MARITIME

Fuel & Technology Outlook

Maritime Energy Sources for the Future

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AGENDA

- TECHNOLOGY OPTIONS
- ALTERNATIVE FUELS
(today and tomorrow)
- ALTERNATIVE TECHNOLOGIES
- SUMMING UP

Shifting to alternative fuels is the only way to carbon-neutral shipping

LOGISTICS AND DIGITALIZATION	HYDRODYNAMICS	MACHINERY	FUELS AND ENERGY SOURCES
Speed reduction	Hull coating	Machinery improvements	LNG/LPG
Vessel utilization	Hull-form optimization	Waste heat	Electrification
Vessel size	Air lubrication	Engine de-rating	Biofuel
Alternative routes	Cleaning	Battery hybridization	Hydrogen etc.
>20%	10%-15%	5%-20%	0%-100%

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SUMMING UP

What are the realistic alternative fuels and technologies to come?

MGO / Distillates

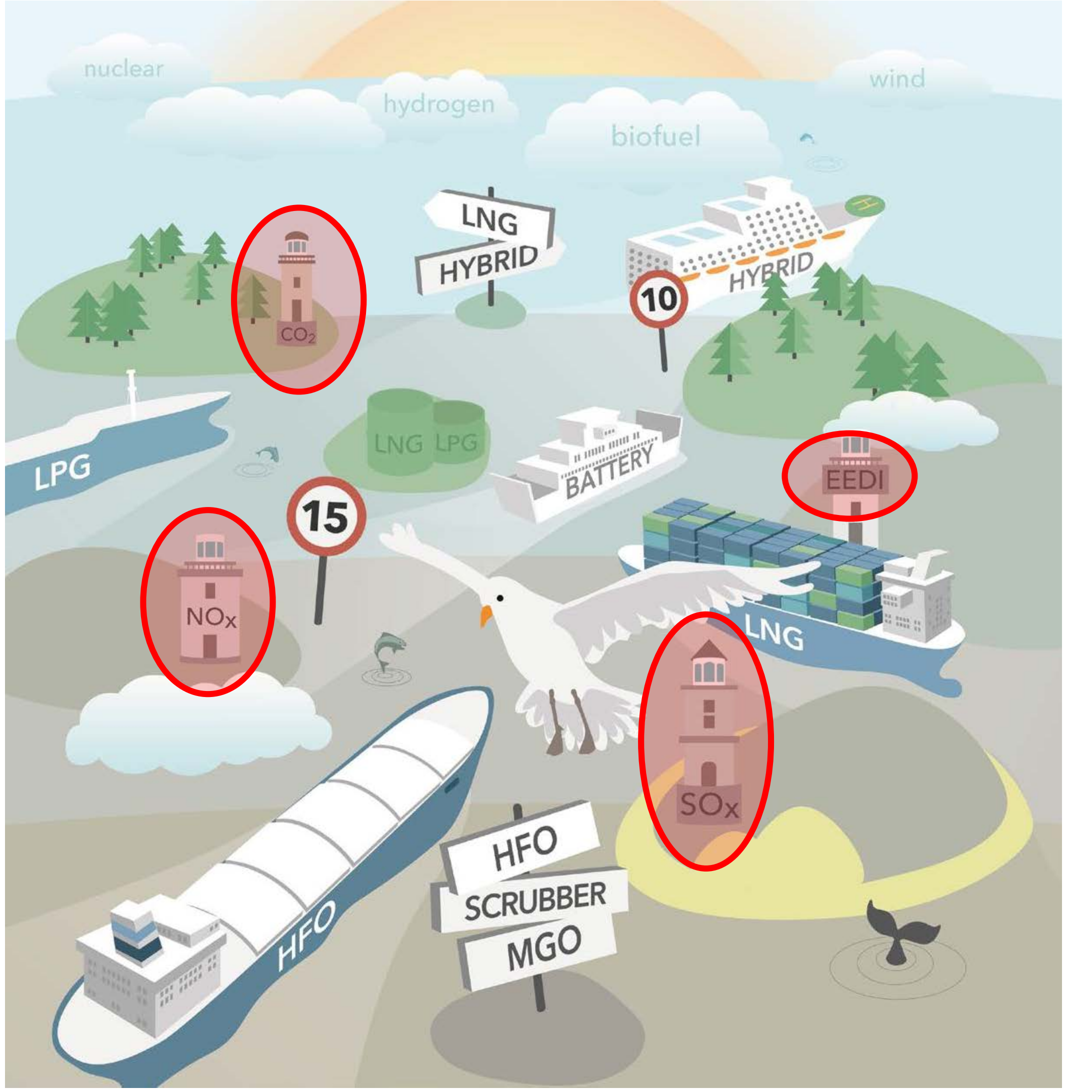
HFO + Scrubber

New Compliant Fuels (0.5% S)

Alternative Fuels & Technologies

Fuels	Technologies
LNG	Batteries
LPG	Fuel Cells
Methanol	Wind-assisted propulsion
Biofuel	
Ammonia	
Hydrogen	

Regulations | **Fuel prices** | **Fuel availability** | **Emissions**



Alternative Fuels: LNG (CH_4)

LNG as fuel:

✓ LNG has good environmental performance

✓ reduced NO_x, can reach NO_x Tier III limits (depending on combustion process)

✓ no SO_x, nearly no PM/BC

✓ reduced CO_2, positive EEDI impact

✓ sufficiently existence to fuel shipping

– high invest for newbuilds, retrofit possible but costly

– regional price volatilities

– lower energy density compared to HFO/MGO

– methane slip might lower overall GHG benefit

CO_2: Tank to Wake basis in this case

Alternative Fuels: LPG (C_3H_8, C_4H_{10})

- LPG is widely accepted (land-based and marine) mixture of propane & butane
- meets **SO_x requirement** (max. 0.1% sulphur)
