Webinar:

Are fuels the full solution to Decarbonations?

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First Methanol fueled feeder vessel from Maersk

Name giving event ceremony will be held in Denmark, Copenhagen on September 18 – 21, 2023

Classed by ABS

MarE-Fuel Project – Overview of Assessed Fuels

Torben Anker Invest, DTU, Maersk, DFDS, OMT and Copenhagen economics – (ABS has delivered input to TCO)

Fuel cost:
Biomass availability plays an essential role in climate mitigation efforts towards net-zero by 2050.

Three scenarios were investigated:
1 - High availability of biomass
2 - Medium availability of biomass
3 - Low availability of biomass

Plant simulation had focus on ammonia and methanol production.

Abbreviation	Name	Description
HFO	Heavy Fuel Oil	Conventional fossil fuel.
VLSFO	Low Sulphur Fuel Oil	Conventional fossil fuel. Sulphur content ≤0.5%
MDO	Marine Diesel Oil	Conventional fossil fuel.
MGO	Marine Gasoline Oil	Conventional fossil fuel.
LNG	Liquefied Natural Gas	Conventional fossil fuel.
LPG	Liquefied Petroleum Gas	Conventional fossil fuel.
MET-Grey	Methanol (grey)	Conventional methanol produced from fossil natural gas.
MET-e-bio	Methanol (e-bio)	Methanol produced from gasification of residual biomass and hydrogen from water electrolysis.
MET-PS	Methanol (PS)	Methanol produced from point source (PS) carbon bio energy carbon capture and utilization (BECCU), and hydrogen from water electrolysis.
MET-DAC	Methanol (DAC)	Methanol produced from carbon from direct air capture (DAC) and hydrogen from water electrolysis.
AMM-grey	Ammonia (grey)	Conventional ammonia produced from fossil natural gas.
AMM-blue	Ammonia (blue)	Ammonia produced from fossil natural gas with carbon capture.
AMM-green	Ammonia (green)	Ammonia produced from water electrolysis.
Refined-PO	Refined pyrolysis oil	Oil from pyrolysis of residual biomass refined to a quality enabling drop-in use in HFO/VLSFO engines.
LBG	Liquefied Biogas	Liquefied biogas generated from manure or organic waste.

Table 1: Overview of assessed fuels.

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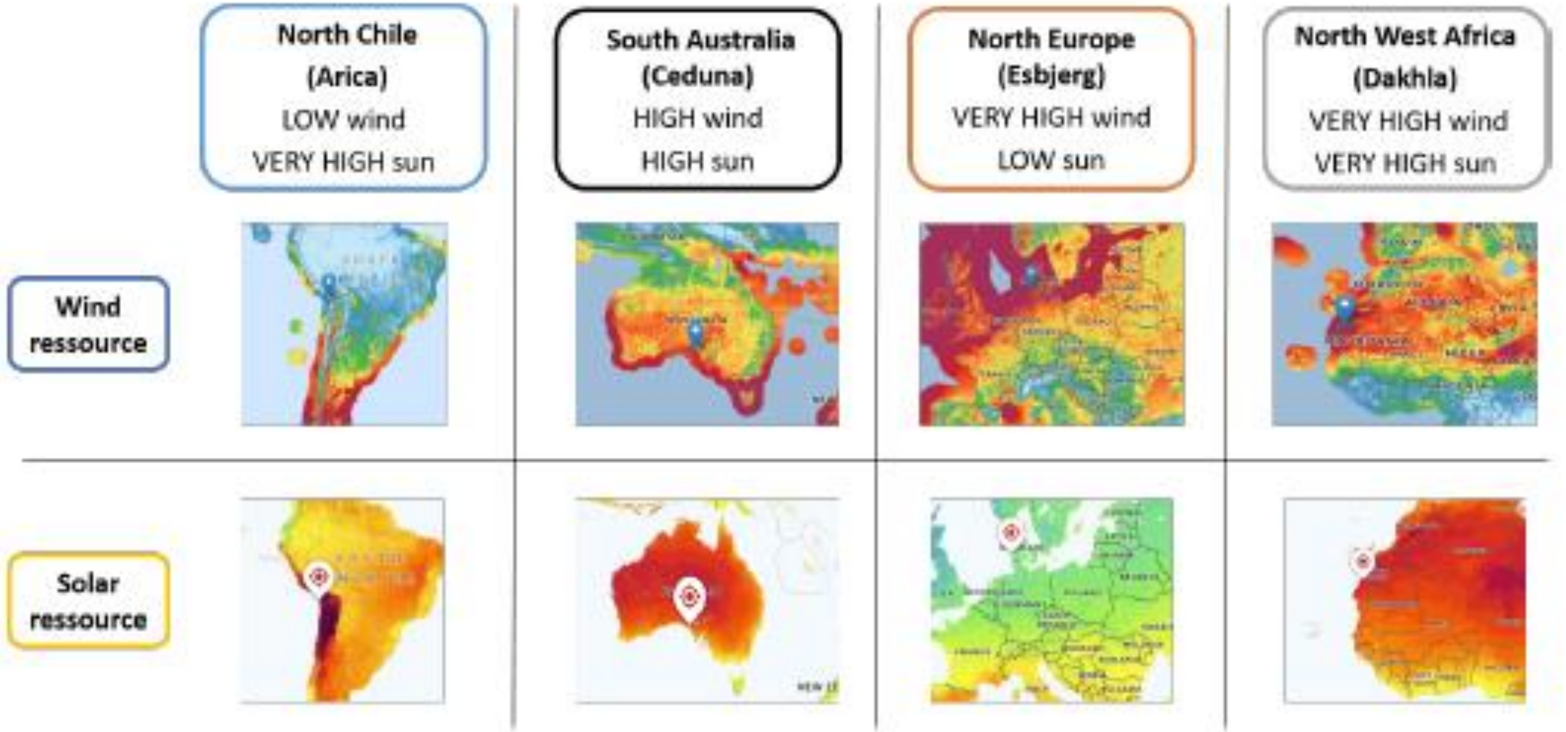
Location of Plant for Production on Renewable

