Perspectives of Hydrogen Usage in IWT

A Feasibility Study

Sören Tinz
Institute for Combustion Engines VKA, RWTH Aachen University
Leer, June 28, 2018

INTERREG Deutschland Nederland
Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Project Partners

Electric Ship Facilities

DST

MARIKO

abh INGENIEUR-TECHNIK GMBH

H2

VBW

TU/e Technische Universiteit Eindhoven University of Technology

TU Delft

University of Applied Sciences HOCHSCHULE EMDEN·LEER

vka Institute for Combustion Engines

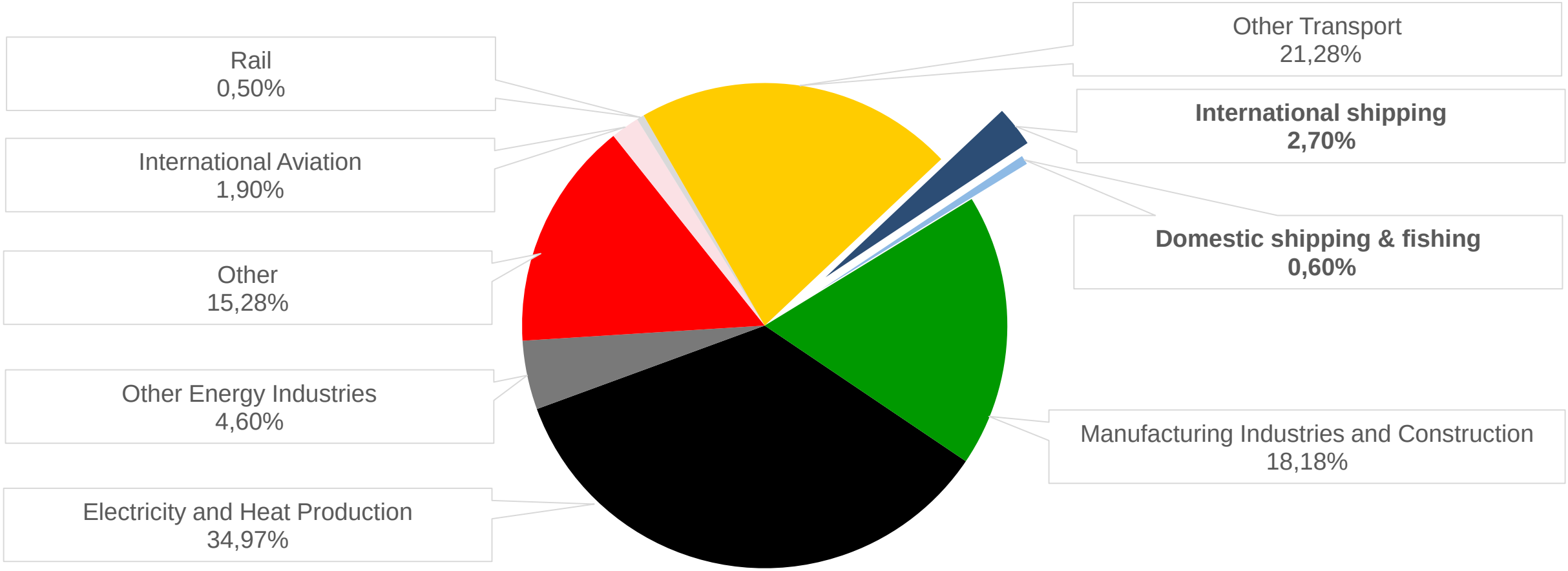
RWTH AACHEN UNIVERSITY

INTERREG Deutschland Nederland

Europäische Union Europese Unie

MariGreen Maritime Innovations in Green Technologies

Global CO_2 emissions and goals challenge all sectors



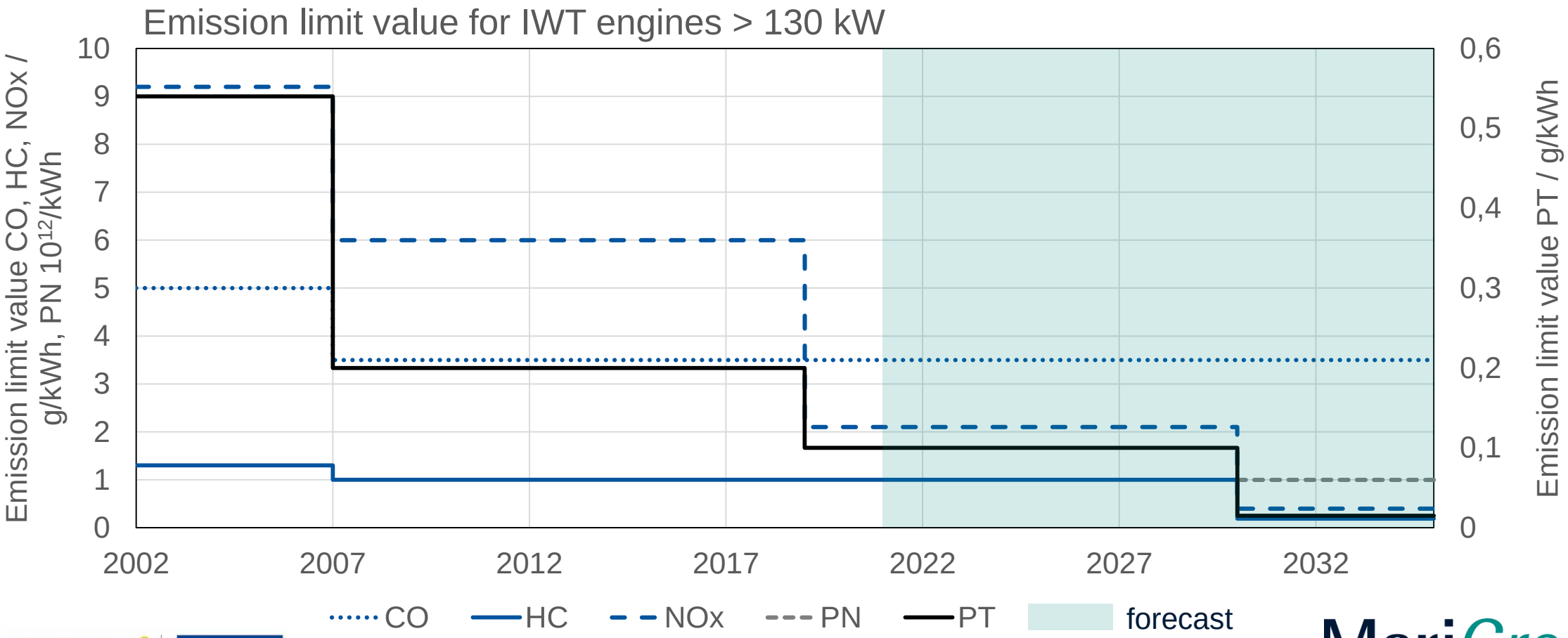
Source: Thomas Guesnet. “Energy efficiency of inland water ships - and how to improve it” (2011)

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Further reduction of emission limits will force new technologies



