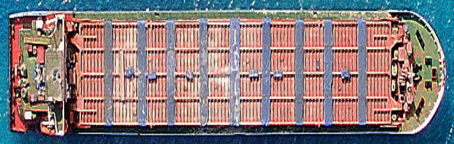
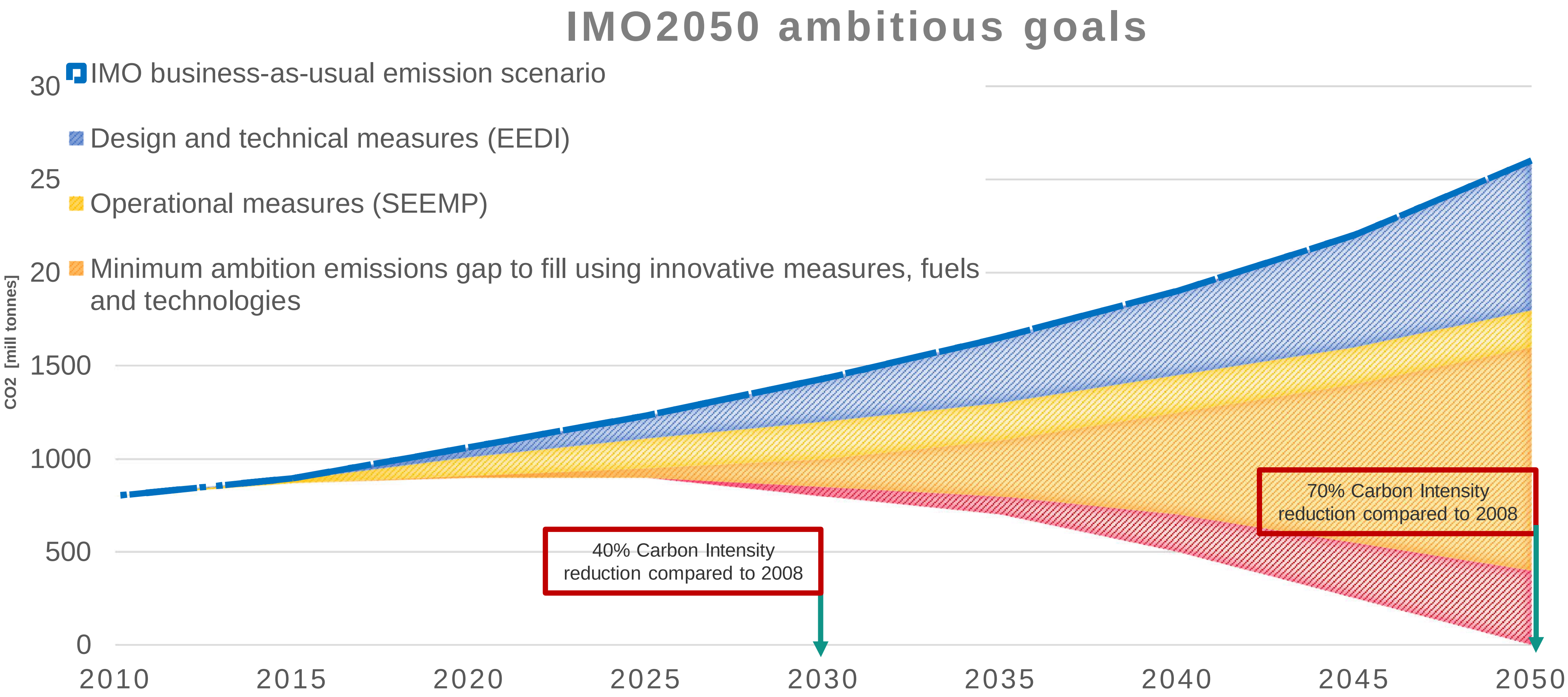
Decarbonizing our industry
Alternative fuels - overview



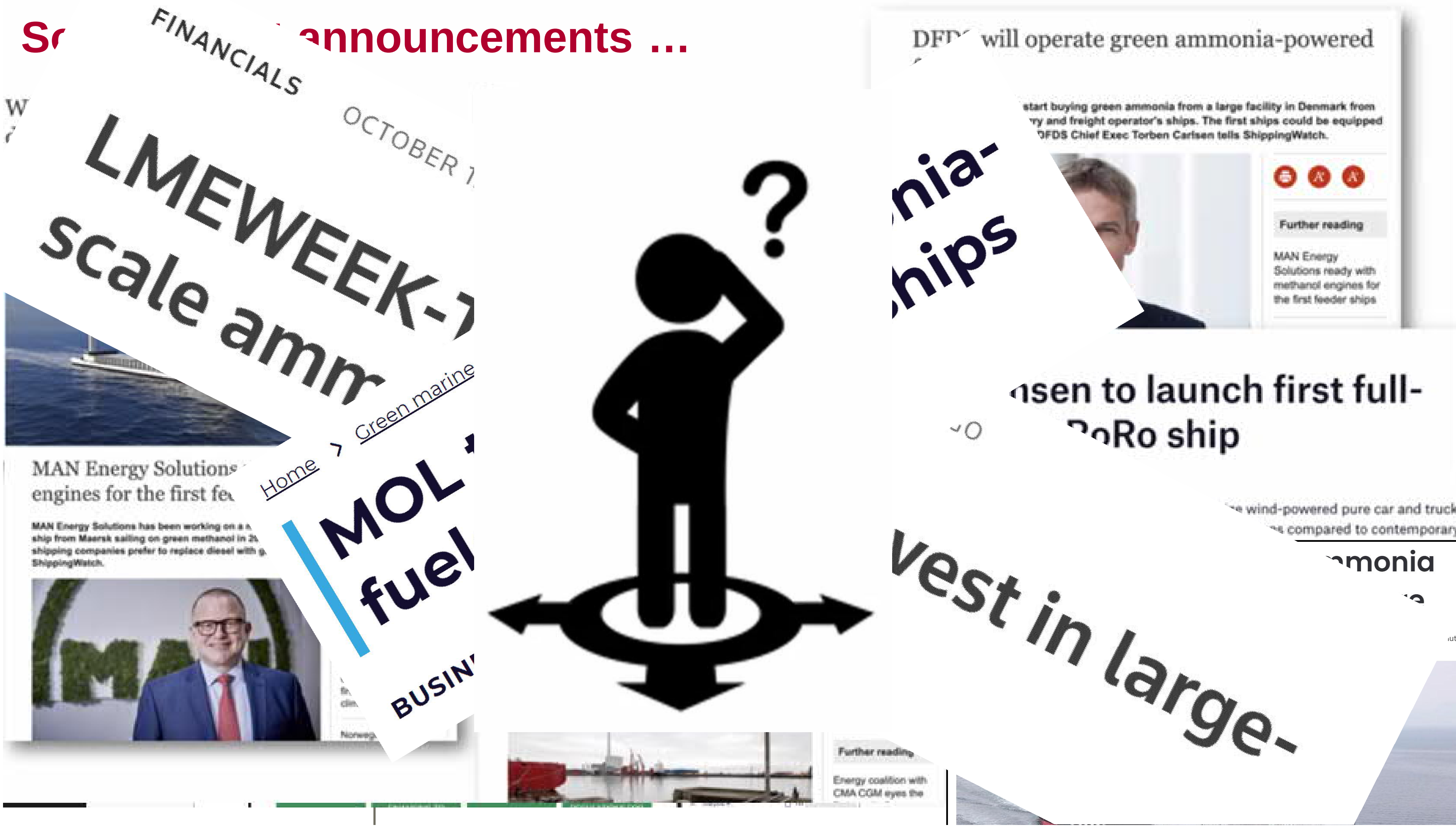
BUREAU VERITAS MARINE & OFFSHORE

Dipl. Ing. Ramona Zettelmaier
Head of Sales & Customer Relation

How will the IMO goals be achieved

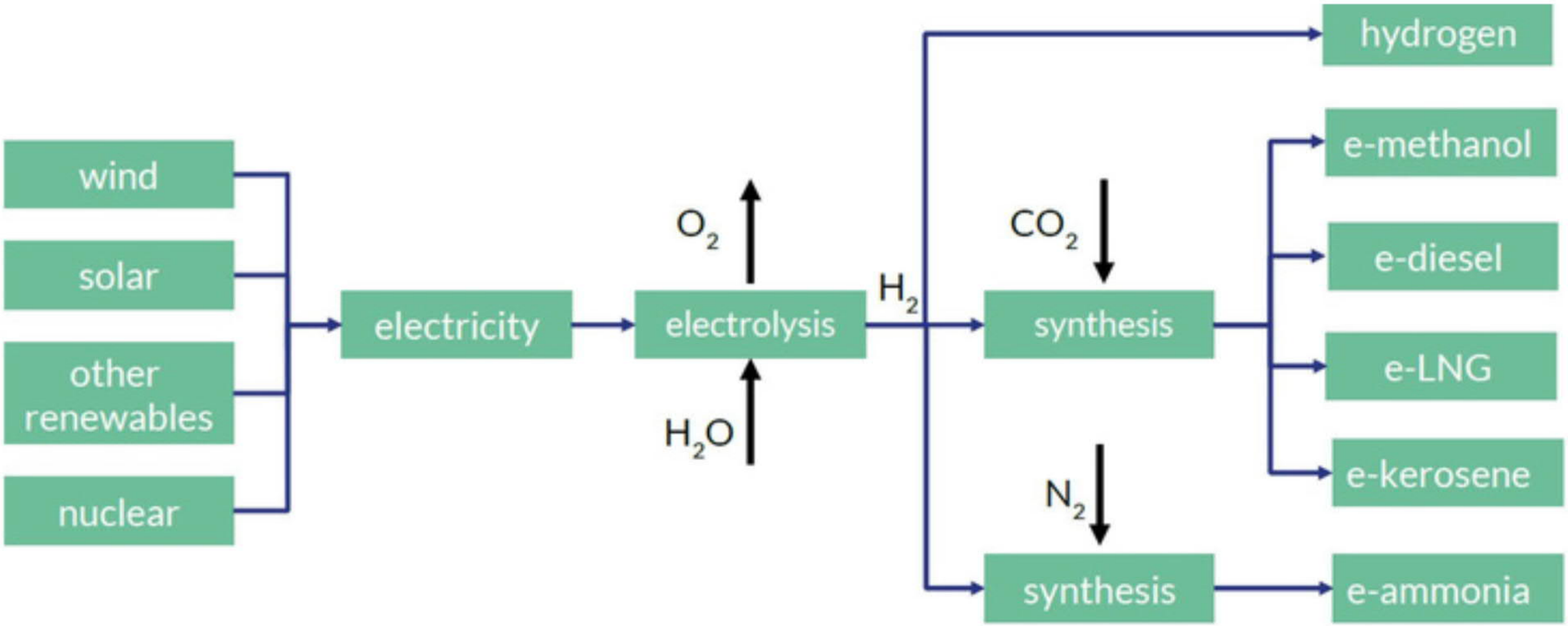


Sc announcements …



Hydrogen as root energy source for e-fuels development

The most promising e-fuels other than hydrogen today are e-ammonia, e-methanol and e-LNG. Both ammonia and methanol are chemical commodities and many assume that it therefore should be fairly easy to roll them out for marine applications.



