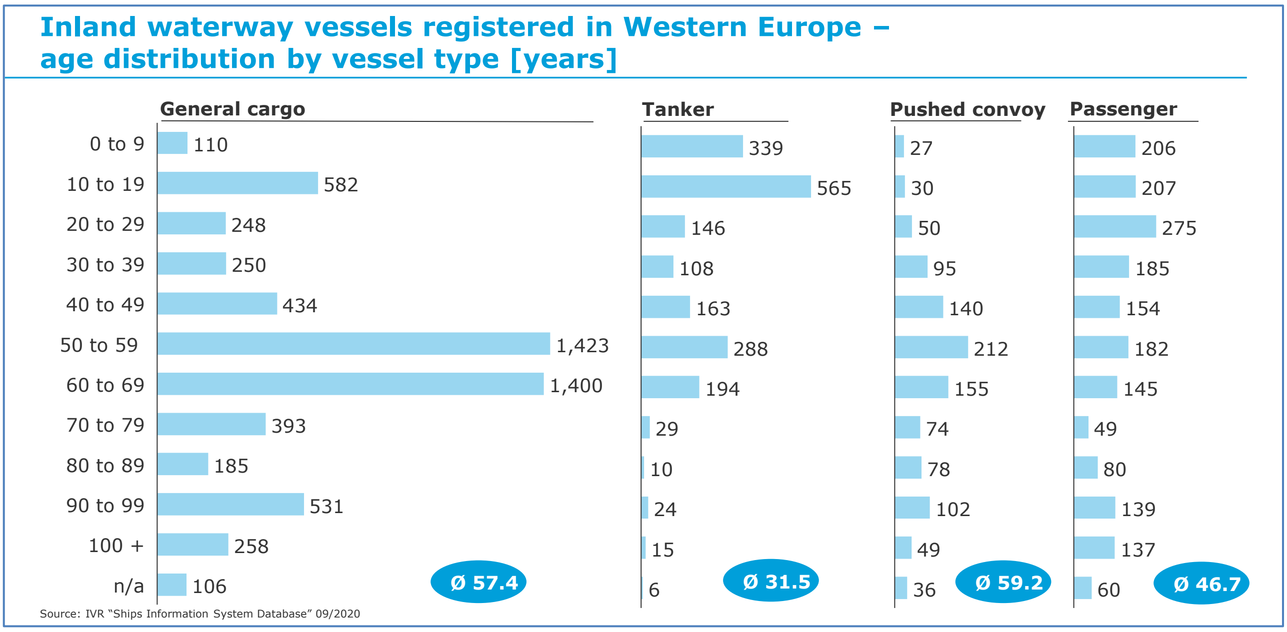


Figure 11: Inland waterway vessels registered in Western Europe – age distribution

Vessel sizes

Looking at vessel sizes about 54% of the vessels with known deadweight are below 1,000 dwt, 26% between 1,000 and 1,999 dwt and only 3% above 4,000 dwt.

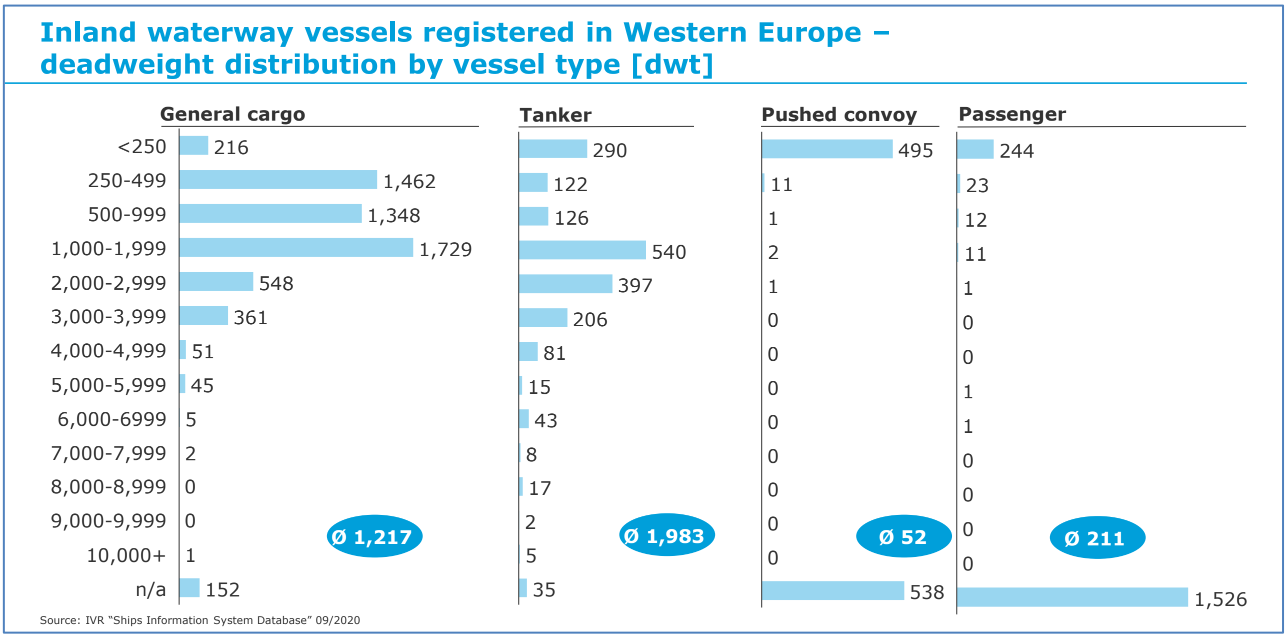


Figure 12: Inland waterway vessels registered in Western Europe – deadweight distribution

This size distribution roughly holds true for the general cargo vessels, whereas there are only few vessels below 250 dwt. Tankers peak between 1,000 and 1,999 dwt with also a significant share between 2,000 and 2,999 dwt. Pushed convoys and "other" vessel types are regularly below 250 dwt.

Engine power

Looking at engine power one third of the vessels with known engine power is below 250 kW, another 17% below 500 kW, 14% below 750 kW and only 8% above 1,500 kW.

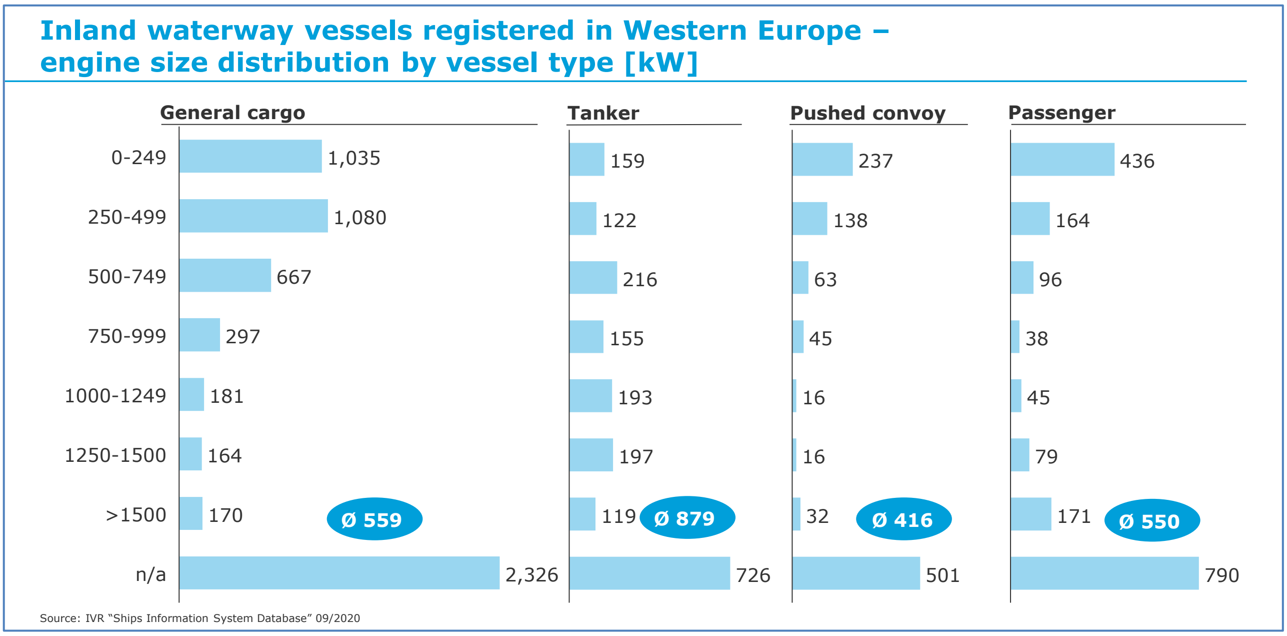


Figure 13: Inland waterway vessels registered in Western Europe – engine size distribution

Across the various vessel segments, the following distribution of vessel sizes and engine power can be found in Table 1.

Table 1: Relation between vessel size and engine power

Count of order	DWT cluster														
kW Cluster	<250	250-499	500-999	1,000-1,999	2,000-2,999	3,000-3,999	4,000-4,999	5,000-5,999	6,000-6999	7,000-7,999	8,000-8,999	9,000-9,999	10,000+	n/a	Grand Total
0-249	4.8%	7.2%	0.8%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.1%	2213
250-499	1.1%	2.1%	5.4%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	1586
500-749	0.3%	0.1%	0.7%	6.4%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.3%	1071
750-999	0.2%	0.0%	0.0%	2.6%	1.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	546
1000-1249	0.0%	0.0%	0.1%	0.5%	1.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	446
1250-1500	0.1%	0.0%	0.0%	0.2%	1.1%	1.5%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	464
>1500	0.1%	0.1%	0.1%	0.2%	0.5%	0.6%	0.4%	0.3%	0.3%	0.1%	0.1%	0.0%	0.0%	1.8%	522
n/a	8.3%	4.5%	5.7%	7.4%	3.1%	2.0%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	9.4%	4795
Grand Total	**1747**	**1642**	**1490**	**2286**	**949**	**567**	**132**	**62**	**50**	**10**	**17**	**2**	**7**	**2682**	**11643**

Vessel cluster

Intending to define a limited yet overall representative number of ship clusters for consumption modelling 12 clusters have been selected. Thy are characterized by segment, deadweight and engine power. While they represent 24% of the fleet directly (i.e. same segment, same dwt group and same engine power group), they represent 58% when considering also vessels for which data in one of three categories are missing in the IVR database (e.g. same segment, same dwt group, engine data not available).

Table 2: Selected vessel clusters

#	Vessel type	dwt group	kW group	Represented Vessels	Represented Share
1	General cargo	250-499	0-249	1,285	11.0%
2	General cargo	500-999	250-499	1,209	10.4%
3	General cargo	1,000-1,999	500-749	1,252	10.8%
4	General cargo	2,000-2,999	750-999	322	2.8%
5	General cargo	3,000-3999	1,250-1,500	255	2.2%
6	Tanker	1,000-1,999	500-749	366	3.1%
7	Tanker	2,000-2,999	1,000-1,249	271	2.3%
8	Passenger/Cruise	0-249	0-249	588	5.1%
9	Pushed convoy	0-249	0-249	547	4.7%
10	Ferry	0-249	0-249	9	0.1%
11	Ferry	N.N.	500-749	8	0.1%
12	Other	0-249	0-249	578	5.0%

These vessel clusters are being used for consumption modelling.

3.2 Trade and operational profile overview

This chapter provides an overview on the types of good transported on the Rhine, on the volume by area of activity and on typical parameters of operational profiles. As outlined already in chapter Baselining the there are various sources providing an overview on trade and operational profile of vessels operating on the river Rhine:

- CCNR Annual Report 2020 “Inland Navigation in Europe – Market Observation”
- CCNR “Market Insight on Inland Navigation”, April 2020
- CCNR Thematic Report “RIVER-SEA TRANSPORT IN EUROPE”, January 2020
- EU Statistical Pocketbook 2019 “EU Transport in Figures“
- BAW “Driving Dynamics of Inland Vessels”, 2016
- Bundesverband der Deutschen Binnenschiffahrt “Daten und Fakten 2018/2019“
- BLN-Schuttevaer Info graphic „De Nederlandse Binnenvaart“
- Stichting Projecten Binnenvaart PROMINENT report „D1.1 List of operational profiles and fleet families”, 2016
- Vesseltracker AIS data

Furthermore, facts especially on engine loads and bunkering have been collected during the interviews with ships operators and bunker suppliers.

Trade volumes

The overall inland waterway transport performance in Europe is fairly stable since more than one decade. Referring to Eurostat, the CCNR Annual Report 2020 states about 140 billion ton kilometres/year between 2007 and 2019 with a volatility of less than 10% between bottom years 2009 and 2018 vs. peak years as 2010 and 2013. Germany and the Netherlands both contribute with about 50 billion ton kilometres/year each, Belgium and France account for about 10 billion ton kilometres/year each.

For the traditional Rhine (Rhine between Basel and German/Dutch border) the CCNR Annual Report 2020 depicts a slight decrease of transported cargo with a CAGR of about -1% between 2005 and 2019. The decrease is driven particularly by reduced transport of coal, iron ore and metal as well as agri bulk, while sand, stone and gravel are increasing, container transport is stable and tankers face only a slight decrease in transported cargo.

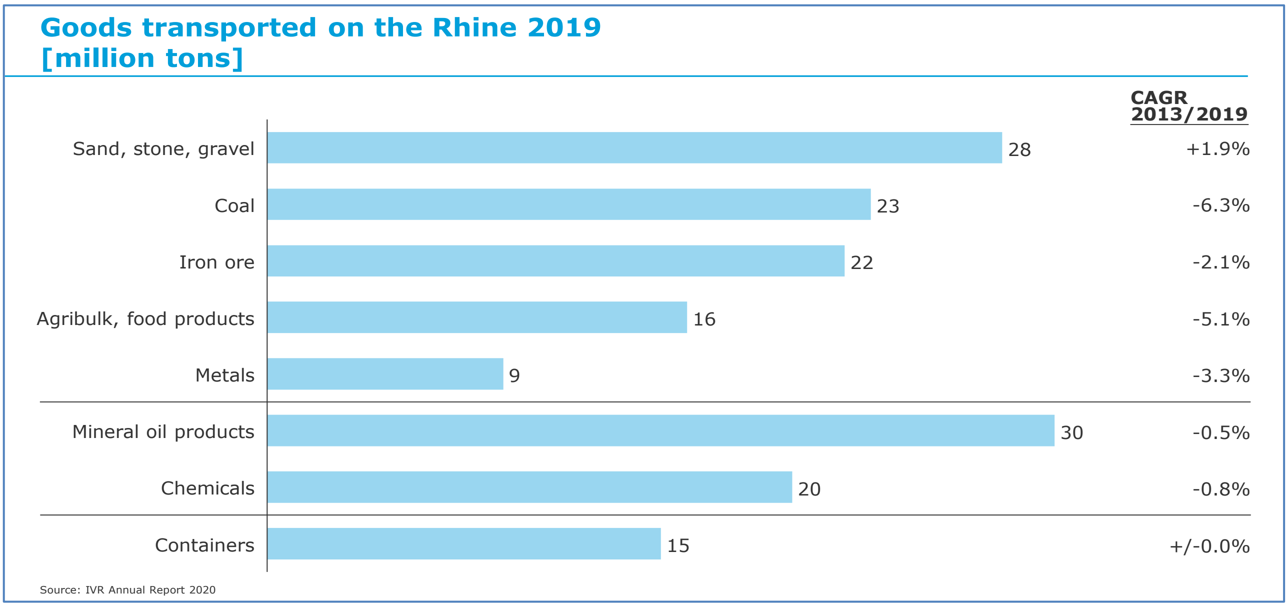


Figure 14: Goods transported on the Rhine 2019 – by type of good

Trade areas

Whereas the amount of transported cargo is fairly stable on the upper Rhine, decrease affects more the middle and especially the lower Rhine.