Source: http://www.ast-suedwest.gdws.wsv.de/wir_ueber_uns/veroeffentlichungen/oeffentlichkeitsarbeit/informationsschrift_2005/pdf/Seite-78-79-Abgasgrenzwerte-Dieselmotoren.pdf
https://www.dieselnet.com/standards/eu/nonroad.php#s5

INTERREG Deutschland Nederland

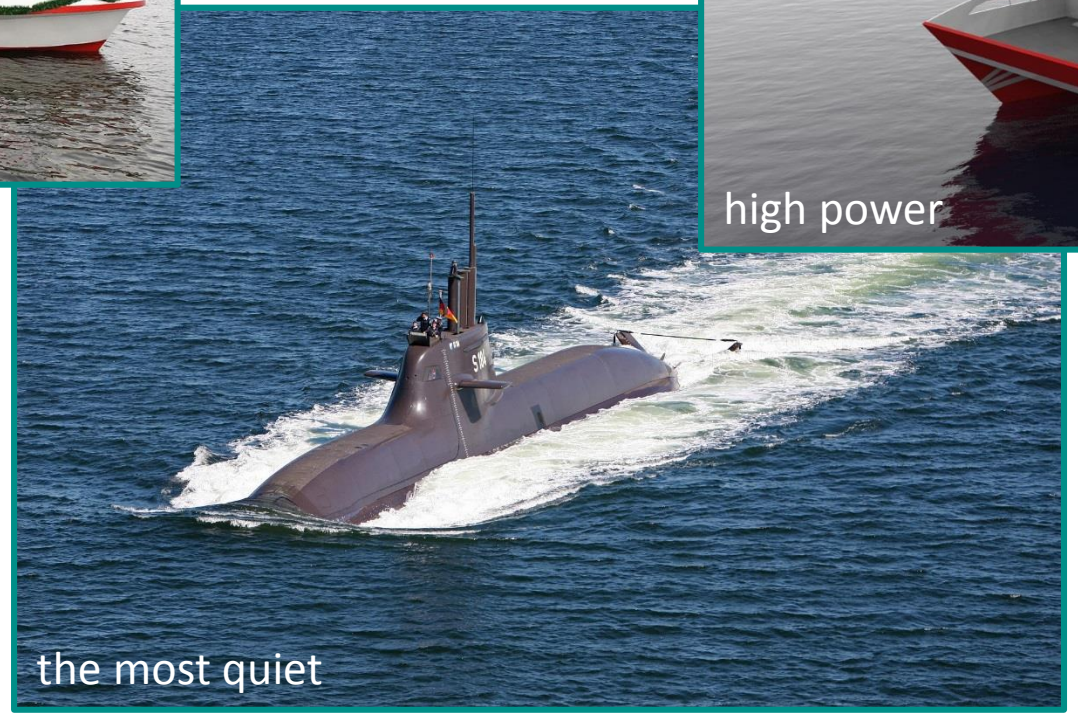
Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Former and current hydrogen projects aim at niche applications