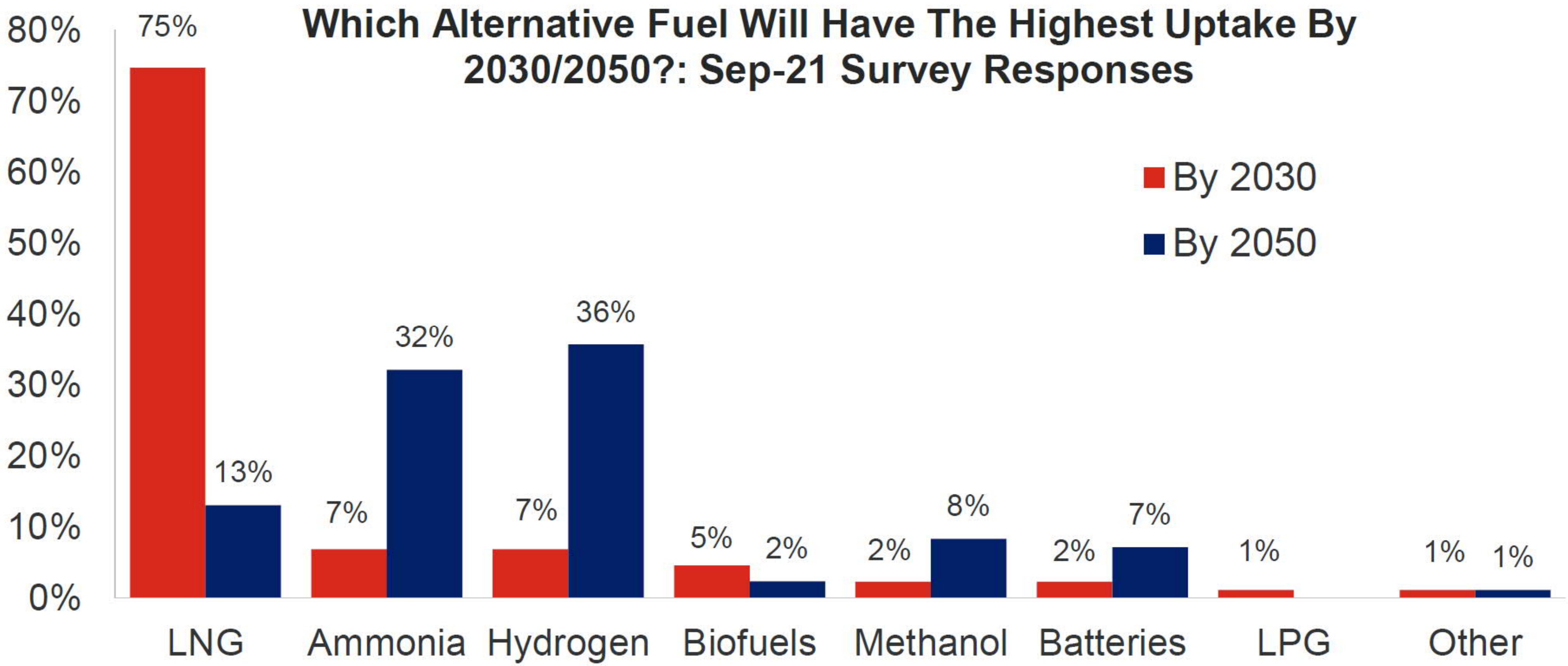
Schematic representation on the role of hydrogen and relevant e-fuels (source TNO)

Alternative fuels energy density and storage characteristics

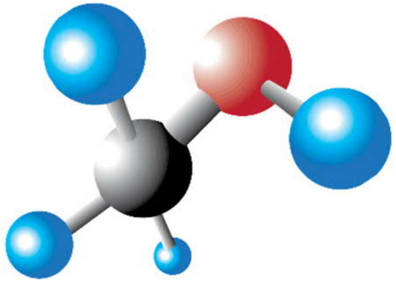
Fuel type	Mass energy density LHV [MJ/kg]	Volumetric energy density LHV [GJ/m3]	Storage pressure [bar]	Storage temperature [°C]	Relative tank volume (without insulation)	CO2 reduction (base FO) tank to wake
Marine Gas Oil	42.8	36.6	1	20	1	0
LNG / e-Methane	50.0	23.4	1	-162	1.6	-20%/100%
Ethanol	26.7	21.1	1	20	1.7	-10%
Methanol	19.9	15.8	1	20	2.3	-10%/100%
LPG	50.3	26.7	1 to 7	-42	1.4	-7%
Ammonia	18.6	12.7	1 to 10	-34	2.9	-100%
Liquid Hydrogen	120	8.5	1	-253	4.3	-100%
Compressed Hydrogen	120	7.5	700	20	4.9	-100%
LOHC		9	1	20	4	-100%
LNG and Carbon Capture	50.0	23.4	1	-162	3.2*	From -30 to -100%

*(1.6 + 1.6)

Clarkson report September 2021



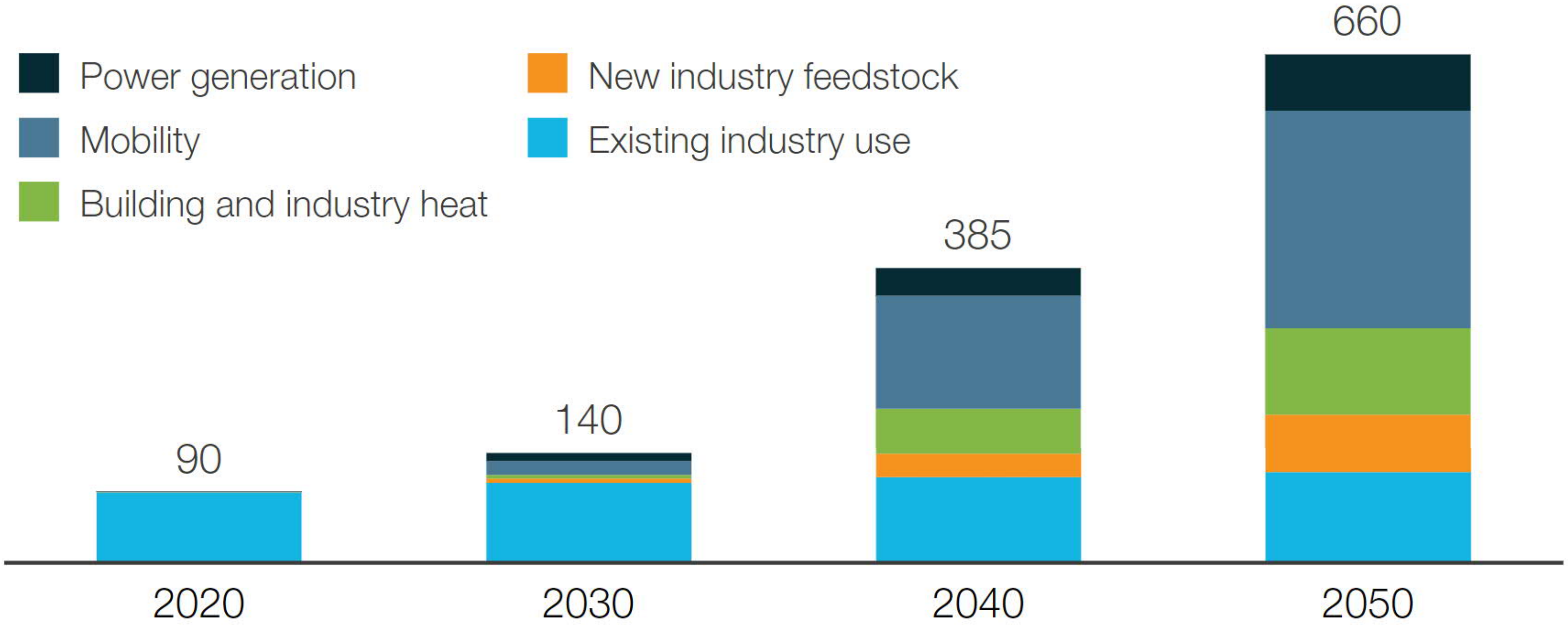
Global bunker market - some figures



- **Heavy Fuel Oil** **207 MT**
- **Marine Gas Oil** **65 MT**
- **LNG bunker** **> 3MT**

Global hydrogen demand by segment until 2050

Hydrogen end-use demand by segment, MT hydrogen p.a.



