The role of hydrogen and synthetic fuels

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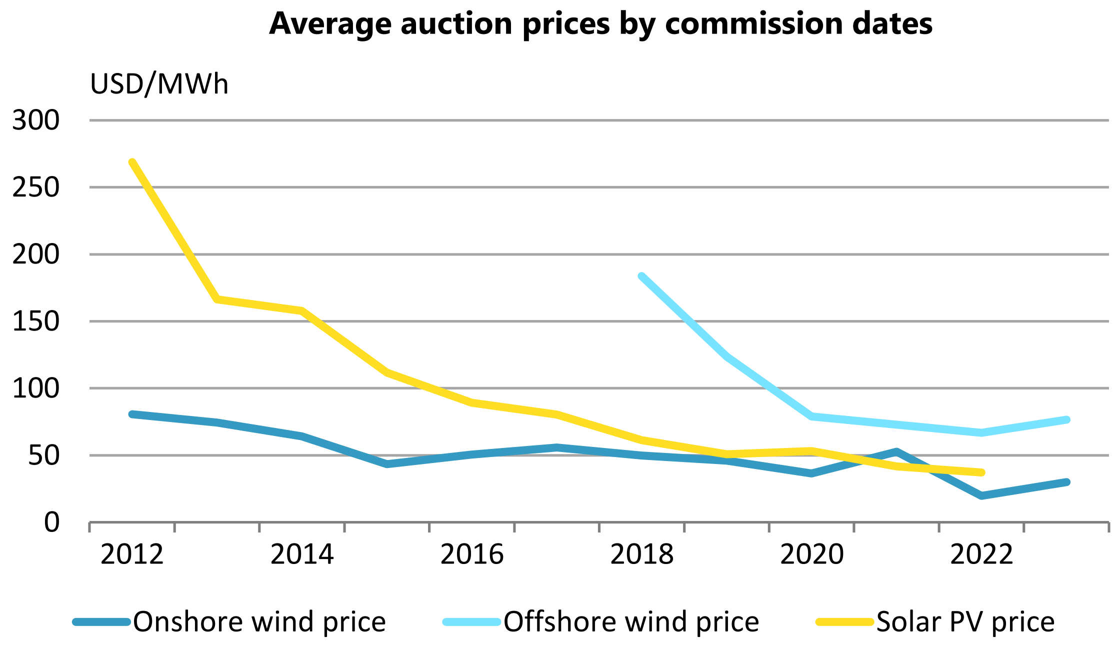
Prospects for energy and maritime transports in the Nordic region

World Maritime University, Malmö, Sweden, 26 February 2020

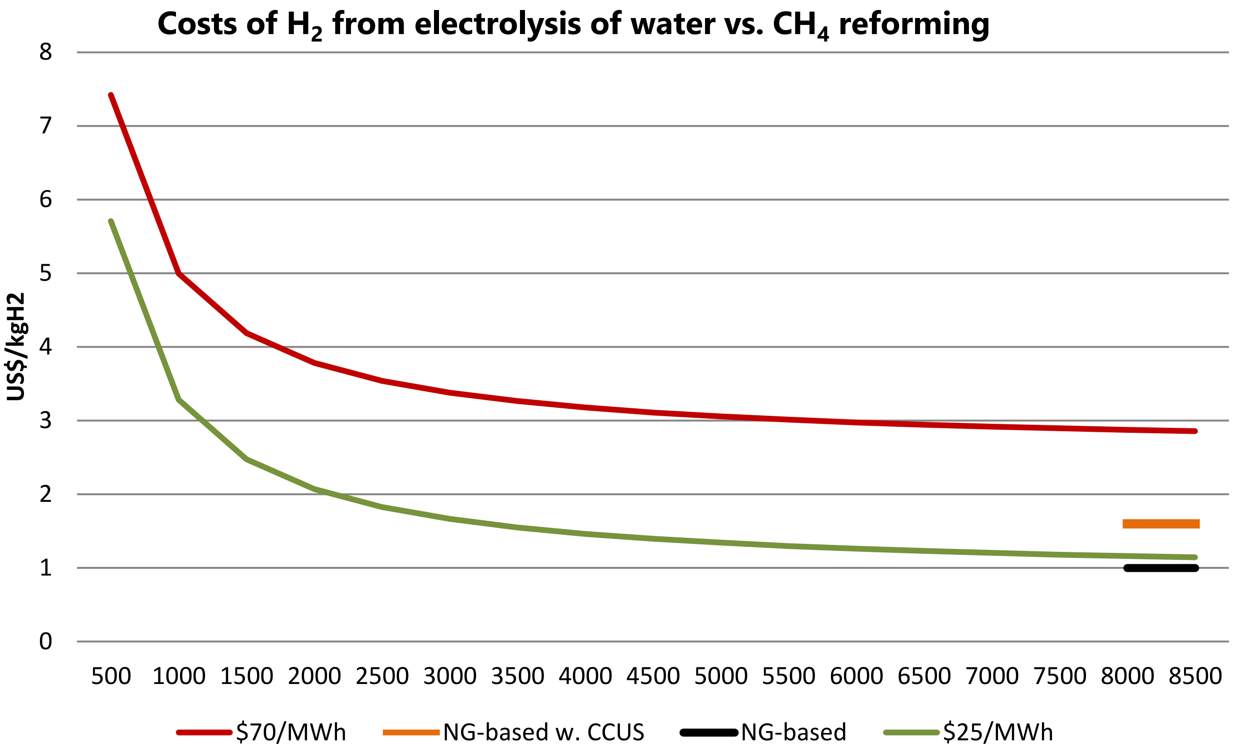
The emergence of low-cost renewable power is a game-changer



Source: IEA, *Renewables 2017*

The cost decline of solar and wind power opens up new possibilities for global decarbonization through electrification of energy end-uses – directly of via hydrogen production by electrolysis

Hydrogen from electrolysis close to compete with grey hydrogen



Source: Adapted from IEA 2017, *Renewable Energy for Industry*

The cost of green electricity dominates that of hydrogen with sufficent electrolyser capacity factor – and keeps plumetting