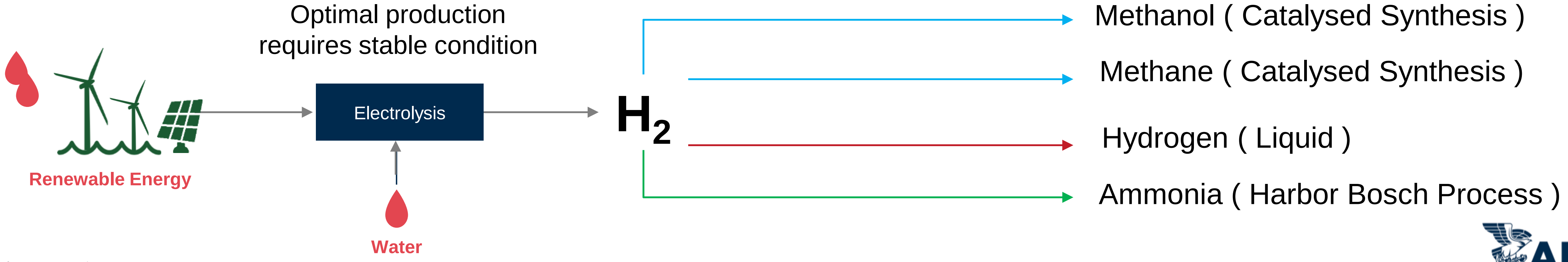
Requirement for the optimum location

- High wind resources
- High solar resources
- Access to a port
- Access to fresh water
- Access to large area of land

