DNV

WHEN TRUST MATTERS

Overview of Alternative Fuels for the Marine Industry

Maritime Decarbonization 101

Online Workshop on Greening Canada's Marine Transportation
April 20-21, 2022

CISMaRT

CANADIAN NETWORK FOR INNOVATIVE SHIPBUILDING, MARINE RESEARCH AND TRAINING | RÉSEAU CANADIEN POUR L'INNOVATION DANS LA CONSTRUCTION NAVALE, LA RECHERCHE MARINE ET LA FORMATION

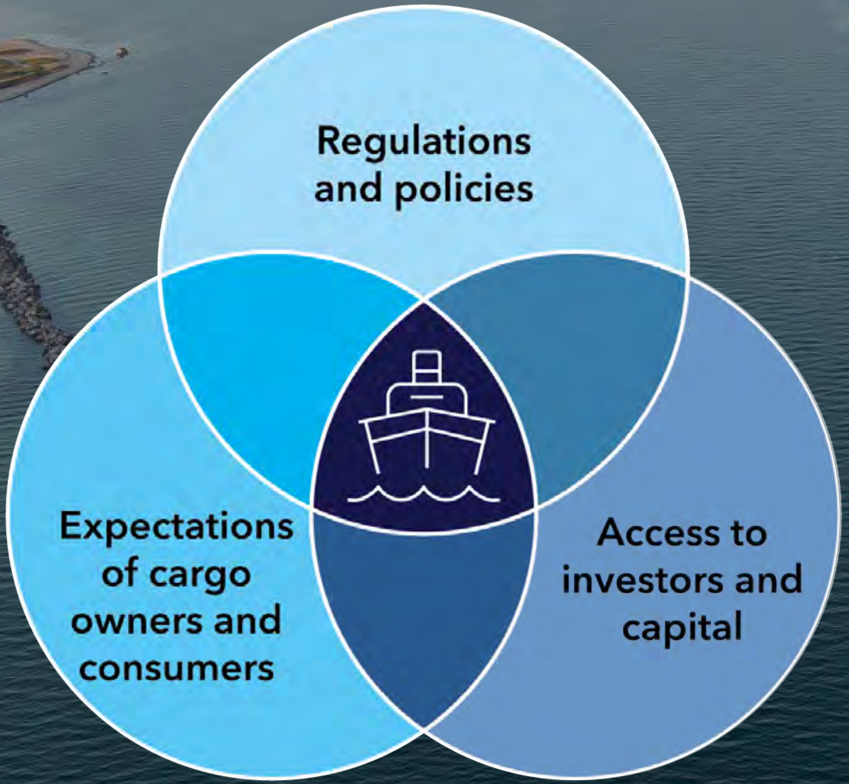
Agenda

- GHG Regulations & Current Status
- Emissions by shipping in Canadian waters
- Alternative marine fuels & technology
- Questions ??

Regulations & Current Status

Forecast for maritime decarbonization

Three fundamental key drivers are increasing the pressure for decarbonization



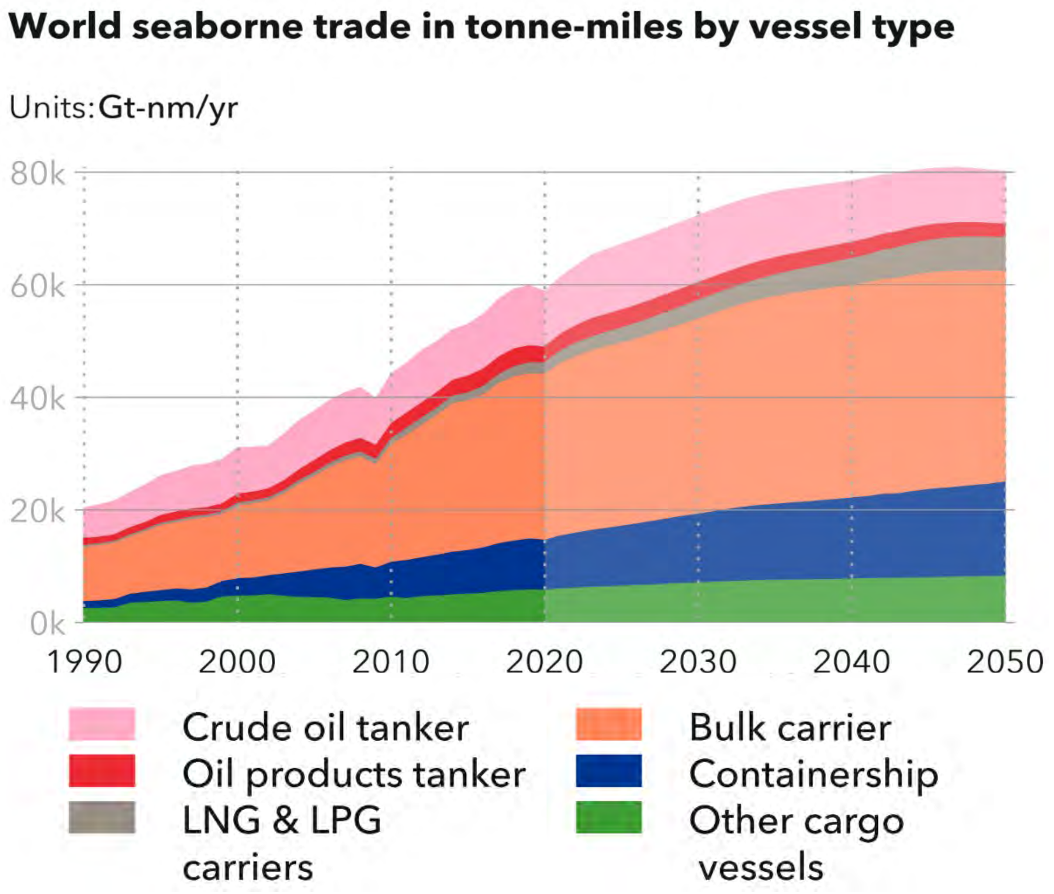
Regulation of GHG emissions is taking effect from 2023 and will strengthen rapidly.

Poorly performing shipping companies will be less attractive on the charter market and may also struggle to gain access to capital.

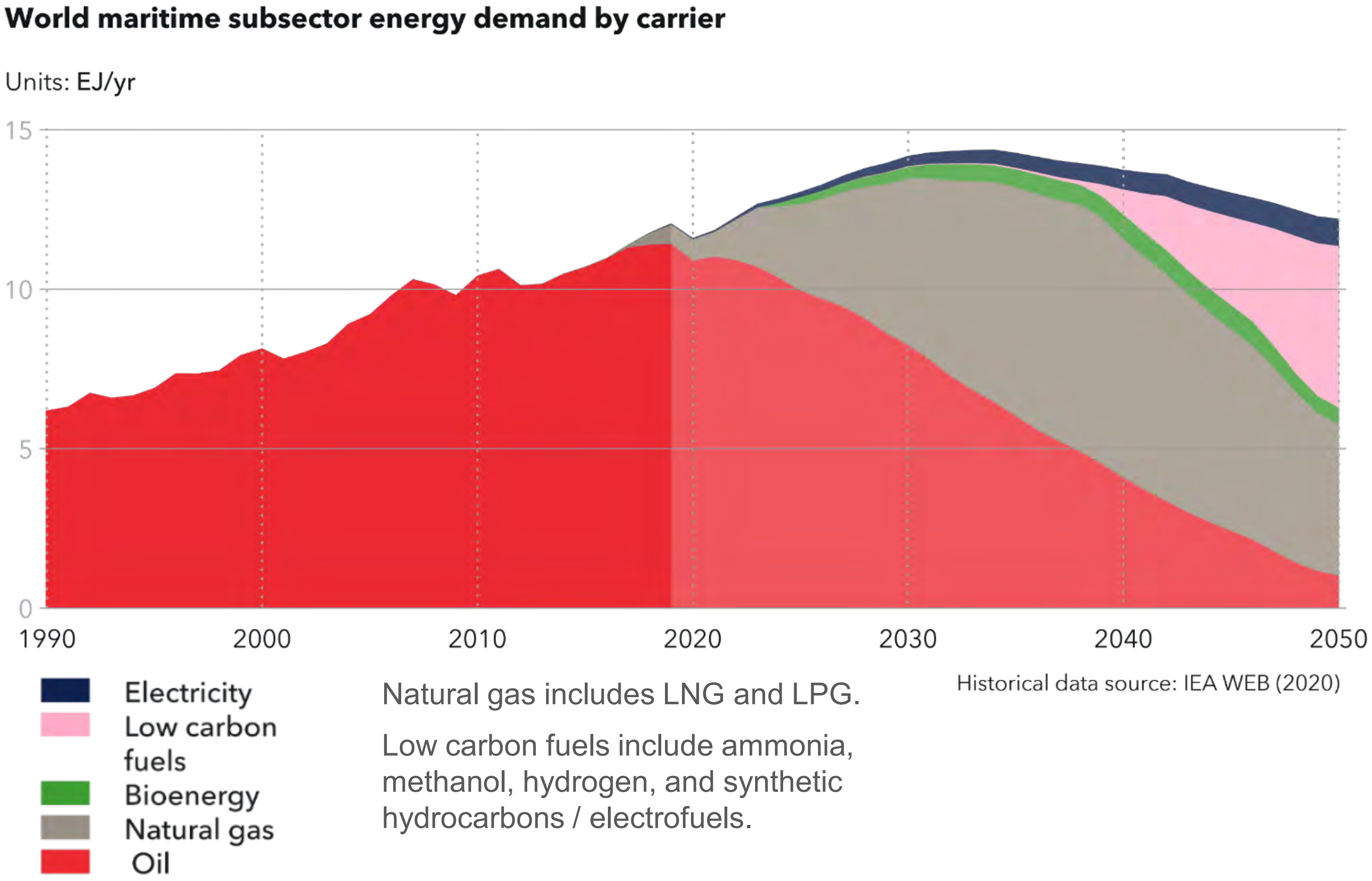
Growing commercial pressure may push shipowners to aim for a leading position in decarbonization.

Outlook for maritime transportation

- Global cargo transportation needs will continue to grow.
- Decarbonization in the rest of the economy will see a 20% drop in oil and oil product transportation demand by 2050.
- Today maritime transportation represents ~3% of global energy demand and 2-3% of carbon emissions.
- The relative share of emissions will increase as other sectors decarbonize.



The maritime fuel mix will change dramatically



- Uptake of **gas as fuel will accelerate** through the next decade.
- Electrification will accelerate and **battery-hybrid solutions** will become more common.
- Globally, **sustainable bio-fuels will play a limited role**, but may make an important contribution for blending and in local trades.
- Use of low-carbon fuels at scale will be delayed by supply constraints until the 2040s.

What are our options?

Reduce energy consumption

LOGISTICS AND DIGITALIZATION

Speed reduction

Vessel utilization

Vessel size

Alternative routes

>20%

HYDRODYNAMICS

Hull coating

Hull-form optimization

Air lubrication

Cleaning

5%-15%

MACHINERY

Machinery improvements

Waste-heat recovery

Engine de-rating

Battery hybridization

5%-20%

Low-carbon energy

FUELS AND ENERGY

LNG, LPG

Biofuels

Electrification

Methanol

Ammonia

Hydrogen

Harvesting from the surroundings

0%-100%

Clean up exhaust

AFTER TREATMENT MEASURE

Carbon capture and storage

>30%

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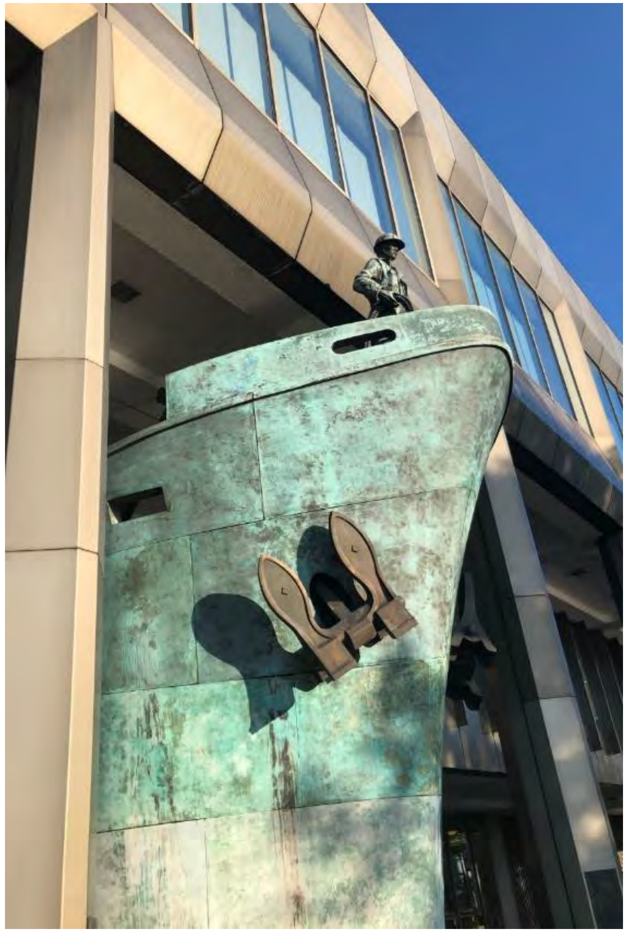
GHG Regulations Status / Outlook

IMO – GHG at a glance

Adopted regulations:

- EEDI for Existing Ships (**EEXI**):
  retroactive one-off requirement applied to existing ships
- Carbon Intensity Indicator (**CII**) / Enhanced **SEEMP** :
  mandatory annual reduction targets for operational emissions
- Entry into force: Nov. 1st 2022 – **effective as of Jan. 1st 2023**



Work on additional measures ramping up:

- Guidelines on fuel well-to-wake GHG footprint – **completion in 22/23**
- Review of GHG strategy and decarbonization ambitions – **decision by 2023**
- Workplan for mid- and long-term measures – **decision by 2023**
  - Increasingly challenging discussions on **carbon pricing**
  - Proposals for a **fuel greenhouse gas intensity standard** emerging

EEXI

Energy Efficiency Existing Ship Index (EEXI)

- **Scope: Cargo, ro-pax and cruise ships** (same as for EEDI – see list) regardless of contract date
- **Requirements:**
  - Attained EEXI to be calculated for ships above 400 GT
  - **Attained EEXI ≤ Required EEXI** for ships above segment specific size thresholds. Requirements similar to EEDI Phase 2/3, with some relief for a few ship types
  - Operators decide how to comply (Engine Power Limitation, fuel change, energy saving devices, retrofitting etc.)
- **Application:**
  - On first annual, intermediate or renewal IAPP survey or the initial IEE survey on or after 1 January 2023
- **Survey and Certification:**

Ship and company actions		Verification		Surveys and audits
EEXI calculation and technical file	→	EEXI technical file verification	→	First annual survey – new IEEC issued

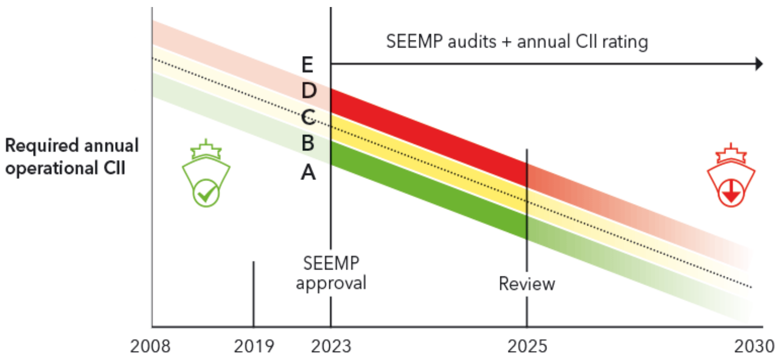
Ship type	Required EEXI*
Bulk carrier	∆15-20% by size
Tanker	∆15-20% by size
Container	∆20-50% by size
General cargo	∆30%
Gas carrier	∆20-30% by size
LNG carrier	∆30%
Reefer	∆15%
Combo	∆20%
Ro-ro/ro-pax	∆5%
Ro-ro (vehicle)	∆15%
Cruise ship	∆30%

**) Reduction from EEDI reference line*

CII

Carbon Intensity Indicator rating

- **Scope: Cargo, ro-pax and cruise ships above 5000 GT**
- **Requirements:**
  - **Every year from 2023:** Annually calculate and report Carbon Intensity Indicator and rating A to E. Each ship needs to **achieve rating C or better**
- **Enforcement:**
  - If rating D for 3 consecutive years or rating E: develop and implement an **approved corrective action plan** as part of SEEMP to achieve rating C or better
  - Annual Statement of Compliance issued.
- **Other elements:**
  - Review to be conducted by 1 January 2026 – particularly:
    - Reduction factors for 2027-2030
    - Strengthened corrective actions
    - Need for enhancement of the enforcement mechanism
  - Carbon Intensity Code to be developed to ensure mandatory application



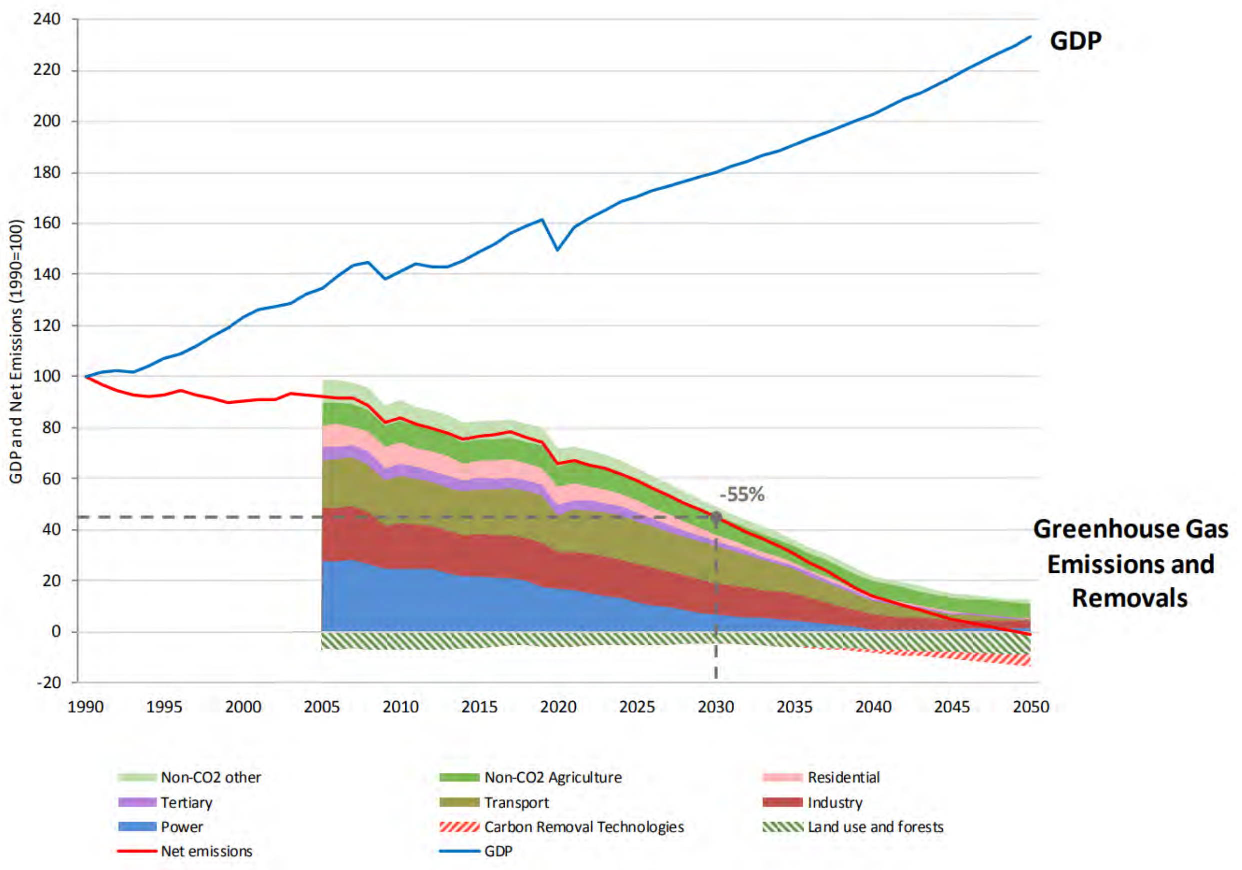
Year	Reduction from 2019 ref. (mid-point of C-rating band)
2023	5 %
2024	7 %
2025	9 %
2026	11 %
2027-2030	To be decided

EU Fit for 55

EU Green Deal – a climate neutral Europe by 2050

- Estimated **90% reduction in maritime transport emissions** relative to 1990 needed by 2050

- Fit for 55 package proposed by Commission on 14 July 2021. Key elements for shipping:
  - Inclusion of shipping in the **European Trading System**
  - **Fuel EU Maritime:** requirements on lifecycle GHG intensity of energy
  - Revision of **Alternative Fuels Infrastructure Regulation**: Shore side electricity and LNG in core network ports by 2030 (electricity) and 2025 (LNG)
  - Revision of **Energy Taxation Directive**: Ending tax exemptions for marine fuels within EU



Source: EU Commission, COM(2020) 562 final

Emissions by shipping in Canadian waters

ALTERNATIVE FUELS FOR CANADA

Pointing the direction towards low/zero-emission shipping

WWF-Canada

Modeling of shipping air emissions in the Canadian waters in 2019 and assess reduction options

- Detailed overview of the maritime traffic and the associated emissions to air for Canadian waters in 2019, using AIS (Automatic Identification System) ship movement data.
- Assess low- and zero-emission technologies available to reduce the emission footprints.
- Discuss regulatory and policy measures relevant for reducing emissions to air in Canadian waters.

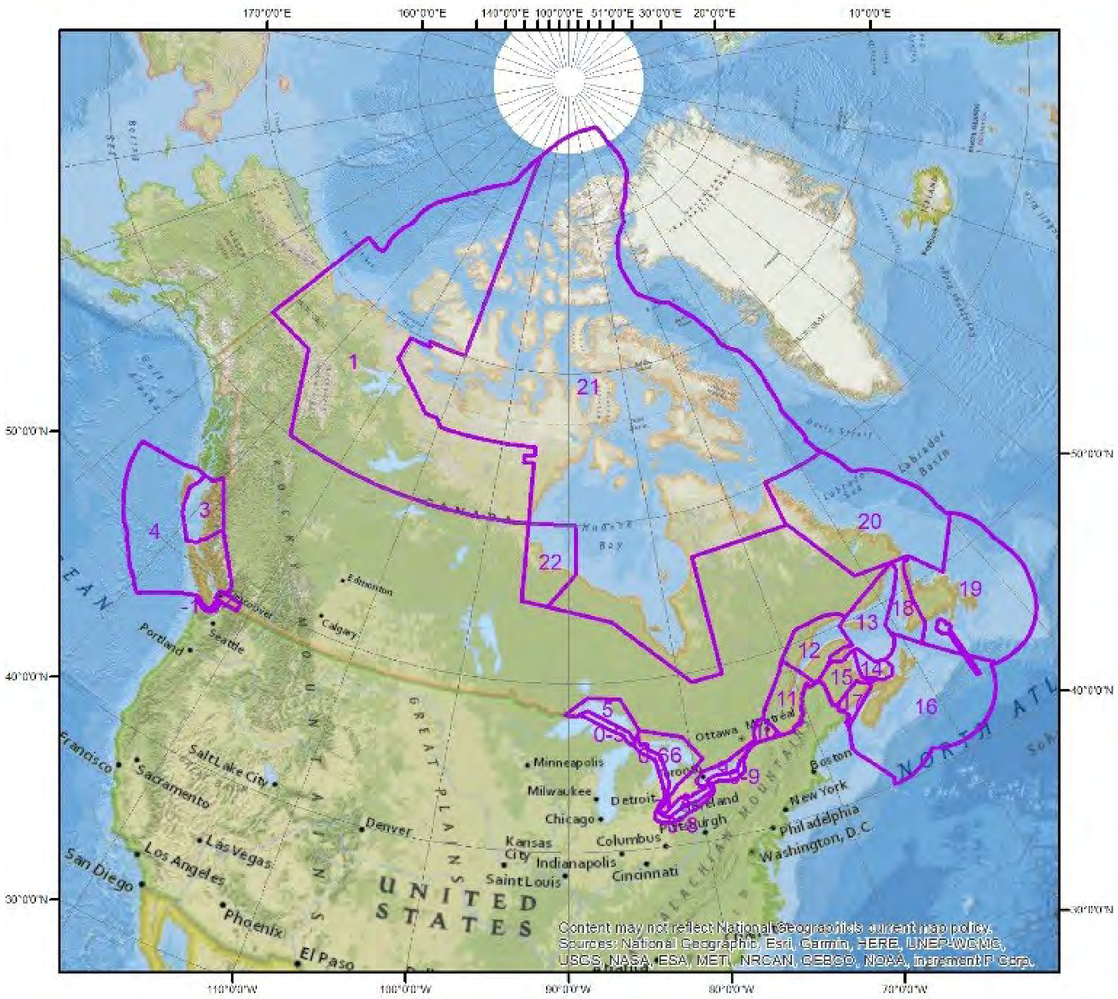
Summary:

The AIS-based modelling shows that a total of 6078 individual vessels operated in Canadian waters, consuming about 2,500 thousand tons of fuel oils in 2019, and emitting;

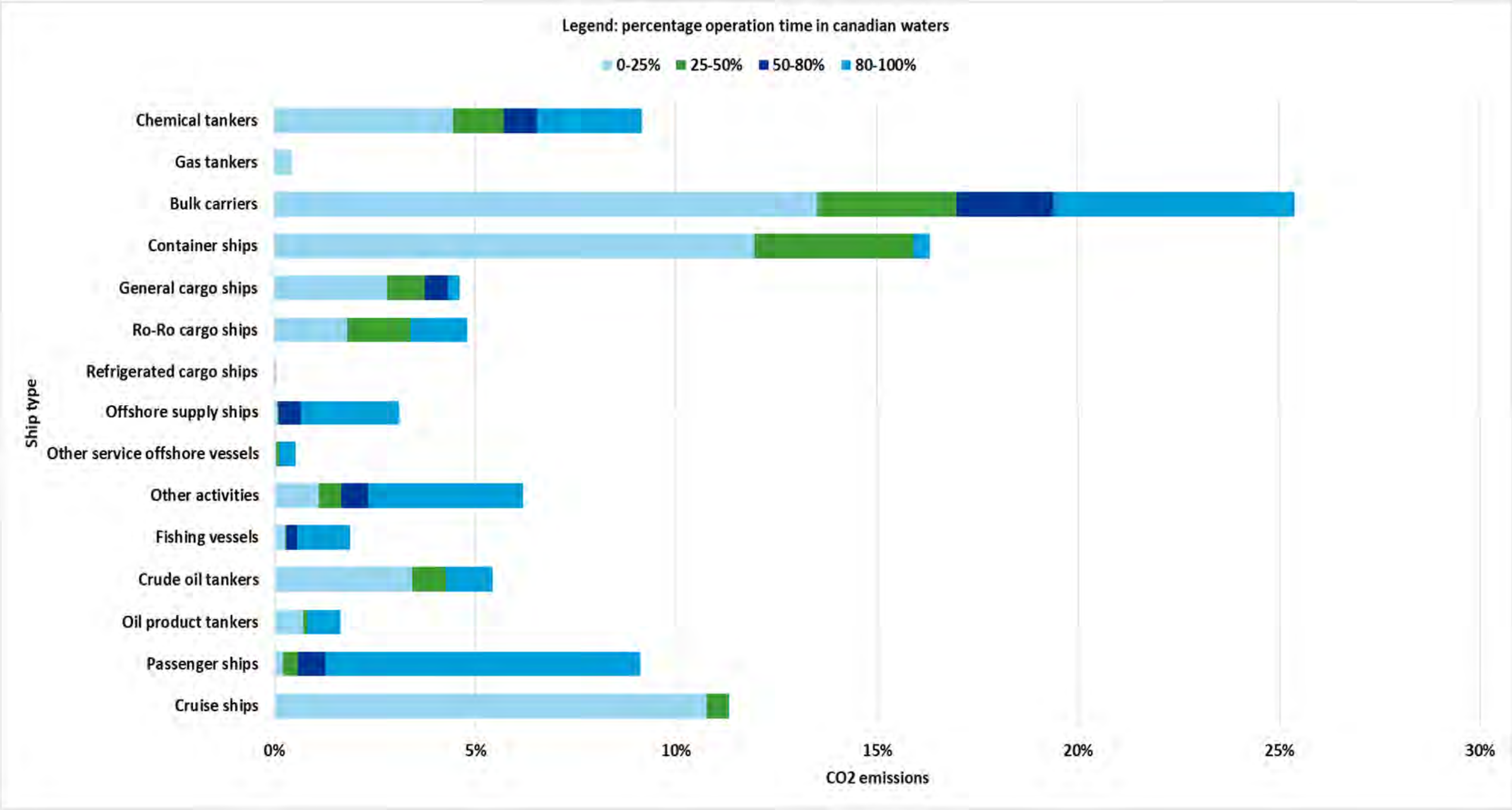
- 8 million tons of carbon dioxide (MtCO2)
- 156 thousand tons (kton) of nitrogen oxides (NOx)
- 3.5 kton of particulate matter (PM) 2.5 and 3.7 kton of PM10
- 0.4 kton of black carbon (BC)
- 5.6 kton of sulphur oxides (SOx).

