

Prospects of sustainable marine fuels - An outlook

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"If there is a regulation we will follow it at lowest cost"

IMO – regulations have determined the focus:

- **Sulphur**, 0,1 % SECA 2015, International 0,5 % 2020
- **NO_x**, Tier II, globally, Tier III NECA 2016 in North America , 2021 in Baltic/North Sea
- **GHG**, treated as energy efficiency. EEDI, SEEMP...
- but now (April 2018) MEPC 72 adopted initial strategy with vision to reduce total GHG from international shipping
 - **Phase out "as soon as possible in this century"**
 - **Level of ambition "by at least 50% to 2050 compared to 2008"**

What is "alternative fuel"?

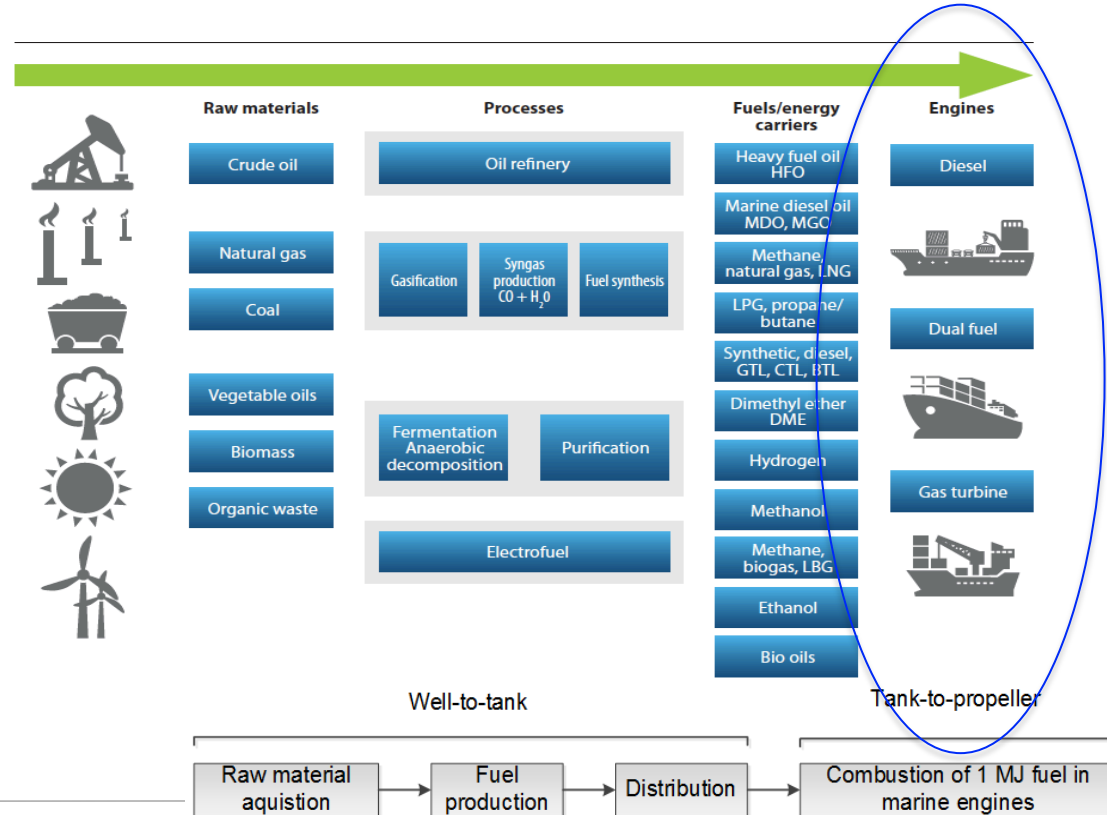
Policy definitions - Non-petroleum or non-fossil?

- Europe:
 - "Alternative fuels are urgently needed to **break the over-dependence of European transport on oil**". Includes: Electricity, **CNG**, Hydrogen, **LNG, LPG**, Biofuels, Synthetic fuels (ec.europa.eu/transport/themes/urban/cpt_en)
- US EPA
 - "Alternative fuels are **derived from sources other than petroleum**" Includes: biodiesel, E85, **CNG, Propane** and Hydrogen ([US DOE, www.fueleconomy.gov](https://www.fueleconomy.gov))
- Wikipedia
 - Alternative fuels, known as non-conventional and advanced fuels, are **any materials or substances that can be used as fuels, other than conventional fuels like fossil fuels** (petroleum(oil), coal, and natural gas) (*Wikipedia*)"



Sustainability - Zero emission, energy efficiency or zero GHG?