660 MT

hydrogen required p.a. in 2050 for net-zero

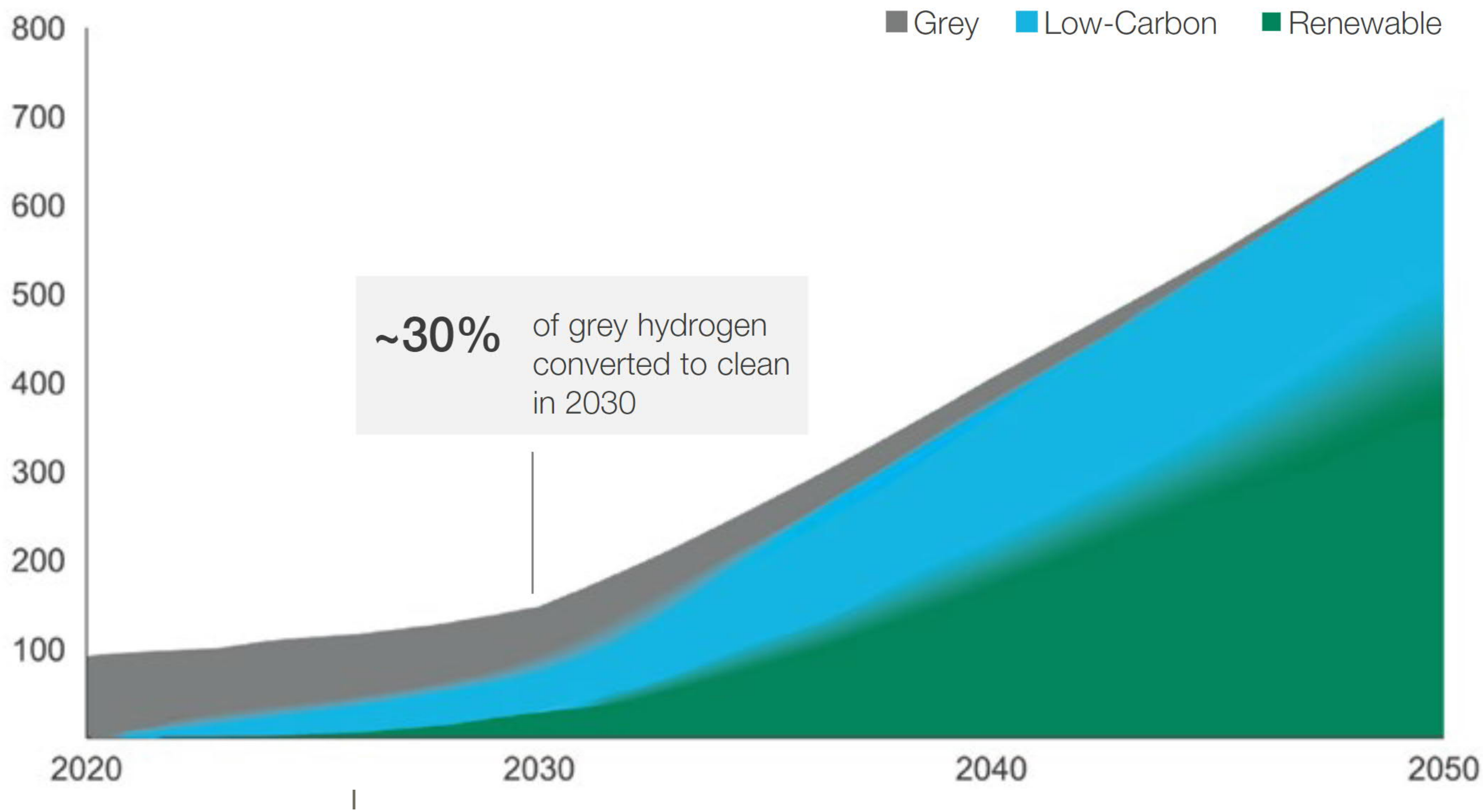
22%

of global final energy demand[1]

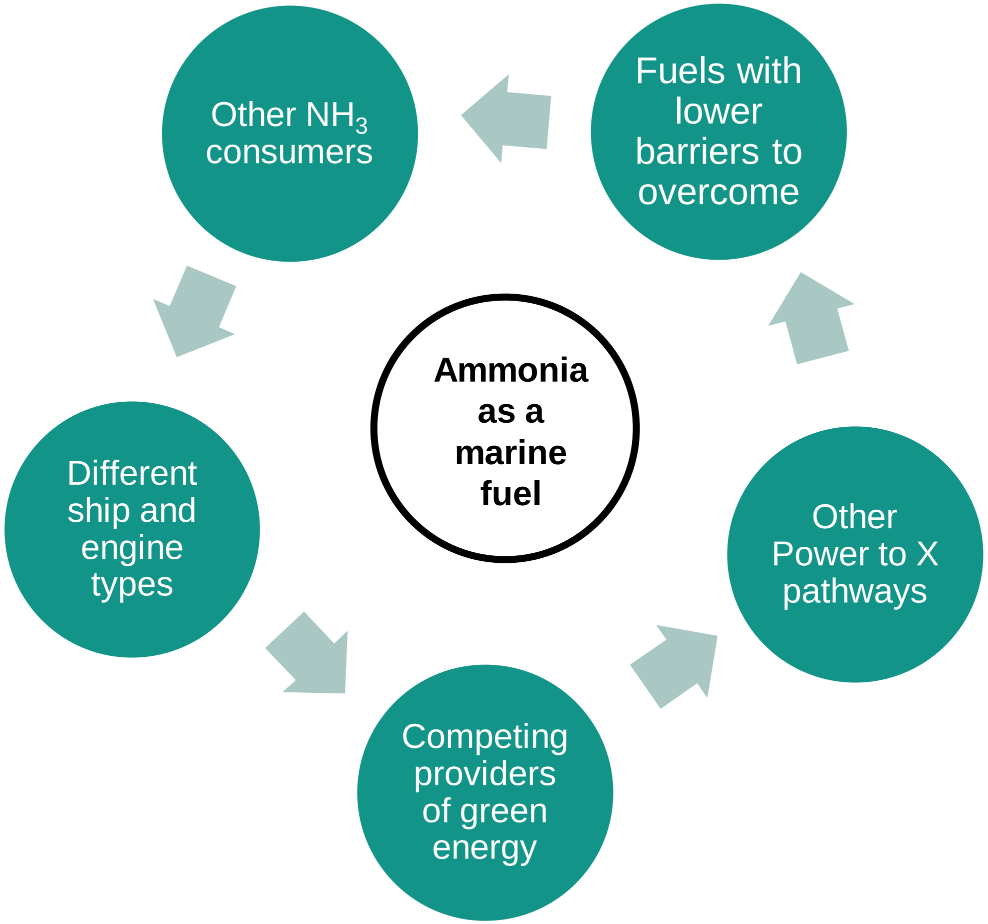
1. IEA net-zero scenario with 340 EJ final energy demand in 2050. HHV assumed. Excluding power.

Clean supply is critical - Hydrogen supply mix over time

Hydrogen supply by production method (indicative)
MT hydrogen p.a.



Zero carbon fuels as ultimate fuels of choice - challenges

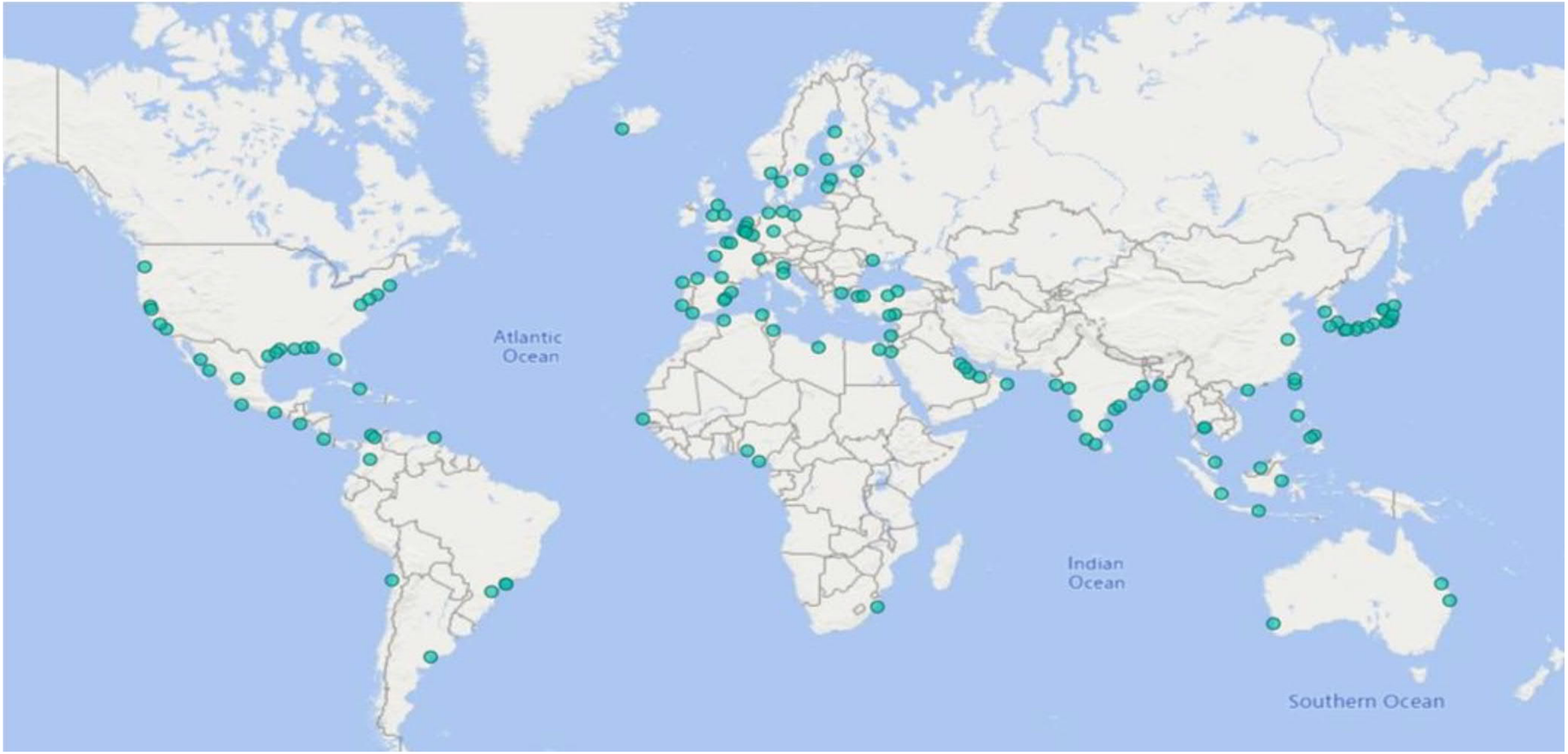


The overall energy transition is mobilising all industry sectors. How is this opportunity enabled or even challenged by the external perspectives ?

*"**Alternative fuels' production is ~2-8x costlier than the price of fossil fuels**. Such a wide gap cannot be closed by technological progress alone. Additional industry measures are needed to bridge the cost gaps "*
Maersk Mc-Kinney Moller Center - Industry Transition Strategy
October 2021

“Grey”Ammonia availability and infrastructure as of today

Source : Argus



Annual global production of NH_3 is over **180 million metric tons**, **10%** of which are transported by **ammonia tankers**.