- Bulk carriers and container ships account for around 40% of total fuel consumption and CO2 emissions.
- Large ships above 10,000 gross tonnage (GT), around 80% of the total
- Half of the fuel is consumed by ships spending less than a quarter of the year in Canadian waters.
- Nearly one third is consumed by ships spending almost all their time in Canadian waters.

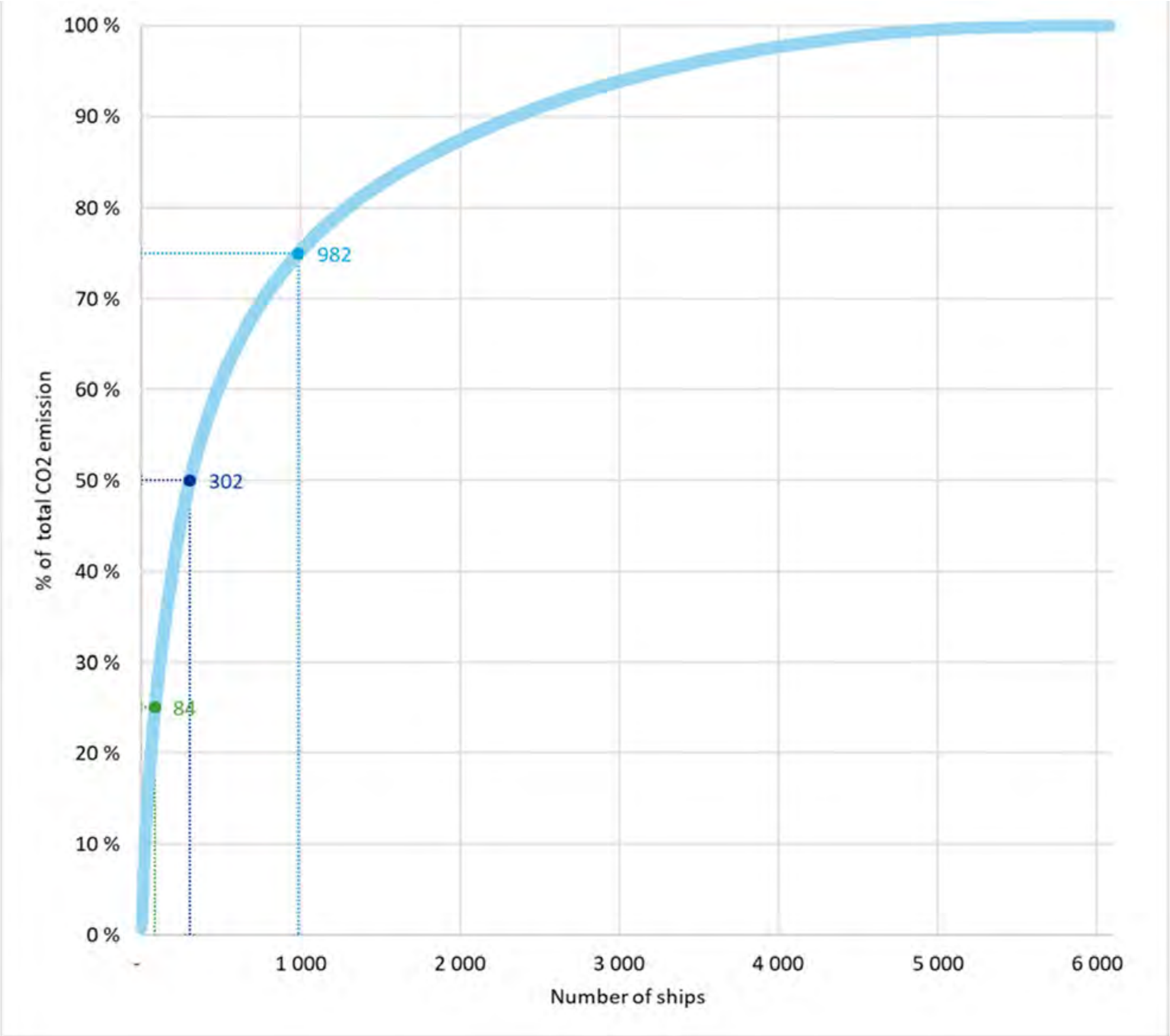
Area Covered



Distribution of total CO2 emissions in Canadian waters in 2019 by ship type and time in Canadian Waters



Accumulated CO2 contribution



Recommendations in the report

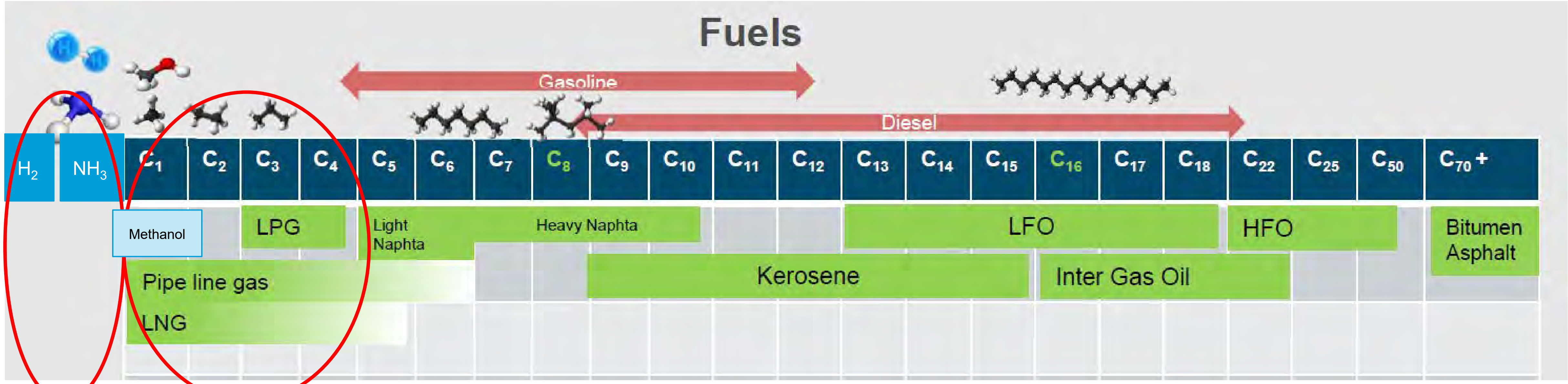
- Canada needs a national plan with concrete targets and timelines that consider potential fuels, technologies, regulations and incentives for reducing GHG emissions
- The maritime industry has a unique opportunity to help lead the changes toward a more sustainable future.
- Cost-benefit analysis calculating emission reductions and costs associated with measures for the ships in the Canadian fleet.
- Develop a roadmap for the green transformation of the maritime sector in Canada.

Alternative Fuels

Overview of possible options

- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear/CCS

What are our fuel options?



Source: Wärtsilä

Carbon-free

10-20% Lower carbon content compared to MGO-HFO

Grey, Blue and Green Fuels

Grey

- Fossil fuels, typically used today
- LNG, LPG have 15-20% lower carbon content
- H_2, Ammonia produced from natural gas/coal fall in this category

Blue

- H_2, Ammonia produced from natural gas/coal with Carbon Capture & Storage
- e-fuels produced with CO_2 from Carbon Capture from another combustion process

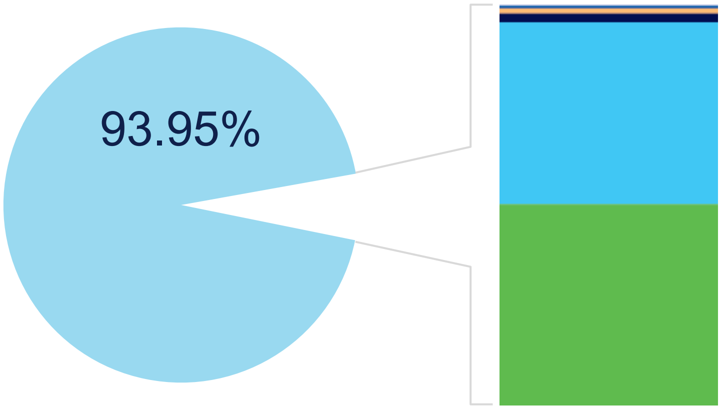
Green

- Biofuels (sustainability requirements apply)
- H_2, Ammonia produced from carbon-free electricity
- e-fuels produced with CO_2 directly extracted from the atmosphere

The maritime fuel transition has started and is gaining momentum

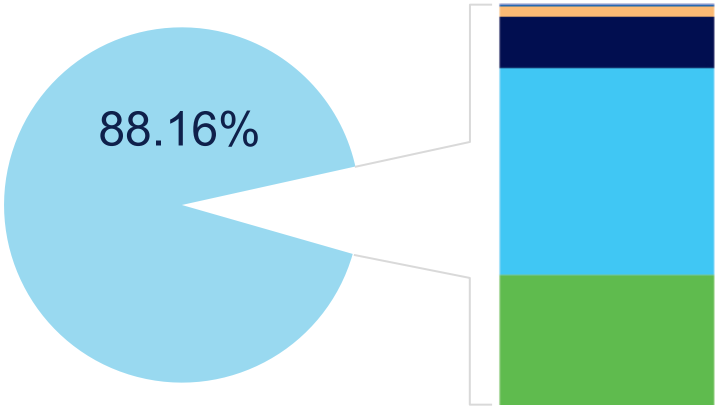
Ships on order, alternative fuel uptake in number of vessels

2019



Hydrogen	0.04%
Methanol	0.08%
LPG	0.13%
LNG	2.73%
Battery	3.07%
Total	**6.05%**

2021

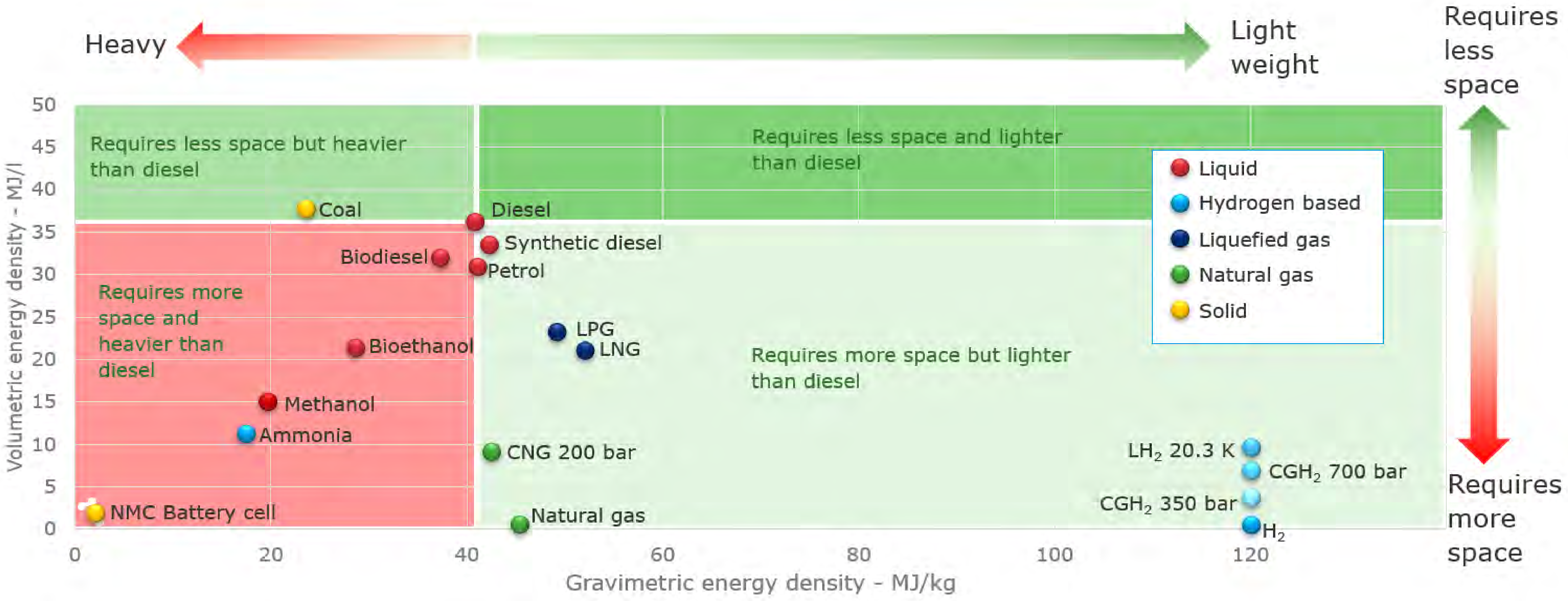


Ammonia	0.02%
Hydrogen	0.06%
Methanol	0.30%
LPG	1.51%
LNG	6.10%
Battery	3.85%
Total	**11.84%**

What is the best fuel option?

	Availability	Infrastructure & Storage (Abundance)	Maturity of technology	Energy density	Price (Affordability)	Green credentials
VLSFO/MGO						
LNG						
LPG						
Methanol						
Biofuels						
Hydrogen						
Ammonia						

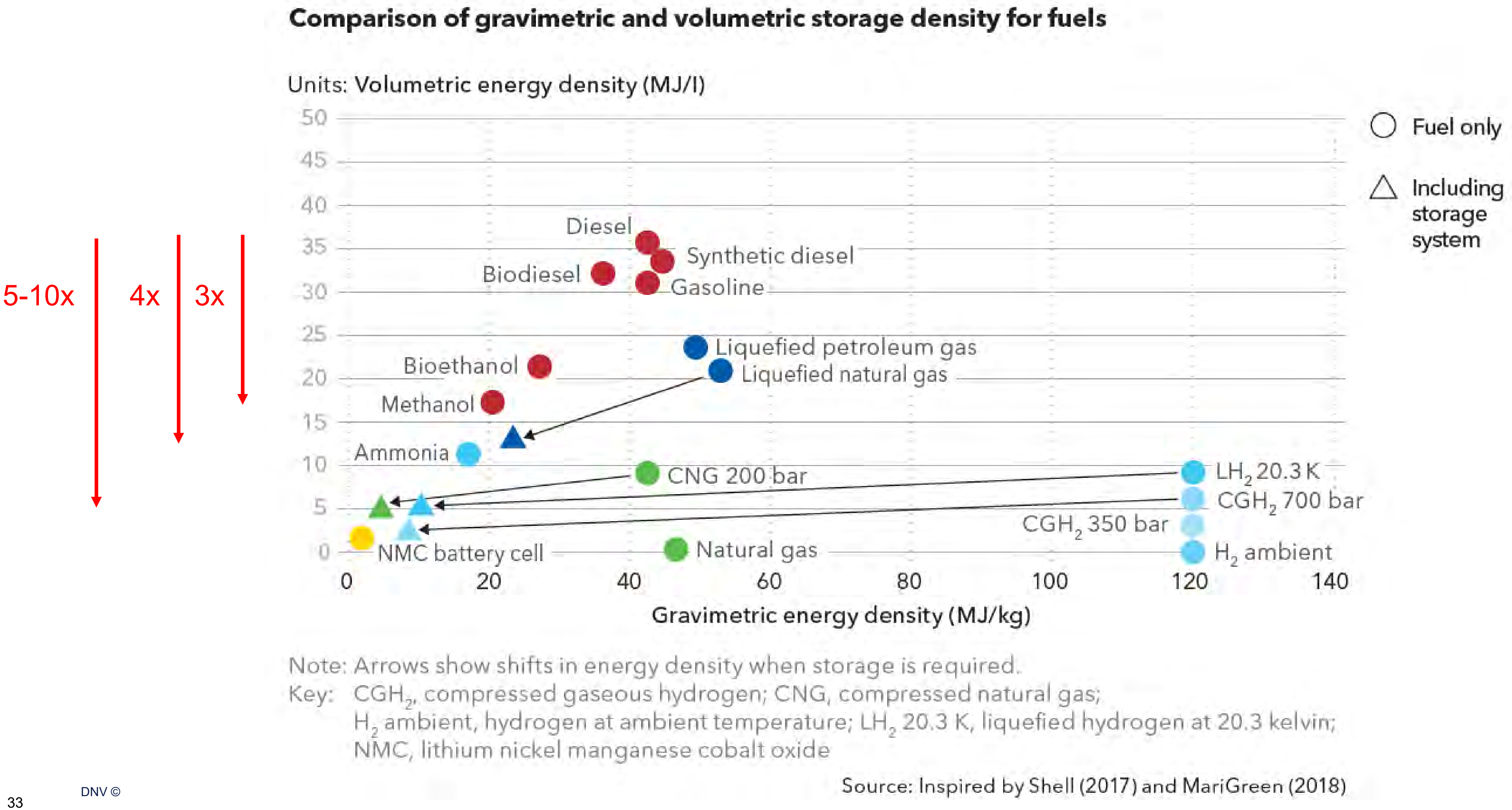
Energy Density



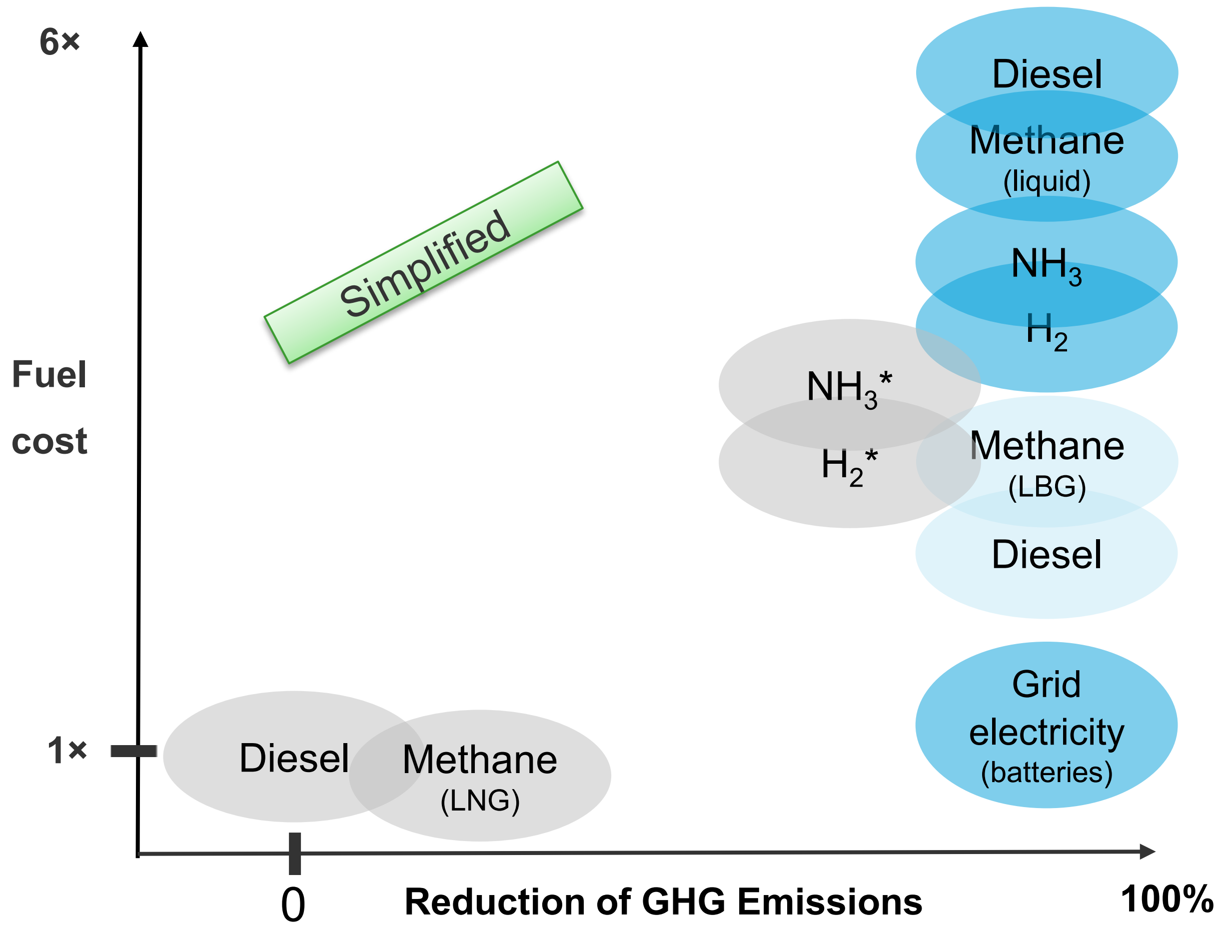
*The above figure does not take into account the mass and volume of the storage system associated with each fuel

Source: DNV GL Comparison of Alternative Marine Fuels, 2019

Fuel storage limitations



Fuel costs



- Future alternative fuel prices are highly dependent on technological progress and market developments. The figure to the left gives indicative fuel-cost of alternative fuels **based on current production-costs**.

Fossil-based

Electricity-based**

Bio-based

*Assuming CCS

** from renewable sources; CO_2 for electro-fuels need to be captured from the atmosphere

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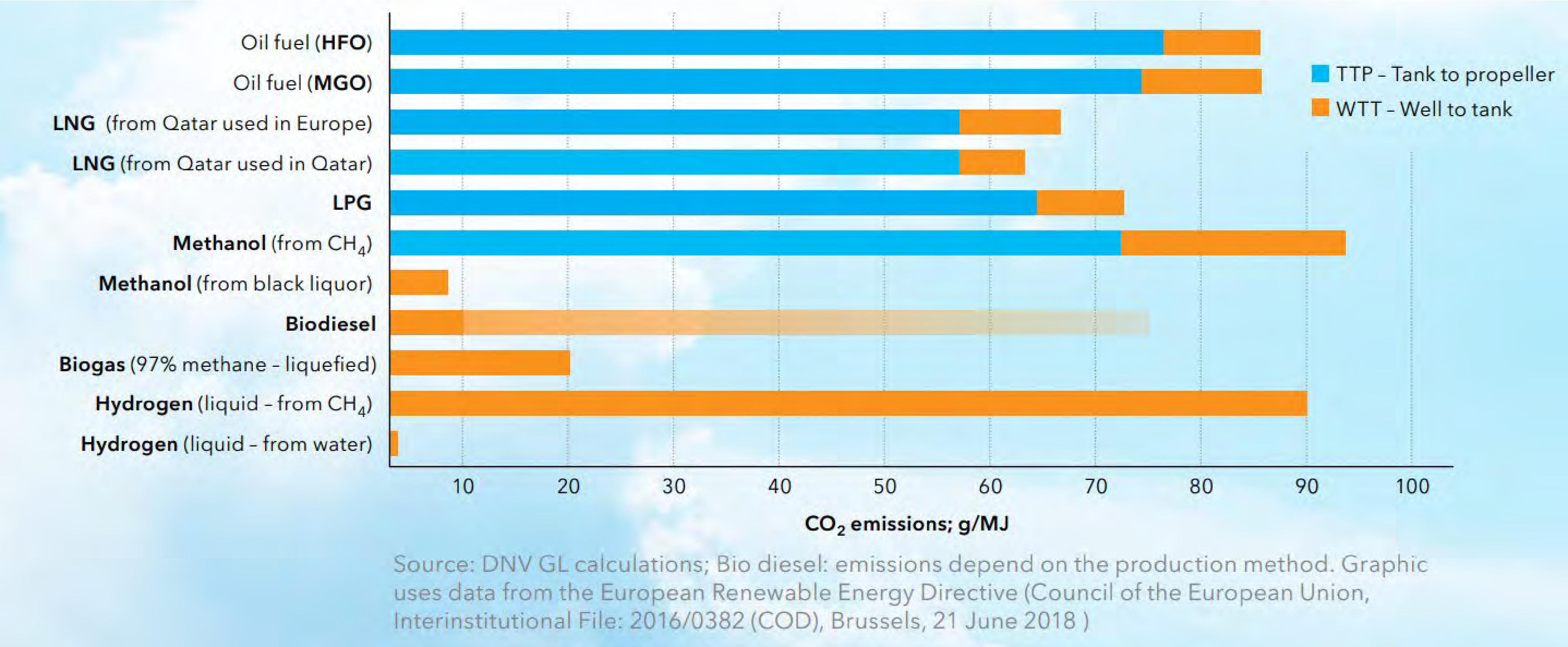
CO_2 Emissions



- The above figure is taken from *DNV GL Comparison of Alternative Marine Fuels*, and is based on given production pathways. Potential methane emissions are not included in this graph.

