



The role of hydrogen and synthetic fuels

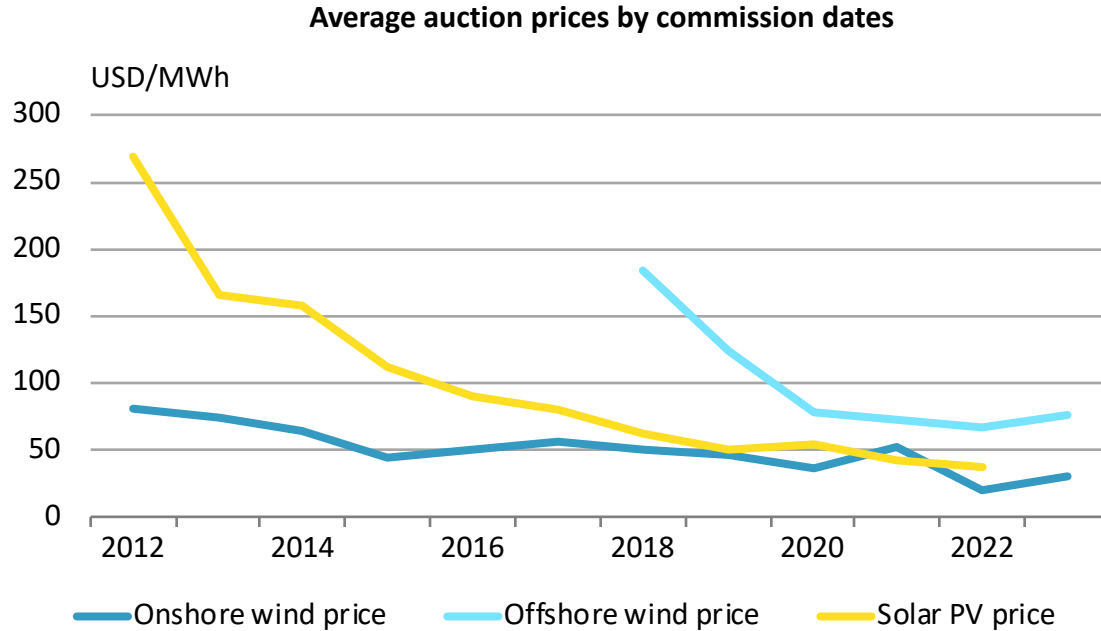
Cédric Philibert *former International Energy Agency senior analyst*