The comparison of total transport of goods on the traditional Rhine with 176 million tons/year in 2019 with the amounts transported on lower, middle and upper Rhine shows, that about 90% of transports pass the lower Rhine, 40% the middle Rhine and 28% the upper Rhine. This, of course, differs by type of cargo. Coal and iron ore are typically transported from ARA ports (Amsterdam, Rotterdam, Antwerp) to power plants and steel mills in the Ruhr area, while only limited amount of coal is transported further up to powerplants located at the middle or upper Rhine. Mineral oil products as are typically also transported Rhine upwards from ARA ports to consumption areas at lower, middle and upper Rhine. Same applies for containers.

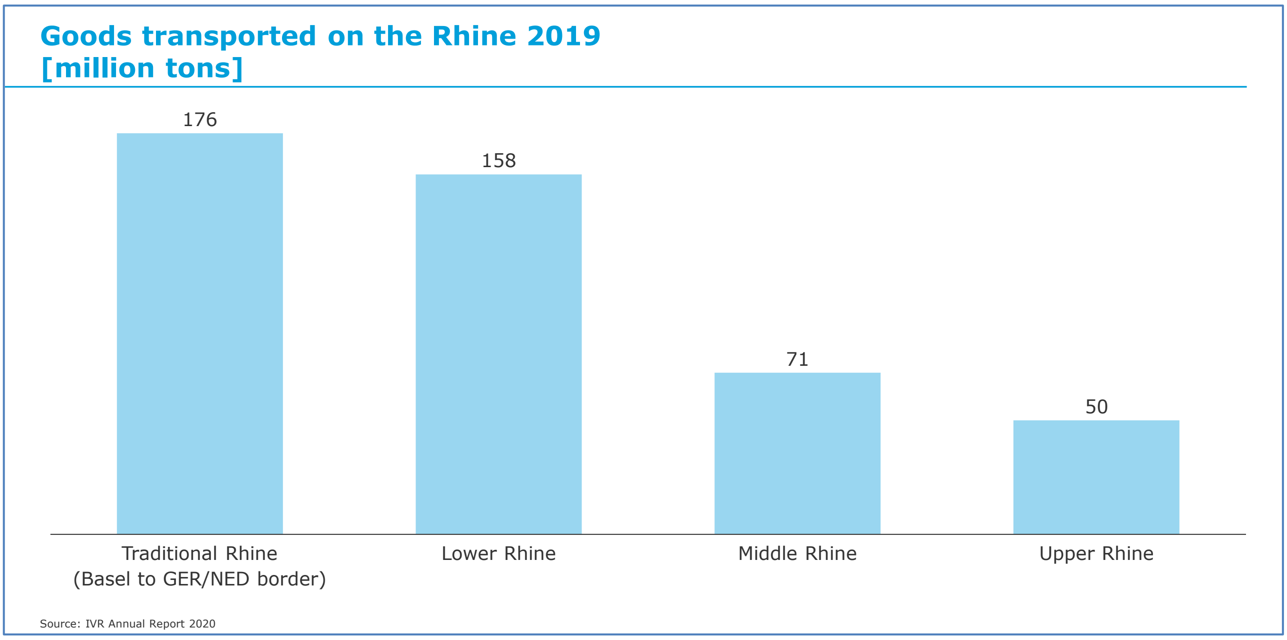


Figure 15: Goods transported on the Rhine 2019 – by area

Operational profiles

The best available overview of inland water transport relations in Europe between origination and destination is given in the PROMINENT report „D1.1 List of operational profiles and fleet families" prepared by Stichting Projecten Binnenvaart in 2016. Annex A2 displays the top 96 relations in terms of transported tons referring to data from ETIS plus.

The trade flows outlined above are reflected in the operational profiles. As little analytic of AIS data of actual voyages of inland waterway vessels sailing on the Rhine has been done yet, the most comprehensive overview on operational profiles is given by the above-mentioned PROMINENT report. However, data are modelled for a number of vessel types based on representative journeys only. They are not based on actual data. Hence, it has been decided to use the insights gained in the interviews in course of the qualitative assessment instead. They can be summarized as follows:

- Operating time per year: > 90%
- Typical speed upstream: 8-9 km/h
- Typical speed downstream: 17-20 km/h
- Typical engine load upstream: 60% MCR
- Typical engine load downstream: 20% MCR
- Effect of shallow water: reduced cargo intake, engine load upstream about 50%
- Effect of high water: increased engine load upstream, about 90%
- Time share in port: 20-40% (up to 50% for special segments)
- Average load in port when idle: 1% (cruise about 50%)

Speed data as well as time shares in port have been validated based on AIS data for a number of vessels in each of the main segments.

3.3 Fuel demand

Official statistics on fuel demand of inland waterway vessels operating on the river Rhine, respectively amount of fuel bunkered in Rhine and ARA ports to inland waterway vessels are apparently not available. Interviewed experts estimate the annual fuel consumption of vessels sailing on the Rhine between 800,000 m³ (about 700,000 t) and 4.8 million m³ (4.0 million t). To some degree the uncertainty may arise from the fact that many vessels sailing on the Rhine are not operating on the Rhine only, but also in adjacent regions/waterways. Another uncertainty is that both inland waterway vessels as well as seagoing vessels bunker in the ARA ports.

In order to create a consumption baseline for the modelling of potential hydrogen demand, we have built a simplified consumption model for the afore mentioned 12 vessel clusters.

The model builds on the following input factors per cluster:

- Time share operations per year (due to shallow water, market-related downtime)
- Time share port of operating time
- Speed upstream
- Speed downstream
- Engine kW
- Engine load upstream, incl. required auxiliary power
- Engine load downstream, incl. required auxiliary power
- Engine load port/idle, auxiliary power
- Specific fuel oil consumption engines
- Density fuel

Assumptions have been made based on expert interviews, AIS analytic and literature. We acknowledge the uncertainties of the assumptions made. Operating profiles, i.e. time shares of different operating modes and sailing speeds, actual engine loads and engine specific may deviate between model and actual vessels. Individual deviations may be up to 40% within a cluster.

Table 3: Assumed operational parameters – by vessel cluster

Type cluster	DWT cluster	kW Cluster	Typical speed upstream (km/h)	Typical speed downstream [km/h]	Time share port [%]	Operational time per year [%]	Load upstream [%MCR]	Load downstream [%MCR]	Load in port [%MCR]	Total annual consumption per vessel [t]	Total annual consumption per vessel [m³]
General cargo	250-499	0-250	9	18	25%	85%	60%	20%	4%	**93**	**112**
General cargo	500-999	250-499	9	18	25%	85%	60%	20%	4%	**280**	**337**
General cargo	1,000-1,999	500-749	9	18	28%	85%	60%	20%	4%	**457**	**551**
General cargo	2,000-2,999	750-999	9	18	32%	85%	60%	20%	3%	**616**	**743**
General cargo	3,000-3,999	1,250-1,500	9	18	40%	85%	60%	20%	3%	**918**	**1,107**
Tanker	1,000-1,999	500-749	9	18	18%	85%	60%	20%	4%	**491**	**592**
Tanker	2,000-2,999	1,000-1,249	9	18	30%	85%	60%	20%	3%	**803**	**968**
Passenger/Cruise	<250	0-249	9	18	40%	85%	60%	20%	4%	**85**	**102**
Pushed convoy	<250	0-249	9	18	25%	85%	60%	20%	4%	**93**	**112**
Ferry	<250	0-249	9	18	25%	85%	60%	20%	4%	**93**	**112**
Ferry	All	500-749	9	18	25%	85%	60%	20%	4%	**467**	**562**
Other	<250	0-249	9	18	50%	85%	60%	20%	4%	**80**	**96**

Multiplying the modelled annual consumption per vessel for each cluster with the number of vessels in the cluster results in the approximated annual consumption per cluster. Total annual consumption of the12 clusters amounts to 2.0 million tons, respectively 2.4 million m³. Considering that the clusters stand for 58% of the total Western European fleet of inland waterway vessels and assuming that scaling up numbers to 100% would be justifiable, the total annual consumption of the Western European fleet would be 3.5 million tons, respectively 4.2 million m³. Assuming that 75% of that fuel consumption would be on the Rhine (between Rotterdam and Basel), total fuel consumption of inland waterway vessels on the Rhine would amount to 2.6 million tons/year, respectively 3.2 million m³/year. We acknowledge that the number is based on various of assumptions but see that it is within the range of expert estimates.

Table 4: Modelled consumption – by vessel cluster

Type cluster	DWT cluster	kW Cluster	Total annual consumption per vessel [t]	Total annual consumption per vessel [m³]	No. of ships	Share	Total annual consumption per cluster [t]	Total annual consumption per cluster [m³]
General cargo	250-499	0-250	**93**	**112**	1,285	11.0%	119,956	144,526
General cargo	500-999	250-499	**280**	**337**	1,209	10.4%	338,585	407,934
General cargo	1,000-1,999	500-749	**457**	**551**	1,252	10.8%	572,304	689,523
General cargo	2,000-2,999	750-999	**616**	**743**	322	2.8%	198,464	239,113
General cargo	3,000-3,999	1,250-1,500	**918**	**1,107**	255	2.2%	234,195	282,162
Tanker	1,000-1,999	500-749	**491**	**592**	366	3.1%	179,767	216,586
Tanker	2,000-2,999	1,000-1,249	**803**	**968**	271	2.3%	217,745	262,344
Passenger/Cruise	<250	0-249	**85**	**102**	588	5.1%	49,706	59,887
Pushed convoy	<250	0-249	**93**	**112**	547	4.7%	51,063	61,522
Ferry	<250	0-249	**93**	**112**	9	0.1%	840	1,012
Ferry	All	500-749	**467**	**562**	8	0.1%	3,734	4,499
Other	<250	0-249	**80**	**96**	578	5.0%	46,029	55,457
						57.5%	**2,012,388**	**2,424,564**
						100.0%	**3,502,278**	**4,219,612**
						75.0%	**2,626,708**	**3,164,709**

4 QUALITATIVE ASSESSMENT OF MARKET POTENTIAL FOR HYDROGEN

Objective of the qualitative demand assessment is to create an overview on the industry's perspective on green fuels in general and on hydrogen in particular. Key drivers as well as potential challenges and incentives need to be reflected to understand the market potential of hydrogen and derive scenarios for penetration rates in ship newbuilds and retrofits of existing vessels.

The qualitative assessment is based on:

- Semi-structured interviews with operators, bunker suppliers and industry associations
- Workshop discussion with RH2INE members
- DNV project experience/expert knowledge on introduction of alternative fuels
- External reports on market adoption of alternative fuels and effectiveness of related programs
- External reports and articles on newbuild and conversion projects using hydrogen as fuel

Technical, regulatory, infrastructure-related and finally (positive and negative) economic drivers of the demand for hydrogen as fuel for IWT vessels on the Rhine corridor are being derived. Potential challenges hindering demand and incentives fostering demand are being identified. Different scenarios are being defined with effects on penetration rates in newbuilding and retrofitting of ships with hydrogen as fuel.

4.1 Bunkering

Before conducting the qualitative assessment of the market potential for alternative fuels and hydrogen in particular, an overview needs to be given of today's structure and practices of bunkering conventional diesel fuel. The overview is based on the interviews with vessel operators, bunker suppliers and industry associations. Whereas the conclusions originate from a limited number of interviews, they appear largely generalizable.

In terms of bunkering mode, ship-to-ship (STS) bunkering is dominating by far over terminal-to-ship bunkering. Truck-to-ship bunkering is a small niche of the bunkering market. Interviewees estimate that STS bunkering reflects about 70-80% of the bunkering for vessels operating on the Rhine. STS allows bunkering during cargo operation and without any time loss, while vessels need to make a fuelling stop for terminal-to-ship bunkering. For general cargo (dry bulk) vessels and tankers fuelling stops appear partially acceptable, while container vessels, which are subject to tightest schedules, strongly favour bunkering in STS mode.

The bunkering frequency depends especially on consumption, tank volume and operating pattern. Vessels operating in round trips (e.g. from Rotterdam to Duisburg or Basel and back) tend to bunker once per roundtrip. Depending on the service this can be e.g. weekly, every ten days, every two or even every three weeks. Higher bunkering frequencies (less than one week) are not typical. Several interviewees mentioned lower bunker prices in the Netherlands than in Germany, reasoning that with lower logistic costs of fuels being provided in ARA ports compared to fuels being shipped Rhine upwards and bunkered there. Taxation differences and competition may be further drivers of the price difference. As a result, it can be assumed that more than 70% of diesel consumed by inland waterway vessels on the Rhine is being bunkered in the Netherlands.

Depending on consumption, tank volume and operating pattern inland waterway vessels typically bunker between 10 and 75 m^3 of diesel per bunkering event. River cruise vessels and high-powered push boats may bunker up to 75 m^3, container vessels and average push boats between 20 and 30 m^3 per round trip, whereas smaller dry cargo vessels and tankers on possibly shorter trades may bunker only 6-10 m³ per event. However, there are significant deviations based on the above-mentioned drivers.

Bunkering typically takes between 30 minutes and 2 hours depending on bunkering volume and pumping rate of the bunker technology used. In case of STS bunkering it is typically done during cargo operation, in case of river cruise vessels also with passengers being on board.

4.2 Perspective on alternative fuels

Hydrogen is one among a number of alternative, more or less green and potentially emission free fuels, such as:

- Power-to-X fuels
  - Electricity/battery
  - Hydrogen (pressurized, liquid or material-based)
  - Ammonia
  - Methanol
  - Synthetic diesel
  - Synthetic gas (Synthetic LNG)
- Biofuels
  - Biodiesel
  - Hydrated vegetable oil (HVO)
  - Ethanol
  - Biogas (Bio LNG)

which can be applied for inland waterway vessels. Hence, a general perspective on alternative fuels shall be taken before looking at hydrogen in particular. The alternative fuel pathways for Power-to-X fuels and Biofuels are given in Figure 16 & 17, respectively.