Source: DNV GL Comparison of Alternative Marine Fuels

Overview of possible marine fuels

- LNG
- LPG
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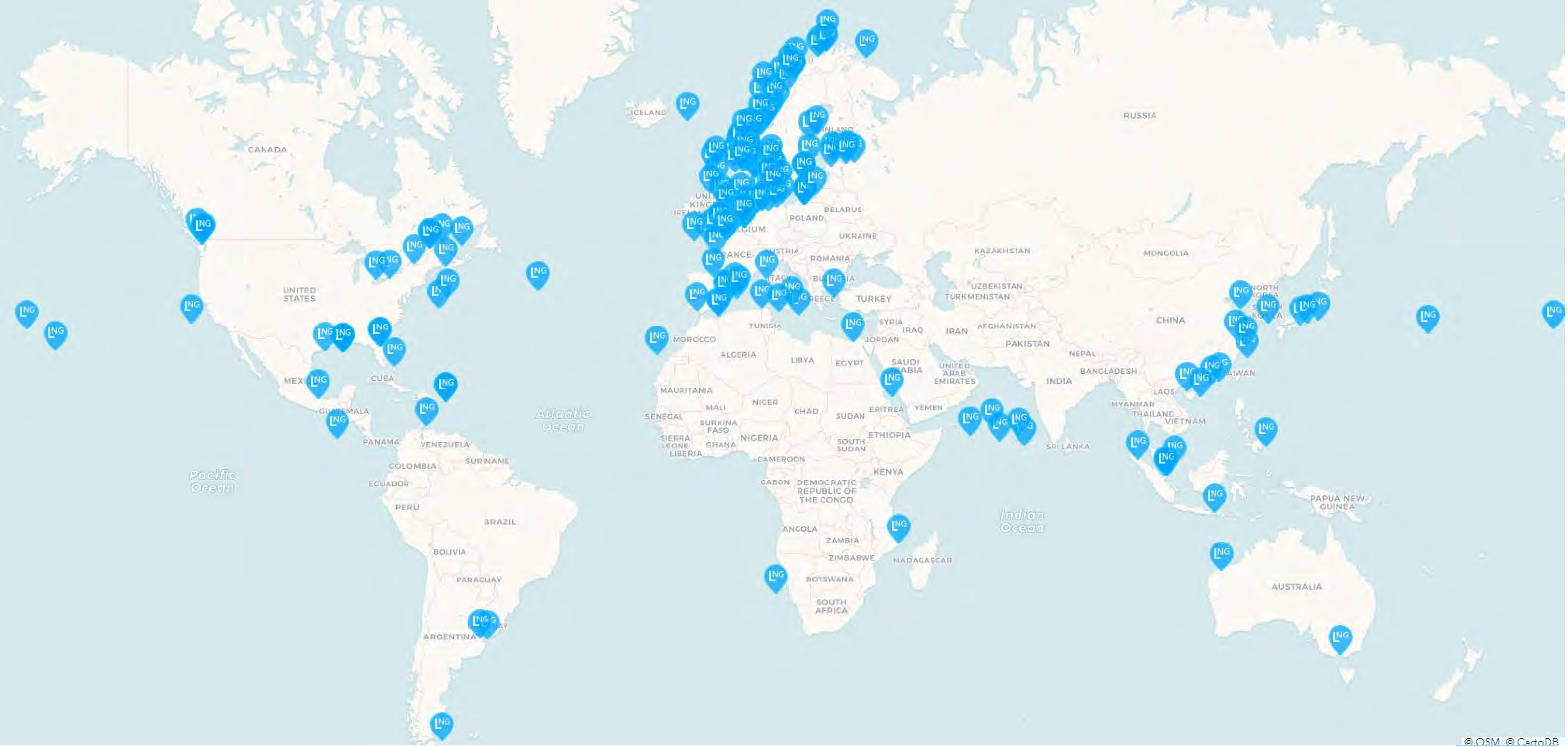
- Biofuels
- Electrification
- Nuclear/CCS

LNG - key characteristics

Availability	In principle, LNG is available worldwide (large scale import and export terminals), and investments in bunkering infrastructure are being made globally. Currently, a large share of LNG bunkering as well as LNG distribution to bunkering locations is still taking place by road. However, 2017 and 2018 saw several LNG bunkering vessels being delivered for operation in key areas including the North Sea, coast of Florida, and Rotterdam. Within the next few years, other areas such as the Western Mediterranean, Gulf of Mexico, and Singapore will be serviced by LNG bunkering vessels currently under construction.
Storage	LNG is stored in insulated tanks at a very low temperature of approximately -162°C, at atmospheric pressure. Inevitably, boil-off natural gas is generated inside LNG fuel tanks due to ambient heat ingress. Consequently, a system for handling boil-off gas must be in place. When taking into account the entire fuel storage system, LNG has a relatively low volumetric fuel density (less than half that of MGO/HFO). As a result, more space must be allocated on board ships for storage of LNG, when compared to conventional marine fuels.
Application	LNG may be applied as a fuel in ICEs, FCs or steam turbines. Different types of ICEs available on the market are capable of running on LNG. Engine-types include 2-stroke Dual Fuel ICEs (high- and low pressure), and 4-stroke dual-fuel and mono-fuel ICEs. Less commonly, is the application of LNG in gas turbines. LNG may also be applied directly in high-temperature FCs such as SOFCs.
Technological maturity	Gas engines, gas turbines and LNG storage and processing systems have been available for land installations for decades. Sea transport of LNG by LNG carriers also has a long history going back several decades. Developments to use LNG fuel in the general shipping fleet, with the exception of LNG carriers, began early in the current century. Today, the technology required for using LNG as ship fuel is readily available on the market. ICEs including piston engines and gas turbines, several LNG storage tank types as well as process equipment are also commercially available. Application of LNG in high-temperature fuel cell systems such as SOFCs is still relatively immature, and pilot projects are taking place to explore its usage on ships.
Environmental performance	Due to the low sulphur-content of LNG, it is associated with virtually zero emissions of SOx when consumed on board ships. NOx emissions are also lower than those that result from combustion of HFO or MGO. Methane-slip must, however, be considered when evaluating the GHG reduction potential of LNG. Assuming no methane-slip occurs, LNG has the potential to reduce GHG emissions by a maximum of 26 per cent, compared to conventional ship propulsion systems run on HFO.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

LNG fueled ships from DNV AFI



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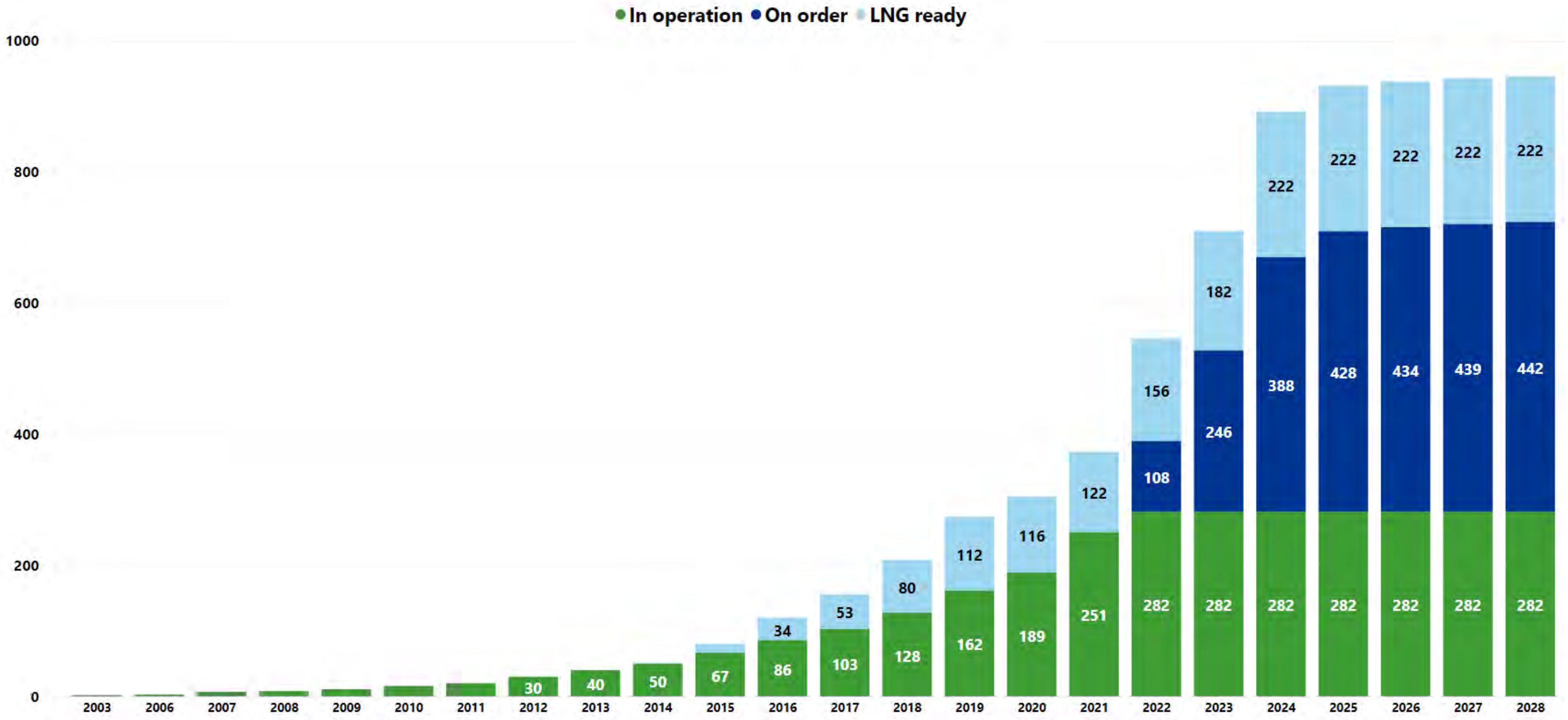
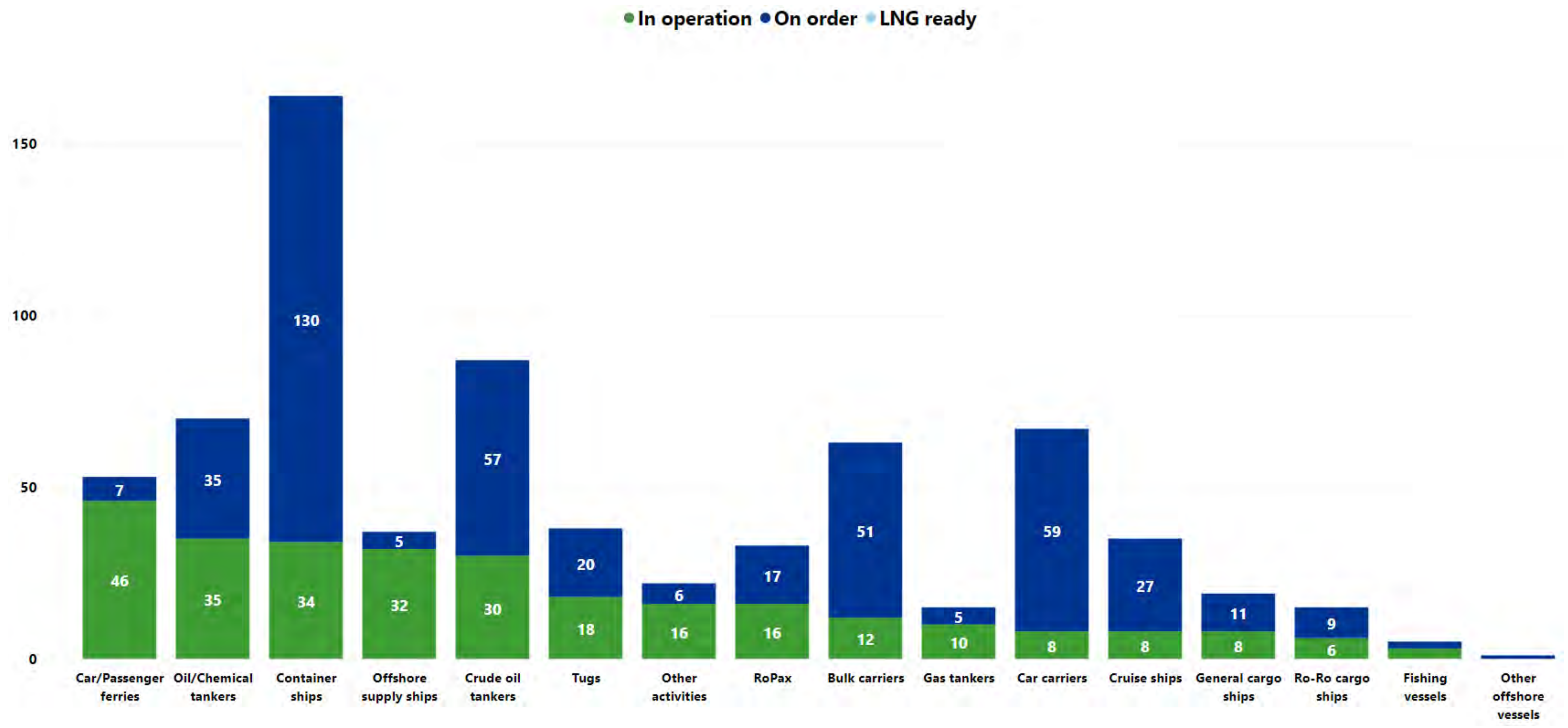
There are currently 724 confirmed LNG fueled ships, and 222 additional LNG ready ships

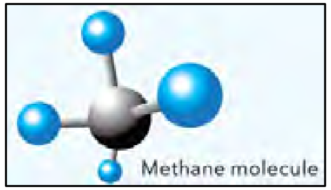


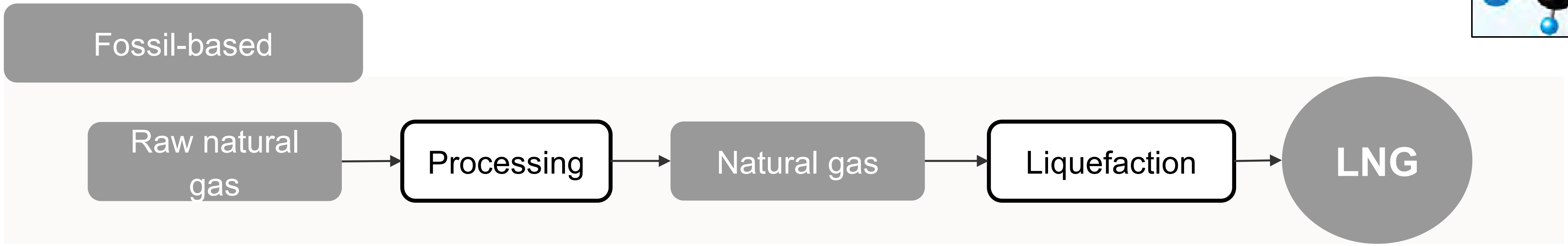
Showing delivery year of <u>existing</u> orders only. Future contracts will increase the number of LNG fueled ships delivered in 2023 and onwards.

LNG fueled fleet by vessel type



LNG – production pathways





General

The main component of liquefied natural gas (LNG) is methane (CH_4), the hydrocarbon fuel with the lowest carbon content and therefore with the highest potential to reduce CO_2 emissions. Ethane, is the other major component of LNG. LNG has more or less the same composition as natural gas used in households, for power generation and by the industry. LNG, as its name implies, only has one production pathway, which is the liquefaction of natural gas from a natural gas processing plant.

Overview of possible marine fuels

- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear/CCS

LPG - key characteristics

Availability

There is an extensive network of LPG import and export terminals worldwide. It is reported that there are more than 1,000 import and secondary terminals for pressurized LPG. Recently more LPG export terminals have been developed in the US to cover the increased demand for competitively priced LPG products. It is relatively easy to develop bunkering infrastructure at existing LPG storage locations or terminals by simply adding distribution installations. Distribution to ships can occur either from dedicated facilities or from special bunker vessels.

Storage

LPG is mostly stored in three different states; fully refrigerated (~-50ºC, ~1 bar), semi-pressurized (~-10ºC, ~5 bar), or fully pressurized (~20ºC, ~17 bar). When taking into account the entire storage system, storage of LPG will take up significantly more space than HFO or MGO. However, the volumetric density is higher than that of LNG.

Application

ICEs are considered to be the LPG energy-converter of choice on ships. Different engine concepts for combustion of LPG exist, including diesel-cycle 2-stroke engines, and otto cycle, lean-burn, 4-stroke engines (currently only available for stationary power plants). Gas turbines, compatible with LPG, are also available for marine propulsion.

Technological maturity

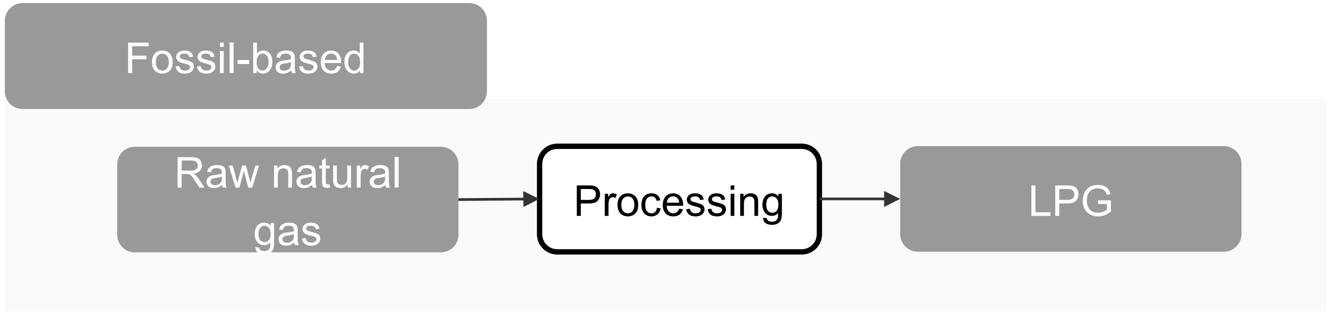
Engines fueled by LPG has recently been developed for the marine market and is commercially available. The first major ships fueled by LPG are set to enter operation in 2020. To date (January 2020) LPG has no operational track-record on board ships as a fuel.

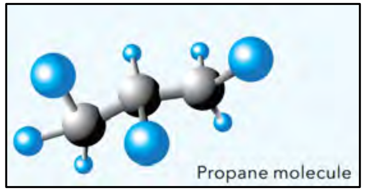
Environmental performance

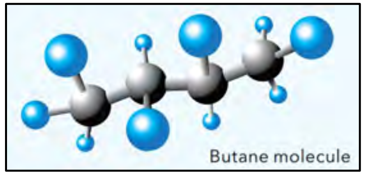
LPG combustion results in GHG emissions that are approximately 16 per cent lower than those of HFO. When accounting for the complete lifecycle, including fuel production, the GHG savings amount to roughly 17 per cent. The global warming potential of propane and butane as greenhouse gases is three to four times higher than that of CO_2. This has to be taken into consideration
when addressing the issue of unburned LPG potentially escaping into the atmosphere (LPG slip). At the same time, using LPG virtually eliminates Sulphur emissions. LPG is also expected to reduce particulate matter (PM) emissions significantly. The reduction of NOx emissions depends on the ICE technology applied.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL LPG as a Marine Fuel

LPG – production pathways







General

Liquefied petroleum gas (LPG) is by definition any mixture of propane and butane in liquid form. In the USA, the term LPG is generally associated with propane. Specific mixtures of butane and propane are used to achieve desired saturation, pressure and temperature characteristics.

LPG as fuel

Greenhouse Gas Reduction: 15-20%

Propulsion engines available

- First vessels started operation in 2020

Lower investment costs

Global availability

Competitive price

Most suitable technology for ammonia-ready

Overview of possible marine fuels

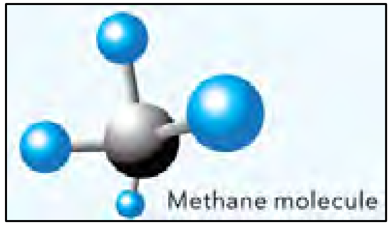
- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear

LBG - key characteristics

Availability	In 2018, total production of LBG made up less than 0.2 Mtoe. Considering that the total fuel consumption of the world fleet was approximately 274 Mtoe in 2018, a massive upscale of LBG production is needed if it is to serve as a marine fuel. Since LBG is practically identical to LNG, it may use infrastructure including bunkering stations already built to serve the LNG-market.
Storage	Reference is made to section on LNG. LBG is stored in isolated tanks at a very low temperature of approximately -162°C, at atmospheric pressure. Inevitably, boil-off natural gas is generated inside LBG fuel tanks due to ambient heat ingress. Consequently, a system for handling boil-off gas must be in place. When taking into account the entire fuel storage system, LBG has a relatively low volumetric fuel density (less than half that of MGO/HFO). As a result, more space must be allocated on board ships for storage of LBG, when compared to conventional fuels.
Application	Reference is made to section on LNG. LBG may applied as a fuel in ICEs, FCs or steam turbines. Different types of ICEs available on the market are capable of running on LBG. Engine-types include 2-stroke Dual Fuel ICEs (high- and low pressure), and 4-stroke Dual-fuel and Mono-fuel ICEs. Less commonly, is the application of LBG in gas turbines. LBG may also be applied directly in high-temperature FCs such as SOFCs.
Technological maturity	Reference is made to section on LNG. Gas engines, gas turbines and LNG/LBG storage and processing systems have been available for land installations for decades. Sea transport of LNG by LNG carriers also has a long history going back several decades. Developments to use LNG/LBG fuel in the general shipping fleet, with the exception of LNG carriers, began early in the current century. Today, the technology required for using LBG as ship fuel is readily commercially available. ICEs including piston engines and gas turbines, several LNG/LBG storage tank types as well as process equipment are also commercially available. Application of LNG/LBG in FC systems such as SOFCs is still relatively immature, and pilot projects are taking place to explore its usage on ships.
Environmental performance	Although combustion of LBG produces GHG comparable in magnitude with those resulting from combustion of LNG, the overall net lifecycle GHG emissions has the potential to be zero since it is produced from biomass derived from feedstock which absorbs CO_2 from the atmosphere when growing. If LBG is produced from biomass derived from waste sources such as municipal solid waste, carbon-negativity is possible to achieve, preventing methane resulting natural decomposition of waste to escape to the atmosphere.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

LBG – production pathways



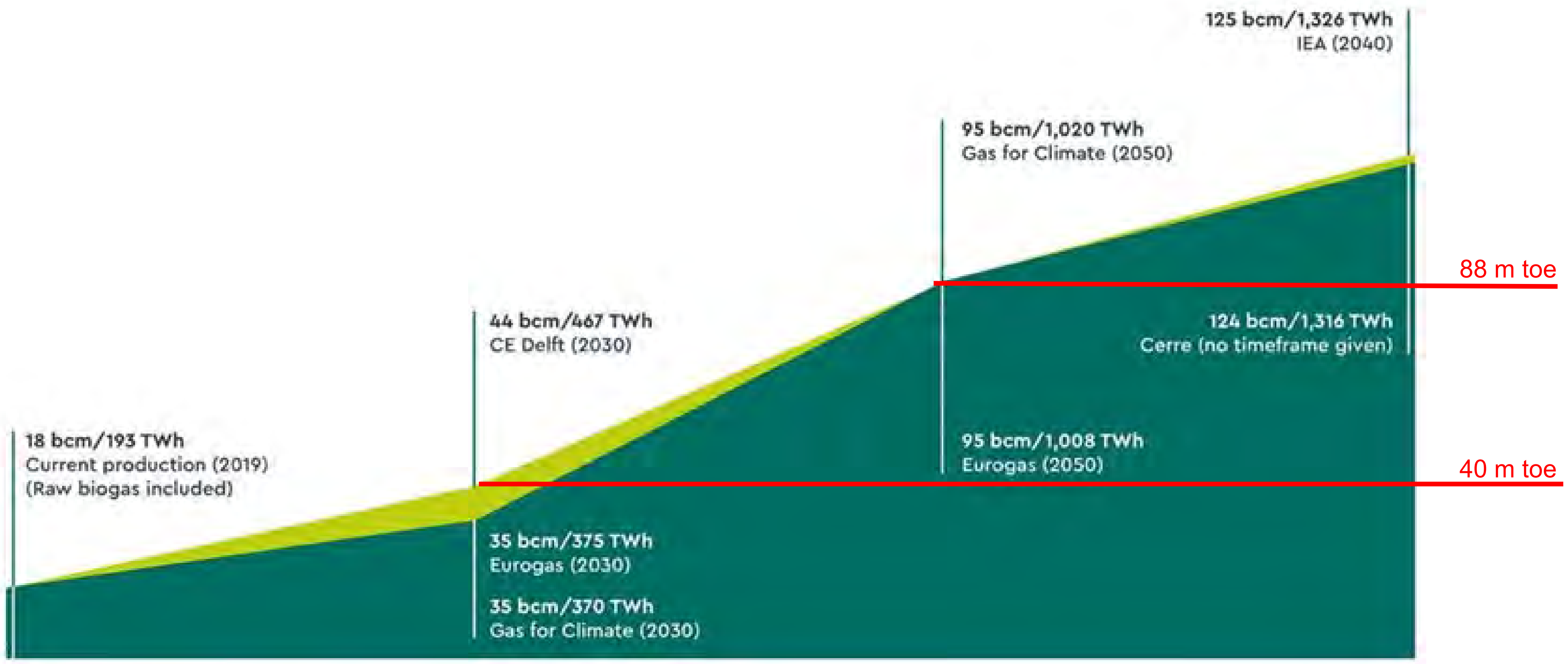
Bio-based

Biomass → Aerobic/ Anaerobic digestion → Biomass → Purification → Biogas → Liquefaction → LBG

General

Liquefied biogas (LBG) is practically identical to liquefied natural gas (LBG), and is most commonly produced via aerobic/anaerobic digestion of waste from agriculture, as well as municipal waste. Even though biogas is, technically, a mixture of methane, CO_2, and other impurities, LBG refers to liquefied biomethane. Hence, biogas needs to be purified and liquefied before it may be defined as LBG.