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



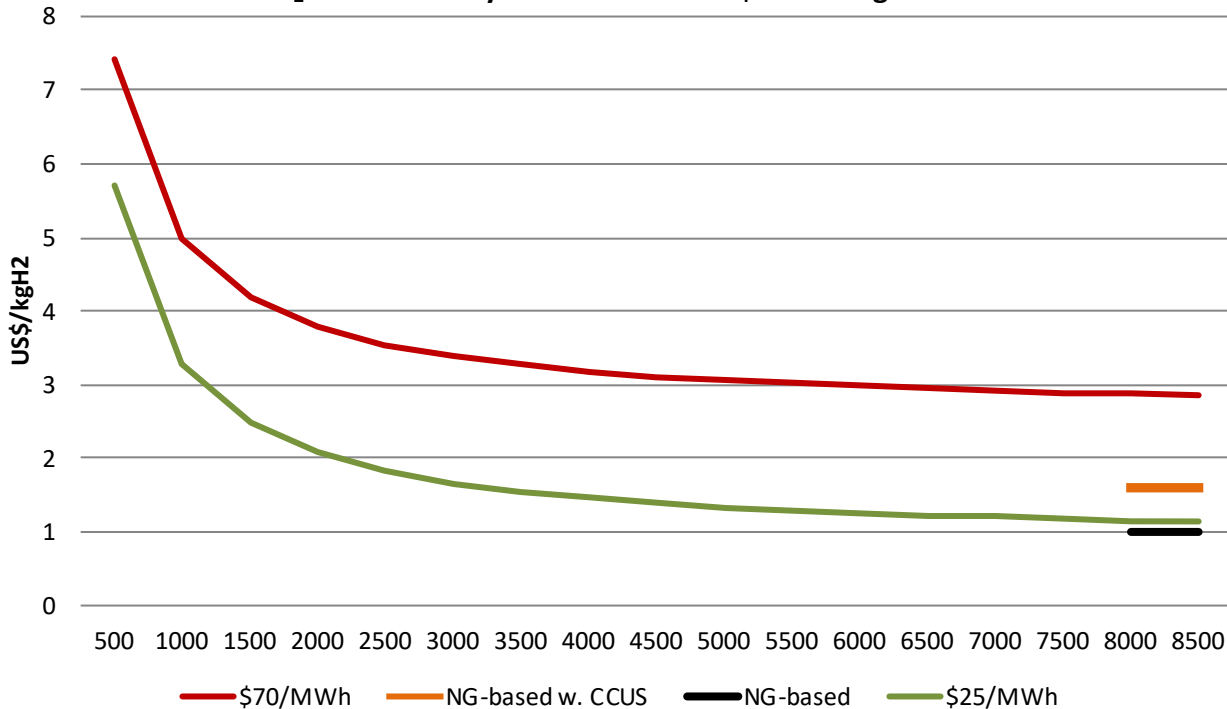
Source: IEA, *Renewables 2017*

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

Hydrogen from electrolysis close to compete with grey hydrogen



Costs of H₂ from electrolysis of water vs. CH₄ reforming



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

The cost of green electricity dominates that of hydrogen with sufficient electrolyser capacity factor – and keeps plummeting