Alsterwasser

U212A



SF Breeze

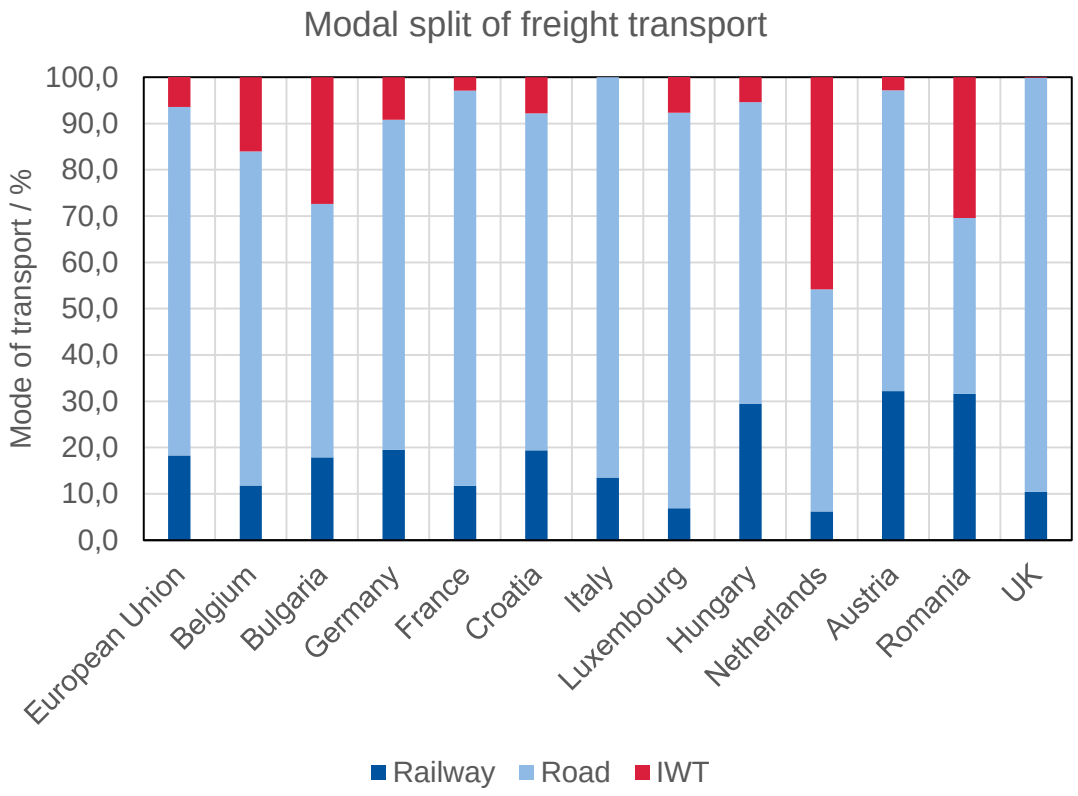
INTERREG Deutschland Nederland

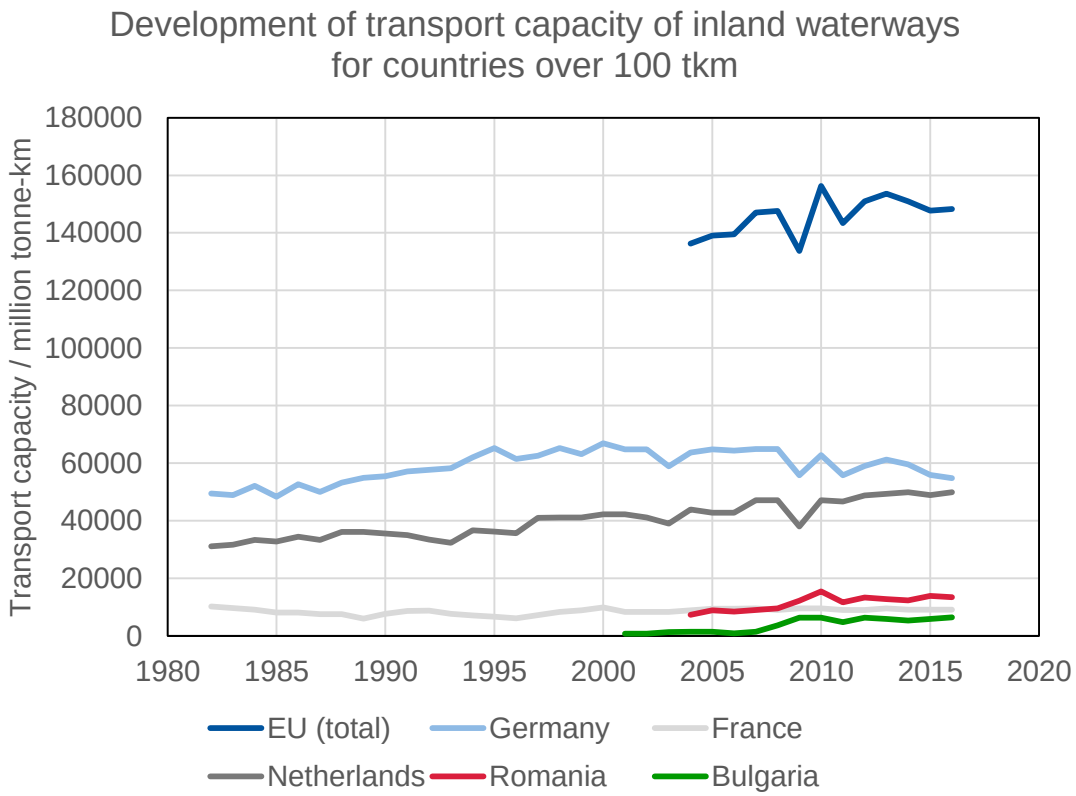
Europäische Union
Europese Unie

Source: www.hzwei.info, Wikipedia, Sandia National Laboratories

MariGreen
Maritime Innovations in Green Technologies

IWT is a notable mode of transport in Europe





Source: Eurostat

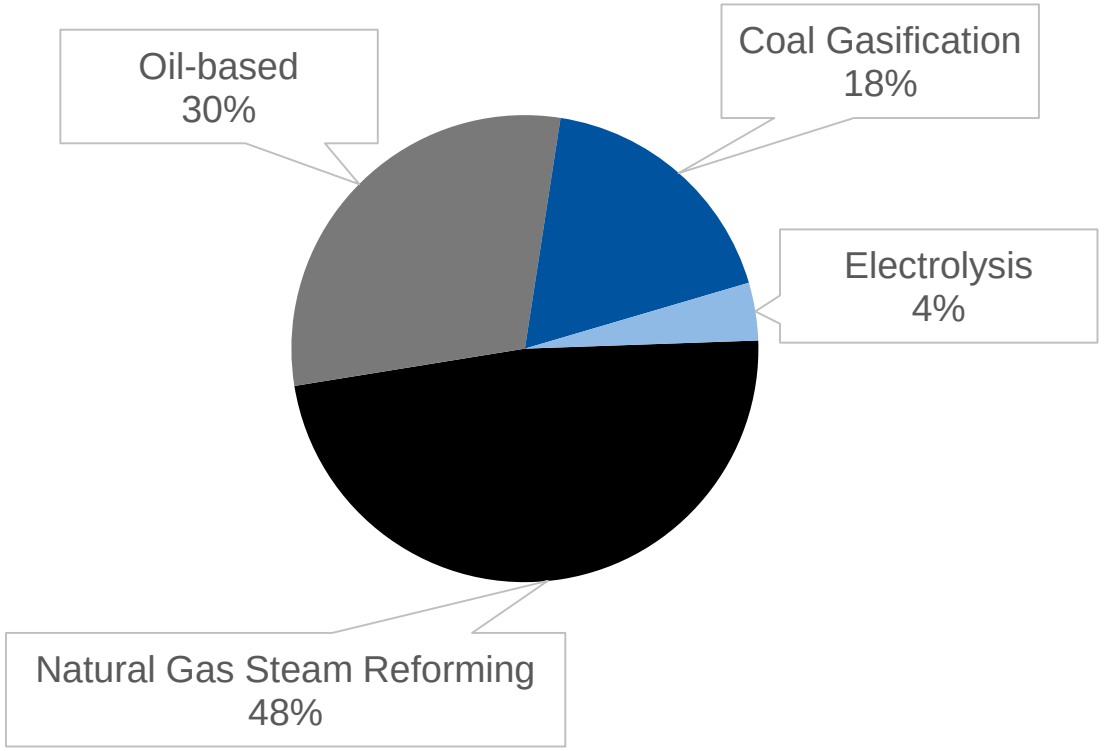
INTERREG Deutschland Nederland

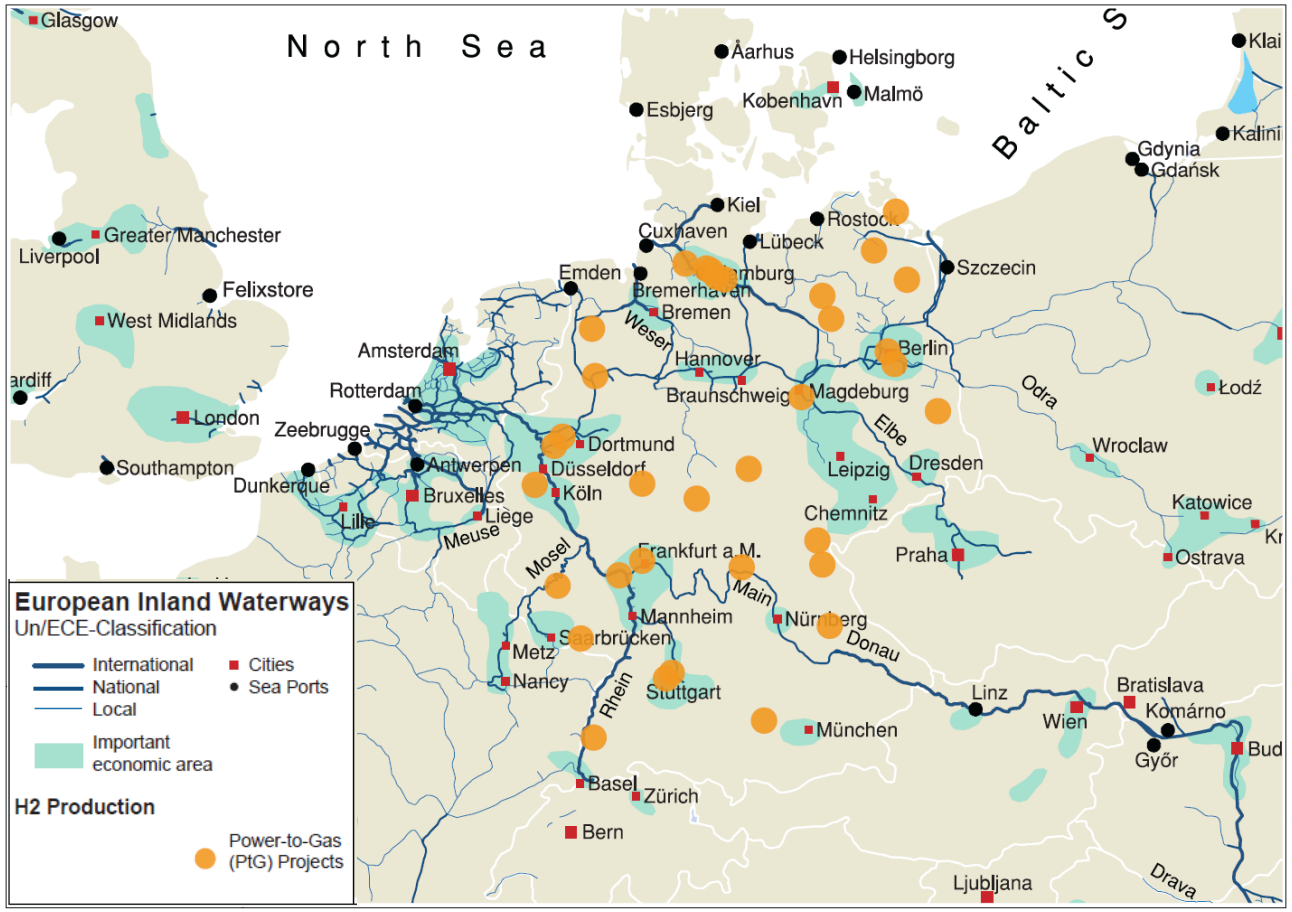
Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Currently most hydrogen is produced from fossil fuels