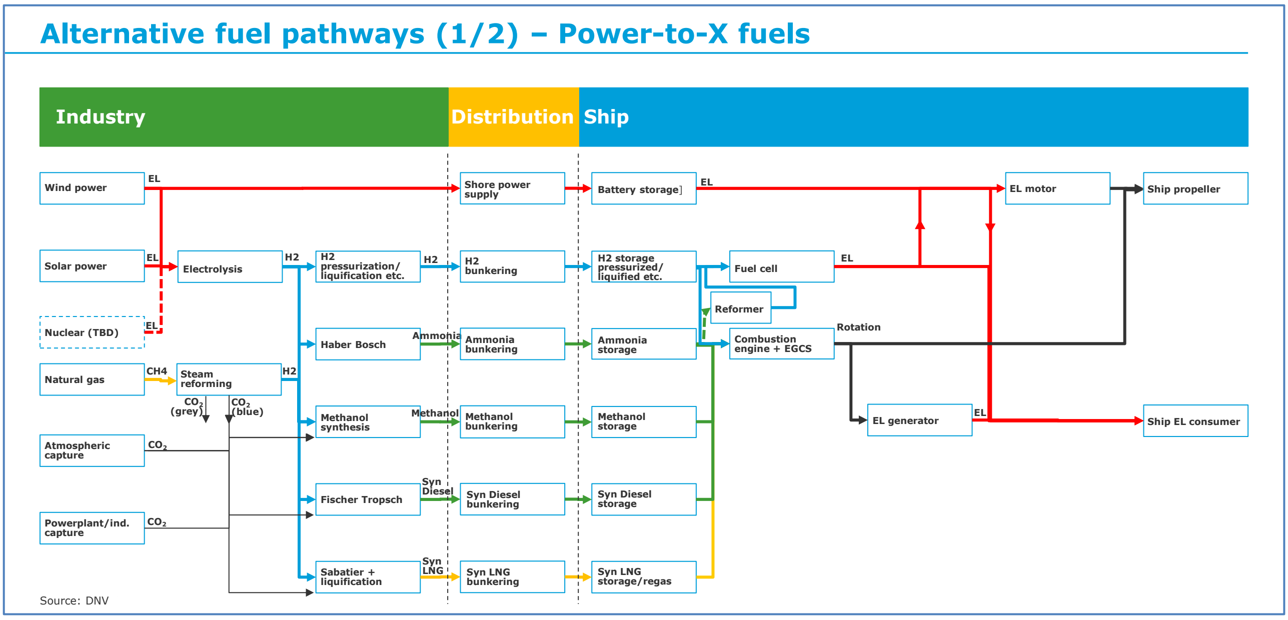


Figure 16: Alternative fuel pathways – Power-to-X fuels

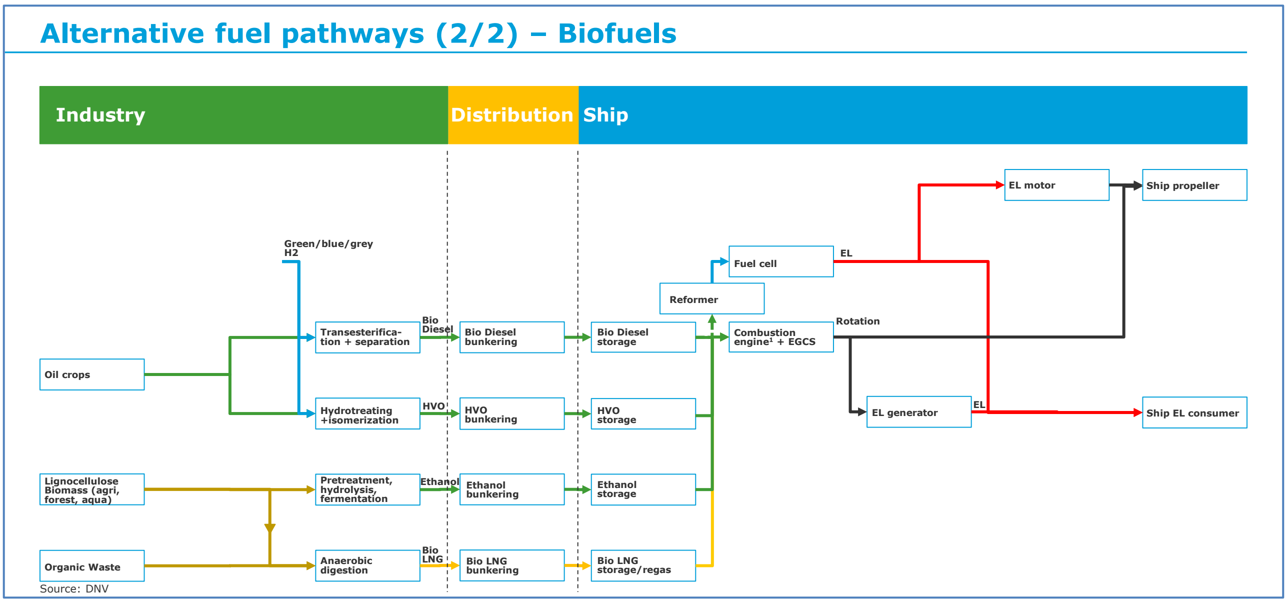


Figure 17: Alternative fuel pathways – Biofuels

Effectively all interviewees acknowledge the societal requirement to the IWT industry to further reduce emissions over the coming years. Most stress the efforts they have been or are taking to meet the stage V requirements of the EU emission regulation for non-road mobile machinery (NRMM)[1], which causes significant investment requirements for retrofitting of existing vessels respectively higher newbuilding costs. Still, the industry regards the need for emission reduction generally positive, also considering favourability compared to other means of transport, if new regulations safeguard a level playing field also vs. rail and road transport. According to a survey of the Dutch IWT association BLN-Schuttevaer about 95% of their members have a positive view on green fuels. There is a general understanding among interviewees that, if every operator had to use green and potentially emission free fuels based on the same and stable regulatory boundaries, the overall profitability of the industry would be largely unchanged.

Besides investments into stage V compliance, a number of ship owners have invested in innovative, greener technology already. E.g. the Dutch Danser Group has decided for a first LNG-fuelled push-barge combination in 2013, which assumed service in 2015. By now there are about ten inland waterway vessels running on LNG. A-rosa will receive a river cruise newbuild with hybrid technology. Further projects using alternative fuels or propulsion concepts are currently being pursued, e.g. by HTS Group, by HGK, by Future Proof Shipping, the HydroTug of BeHydro for the Port of Antwerp and the hydrogen fuelled water taxi of the SWIM consortium for Rotterdam.

Asked for decision criteria on green fuels compared to conventional fuels respectively between different green fuel options interviewees name the following aspects, which are partly interlinked:

- GHG compliance
- Technology readiness
- Operability
- Regulation
- Availability

[1] Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC

- Business case

GHG compliance

As Figure 16 and Figure 17 above show, alternative fuels have different shades of green respectively result in different degrees of emission reduction compared to conventional fuel. Not all of the alternative fuels are actually emission- or at least CO2-free. CO2 or other greenhouse gas (GHG) emissions can occur during fuel production (e.g. grey hydrogen from steam reforming of natural gas, biodiesel from palm oil plantation on deforested land) or during combustion (e.g. combustion of methanol without CO2 capturing). Hence, the compliance of the different fuels with existing and future regulation may differ and will be a key criterion for owners in order “not to bet on the wrong horse” – a fuel which may appear compliant (green) today could be subject to regulatory limitations in the future.

In view of the regulatory treatment of achieved emission reduction of the various alternative fuels, interviewees shared the following considerations:

- Which emissions will the regulator cover by what means? Which will be addressed by market-based measures, which by direct regulations (e.g. phase out of technologies, limitation of power, emissions etc.)?
- Will the regulator be technology open and incentivise an emission reduction, not a specific technology?
- Will the achieved emission reduction be acknowledged for the investment horizon or will the acknowledged effect be reduced due to shifting baselines?
- How will emission costs of the conventional technology be priced over the investment horizon?
- How will incentives as investment CAPEX subsidies (direct grants, favourable credit conditions) develop over time? Will they decrease following a technology cost digression or increase as the regulator realizes that more incentives are needed to achieve the required emission reduction?
- Will the regulator safeguard a level playing field e.g. between different means of transport and across countries?

Interviewees call for reliability of regulatory decisions. The clearer the regulators give their direction, ideally for a significant time share of the investment horizon, the higher is the interviewees’ willingness to take risk of alternative technology and fuel as opposed to conventional technology and fuel. Though, several interviewees mention examples of earlier regulations, which have been postponed or were less ambitious than initially announced, causing disadvantage for early movers.

Technology readiness

Second criterion mentioned by most interviewees is technology maturity. Whereas there is typically some willingness to test promising new technologies (and fuels), the technology needs to be available latest once the newbuild or retrofit project starts. However, most owners would decide for a technology only, if it has proven operability and certain lifetime in other commercial applications. Tests on laboratory scale and tests on land are typically not regarded as sufficient to decide for implementation of the technology on a vessel (with more difficult maintenance etc.). Temporary test of few thousand running hours are typically not regarded as sufficient to build confidence for a commercial decision on a significant investment. Ship owners often look at test installations of new technology at reputable ship owners known for their technical competence. Confidence also increases with the reputation and financial strength of the technology provider. Ship owners would ask if the provider has the financial strength and strategic interest to overcome initial challenges of the technology and be available for after sales service for at least five years. – Technology maturity of various alternative propulsion concepts and involved technology differs. Some technologies are mature with hundreds of installations on vessels (e.g. LNG technology), while others have not left laboratory scale tests.

Operability

Third criterion mentioned by the interviewees is ease of operation or operability. The alternative technology and fuel shall imply as little adverse effects on normal vessel operation as possible when compared to conventional propulsion technology and fuels or even imply positive effects. This is a wider field comprising aspects as:

- loss of cargo space or payload
- increased safety distances limiting simultaneous operation (cargo operation, presence of passengers)
- increased bunkering frequency or additional time required for bunkering
- reduced engine flexibility (low-load operation, ramp-up to peak load)
- increased maintenance
- special requirements to qualification and number of crew

Regulation

The criterion regulation relates to the permission process of applied technology and bunkering operation in view of safety. As regulation is typically not clearly defined for novel technology and fuels (especially low flashpoint fuels), the first applications regularly needs to be permitted on case-by-case basis, whereas responsibility of potentially relevant authorities is not always clear and lack of examples or guidelines may lead to increased requirements, both resulting in uncertainty with regard to duration of the permission process and costs of the solution (CAPEX but also OPEX implications). This is a clear barrier for application of innovative alternative fuel technology compared to conventional technology.

Availability

The fifth criterion stressed by the interviewees is the availability of the alternative fuel. This relates to fuel production as well as to provision of bunkering infrastructure in a sufficient number of ports in the operating area. Dependency on single suppliers is regarded as a clear disadvantage, even is the supplier (fuel producer and bunkering company) is financially sound and regards the alternative fuels as strategically relevant. All alternative fuels require setting up of new bunkering infrastructure. Some even require setting up of new fuel production capacity. Especially for the bunkering infrastructure the typical chicken or the egg problem exists, with ship owners potentially waiting for suppliers before taking an investment decision and suppliers waiting for a critical mass of ship owners. This applies even more as the investment into LNG bunkering infrastructure has started about 10 years ago, while the number of LNG fuelled vessels is still limited. Many potential suppliers of alternative fuels may be more cautious now based on the experience with LNG.

Business case

Whereas the business case is mentioned last in the order of criteria here, it is finally the most comprehensive and important one as it is influenced by all other criteria listed above.

Nearly all interviewees stressed the business case as key criterion for the fuel choice decision. Their companies operate inland waterway vessels to earn money. Looking at the revenue side of the business case first, several operators across different cargo segments outline that their customers (cargo owners) do not have an increased price willingness for greener transports, as long as a cheaper conventional alternative exists. Several operators tried charging (little) mark-ups on the freight rate for reduced emissions (e.g. due to early introduction of stage V of the European NRMM regulation) but failed as cheaper operators were available. In turn, this means that higher costs affecting the entire industry can most likely be passed on to customers – at least to the degree they affect the least affected operator. Looking at the cost side, most interviewees took a total cost (lifetime cost) perspective, i.e. considering both investment CAPEX as well as ongoing OPEX incl. fuel costs. Interviewees concluded that if alternative fuels don't result in increased revenue for the time being, their total costs must not (significantly) exceed costs of the conventional propulsion system and fuel. While the investment CAPEX for vessel newbuilding or retrofit (required engine exchange after 15-20 years) is typically higher for vessels with alternative fuels, their OPEX incl. fuel costs may be lower over the vessel's lifetime. This may originate from lower fuel prices (the assumption can be made for LNG compared to diesel over a longer time horizon; temporarily biodiesel was also cheaper in some occasions than conventional diesel) or lower emission costs, if assuming that emissions (probably beginning with CO2) will be priced in future. Of course, also investment CAPEX subsidies as direct grants e.g. from EU and/or national government or reduced capital costs due to favourable credit conditions (backed by the European Investment Bank or national export credit agencies or promotional banks with governmental shareholder) may help balancing the total costs of the alternative fuels case vs. the conventional fuel case. All in all, nearly every potential owner of a vessel newbuild or retrofit will decide for a greener, emission reduced or emission free propulsion technology and fuel only, if he assumes a positive business case over the vessel's lifetime. And the business case is decided on the cost assumptions rather than on the revenue assumptions.

It appears evident that the six criteria mentioned by the interviewees are partially overlapping, e.g. technical challenges have operational implications and cost impact.

An alternative but effectively similar categorization of barriers for innovation uptake related to greening technologies for inland waterway vessels is provided in the PROMINENT report "D1.3 Analysis of barriers and facilitating factors for innovation uptake" prepared by Ecorys in 2015, which is probably the most specific report on barriers and incentives related to inland waterway vessels:

- Technical: Barriers caused by immaturity of technology or operational requirements

- Legal: Barriers caused by regulations and laws
- Financial: Barriers caused by access to capital and business case
- Knowledge: Barriers caused by lack of expertise or skills
- Market: Barriers caused by market conditions, infrastructure and the supply chain
- Cultural: Barriers caused by behavioural routines

All above mentioned criteria and barriers generally apply to both vessels newbuilds with alternative, greener and potentially emission free fuels as well as to retrofits of existing vessels. The latter are typically technically more challenging and the business case may be less favourable, as extra costs compared to conventional propulsion technology and fuels are higher, the investment horizon may be shorter and access to capital may suffer from a lower security value of the mortgaged vessel.

4.3 Perspective on hydrogen

The qualitative assessment of the market potential of hydrogen as fuel for inland waterway vessels on the Rhine follows the criteria mentioned by the interviewees and are elaborated for alternative fuels in general in the previous paragraph. However, it needs to be acknowledged that some aspects relate to various criteria, as e.g. regulation is affecting the business case.

GHG compliance

Whereas hydrogen can be grey (produced by steam reforming of natural gas without CO2 capture), blue (produced of natural gas with CO2 capture) or green (produced by electrolysis of water with green electricity) and green hydrogen has a minority share yet, all interviewees assume future hydrogen to be green and thereby truly GHG free in Western Europe. This seems in line with the EU's and the national governments' agendas. Hence, hydrogen as fuel for inland waterway vessels can be regarded as fully GHG compliant. Thereby it can be regarded as equal to electricity/battery and has some favourability compared to most other alternative fuels.

Technology readiness

Considering both the interviewees' perspective and numerous external sources the technology readiness of hydrogen as ship fuel appears overall medium at best. Whereas hydrogen in combination with fuel cells is used in silent running of submarines today and there are several applications on commercial vessels globally, experience with applications on inland vessels is very limited yet. There are a few application cases with hydrogen fuel cell technology (e.g. passenger boat "Alsterwasser" in Hamburg) which have been implemented and more projects are currently being implemented.

The first technological challenge is the storage of hydrogen. Especially gaseous storage in pressure levels between 300 and 500 bar suffers from a very unfavourable gravimetric energy density. While hydrogen itself has about three times as high energy density per kg compared to diesel, one ton of hydrogen (equals about 3 tons of diesel) currently requires a tank weight of nearly 20 tons, i.e. the gravimetric energy density including containment system is about one seventh of the one of diesel (see Figure 18). Liquid storage in super insulated vacuum tanks at about -253°C has the potential to achieve a gravimetric energy density of about half the one of diesel. Storage in form of Sodium Borohydride (NaBH4) may result in a further improvement in future. However, technology is in the development stage still and may take 5-10 years to commercial viability.