“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 & planes

The Future of Hydrogen

Seizing today's opportunities



Report prepared by the IEA
for the G20, Japan

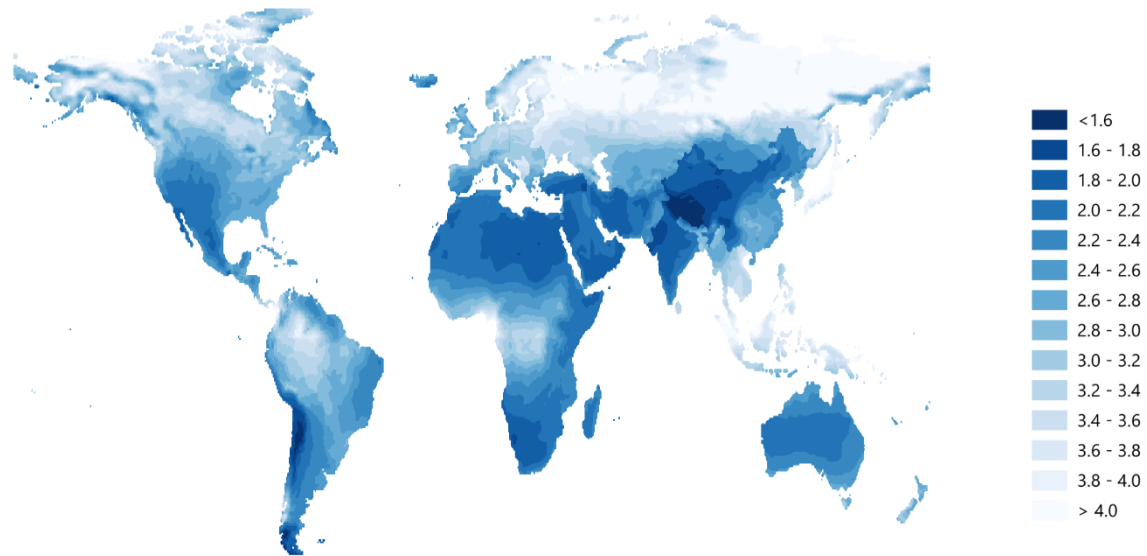




The future of energy cargoes – 45% of all cargoes

- 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

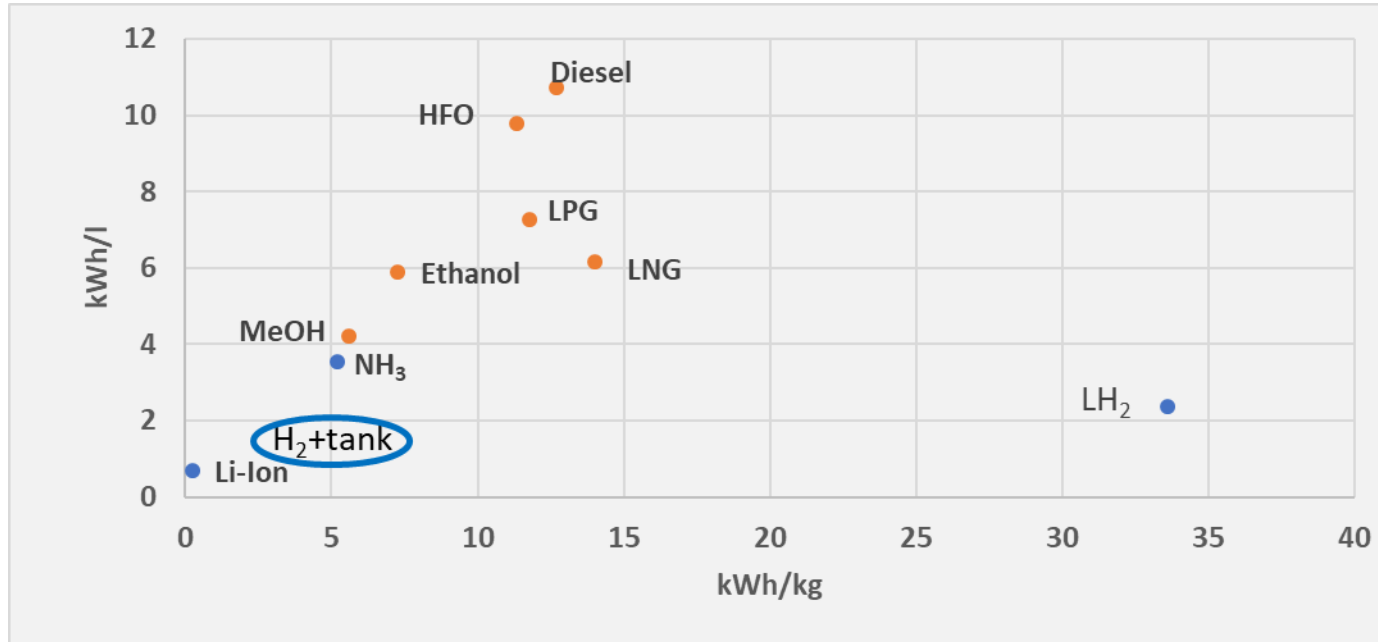


Source: IEA 2019

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

The consensus on ammonia in shipping is growing by the day



Engineering
the future
two-stroke
green-ammonia
engine

MAN Energy Solutions
Future in the making



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°C	-161.6°C	Ambient temperature and pressure	Ambient temperature and pressure	-33.6°C or 10bar	-252.8°C
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