Systems perspective?



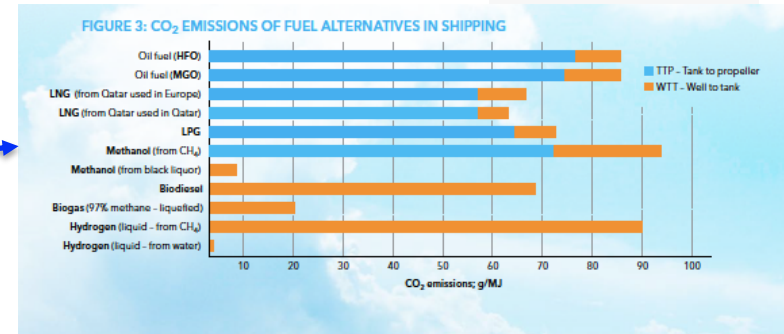
Many recent reports on Zero emitting marine fuels (GHG)

- KIRSTEIN, L., HALIM, RONALD, MERK, OLAF 2018. Decarbonising Maritime Transport - Pathways to zero-carbon shipping by 2035. OECD International Transport Forum, Paris
- LLOYDS REGISTER & UMAS 2017. Zero-emission Vessels 2030. How do we get there? Lloyds register, London
- DNV-GL 2018. Assessment of selected alternative fuels and technologies. DNV GL Maritime, Hamburg.

Measures
Advanced biofuels
LNG
Hydrogen
Ammonia
Fuel cells
Electricity
Wind
Solar
Nuclear

Technologies

- Electric
- Hybrid hydrogen
- Hydrogen fuel cell
- Hydrogen + ICE
- Ammonia fuel cell
- Ammonia + ICE
- Biofuel



On-going projects and initiatives

Various levels of "technology readiness"

- **Commercial/full scale – LNG, biodiesel, electricity**
- **Pilot projects or tests – methanol, electricity, fuel cells**
- **Lab tests, development going on – electricity, fuel cells**
- **Calculations and discussed – anhydrous ammonia,.....**

Methane – LNG/LBG globally as per March 2018

- Ships in service - 103
- Ships on order - 97

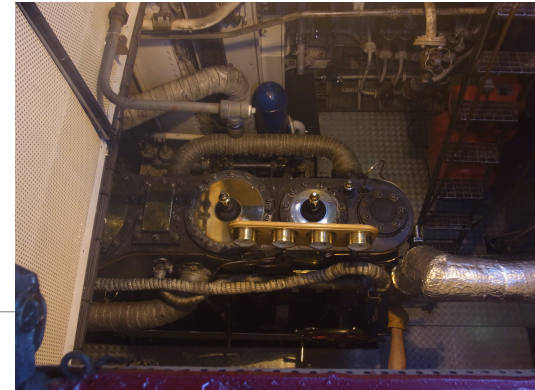


LNG LBG ?

- **LBG production in Sweden**
 - in Lidköping (Air Liquide) since 2014.
 - Production in 2017, 4900 tonnes (65 GWh)
 - EU project "Flytande biogas till land och till sjöss". Gotland, Kalmar, Kronoberg.
 - Minimum economic viable size of production facility for competition with land sold diesel, 50 GWh/y
 - Produced CNG today 50 GWh, potential for expansion up to 190 GW
 - For shipping - Full scale changeover dependent on regulation or economic incentives
- **Norway**
 - "Biokaft Skogn" started 2017, annual capacity 10 000 tonnes

BIOFUEL/BIODIESEL

- Produced for whole transport sector in various processes
- For shipping only in small segments
 - Made available in ports of Amsterdam and Singapore
 - Pilot project with Heineken on inland transport barge
 - Australian Navy testing
 - Royal Caribbean Cruises testing on Jewel of the Seas.
 - Cargo ship test in Canada with mix of B20 and animal fat and cooking oil.
 - Maersk testing FAME on bord Maersk Kalmar.
 -



Electricity/Batteries – ”much is happening”

- **Public transport in Stockholm**
- **”Yellow ferries” (trafikverket) on cable or battery**
- **HH ferry Helsingborg - Helsingör**
- **Stena developing**
- **..**

Fuel cell

- Can use hydrogen but also other energy carriers, like methanol
- Hydrogen may be stored in “liquid hydrogen carriers” like methanol, ammonia.....
- In Norway a fuel cell powered ferry will be designed and built. Pilot version of a hybrid hydrogen/battery powered ferry, operational in 2020. Shipbuilder Fiskerstrand with funding from the Norwegian Maritime Authority