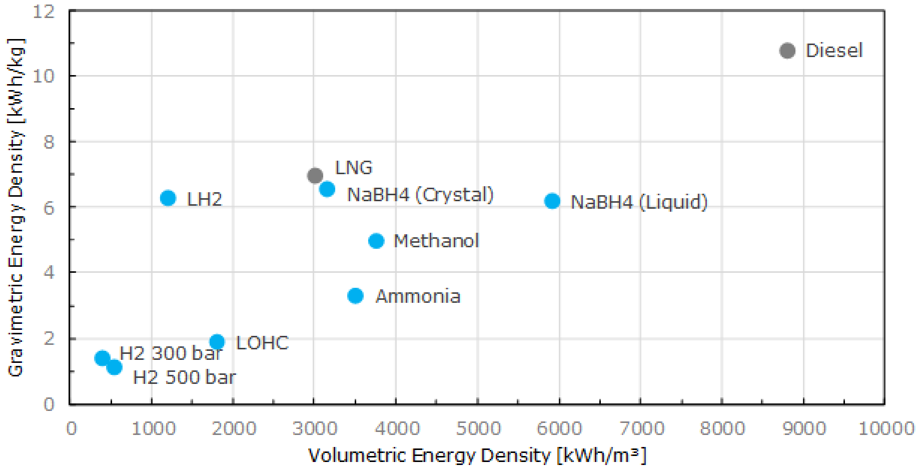


Figure 18: Energy density of hydrogen in different forms incl. storage system

The second technological challenge are the yet limited durability and power output of existing fuel cells. Fuel cells with 300 kW have been implemented on submarines, which would require a combination of a number of fuel cells for mid-sized and larger inland waterway vessels. The durability of polymer electrolyte membrane (PEM) fuel cells still appears significantly shorter than of combustion engines. 5,000 hours correspond to about one year of vessel operation. Hence, frequent replacement (after technical downtime) is to be expected. Furthermore, fuel cells yet suffer from limited load flexibility, which requires a (costly and heavy) combination with significant battery capacity for peak load and possibly a selective use of only one fuel cell (of a batch) for low-load operation downstream and in port. Manufacturers of fuel cells currently work on all three challenges and improvement can be expected for the coming years following an industrial learning curve supported by the numerous pilot applications across various industries.

A third aspect with regard to technology readiness are dual-fuel hydrogen combustion engines, which could be an alternative to fuel cells. Such engines are currently being developed and commercialized by BeHydro, a joint venture between Anglo Belgium Corporation and CMB. The engines shall run on 85% hydrogen and 15% MGO as pilot fuel. While the first application is planned for a tug in the Port of Antwerp, overall technology readiness appears to be behind that of fuel cells yet. Furthermore, also pure hydrogen combustion engines are being developed and will be implemented in some pilot projects (e.g., HyMethShip).

Operability

Related to the energy density challenge outlined above is the effect on ship weight respectively payload, if hydrogen is used as ship fuel. Depending on vessel type, engine size, consumption, operating profile and bunkering frequency, the effect may be significant. Assuming an unchanged bunkering frequency, a vessel, which has been bunkering 10 m³ diesel (e.g. smaller dry cargo vessel or tanker) would lose about 50 tons of payload if carrying the same energy amount of hydrogen in pressure tanks. For a vessel, which has been bunkering 50 m³ diesel (e.g. larger push boat) the ship weight would increase by about 250 tons. Weight increase respectively loss of payload are a significant disadvantage, especially in case of shallow water.

The effect could be compensated to some degree by an increased bunkering frequency. Instead of one bunkering per round trip, the vessels would need to bunker several times, whereas the tank would need to be dimensioned for the leg with the highest consumption, e.g. Rotterdam to Kehl if this would be the first stop of a liner service from ARA ports to Basel. As outlined before, most operators favour STS bunkering during operation in order not to lose time and regard the need for additional bunkering stops as clear disadvantage of hydrogen. However, some interviewees acknowledge that one or even two bunkering stops per week might be acceptable, if they were short and led to little time loss.

Today, however, bunkering rates of gaseous pressurized hydrogen yet appear too low for that (note that literature and market insights are somewhat contradictory in this aspect, this aspect is discussed in more detail in sub-activity 1.1b), resulting in unfavourably long to bunkering times even for the reduced energy amounts required at increased bunkering frequency. This may be overcome by increased bunkering rates of liquid hydrogen in the future (1,000-4,000 kg/h) or by using swappable hydrogen tanks which are pre-filled at land and loaded onto the hydrogen fuelled vessels within few minutes.

Such swappable tanks (both as pressure tanks of 300 bar as well as super insulated vacuum tanks for liquid hydrogen) are currently being developed and tested in first applications. Whereas they inevitable contribute to the above-mentioned payload effect and thereby call for higher bunkering frequency, they appear to be a viable solution in particular for container vessels. Their flexibility (carry just as much tank volume as you need) is an additional advantage compared to fixed tank installations. However, a technical solution for the application on vessel types other than container vessels still needs to be found. It remains to be seen, if these other vessels types will have to call container terminals for swapping of tank-containers then or if a separate infrastructure for swapping tank-containers will be build up for the other vessel segments.

Overall hydrogen as a fuel bears a number of operational challenges compared to both conventional diesel fuel but also to some of the other alternative fuels. Whereas they are not regarded as show-stopper by the interviewees they are at least regarded as disadvantage.

Regulation

Hydrogen is a low-flashpoint fuel, which is not yet covered by established regulation for ship design and (especially bunkering) operation. Until such regulation will be developed and adopted by the relevant authorities, the first projects require permissions on case-by-case basis. For LNG the process from first permissions on exceptional basis to established regulations has taken about one decade. Still not all ports are prepared to grant permissions for LNG bunkering. It can be assumed that the same process will be somewhat quicker, also as LNG as another low-flashpoint fuel has prepared the way and helped authorities clarifying the required stakeholder involvement, risk analyses and the permission process. However, it still may take more than five years until a common regulation on ship design and (bunkering) operation for hydrogen as ship fuel will be established. In the meantime, projects will have to deal with case-by-case decisions, which require significant management attention and bear risks for the business case in terms of both CAPEX and OPEX.

This is clearly a disadvantage of hydrogen compared to conventional fuel and higher flashpoint alternative fuels.

Availability

As outlined before, the availability of relates to fuel production as well as to provision of bunkering infrastructure in a sufficient number of ports in the operating area during the investment horizon.

Currently the production of green hydrogen from renewable electricity is limited in Europe and several industries (as e.g. steel and chemical industry) have an increasing demand and possibly a higher paying power than the IWT. However, stimulated by the political development of the past 18 months with the European Green Deal of December 2019 and numerous national hydrogen strategies in the EU member states unveiled, it can be assumed that the production of green hydrogen (from on- and offshore wind and photovoltaic) is ramping up quickly over the coming years. Suppliers will be both utility companies, established gas manufacturers with experience in cryogenic and pressurizes gases, and possibly traditional oil majors on their way towards new businesses, probably also joint ventures between different types of players. The risk of dependency on single suppliers for pressurized and liquid hydrogen appears limited. For material-based hydrogen (e.g. LOHC or Sodium Borohydride) this may be different for the next ten years.

Setting up and operating infrastructure for hydrogen bunkering is a different business than the fuel production. Given the slow uptake of LNG as fuel for (inland waterway) vessels and considering the yet immature hydrogen bunkering technology, it appears questionable if suppliers of conventional bunkering along the Rhine are willing to take the significant investment risk of setting up hydrogen bunkering infrastructure. This especially applies, if they had to own a large number of swappable tank-containers. Instead, 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 in the steel and chemical industry along the Rhine. 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 in the Ruhr area.

Direct grants or favourable financing conditions supporting the investment CAPEX in line with EU and national hydrogen strategies might help turning the business case for a potential hydrogen bunker supplier positive.

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. Such a supply risk has stopped the passenger boat “Alsterwasser” in Hamburg, which ended service after hydrogen supply had stopped. Hence, owners need to build on financially sound suppliers with strategic interests in developing this new business area and fix hydrogen prices with them for a significant share of the investment horizon.

Overall availability of hydrogen for inland waterway vessels is and remains more challenging than availability of conventional diesel fuel, but there seems no disadvantage compared to other emission neutral or low flashpoint alternative fuels.

Business case

The business case is the primary criterion in the decision process for alternative fuels and hydrogen in particular. All interviewees named it as the most comprehensive and important criterion, which is influenced by all criteria outlined above.

As previously stated, none of the interviewees would build a business case on a significant mark-up on the freight rates for transportation with alternative fuels. However, some expect to score a little higher in freight tenders and win a few additional customers. This particularly applies for container vessels, which are generally closer to end customers than dry bulk vessels and tankers, and to river cruise vessels of course.

In turn, interviewees would decide for hydrogen only, if the business case is favourable compared to conventional fuels and other alternative fuels from a cost perspective. Today both CAPEX and OPEX for hydrogen as fuel are significantly more expensive than conventional propulsion technologies and fuels. Hence, the business case can only become positive with several regulatory changes respectively governmental incentives and the commitment of a hydrogen supplier with strategic interest in developing the market and willingness to offer green hydrogen in a longer-term contract at conditions below todays regular price levels.

First requirement for a positive hydrogen business case (as well as the cases of other alternative fuels) is that emissions need to result in costs for the emitter. Whereas also the introduction of stage V requirements of the EU NRM had a positive effect for hydrogen compared to conventional fuels, even though targeting NOx and not CO2 emissions, a significant impact on the business case would come with introduction of CO2 prices. Economically it would not matter, if the price is a result of emission trading or CO2 taxation, as long as the price is sufficiently high. A price level of about 25 EUR/ton as currently effective in the EU ETS and planned by the German government for the transportation sector from 2021 would have little impact. The planned increase to 55-65 EUR/ton CO2, equivalent to about 170-200 EUR/ton diesel, would strengthen the business case for hydrogen. The break-even price depends on the individual project and would likely be even higher in many cases.

Second requirement for a positive business case are investment CAPEX subsidies either as direct grant or as e.g. from EU and/or national government or reduced capital costs due to favourable credit conditions (backed by the European Investment Bank or national export credit agencies or promotional banks with governmental shareholder). The Dutch Green Deal for shipping, IWT and ports can be a significant contributor for the hydrogen business case. One of the ambitions is to fit 150 inland vessels with zero-emission power trains by 2030. Besides other measures a European sustainability fund for inland waterway vessels shall be established. As a first step 15 million EUR shall be granted promoting clean engine technology. This comes in parallel to a 79 million EUR programme for retrofitting of existing inland waterway vessels with Selective Catalytic Reduction (SCR) or other NOx reduction technology. A combination of emission pricing and CAPEX subsidies for investment in clean technology, like implemented in the Norwegian NOx fund, can be considered in order to stimulate penetration of low or zero emission technology (as hydrogen) in a cost neutral way for the governments. However, interviewees stress that technology openness and a level playing field across countries and transport means shall be safeguarded.

Without introduction of emission prices and investment CAPEX subsidies hydrogen does currently not have a positive business case. Neither compared to conventional diesel fuel nor to some other alternative fuels with lower (but not zero) emissions as biofuel. Even a CAPEX digression following an industry learning cost curve would presumably not be sufficient to turn the case. Emission pricing is a prerequisite for the success of all alternative fuels.

4.4 Synthesis

Subsequent Figure 19 synthesizes the competitiveness of hydrogen vs. conventional diesel and other alternative fuel options for inland waterway vessels as of today along the six criteria important to the interviewees.

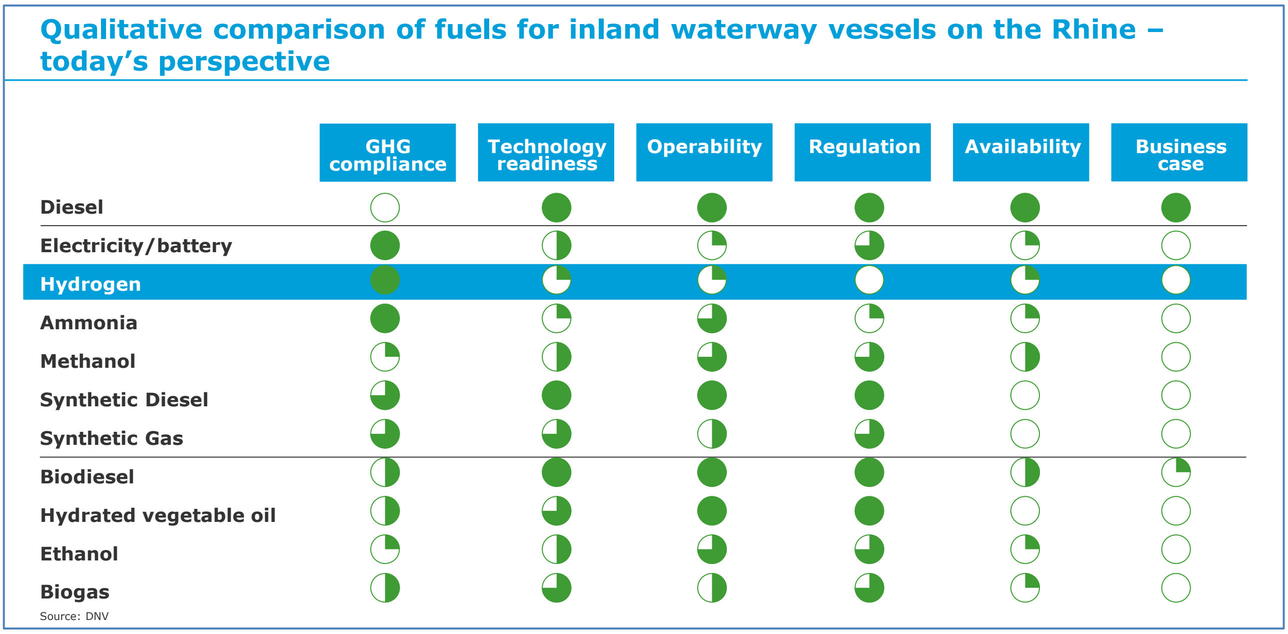


Figure 19: Qualitative assessment of fuels for inland waterway vessels – today's perspective

Hydrogen is, among electricity/batteries and ammonia, the only GHG-emission-free fuel and will have to be part of the solution space, unless other alternative fuels are combined with carbon capture and storage.

With regard to technology readiness hydrogen is inferior to fuels of diesel-like properties burned in combustion engines. This applies both for the use of hydrogen in fuel cells as well as possibly in combustion engines. However, it is at eye level with ammonia and just a little behind electricity/battery technology.

Operability is limited especially due to the gravimetric energy density resulting in reduced payload or higher bunkering frequency with the need for swappable tank-containers due to yet low bunkering rates.

Regulation of ship design and permission process of the bunkering process is yet to be developed, which may, even with the experience from LNG, take five or more years. This seems easier and potentially shorter for most of the other alternative fuels, including electricity/battery and to some degree ammonia.

The availability is limited yet. Same applies for ammonia and electricity as shore power for quick recharging of batteries or even swappable batteries. Though, in line with the national hydrogen strategies, it can be assumed that the production of green hydrogen will ramp up quickly within the next few years and there will be industrial players setting up hydrogen bunkering infrastructure at least in ARA ports and the Ruhr area. However, this may be initially limited to container terminals for swapping tank-containers. Other vessels types may have to accommodate to that unless hydrogen suppliers set up a parallel infrastructure for other vessel types.

Under today's regulatory regime without emission pricing, there is not a business case for any alternative fuel, with few exceptions for biodiesel in the Netherlands due to feed-in requirements. With significant emission pricing, considering also the well to tank emissions of e.g. biofuels or grey hydrogen, and temporary investment CAPEX subsidies, however, there can be a business case for green hydrogen depending on the operating pattern and other above-mentioned drivers.