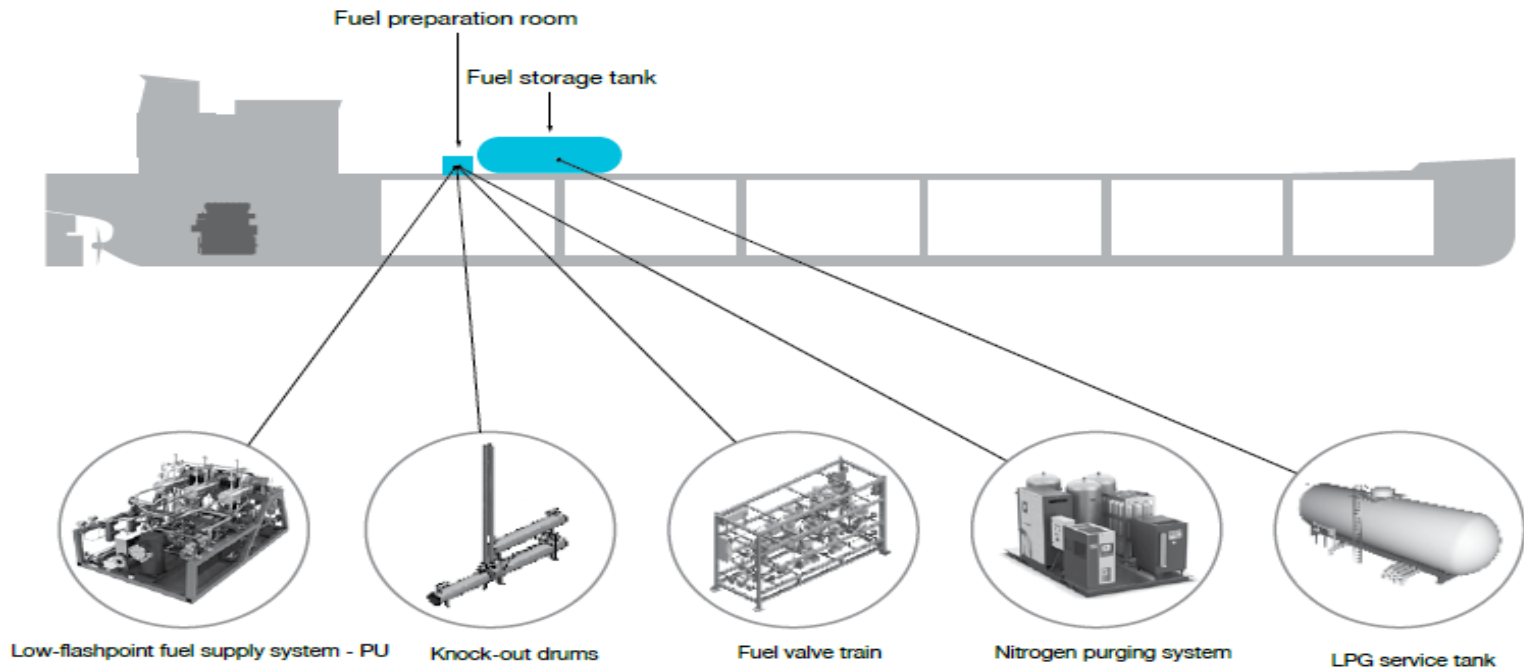


Acceptable



Undesirable

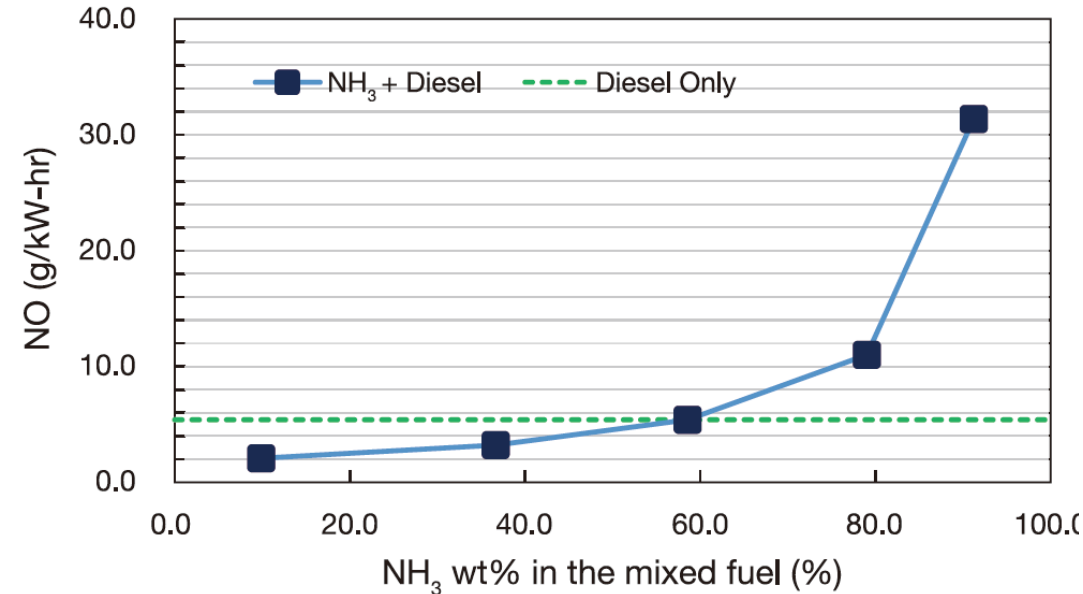
Modern engines can be adapted to ammonia – at a cost



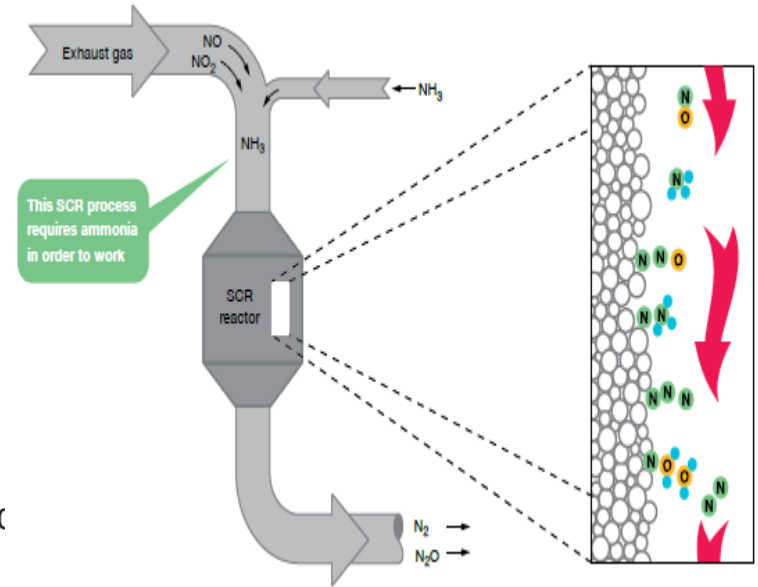
Source: MAN ES, 2019, *Engineering the future two-stroke green-ammonia engine*