Minimize storage of Hydrogen

- Access to grid electricity

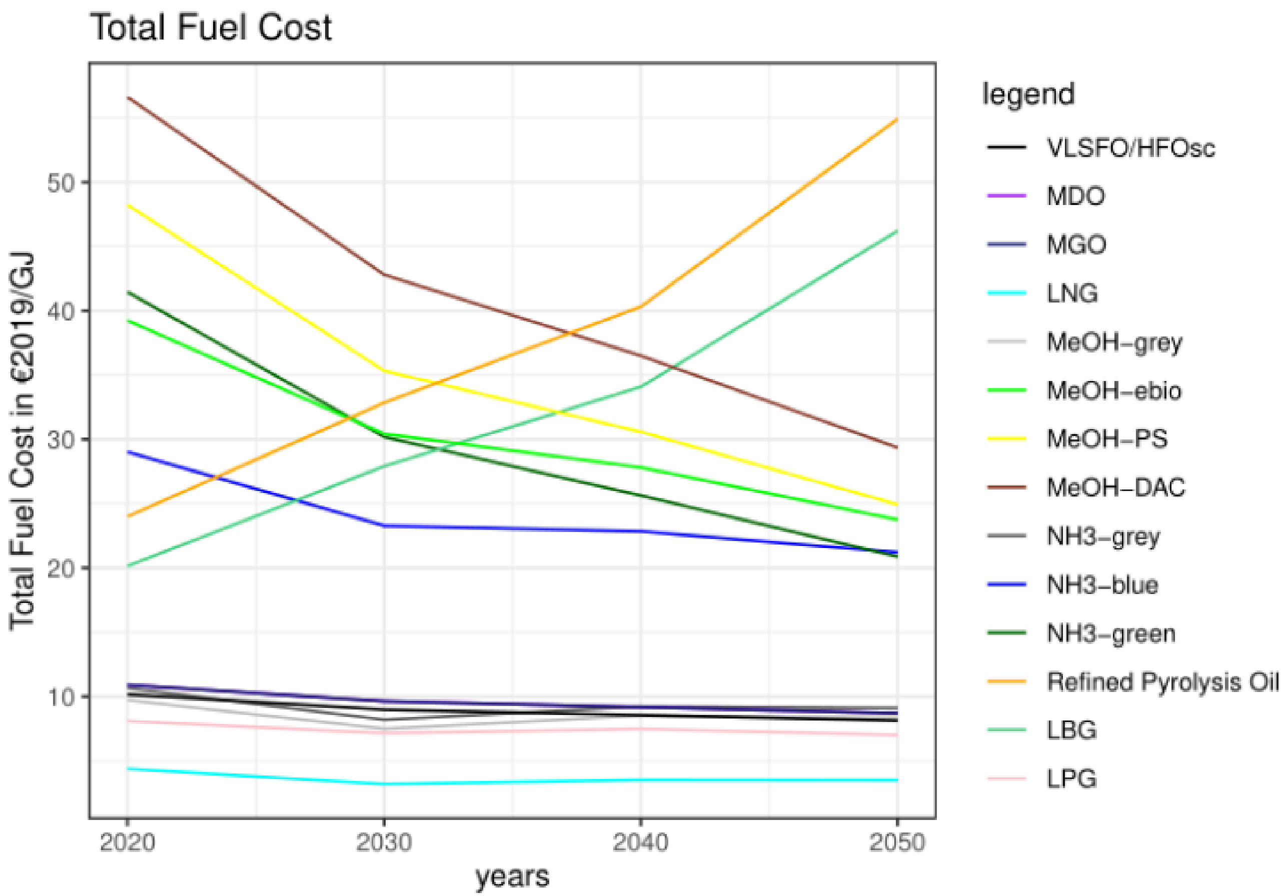




Result from MarE-fuel Study

BHM Grid –Total Fuel Cost per Fuel Type

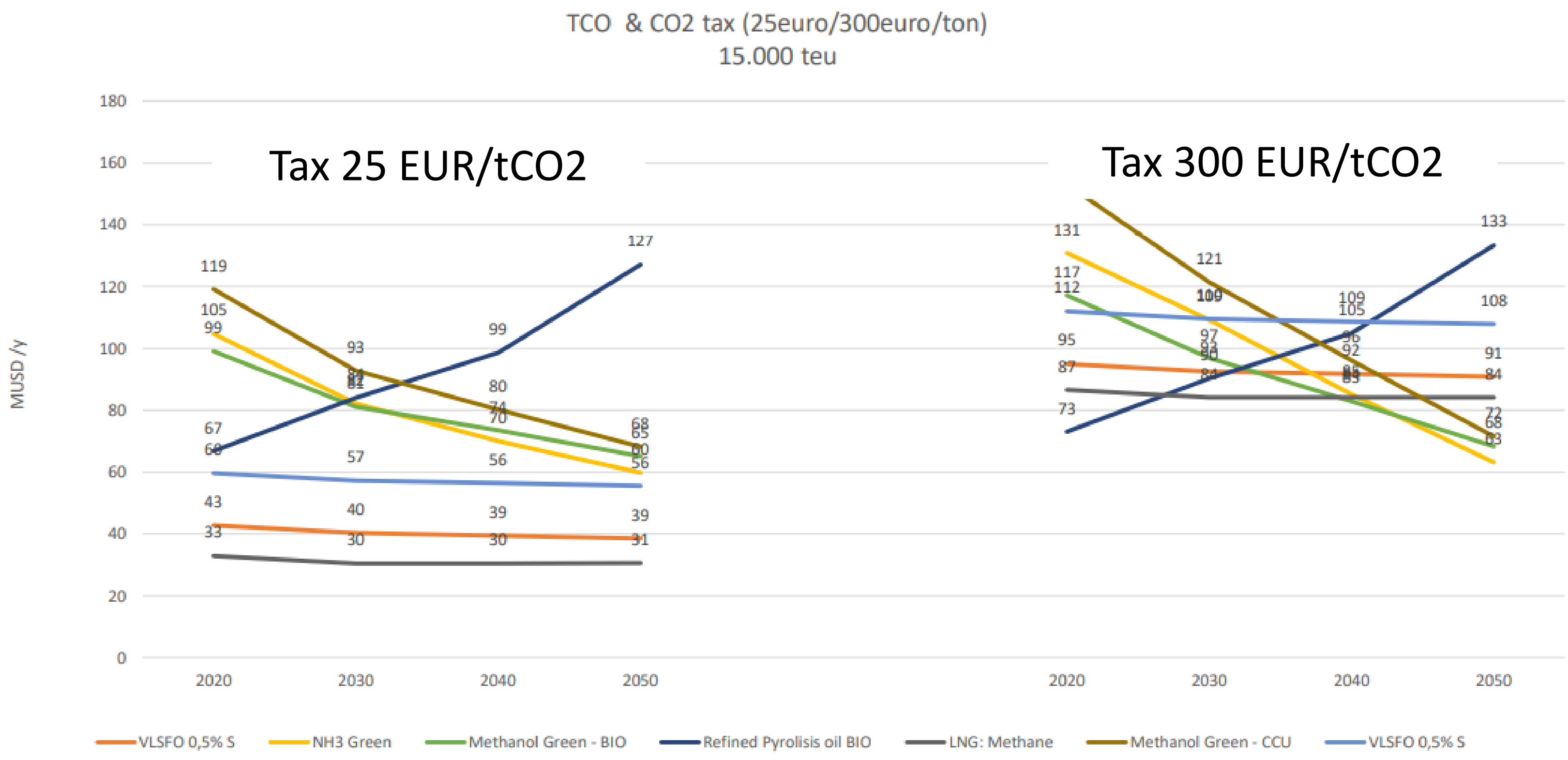
- Production of biofuels and e-fuels was simulated to estimate the fuel cost.
- Observations
  - The cost of fossil fuel cannot be beaten
  - CO_2 tax of 200 (→350) EUR/tCO_2eq is needed to make renewable fuels competitive
  - Cost of e-fuel reduces when production is increased
  - Cost of biofuel increases when production is increased
- Breakeven point between cost of MEOH-PS vs. MEOH-ebio in 2050 or later.
- In 2050, the cost of MEOH - DAC is still higher
- Ammonia seems to become cheapest in the end
- The availability of Bio-C has a big impact on prices



MarE-fuel Study

15.000 teu container ship: M/E 50.0 MW and A/G 13.7 MW

TOTAL COSTS DYNAMICS



Blue curve is VLSFO -- price Feb 2022
Orange curve is VLSFO -- price at the end of 2019

Estimated Demands for Carbon Containing Fuels and Feedstocks at Max. Electrification

Source: Professor Henrik Wenzel SDU

Sector	Demand 2050 (EJ/y) Low	High	Alternatives to fossil fuels and feedstock	Comments
Steel	5	20	Hydrogen, biomass/bio-coke, CCS,	Focus on hydrogen in Germany. Hydrogen-based technology being developed by Thyssen-Krupp
Cement	0*	30	Waste (SRF), waste from landfill mining, CCS, bio-methane, wood chips	Can take dirty, waste-based fuels. Ålborg Portland mentions landfill mining as potential future option. Also focus on CCS. * = 0 presumes all on landfill mining or CCS. Concrete re-absorbs CO_2 during its lifetime. Landfill mining + CCS + enhanced re-absorption => cement/concrete can have a very large negative carbon footprint
Plastic + other chemicals	60	[illegible]	Mechanical & chemical recycling, electrification, ...tic, e-naphta	According to LEGO, Dow and Shell work on electrification of crackers. Around 75 % of of processing energy for plastic making judged to be electrifiable
Buildings	30	40	[illegible] Mor...	Main demand for biomass in buildings judge to be in floors, ceilings, kitchens, furniture. Growing population and living standards judged to be main driver for increase
Industry	20	40	Electric boilers, bio...	Electric biolers possible in many cases, but not for high temperature and flame
Peak load heating	30	50	Electric boilers, heat pumps, CCS, ...	...load heating calls for low investment cost/MW => fuel based
Electricity balancing	10	20	Bio-methane, wood chips, CCS, ammonia, hydrogen	...alls for low investment cost/MW => bio-methane
Road transport	5	10	Bio-methane, biofuels, e-fuels, hydrogen	
Jetfuel	15	20	Electrification, hydrogen, HVO type bio-fuel, HTL, pyrolysis/gasification, e-fuels	Airbus claims focus on hydrogen. ... ...ds kerosens type. Due to slow fleet transition => min 75 % needs keroseene ty...
Marine fuel	0*	20	Hydrogen, ammonia, bio-methanol, e-methanol, bio-methane, e-methane,	End fuel demand = 20 EJ/y by 2050 + conversion losses. * = 0 ...sumes all on non-carbon-based propulsion like electricity, hydrogen or ammonia
Food/feed/meat	(45)	(50)	Animal feed from BMP from CO_2, N_2 + H_2	Also a competitor for land/biomass. Demand not included in summation 'Total'
Total	175	370		BAU scenario says total primary energy demand by 2050 = 900 EJ/y (WEC, 2013) Availability = 150-200 EJ/y by 2050 – newest study from ETC says 40-60 EJ/y

There is far from enough bio-C for all sectors

Rough estimates, largely based on extrapolation of Danish system design studies on electrification possibilities applied to world scale