- potential fuel cost savings (**cheaper than MGO**)
- Comparable cost to SO_x scrubber solution
- Easier to handle than LNG, no cryogenic temperatures
  - Cheaper containment system than LNG
- Retrofit solution possible
- Speculation in future fuel cost variation (flexible fuel utilisation)
- **for gas carriers:** savings of both time and fees for not bunkering when fuel can be taken from cargo tanks

New Fuels Emission Reductions (cf. Tier II engines on HFO)*

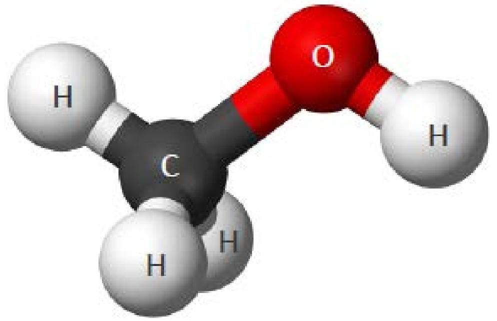
	NO_x	SO_x	PM	CO_2
LNG	20-30%	90-99%	90%	24%
LPG	**10-15%**	**90-100%**	**90%**	**18%**
Methanol	30-50%	90-97%	90%	5%

Data derived by: MAN Energy Solutions: ME-LGIP Dual-Fuel LPG Engine

** Source: MAN Energy Solutions*

Alternative Fuels: Methanol (CH_3OH)

- **Technically** methanol could be a viable fuel option for shipping
  - green fuel (when produced from biomass or PtX)
  - due to its toxicity and low flash point, methanol is more complicated to handle compared with HFO/ MGO but easier to handle than LNG
  - tank and engine technology is available (in general)
- **Commercially** methanol is not attractive at this stage (much higher price compared with MGO/HFO) and additional investments are necessary to allow vessels to use methanol fuel
- Methanol as fuel does not solve the NO_x / Tier III challenge on its own but engines need to be equipped with smaller EGR/SCR systems



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Alternative Fuels: Methanol (CH_3OH)

- Distribution to ships can be accomplished either by truck or bunker vessel.
  In the port of Gothenburg, **Stena Lines** has created a dedicated area for **bunkering the vessel Stena Germanica**, which includes a few simple safety barriers to avoid problems in case of a leak.