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

4.5 Scenarios

In order to reflect the uncertainty about the development GHG-related regulation of inland waterway transport, technical developments and market development of alternative fuels, we derive three specific scenarios, which are also reflected in the consumption model:

- Scenario 1: Current instruments, moderate technology development pace
- Scenario 2: Green Deal, medium technology development pace
- Scenario 3: Zero GHG emissions by 2050, rapid technology development

Scenario 1: Current instruments, moderate technology development pace

Political instruments: Scenario 1 is based on the political instruments currently in place respectively decided for implementation during the next years. Political ambitions, which have not yet been transferred into specific instruments, are not considered. That means that there is neither a cap of specific or absolute GHG emissions nor a direct emission taxation or pricing for inland waterway vessels. CO2 prices, which will be applied for road transportation are not applied on IWT. – However, there are EU and national funds supporting investment CAPEX into innovative emission reduction and particular zero-emission technology. These funds support first fuel cell and hydrogen projects in course of vessel newbuilds as well as potentially retrofits. They can also be accessed to set up hydrogen bunkering infrastructure. Though, the total amount of funds per year is not sufficient to cover more than two thirds of the extra costs compared to conventional technology. – Favourable financing conditions for investment in such technology is accessible on EU level via the European Investment Bank as well as on national level via banks with promotional mandate due to governmental share- or stakeholder.

Technical developments: In Scenario 1 the technical development progresses with moderate pace. Liquid hydrogen will replace pressurized hydrogen between 2025 and 2030. Material based hydrogen with higher gravimetric energy density (as e.g. LOHC or Sodium Borohydride) will be viable for large scale application by about 2030. Bunkering technology will have reached 1,500 kg/h in 2025 and 4,000 kg/h by 2028. – Fuel cells will have been scaled up to 2-3 MW by 2025. Durability of fuel cells will have extended from currently one year of operation to five years by 2030. – Dual fuel hydrogen combustion engines or pure hydrogen combustion engines will have been successfully tested in a number of applications by 2025 but still require exhaust gas cleaning technology to remove NOx. – Other alternative propulsion and fuel technology will also have developed with moderate pace. Energy density of batteries will have improved by 2030 but weight and fast loading are still challenges for inland waterway vessels.

Market development: The market development of alternative fuels including hydrogen follows the moderate political incentivation and the moderate technical development pace. Hydrogen in pressurized and liquid form is being produced in sufficient amounts to serve – among other – the inland waterway vessels. However, the development of bunkering infrastructure is moderate. Based on slow uptake experience with LNG potential suppliers have set up bunkering infrastructure in the ARA ports as well as in the Ruhr area only. The number of competing suppliers is limited to one to two by port.

The overall number of inland waterway vessels operating on the Rhine, their transport work (in ton miles) and their overall annual energy consumption are stable over time. Decreasing transport work in some segments (e.g. coal, iron ore) is balanced by increasing transport work in other segments (e.g. containers, river cruise, tank). The energy demand per ton mile is constant. Newbuild numbers remain at about 80 per year, replacing old tonnage, which is scrapped.

Implications for newbuilds: Above mentioned regulatory, technical and market developments lead to overall moderate uptake of alternative propulsion technology and fuels in vessel newbuilds. Across all segments and vessel clusters about 10% of (currently 80) newbuilds are equipped with alternative technology. These newbuilds are driven by the assumption of accelerating regulation and supported by direct grants compensating for two thirds of the extra investment cost. One third of the newbuilds with alternative fuels will be running on hydrogen.

Implications for existing vessels: There is little incentive to retrofit existing vessels with alternative propulsion technology. Even if main engines need to be replaced after (on average) 20 years, owners rarely decide for zero emission technology. Only 2% of vessels reaching an age of 20 years are retrofitted for alternative fuels, while the owners of the other vessels regard drop-in fuels (e.g. biofuels) as potential solution in case accelerating regulation would require emission reduction. One third of the retrofits towards alternative fuels will be running on hydrogen.

Subsequent Figure 21 synthesizes the competitiveness of hydrogen vs. conventional diesel and other alternative fuel options for inland waterway vessels in the year 2030 under Scenario 1.

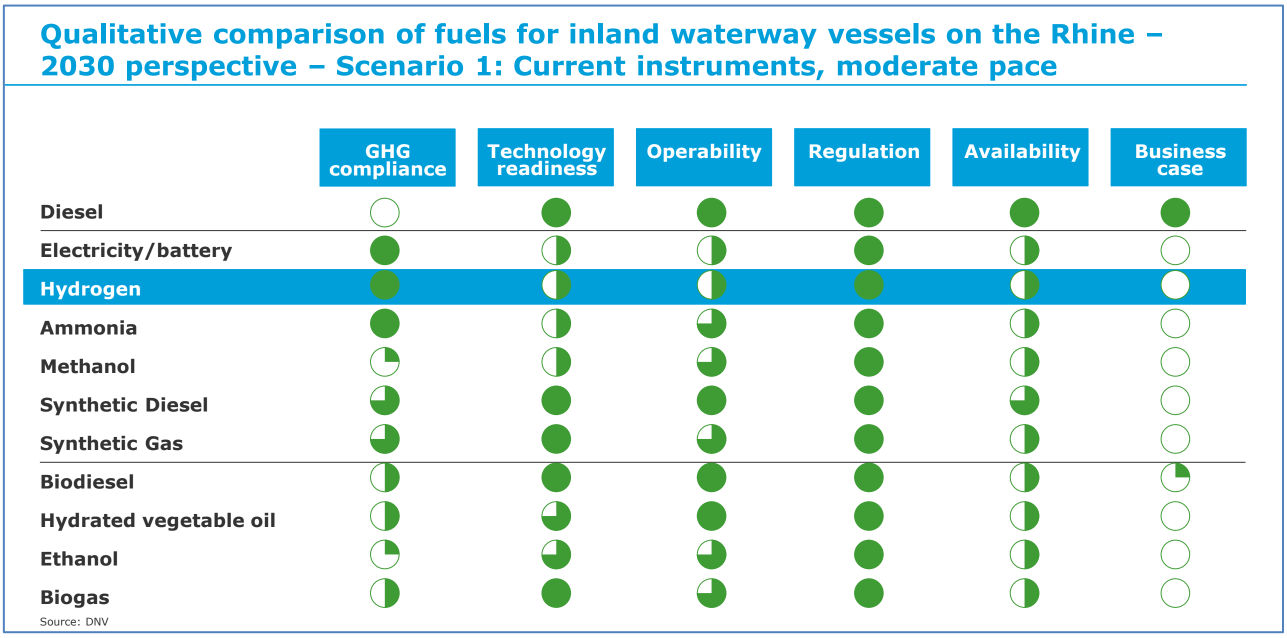


Figure 20: Qualitative assessment of fuels for inland waterway vessels – 2030, scenario 1

Scenario 2: Green Deal, medium technology development pace

Political instruments: Scenario 2 is based on the ambitions outlined in the Dutch Green Deal, i.e. 20% CO2 reduction by 2024 (vs. 2015), 40% by 2030 and 70% by 2050 together with a target of 150 zero emission vessels in the Dutch fleet by 2030. It is assumed that the same ambition is shared also by Germany, Belgium and the other countries registering vessels operating on the Rhine. This would require about 280-290 zero emission vessels on the Rhine. It is assumed that the ambitions are fully backed by specific political instruments. CO2 emissions are subject to an effective price scheme, either as taxation or through emission trading. The CO2 price level is assumed to increase from 50 to more than 100 EUR/t CO2 by 2030. Furthermore, EU and national funds are supporting investment CAPEX into innovative emission reduction and particular zero-emission technology are in place. These funds support first fuel cell and hydrogen projects in course of vessel newbuilds as well as retrofits. They can also be accessed to set up hydrogen bunkering infrastructure. Over time the direct grants will be reduced in line with CAPEX digression based on an industrial learning cost curve and the increasing effect of the CO2 price. Favourable financing conditions for investment in zero emission technology is accessible on EU level via the European Investment Bank as well as on national level via banks with promotional mandate due to governmental share- or stakeholder. For newbuilds hydrogen has a break-even business case compared to conventional fuel and other zero emission fuels. Though for existing vessels the use of drop-in fuels (incl. biofuel) is still favourable.

Technical developments: In Scenario 2 the technical development progresses with medium pace. Liquid hydrogen will replace pressurized hydrogen between 2025 or shortly thereafter. Material based hydrogen with higher gravimetric energy density (as e.g. LOHC or Sodium Borohydride) will be viable for large scale application by about 2030. Bunkering technology will have reached 1,500 kg/h in 2023 and 4,000 kg/h by 2025. – Fuel cells will have been scaled up to 2-3 MW by 2025. Durability of fuel cells will have extended from currently one year of operation to five years by 2030. – Dual fuel hydrogen combustion engines and/or pure hydrogen combustion engines are successfully applied in on numerous vessels from 2025 onwards but still require exhaust gas cleaning technology to remove NOx. – Other alternative propulsion and fuel technology will also have developed with medium pace. Energy density of batteries will have improved by 2025 to 2030 but weight and fast loading are still challenges for inland waterway vessels.

Market development: The market development of alternative fuels including hydrogen follows the medium political incentivation and the medium technical development pace. Hydrogen in pressurized and liquid form is being produced in sufficient amounts to serve – among other – the inland waterway vessels. Also, the development of bunkering infrastructure is medium. A number of suppliers is offering service in ARA ports and the Ruhr Area. Infrastructure is also available around Cologne, Mannheim, Kehl and Basel.

The overall number of inland waterway vessels operating on the Rhine, their transport work (in ton miles) and their overall annual energy consumption are stable over time. Decreasing transport work in some segments (e.g. coal, iron ore) is balanced by increasing transport work in other segments (e.g. containers, river cruise, tank). The energy demand per ton mile is constant. Newbuild numbers remain at about 80 per year, replacing old tonnage, which is scrapped.

Implications for newbuilds: Above mentioned regulatory, technical and market developments lead to overall medium uptake of alternative propulsion technology and fuels in vessel newbuilds. Across all segments and vessel clusters a steadily increasing share of (currently 80) newbuilds is equipped with alternative technology. One third of the newbuilds with alternative fuels will be running on hydrogen, while battery, ammonia and methanol make up for the rest.

Implications for existing vessels: CO2 emission reduction of existing vessels is still largely achieved by the use of drop-in fuels, initially biofuels, later on increasingly power-to-X fuels. If main engines need to be replaced after (on average) 20 years, an increasing number of owners decides for zero emission technology. One third of the retrofits towards alternative fuels will be running on hydrogen.

Subsequent Figure 21 synthesizes the competitiveness of hydrogen vs. conventional diesel and other alternative fuel options for inland waterway vessels in the year 2030 under Scenario 2.

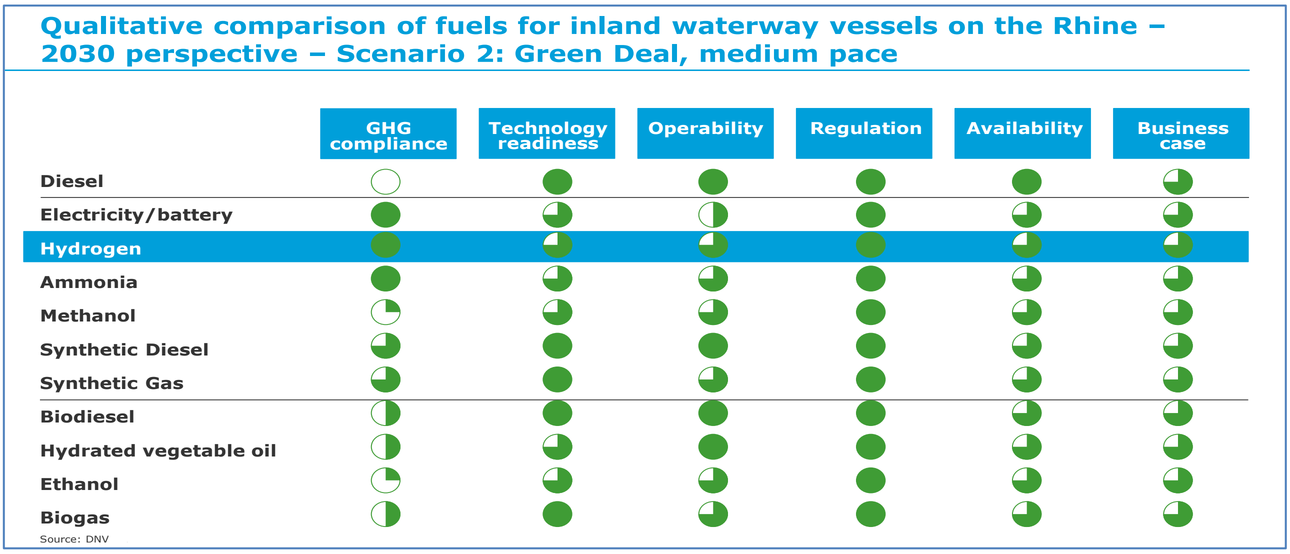


Figure 21: Qualitative assessment of fuels for inland waterway vessels – 2030, scenario 2

Scenario 3: Zero GHG emissions by 2050, rapid technology development

Political instruments: Scenario 3 assumes that inland shipping needs to be GHG emission free by 2050 with the need for an 80% specific emission reduction already by 2040. This need is backed by the respective political instruments. CO2 emissions are subject to an effective price scheme, either as taxation or through emission trading. The CO2 price level is assumed to increase to more than 100 EUR/t CO2 by 2030. Furthermore, EU and national fund are supporting investment CAPEX into innovative emission reduction and particular zero-emission technology are in place. These funds support first fuel cell and hydrogen projects in course of vessel newbuilds as well as retrofits. They can also be accessed to set up hydrogen bunkering infrastructure. Over time the direct grants will be reduced in line with CAPEX digression based on an industrial learning cost curve and the increasing effect of the CO2 price. Favourable financing conditions for investment in zero emission technology is accessible on EU level via the European Investment Bank as well as on national level via banks with promotional mandate due to governmental share- or stakeholder. For newbuilds hydrogen has a positive business case compared to conventional fuels and is break-even when compared to other zero emission fuels. For existing vessels it is partially favourable to retrofit towards zero-emission technology and fuel. Older vessels favour power-to-X fuels as drop-in fuels.

Technical developments: In Scenario 3 the technical development progresses rapidly. Liquid hydrogen will replace pressurized hydrogen between 2025. Material based hydrogen with higher gravimetric energy density (as e.g. LOHC or Sodium Borohydride) will be viable for large scale application between 2025 and 2030. Bunkering technology will have reached 1,500 kg/h in 2023 and 4,000 kg/h by 2025. – Fuel cells will have been scaled up to 2-3 MW by 2025. Durability of fuel cells will have extended from currently one year of operation to 10-15 years by 2030. – Dual fuel hydrogen combustion engines and/or pure hydrogen combustion engines are successfully applied in on numerous vessels from 2025 onwards but still require exhaust gas cleaning technology to remove NOx. – Other alternative propulsion and fuel technology will also have developed with rapid pace. Energy density of batteries will have improved by 2025 but weight is still a challenge for inland waterway vessels.

Market development: The market development of alternative fuels including hydrogen follows the strong political incentivation and the rapid technical development pace. Hydrogen in various forms (liquid, material based) is produced in large amounts to serve – among other – the inland waterway vessels.

Bunkering infrastructure is available in all relevant Rhine ports from ARA to Basel with competition among suppliers and different bunkering technology available (swappable containers, STS).

The overall number of inland waterway vessels operating on the Rhine, their transport work (in ton miles) and their overall annual energy consumption are stable over time. Decreasing transport work in some segments (e.g. coal, iron ore) is balanced by increasing transport work in other segments (e.g. containers, river cruise, tank). The energy demand per ton mile is constant. Newbuild numbers remain at about 80 per year, replacing old tonnage, which is scrapped.