Green ammonia development as of today

Timeline	Country	Main developers	Plant location	Annual capacity (t)	Energy source
2021	New Zealand	Ballance-Agri Nutrients Hiringa Energy	Kapuni	5.000	Wind
2022	Denmark	Halder Topsoe Vestas	Western Jutland	5.000	Solar and wind
2024	Chile	ENAEX ENGIE	Mejillones	18.000	Solar
2025	Saudi Arabia	Air Products ACWA Power NEOM	Red Sea Coast	1.200.000	Solar, wind, energy storage
2026	Norway	Yara International NEL Hydrogen	Porsgrunn	500.000	Hydro electricity
Mid 2020s	Australia	Origin Energy	Tasmania Bell Bay	420.000	Hydro electricity
2030	Australia	Yara International ENGIE	Pilbara	24.000	Solar

2.132.000 t/y

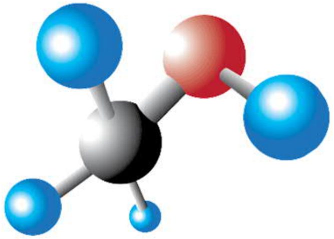
Toxicity, Corrosivity, Pollution and GWP

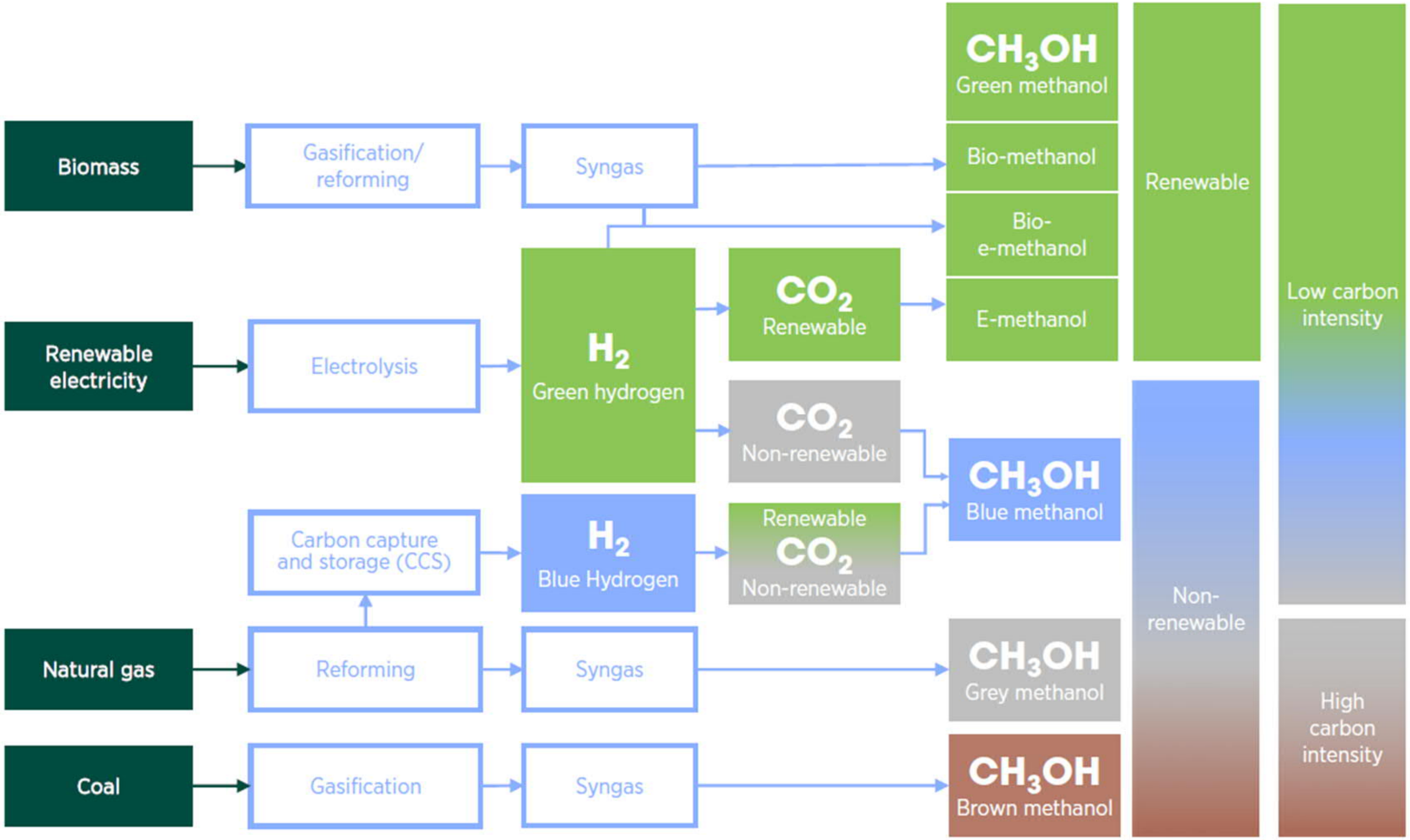
	Characteristics	Toxicity	Environmental impact
NH_3	NH3 vapours: • are lighter than air • may also be heavier than air (aerosols) in case of high humidity	Inhalation: • 5 to 50 ppm: odor detection level • 30 ppm: limit for 8 h exposure • 100 - 200 ppm (depending on exposure time): Irreversible health effect Sea water: toxic to aquatic life (unionized)	• GWP = 0 • ODP = 0
	Exhaust emissions from engines running on ammonia		
N_2O	Nitrous oxide « Laughing gas »	Not toxic	• Potent greenhouse gas with GWP = 300 x that of CO2 • ODP = 0.017
NO_X (NO / NO2)	As for engines supplied with FO but non information regarding concentrations in exhaust gases		
NH_3 (unburnt)	See above		

- Ammonia is **corrosive** to the eyes, skin and respiratory tract.
- Ammonia corrodes copper and copper alloys, cast iron and galvanized surfaces.
- Ammonia is **highly soluble in water** in the ionized form NH4+ (to form ammonium hydroxide NH4OH) and in the ionized form (free NH3).
- Ammonia **dissolution in water is very exothermic** : 2000 kJ per kilogram of ammonia dissolved in water.
- The latent heat of vaporization of ammonia is **very high** (1370 kJ/kg vs 510 kJ/kg for methane), which results in a rather **slow vaporization**.

Methanol properties

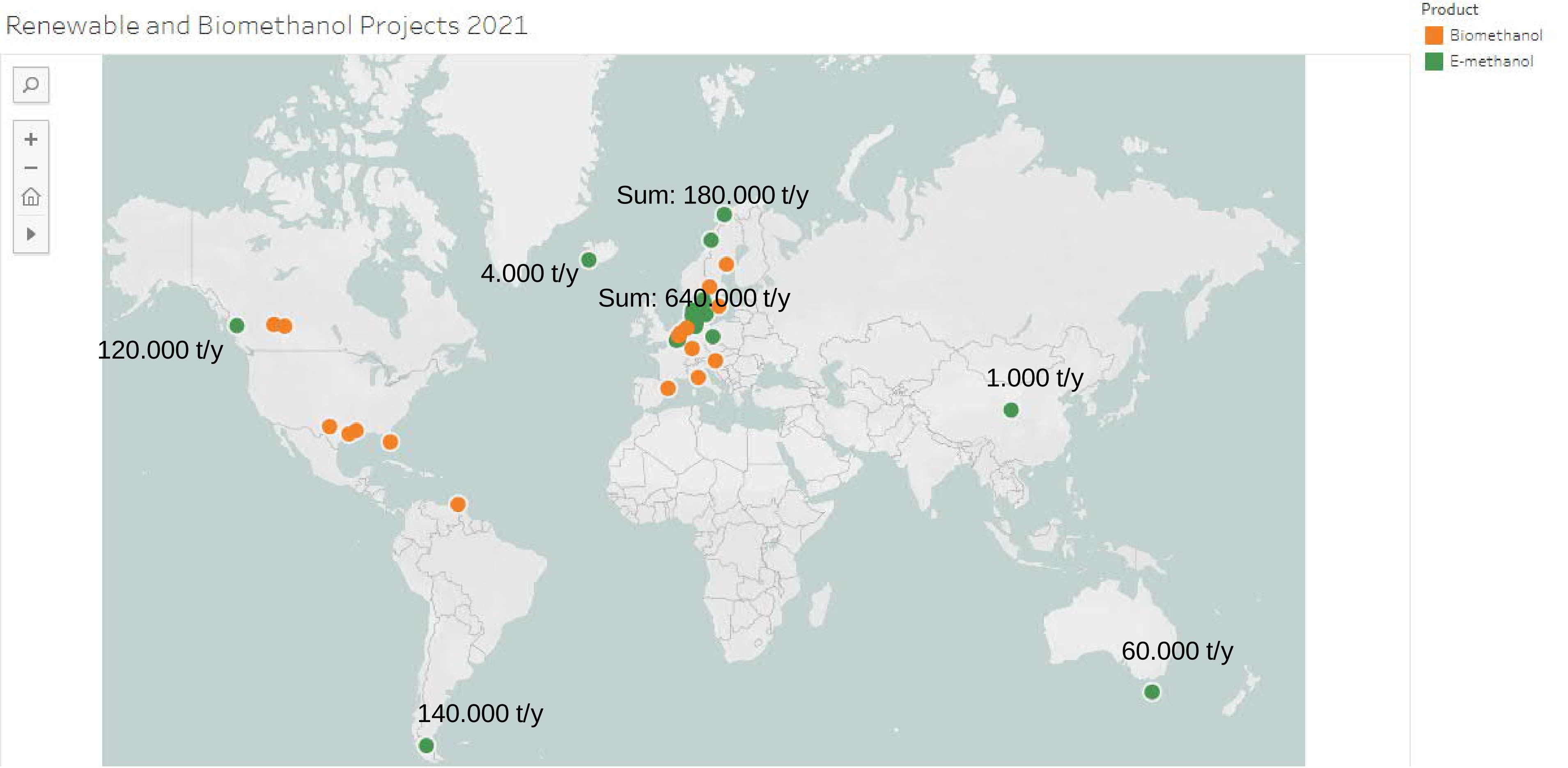
A possible Very Low Emissions carbon fuel