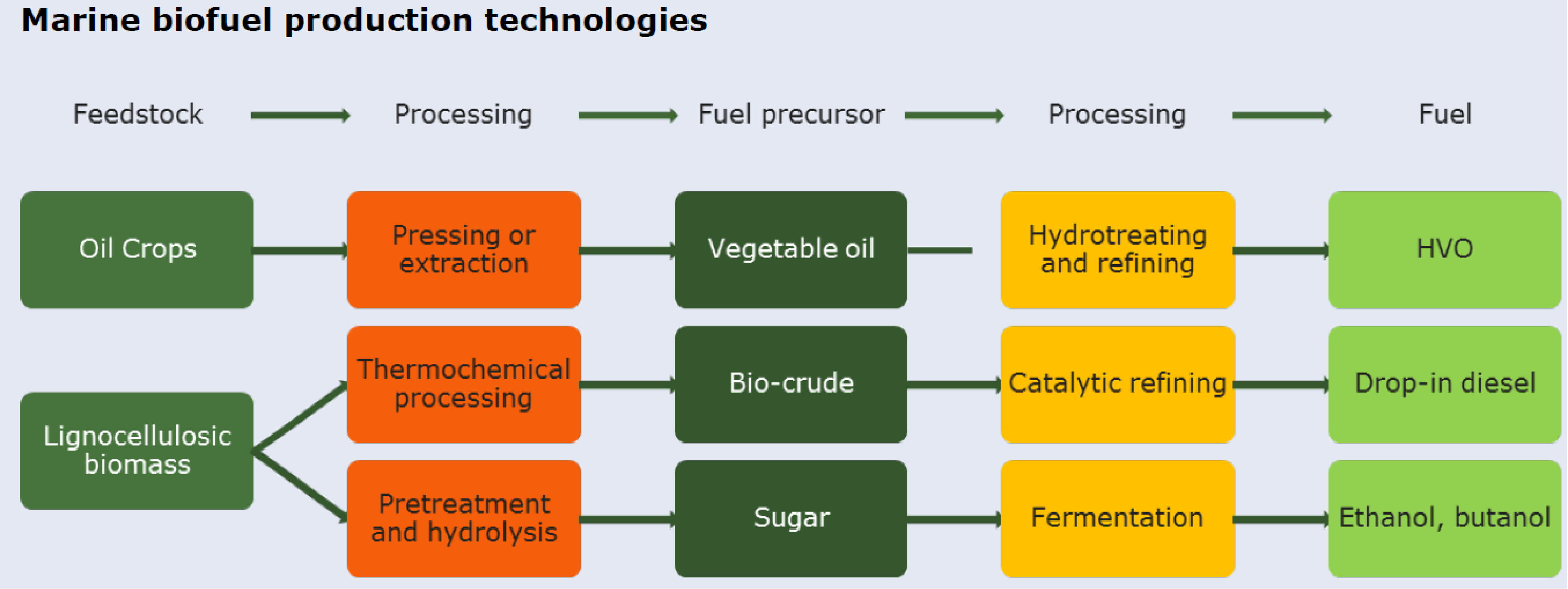
- In Germany, the first methanol infrastructure chain, from production using renewable energy to trucking and ship bunkering through to consumption in a fuel cell system on board the inland passenger vessel MS Innogy, was launched in August 2017.

7 chemical tankers operated on Methanol

Alternative Fuels: Biofuel

- Production of biofuel is commonly categorized based on their (carbon) source:
  - First-generation biofuels: directly extracted from plants / fruits sources may include sugar, starch or lipid
  - Second-generation (advanced) biofuels: derived from woody crops, purpose-grown non-food feedstock, and wastes/residues
  - Third-generation (advanced) biofuels: derived from aquatic autotrophic organisms (e.g. algae*)
- Advanced biofuels are considered more sustainable since they do not compete with food crops.
- Most promising biofuels for ships are biodiesel, fatty acid methyl ester (FAME) and liquefied biogas (LBG)
  - **Biodiesel** is most suitable for replacing MDO/MGO
  - **LBG** is the best replacement of fossil LNG
  - Straight vegetable oil (**SVO**) may substitute HFO
- Since 2006, several demonstration projects have tested technical feasibility of various FAME biodiesel blends in shipping.
- **Challenges for FAME biofuels** include fuel instability, corrosion, susceptibility to microbial growth, and poor cold-flow properties. Recently, ferries operating in Norway have started to use **HVO** (hydrotreated vegetable oil) biodiesel.
- **Renewable HVO biodiesel** is a high-quality fuel in which oxygen has been removed using hydrogen, which results in **long-term stability**.
  - Compatible with existing infrastructure and can be used in existing engines, subject to approval by manufacturer.
  - no SO_x, reduced NO_x and PM emissions