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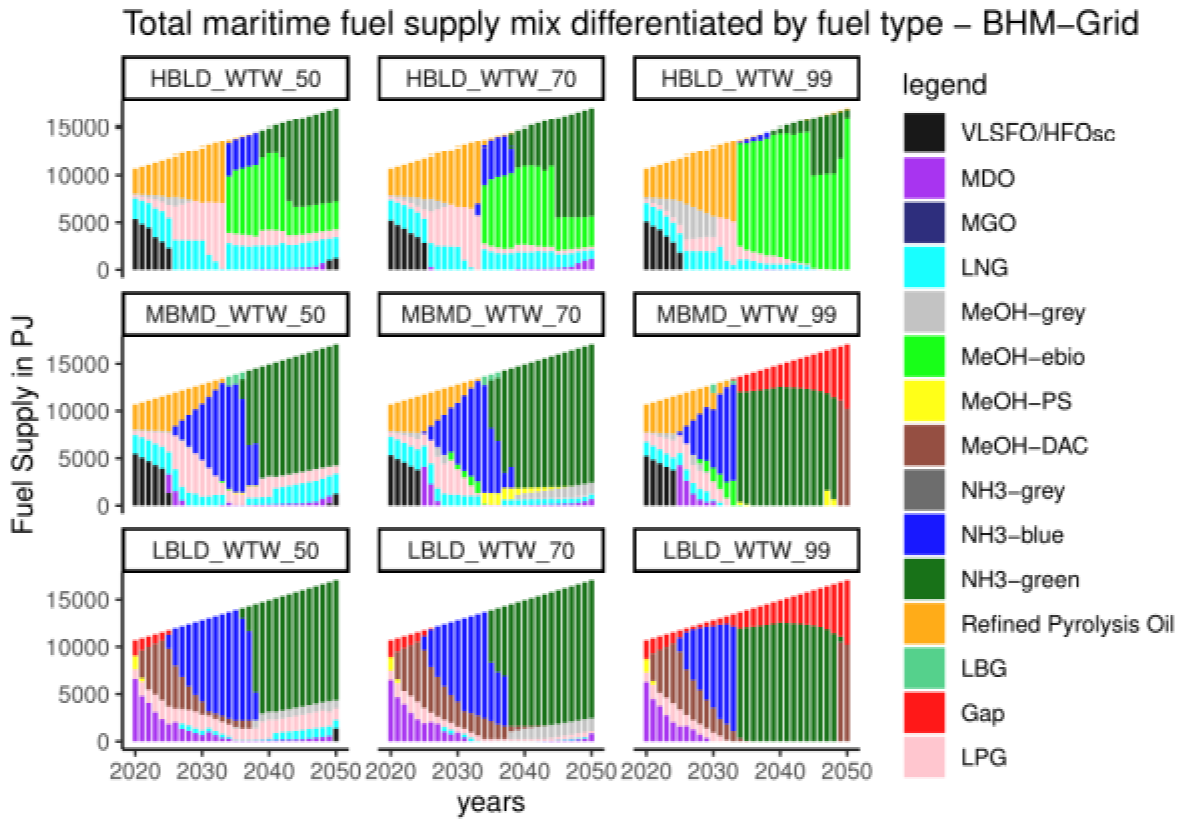
Future Fuel Mix – Which Fuel Will Dominate

1 - High availability of biomass

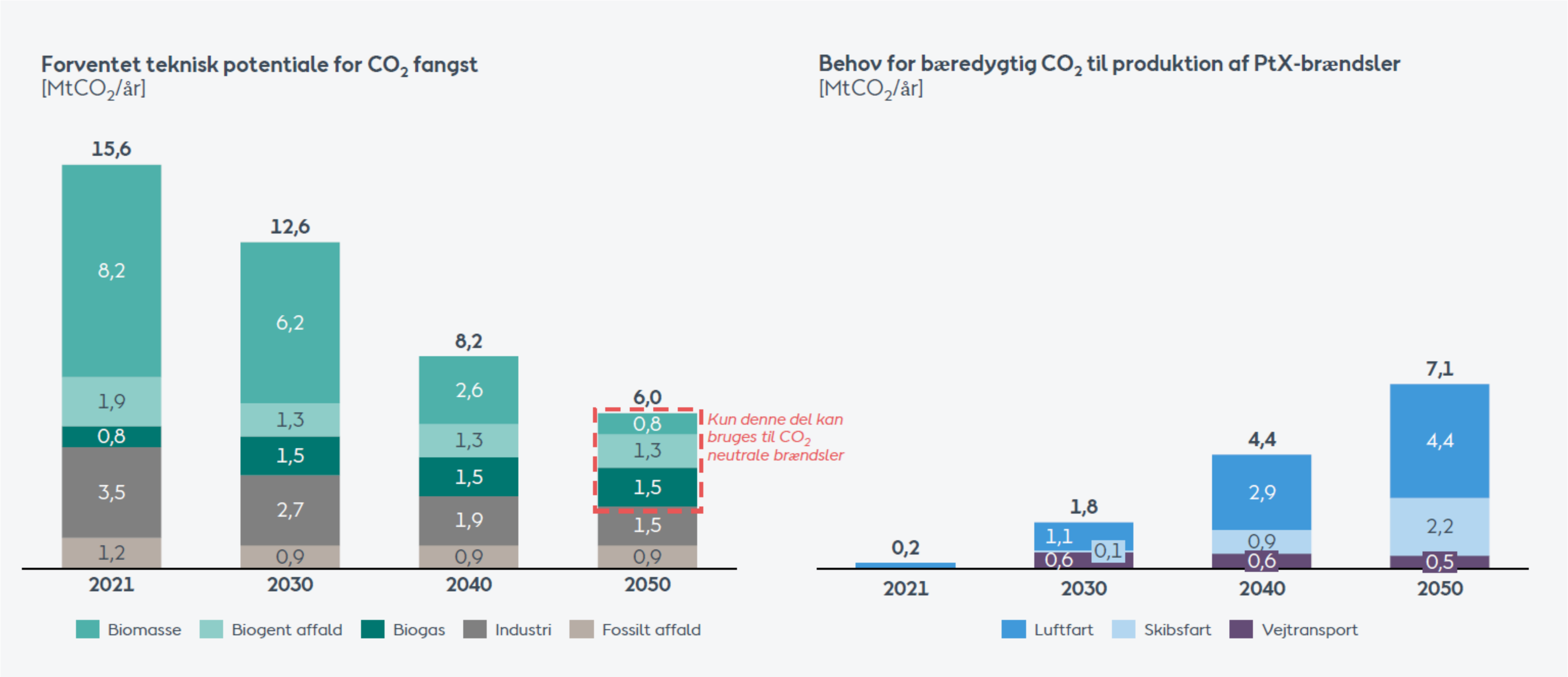
2 - Medium availability of biomass

3 - Low availability of biomass



Expected Future CO_2 Shortage – as a Result of Electrification

Ørsted presentation at DI webinar on CO_2 as feedstock for future fuels, June 23, 2021



Kilde: Dansk Energi

Ørsted

Points:

1. There won't be enough green CO_2 in flue gases
2. Is the market for CO_2 transportation long term?

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EMSA Reports – 6 Reports in total

Ammonia and Biofuel reports is completed.