Distribution of H_2 production on the production lines





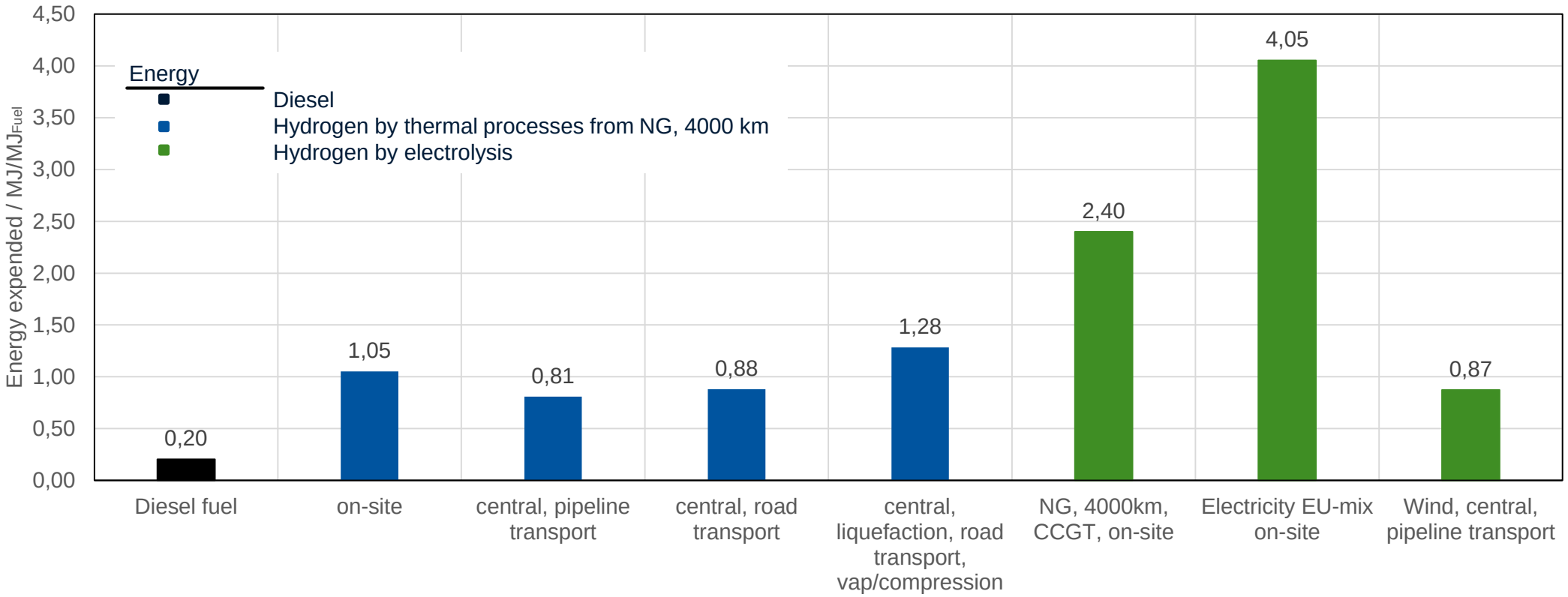
Source: Air Products, Joint Research Center

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

WTT Analysis (2020+): Primary energy consumption strongly depends on the way of hydrogen production



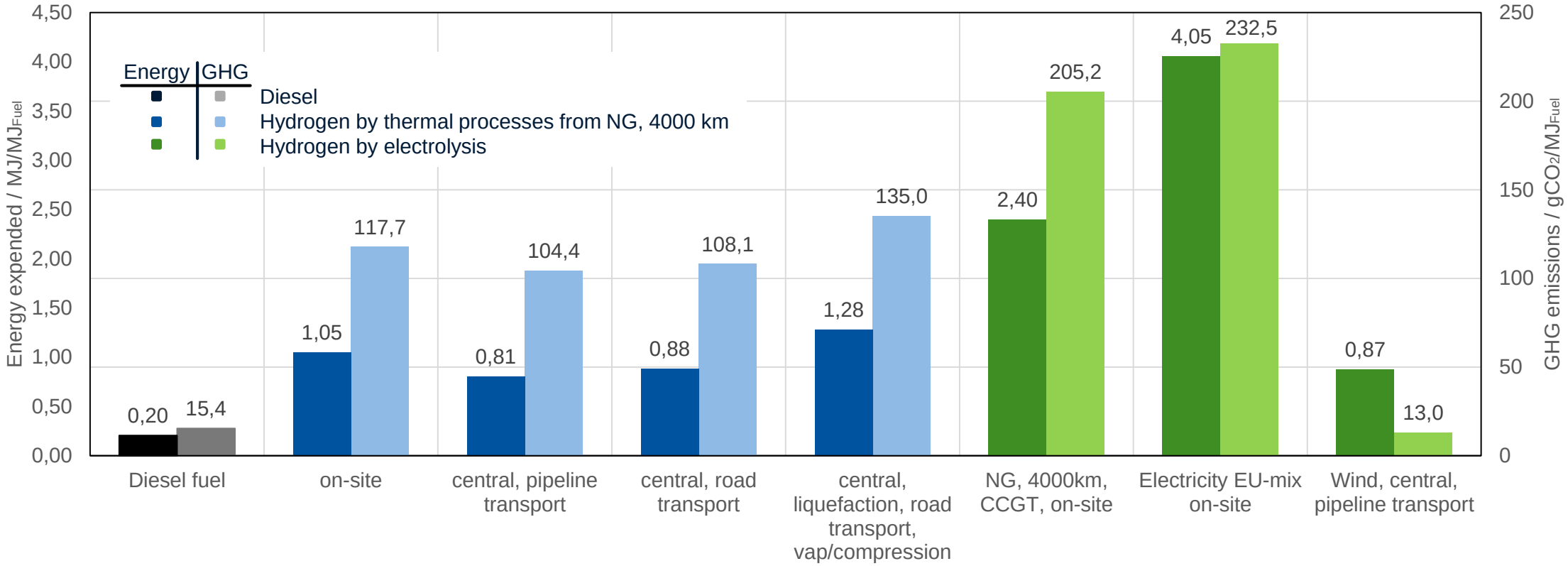
Source: Joint Research Center

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Only full renewable H_2 production is CO_2competitive in a well to tank consideration