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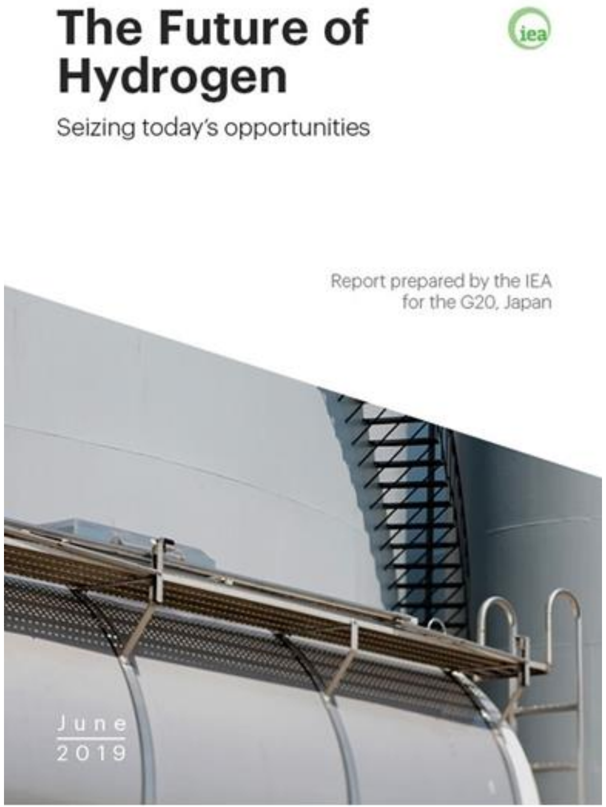
Dr. Fatih Birol, IEA ED, G2O Ministerial, Japan, 14 June 2019

"Hydrogen can help overcome many difficult challenges:

- ***Integrate more renewables***, including by enhancing storage options and "exporting sunshine & wind" from places with abundant resources
- ***Decarbonize "hard to abate" sectors*** – steel, chemicals, trucks, ships & <u>planes</u>



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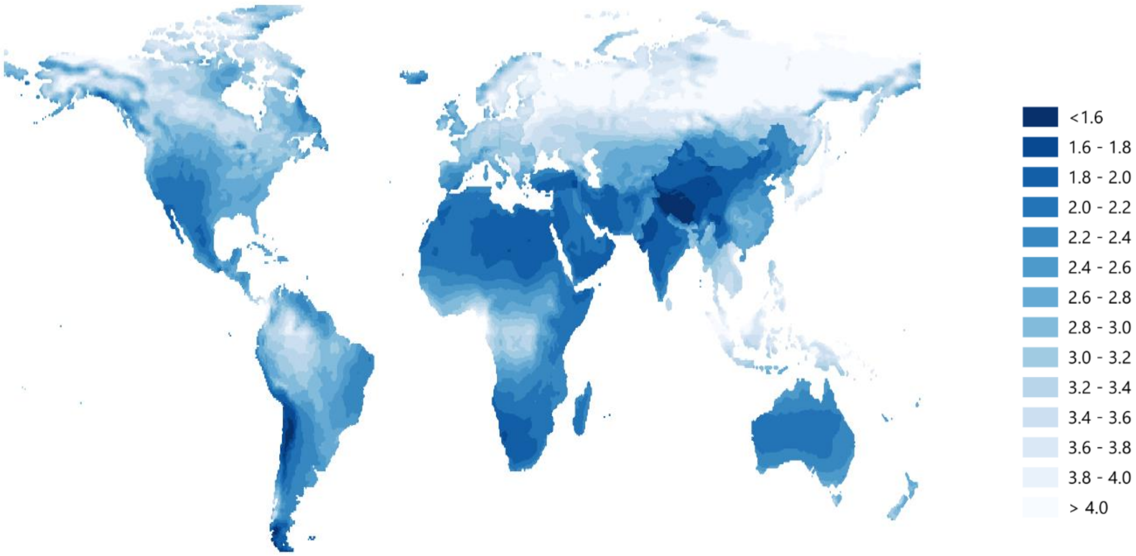
The future of energy cargoes – 45% of all cargoes

- Hydrogen-rich feedstocks and fuels, easy to store and ship, will be traded over seas
- Ammonia for shipping and balancing thermal power plants, methanol for the chemical industry, synfuels for aviation… Hot-briquetted iron… Scrap of various kinds…
- Still, electrification of final energy demand and transition to renewables will *reduce* the volume of international energy trade, as more energy will be supplied close to consumption