On-board storage will be larger, and injection system of dual-fuel engines further adjusted; ammonia combustion will be facilitated by <5% diesel... or H₂ easily extracted from NH₃

Beyond 60% NH₃ in the mix, NO_x emissions must be addressed



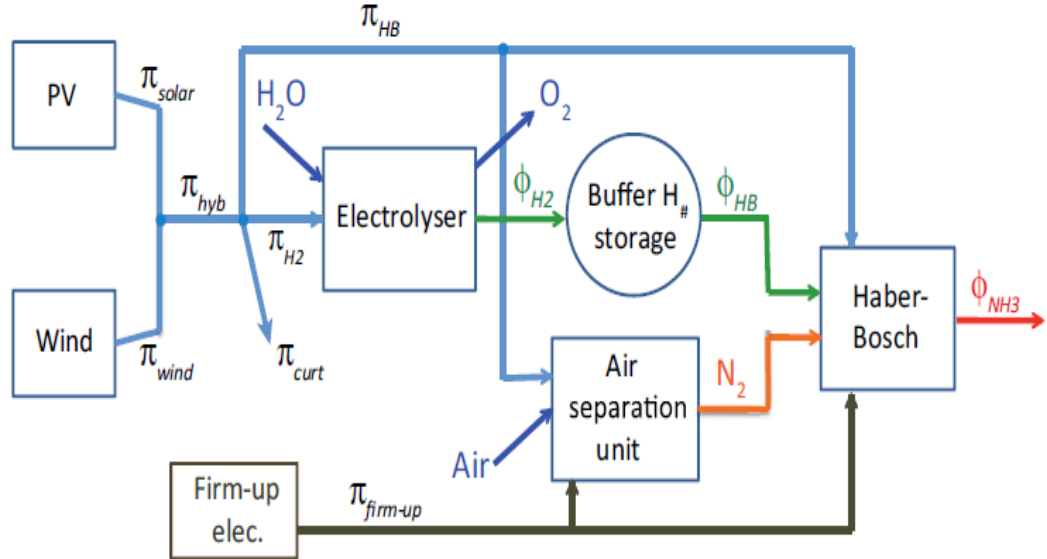
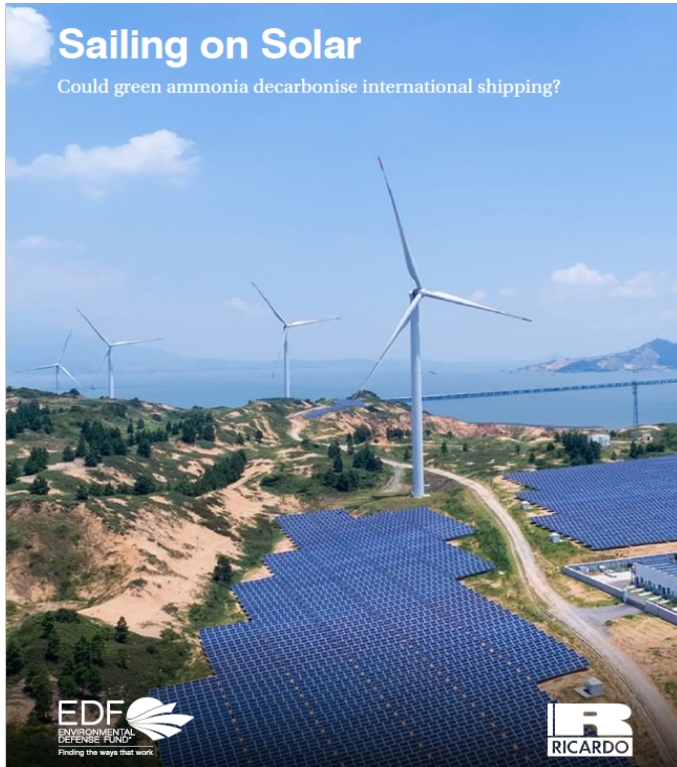
Source: Korean Register, 2020, *Forecasting the Alternative Marine Fuel - Ammonia*