Expected availability of biogas



Source: European Biogas Association

Overview of possible marine fuels

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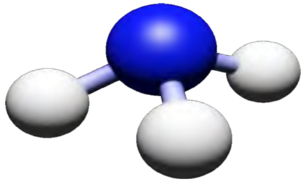
- Nuclear/CCS

Ammonia as a marine fuel: The motivation

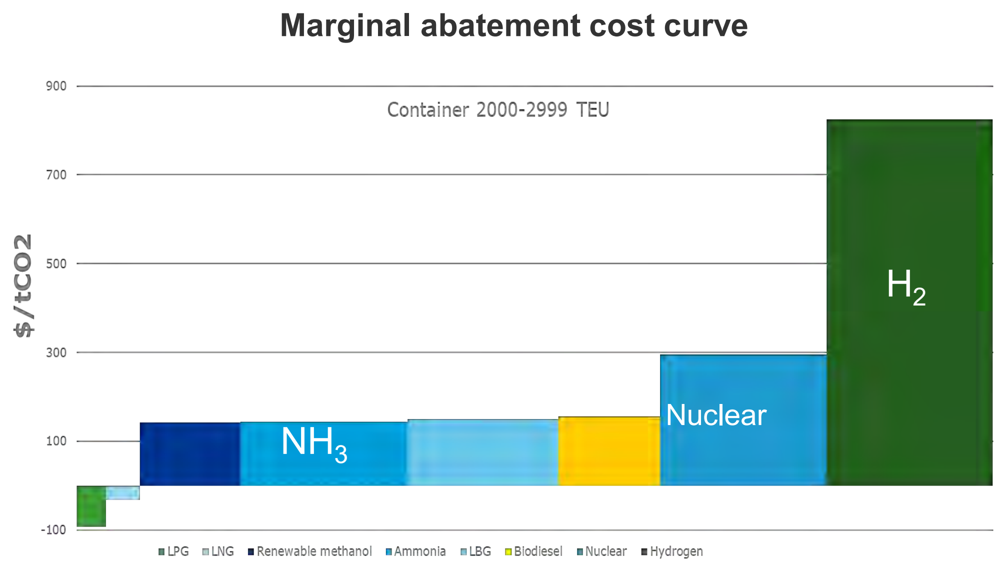


- Carbon Free - NH_3 does not contain carbon

- Liquid at -33°C
- Liquid at 20°C, 7.5 bar ⇒ no cryogenic temperatures required

- On-board storage more easy

- Compared to hydrogen:
  - Cheaper and easier to store (10 bar at ambient temperature)
  - Energy density higher than compressed hydrogen



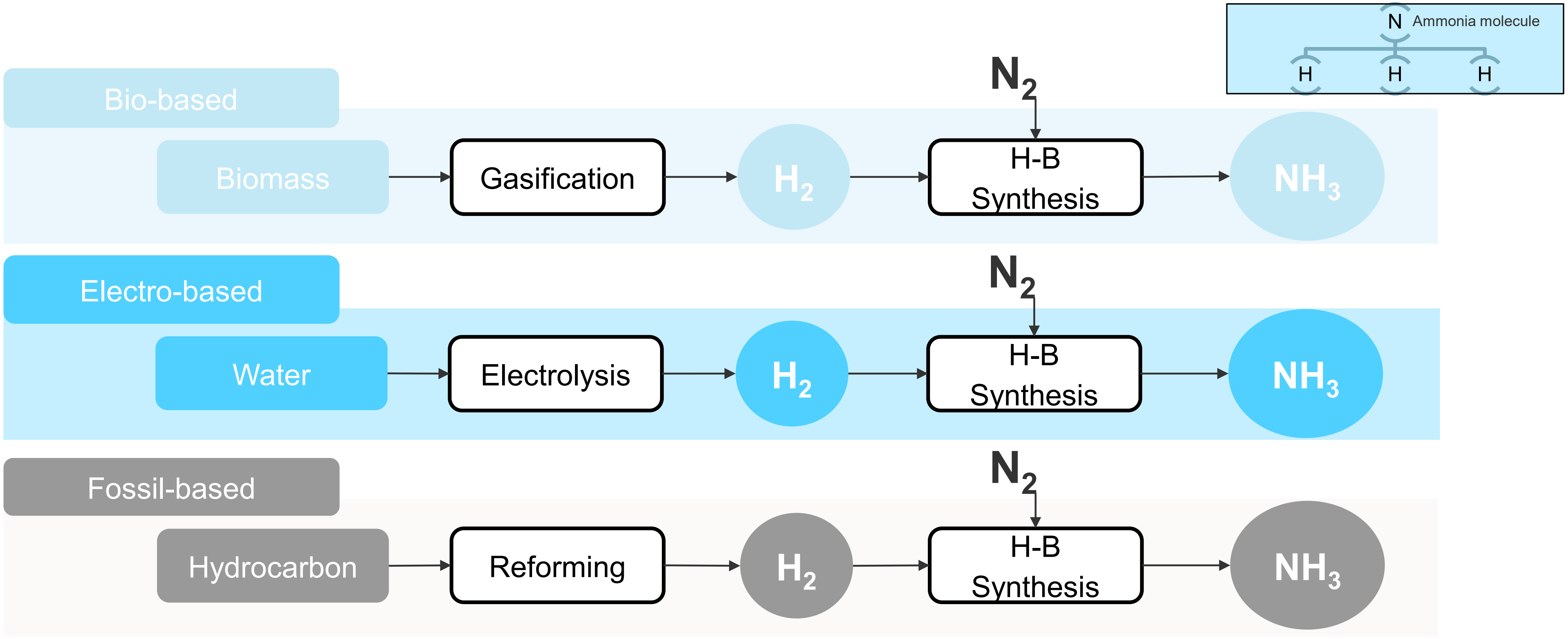
Ammonia - key characteristics

Availability	Production of ammonia from hydrogen (derived from hydrocarbons) and nitrogen through H-B synthesis is a well-known commercial process, with total production of ammonia equivalent to approximately 76 Mtoe per year. The largest producers are China with 32% of global production, Russia (9%), and India (8%). Infrastructure for transport and handling of ammonia exists, due to its use in production of fertilizers. However, bunkering infrastructure for ships is currently non-existent and needs to be developed.
Storage	Ammonia is stored as a liquid, primarily in three different states: i) fully-pressurised (~18 bar, 20°C). ii) semi-pressurised (~5 bar, ~-10°C), or iii) fully refrigerated (1 bar,~-33°C), depending on the quantity stored. For use as fuel on ships, fully pressurised or semi-refrigerated storage is the most applicable. Liquid ammonia has a significantly lower volumetric energy density compared to conventional fuels like HFO. Consequently, significantly more space is needed relative to MGO/HFO, but less than other alternative fuels such as liquefied hydrogen.
Application	Ammonia may technically be applied as a fuel in both ICEs and FCs. As far as FCs are concerned, ammonia may be consumed directly in high-temperature fuel cells such as SOFCs, or after being cracked into hydrogen and purified for traces of ammonia for use in low-temperature fuel cells such as PEMFCs.
Technological maturity	No ammonia-fuelled propulsion systems are currently available on the market. However, given the similarity of ammonia-fuelled ICEs with current commercially-available engine-designs, there is reason to believe that ammonia-fuelled ICEs could be available within the next few years. Notably, the engine manufacturer MAN ES is developing a concept for applying ammonia as a fuel in two-stroke dual fuel engines[1]. Research efforts are being made with respect to the application of ammonia in FCs, however, there is still a long time before the technology is expected to be commercially available.
Environmental performance	The end-use of ammonia in ICEs or FCs does not cause any GHG- or SOx emissions. For use in ICEs, depending on the choice of engine-technology, emissions of NOx will be generated. Considering a well-to-tank perspective, regardless of the selected production pathway, ammonia has the potential to be carbon-neutral. However, that is only valid under the given assumption that fossil-based production is supplemented by CCS, or that the electricity-input in electro-based ammonia is produced from carbon-neutral sources.

[1](MAN ES, 2019), *Engineering the future two-stroke green-ammonia engine*

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies, DNV GL Maritime Forecast to 2050

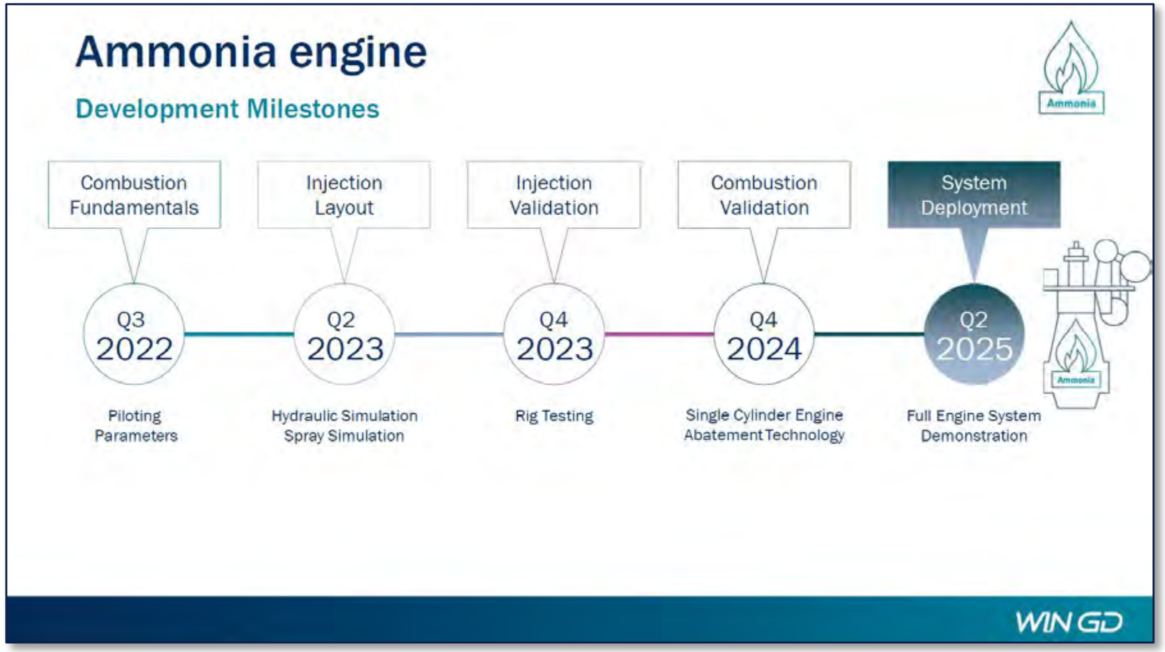
Ammonia – production pathways

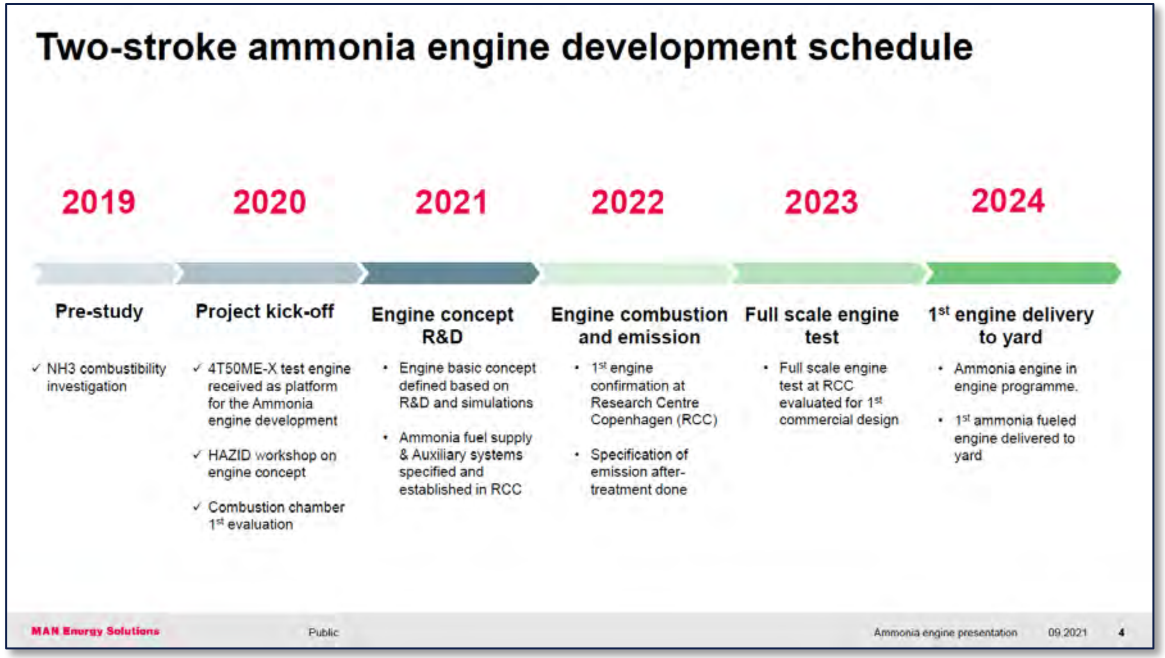


General

Ammonia is a compound consisting of nitrogen and hydrogen, with chemical formula NH_3. Currently, the vast majority of ammonia is produced via reforming of natural gas, followed by Haber-Bosch synthesis. In the future however, other production routes based on electricity (electro-based) or biomass (bio-based) are considered.

Ammonia engine developments





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Ammonia: engine development challenges

- Several **challenges** to overcome
  - Ammonia difficult to ignite and burn $\Rightarrow$ pilot fuel injection required
  - Increased NO_x emissions $\Rightarrow$ SCR aftertreatment system
  - Potential for small amounts of unburned NH_3: very unpleasant odour
    - Dangerous for humans above 25 ppm
  - Potential for N_2O emissions $\Rightarrow$ very potent GHG
  - Availability of green ammonia?
- Internal Combustion Engines under development:
  - **2-stroke dual-fuel**, MAN-ES
  - **4-stroke dual-fuel**, Wärtsilä
- Fuel cell development (2 MW)

Commercially available: 2023-2024

Ammonia as fuel – A kind product?

Corrosive

Toxic

Environmental hazard
(

Safety limits NH_3

8-hour: 20-25 ppm

15 min: 35-50 ppm

Health effects: 300 ppm

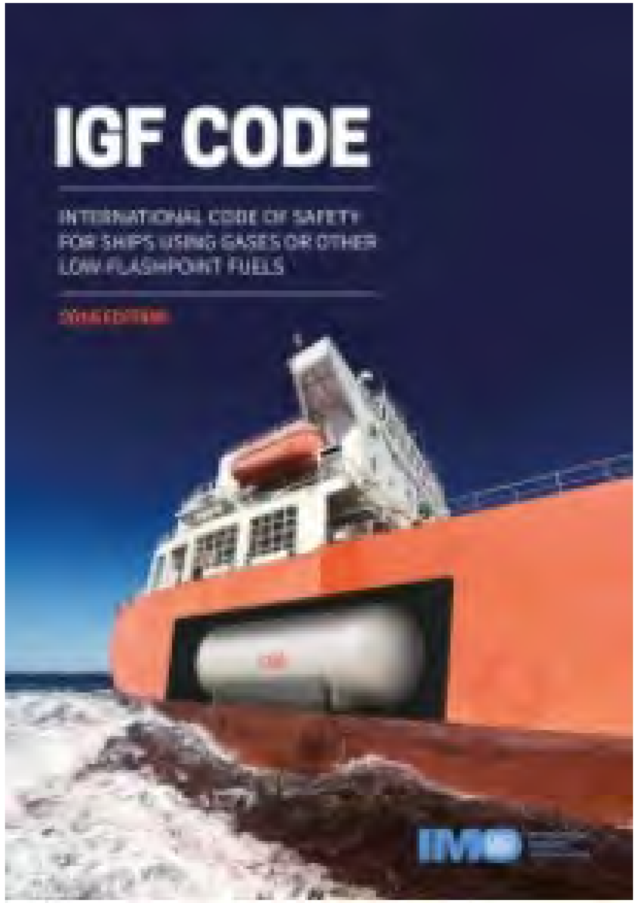
Lethal: 5000 ppm

Regulatory framework for ammonia – does it exist?

- Ships with low flashpoint fuels → IGF
- Ships carrying liquefied gasses and use them as fuel → IGC (but no toxic fuels)
- Explicit prescriptive rules for LNG as a fuel in IGF code
- All other fuels:

Principle of equivalence:

If acceptable to the Administration, other cargo gases may be used as fuel, providing that the same level of safety as natural gas (IGC) / oil-fueled (IGF) is ensured.



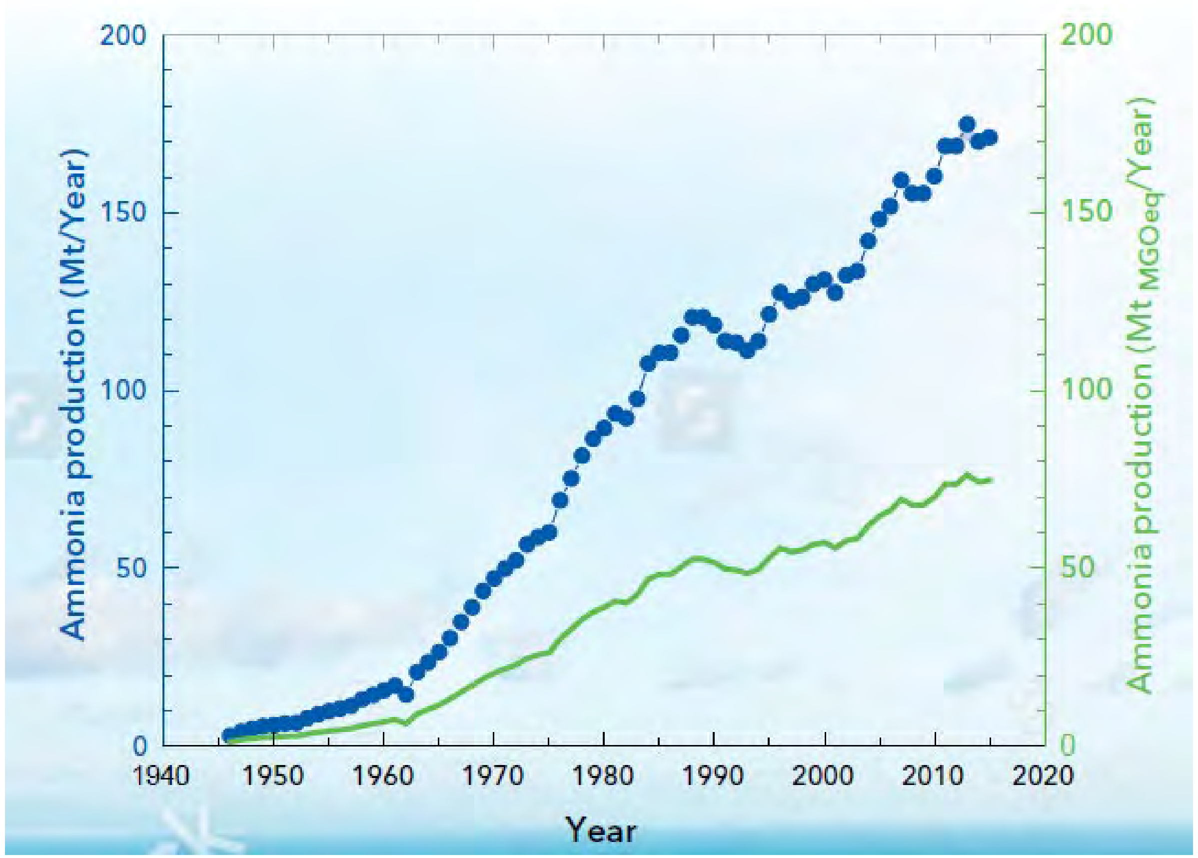
Fuelling

Carrying as cargo

DNV

Availability

- Production: 170 million tonnes (80 million tonnes of oil equivalent)
- Fuel consumption all ships 300 million tonnes
  - Corresponds to 650 million tonnes NH_3
  - Ammonia as fuel competes with food production (it is used as fertilizer)
  - Therefore, limited available capacity for fuel today
- When used as marine fuel, it needs to be based on new production capacity from green electricity.
- Today: 68% from natural gas, 28% from coal and 4% from oil.



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GROUP TECHNOLOGY & RESEARCH, WHITE PAPER 2020

AMMONIA AS A MARINE FUEL

AMMONIA AS A MARINE FUEL

SAFETY HANDBOOK

DNV·GL

Green Shipping Programme

Sjøfartsdirektoratet
Norwegian Maritime Authority

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Overview of possible marine fuels

- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear/CCS

Is Hydrogen able to give a long term solution?

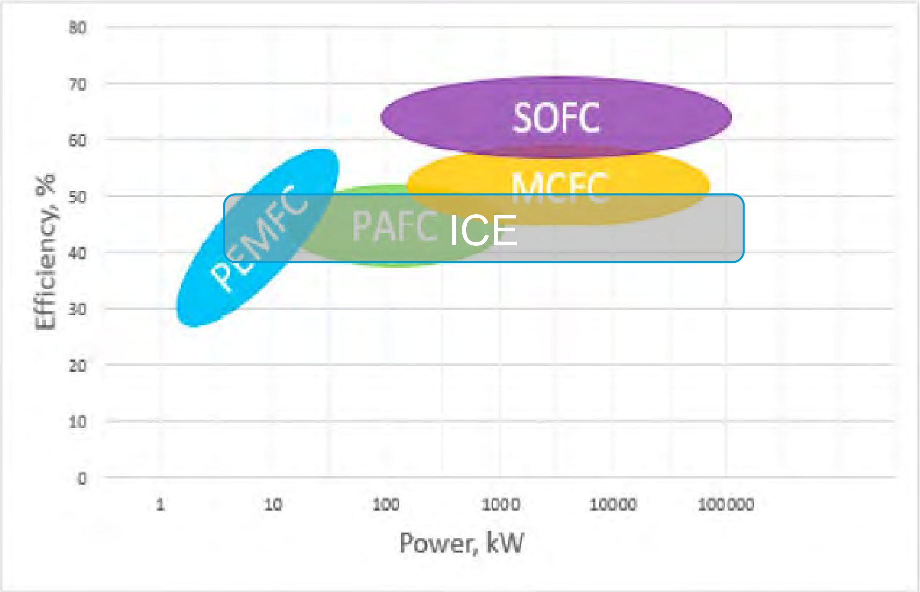
Hydrogen can be used in

- Fuel Cells (in operation): potential for high efficiencies
- Internal Combustion Engines (under development)

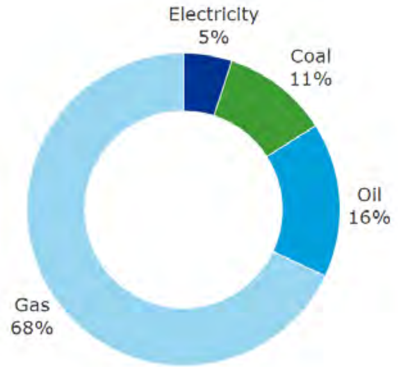
Key challenges:

- Size of fuel tanks: 6-10 times larger than oil
- Extreme temperatures, pressures

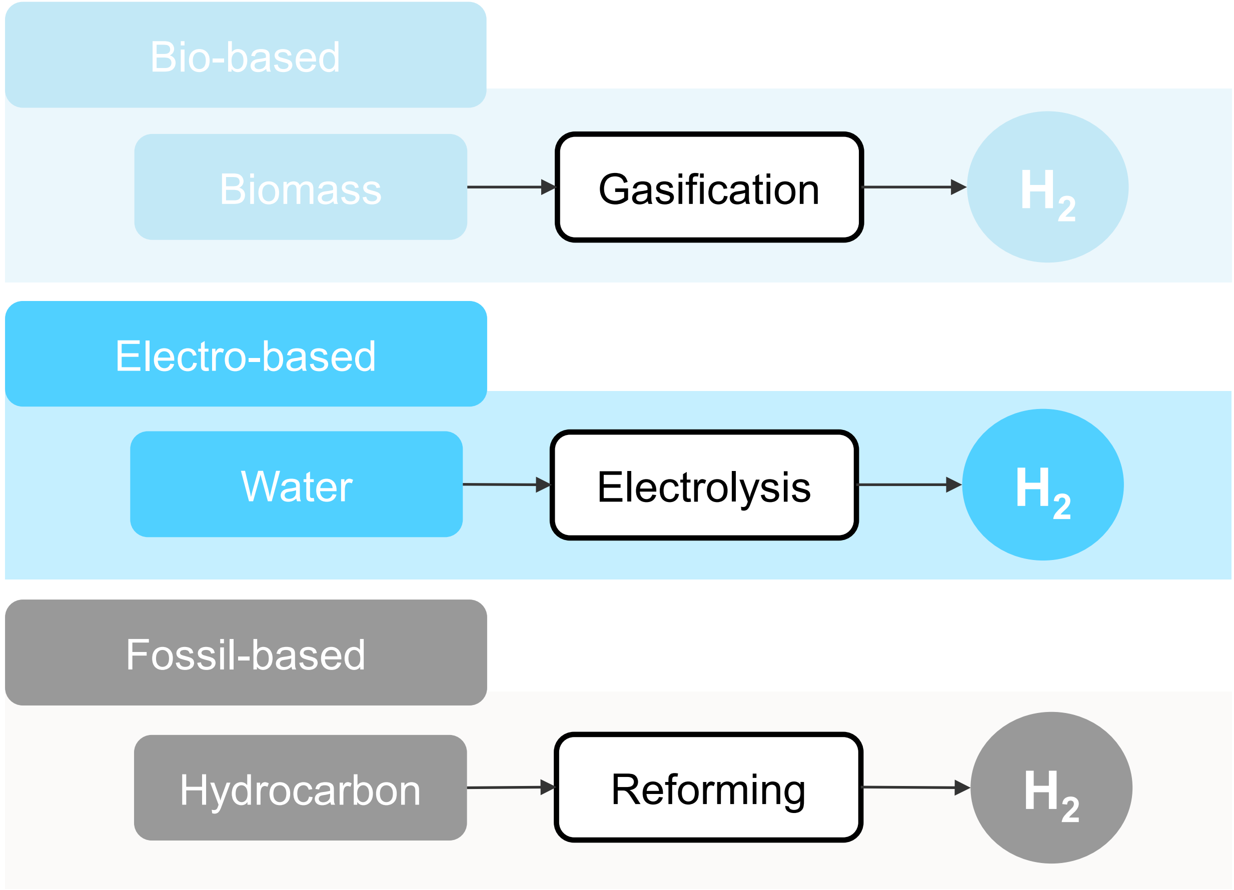
  ⇒ Very high investment cost
- Lifetime of fuel cells
- Cost of fuel cells
- Availability/Infrastructure for bunkering



Hydrogen production



Hydrogen – production pathways



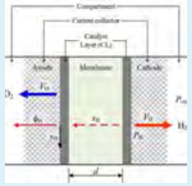
General

Hydrogen (H_2) is a colourless, odourless and non-toxic gas. Hydrogen is an energy carrier and a widely used chemical commodity. It can be produced from various energy sources, such as by electrolysis of renewables, or by reforming natural gas. Today, 95 per cent of hydrogen is produced from fossil fuels, mainly natural gas. Five per cent of current hydrogen production uses electrolysis, and is hence electro-based.