Green hydrogen costs are set to decline



Source: IEA 2019

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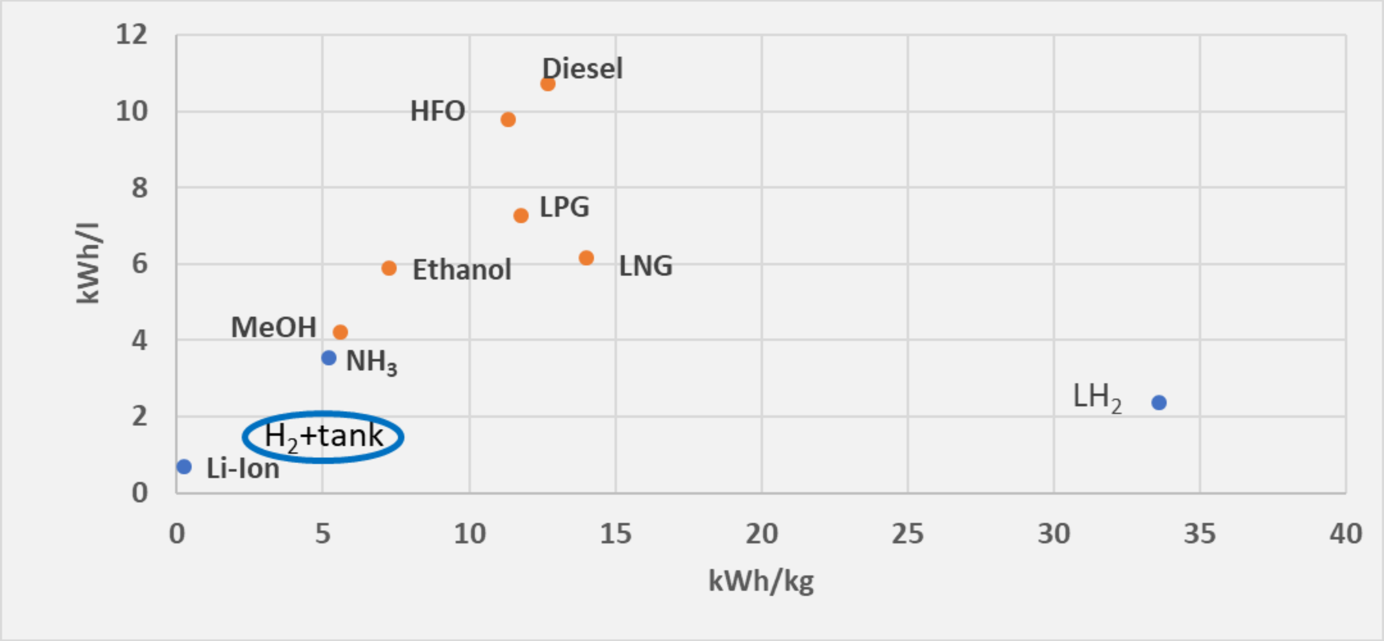
Rivalling with the energy of fossil fuels is no easy task

Specific energy and energy density of various fuels for shipping



Only biofuels could be carbon-neutral « drop-in » fuels requiring no change on the ships

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The consensus on ammonia in shipping is growing by the day

Viking Energy will run on FC with Ammonia

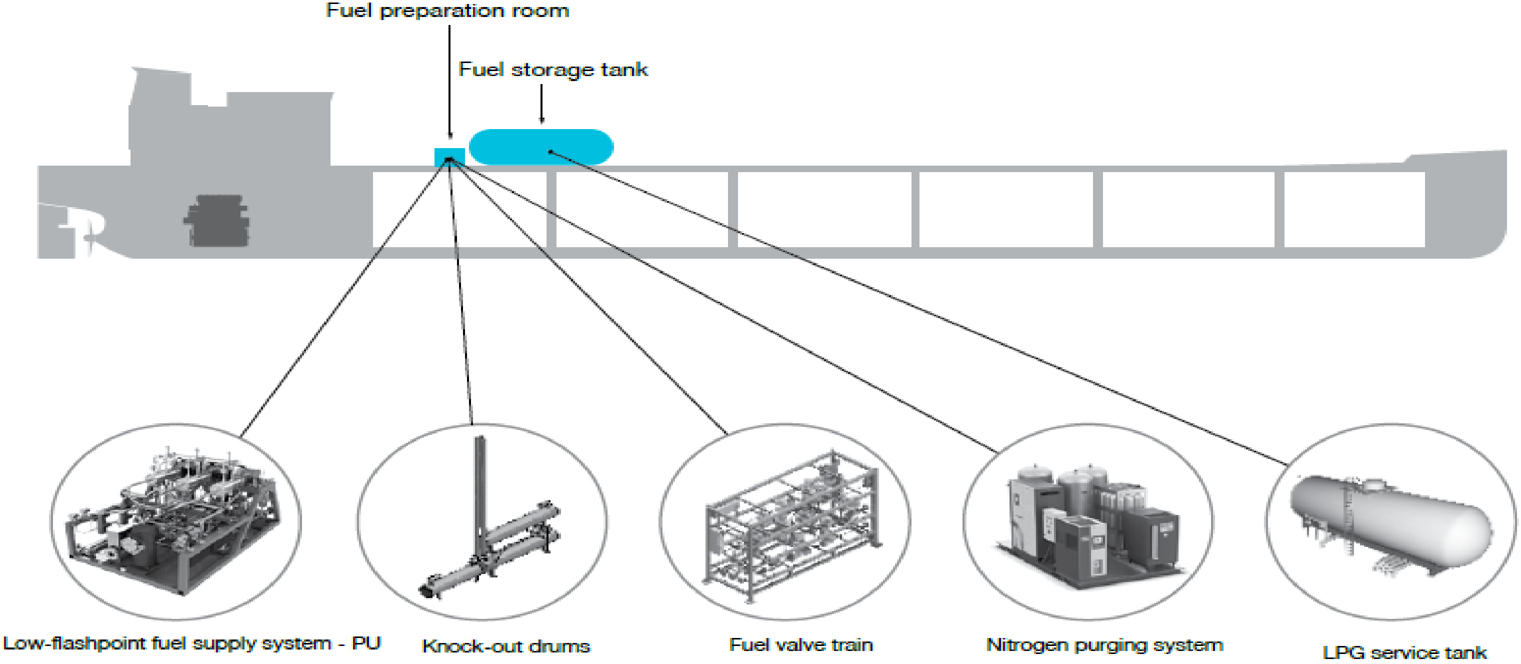
Alternative fuels seen by Korean Register

Type	MGO	LNG	Bio gas	Bio diesel	Methanol	Ammonia	Hydrogen
Fuel type	Fossil fuel		Carbon-neutral fuel				
Storage condition	Ambient temperature and pressure	-161.6℃	-161.6℃	Ambient temperature and pressure	Ambient temperature and pressure	-33.6℃ or 10bar	-252.8℃
Relative Fuel Tank size[27]	1	2.3	2.3	1	2.3	4.1	7.6
Relative CAPEX	1	~1.3	~1.3	1	~1.15	~1.2	Very expensive
Fuel cost & Availability	Less expensive and rich reserves		Difficult to mass produce due to the fuel sourcing problem	Difficult to forecast the price due to unstable supply and demand and the food security problem	High cost of CO_2 capture* (when capturing CO_2 from air)	Expensive but relatively low priced for carbon-neutral fuel	Reasonable fuel production cost but high storage and transport costs

*Although it is possible to lower the cost by capturing carbon dioxide from combustion gas (exhaust gas from power plants), it is not the carbon–neutral fuel since it uses carbon dioxide produced by fossil fuel.