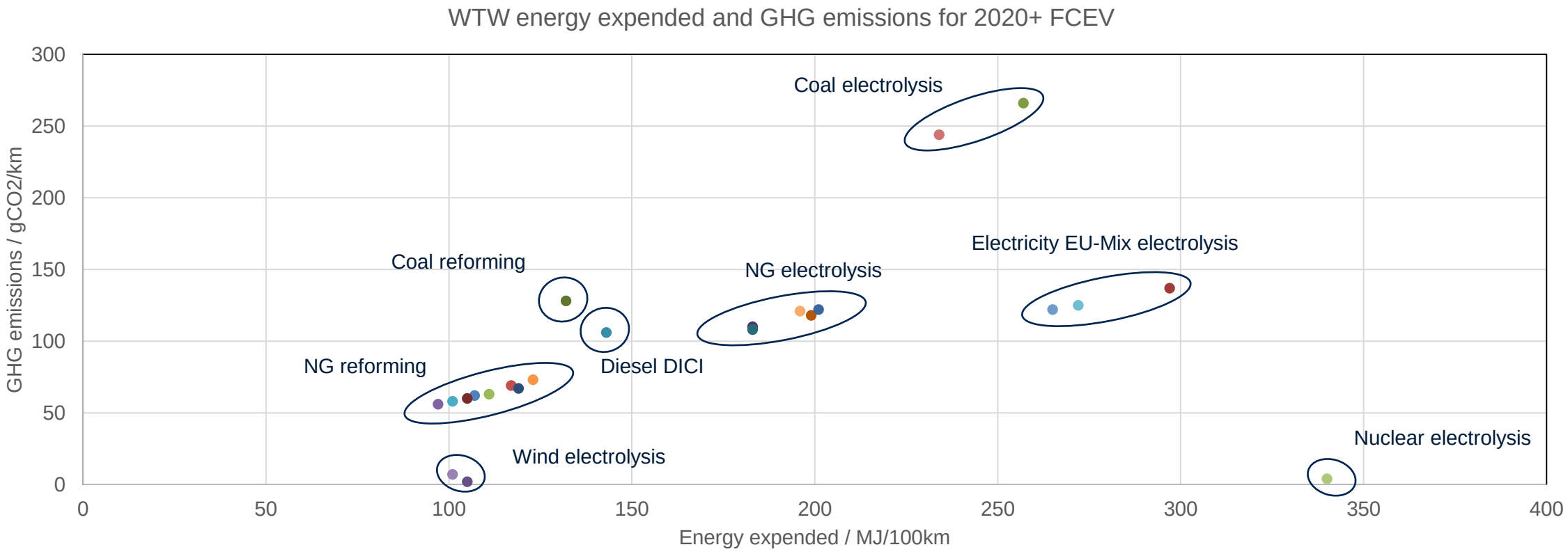
Source: Joint Research Center

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Significant advantages turn out in a well to wheel consideration

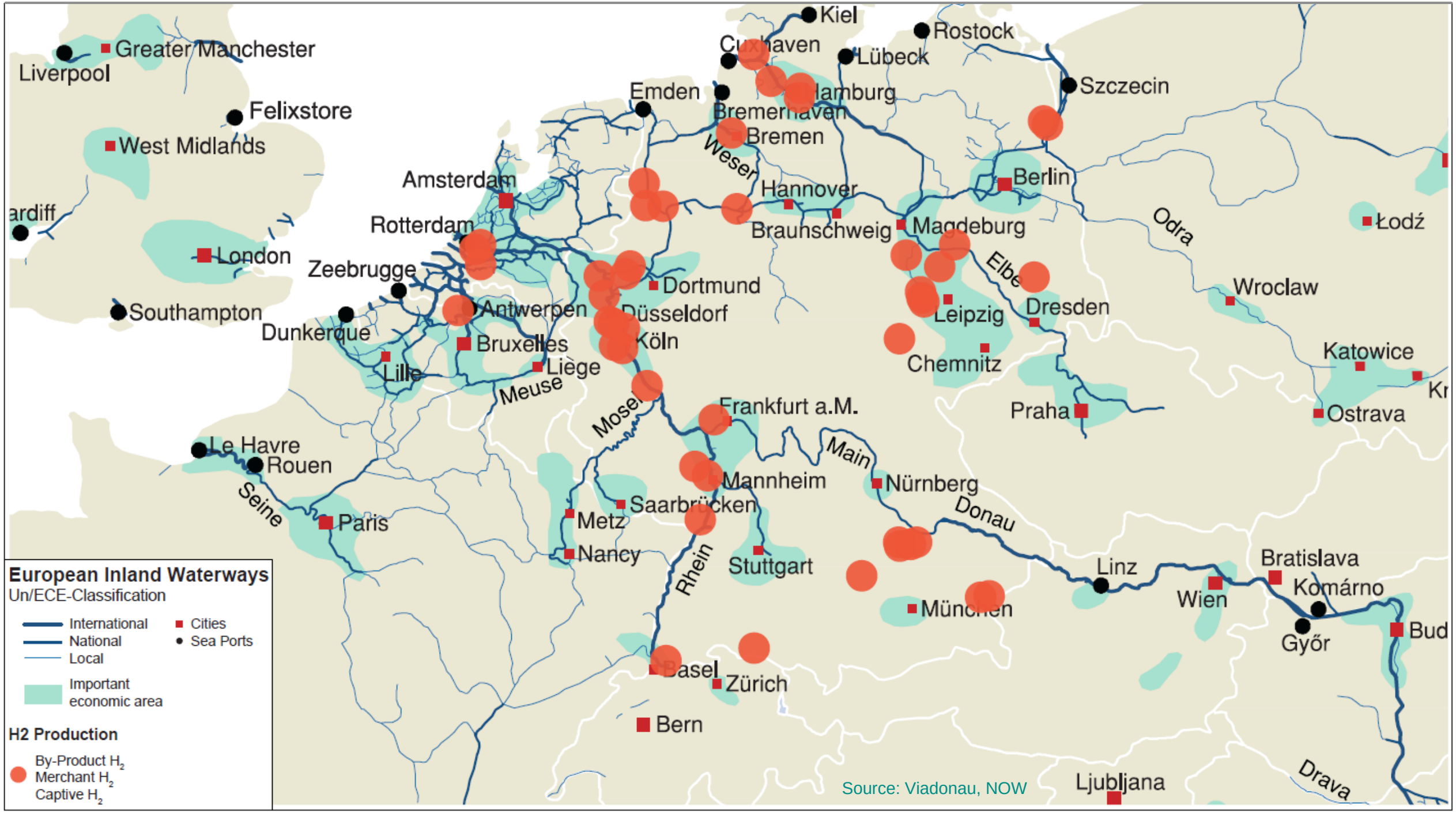


Source: Joint Research Center

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies


Kiel
Rostock
Cuxhaven
Lübeck
Greater Manchester
Liverpool
Szczecin
Emden
Hamburg
Bremerhaven
Felixstowe
Bremen
West Midlands
Weser
Amsterdam
Berlin
Hannover
Rotterdam
Braunschweig
Magdeburg
Łodź
Odra
London
Zeebrugge
Elbe
Dortmund
Wroclaw
Southampton
Antwerpen
Düsseldorf
Leipzig
Dresden
Dunkerque
Bruxelles
Köln
Katowice
Chemnitz
Lille
Liège
Meuse
Mosel
Frankfurt a.M.
Praha
Ostrava
Main
Le Havre
Rouen
Mannheim
Nürnberg
Seine
Saarbrücken
Donau
Paris
Metz
Nancy
Rhein
Stuttgart
Linz
Bratislava
Komárno
Wien
München
Győr
Basel
Zürich
Bern
Ljubljana
Drava
European Inland Waterways
Un/ECE-Classification
International
National
Local
Cities
Sea Ports
Important economic area
H2 Production
By-Product H2
Merchant H2
Captive H2
Source: Viadonau, NOW