Hydrogen production

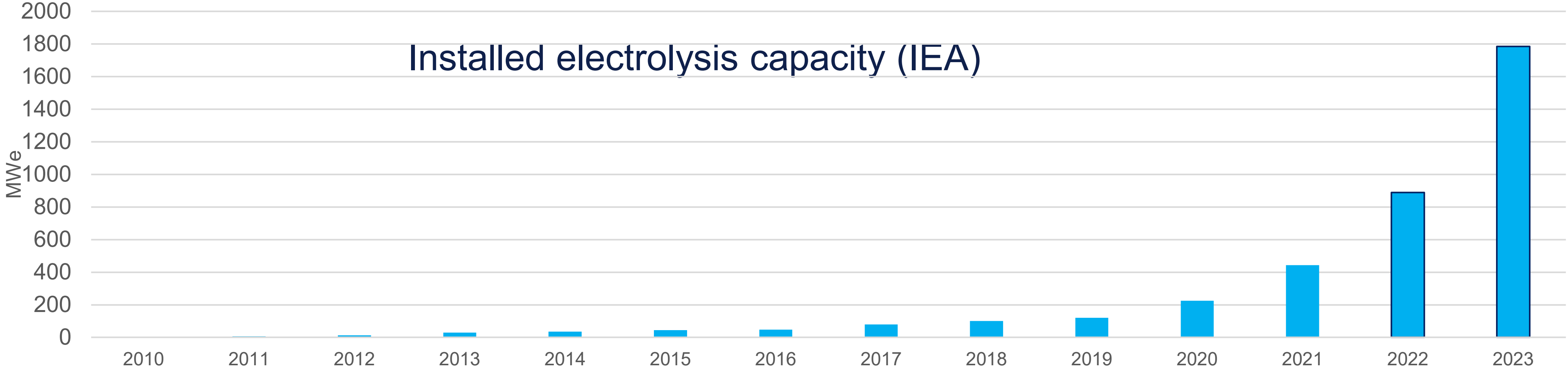
Electrolysis:

Alkaline water



Proton exchange membrane

Solid oxide



HANDBOOK FOR HYDROGEN-FUELLED VESSELS

Hydrogen - key characteristics

Availability	Currently, infrastructure and bunkering facilities are not developed. Hydrogen production from electrolysis is a well-known and commercially available technology suitable for local production of hydrogen, e.g. in port as long as an adequate supply of electricity is available. This would eliminate the need for long-distance distribution infrastructure. In the future, liquid hydrogen might be transported to ports from storage sites where hydrogen is produced from surplus renewable energy, such as wind power, whenever energy production exceeds grid demand. Hydrogen can also be produced from natural gas, which is globally available.
Storage	For use on ships, hydrogen can either be stored as a cryogenic liquid (at ~-253°C), as compressed gas (200 – 700 bar). Hydrogen storage as a liquefied gas achieves a significantly higher energy-density than that of compressed hydrogen. Due to the very low boiling point of hydrogen, super-insulated pressure vessels are used for storage in liquid (cryogenic) form. Boil-off is unavoidable, and the boil-off rate, which depends on the relationship between tank surface area and volume, can be 0.3 to 0.5 per cent per day depending on technology and conditions. A major barrier to the implementation of hydrogen as a fuel on larger ocean-going ships is its volumetric energy density, which is much less than that of LNG.
Application	Fuel cells is considered the key technology for hydrogen, however, other applications are also under consideration, including gas turbines and internal combustion engines in stand-alone operation or in arrangements incorporating fuel cells. The first major hydrogen-fueled ferry is set to enter operation in 2021 with low-temperature PEMFCs.
Technological maturity	Currently, the usage of hydrogen as fuel for ships has been restricted to large-scale piloting. Developments are, however, fast-paced with a hydrogen-fuelled ferry with capacity of 299 passengers set to enter operation in Norway in 2021. In the past, hydrogen has been used as a fuel for fuel cells in niche applications such as for some submarines. Developments of hydrogen-fuelled vessels has so far favoured its use in PEMFCs, with its application in other fuel cells and in ICEs at a less mature stage.
Environmental performance	Electro-, bio-, or fossil-based hydrogen may be produced environmental-friendly in different ways. Notably, current development initiatives explore hydrogen production from natural gas while safely capturing and storing the resulting CO_2 (CCS). Hydrogen used in fuel cells as energy converters does not produce any CO_2 emissions and could eliminate NOx, SOx and particulate matter (PM) emissions from ships, resulting in zero-emission. Hydrogen-fuelled internal combustion engines for marine applications could also minimize greenhouse gas (GHG) emissions, while NOx emissions cannot be avoided when using combustion engines.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Overview of possible marine fuels

- LNG
- LPG
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- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear/CCS

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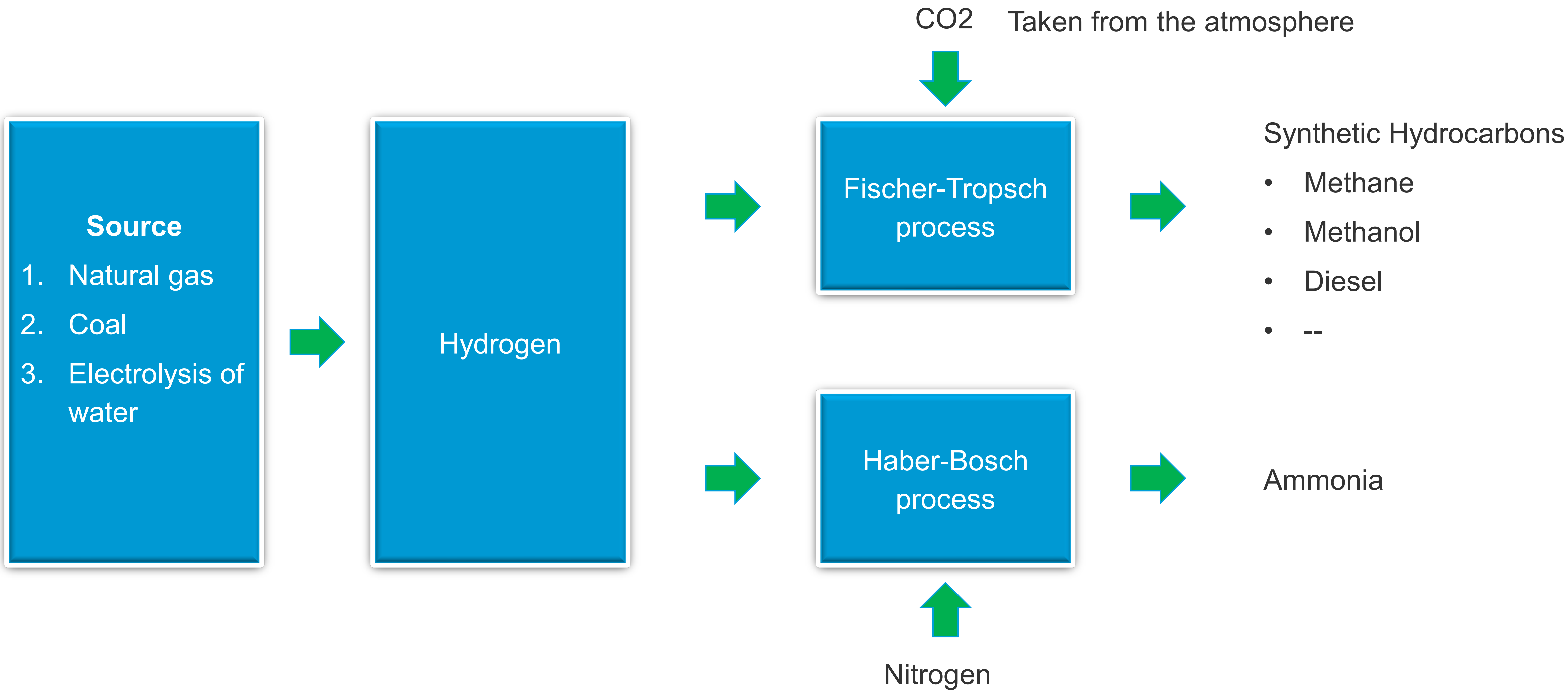
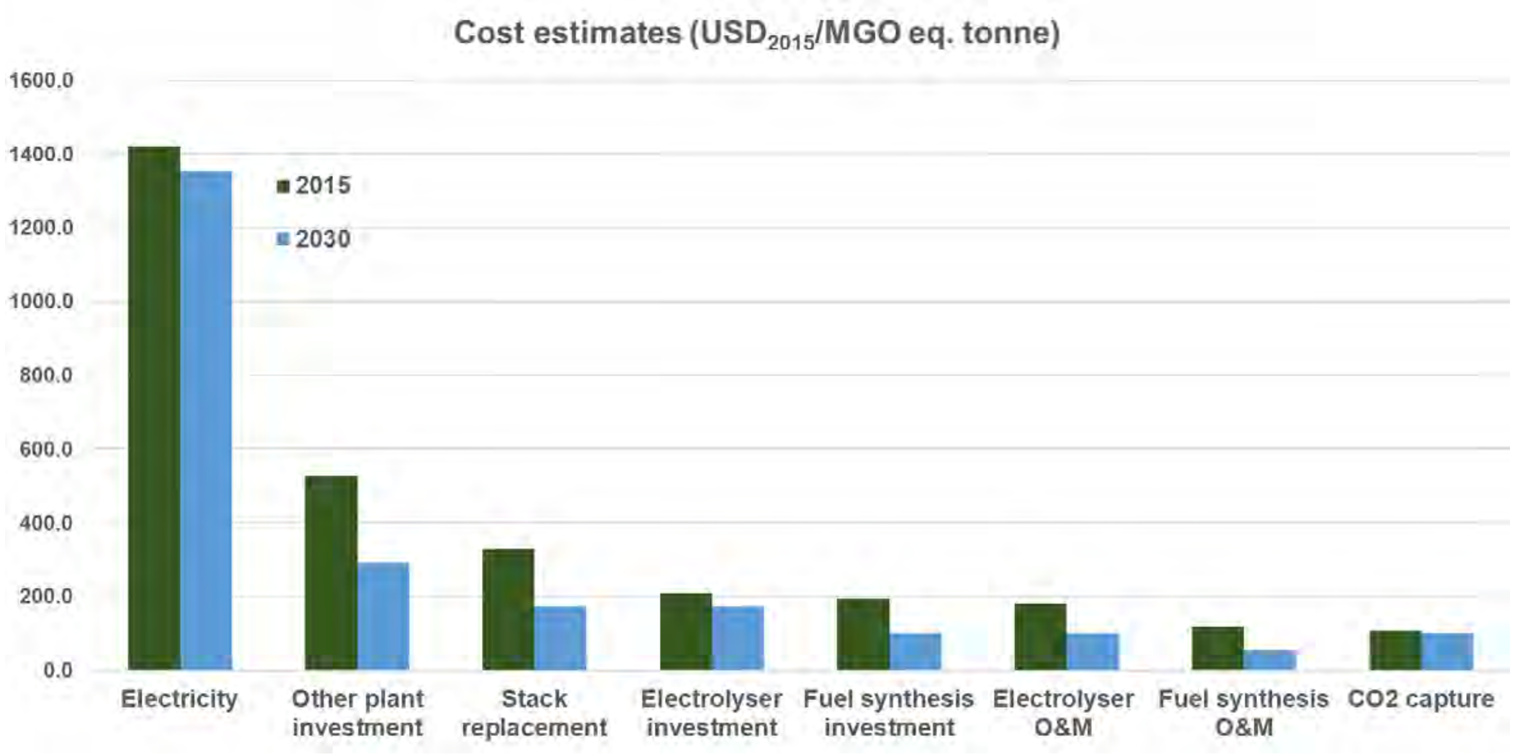
Hydrogen – a stepping stone to Synthetic Fuel



Cost and emission from electrofuel production

Literature overview of cost:



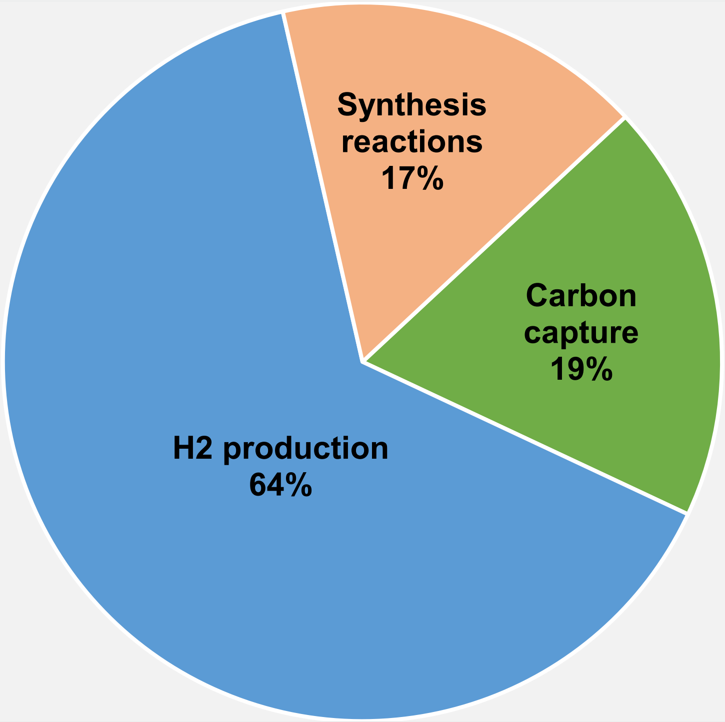
adapted from Brynolf *et al.* (2018)

Literature shows…

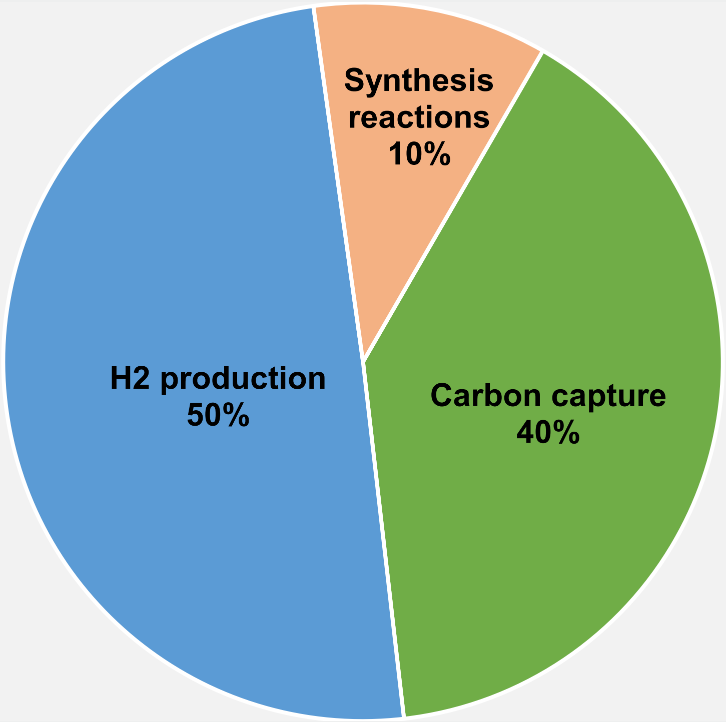
- Cost of electrofuels declining fast driven by reduction in renewable electricity cost
- Electrofuel production costs (USD/MGO eq. tonne) to be 2640–3720 for 2015 and 2110–2760 for 2030
- Audi claimed in 2015 to produce e–diesel that can be sold at 1264–1896 USD/MGO eq. tonne in Germany

Cost and emission from electrofuel production

Cost distribution: Total

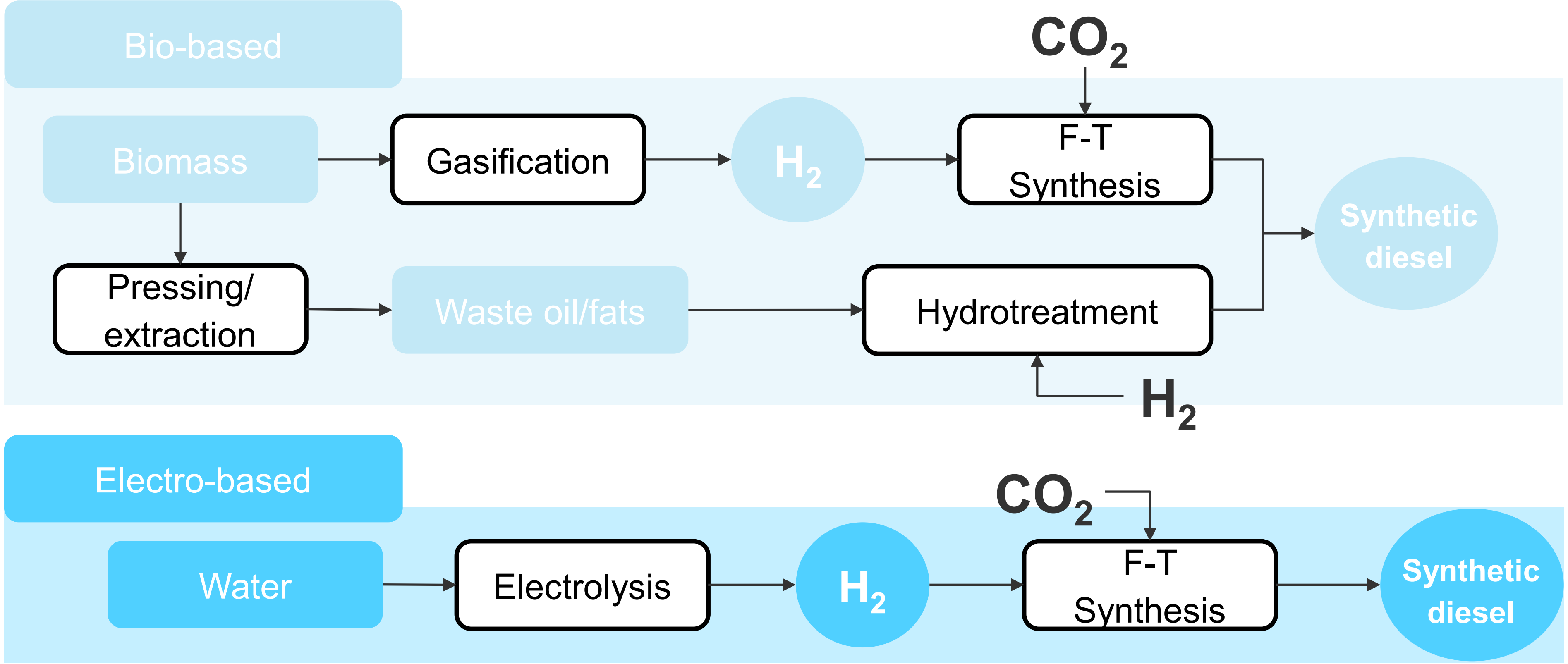


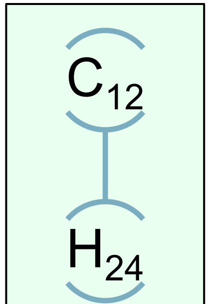
Capital expenditures of the plant



Operational expenditures of the plant

Synthetic diesel – production pathways



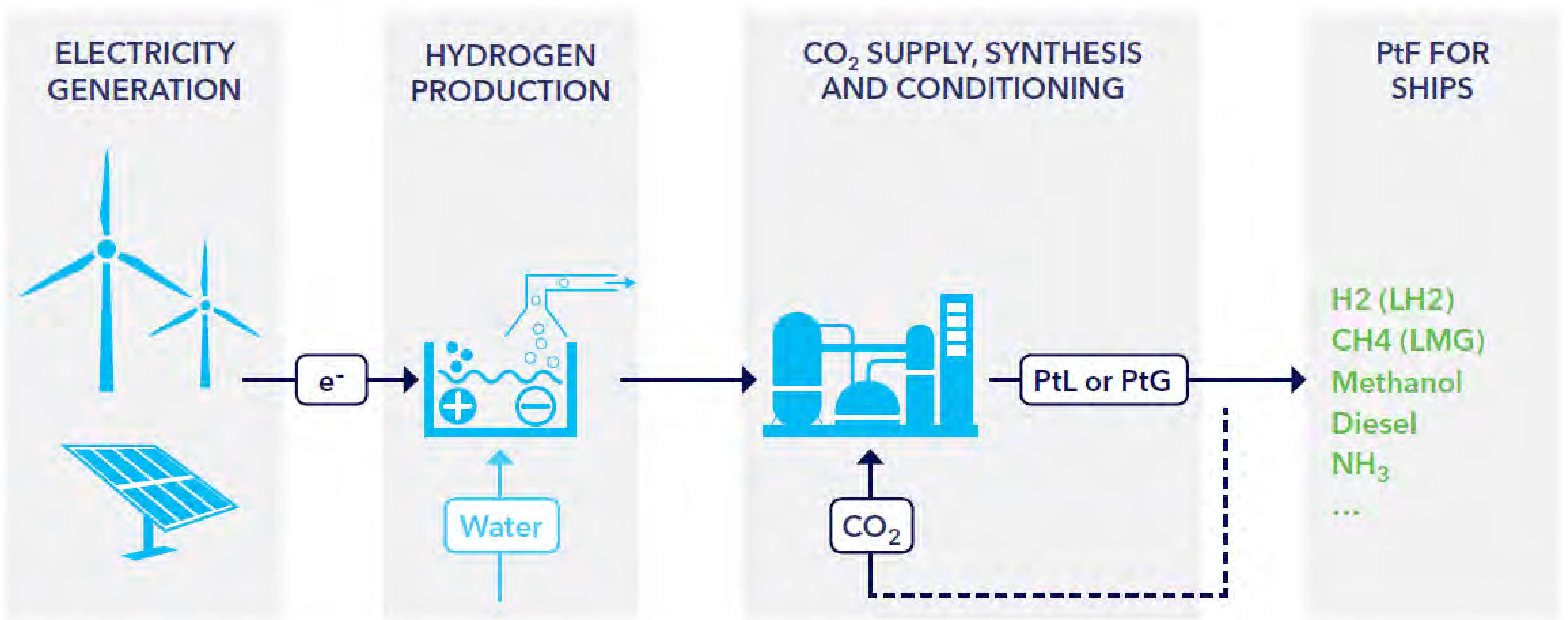


Possible diesel molecular formula

General

Synthetic diesel has two primary production pathways, bio-based or electro-based. Using biomass, synthetic diesel may be produced in different ways including hydrotreatment of waste oils and fats (known as hydrotreated vegetable oil) or from Fischer-Tropsch synthesis using hydrogen produced from gasification of biomass. As implied by its name, synthetic diesel is a hydrocarbon with equivalent properties to those of fossil-based conventional diesel.

How will e-fuels be produced in the future?



Most energy needed to produce large hydrocarbons

Most effective production for H_2, ammonia, methanol, LNG

Synthetic diesel - key characteristics

Availability	Synthetic diesel may be distributed using existing infrastructure in place for MGO or HFO. Unlike MGO and HFO, the current production of synthetic diesel is very limited. Bio-based synthetic diesel (more specifically hydrotreated vegetable oil (HVO)), is by far the largest production-pathway for synthetic diesel, and its production amounted to the equivalent of 5.8 Mtoe. When considering that the total consumption of marine fuel was at the level of approximately 274 Mtoe in 2018, a massive production-upscale is needed if synthetic diesel is to play a significant role in the future marine fuel-mix.
Storage	Synthetic diesel is, similarly to conventional diesel, stored as a liquid in standard tanks.
Application	Synthetic diesel may be applied on board ships compatible with HFO or MGO. This includes various slow-, medium-, and high-speed engines.
Technological maturity	The technical maturity of on board propulsion and energy storage systems for synthetic diesel is very high, owing to the fact that it is compatible with existing systems designed for use with MGO or HFO.
Environmental performance	The GHG reduction potentials for synthetic diesel is largely dependent on the production-pathway. For electro-based synthetic fuels, carbon-neutrality is possible assuming that renewable electricity is used for hydrogen production. For bio-based synthetic diesel, carbon neutrality is possible because biomass is derived from feedstock which absorbs CO_2 from the atmosphere when growing. However, in practice, taking a lifecycle approach, carbon-neutrality will depend on the type of biomass used for production of synthetic diesel. SOx emissions are virtually extinguished when using synthetic diesel as a marine fuel, the fuel contains little (if any) sulphur. NOx emission will inherently still be present due to the use of ICEs for propulsion.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Overview of possible marine fuels

- LNG
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- Biofuels
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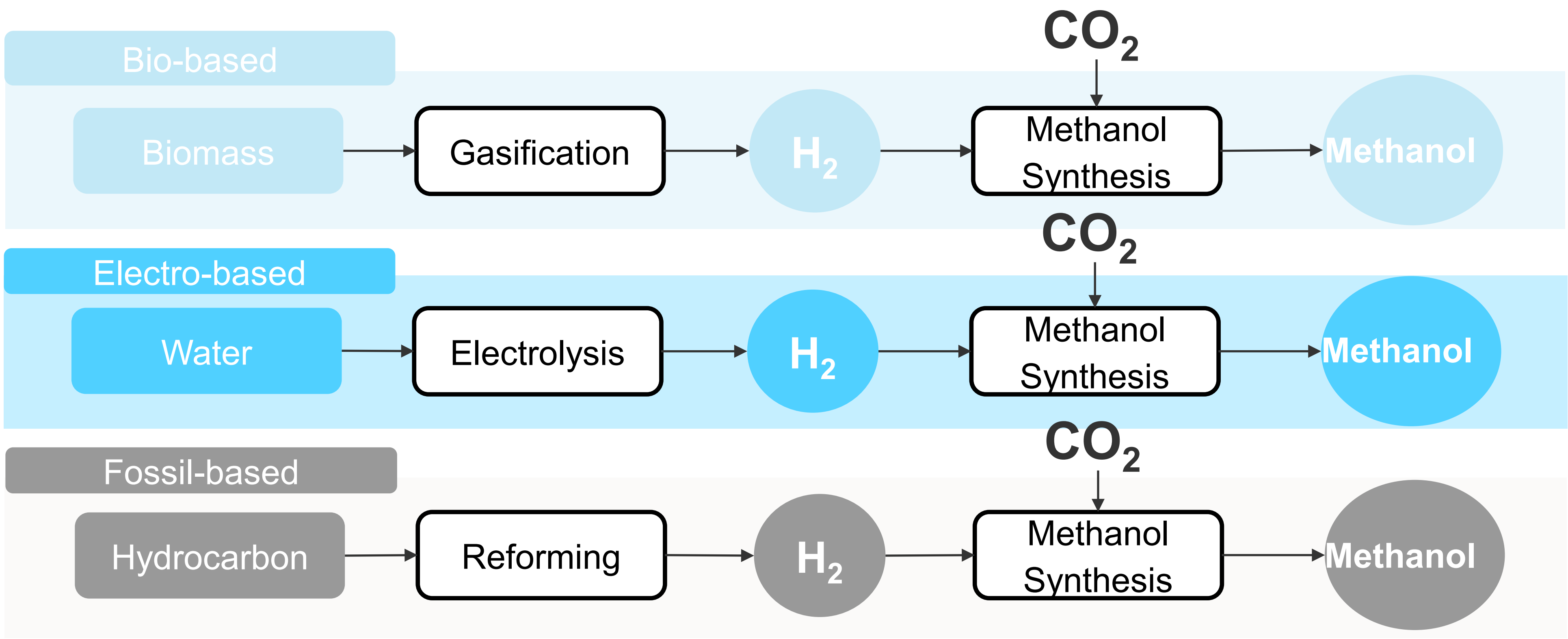
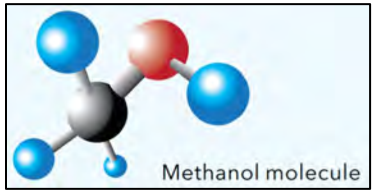
Methanol as a fuel

- Methanol is the simplest hydrocarbon
- Can be produced as
  - bio-methanol
  - e-methanol
- Much easier/cheaper to produce than any other hydrocarbon
- Easy to handle
- Infrastructure easy to adapt
- HOWEVER: Green methanol not readily available today

Methanol – production pathways





General

With its chemical structure CH_3OH, methanol is the simplest alcohol with the lowest carbon content and highest hydrogen content of any liquid fuel. Methanol is a basic building block for hundreds of essential chemical commodities and is also used as a fuel for transport. It can be produced in three primary ways, from biomass, hydrocarbons, or electrolysis of water. In each case, a source of CO_2 is required for methanol synthesis.

Methanol fuel – key properties vs mitigation measures

Key properties	Mitigation measures	
Liquid mode	Relatively easy for storage onboard and engine tech	
Low flash point fuel	Alternative design and approval	
Toxic, contact/inhaled	**Segregation** Protect gas fuel installation from external events	**Double barriers** Protect the ship against leakages
Vapour heave than air	**Leakage detection** Give warning and enable automatic safety actions	**Emergency shutdown** Reduce consequences of a leakage
LCV relative low	Bigger storages or more frequent bunkering	

Note: LCV – Low Calorific Value

Methanol Fuel – ICE, overview@2021-12 limited supply of engines, and no boiler yet

	2 stroke	4 stroke	Boiler – Not yet
MAN Energy Solutions Future in the making	Focus on existing size G50 and G95	Under development 2022/2024 limited types NB HP 300bar Retrofitting LP 10 bar	1st one AiP (ALFA LAVAL)
WÄRTSILÄ	*? Retrofitting?*	1st retrofitting in 2015 HP 600 bar No NB order so far Future Retrofitting?	Item more important for tankers
WIN GD	Under development 2024		
HiMSEN Propulsion System		H32DF-LM underway HP 300 bar NB 6&9 cylinders	
High speed engines ScandiNAOS AB, WEICHAI		A conversion case on pilot boat	
ANGLO BELGIAN CORPORATION We power your future CAT Marine Power		?	

