Overview of existing and future fuels

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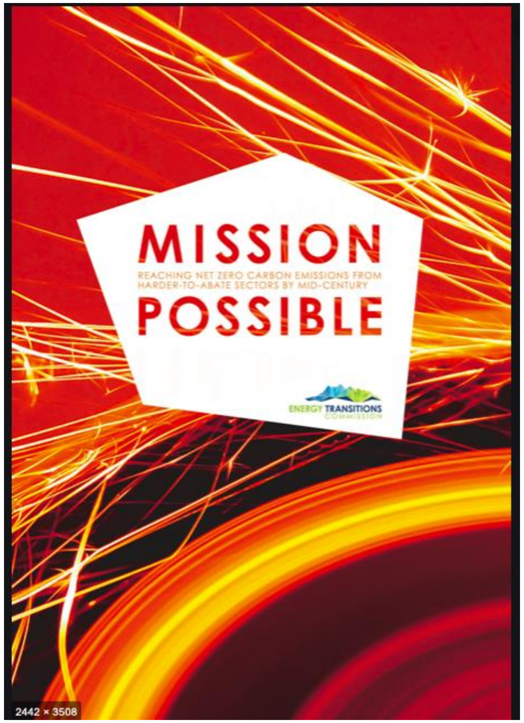
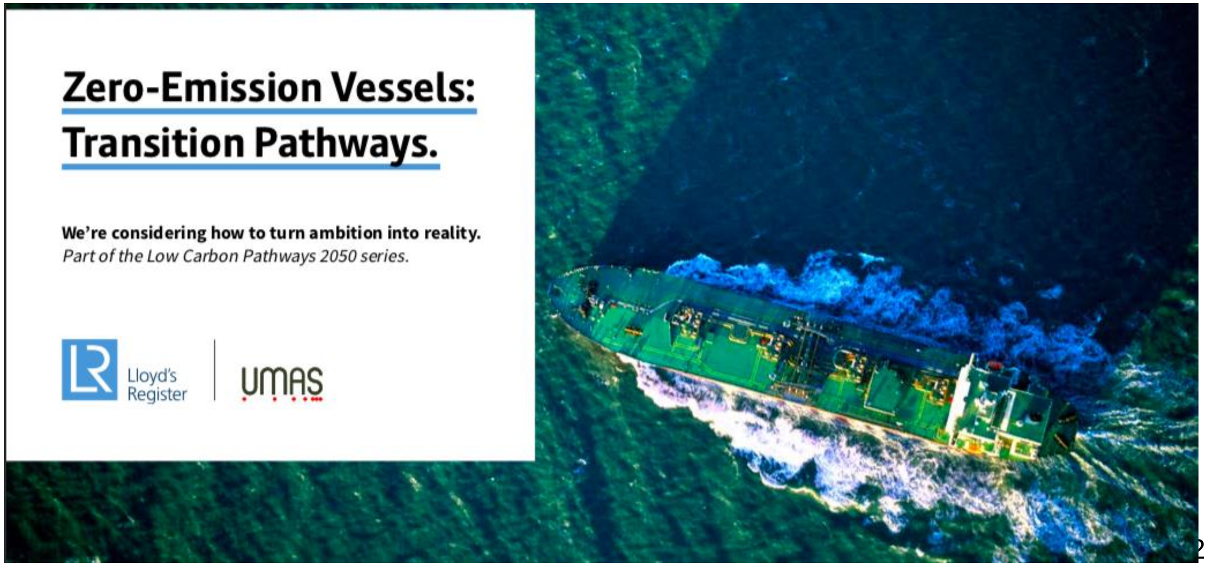
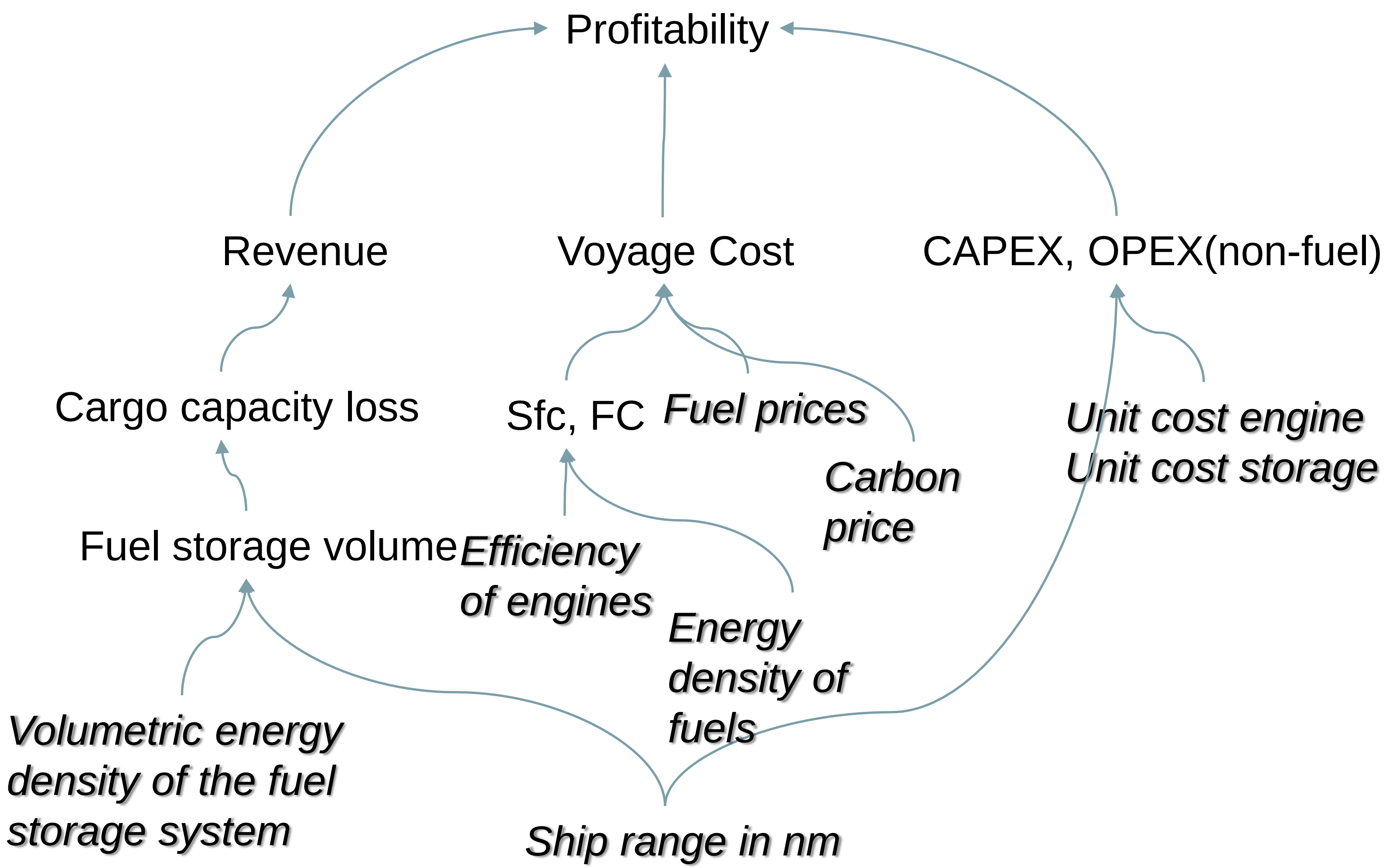