Source: UNECE

Cargo vessel

Technical Data		
Dimensions	Length	110 m
	Width	11.45 m
	Max. draught	3.65
	Cargo capacity	3285 t
	Container capacity	192 TEU
Propulsive power	Main engine	1300 kW
	Bow thruster	500 kW

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Pushed convoy

Technical data					
	Dimensions	Length	Width	Max. draught	Cargo capacity
		193 m - 268.5 m	11.4 m – 34.2 m	Push boat: 1.7 m Barges: 2.8 m	16000t
	Propulsive power	Main engine		Bow thruster	
		3 x 1360kW		2 x 400kW	

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Rhine ferry

Technical Data		
Dimensions	Length	35 m
	Width	10 m
	Max. draught	1 m
	Cargo capacity	60 t
Propulsive power	Main engine	300 kW

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Cabin vessel

Technical data

Dimensions	Length	Width	Max. draught	Passengers	Crew
	135 m	11.45 m	2 m	190	45

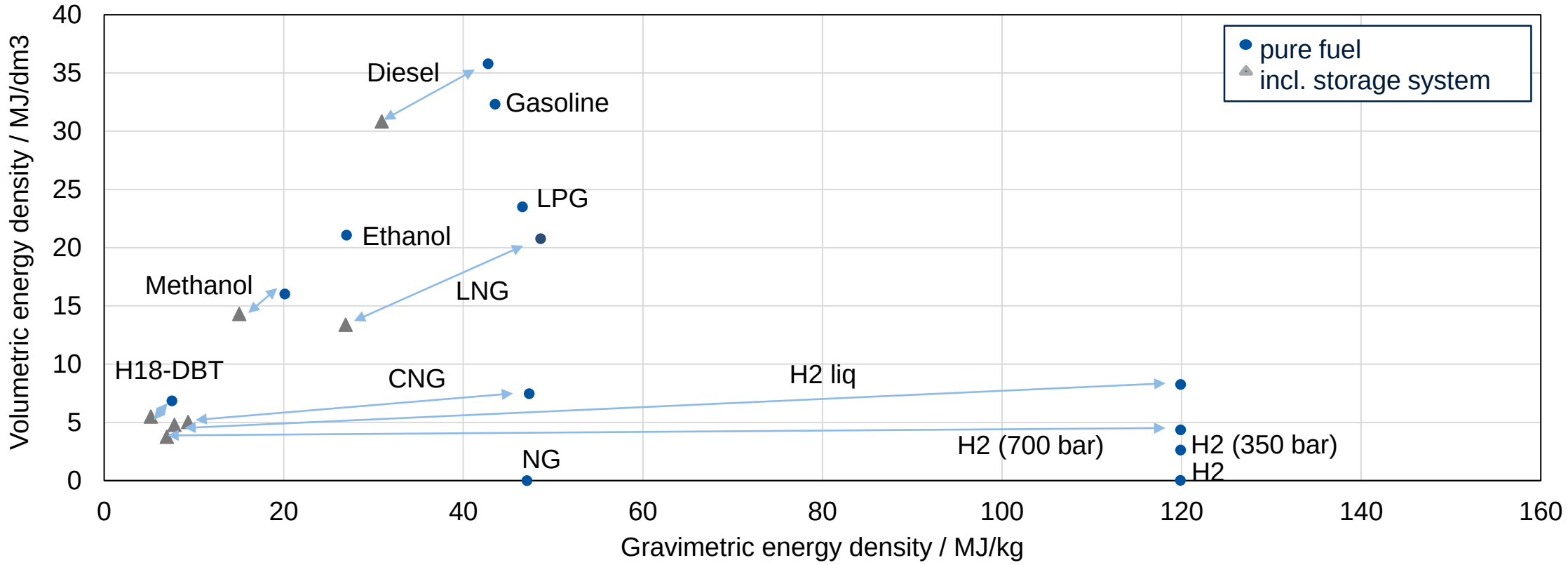
Propulsive power	Diesel electric engine gensets		Propulsion	Pumpjets
	2 x 994 kW	2 x 383 kW	4 x 300kW	2 x 340 kW

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

High energy density of Hydrogen is used up by heavy and spacious storage



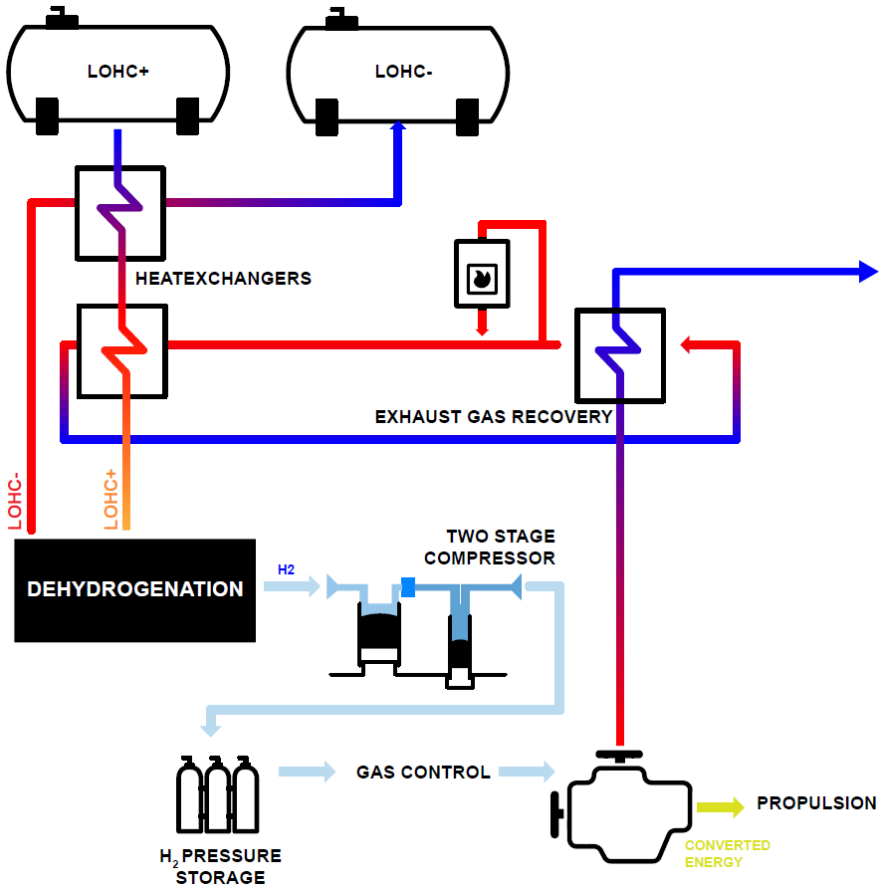
Source: Shell Hydrogen Study (2017); Biert, L. v., Godjevac, M., Visser, K., & Aravind, P. (2016). A review of fuel cell systems for maritime application; Klell, M. (2010). Storage of Hydrogen in the Pure Form;