Methanol - key characteristics

Availability	The global methanol demand was approximately 80 million tonnes in 2016, twice the 2006 amount. The production capacity is more than 110 million tonnes. The energy content of these 110 million tonnes is equal to approximately 55 Mtoe. Most methanol is currently consumed in Asia (more than 60 per cent of global demand), where demand has been increasing for the last few years. Methanol is one of the top five chemical commodities shipped around the world each year. It is readily available through existing global terminal infrastructure and well positioned to reliably supply the global marine industry. However, dedicated bunkering infrastructure for ships is currently limited. Distribution to ships can be accomplished either by truck or by bunker vessel.
Storage	Methanol is a liquid between –93°C and 65°C at atmospheric pressure, which entails that it is more easily stored on board ships than some other alternative fuels such as LNG. It may be stored in standard fuel tanks with minor modifications. Its volumetric energy density is, however, significantly lower than conventional fuels. Therefore, when compared to a conventional fuel like MGO, approximately twice as much volume is needed to store the same amount of energy on board ships.
Application	There are two main options for using methanol as fuel in conventional ship engines; in a two-stroke diesel-cycle engine or in a four-stroke, lean-burn Otto-cycle engine. Both options has seen real-life operation for extended periods of time on board ships, and use pilot fuel oil ignition. Another possibility would be to use methanol in fuel cells, which is in a less mature technical stage.
Technological Maturity	For the time being, only methanol-fuelled two-stroke dual fuel diesel engines, as part of the MAN ME-LGI series, is commercially available on the marine propulsion market. Wärtsilä 4-stroke engines are, however, in operation on board the passenger ferry Stena Germanica, fuelled by methanol. Use of methanol as a fuel on major ships has a relatively short track-record (first ship retrofitted in 2015), and so far it has largely been restricted to the niche market of methanol tankers.
Environmental performance	Methanol-combustion in an internal combustion engine reduces CO_2 emissions (tank-to-propeller) by approximately 10 per cent compared to oil. The exact value may differ depending on whether methanol is compared with HFO or distillate fuel. When considering the complete life cycle (well-to-tank and tank-to-propeller) including the production of the fuel from natural gas (without CCS), the total GHG emissions are equivalent to or slightly higher (in the order of 5 per cent) than the corresponding emissions of oil-based fuels. The well-to-tank emissions of bio-based or electro-based methanol have the potential to be carbon-neutral. If used along with a CCS system, fossil-based methanol also has a large potential for GHG reduction. Using methanol as a marine fuel virtually eliminates sulfur oxide emissions. It is also expected that particulate matter (PM) emissions will be significantly lower. The reduction of NOx emissions depends on the engine-technology used.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Overview of possible marine fuels

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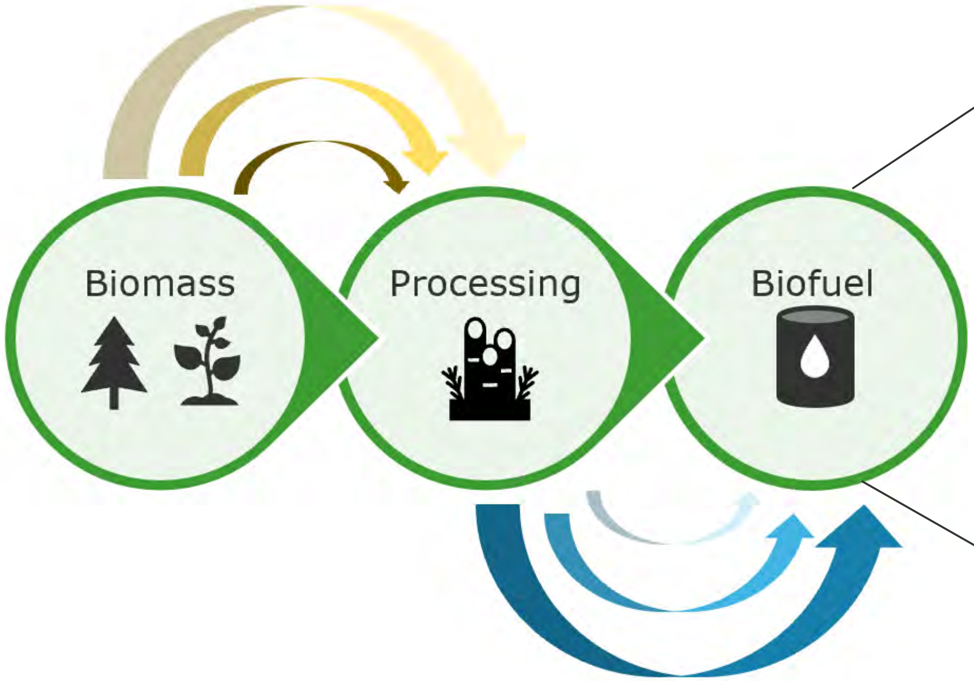
Why biofuels?

+ Potential to reduce GHG emissions
+ technical compatibility (not all)
+ high energy-density (not all)
+ sulphur-free

Carbon cycle

(simplified)

What are biofuels?



FAME

Hydrogen

LBG (Methane)

Methanol

Ethanol

DME

Ammonia

SVO

Upgraded pyrolysis oil

F-T diesel

HVO

+ more

HVO: Hydrotreated Vegetable oil
SVO: Straight Vegetable Oil
DME: Dimethyl Ether
FAME: Fatty Acid Methyl Ester
F-T diesel: Fischer-Tropsch diesel
LBG: Liquefied biogas

The term ***biofuel*** is very generic

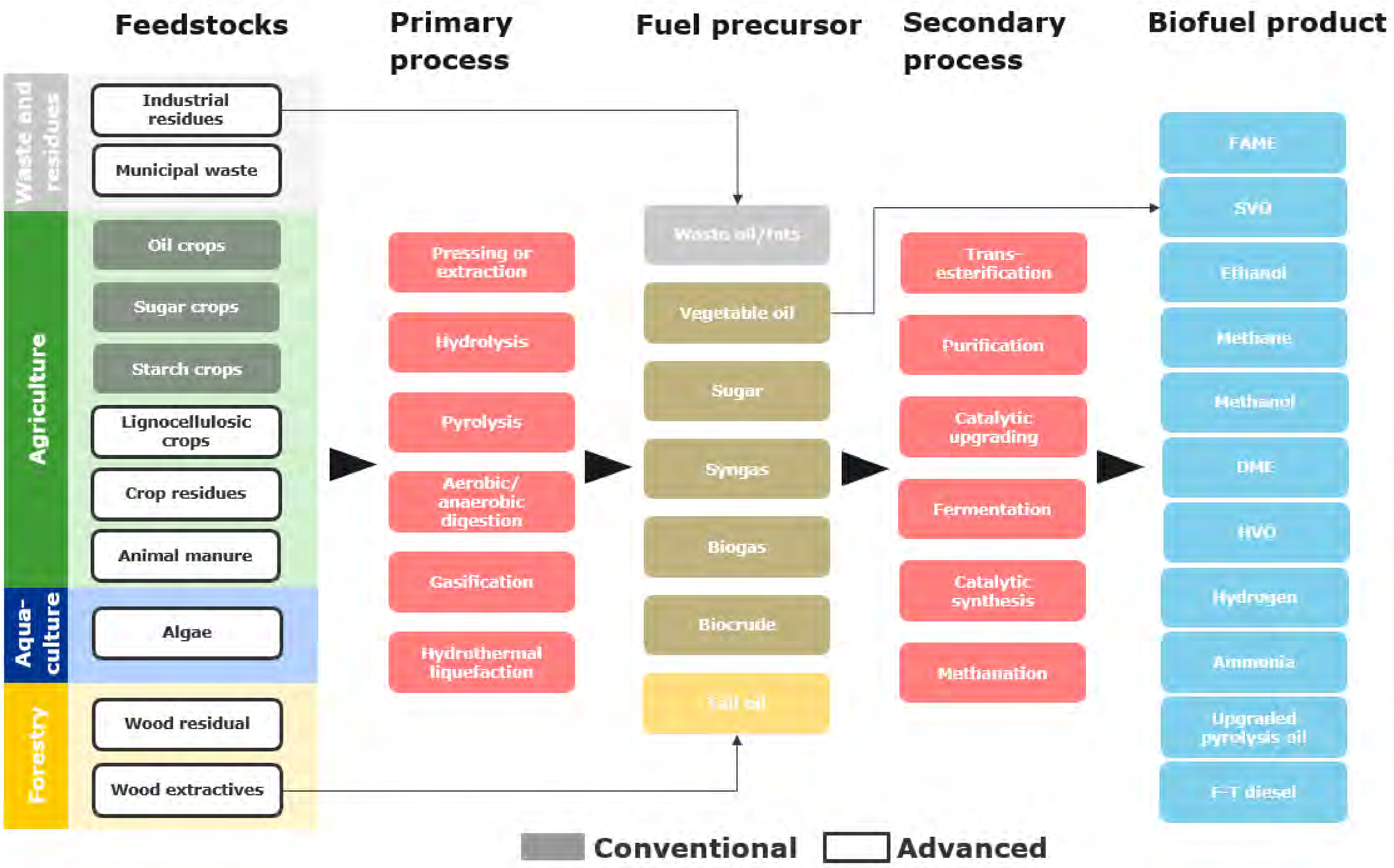
The ***biofuel family*** is very diverse

Biofuel production pathways

Biofuels are produced from **different feedstock sources**

Biofuels made from oil, sugar, and starch crops are often designated as *conventional,* contrary to *advanced* biofuels

Advanced biofuels score higher on sustainability



Sustainability

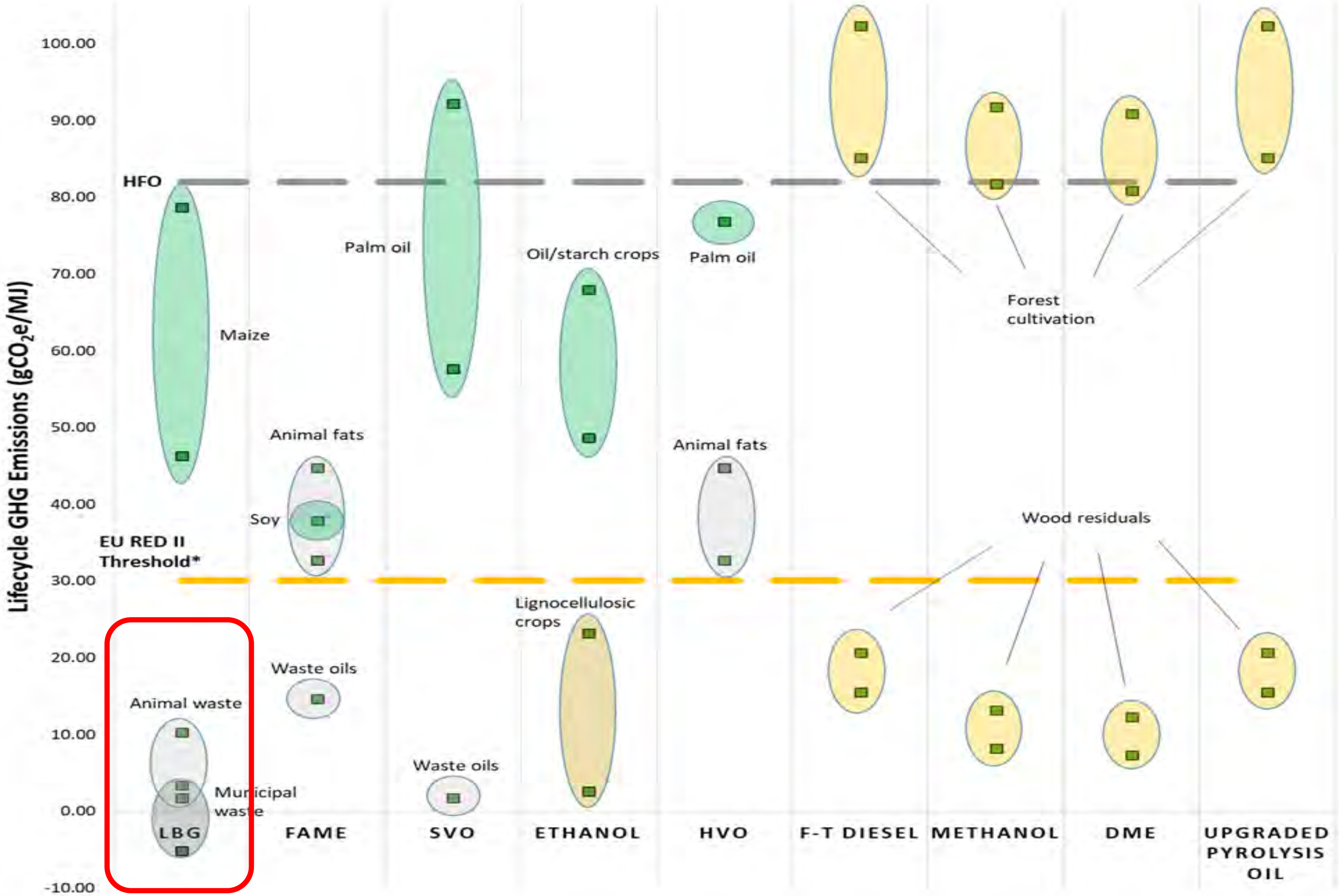
- Food vs. fuel debate
  - A rise in food-commodity prices, coincided with an upscale in biofuel production

- Land-usage change (direct & indirect)
  - Release of carbon stocks (direct)
  - Displacement of food-production (indirect)

Certification & reporting requirements for low carbon fuels

GHG emissions depend on source of biomass

Advanced biofuels have lower emissions than *conventional*



Based on data from various sources

Current production

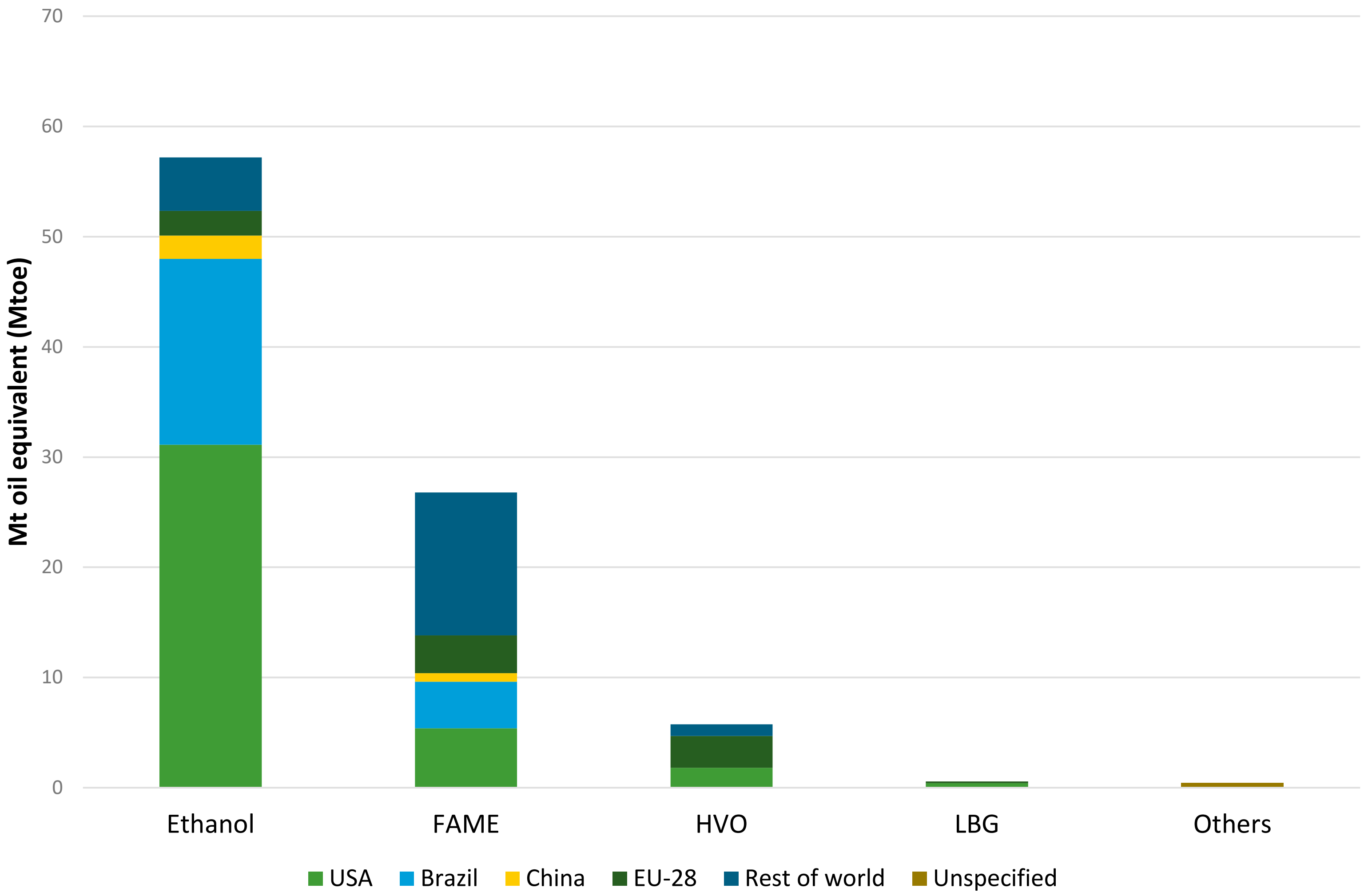
Total production in 2018:

90 Mtoe

Energy consumption of world fleet in 2018:

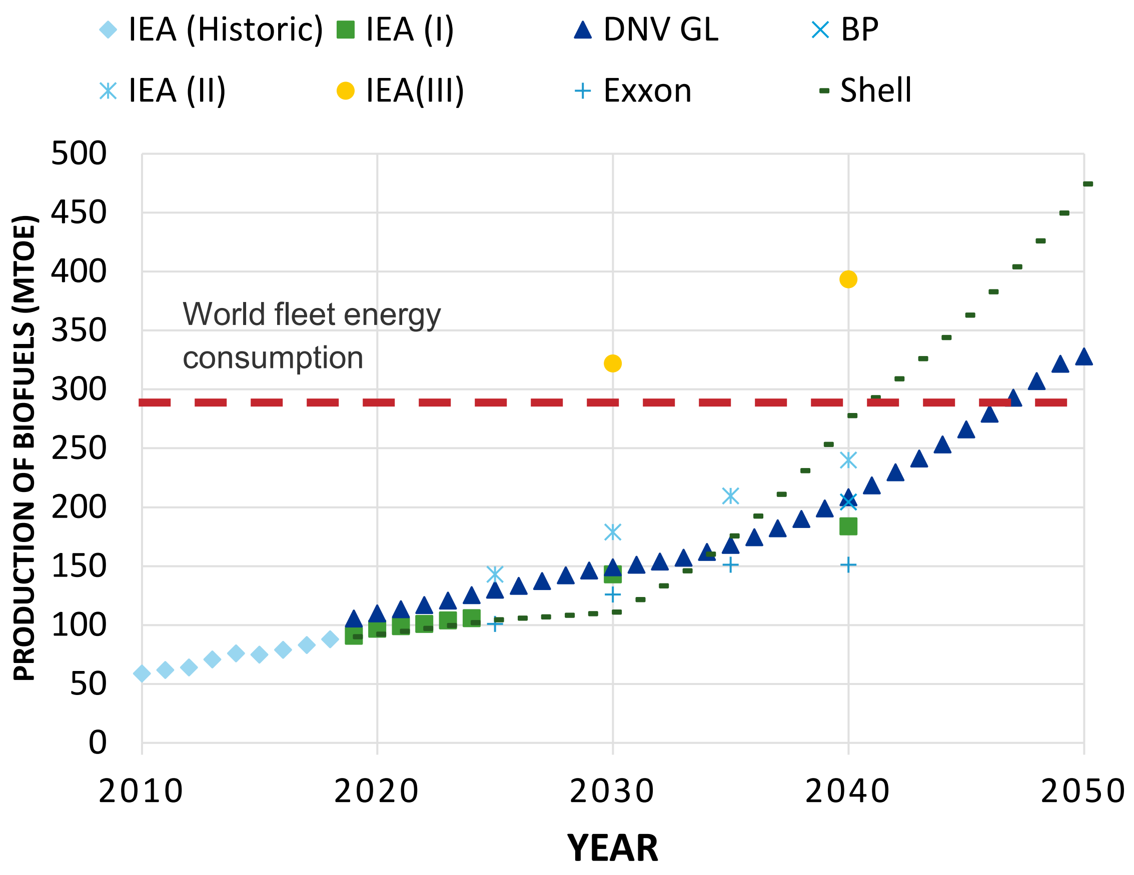
~274 Mtoe

Production of biofuels other than ethanol, FAME, and HVO is low

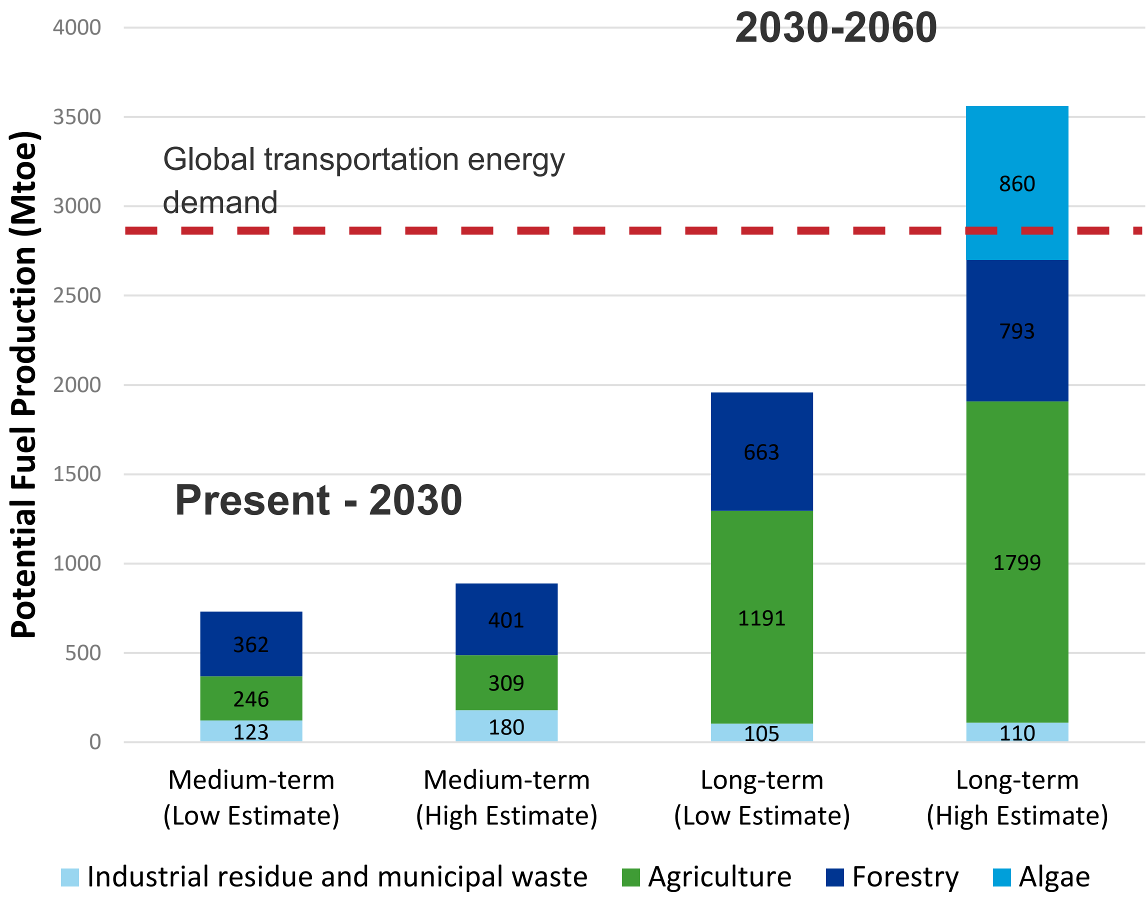


Based on data from (DNV GL, 2019) and (GSR, 2019)

Future outlook



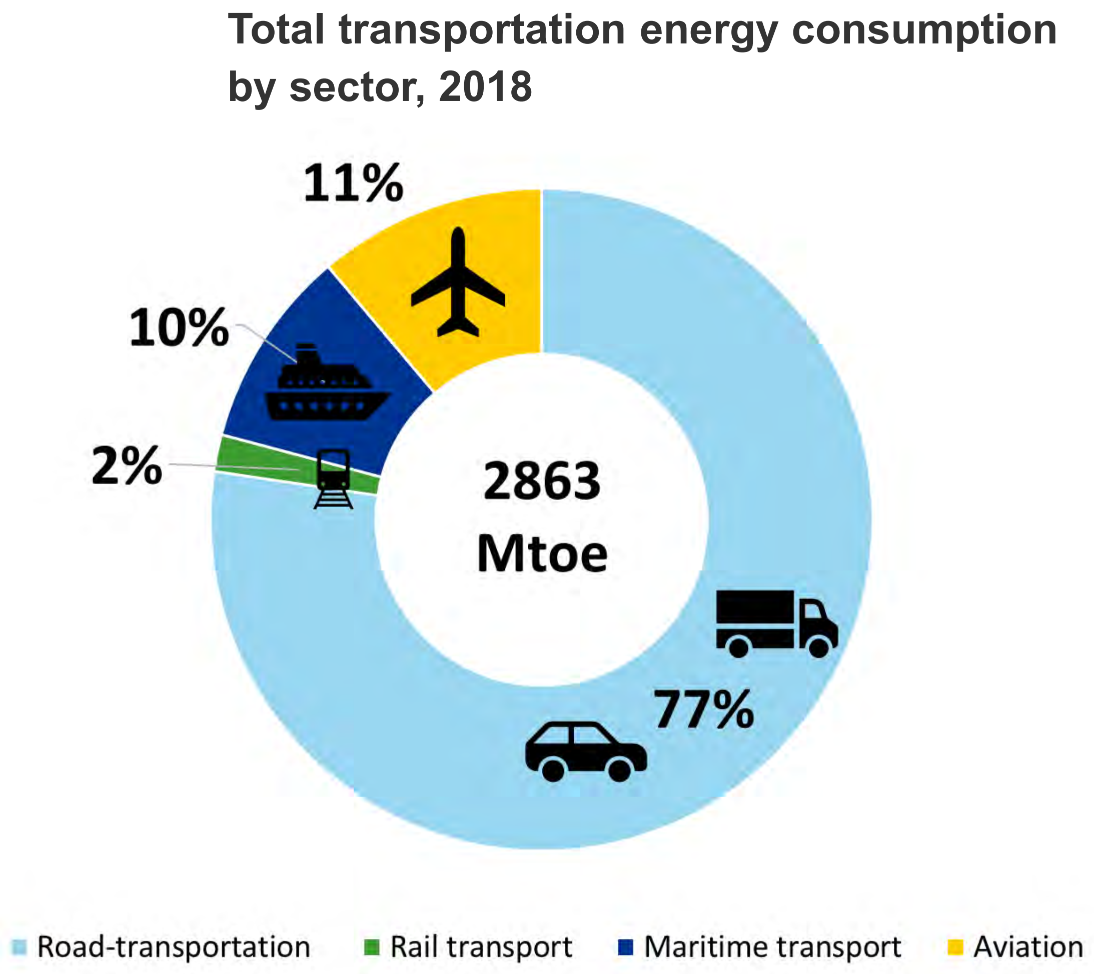
Production forecasts

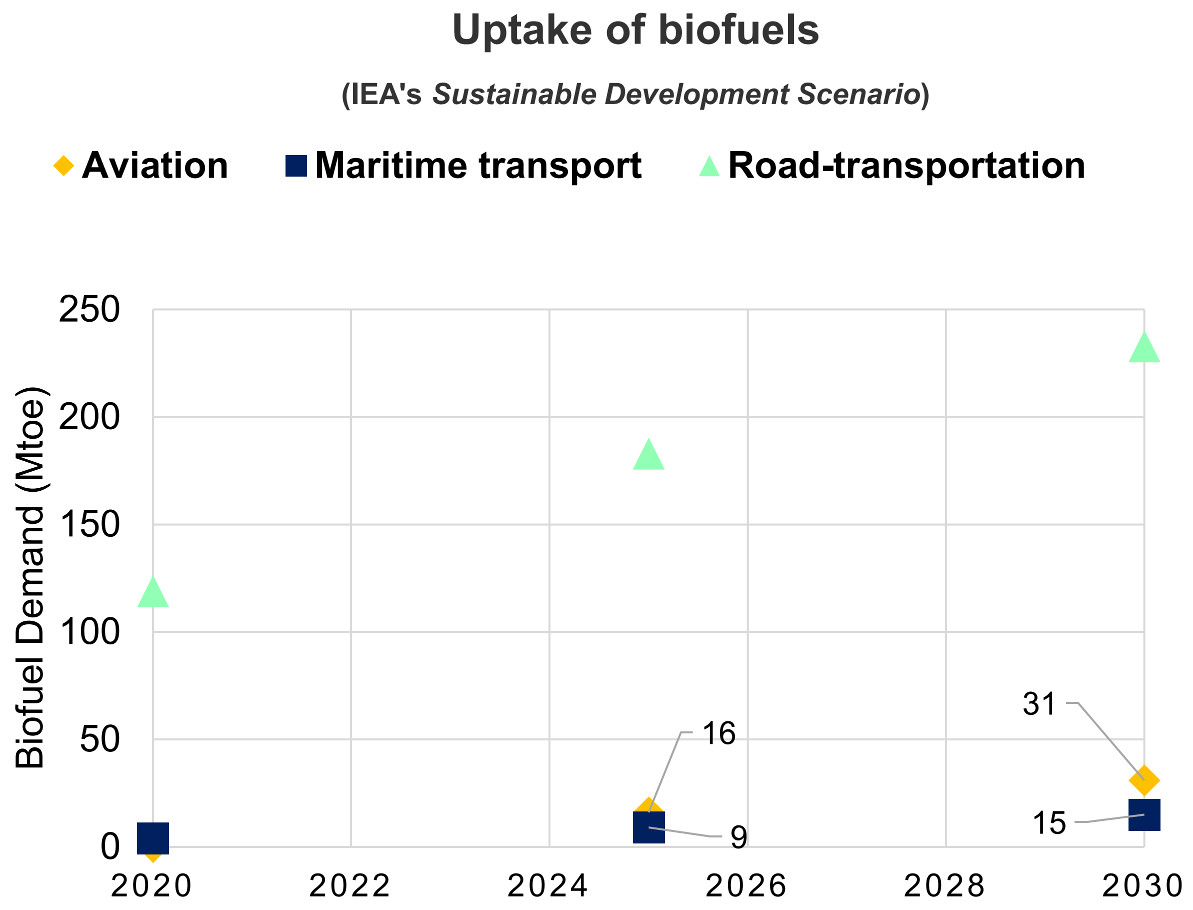


Potential production (annual)