Implications for newbuilds: Above mentioned regulatory, technical and market developments lead to overall strong uptake of alternative propulsion technology and fuels in vessel newbuilds. Across all segments and vessel clusters a steadily increasing share of (currently 80) newbuilds is equipped with alternative technology. One third of the newbuilds with alternative fuels will be running on hydrogen, while battery, ammonia and methanol make up for the rest.

Implications for existing vessels: For older vessels CO2 emission reduction is largely achieved by the use of drop-in fuels, primarily zero-emission power-to-X fuels. If main engines need to be replaced after (on average) 20 years, an increasing number and finally majority of owners decides for zero emission technology. One third of the retrofits towards alternative fuels will be running on hydrogen.

Subsequent Figure 23 synthesizes the competitiveness of hydrogen vs. conventional diesel and other alternative fuel options for inland waterway vessels in the year 2030 under Scenario 3. Technology, regulation and availability will be safeguarded; and alternative fuels have a favourable business case compared to diesel and compete between each other.

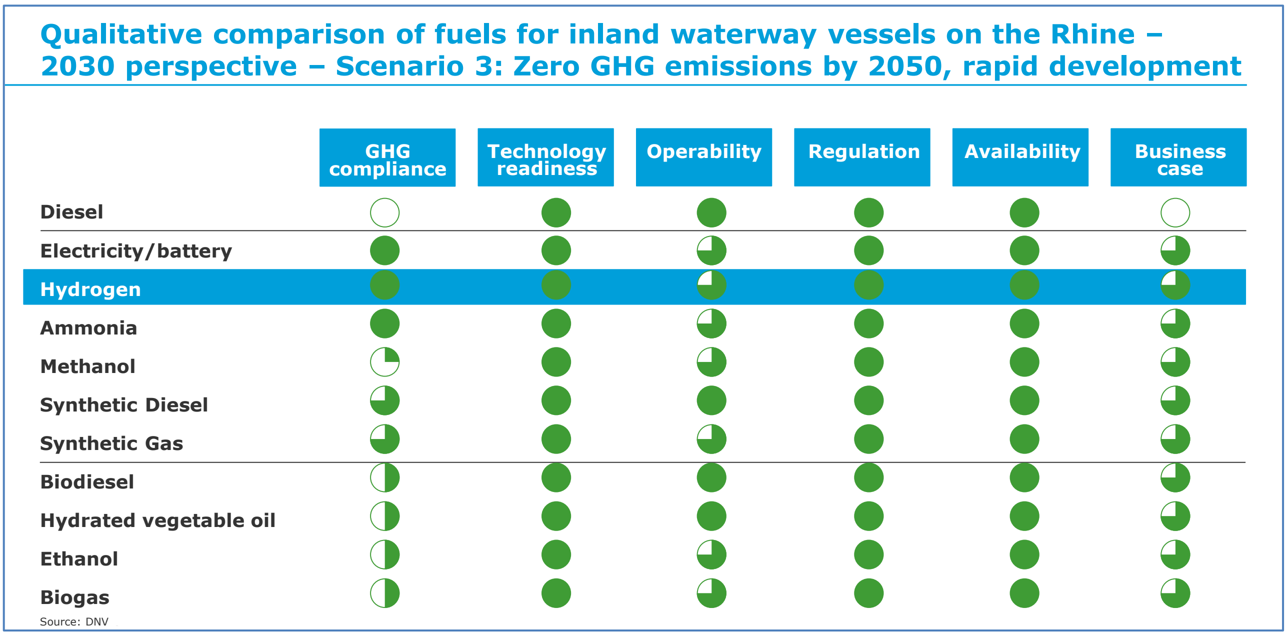


Figure 22: Qualitative assessment of fuels for inland waterway vessels – 2030, scenario 3

5 QUANTITATIVE ASSESSMENT OF MARKET POTENTIAL FOR HYDROGEN

The objective of the quantitative assessment is to combine theoretical or technical demand by ship cluster determined in step 1 (baselining) with assumed market penetrations in newbuilding and retrofitting developed in step 2 (qualitative assessment) to prognose the demand of hydrogen by inland navigational vessels on the Rhine corridor in a time frame 2020 to 2040. Before summarizing the model results, an overview on the assumptions shall be provided.

5.1 Assumptions

The model assumptions comprise assumptions, which are common across the scenarios as well as scenario-specific assumptions.

Common assumptions across scenarios

Based on overall fleet and trade development over the past 15 years, the simplifying assumption is made that the overall number of inland waterway vessels operating on the Rhine, their transport work (in ton miles) and their overall annual energy consumption are stable over time. Decreasing transport work in some segments (e.g. coal, iron ore) is balanced by increasing transport work in other segments (e.g. containers, river cruise, tank). The energy demand per ton mile is constant.

Newbuild numbers remain at about 80 per year with a similar distribution across segments and sizes as seen over the past 5 years. Following the table below, it is assumed that 55 vessels per year fall into the twelve clusters. It is assumed that newbuilds replace old tonnage (typically above 40 years), which is scrapped.

Table 5: Assumed newbuilds – by vessel cluster

Assumed newbuilds per year

Type cluster	DWT cluster	kW Cluster	Newbuilds
General cargo	250-499	0-250	1
General cargo	500-999	250-499	2
General cargo	1,000-1,999	500-749	5
General cargo	2,000-2,999	750-999	6
General cargo	3,000-3,999	1,250-1,500	6
Tanker	1,000-1,999	500-749	11
Tanker	2,000-2,999	1,000-1,249	11
Passenger/Cruise	<250	0-249	5
Pushed convoy	<250	0-249	1
Ferry	<250	0-249	1
Ferry	All	500-749	1
Other	<250	0-249	5

Furthermore, it is assumed that main engines need to be replaced every 20 years. Hence, it is assumed that retrofits of engine, propulsion system and fuel type is considered once a vessel gets 20 years old. A certain share (see penetration rates under the three scenarios) of vessels is retrofitted from a conventional combustion engine running on diesel to alternative fuel technology, of which fuel cell or potentially hydrogen combustion engine and hydrogen have a certain share (see scenarios). – Even if the engines may need a second replacement at the ages of 40, 60 etc., it is considered that retrofit to hydrogen does (exceptions may exist) not have a favourable business case compared to other options.

Based in the IVR database, the following age distribution, respective number of vessels reaching an age of 20 years between 2020 and 2040 have been identified for the twelve vessel clusters.

Table 6: Vessels reaching an age of 20 years – by vessel cluster

Vessels reaching an age of 20 years

Type cluster	DWT cluster	kW Cluster	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
General cargo	250-499	0-250	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
General cargo	500-999	250-499	2	1	2	2	0	1	0	2	1	2	1	0	0	0	0	0	0	1	1	0	0
General cargo	1,000-1,999	500-749	18	5	11	5	3	3	3	2	1	5	3	0	0	1	0	0	1	3	5	0	1
General cargo	2,000-2,999	750-999	14	10	7	3	4	7	8	6	6	15	7	2	0	0	0	0	1	0	1	0	1
General cargo	3,000-3,999	1,250-1,500	9	8	7	7	9	14	26	34	40	36	6	1	2	0	0	0	1	3	1	1	0
Tanker	1,000-1,999	500-749	5	0	1	7	7	3	6	6	16	16	10	8	8	9	3	7	4	8	6	12	1
Tanker	2,000-2,999	1,000-1,249	5	4	5	12	7	13	6	5	13	25	9	4	9	7	9	2	8	12	6	13	2
Passenger/Cruise	<250	0-249	4	9	7	3	3	4	0	4	2	3	2	3	0	0	0	0	3	1	0	0	0
Pushed convoy	<250	0-249	2	1	1	1	0	0	3	1	1	1	0	2	0	0	2	0	0	0	0	0	0
Ferry	<250	0-249	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferry	All	500-749	0	0	2	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0
Other	<250	0-249	3	3	3	2	1	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0

As outlined before, the vessels of the twelve clusters represent 58% of the fleet in the IVR database for Western Europe. It is assumed that the distribution is representative for the vessel operating on the Rhine. Furthermore, it is assumed that it is justifiable to scaling up the numbers to 100% in order to cover the entire fleet. Finally, it is assumed that 75% of the fuel is consumed on the Rhine between Rotterdam and Basel.

Scenario 1: Current instruments, moderate technology development pace

Based on the considerations outlined for Scenario 1 in chapter Scenarios the following assumptions have been made for the penetration rates of alternative propulsion technology and related fuels in newbuilds and existing vessels once they reach an age of 20 years. Numbers do not include drop-in fuels.

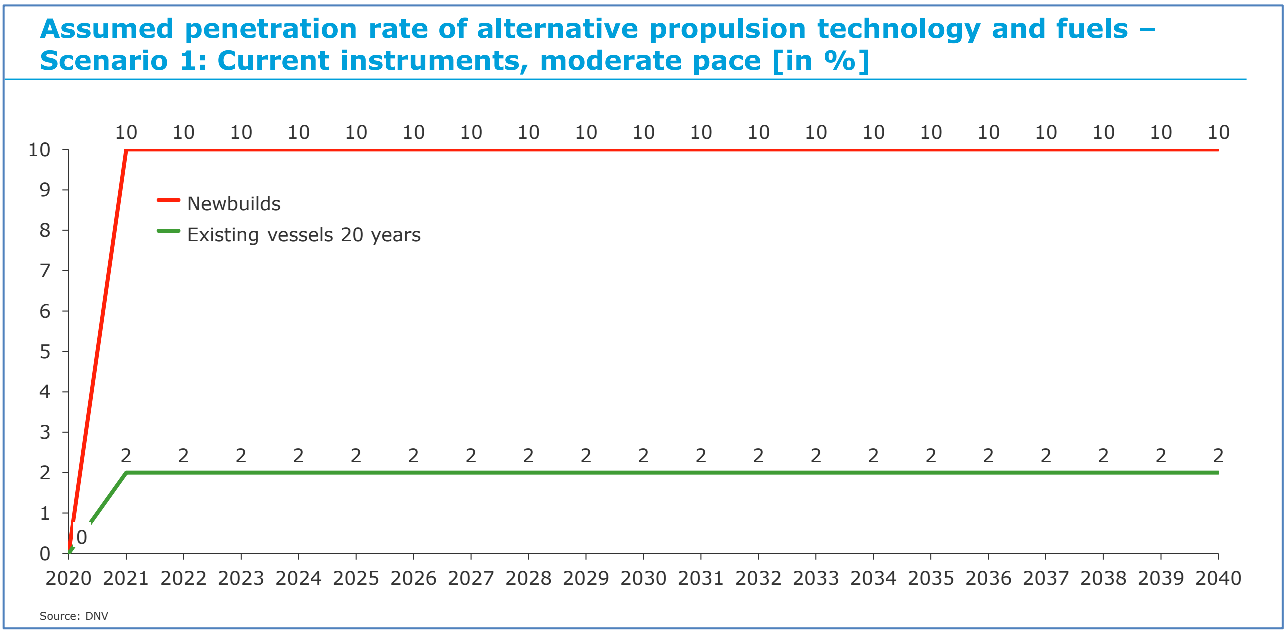


Figure 23: Assumed penetration rate of alternative prop. technology and fuels – scenario 1

It is assumed that hydrogen has a share of one third of the vessels which are equipped with alternative propulsion and fuel technology.

Scenario 2: Green Deal, medium technology development pace

Based on the considerations outlined for Scenario 2 in chapter Scenarios the following assumptions have been made for the penetration rates of alternative propulsion technology and related fuels in newbuilds and existing vessels once they reach an age of 20 years. Numbers do not include drop-in fuels.

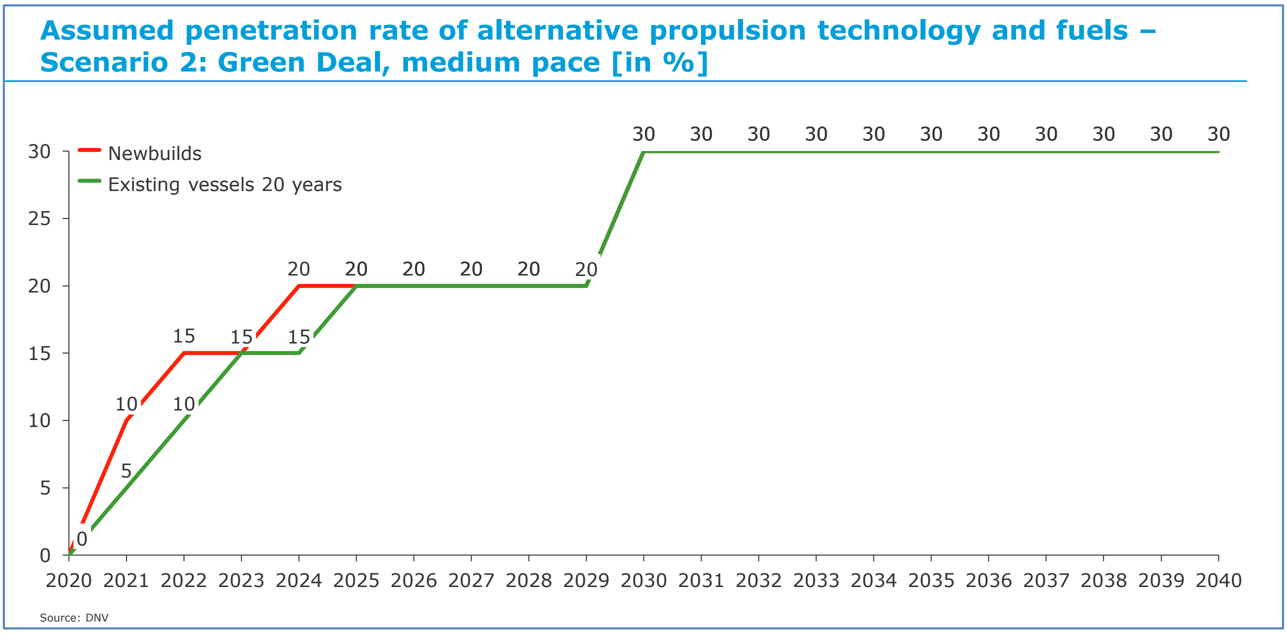


Figure 24: Assumed penetration rate of alternative prop. technology and fuels – scenario 2

It is assumed that hydrogen has a share of one third of the vessels which are equipped with alternative propulsion and fuel technology.

Scenario 3: Zero GHG emissions by 2050, rapid technology development

Based on the considerations outlined for Scenario 3 in chapter Scenarios the following assumptions have been made for the penetration rates of alternative propulsion technology and related fuels in newbuilds and existing vessels once they reach an age of 20 years. Numbers do not include drop-in fuels.