Source: IRENA AND METHANOL INSTITUTE

Bio and E- Methanol projects

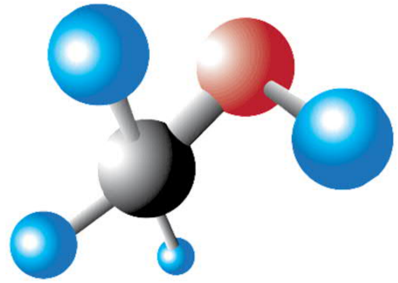


Source: Methanol-institute

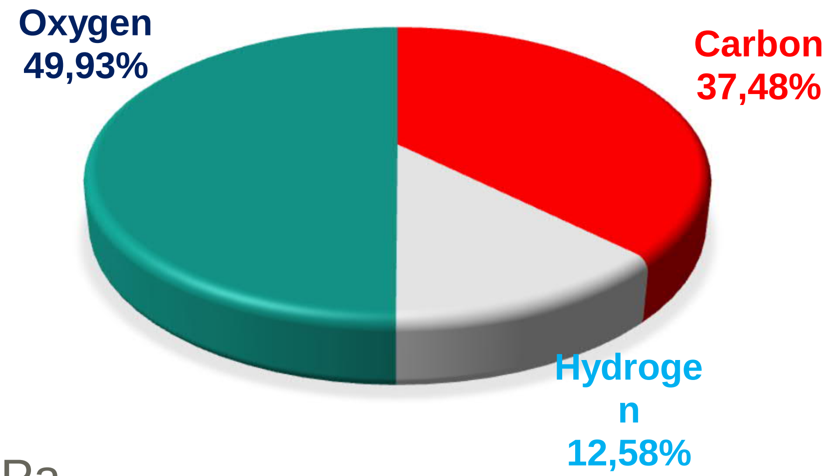
Total E- Methanol: 1.145.000 t/y

Methanol properties

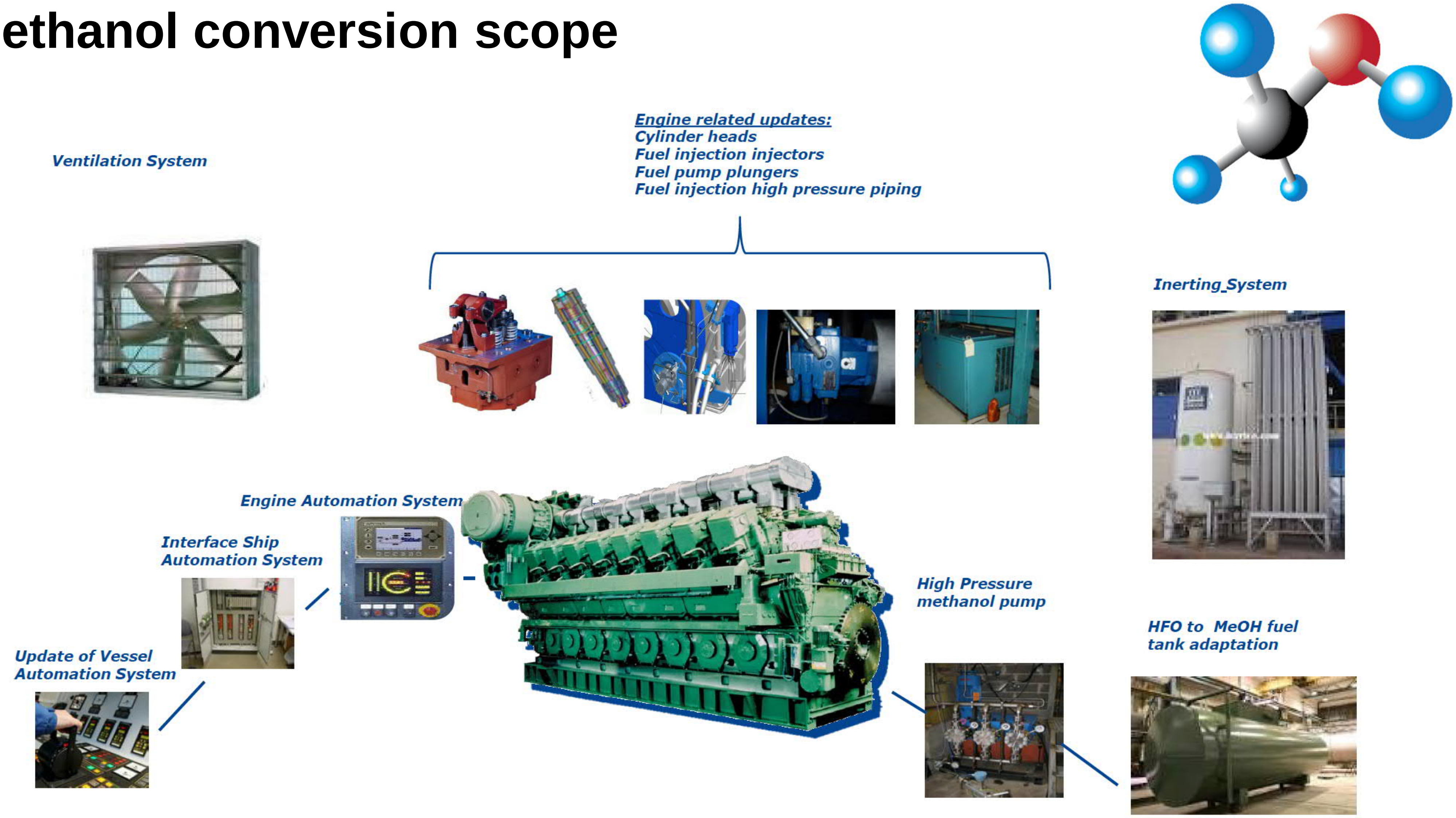
Methanol: CH_3OH



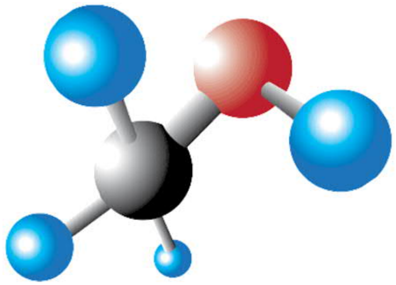
- CAS: 67-56-1 (UN 1230)
- Molar mass: 32.042 g/mol
- Boiling point Patm: 64.6°C
- Minimal Ignition Energy (MIE): 0.14 mJ
- Flash-point: 11 °C
- Auto-ignition temperature (AIT): 385°C
- Lower Heating Value (LHV): 19,900 kJ/kg
- Vapour pressure at 20°C: 12,900 Pa
- Vapour pressure at storage temperature: 12,900 Pa
- Liquid density / liquefied gas density at storage temperature: 0.792 kg/m3
- Flammable limits LEL (lower explosion limit) - UEL (Upper explosion limit): 6-36%vol
- Threshold Limit Value - Time Weighted Average (TLV - TWA): 200 ppm
- Threshold Limit Value - Short Term Exposure Limit (TLV-STEL): 250 ppm



Methanol conversion scope



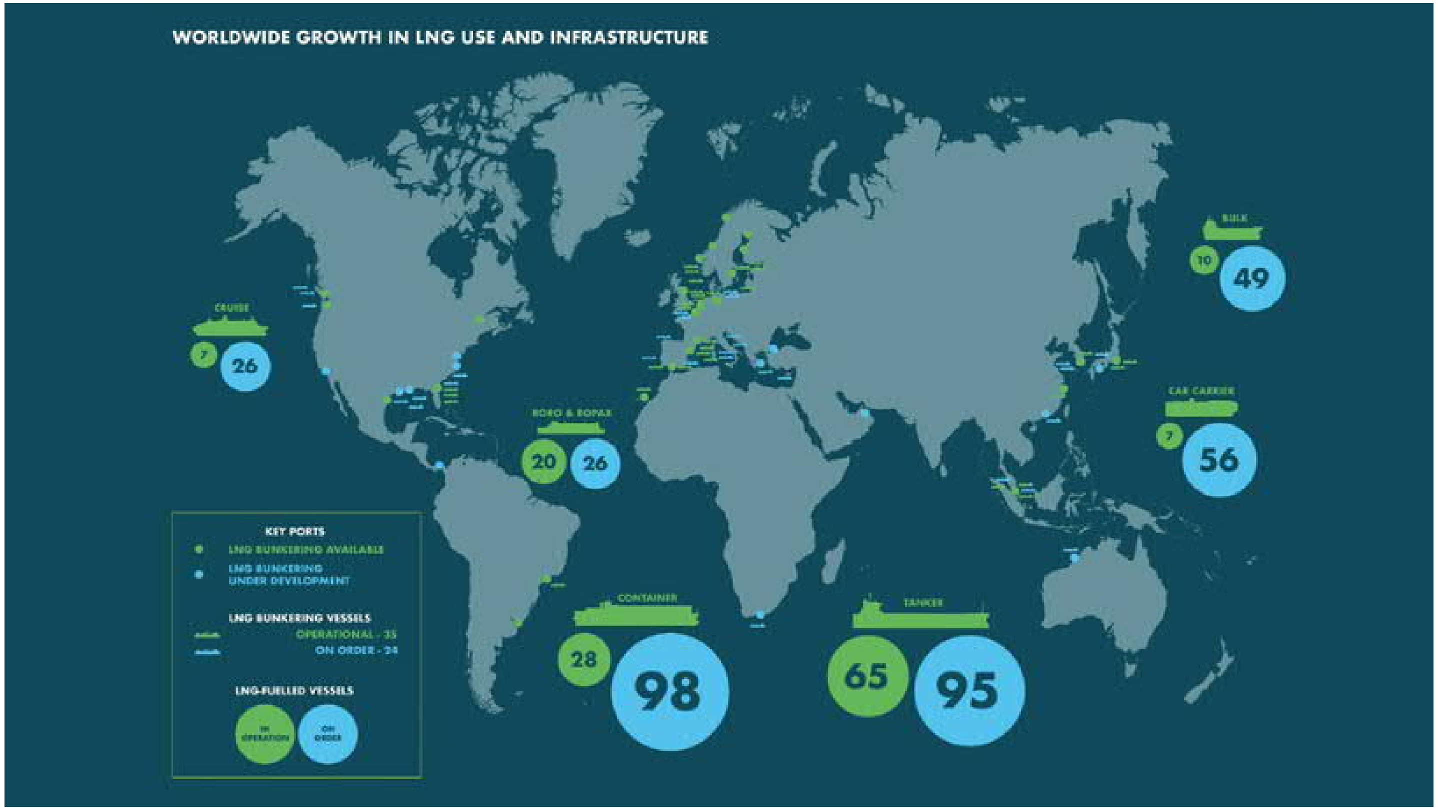
LNG is a viable and effective low carbon marine fuel as of today



LNG is fully compliant with all global Emission Control Areas (ECAs) and the IMO's global sulphur cap, and future-proofs ship owners against more stringent local emissions regulations.

The use of LNG cuts greenhouse gases (GHGs) by up to 20% on a tank-to-wake basis and it offers a potential decarbonisation pathway for shipping via liquefied biomethane, produced from biomass, or liquefied synthetic methane, produced from renewable electricity.

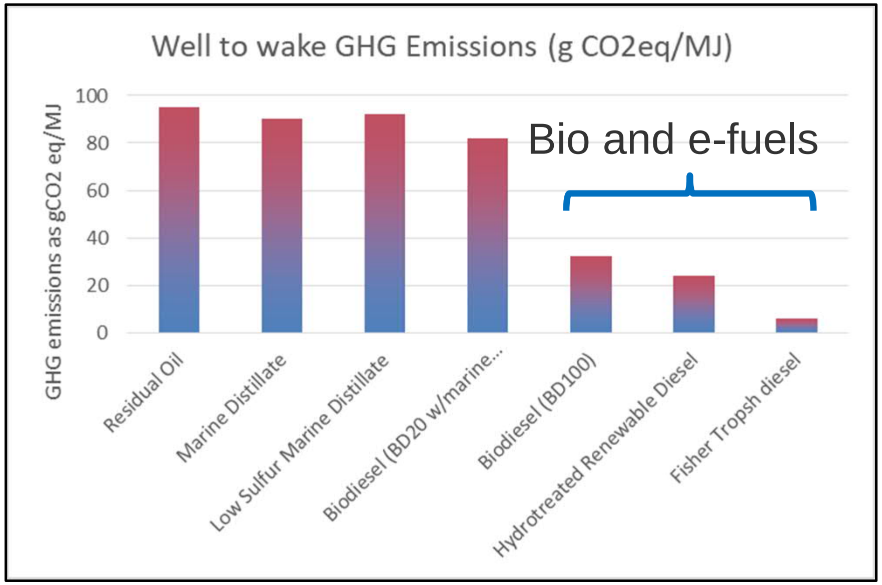
LNG bunkering infrastructure is growing rapidly