Based on data from various sources

Competition for biofuels



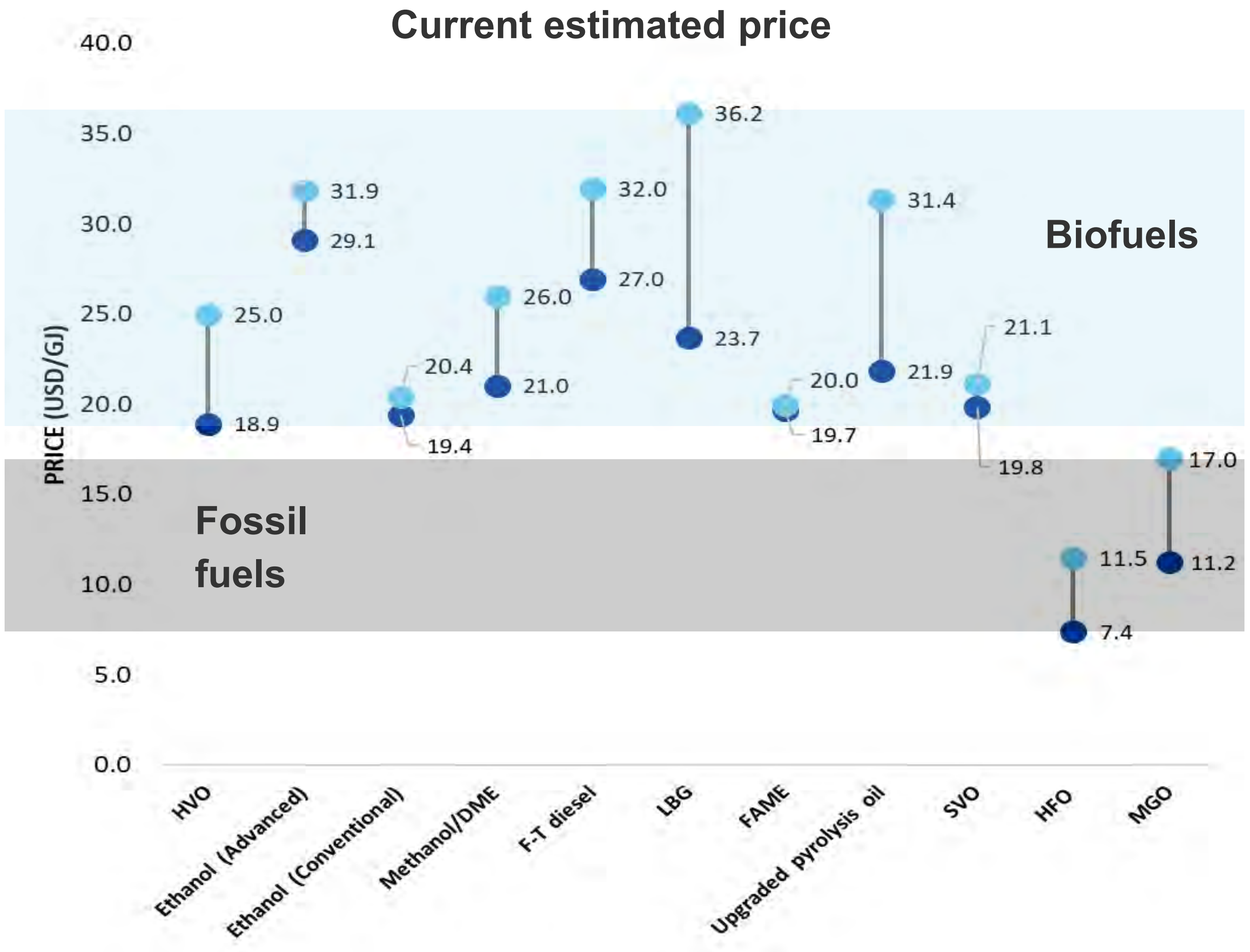


Based on data from (IEA, 2019) and (GSR, 2019)

Economics - Current

Price is a major barrier for uptake of biofuels in shipping

Some biofuels have not been produced at commercial scale yet; therefore high uncertainty in estimated costs



HFO and MGO prices are based on max/min price in Rotterdam in 2018

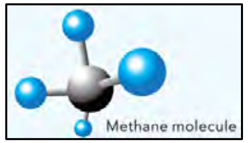
Based on data from various sources

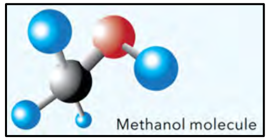
Main take-aways

1

The term *biofuel* is very generic, and sometimes misleading

- ❑ The biofuel family consists of a series of fuels, arguably more diverse than fossil fuels





2

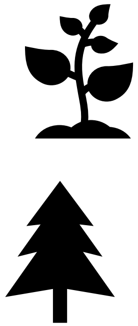
Biofuel-production will likely see strong growth in the future

- ❑ Road-transportation will likely be the main market for biofuels in the short-to-medium term, however, a growing share may be consumed by shipping

3

Source of biomass is a major determinant of biofuel lifecycle GHG emissions

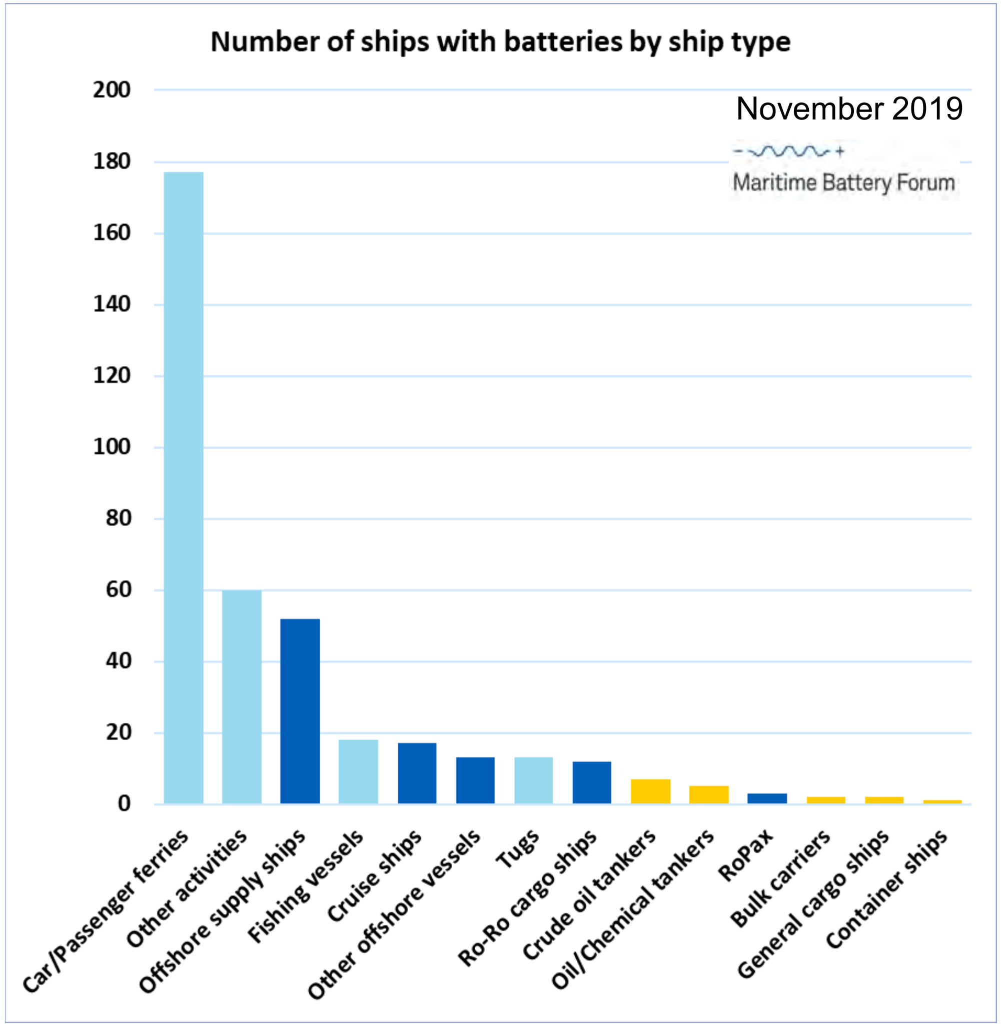
- ❑ In general, the GHG-reduction potential of conventional biofuels is lower than for advanced biofuels

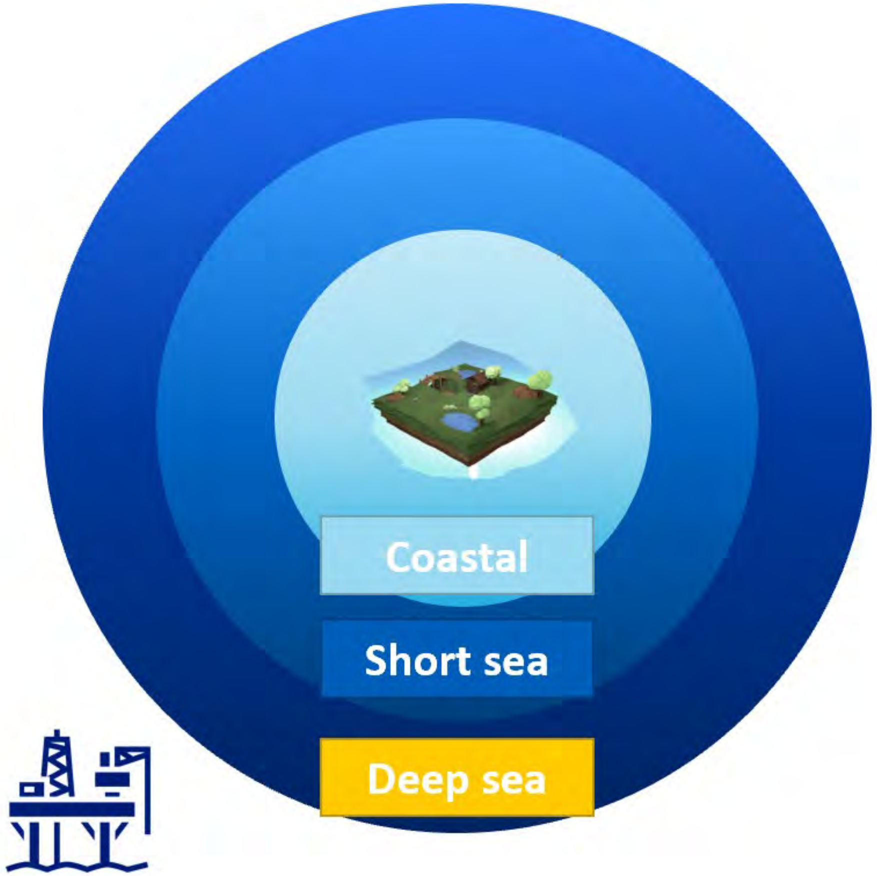


Overview of possible marine fuels

- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- E-fuels
- Methanol
- Biofuels
- Electrification
- Nuclear/CCS

Who are using batteries?





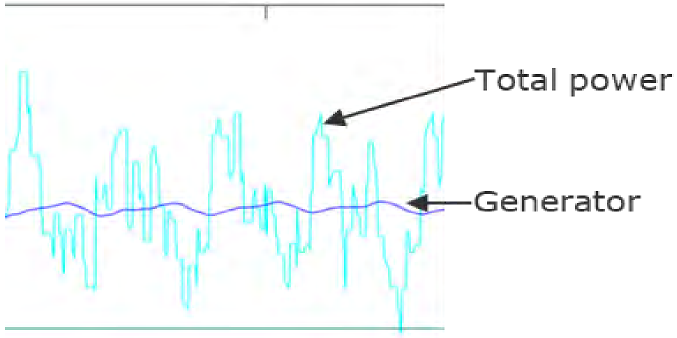
Typical hybrid cases

- **Ferries**
  - Predictable, short and fixed route. This makes them suitable for all electric operation. All electric ferries, or hybrid where the battery either provides a certain amount of energy or acts as spinning reserve or potentially peak shaving. Large ferries like Color Hybrid go all electric close and is charged at port.
- **OSV vessels, and other vessels operating in DP**
  - OSVs typically have high requirements for redundancy. Therefor they are running many generators in case of load spikes or if one generator fails. With batteries this can be avoided, saving both fuel and maintenance, and potentially CAPEX.
- **Fishing vessels**
  - Batteries are used during hauling, production, while laying still at the field and discharging at port. The batteries are charged while the vessel is in port and while the diesel engine is running.
- **Tugs**
  - Tug operation is usually short bursts of power. These power peaks can be handled by batteries resulting in smaller or fewer engines running. The running machinery can be operating at more optimal load.

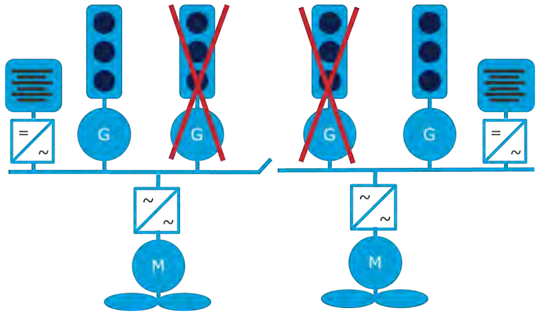
When are batteries useful?

IF | Enables | Fuel savings

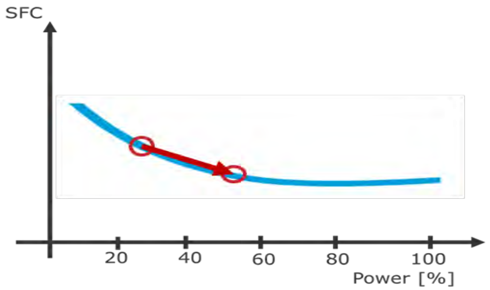
Peak shaving/load levelling



Reducing running engines



Improve machinery efficiency



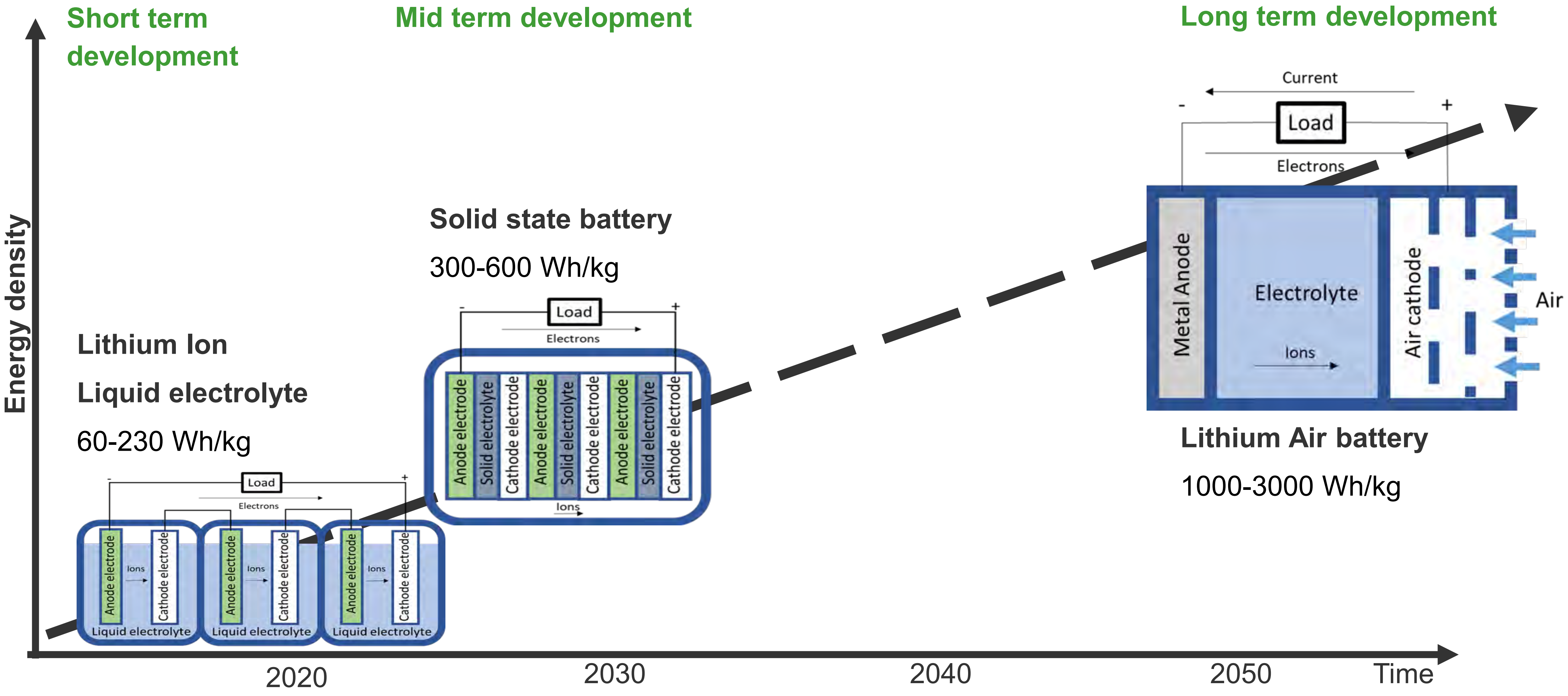
- Peak shaving alone do not have significant effect.

Need to identify operational modes with:

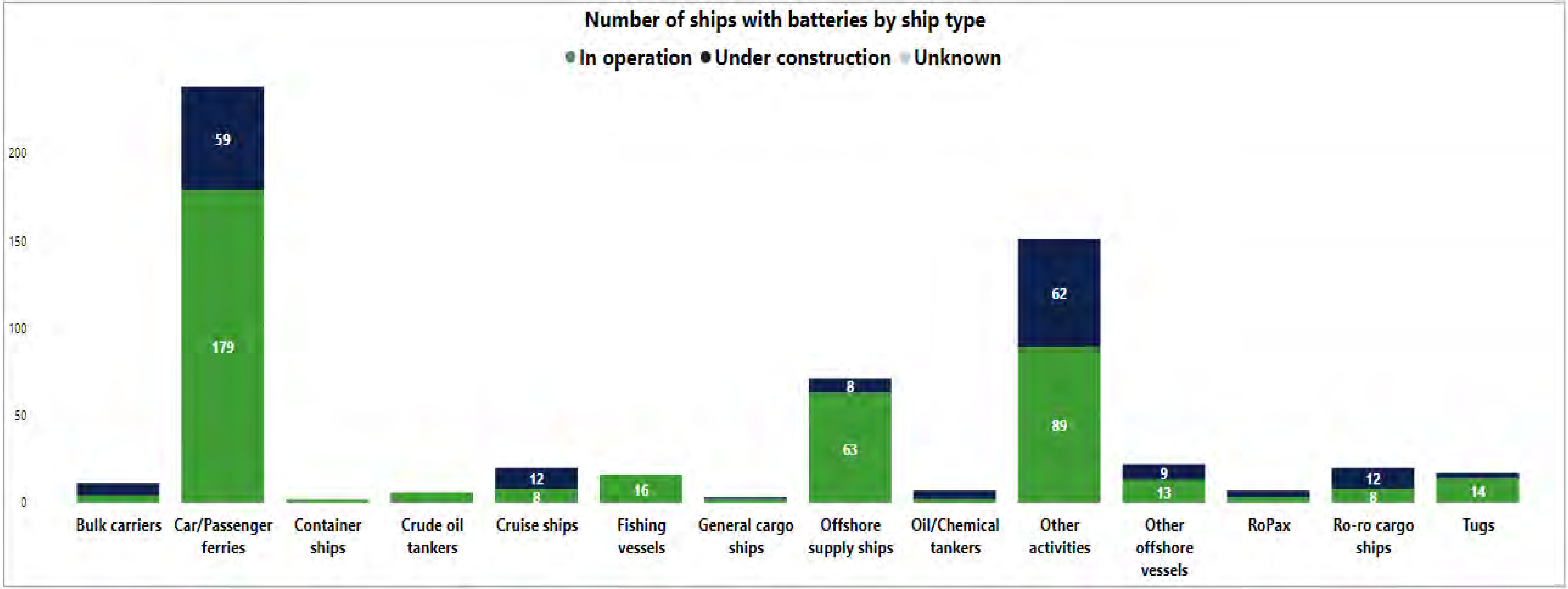
1. **Low average engine loads**
2. **High load variations**

- Other operational factors like closed bus, prioritized load reduction/shedding strategy will improve battery benefit

Roadmap for energy dense batteries



Battery installations



Source: DNV AFI – https://afi.dnv.com

Overview of possible marine fuels

- LNG
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- Nuclear/CCS

Nuclear power

Technical Developments

Extensive experience with nuclear propulsion in naval vessels

- Not commercially feasible
- Safety and security risks

Molten Salt Reactors (MSR)

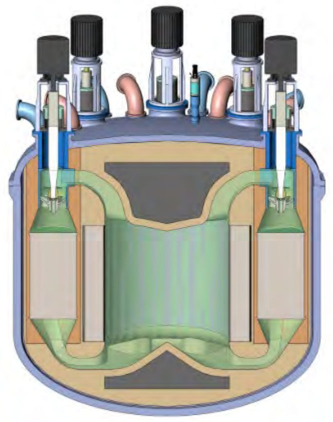
- Inherently safe technology
- Demonstrator expected by 2024 (100kW-1 MW)
- First marinized reactor by 2028-2030
- Leasing scheme to make cost competitive

Other aspects

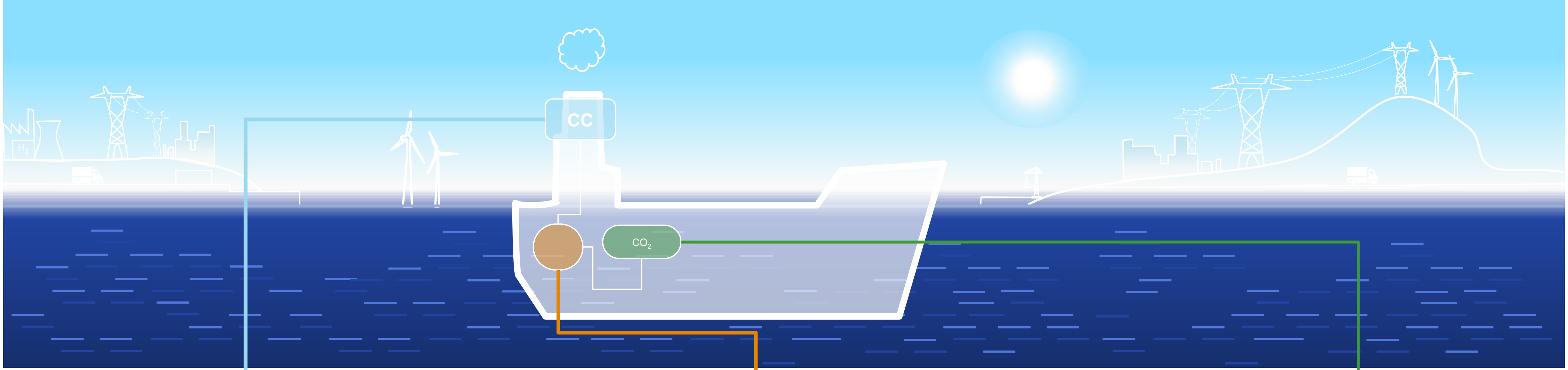
International regulations: SOLAS has to be modernized and updated

Public perception

Commercial uptake not before 2035-2040



Carbon capture: a possible solution for decarbonization in shipping?