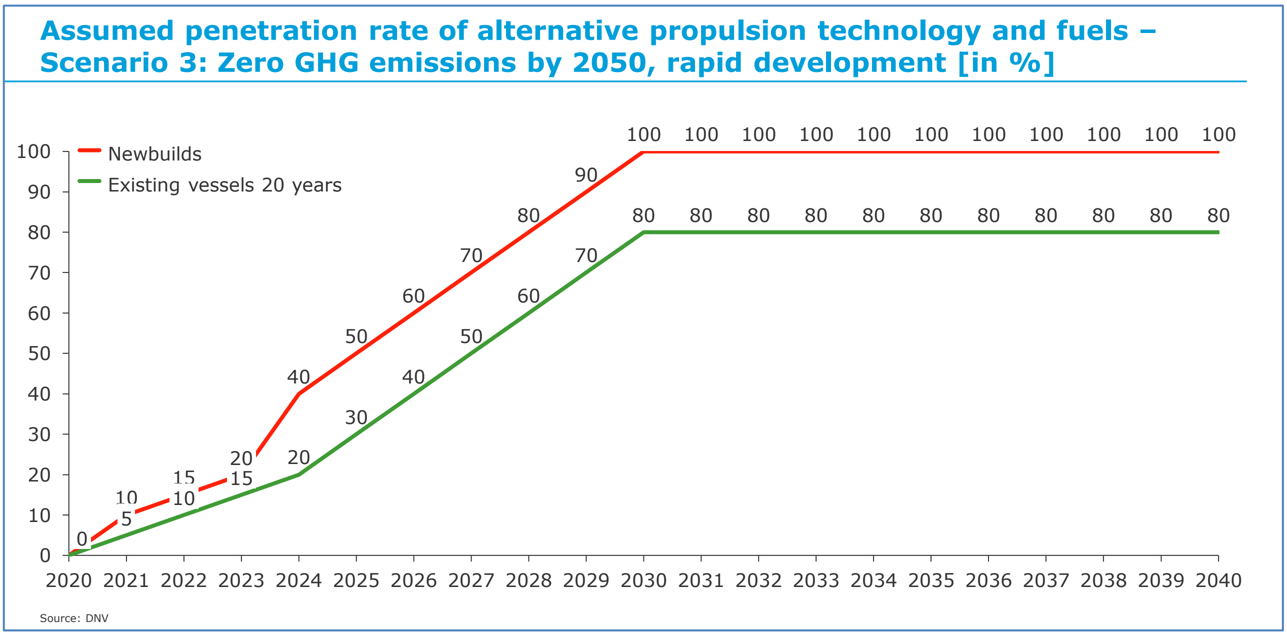


Figure 25: Assumed penetration rate of alternative prop. technology and fuels – scenario 3

It is assumed that hydrogen has a share of one third of the vessels which are equipped with alternative propulsion and fuel technology.

5.2 Model results

Based on the assumptions outlined above, hydrogen consumptions of vessels operating on the Rhine have been modelled for the time frame 2020 to 2040.

Scenario 1: Current instruments, moderate technology development pace

In Scenario 1 inland waterway vessels will consume about 5,000 tons/year of hydrogen in 2030 and 10,000 tons/year in 2040 when operating on the Rhine. In both cases about 80% of the consumption (about 4 respectively 8,000 tons) will be consumed by vessels which will be built over the coming years. Only 20% of the consumption will come from existing vessels, which will have been retrofitted to hydrogen as fuel.

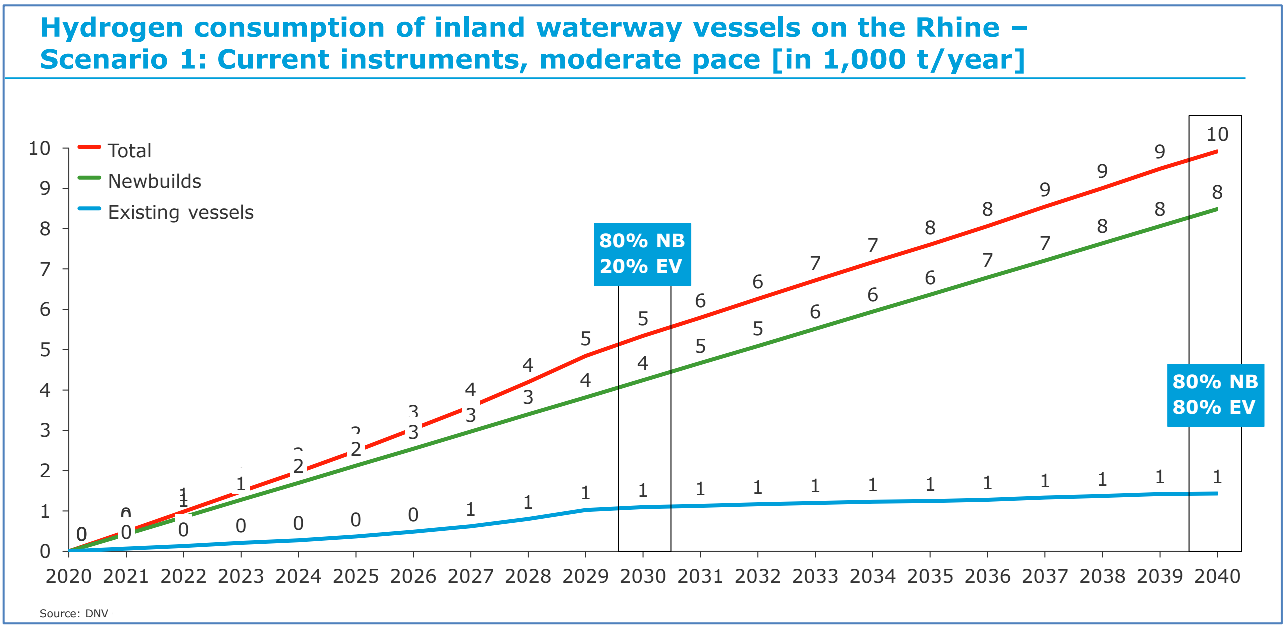


Figure 26: Hydrogen consumption of inland waterway vessels on the Rhine – scenario 1

Scenario 2: Green Deal, medium technology development pace

In Scenario 2 inland waterway vessels will consume about 18,000 tons/year of hydrogen in 2030 and 36,000 tons/year in 2040 when operating on the Rhine. In 2030 about 45% of the consumption will originate from newbuilds, which will have been delivered between 2021 and 2030, while about 55% will originate from existing vessels which will have been retrofitted to hydrogen. In 2040 the ratio will have changed: About 58% (or 21,000 tons/year) of hydrogen will be consumed by vessels which will have been newly built by then, while only 42% (or 15,000 tons/year) relate to existing retrofitted vessels.

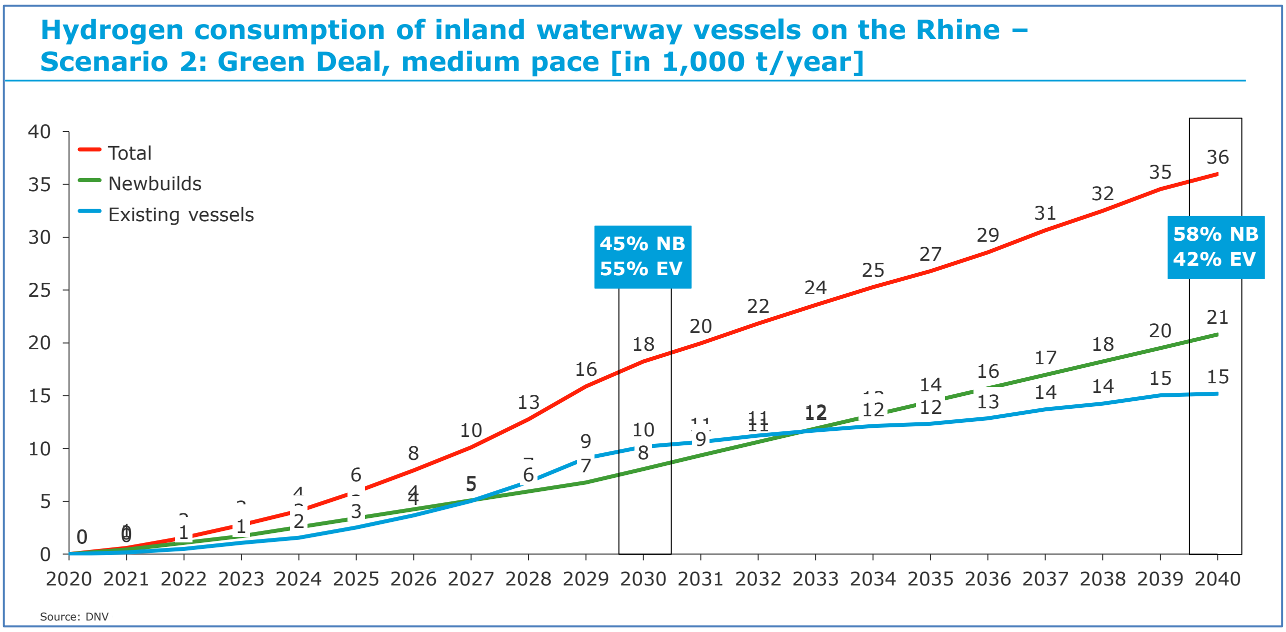


Figure 27: Hydrogen consumption of inland waterway vessels on the Rhine – scenario 2

Scenario 3: Zero GHG emissions by 2050, rapid technology development

In Scenario 3 inland waterway vessels will consume about 48,000 tons/year of hydrogen in 2030 and 104,000 tons/year in 2040 when operating on the Rhine. In 2030 about 52% (or 25,000 tons) of the consumption will originate from newbuilds, which will have been delivered between 2021 and 2030, while about 48% (or 23,000 tons/year) will originate from existing vessels which will have been retrofitted to hydrogen. Until 2040 more demand growth will come from additional newbuilds, which will consume 65,000 tons/year (63%). Retrofitted existing vessels will consume about 38,000 tons/year (37%).

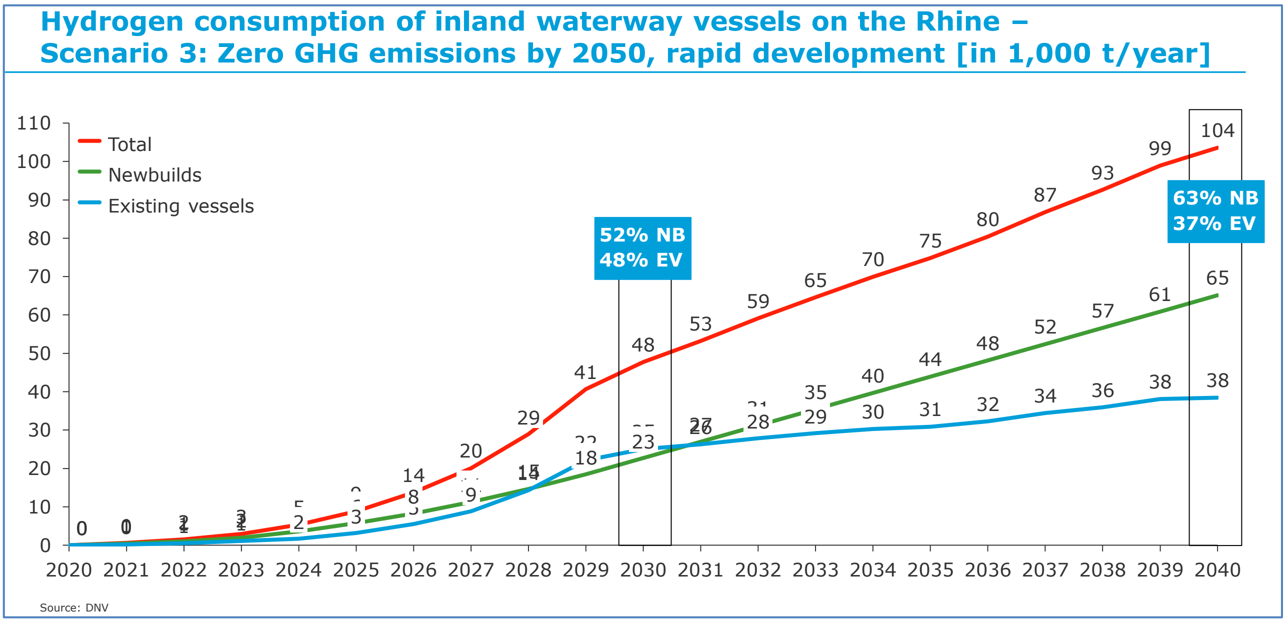


Figure 28: Hydrogen consumption of inland waterway vessels on the Rhine – scenario 3

Comparison of scenarios

Depending on regulatory pathway and technology development pace between about 5,000 and 50,000 tons/year of hydrogen will be consumed by inland waterway vessels on the Rhine in the year 2030. While the low case scenario strongly depends on vessels newbuilds equipped for hydrogen, in both other scenarios newbuilds and retrofitted existing vessels will each contribute about half to the demand. – Until 2040 the spread between the scenarios remains fairly constant with a range from 10,000 to little more than 100,000 tons/year. Vessels built between 2020 and 2040 will create between 60 and 80% of the demand.

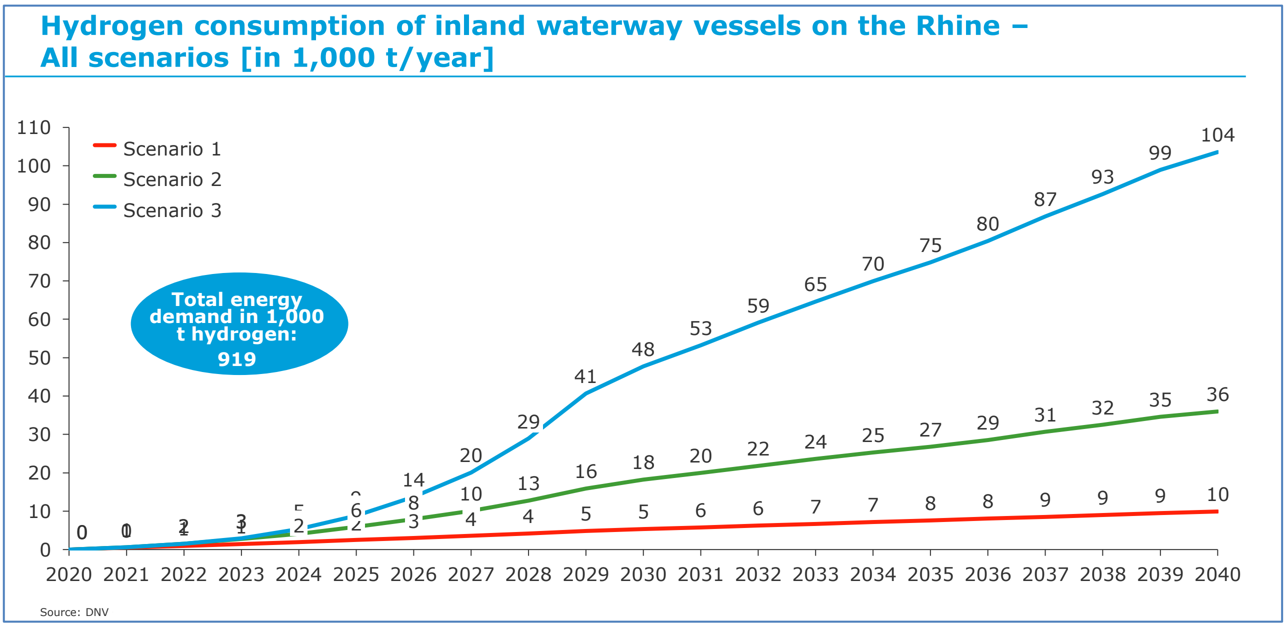


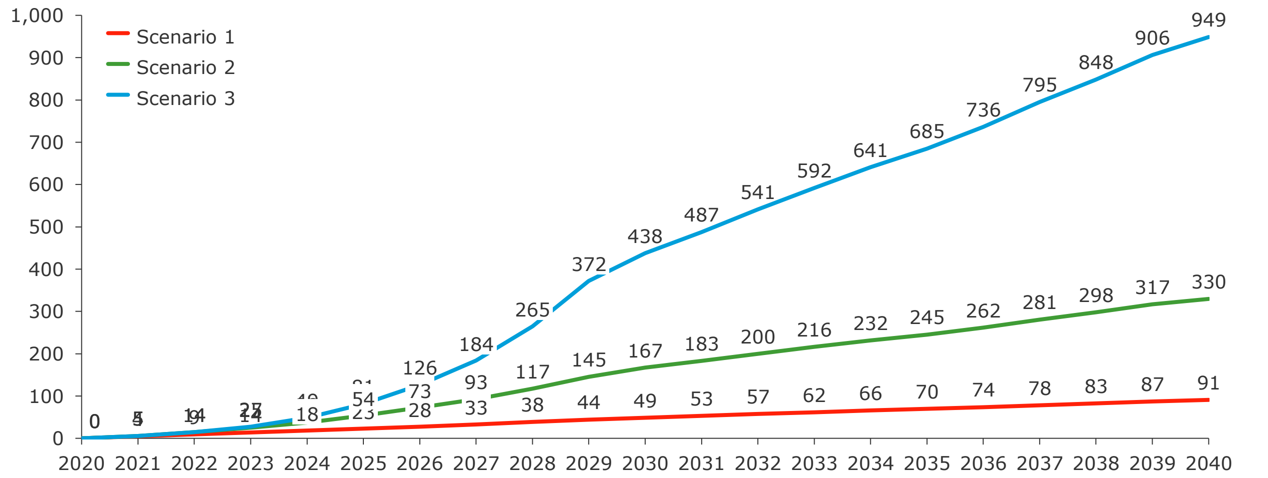
Figure 29: Hydrogen consumption of inland waterway vessels on the Rhine – all scenarios

Comparing the projections for 2040 with the total energy demand of inland waterway vessels operating on the Rhine (equivalent to about 900,000 tons/year), hydrogen will be one fuel among others with a total share between 1 and 10%. The big gap originates from the huge fleet of vessels which are already older than 20 years and will most likely rather use emission reduced or zero-emission drop in fuels with conventional combustion engines.