A joint Maersk and LR study has researched the best fuels to develop into net-zero fuels

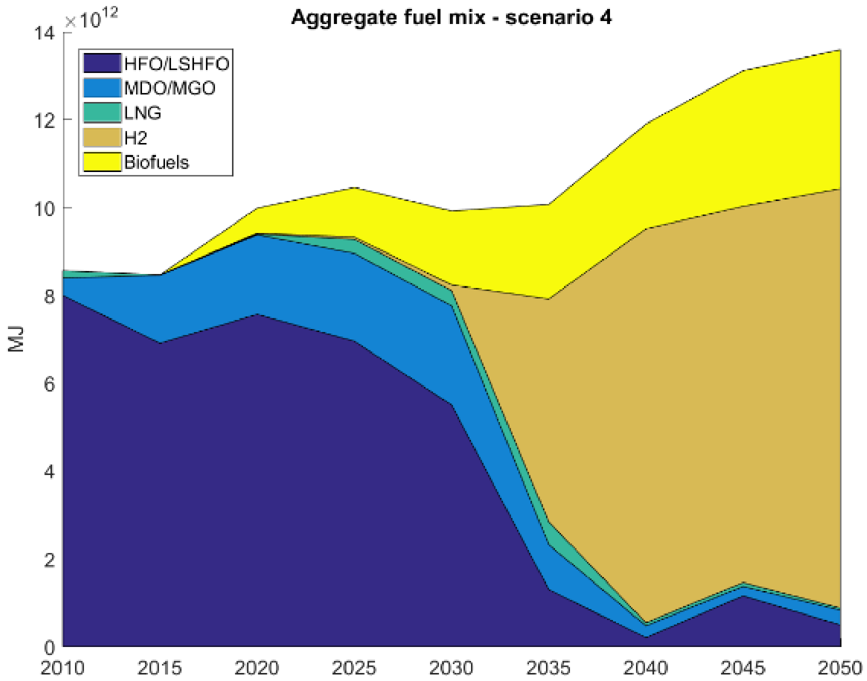
Maersk: ammonia, alcohol, biomethane best fuels to reach net-zero emissions