Excellent   Acceptable   Undesirable

Modern engines can be adapted to ammonia – at a cost



Source: MAN ES, 2019, *Engineering the future two-stroke green-ammonia engine*

On-board storage will be larger, and injection system of dual-fuel engines further adjusted; ammonia combustion will be facilitated by <5% diesel… or H_2 easily extracted from NH_3

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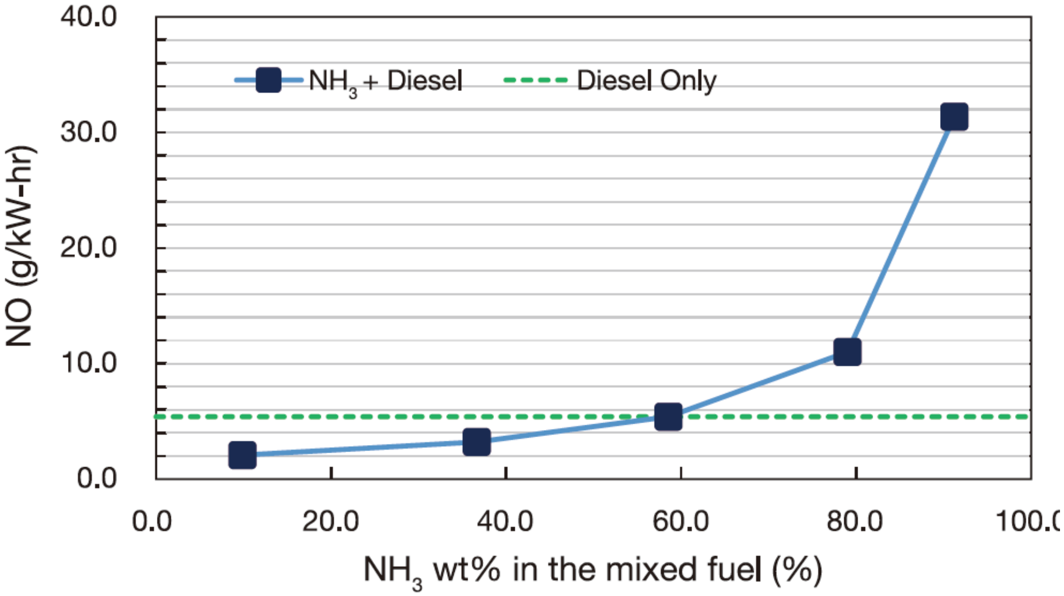
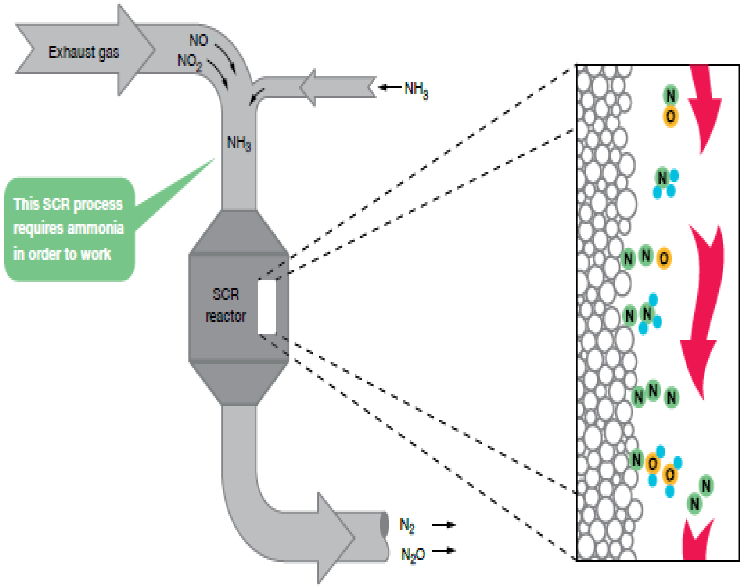
Beyond 60% NH_3 in the mix, NOx emissions must be addressed



Source: Korean Register, 2020, *Forecasting the Alternative Marine Fuel - Ammonia*



Source: MAN ES, 2019

Ammonia is the main fuel, provides the auxiliary fuel *and* the additive for reducing NO_x emissions