Looking at the CO2 abatement, which will be achieved by introduction of hydrogen as fuel for inland waterway vessels, again the results vary for the three scenarios.

In Scenario 1 about 49,000 tons/year of CO2 will be abated in 2030 (cumulated 260,000 tons) and 91,000 tons/year in 2040 (cumulated 980,000 tons). In Scenario 2 the abatement is near 170,000 tons/year in 2030 (cumulated 730,000) and 330,000 tons/year in 2040 (cumulated 3.3 million tons). In the ambitious Scenario 3 about 440,000 tons/year of CO2 will be abated in 2030 (cumulated 1.6 million tons) and even 950,000 tons/year in 2040 (cumulated 8.7 million tons).

CO2 abatement of inland waterway vessels using hydrogen on the Rhine – All scenarios [in 1,000 t CO2/year]



Source: DNV model

Figure 30: CO2 abatement of inland waterway vessels using hydrogen – all scenarios

6 CONCLUSION

This report has **two objectives**:

- **Qualitative assessment:** Create an overview on the industry's perspective on hydrogen as fuel for inland waterway vessels in the context required emission reduction and available green fuels. Identify key drivers for adoption in ship newbuilds and existing vessels as well as potential challenges and incentives.
- **Quantitative assessment:** Quantify the demand for hydrogen as fuel for inland waterway vessels operating on the Rhine for the time frame 2020 to 2040 considering scenarios for regulatory and technology development. Quantify potential greenhouse gas (GHG) abatement.

The qualitative assessment is based on a number of semi-structured interviews with operators of larger fleets, bunker suppliers and industry associations, a workshop with more than 20 RH2INE members, DNV experience/expert knowledge and several external reports on market adoption of alternative fuels and effectiveness of related programs.

The quantitative assessment combines the consumption baseline of the current fleet with the scenarios developed as result of the qualitative assessment in a model determining future hydrogen demand and respective GHG abatement.

Together both result in the following **four main conclusions**:

(1) The inland waterway industry is committed to contribute its fair share to the required reduction of greenhouse gas emissions by 2030, 2040 and beyond

- Effectively all interviewees acknowledge the societal requirement to the inland waterway industry to reduce emissions over the coming years. 95% of the members of BLN-Schuttevaer expressed a positive view on green fuels.
- There is a general understanding that, if every operator had to use green and potentially emission free fuels based on the same and stable regulatory boundaries, the overall profitability of the industry would be largely unchanged.
- Lower specific energy demand and emissions per ton mile compared to other means of transport (esp. road) may have a favourable effect on the inland waterway industry, if emissions are priced on a level playing field.

(2) Ship owners take the choice of alternative propulsion technology and green fuels based on six factors, with the specific business case being the ultimate decision criterion

- GHG compliance (emission reduction credited by the regulator)
- Technology readiness (storage system, energy converter)
- Operability (potential adverse or positive effects compared to diesel)
- Regulation (ship design, local permission process)
- Availability (fuel production and bunkering infrastructure, number of suppliers)
- Business case (CAPEX, OPEX, revenue), influenced by the other factors

(3) The penetration of alternative fuels in general and hydrogen in particular strongly depends on the regulatory boundaries set by EU and its member states

- The wide demand spread between 10,000 and more than 100,000 tons/year of hydrogen in 2040 is mainly caused by differing regulatory boundaries.

- Pricing of emissions, in particular CO2-pricing, has a major effect on the penetration rate of alternative fuels.

- Direct grants (investment CAPEX subsidies) can play an important role to accelerate the technology development and overcome technical and related operational challenges of hydrogen as well as of other zero-emission and emission-reduced fuels.

- OPEX subsidies (e.g. guaranteed hydrogen prices for a 5-year period) are being discussed but can set unwanted incentives.

- A mechanism comparable to the Norwegian NOX-Fund may be considered to stimulate the penetration of alternative fuels. Funds raised by pricing emissions (e.g., GHG taxation collected via the bunker suppliers) of all inland waterway vessels operating on the Rhine are 100% recycled to the industry for direct grants for investment into clean technology.

(4) Whereas hydrogen can be a significant part of the solution for newbuilds and younger existing vessels, additional solutions need to be found for older existing vessels

- The total energy demand of inland waterway vessels operating on the Rhine equals about 2.6 million tons/year of diesel or 920,000 tons/year of hydrogen

- Depending on regulatory pathway and technology development pace between about 10,000 and 100,000 tons/year of hydrogen will be consumed by inland waterway vessels on the Rhine in the year 2040. This equals a share of 1 to 10% of the total energy demand and saves 90,000 to 950,000 tons/year CO2 in 2040.

- If all newbuilds from 2020 onwards would be fuelled with hydrogen, the total demand of these vessels would amount to about 270,000 tons/year in 2040, 29% of the total energy demand. This equals about 770,000 tons/year of diesel and 2.5 million tons/year of CO2 saving.

- If in addition all vessels reaching an age of 20 years would be retrofitted to hydrogen from 2020 onwards, this would contribute another 230,000 tons/year, 25% of total energy demand. This equals about 660,000 tons/year of diesel and 2.1 million tons/year of CO2 saving.

- About 420,000 tons/year (46% of total energy demand) would be the remaining gap caused by vessels, which are older than 20 years and appear (from a commercial perspective) not to be predestined for hydrogen retrofitting when their main engines need to be replaced in the age of 40 or older. It appears that emission-reduced or emission-free drop-in fuels will be required for these vessels.

7 REFERENCES

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/4/ CCNR Annual Report 2020 “Inland Navigation in Europe – Market Observation”

/5/ CCNR “Market Insight on Inland Navigation”, April 2020

/6/ CCNR Thematic Report “RIVER-SEA TRANSPORT IN EUROPE”, January 2020

/7/ Ecorys PROMINENT report “D1.3 Analysis of barriers and facilitating factors for innovation uptake”, Nov. 2015

/8/ EICB, “Waterstof in Binnenvaart en Short Sea”, 2020

/9/ EU Statistical Pocketbook 2019 “EU Transport in Figures“

/10/ IHS Markit “Seaweb”

/11/ IVR “Ships Information System Database”, Sept. 2020

/12/ Stichting Projecten Binnenvaart PROMINENT report „D1.1 List of operational profiles and fleet families”, 2016

/13/ Vesseltracker AIS data

8 APPENDIX

Interview guide
Hydrogen demand of inland waterway vessels on river Rhine

Group:	**Shipping company (1.0)**
Interviewee:	xxx
Company:	xxx
Interviewer:	xxx
Date:	xxx

Intro

- Joint Venture RH2INE (Rhine Hydrogen Integration Network of Excellence) is acknowledging the need for green fuels in the future and aiming at exploring and possibly promoting hydrogen fuelled inland waterway vessels on river Rhine
- Consortium is constituting of about 20 partners, partially authorities, partially companies. E.g. Port of Rotterdam, Duisport and RheinCargo.
- DNV has been asked for a technical feasibility study and a rough assessment of potential penetration rates respectively amount of hydrogen needed

Own business

- Before looking at hydrogen in more detail, please allow us first to understand your business a bit better. What is your main activity? What goods do you ship? What is your key operating area?

1. How does your fleet look like? Segment, propelled/non propelled, size of ships, owned/chartered, age, engine…
2. How does your fleet renewal look like (in the past and in foreseeable future)? What newbuilds, what retrofits?
3. Did you have to adopt to new (green) technology due to increasing regulatory requirements? Do you have any plans to implement green technology?

Bunkering

4. What fuel specification do you typically use?
5. Where, i.e. in which ports, do you bunker?
6. How does the bunker market look like? How many suppliers by port?
7. Are there bunker suppliers active in a number of ports? Who are the key players?
8. How does bunkering of inland waterway vessels work from operational perspective? Does your ship berth at a jetty or does a bunkering vessel come alongside? Do you bunker during cargo operation?
9. How long does bunkering take?
10. What is your bunkering interval in days or km sailed?
11. Could you share any statistics on the bunker market on the river Rhine?

Adaptation of hydrogen as fuel

12. What is your view on "green", carbon-neutral fuels?
13. What fuels have you looked at?
14. What would make you decide for a certain green fuel?
15. In case you had to use green fuel, what are your criteria when comparing different fuel options?
16. What is your assessment for hydrogen looking at the following aspects?
    - technical (e.g. energy density/weight, endurance/longevity of equipment etc.),
    - operational (e.g. bunkering, interference with cargo operation),
    - regulatory (e.g. GHG, safety),
    - infrastructure (e.g. chicken-egg),
    - economic (CAPEX, OPEX, fuel costs; CO_2 price, subsidies etc.)
17. Which challenges or threats do you see regarding implementation/market-penetration of hydrogen?
18. Which incentives might help implementation/market-penetration of hydrogen?
19. Different bunkering modes are being discussed: bunkering at berth, ship-to-ship and handing over of fuel containment systems (mobile tanks). What is your perspective on them?
20. Would hydrogen be a fuel for newbuilds or also for retrofits? If also for retrofits, does it depend on the age? Would e.g. 10-year-old ships be retrofitted, but 20-year-old not anymore? What is your thinking around that?

Ship clusters/quantification

21. By now we spoke more qualitatively about the view of your company. Our challenge is that we shall provide also a quantitative assessment on the potential hydrogen bunker market.
22. For that we would need to cluster the inland waterway fleet into groups and try to understand the average annual consumption of a vessel of this group and likely hydrogen penetration rates.
23. Grouping might be done by e.g. segment, size etc. Say chemical tankers of x tons deadweight, container carriers of x TEU. What clustering would you suggest?
24. Have these clusters certain typical trading patterns? E.g. of the container carriers 25% go from Rotterdam to Duisburg, 25% to Basel…? How would we find out the typical pattern and the total annual consumption?
25. What market penetration rates might hydrogen have in the clusters you are active in? In newbuilds being built in 2020, 2030 and 2040? And how about retrofits? What drives the penetration rates?
26. What data sources can you recommend getting a solid overview of the ships sailing on the Rhine?
    - Fleet technical view?
    - Fleet sailing pattern?
    - Fleet bunkering pattern?

Interview guide
Hydrogen demand of inland waterway vessels on river Rhine

Group:	**Bunker supplier (1.0)**
Interviewee:	xxx
Company:	xxx
Interviewer:	xxx
Date:	xxx

Intro

- Joint Venture RH2INE (Rhine Hydrogen Integration Network of Excellence) is acknowledging the need for green fuels in the future and aiming at exploring and possibly promoting hydrogen fuelled inland waterway vessels on river Rhine
- Consortium is constituting of about 20 partners, partially authorities, partially companies. E.g. Port of Rotterdam, Duisport and RheinCargo.
- DNV has been asked for a technical feasibility study and a rough assessment of potential penetration rates respectively amount of hydrogen needed

Own business

- Before looking at hydrogen in more detail, please allow us first to understand your business a bit better.

1. In which ports do you provide what bunkering services? Ship-to-ship? Terminal-to-ship?
2. What fuel types do you supply?
3. How has that developed over the past years?

Bunkering technology/operation

4. What are common bunkering technologies for inland waterway vessels? Ship-to-ship? Terminal-to-ship? Other?
5. Do ships bunker during cargo operation or take extra time for bunkering?
6. What is the typical bunkering volume? Differentiated by ship type/size…
7. How long does bunkering take?
8. How often do inland waterway vessels bunker? In days or km?

Bunker market

- Is there any statistic on bunkering on the river Rhine (between Rotterdam and Basel)? Any data you could share?
- What would you assume to be the total bunker volume on the river Rhine (between Rotterdam and Basel)?
- Which are the big bunker ports?
- Who are the leading suppliers?
- Are there typically several suppliers by port or is it one per port?

Alternative fuels

- What is your view on "green", carbon-neutral fuels? Do you already supply any, do you have plan to do so? Which fuels have you looked at?
- How do shipping companies think about green fuels?
- In case they had to use green fuel, what are their criteria when comparing different fuel options?
- What is your assessment for hydrogen looking at the following aspects?
  - technical (e.g. energy density/weight, endurance/longevity of equipment etc.),
  - operational (e.g. bunkering, interference with cargo operation),
  - regulatory (e.g. GHG, safety),
  - infrastructure (e.g. chicken-egg),
  - economic (CAPEX, OPEX, fuel costs; CO2 price, subsidies etc.)
- Which challenges or threats do you see regarding implementation/market-penetration of hydrogen?
- Which incentives might help implementation/market-penetration of hydrogen?
- Different bunkering modes are being discussed: bunkering at berth, ship-to-ship and handing over of fuel containment systems (mobile tanks). What is your perspective on them?
- Would hydrogen be a fuel for newbuilds or also for retrofits? If also for retrofits, does it depend on the age? Would e.g. 10-year-old ships be retrofitted, but 20-year-old not anymore? What is your thinking around that?
- Any learnings from other technology implementation based on changing regulatory requirements? How did adaptation progress?

Ship clusters/quantification

- By now we spoke more qualitatively about the bunkering market. Our challenge is that we shall provide also a quantitative assessment on the potential hydrogen bunker market.
- For that we would need to cluster the inland waterway fleet into groups and try to understand the average annual consumption of a vessel of this group and likely hydrogen penetration rates.

- Grouping might be done by e.g. segment, size etc. Say chemical tankers of x tons deadweight, container carriers of x TEU. What clustering would you suggest?
- Have these clusters certain typical trading patterns? E.g. of the container carriers 25% go from Rotterdam to Duisburg, 25% to Basel…? How would we find out the typical pattern and the total annual consumption?
- What market penetration rates might hydrogen have in the various clusters? In newbuilds being build in 2020, 2030 and 2040? And how about retrofits? What drives the penetration rates?
- What data sources can you recommend getting a solid overview of the ships sailing on the Rhine?
    - Fleet technical view?
    - Fleet sailing pattern?
    - Fleet bunkering pattern?

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