Content:

- Availability
- Sustainability
- Suitability
- Total Cost of Ownership
- Regulation
- Gap analysis
- Risk assesment

- **Hydrogen & Wind Asisted Propulsion System (WAPS) report is in the works.**
- **2 More reports to come – E-fuels ? WHR and AirLub?**
- **Carbon capture is not of any interest**

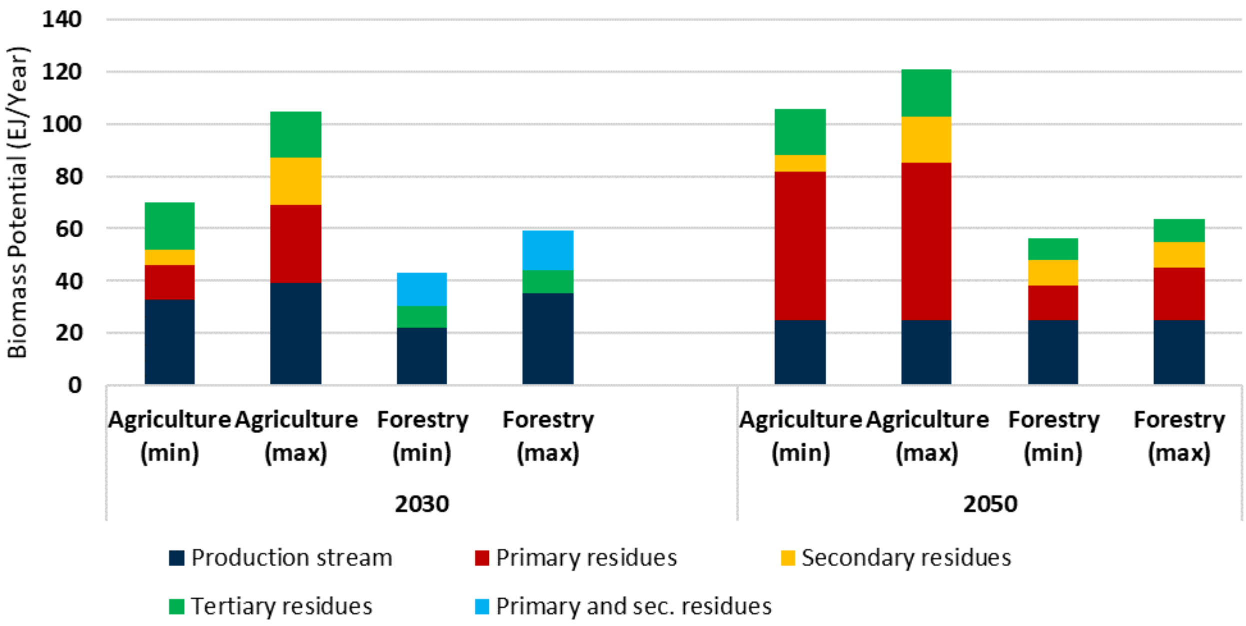
Biofuels availability and scalability

- Biofuel availability for the maritime sector is determined by
  - The availability of feedstocks; and
  - Competition with other sectors.

  - The availability of feedstocks depend on:
    - Sustainability criteria;
    - Type of feedstock: lignocellulosic / algae / carbohydrates / bio oils & fats.

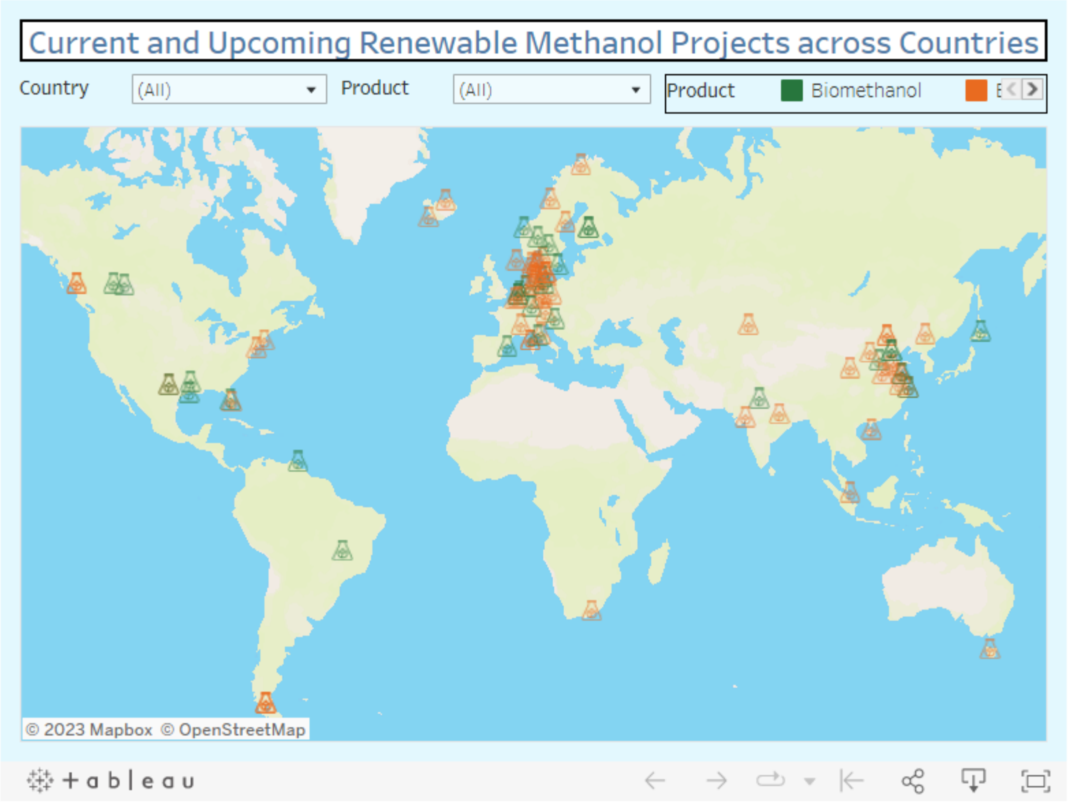
  - Competition with other sectors depends on:
    - Alternative sources; and
    - Policy measures.