source SEA LNG

SHIPS IN OPERATION	SHIPS ON ORDER	LNG READY SHIPS IN OPERATION AND ON ORDER
295	510	229

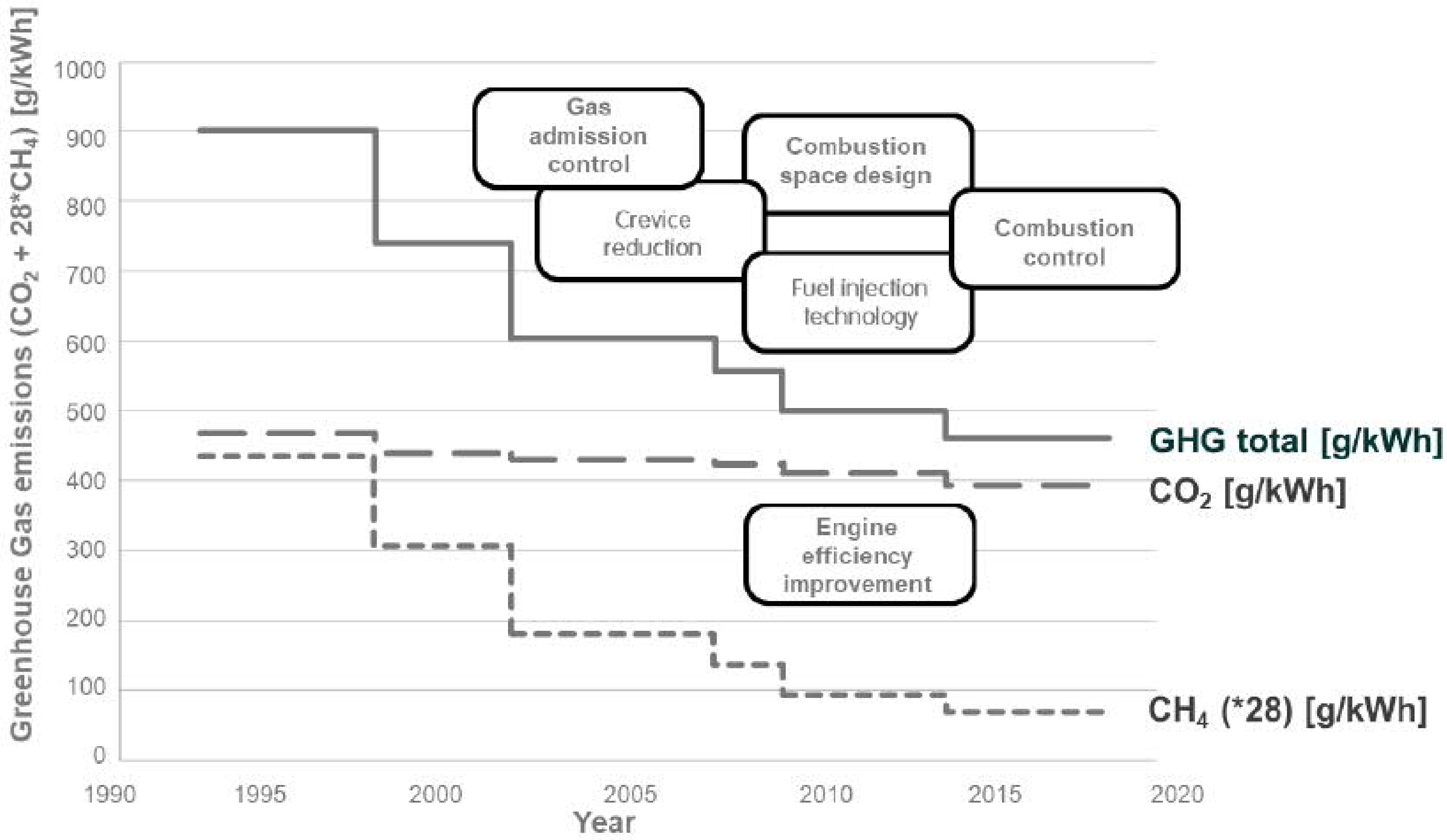
“Drop-in” bio fuels and e-fuels - Lifecycle CO2 (WtW) emissions



Source: US ORNL Biofuels for Marine Shipping 2018

“ElbBLUE“ is the world’s first ship using synthetic natural gas (SNG) when it received approx. 20 tons of the fuel in the Elbehafen in Brunsbüttel. The bunkering is a joint project of MAN Energy Solutions, the shipowner Elbdeich and the charterer Unifeeder. The trio aims at demonstrating the potential for the use of climate neutral fuels in shipping.

Methane slip – GHG emissions development for Gas Fueled Engines - years 1993 to 2018

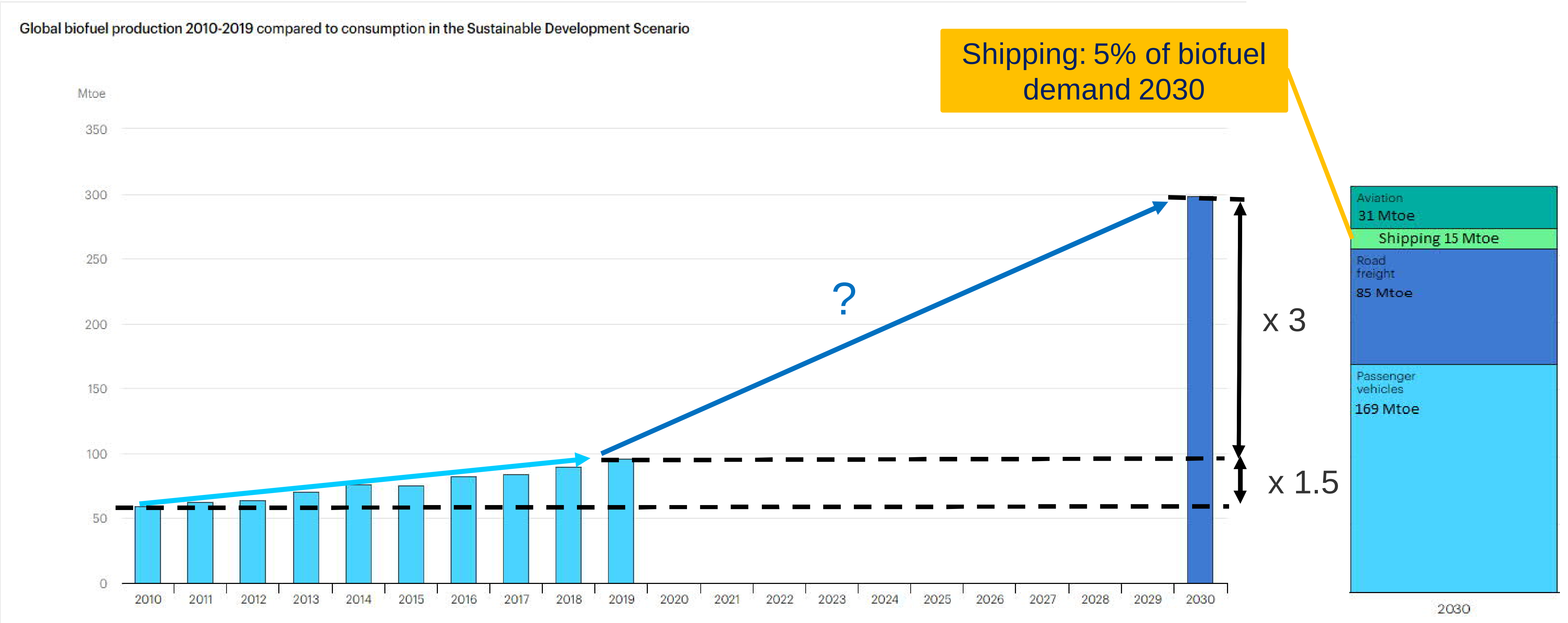


Sources : SGMF & Wartsila, MAN ES, Caterpillar and WIN GD

BIOFUELS GENERATIONS

1st GEN	2nd GEN	3rd GEN	4th GEN
Made from the sugars and vegetable oils found in food crops using standard processing technologies	Production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks	Specially engineered crops such as algae as the energy source.	Uses genetically modified (GM) algae to enhance biofuel production
Ethanol Based Sugar Starch Oil Based Corn Rapeseed Soybean Palm	Agriculture/food processing waste grasses and trees	Transgenic Materials, Low Lignin Eucalyptus, Poplar Trees and Sorghum e.g. higher yield feedstocks and algae	NOTE: Take into account the carbon capture and storage potential on the crops used to produce the required biomass, a well as the energy efficiency of the processing technology that generates the resulting fuel.
Fermentation (bioalcohol) Transesterification (biodiesel)	Fischer Tropsch Biomass-To-Liquid (BTL) Fermentation Gasification	Fischer Tropsch Biomass-To-Liquid (BTL) Fermentation Gasification Algae Processing	
Bio Alcohols Ethanol Biodiesel Fatty Acid Methyl Esther (FAME) Unprocessed Vegetable Oil as fuel	Cellulosic Ethanol Biogas Biohydrogen Fischer Tropsch Diesel	Cellulosic Ethanol Biogas Biohydrogen Fischer Tropsch Diesel Algal Oil	*SOURCE: LEAF LQM www.lqm.com/leaf/*

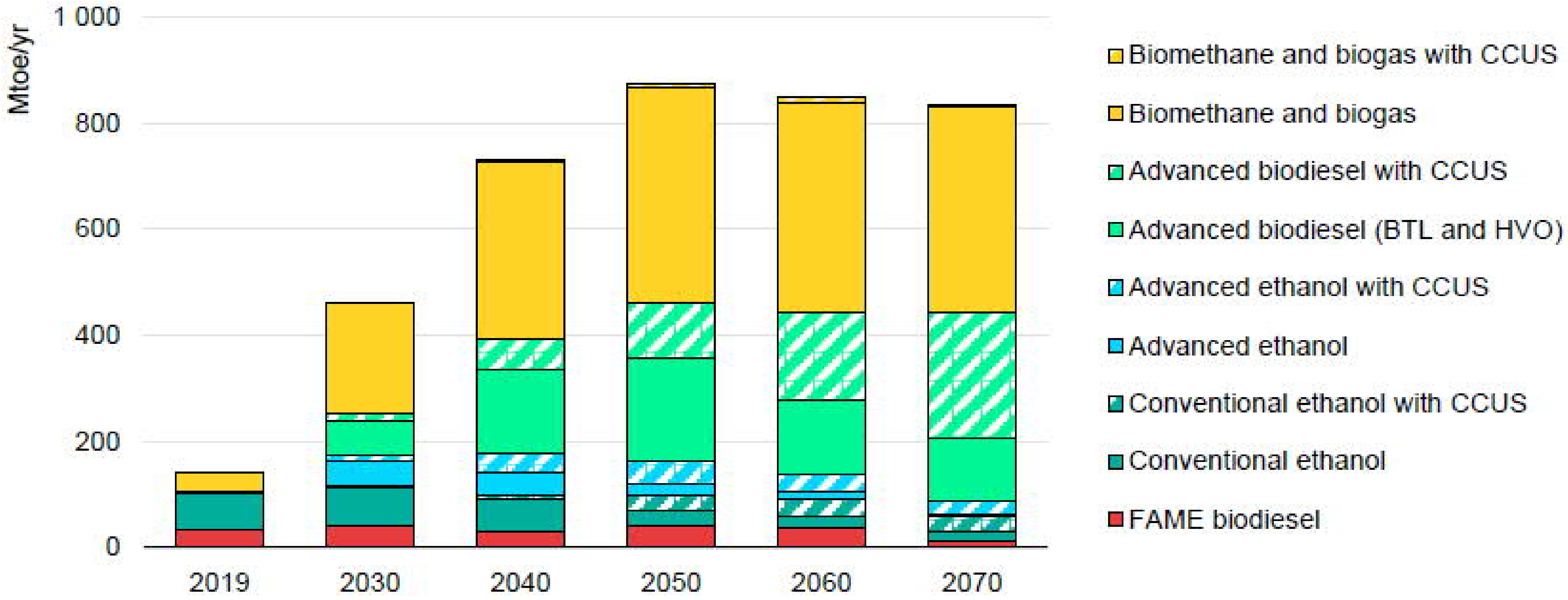
Availability of projected global quantity of biofuels by 2030?