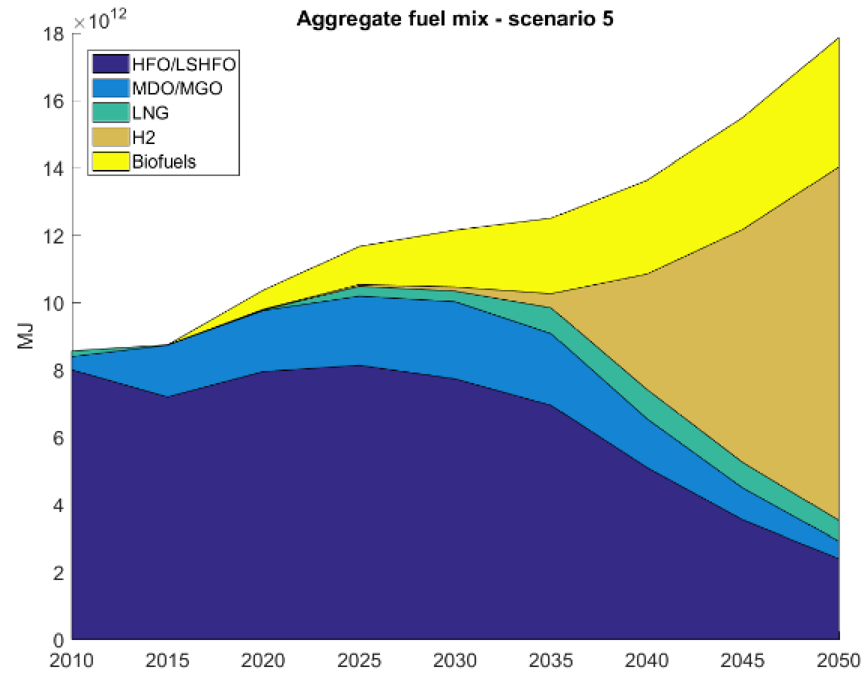
Assessing the profitability of ZEVs



Fuel Mix – possible scenarios for 1.5 and 2 degrees



1.5 degrees

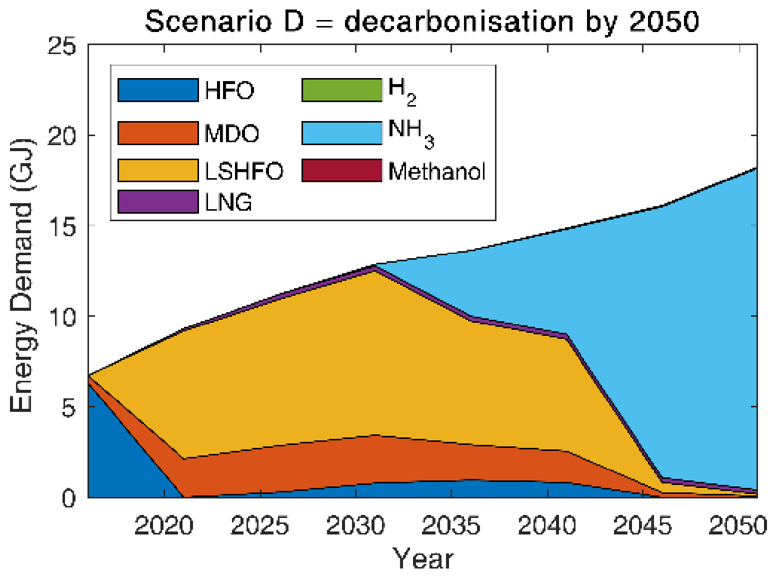


2 degrees

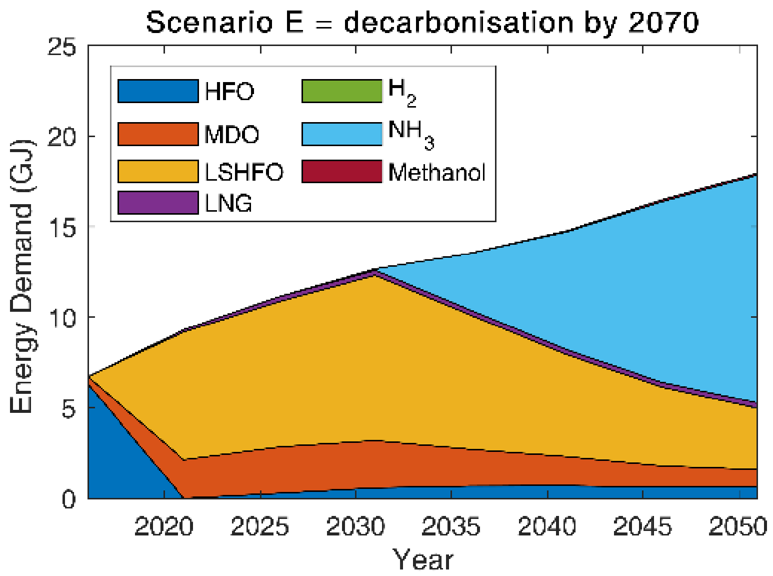
Danish Shipping (2016) / MEPC 71 Belgium et al.