Methanol

- On board tests – Stena Germanica, Pilot boat, methanol tankers

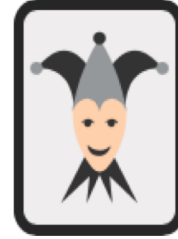


Non-fossil methanol production

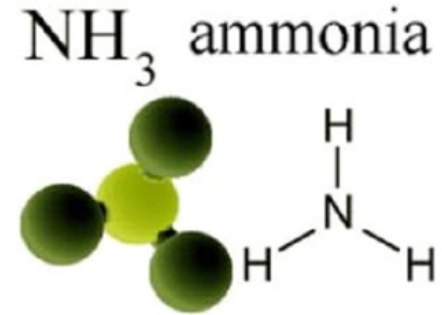
- CRI Iceland
- Edmonton Enerkem municipal waste based plant
- Gasification of glycerine (from biodiesel production), BioMCN, NL
- MefCO2 methanol production plant that is being built in Germany
- FReSMe project, “From Residual Steel Gases to Methanol”
launched in 2016
- Liquid wind
- ScandiNaos et al
- Enerkem Rotterdam partnership
- Enerkem China /Sinobioway
- HyMethShip



Anhydrous ammonia



- Today produced from natural gas (Haber Bosch)
- High energy demand for production
- Can be produced as e-fuel from N_2 and H_2
- Is a gas...30 bar pressure or cryogenic
- Well known as chemical and refrigerant



Ammonia

works in

- Otto engine (high octane number)
- fuel cell (as it is or as "hydrogen carrier")
- For diesel engine, need for ignition enhancer (diesel fuel, hydrogen)

Power system having an ammonia fueled engine.

Patent by Caterpillar 2008

Abstract

- A power system is disclosed. The power system may include an output device and a combustion engine configured to combust ammonia as a primary fuel to generate mechanical power directed to the output device. The power system may also include an electrical unit configured to supplement the mechanical power directed to the output device.

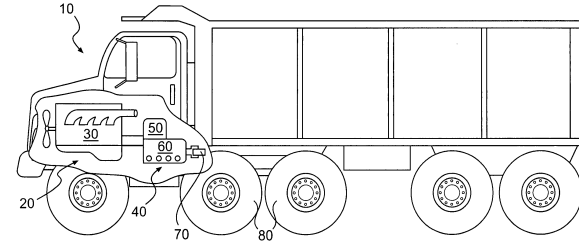
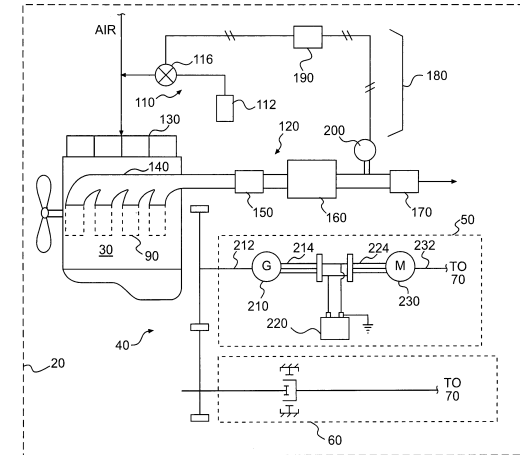


FIG. 1



Comparison of fuels*

	Methanol	Ammonia	LNG	Diesel	Hydrogen
Density, kg/m ³	795	760	430-460	833-881	71
LHV MJ/kg	20,1	18,6	49	42,5	120,1
LHV MJ/l	15,9	14,1	22	35,8	8,4
Flash point, °C	11	na	-136	52-96	-253
Carbon weight %	37,5	0	75	87	0
Flammability limits vol% in air	6,7 - 37	15 - 28	4,2 - 16	1,0 - 5,0	4 - 74

* Data needs references/quality control, do not cite!