Carbon Capture Technology

Options

Maturity

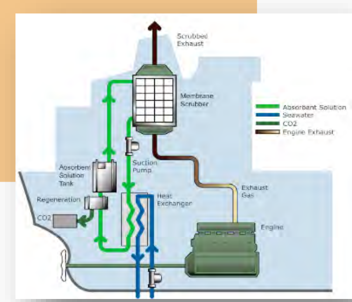
Suitability

Treatment

Feedstocks

Heat & Electricity

Safety



Storage

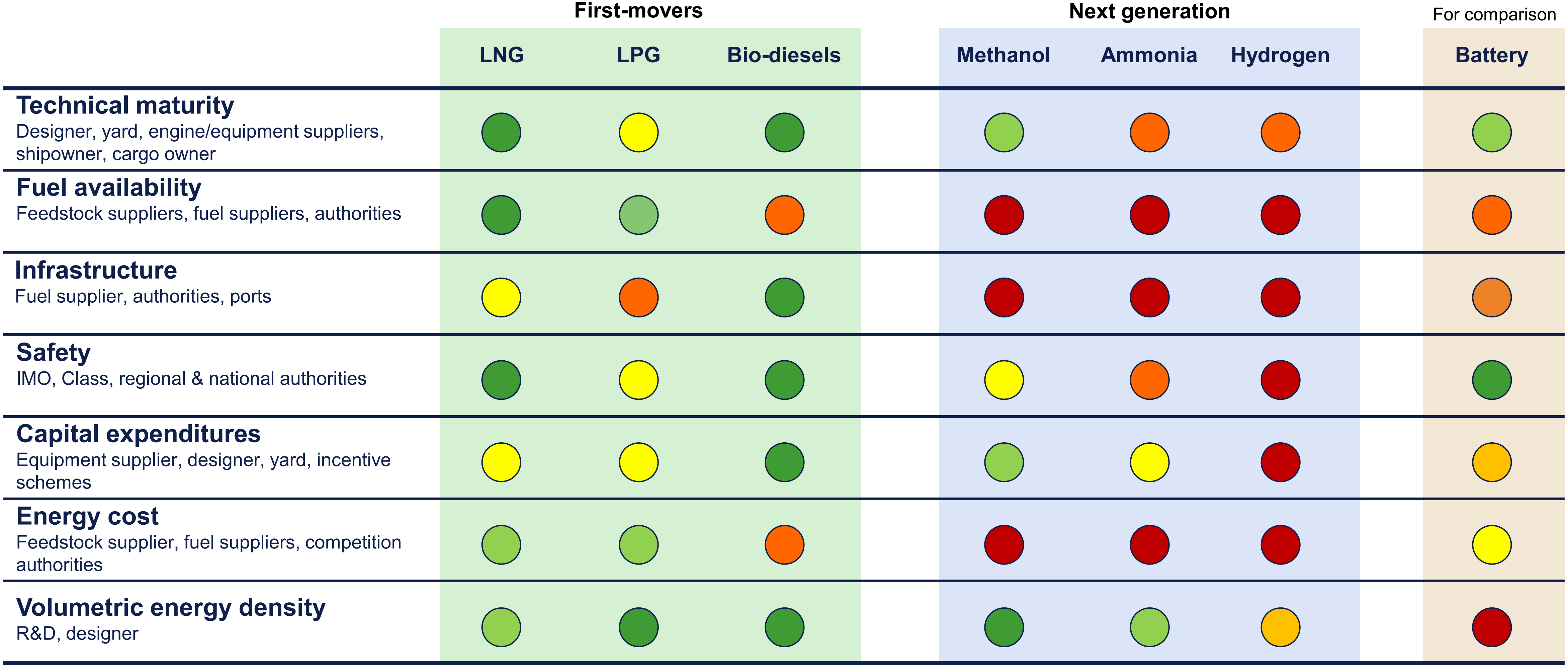
Space & Weight

Supply chain

DNV

Key consideration and strategies

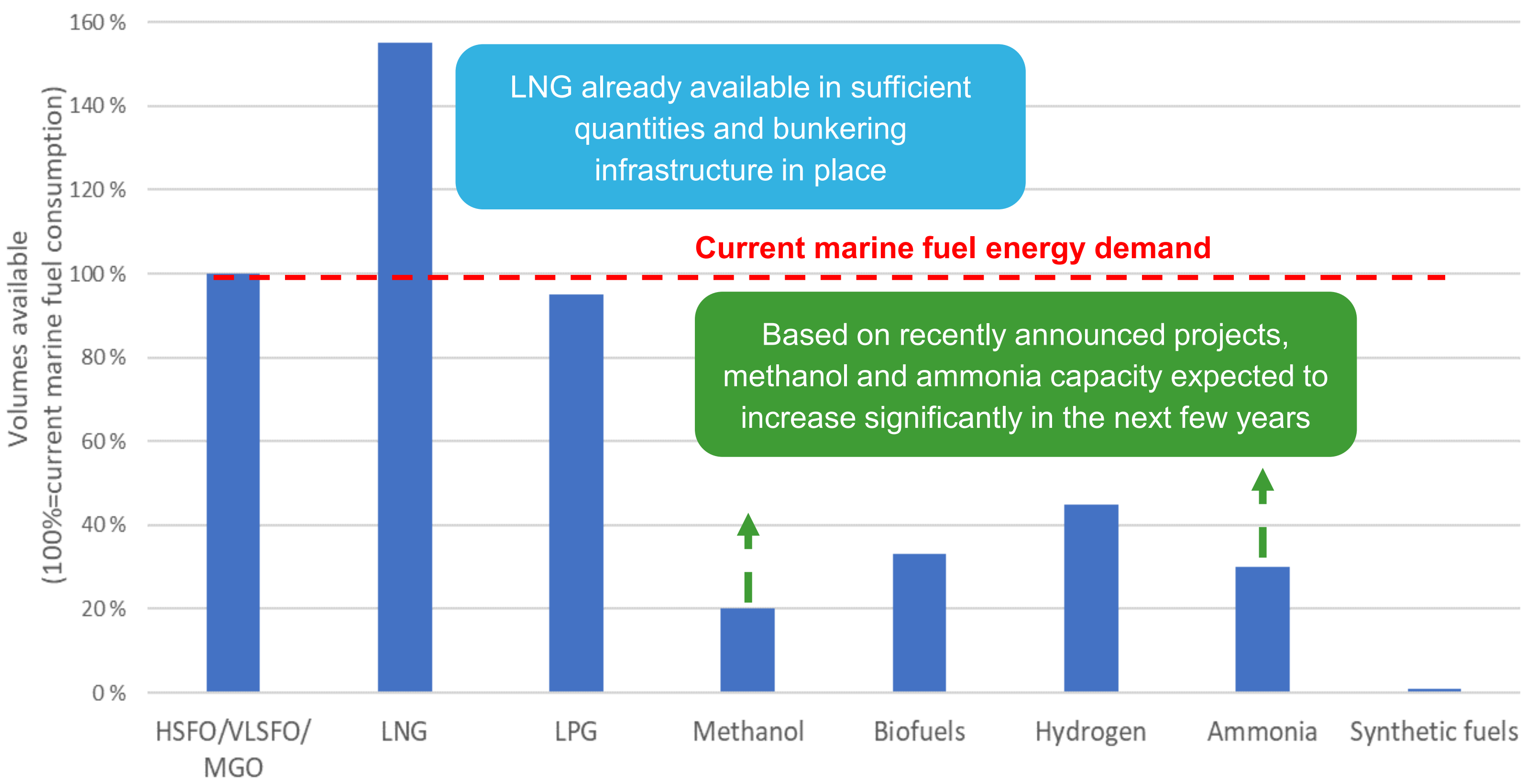
Current status of alternative fuels



Source: DNV Energy Transition Outlook

Sustainable fuel production capacities will take longer to scale

Global production of potential alternative fuels compared to marine energy demand

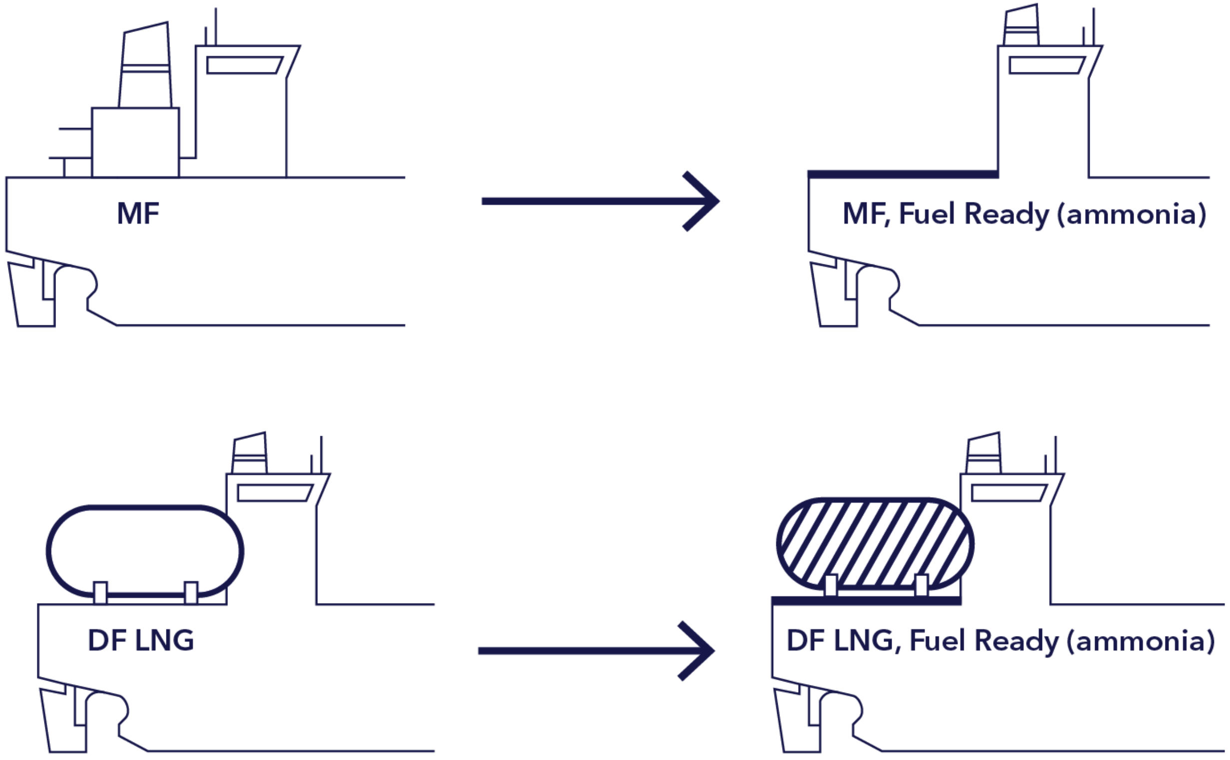


Source: DNV Energy Transition Outlook

Other than gas, no alternative fuels are today produced in volumes that make wide-spread marine adoption feasible.

- Significant new investment in methanol and ammonia capacity are expected in the 2020s.
- Growth in biofuel production is expected but is likely to be limited.

Incorporating basic measures at newbuild stage is key to accommodate fuel flexibility



Preparations for **MF, Fuel Ready (ammonia)**:

- ➢ Ensure feasibility in design including toxic zones
- ➢ Structural preparations
- ➢ Trim and stability
- ➢ Engines suitable for conversion

Preparations for **DF LNG, Fuel Ready (ammonia)**:

- ➢ LNG tanks suitable for ammonia
- ➢ Toxic zones
- ➢ Structural preparations
- ➢ Trim and stability
- ➢ Engines suitable for conversion

Dual-fuel (DF); mono-fuel (MF)

DNV Support

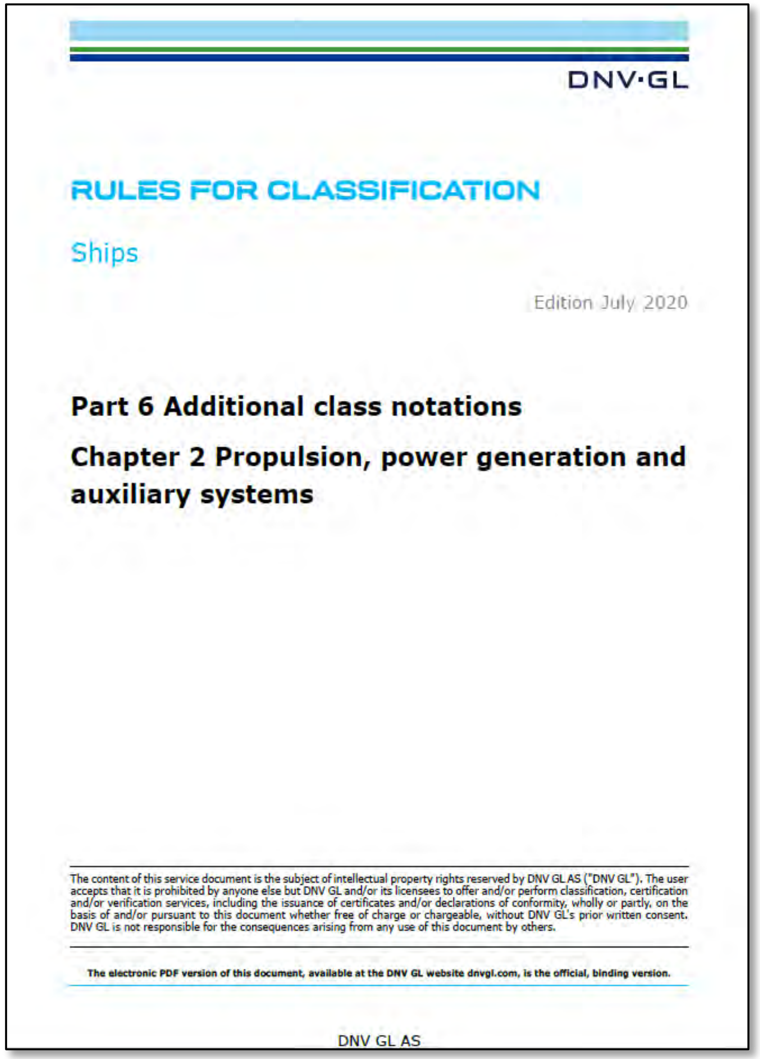
Class Rules

- LNG as fuel, LNG Ready
- LPG as fuel
- Methanol (Low Flashpoint Liquid fuels)
- Ammonia as fuel, Ammonia Ready (July 2021)
- Fuel Cells
- Batteries
- Wind Assisted Propulsion

Developing requirements

- Hydrogen

Support with Alternative Design Approach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RULES FOR CLASSIFICATION

Ships

Edition July 2020

Part 6 Additional class notations

Chapter 2 Propulsion, power generation and auxiliary systems

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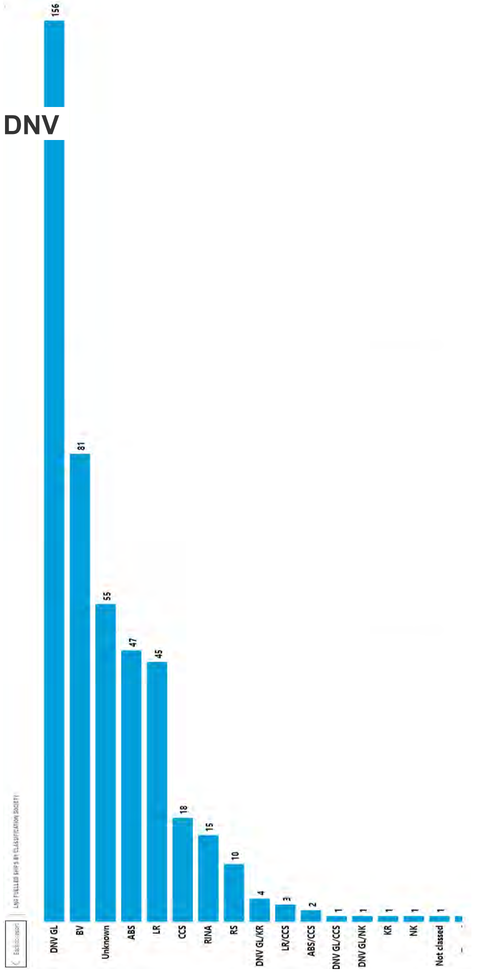
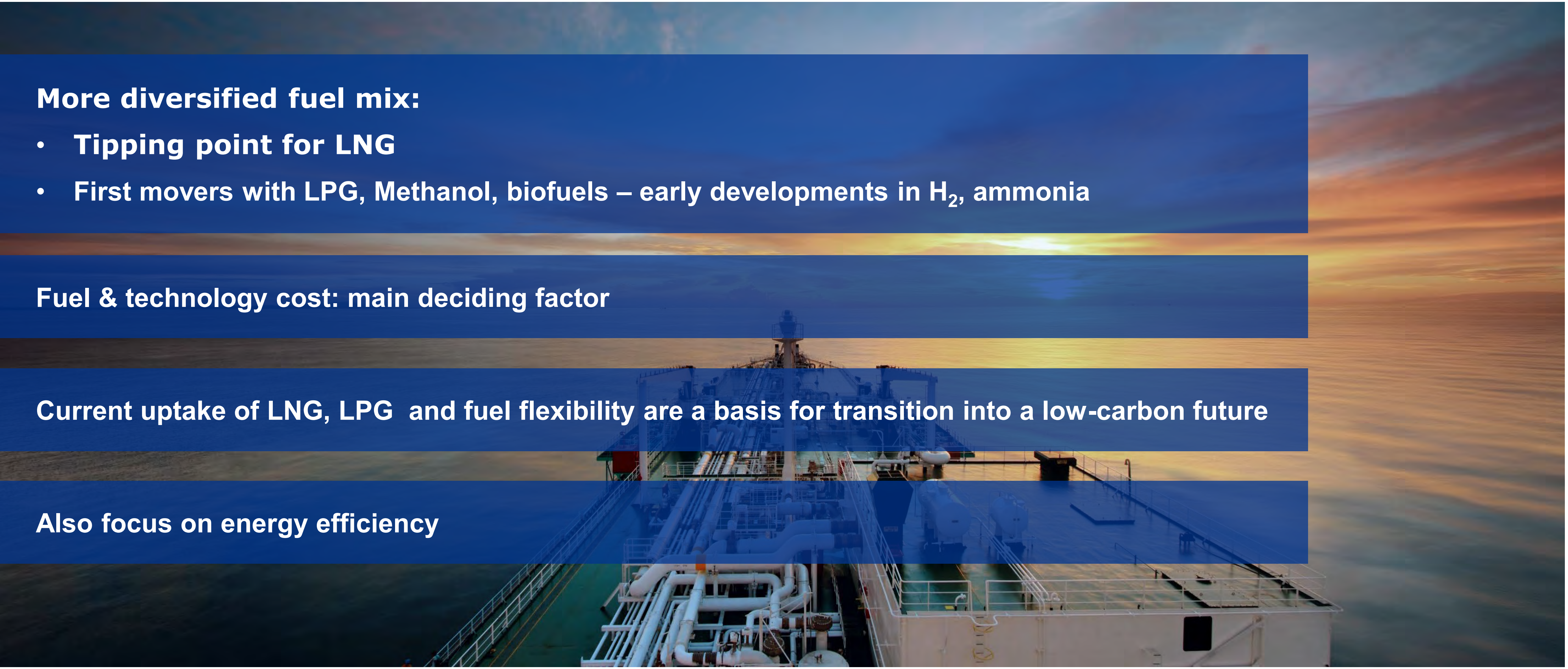
Class of LNG fuelled ships



Key takeaways



More diversified fuel mix:

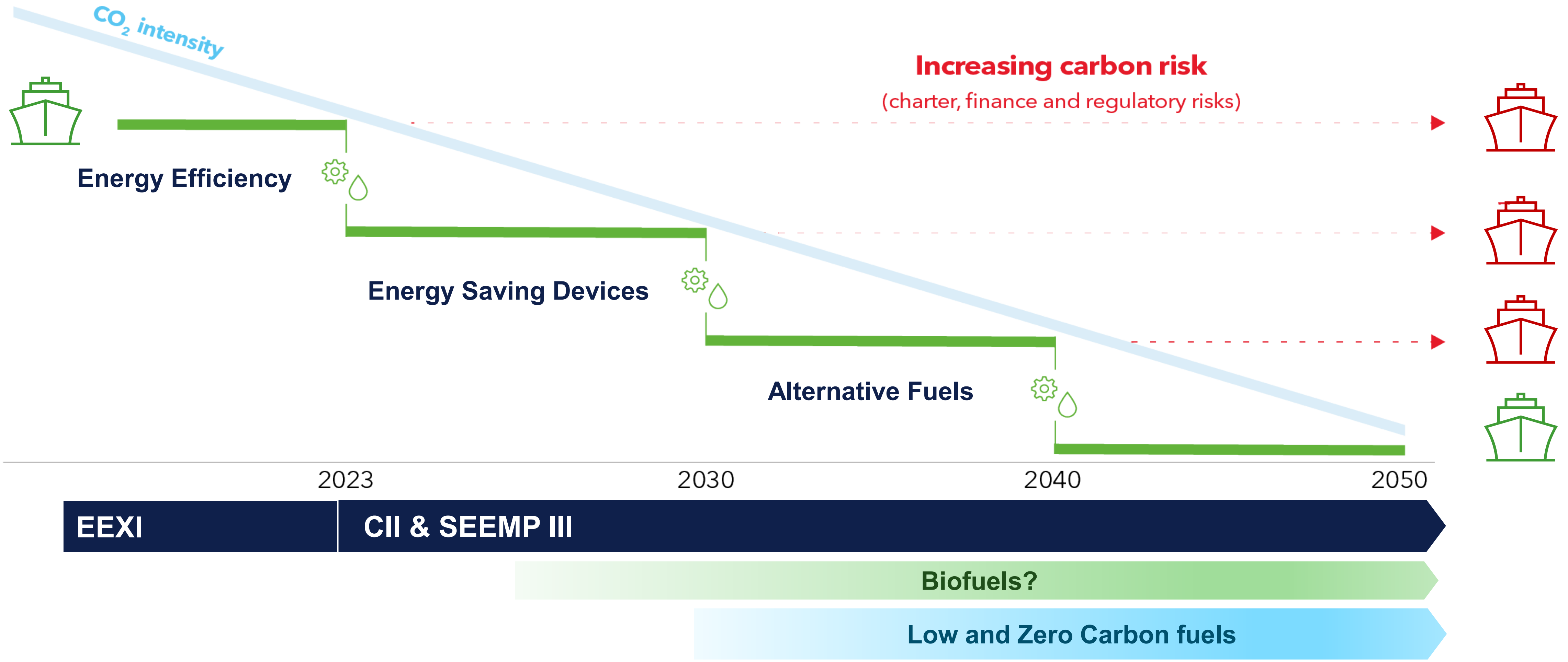
- **Tipping point for LNG**
- **First movers with LPG, Methanol, biofuels – early developments in H_2, ammonia**

Fuel & technology cost: main deciding factor

Current uptake of LNG, LPG and fuel flexibility are a basis for transition into a low-carbon future

Also focus on energy efficiency

Owners will need to navigate a ***"decarbonization stairway"*** to manage carbon risk

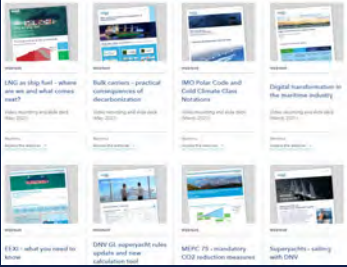


DNV resources on decarbonization, EEXI, CII, Fuels e

Webinars

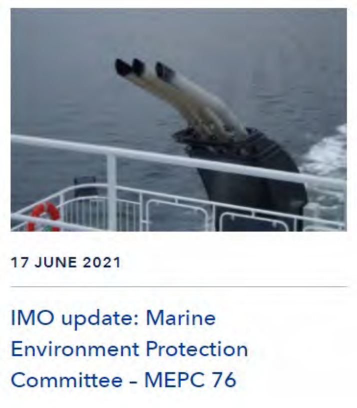
7 July 2021:
EEXI and CII calculations
(invitation will follow)

Video recordings:



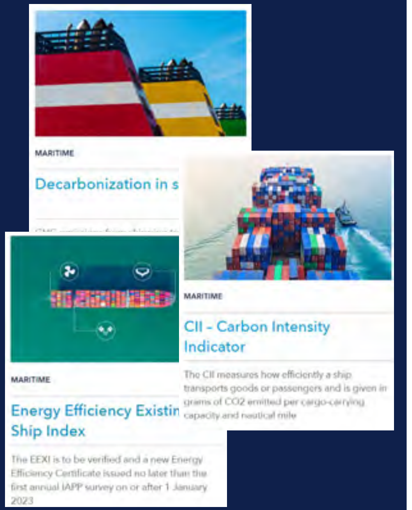
www.dnv.com/webinars

Technical & Regulatory News



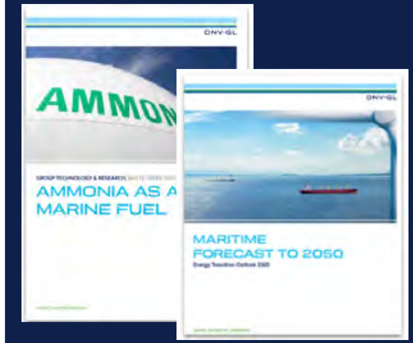
www.dnv.com/tecreg

Topic pages on dnv.com: EEXI, CII, decarb



www.dnv.com/mar-topics

Publications (decarb, alternative fuels…)

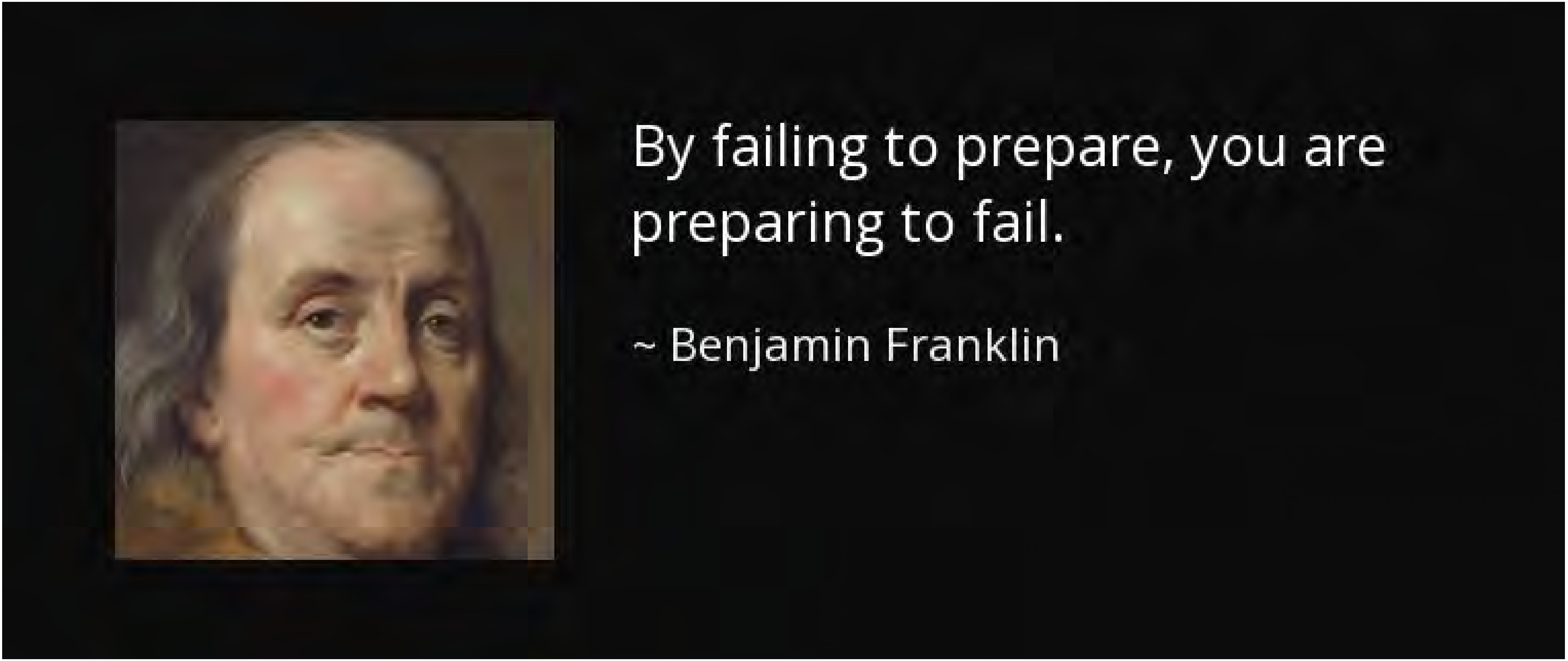


www.dnv.com/maritime/insights

Advisory services

- Decarbonization challenge
- EEXI – design compliance
- CII – operational compliance
- and more

www.dnv.com/mar-topics


By failing to prepare, you are preparing to fail.
~ Benjamin Franklin

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