Source: Web IEA

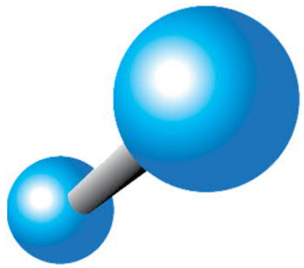
Availability of projected global quantity of biofuels by 2030?

Global Biofuels production (worldwide all sectors) by technology in the Sustainable Development Scenario, 2019-70

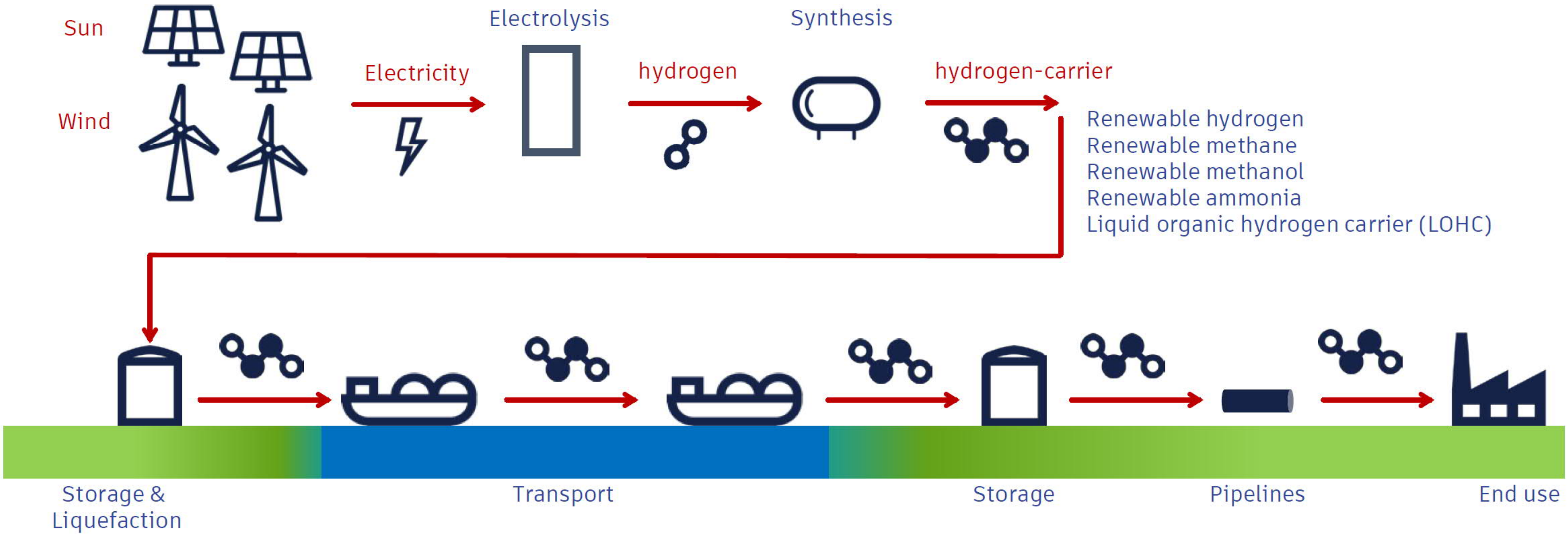


Hydrogen production facilities in Europe

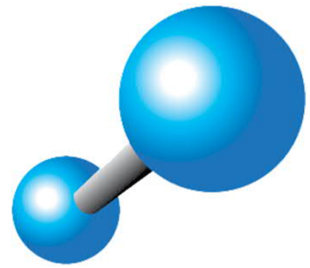
The green hydrogen value chain



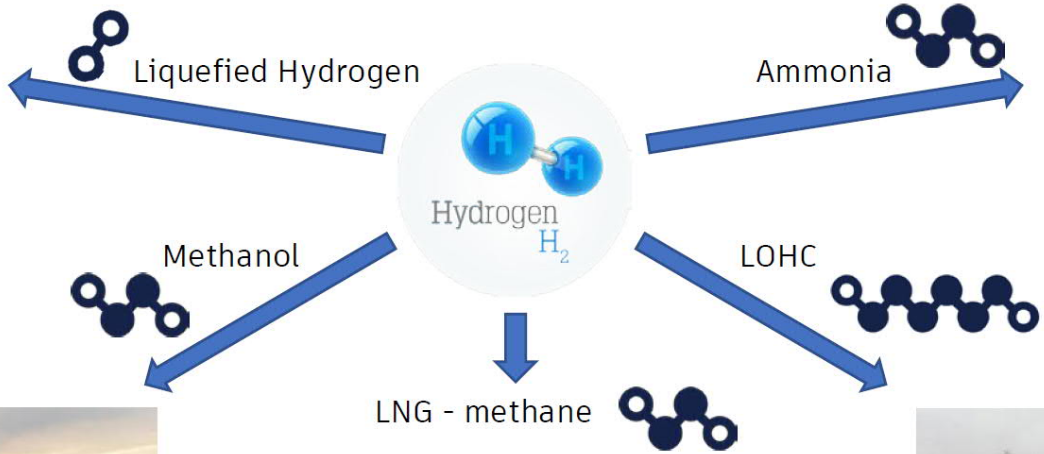
From remote wind and sun to end-user market



Shipping options



Large scale solutions to ship methane, methanol, ammonia are existing
Hydrogen much more difficult to deploy on large scale



Only one ship under construction
Several concepts for larger vessels
(up to 0.43 TWh/vessel)

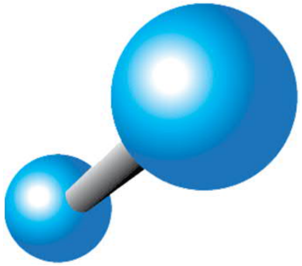
Significant fleet existing
(scalable up to 0,7 TWh/vessel)

Transport in VLCC - large fleet existing (up to 1.61 TWh/vessel)

Large fleet existing
(up to 1.73 TWh/vessel)

Transport in VLCC - large fleet existing (up to 0.72 TWh/vessel)