Biofuels start to gain traction in the market

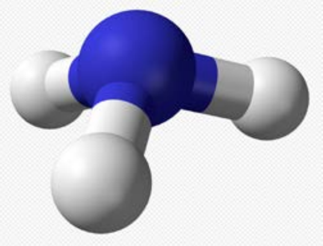


Source: IEA, 2017; http://task39.sites.olt.ubc.ca/files/2013/05/Marine-biofuel-report-final-Oct-2017.pdf

Crucial Question: is / will there sufficient biomass available to fuel shipping?

Alternative Fuels: Ammonia (NH_3)

Ammonia, NH_3 as a green fuel if produced with renewable energy



Benefits of NH_3 as a green fuel:

- No carbon combustion
- Can be reformed to H_2 and N_2
- Can be stored with high energy density at < 20 bar (boiling temp.: - 33°C)

- **BUT:**
  - Very toxic at low concentrations (300 ppm and higher)
  - no experience in combustion details and associated NO_x

Ammonia synthesis from an energy source

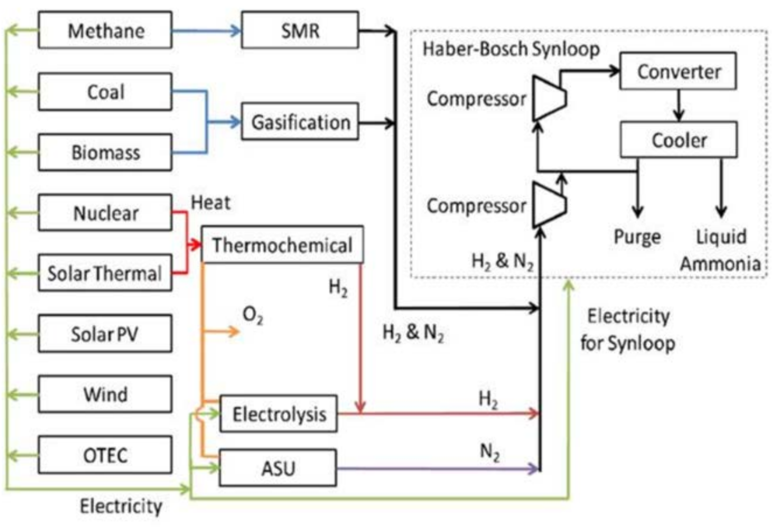
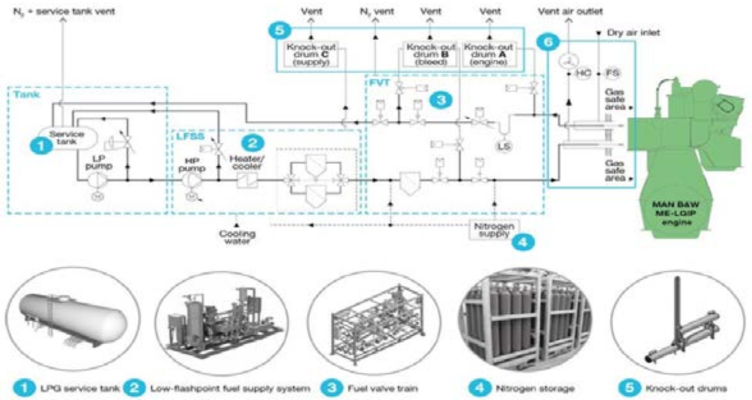


Diagram of methods to produce ammonia from several energy sources

The new MAN B&W ME-LGIP engine

This engine can be modified to burn ammonia as well

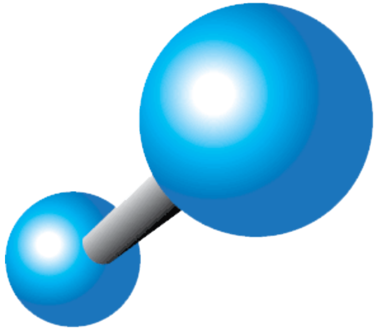


- Development time of an ammonia engine 2-3 years
- We will be ready when the market comes
- Efficiency 50%