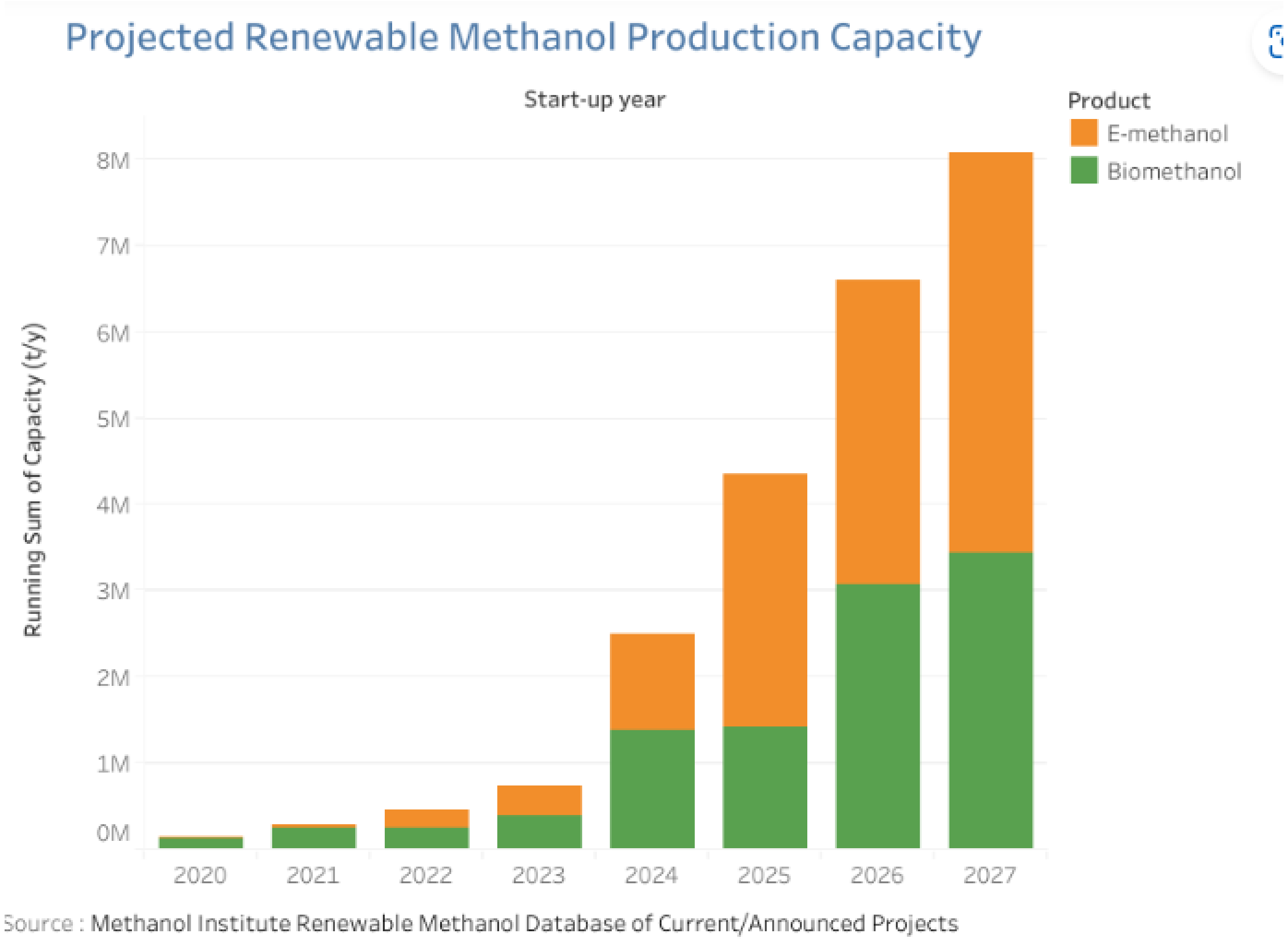
Global sustainable biomass potential



Energy demand from shipping: 18 EJ in 2018

Methanol institute – green methanol - availability





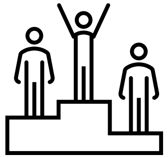
Renewable Methanol | METHANOL INSTITUTE

Conclusions

Bio

Ranking was performed based on:

- Fuel production costs developments
- Production maturity
- GHG reduction potential
- Feedstock availability
- Suitability of engines



1. Bio-methanol, FT diesel, biomethane from digestion of waste and residues and DME arrive very close
2. FAME from FOGs, biomethane from gasification
3. FAME from vegetable oils, HVO from FOGs and from vegetable oils arrive

Main conclusions:

- **We do not see major bottlenecks (Safety aspects)**
- **Regulatory (ship-related) bottlenecks are minor or resolvable**
- **Need for common and harmonized sustainability criteria and LCA guidelines:**
  - International & cross-industry

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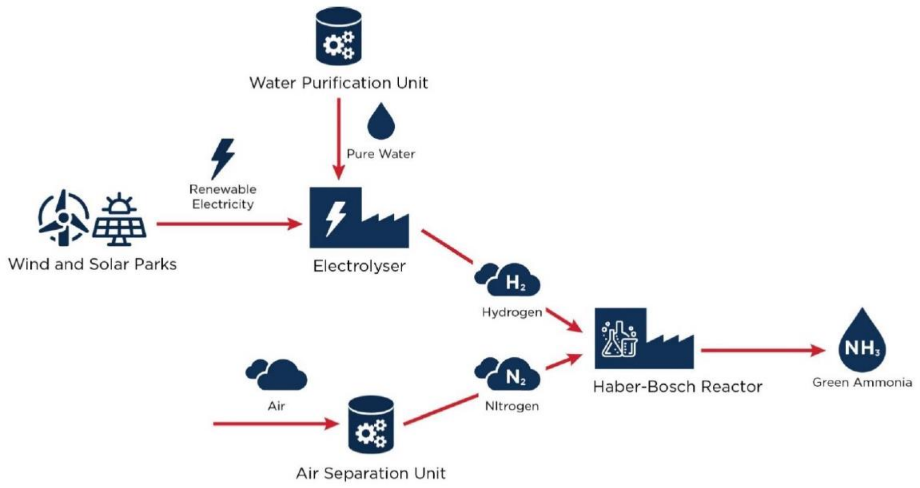
Ammonia Availability and Scalability

NH3 HB is the most mature process



Process Type	Expected Efficiency [up to]
Pathway 1 Electrolysis and Haber-Bosch synthesis	~72%
Pathway 2 Direct solar hydrogen production	9% [up 70%]
Pathway 3 Biogenic hydrogen production	~57%
Pathway 4 Non-thermal plasma synthesis	12-37% [up to 45%]
Pathway 5 Electrochemical ammonia synthesis	14-62% [up to 90%]