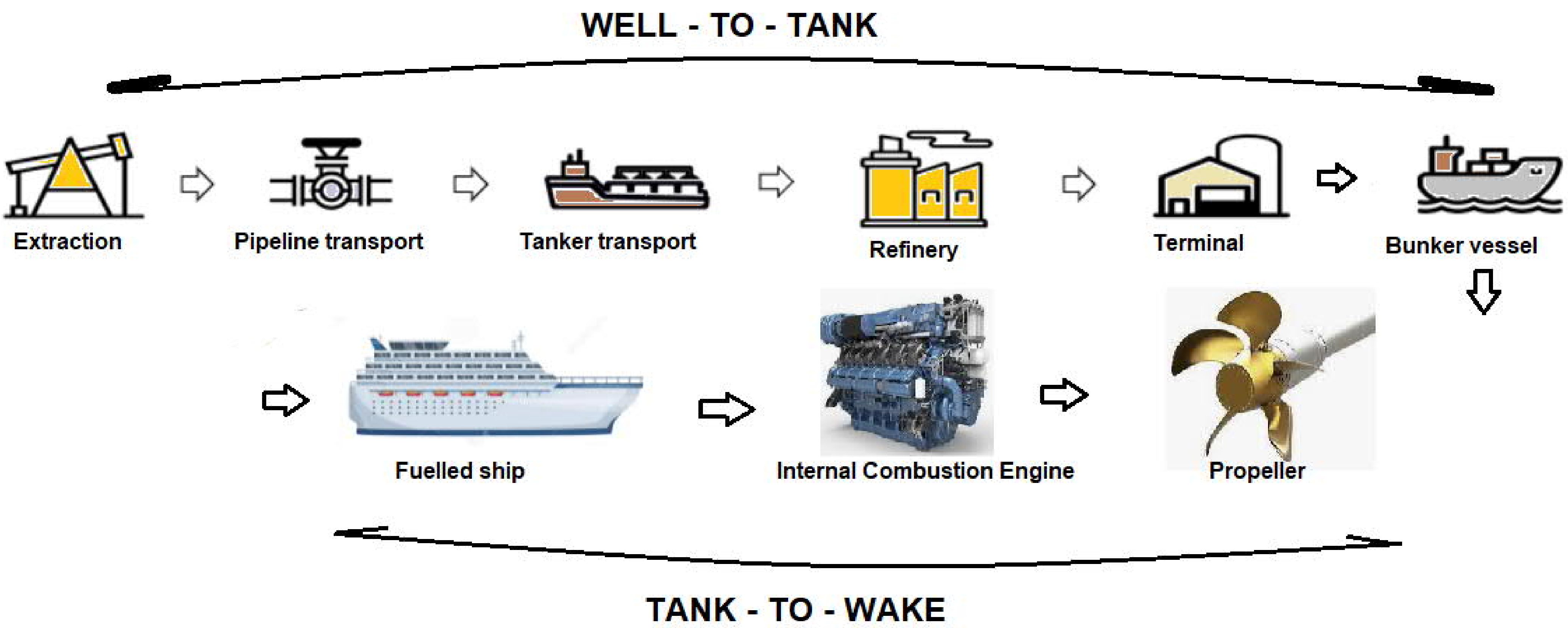
Hydrogen safety



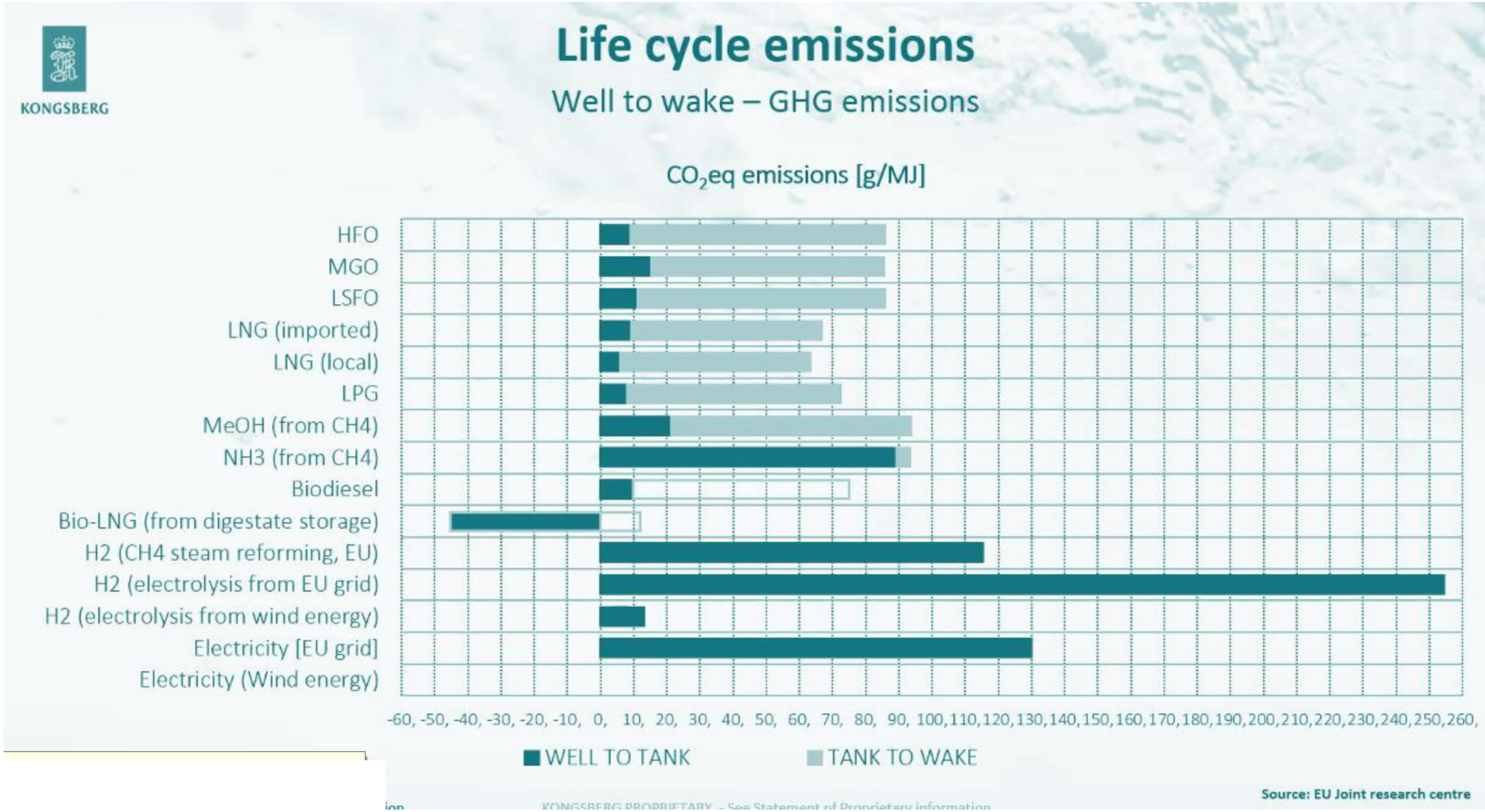
- Low temperature hazard
- High pressure hazard
- Hydrogen embrittlement
- Permeability
- High diffusivity
- Extensive flammable limits
- Low ignitability

	Hydrogen	*Methane*
Boiling temp (K)	20.3 (-253 °C)	111.7 (-161.5°C)
Gas density at standard cod. (273K & 1atm (kg/m^3)	0.09	0.72
Gas density at boiling point (kg/m^3)	1.34	1.82
Liquid density (kg/m^3)	70.8	422.5
Evaporation Latent heat (kJ/L)	31.6	215.8
Flammability range (% vol)	4 - 75	5 - 17
Min. Ignition Energy (mJ)	0.017	0.274
Diffusion Coefficient in air (cm^2/s)	0.61	0.16

LIFE CYCLE ASSESSMENT OF EMISSIONS



Alternative fuels



Progress to be made in the next decade to reach 2050 target

Level Playing field with global regulation

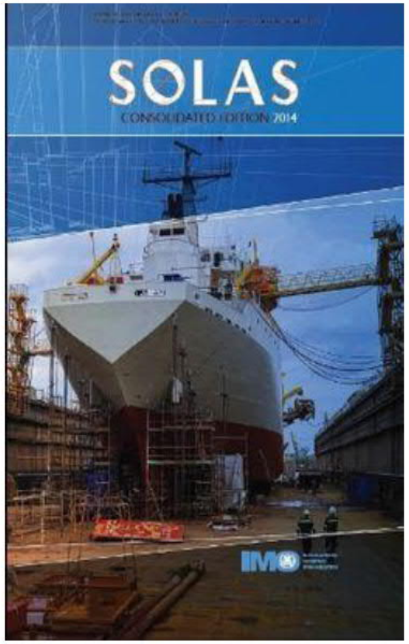
Alternative fuels available at scale

Energy efficiency support across the value chain

Support to first movers

Navigating the regulations and approval processes

IMO regulatory context

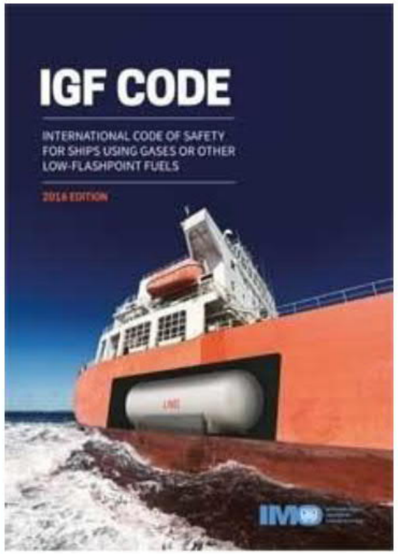


Fuel with flash-point < 60°C:

- Not in line with SOLAS II-2/4.2.1.1
- SOLAS II-1/56 and 57 refers to IGF Code

IGC Code Ch.16 for gas carriers using their cargo as fuel or other low flash point fuel

Note: toxic cargoes not allowed as fuel



- MSC.391(95) issued in June 2015, mandatory starting from 01/01/2017
- Further developments are carried out by IMO CCC subcommittee, reporting to IMO MSC Committee

Navigating the regulations and approval processes

Statutory framework for ammonia fuel vessels

IMO SOLAS Convention
Gas or other low flashpoint fuel:

- Not in line with SOLAS II-2/4.2.1.1
- SOLAS II-1/56 and 57 refers to IGF Code

Gas carriers:
IGC Code Ch.16
The use of **toxic cargoes as fuel is not allowed**

Other ships:
IGF Code -> **Ammonia is not covered in detail => Alternative design is required as per Section 2.3.**

Short term: Flag Administration approval for each project

Longer term: Need for IMO Rule development or amendment, complemented by Class Rules

Alternative fuels - IMO - IGF Code

	LNG / CNG	Fuel Cells	Methanol	LPG	Ammonia	Hydrogen
Functional requirements, goals and principles (Ship design, construction and operation)	IGF Code Part A - Detailed risk analysis - Alternative design approach if no detailed requirements available in IGF Code					
Detailed requirements related to Ship design, construction and operation	IGF Code Parts A-1, B-1, C-1	**Guideline under development** • Draft finalized by CCC7 (09/2021) • To be approved by MSC105 (04/2022)	**MSC.1/Circ.1621** Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel • Approved by MSC102 in November 2020	**Guideline under development** • Work started at CCC6 (2019) • Draft to be finalized at CCC9 (2022) • To be approved by MSC107 (2023) ?	**IMO work item under discussion** • CCC CG to gather safety information • MSC105 (04/2022) to decide whether Guidelines are to be developed	**Guideline to be initiated** Development to be initiated by the CCC correspondance group dedicated to IGF Code-related matters
Functional requirements and goals related to training	IGF Code Part D					

Alternative fuels - BV Rules for Classification

	LNG / CNG	Fuel Cells	Methanol	LPG	Ammonia	Hydrogen
General principles	BV NR529 General part – Requirement for a risk assessment					
Detailed requirements related to Ship design and construction	**BV NR529** • Revised January 2020 • Update Q4 2021	**BV NI547** • Issued in 2009 • Revision under progress – Target publication Q4 2021	**BV NR670** • Issued in 07/2021 • Based on IMO MSC.1/ Circ.1621	**BV NI647** Issued in 2018	**BV NR671** • Issued in 07/2021 • Covers the use of ammonia as fuel based on BV experience	**BV NI547** • Includes requirements for hydrogen storage • Revision under progress – Target publication 2022 as Nx678
Gas-fuelled gas carriers	BV NR467 Pt D, Ch 9, sec 16					
	Bonus BV NR620 – LNG bunkering ships BV NI618 – Guidelines on LNG bunkering					

Energy Observer

ENERGY OBSERVER

ENERGY OBSERVER, FRANCE

Project status: In service

This research vessel is currently in service for worldwide operation, having entered into service in 2017 [14]. Originally designed and built as a sailing racing catamaran, it was converted into a research/campaign vessel. It features compressed H_2 storage, a 60 kW PEM fuel cell, electric and wind propulsion. It has an onboard electrolyzer, supplied by an extensive PV system and hydrogeneration under wind power.

ENERGY OBSERVER

VESSEL INFORMATION

PROJECT LEADER
Energy Observer

PROJECT PARTNERS
Accor, thélem assurances, Delanchy, engie, Toyota, CMA CGM, CCR, Afhypac, Hydrogen Council

PROJECT COMPLETION
In operation since 2017

ROUTES
Worldwide operation

TECHNICAL DATA

HYDROGEN STORAGE
Compressed gaseous

STORAGE LOCATION
Partially enclosed in hull

STORAGE PRESSURE
350 bar

HYDROGEN CAPACITY
62 kg

WIND PROPULSION
2 OceanWing soft wingsails

PHOTOVOLTAIC SYSTEM
141 m²

FUEL CELL POWER
60 kW

LENGTH 30 m
BREADTH 12.80 m

SHAPING A WORLD OF TRUST

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