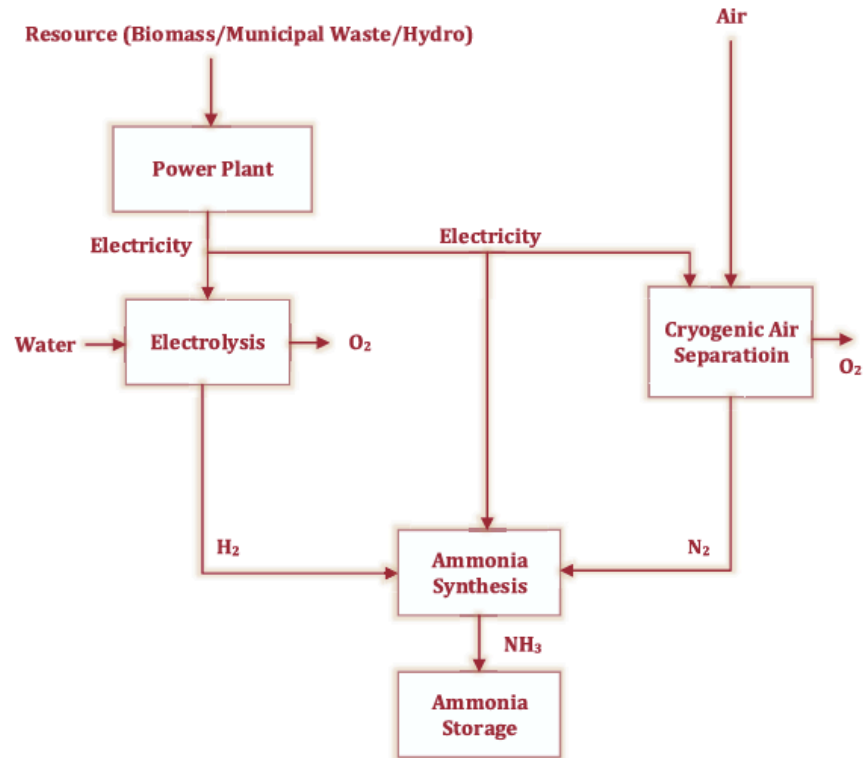


Fig. 3. Ammonia production via hydropower/municipal waste/biomass based electrolysis and Haber-Bosch process.

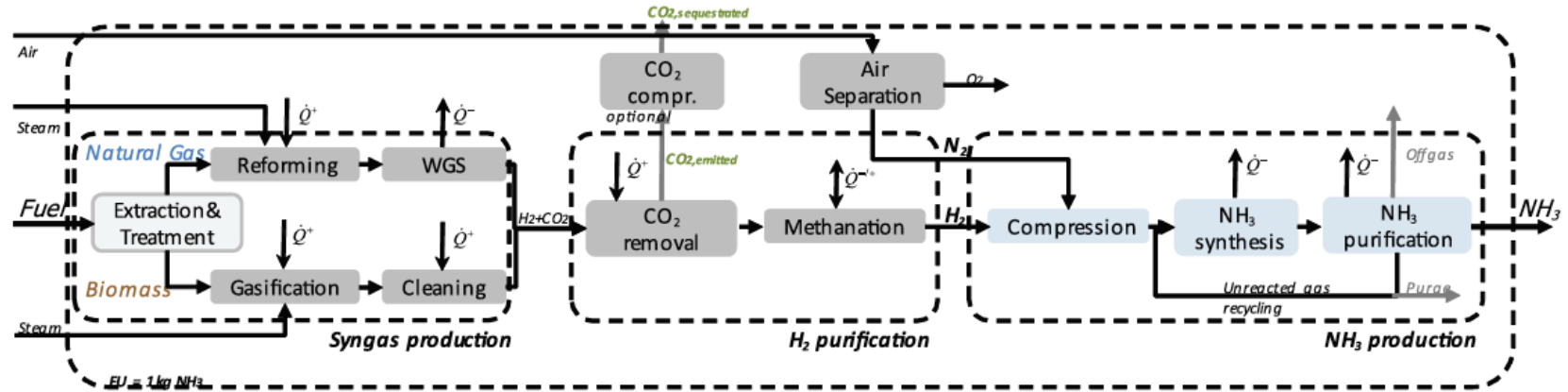


Figure 2. Process superstructure of ammonia process options.

Tock, L., et al. (2015). "Thermo-environomic evaluation of the ammonia production."
The Canadian Journal of Chemical Engineering **93**(2): 356-362.

Why ammonia ... or why not?

- Zero carbon in combustion
- Works in dual fuel diesel engines
- Good Otto fuel - Octane number 130
- Very much used chemical – large world market and logistical system
- Can be produced as "e-fuel"
- Very efficient "hydrogen carrier"
- Needs "Zero carbon" production
- Production cost of green ammonia?
- No present engines developed that can use ammonia
- Comes as liquid, has to evaporate before burning
- Potential NO_x formation
- Health and safety?

We have applied for funding to evaluate better.....



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