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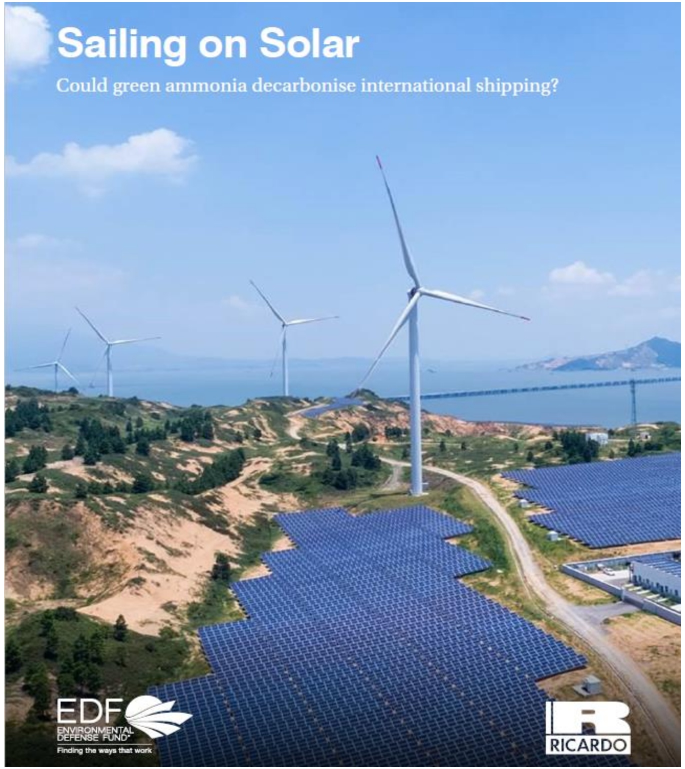
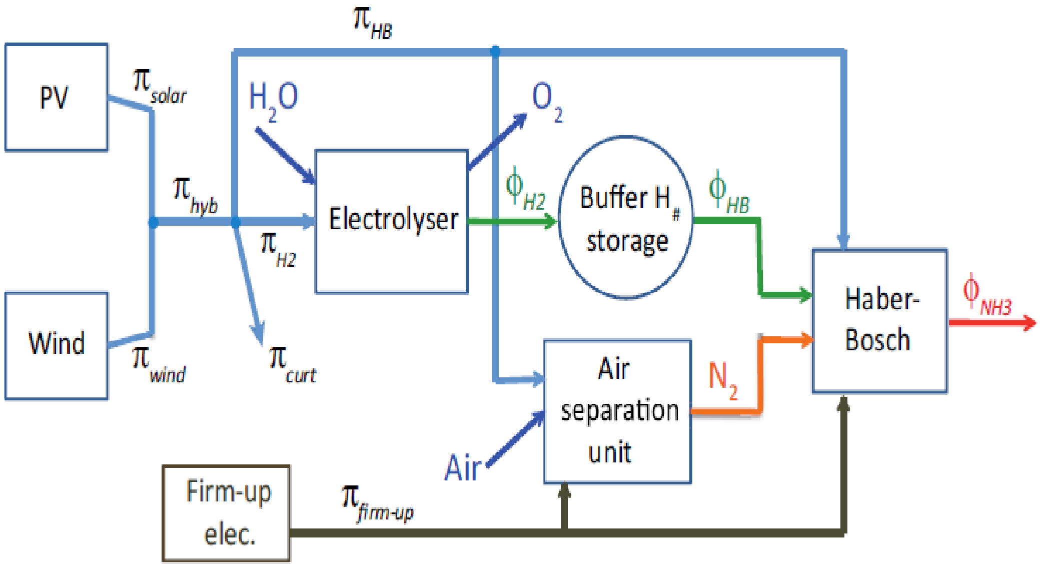
All-electric ammonia production is proven technology

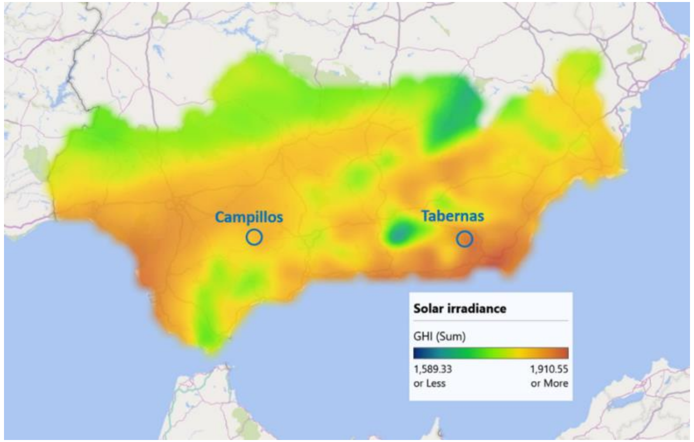


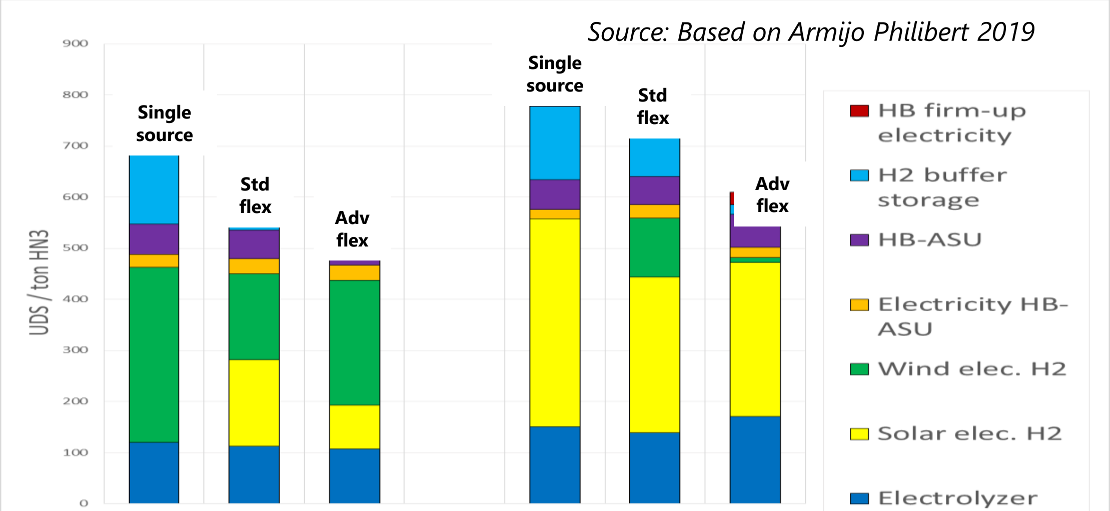


Source: Armijo Philibert, 2019, « Flexible production… », *International Journal of Hydrogen Energy*

Ammonia was produced from hydropower from 1920 to 1990.
The sole novelty is the variability of solar and wind power, which can be addressed

Green ammonia can soon compete with grey ammonia…





Campillos **Tabernas**

Costs	Campillos	Tabernas
Solar (€/MWh)	36	31.6
Wind €/MWh)	36.5	56.6
CF electrolysers	*53.9%*	*33.7%*
Hydrogen (€/kg H_2)	2.44	2.68

- Hybridization improves the CF of electrolysers , reduce curtailment, H_2 storage & firm-up power
- Advanced HB flexibility further reduces curt. & H_2 storage, increases share of the cheapest resource, but reduces CF of electrolysers & H.B. loop