SIEMENS Gamesa RENEWABLE ENERGY

Alternative Fuels: Hydrogen (H_2)

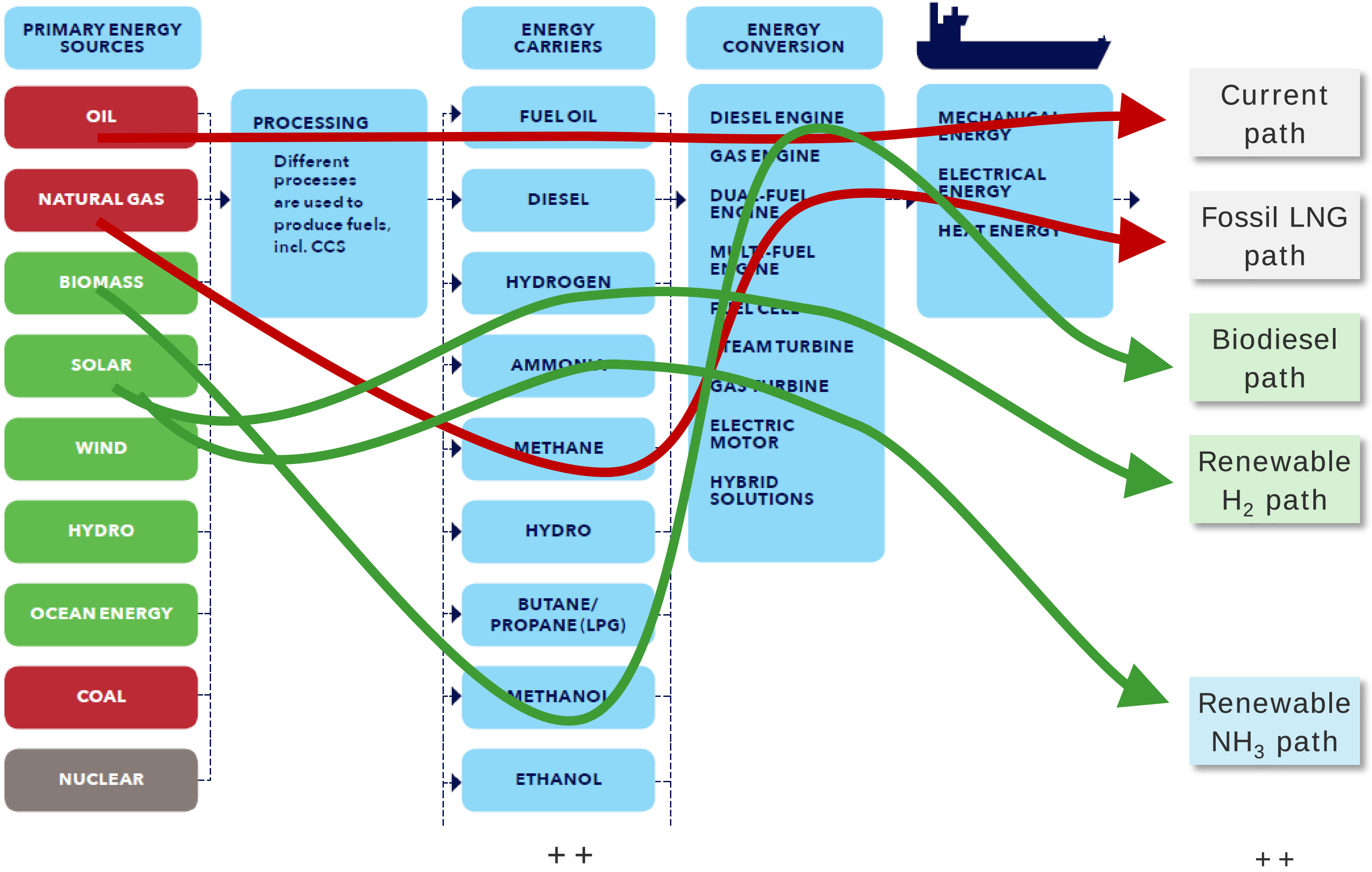
- Two main production paths assumed for H_2:
  – H_2 from natural gas, most common production method today
  – **in future**: H_2 produced by electrolysis using renewable energy
- For use on ships, it can either be stored as cryogenic liquid, compressed gas, or chemically bound.
- Energy density per mass of H_2 is about 3 times higher than energy density of HFO however,
- **Volumetric density of liquefied: H_2 = 71 kg/m3 (7% that of HFO)**
  – approx. 5-7 times more volume/space cf. HFO
  – compressed, approx. 10-15 x volume cf. HFO