Grey NH3 Production

235 Mtons/year

2019

Green NH3 Announced

>133 Mtons/year

*annouced blue and green ammonia production

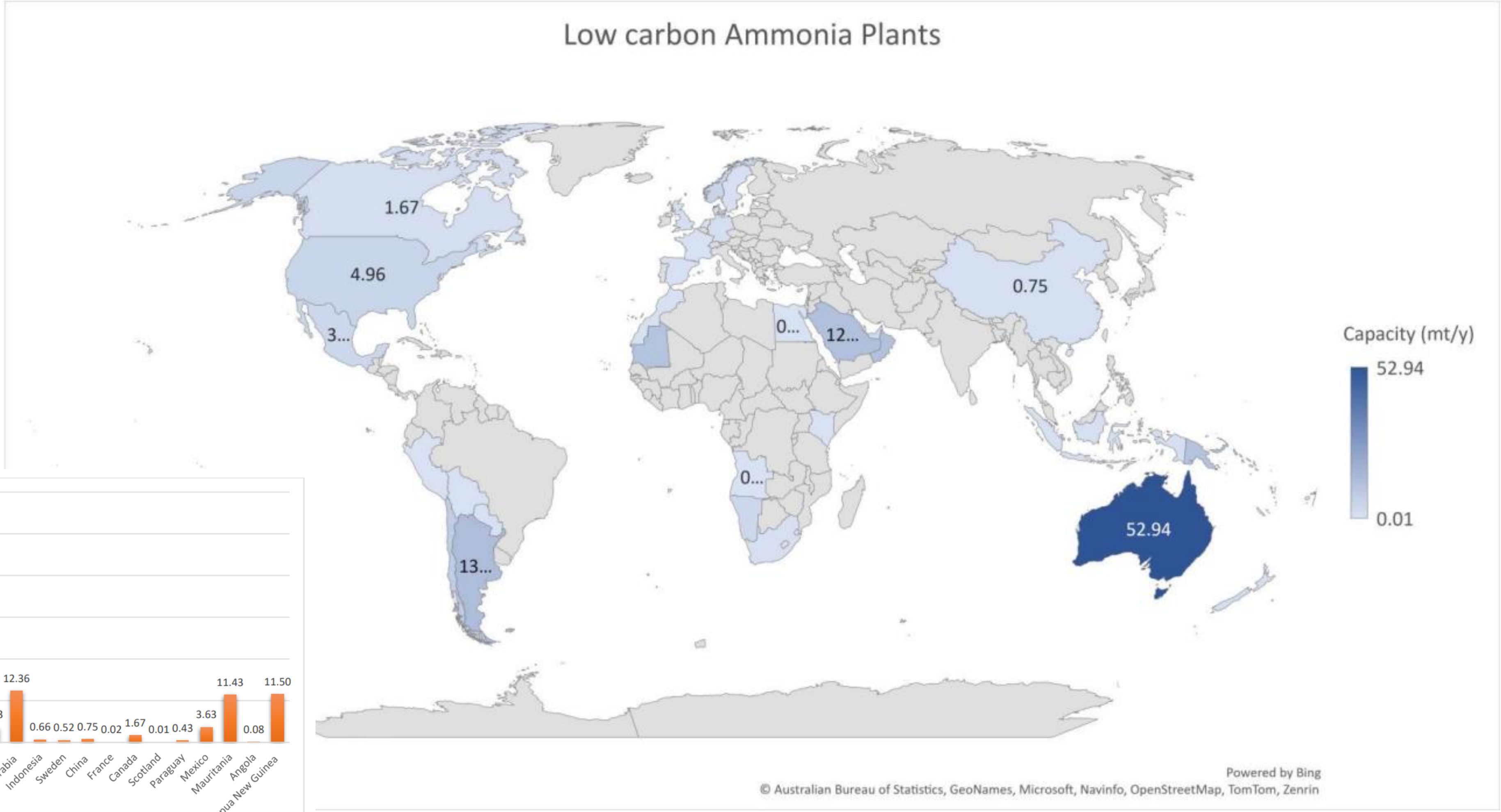
What are the challenges ?

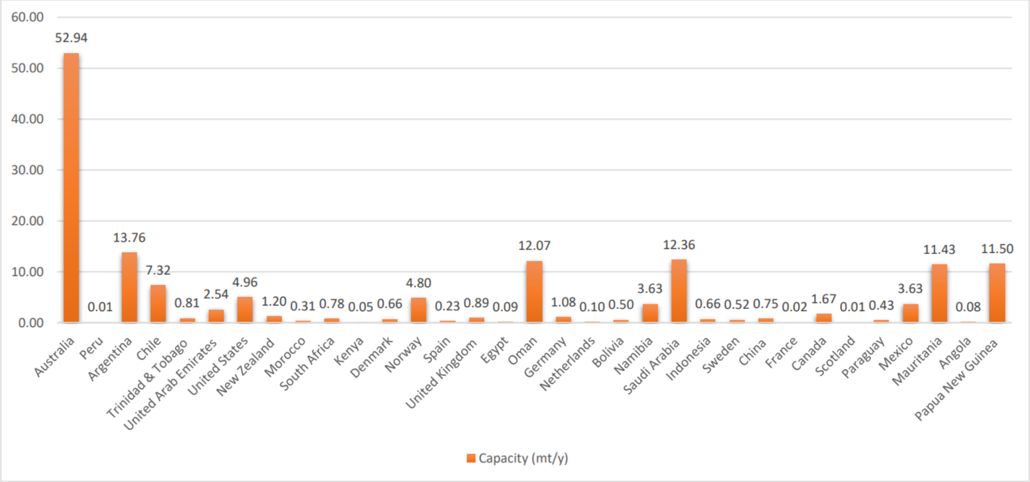
- Many sectors will have demand for green or blue ammonia.
- Green electricity will also be in high demand
- Demand depends on policy, many of which are not yet confirmed
- Green production needs to be efficient, utlized at maximum capacity and this poses challenges:
  - Location, pipelines, access to ports
  - Connection to grid (sustainable?)
  - Potentially oversized

World Map of Gray NH_3 Facilities Currently in Operation

Total Ammonia terminals in operation: 196

Green/blue Ammonia production heat map





Conclusions

NH_3

Ammonia as a fuel is likely to take place. It presents a series of advantages and is a promising fuel:
- Known and well-estabilished production process
- Naturally carbon-free, although attention is to be given to NOx, N2O and Pilot fuel and trully green production pathways
- It is known to shipping as a cargo (IGC covers it), and poses many challenges to be used as a fuel
- There are challenges to overcome to handle its corrosivity and toxicity: bunkering, engine, fuel supply systems.
- However, it has been used for many decades and there is substantial knowledge available. Fuel infrastruture can fairly fast be established from the use of exsisting LPG carriers.