Source: MAN ES, 2019

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

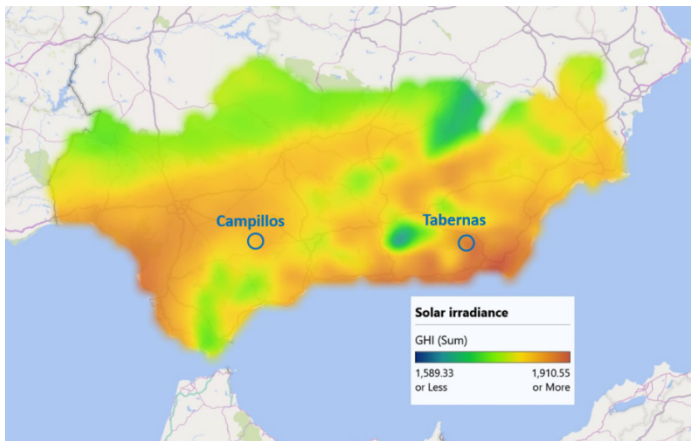
All-electric ammonia production is proven technology



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

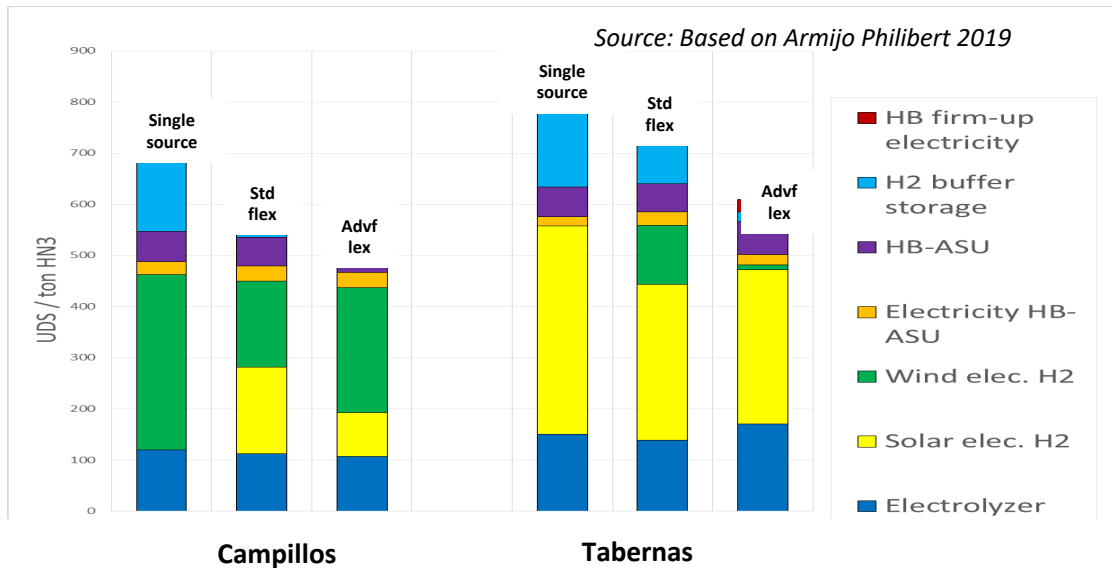
Ammonia was produced from hydropower from 1920 to 1990.
The sole novelty is the variability of solar and wind power, which can be addressed

Green ammonia can soon compete with grey ammonia...



Costs	Campillos	Tabernas
Solar (€/MWh)	36	31.6
Wind €/MWh)	36.5	56.6
CF electrolyzers	53.9%	33.7%
Hydrogen (€/kg H ₂)	2.44	2.68