A hydrogen carrier (e.g. ammonia) will have a 75-99% market share by 2050

2050 decarbonization (1.5ºC aligned)
GJ



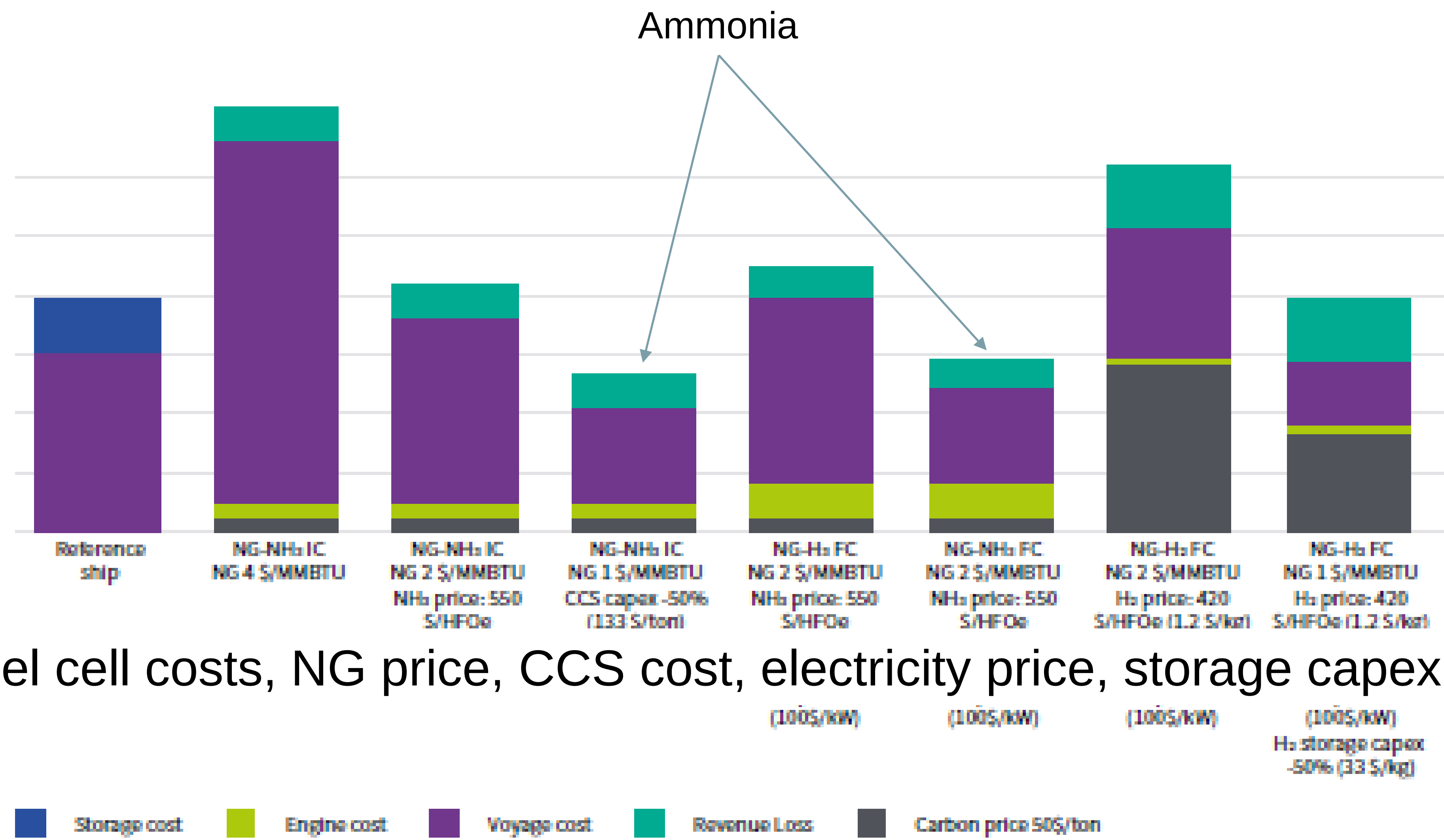
2070 decarbonization (IMO aligned)
GJ



The scenarios suggest ammonia is likely to represent the least-cost pathway for international shipping

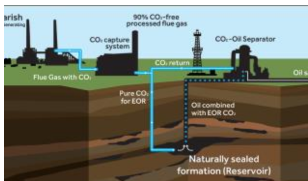
Source: UMAS GloTraM (2019)

Ammonia appears to consistently be a robust preferred solution



Fuel cell costs, NG price, CCS cost, electricity price, storage capex e

Future fuel



Blue – NG+SMR+CCS

Green – Elec+H2O+Electrolyser

Nitrogen carrier (ammonia)
80% of air

Carbon carrier (synth hydrocarbon)
0.04% of air

Pure (liquefaction)

Make some hydrogen

Manipulate the hydrogen

Green ammonia production

Renewable electricity + electrolyser + haber bosch = green ammonia

$340/t ammonia (~$800/t) by 2030?