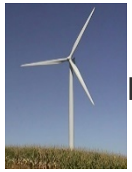


Liquid hydrogen storage tank

- Bunkering of H_2-fuelled ships is subject to national regulations and therefore needs to be evaluated on a case-by-case basis.
- **Bunkering and port regulations for bunkering H_2 fuel does not exist for the time being.** However, several ports do have LNG rules, bunkering is subject to SGMF guidelines and ISO/TS 18683. It is assumed that there will be a significant overlap with future standards for hydrogen.

Three distinct fuel path families: fossil, biomass and electricity





Power to X (PtX)
Gas (PtG) and/or Liquid (PtL)

$H_2O \rightarrow H_2 + ½ O_2$ (**Hydrogen**)

$CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O$: **Methane** (PtG)

$CO_2 + 3 H_2 \rightarrow CH_3OH$: **Methanol** (PtL)

$n{\cdot}CO_2 + n{\cdot}3{\cdot}H_2 \rightarrow (\text{-}CH_2\text{-}){\cdot}n + n{\cdot}2{\cdot}H_2O$ (**Synfuel**: PtL)

You have to have CO_2 and H_2

$N_2 + 3 H_2 \rightarrow 2 NH_3$: **Ammonia** (PtL)

You have to have N_2 and H_2

Inspired by Brynolf S. (2014), 'Environmental assessment of present and future marine fuels'

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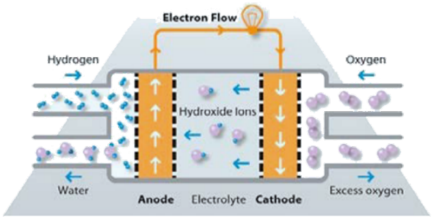
Alternative Technologies: Batteries, Fuel Cells, and Wind-assisted Propulsion

- **Batteries** as an ‘alternative fuel’ have major potential **for ships running on short distances**, and for any ship when used to **increase the efficiency** of the propulsion system. They **cannot substitute fuel** in deep-sea shipping.

- Ship applications of **fuel cell technology** are still in their **infancy**.

- **Wind-assisted** propulsion has a certain potential to reduce fuel consumption when used on slow ships, but the **business case remains difficult**.