Based on a detailed hourly analysis



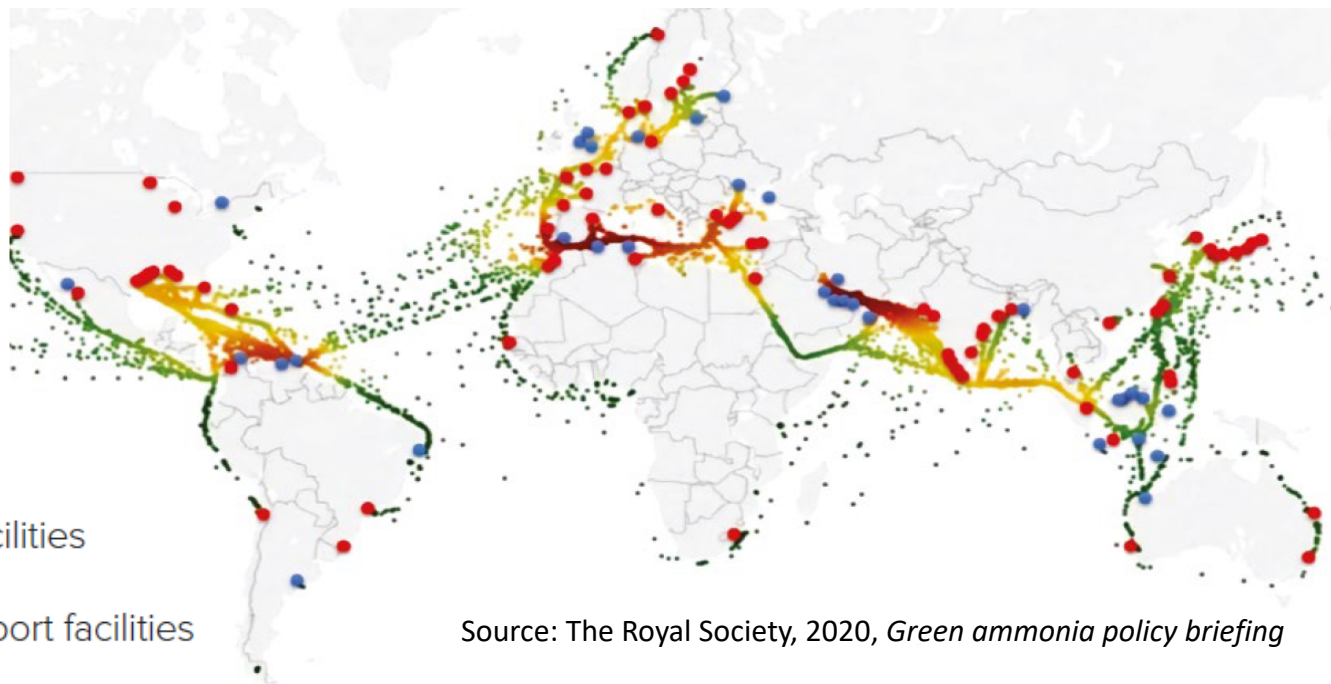
- Hybridization improves the CF of electrolyzers , reduce curtailment, H₂ storage & firm-up power
- Advanced HB flexibility further reduces curt. & H₂ storage, increases share of the cheapest resource, but reduces CF of electrolyzers & H.B. loop

... but remains significantly costlier than HFO/MGO

Ammonia is a global commodity



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



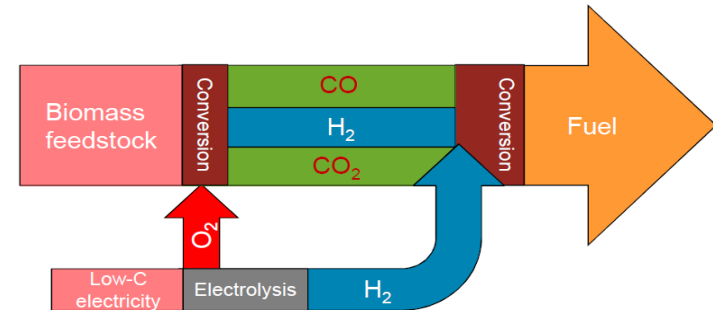
Source: The Royal Society, 2020, *Green ammonia policy briefing*

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



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 CO₂ 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



Enough electricity to power international shipping?