Main challenges:
- Ensure availability of green energy and competition with other sectors
- High costs associated with green ammonia production
- Safety and Regulations concerns: need to accelerate awareness and regulatory framework developments
- Need more knowledge on spillage and other environmental aspects
- IMO Guidelines to be ready by 2025

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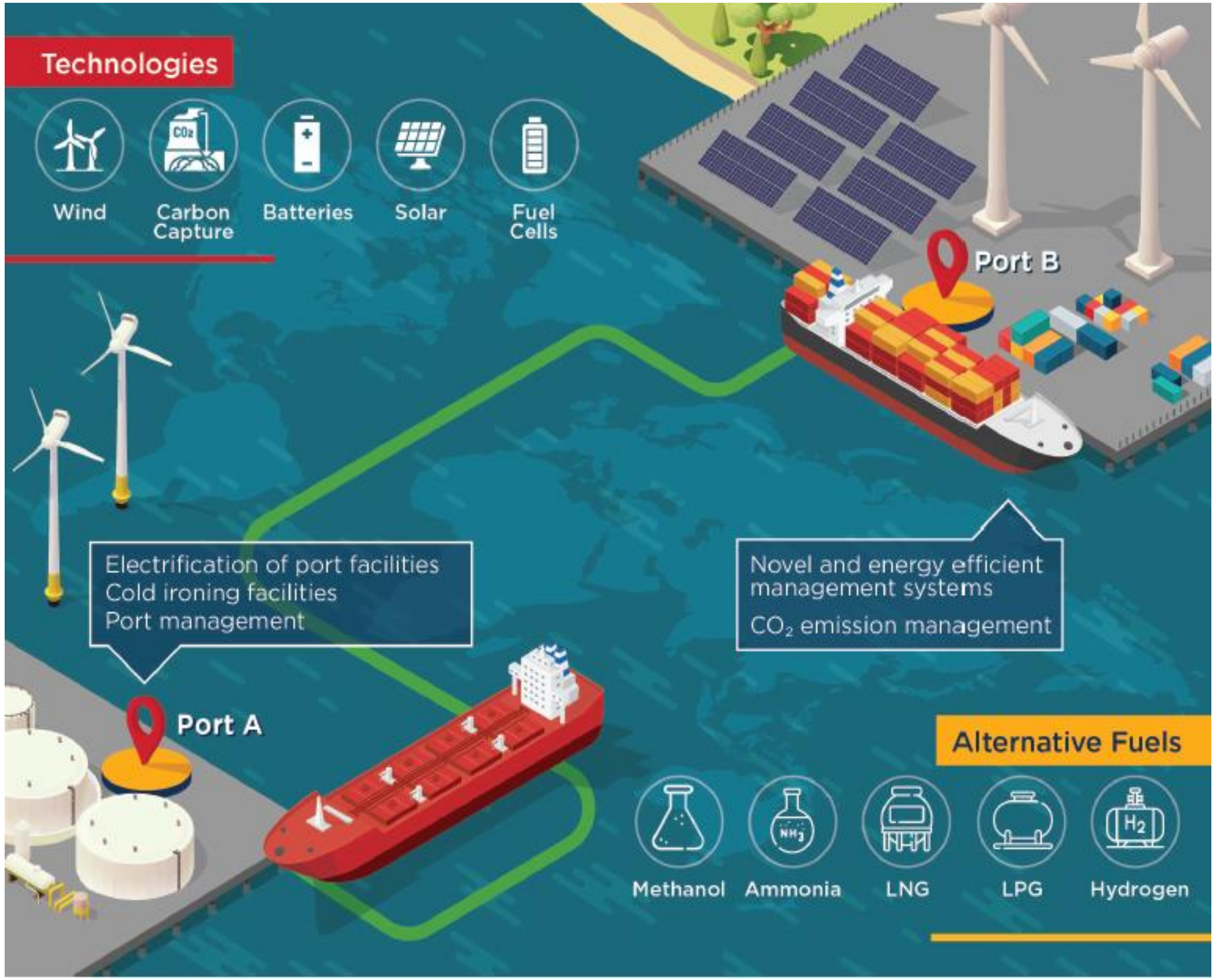
Vision of a Green Corridor

- Decarbonization pathways involve accelerating operational efficiencies and deploying alternative fuels at scale.
- The industry is diverse, disaggregated and globally regulated.
- Help shrink the challenge of coordination between stakeholders down to a more manageable size while retaining scale.
- Any combination of these fuels and technologies could apply based on the techno-economic feasibility of the corridor in question.



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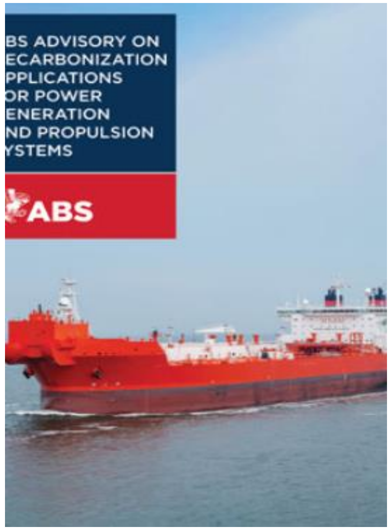
Our Recent Publications

Sustainability Whitepaper 2021: Hydrogen as Marine Fuel

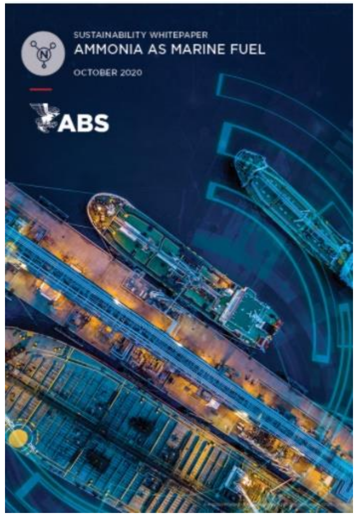
Sustainability Whitepaper 2021: Biofuels as Marine Fuel

View of the Value Chain (2021): Low Carbon Shipping



Advisory on Decarbonization Applications for Power Generation & Propulsion Systems

Sustainability Whitepaper 2021: Methanol as Marine Fuel



Sustainability Whitepaper 2021: Ammonia as Marine Fuel

Please visit: www.eagle.org/sustainability

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