Based on a detailed hourly analysis

… but remains significantly costlier than HFO/MGO

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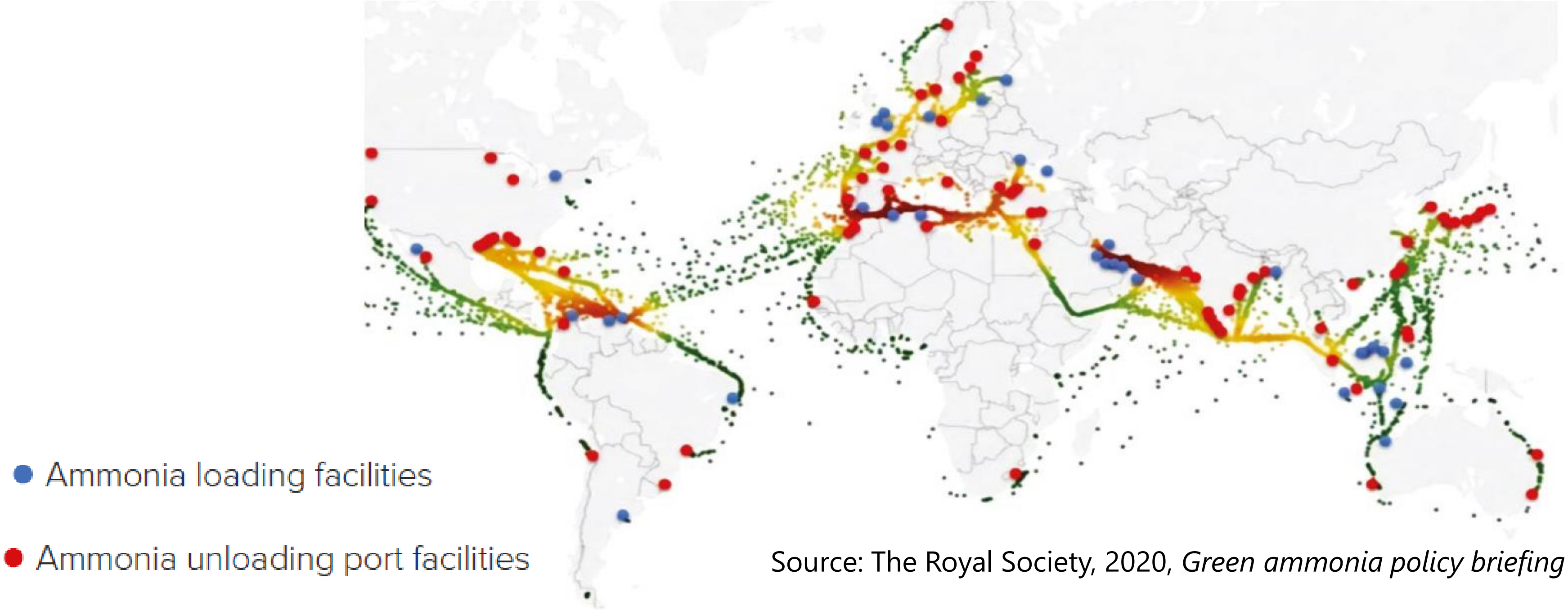
Ammonia is a global commodity

Ammonia shipping infrastructure, including a heat map of liquid ammonia carriers and existing ammonia port facilities



Source: The Royal Society, 2020, *Green ammonia policy briefing*

180 Mt ammonia is produced every year, of which 10% is internationally traded

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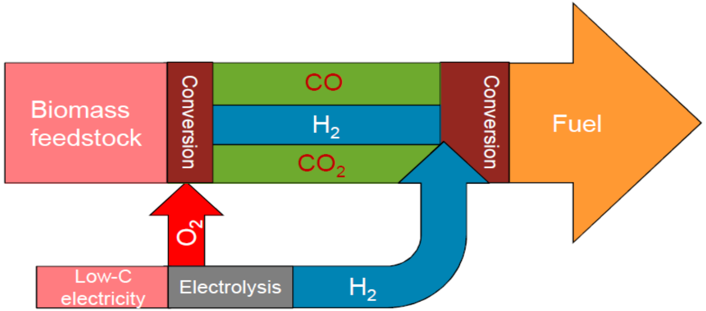
Why not Power&biomass-to-liquid fuels?

- Biomass is mostly used in heat and power. Increased sustainable biomass yield can deliver more transport fuels
- Power & biomass-to-liquid (PBtL) fuels (based on hydrogen) make better use of biomass, almost quadrupling the output
- However, aviation requires the specific energy and energy density of HCs
  - The fuel fraction of long haul airliners is ~45% of maximum weight @ take-off
  - Weight-compounding effect does not allow heavier fuels to replace HCs
- Aviation can support the higher costs of Power & Biomass-to-liquid (FT) fuels



- Power & Biomass to liquid may cover the carbon needs of aviation and petrochemicals
- Direct Air Capture is another possible CO_2 source, with a wide range of cost estimates…
- BECCS and DACCS needed to get to net zero
- Procurement and costs of carbon-neutral renewable synfuels are rather uncertain for maritime and terrestrial transportation

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Enough electricity to power international shipping?

- Marine fuels demand expected by 2040 ~5.8 mboe/d (3600TWh/y)
- ≠aviation, no modal shift would help: maritime transport is most efficient
- Fuel cost increase due to would not significantly affect shipping volume
- Production of ammonia of lhv 3600 TWh would require primary green electricity production of 6500 TWh
- This represents 25% of global electricity generation in 2018
  - 3.5 times global solar and wind generation (1860 TWh) in 2018
  - The Sustainable Development Scenario has 16 300 TWh from solar and wind by 2040 not including additional demand from shipping (nor aviation, etc…)
  - The IEA recently re-assessed the potential for offshore wind power