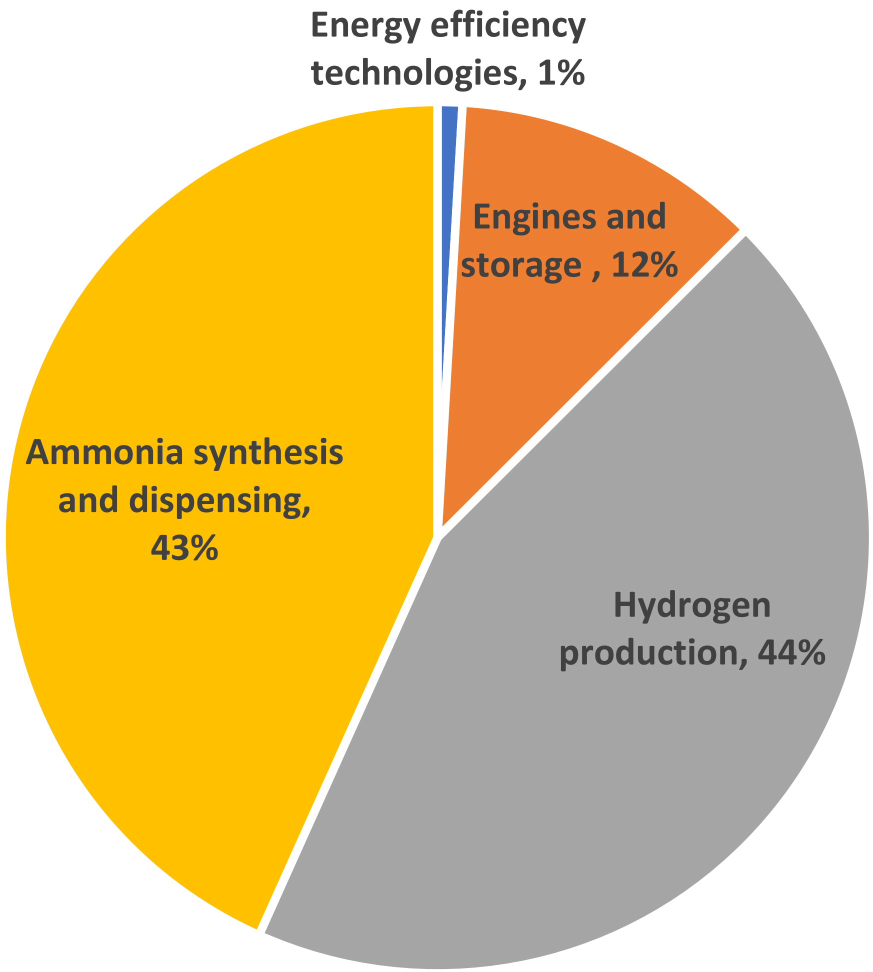
Direct air capture

~1000 to 100 $/t of CO_2 captured

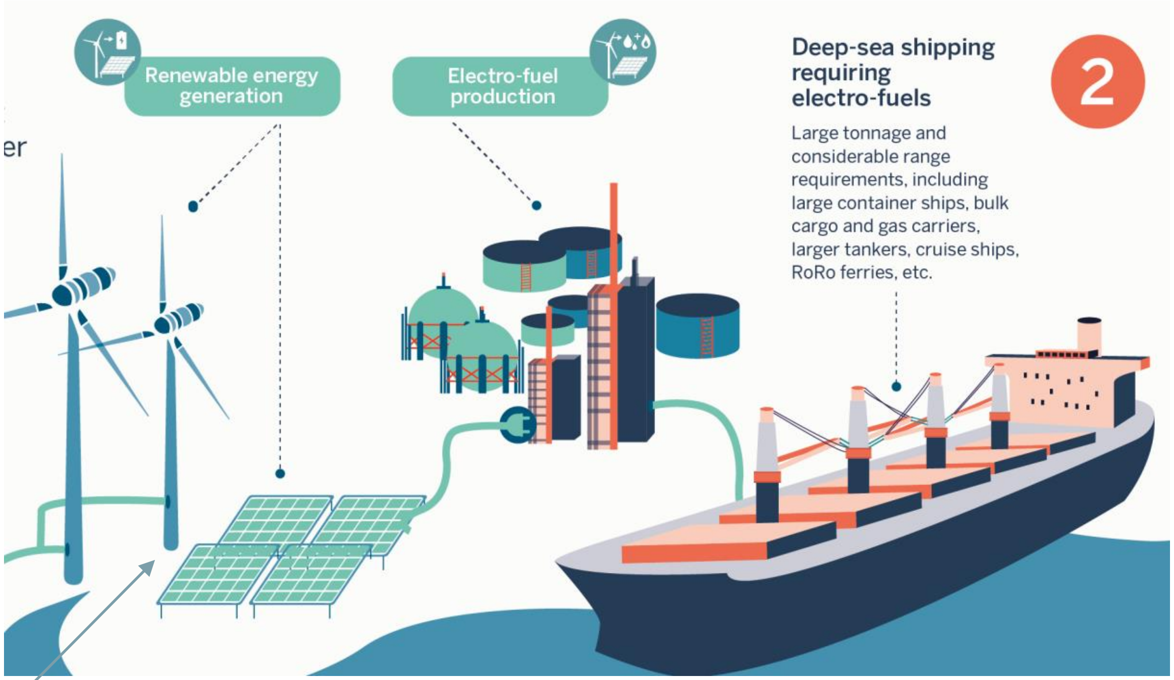
Trade offs

- Ammonia $/MJ is always cheaper than synth hydrocarbons in our scenarios
- But ammonia less energy dense and this can trade off some of the advantage in terms of ship total operating cost, but depends on how bunkering strategy is played
- On “best available science”
  - Ammonia looks best bet
  - Should keep an eye on cost/viability of DAC in case this heads to lower bound limits
- Beware the post-hoc rationalisers…

Overall capital costs for 50% GHG reduction by 2050 are ~$1trillion broken down as:



Policy and carbon pricing…



IMO doesn't regulate this

IMO regulates this

- Need to think how IMO policy could stimulate fuel production decarbonization
- We think traceability/certification of fuels (e.g. spec. in BDN) may be needed

Public		Private
Govt. provide risk capital/guarantee	2020	R&D, trials and pilot projects
IMO sends very clear signal on projected quantities of non-fossil fuel	2023	Very shortlist of long-run solutions
Latest date for IMO adoption of clear policy driver for switch from fossil	2025	Solid investment cases formed on expected IMO policy
IMO and govts. clear on incentivization of upstream decarbonisation	2028	Fleet and infrastructure investment flowing
IMO clear on incentivization of upstream	2030	Zero roll-out

Concluding remarks

- We can make good estimates today (PP, BAS)
- We need a hydrogen carrier, we likely need both electrolysis and natural gas (with CCS) production pathways
- Synthetic hydrocarbons should not be completely discounted, and shouldn't be the assumed solution
- The big challenge is on land not on sea
- This is an extra headache for IMO that I don't think is being thought about much