Batteries



Functional principle of a fuel cell

Fuel Cell Systems

Wind-assisted propulsion

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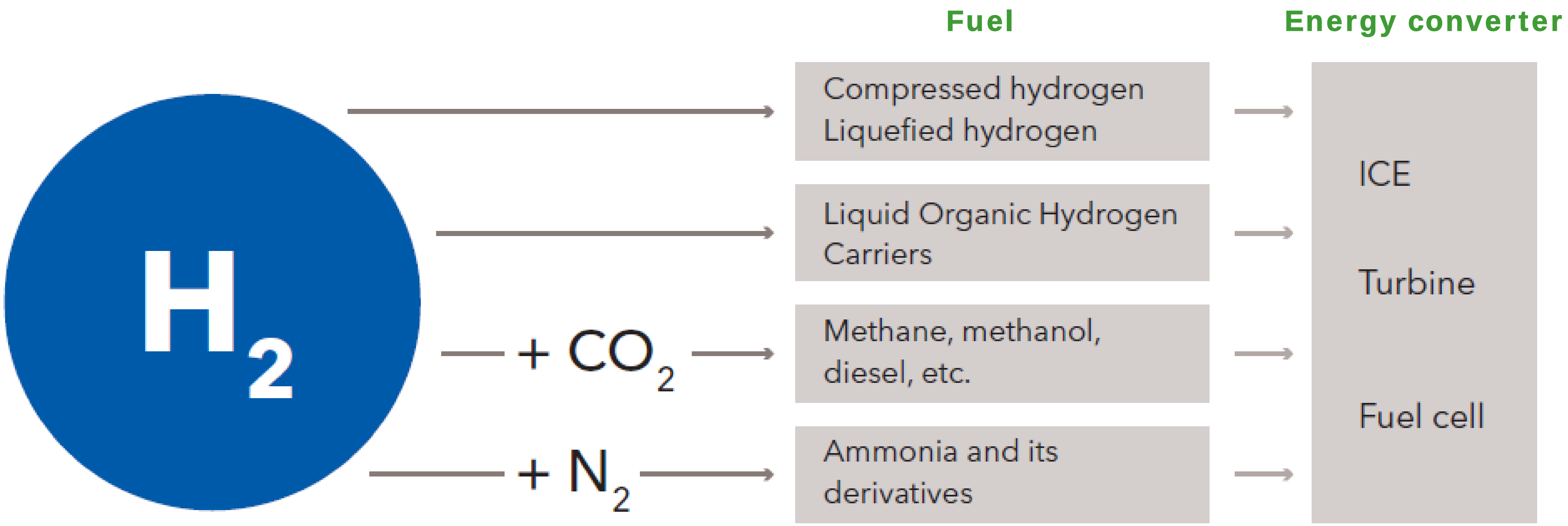
DNV·GL

Electricity based fuels – it all starts with Hydrogen



Key: CO_2, carbon dioxide; H_2, hydrogen; N_2, nitrogen; ICE, internal combustion engine

Source: Inspired by Päivi et al. (2018)

Summary

1. The global constraints to reduce GHG emissions (Paris agreement) and the IMO initial GHG strategy to reduce **GHG emission by 50% within 2050** will become a **game changer**
2. The additional worldwide trend towards **lowering air pollutants** i.e. **SO_x, NO_x and PM/BC** will remain **relevant** in the public and **regulatory domain.**
3. DNV GL identified **LNG, LPG, methanol** and **biofuel** as promising alternative fuels for shipping (within next decade).
4. Further on, **battery** and **fuel cell** systems as well as **wind**-assisted propulsion have reasonable potential for shipping.
5. In a **sustainable energy world** where all **energy is produced by renewable CO_2-neutral sources**, **hydrogen and CO_2** will be the basis for fuel production

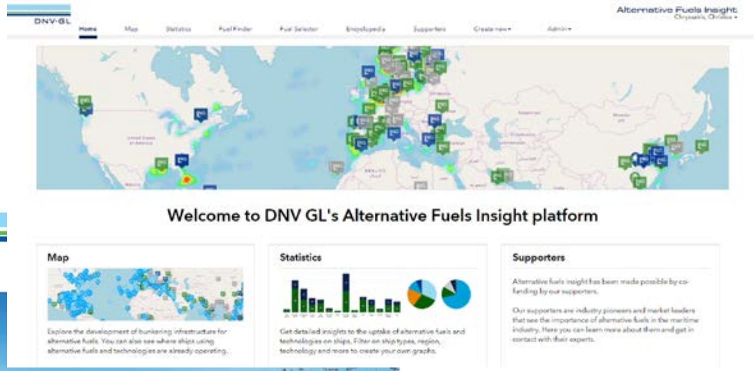
More material

- Alternative fuels guidance published in June 2019
  - Regulations and class rules
  - Overview of fuels: maturity, fuel prices, engine costs

https://www.dnvgl.com/maritime/publications/alternative-fuel-assessment-download.html

- Alternative Fuels Insight Platform
  - http://afi.dnvgl.com

- Energy Transition Outlook 2019 to be released on 11 September
  - World fleet CO_2 barometer
  - Alternative fuel barriers dashboard
  - Fuel flexibility as a bridge towards low-carbon shipping
  - Energy use and projected fuel mix 2018–2050
  - Future-proofing ships



Thank you for your attention!

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