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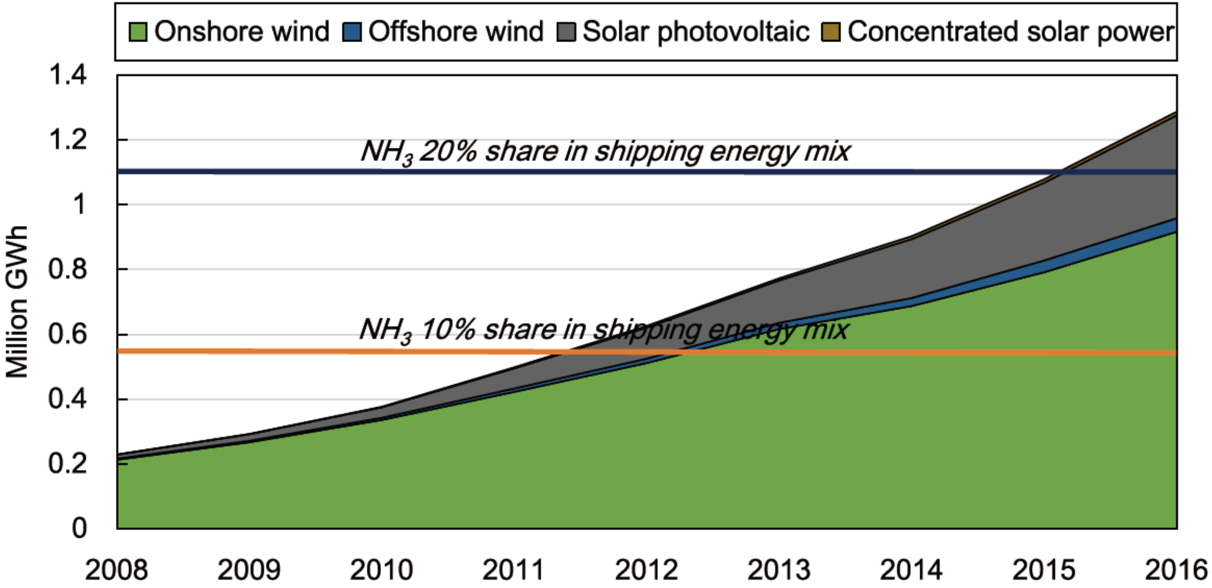
The sector seems to trust that renewables will deliver

« *Solar and wind generations are particularly growing fast with the growth rates of 31;3% and 15.8%, respectively, in 2016* »

Korean Register, 2020



Source: Korean Register, 2020, *Forecasting the Alternative Marine Fuel - Ammonia*

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From offshore wind to ammonia to ships

Vision of the Wärtsilä-led Zero Emission Energy Distribution at Sea (ZEEDS) initiative

Clean energy hubs would be installed in busy shipping corridors, optimising refuelling

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Gone with the winds?

Direct wind propulsion would be more efficient than through power generation, H_2 and NH_3…

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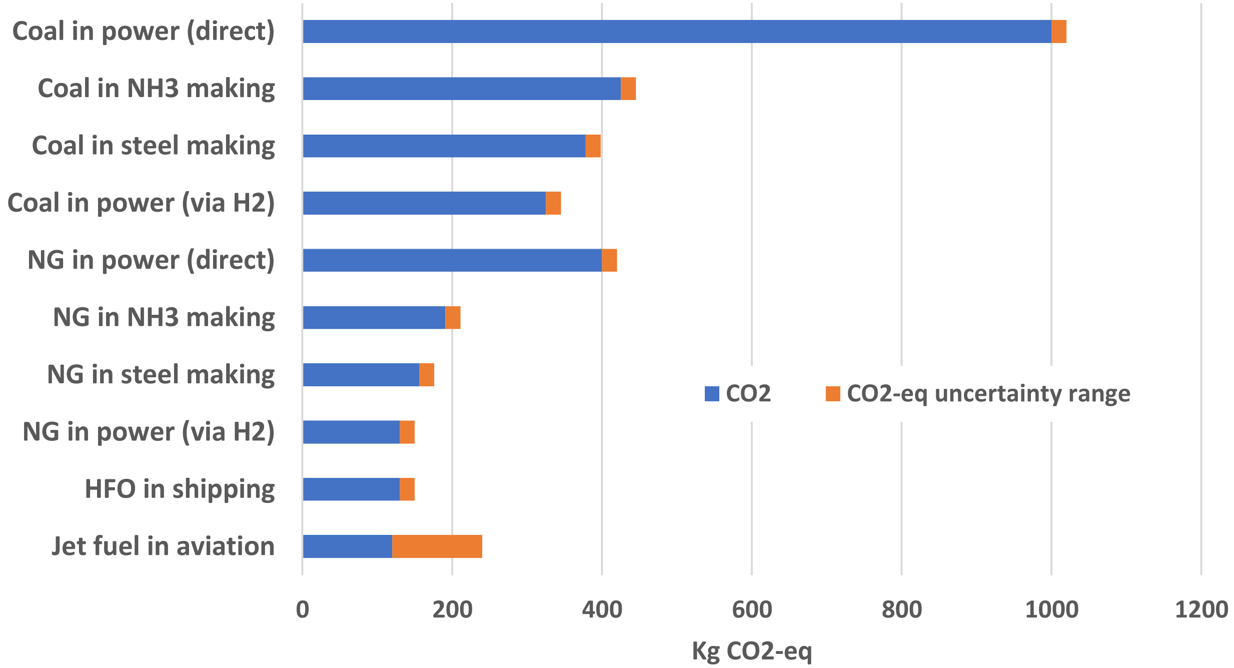
Decarbonisation of the power sector remains the priority

GHG emission reductions from substituting 1 MWh green power

Preliminary results
Work in progress



The case of aviation is the most uncertain due to carbon issues and uncertain non-CO_2 climate effects; shipping may come after power and industry