Thank you very much

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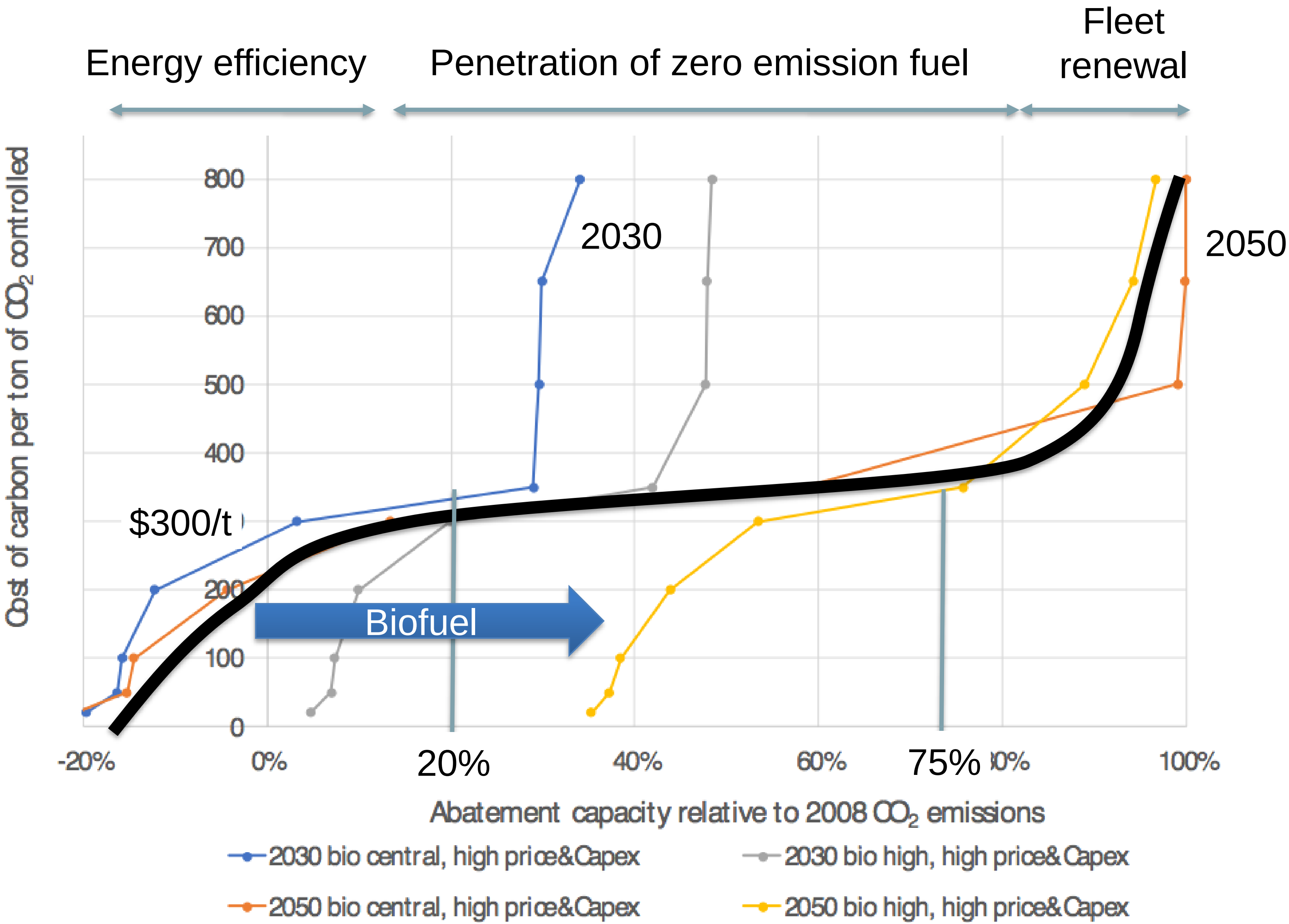
Fuel costs/prices are derived from estimates of their production pathways and specific assumptions for each component/process

E-H2	E-NH3	E-METHANOL	E-DME	E-GASOIL	E-LNG	ELECTRICITY	NG-H2	NG-NH3
Water Treatment	Water Treatment	Water Treatment	Water Treatment	Water Treatment	Water Treatment	Battery storage	Steam methane reforming	Steam methane reforming
Electrolysis	Electrolysis	Electrolysis	Electrolysis	Electrolysis	Electrolysis	Transmission	CCS	CCS
Compression	Air Separation	Carbon Capture (DAC)	Carbon Capture (DAC)	Carbon Capture (DAC)	Carbon Capture (DAC)	Converters	Compression	Air Separation
Storage	Haber-Bosch	MeOH Synthesis	DME Synthesis	Hydrocarbons Synthesis	Methanation		Storage	Compression
Liquefaction	Refrigeration and storage	Storage	Storage	Storage	Liquefaction		Liquefaction	Storage
Liquid storage at port / dispensing					Storage		Liquid storage at port / dispensing	Haber-Bosch
								Refrigeration and storage

Machinery further work needed and areas to reduce costs

- Optimising use of hydrogen in main engines
- Optimising use of ammonia in main engines
- Efficiently controlling NOx in hydrogen/ammonia combustion
- Capture of ammonia slip from ammonia combustion
- Onboard cracking of ammonia for hydrogen
- Cost and life improvement for PEM FC
- Cost improvement and ammonia use for SOFC
- Safety

High renewable fuel price



Low renewable fuel price