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

From fuel to power – LOHC is complex and spacious



Complexity of fuel conversion

- Requirements - Disadvantages
  - Many heat exchangers
  - Dehydrogenation system
  - Compressor
  - → Complex, expensive, spacious

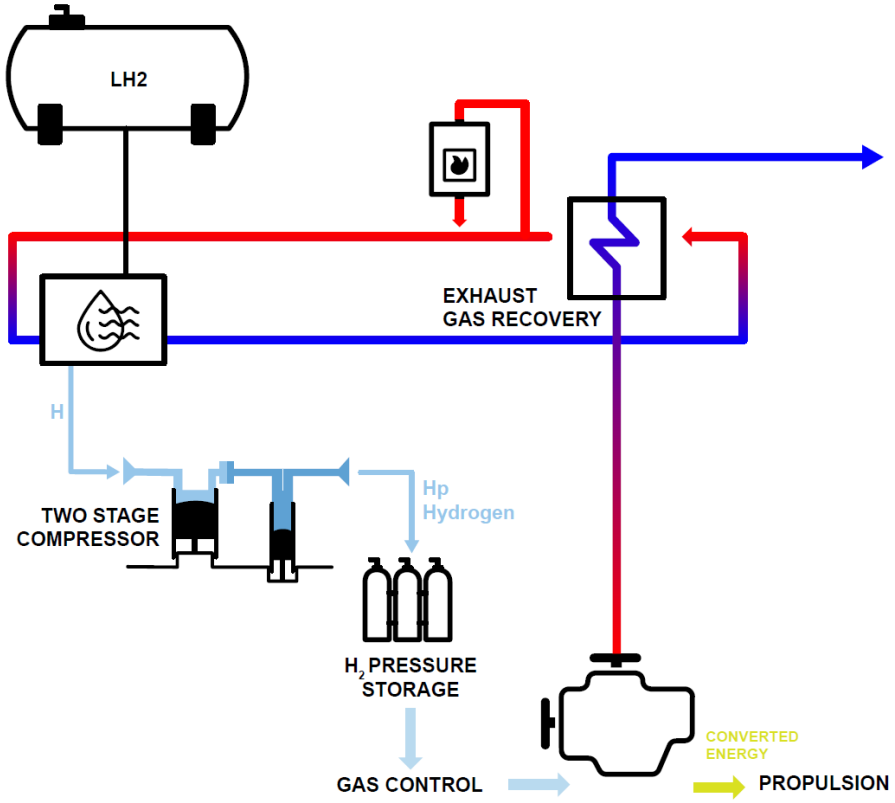
- Advantages
  - Standard simple diesel tanks are sufficient for LOHC storage

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

From fuel to power – Liquid H_2 is compact but difficult to handle



Complexity of fuel conversion

- Requirements – Disadvantages
  - Heat exchanger
  - Evaporator
  - Compressor
  - Insulation
  - Boil-off losses
- Advantages
  - No dehydrogenation system

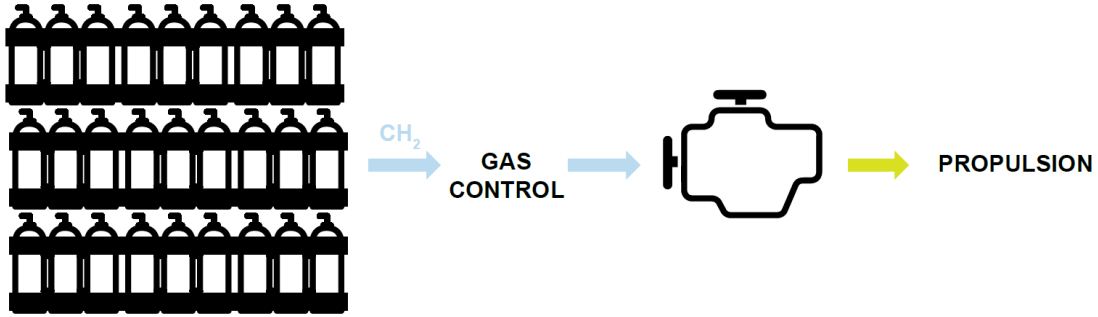
  → Conversion less spacious

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

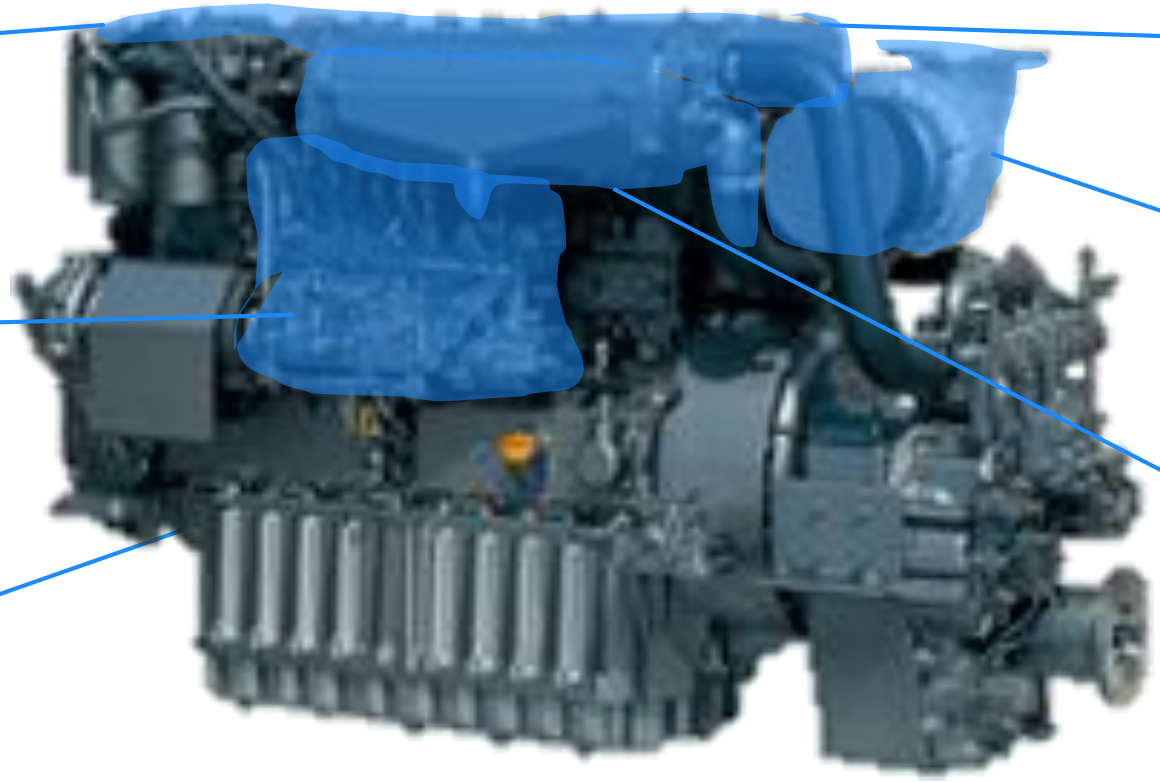
From fuel to power – Comp. H_2 is simple but very spacious