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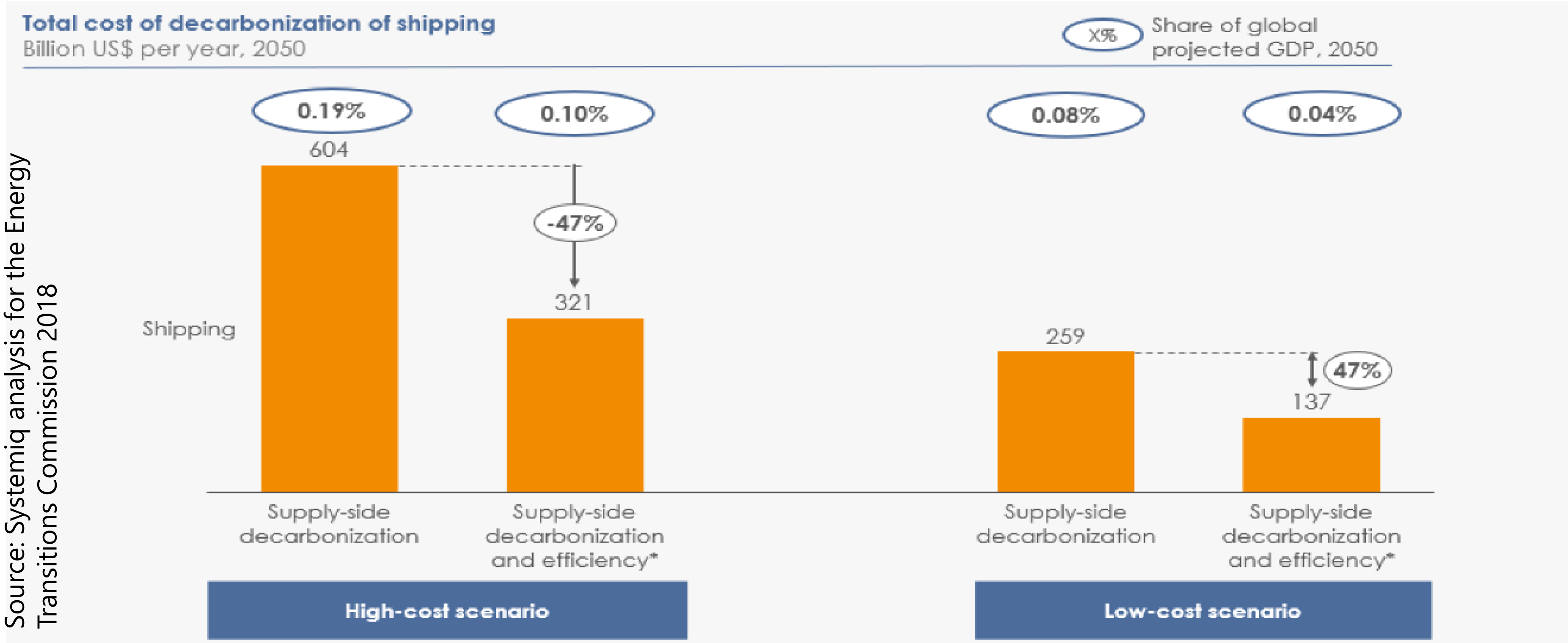
The world can afford the costs of decarbonisation



Source: Systemiq analysis for the Energy Transitions Commission 2018

Efficiency improvements can halve the costs of decarbonisation via renewable fuels
Impacts of green international shpping on most good prices will be lower than 1%

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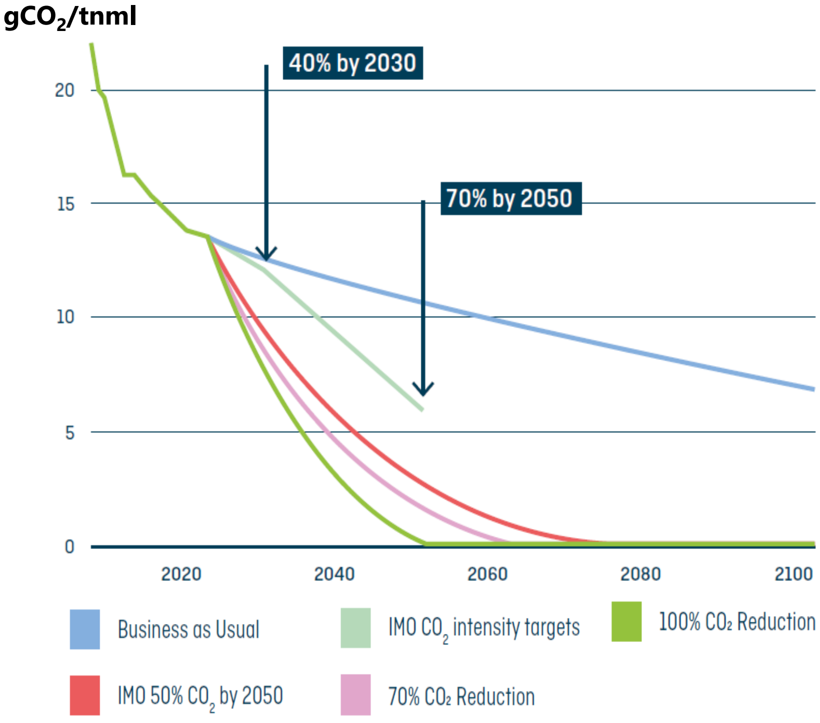
IMO's absolute target dominates over its intensity target

- IMO's Initial Strategy adopted April 2018 aims:
- *To reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008*
- *To reduce CO_2 emissions per transport work by at least 40% by 2030, pursuing efforts towards 70% by 2050 compared to 2008.*
- Depending on future demand for shipping services, the IMO Absolute Target and IMO Intensity Targets may or may not align.
- To enable alignment with climate goals (both IMO and Paris Agreement) the *Poseidon Principles* (a global framework for responsible ship finance) will be linked to the IMO Absolute Target



Source: *Poseidon Principles*, 2019

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Policy conclusions

- For long-haul vessels – bulk carriers, containerships and tankers – NH_3 in efficient two-stroke diesel engines is the best option for new ships and some existing ones
- Ammonia makes the case and policies for green shipping much simpler that those required for green aviation, notably as it involves no carbon atoms
- Decarbonising shipping and aviation with renewables must be additional to the decarbonisation of the power sector, the industry, buildings, other transport means
- *Green ammonia should be produced in regions with excellent renewable resources and no better local use for them, such as replacing coal in power systems*
- Cost increase is important for shipping but minor relative to the value of goods
- Governments may still consider translating the IMO targets with incorporation mandates, and elaborate consistent regulations for national/regional navigation

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