Complexity of fuel conversion

- Requirements – Disadvantages
  - Low storage density of gaseous hydrogen
  - → High space demand
- Advantages
  - Lowest complexity
  - → No further steps of conversion necessary

ICE can be designed for or converted to H_2 operation



Ignition System
- Sparkplug
- Prechamber

Fuel System
- PFI
- DI

Engine control unit
- Calibration

Valvetrain
- Material
- Timing

Turbocharger
- Dimensions

Exhaust gas recirculation
- Controls

Picture Source: http://www.yanmarmarine.eu/theme/yanmarportal/uploadedFiles/Marine/productImages/Commercial%20engine/product_commercial_6CXB_M+H%20rating_200_190.jpg

Conversion Technologies: Fuel Cell

	Unit	LT-PEMFC	HT-PEMFC	SOFC
Operating temperature	°C	40-80	120-180	700-1000
Electrical efficiency	LHV	40-60	40-45	50-65
Fuel purity required		99.999% H_2	CO<3%	Light hydrocarbons (S<20ppm)
Gravimetric power density	W/kg	250-1000	80-230	8-80
Volumetric power density	W/l	300-1550	60-100	4-32
Life time	h	5,000-20,000	10,000-60,000	10,000-40,000
Start-up time		<20 s	10-60 min	30 min to hours
Load transients (0 to 100%)		<10 s	2-5 min	<15 minutes
Cooling		Water cooling	Water cooling	Air cooling
Waste heat recovery		-	+/-	++

Source: Biert, L. v., Godjevac, M., Visser, K., & Aravind, P. A review of fuel cell systems for maritime application (2016)

Promising technology applications are identified systematically

- Definition of requirements
- Rating of requirements to their ship-specific relevance

		Cargo vessel	Pushed convoy	Cabin vessel	Rhine ferry
Operational Aspects	Noise/Vibration	--	--	++	-
	Emission (exceeding regulation)	--	--	+	0
	Range (length of trip)	++	0	-	-
	Reliability	+	+	-	++
	Easy Bunkering	-	+	-	-
	Cost per ton (or person) and km	++	++	0	+
	Handling (req. crew competences)	0	-	--	-

INTERREG Deutschland Nederland
Europäische Union
Europese Unie
MariGreen
Maritime Innovations in Green Technologies

Promising technology applications are identified systematically

- Analysis of technical features for storage and converters separately

		ICE	ICE genset	LT-PEM	HT-PEM	SOFC
Operational Aspects	Noise/Vibration	--	-	++	+	+
	Emission (exceeding regulation)	--	--	++	++	++
	Range (length of trip)	n/a				
	Reliability	++	+	++	--	-
	Easy Bunkering	n/a				
	Cost per ton (or person) and km	++	++	-	--	--
	Handling (req. crew competences)	++	+	-	-	--

		CH_2	LH_2	LOHC
Operational Aspects	Noise/Vibration	++	+	0
	Emission (exceeding regulation)	n/a		
	Range (length of trip)	-	+	+
	Reliability	++	0	-
	Easy Bunkering	+	-	++
	Cost per ton (or person) and km	+	0	-
	Handling (req. crew competences)	+	0	-

- Storage and converter combinations are evaluated

		cH_2	LH_2	LOHC
Technology Combination	ICE	++	+	+
	LT PEM	+	o	--
	HT PEM	+	o	--
	SOFC	+	++	++

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Conditions for the exemplary calculation of a cargo vessel

Route

- Antwerpen ←→ Mainz
- 2 * 542 km = 1084 km
- Driving time: 36 h
- Propulsion power in kW:

Rhine		Rhine Tributary		Canal
Upstream	Downstream	Upstream	Downstream	
700-1300	250	400-600	250	300

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Conditions for the exemplary calculation of a cargo vessel

Antwerp ←→ Mainz

- Total energy needed for one round trip
  - Upstream: 44571 kWh
  - Downstream: 22286 kWh
  - Total: 66857 kWh

- Required amount of fuel
  - Total: 2408 kg H_2

Investigated storage systems

- Compressed Hydrogen → cH_2
- Liquid Organic Hydrogen Carriers →LOHC
- Liquid Hydrogen → LH_2

Comparison of storage systems for selected usecase

	Unit	cH_2	LH_2	LOHC
Hydrogen mass	kg	2408	2408	2408
Hydrogen volume	m^3	61	34	-
Tank volume	m^3	207	35	85 / 53 / 43 *
Storage weight	t	49	21	56

* LOHC storage:

Two separate tanks / 5-chamber tank / diaphragm tank

- Exemplary storage system for cH_2
  - 40 ft container: 1021 kg H_2

Picture Source: ems

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Technology packages for selected application cases

- Matrix combination outputs most favorable technologies for each application case
- Conditions for each usecase defines limits and boundaries

		Storage	Converter
Application Case	Cargo Vessel	Compressed H_2	ICE genset
	Pushed convoy	Liquid H_2	ICE
	Cabin Vessel	LOHC	SOFC fuel cell
	Rhine ferry	Compressed H_2	LT PEM fuel cell

- Wide variation of technologies for further evaluations (cost, typical operation profiles, handling etc.)

Legal Situation and Training

- Legal Situation
  - Analysis of status quo
  - Identification of blank gaps
- Instruction and Training
  - Definition of requirements
  - Various jobs, levels of education
  - Parallels to training in other sectors

INTERREG Deutschland Nederland
Europäische Union
Europese Unie

Picture Source: NSSGA

MariGreen
Maritime Innovations in Green Technologies

Key Take-aways

- Today hydrogen technology is not economic.
- Regarding future trends it is worth introducing this technology.
- Current local distribution of hydrogen sources facilitates this introduction.
- Different technical solutions exist for all application cases.
- Demonstrator projects could further prove the technical concepts.

Picture Source: LabManager

Thank you for your attention.

INTERREG Deutschland Nederland

Europäische Union
Europese Unie

MariGreen
Maritime Innovations in Green Technologies

Project Partners

Electric Ship Facilities

DST

MARIKO

abh INGENIEUR-TECHNIK GMBH

H2

VBW

TU/e Technische Universiteit Eindhoven University of Technology

TU Delft

University of Applied Sciences HOCHSCHULE EMDEN·LEER

vka Institute for Combustion Engines

RWTH AACHEN UNIVERSITY

INTERREG Deutschland Nederland

Europäische Union Europese Unie

MariGreen Maritime Innovations in Green Technologies