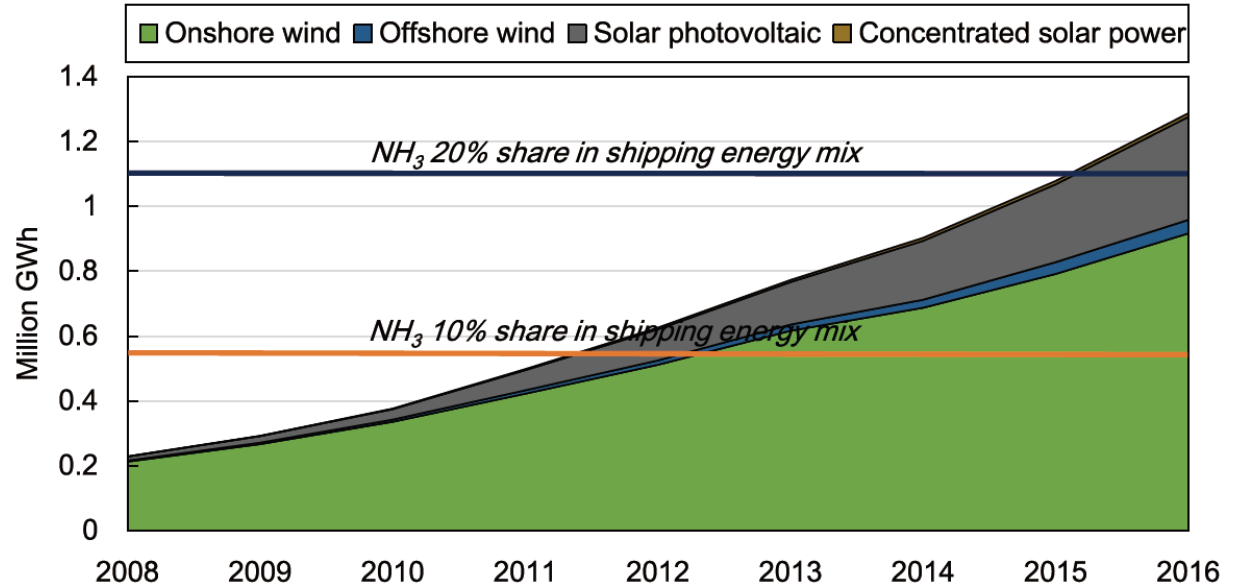
- Marine fuels demand expected by 2040 ~5.8 mboe/d (3600TWh/y)
- ≠aviation, no modal shift would help: maritime transport is most efficient
- Fuel cost increase due to would not significantly affect shipping volume
- Production of ammonia of l_{h_v} 3600 TWh would require primary green electricity production 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

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*

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

Gone with the winds?



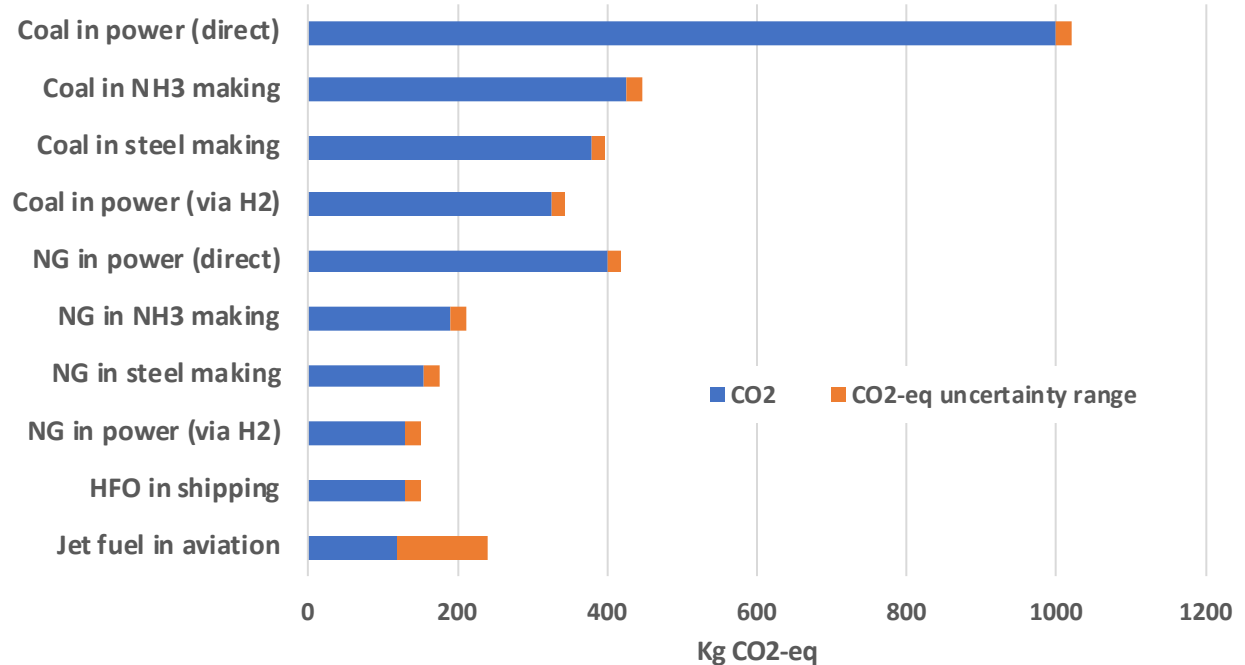
Direct wind propulsion would be more efficient than through power generation, H_2 and NH_3 ...

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-CO₂ climate effects; shipping may come after power and industry



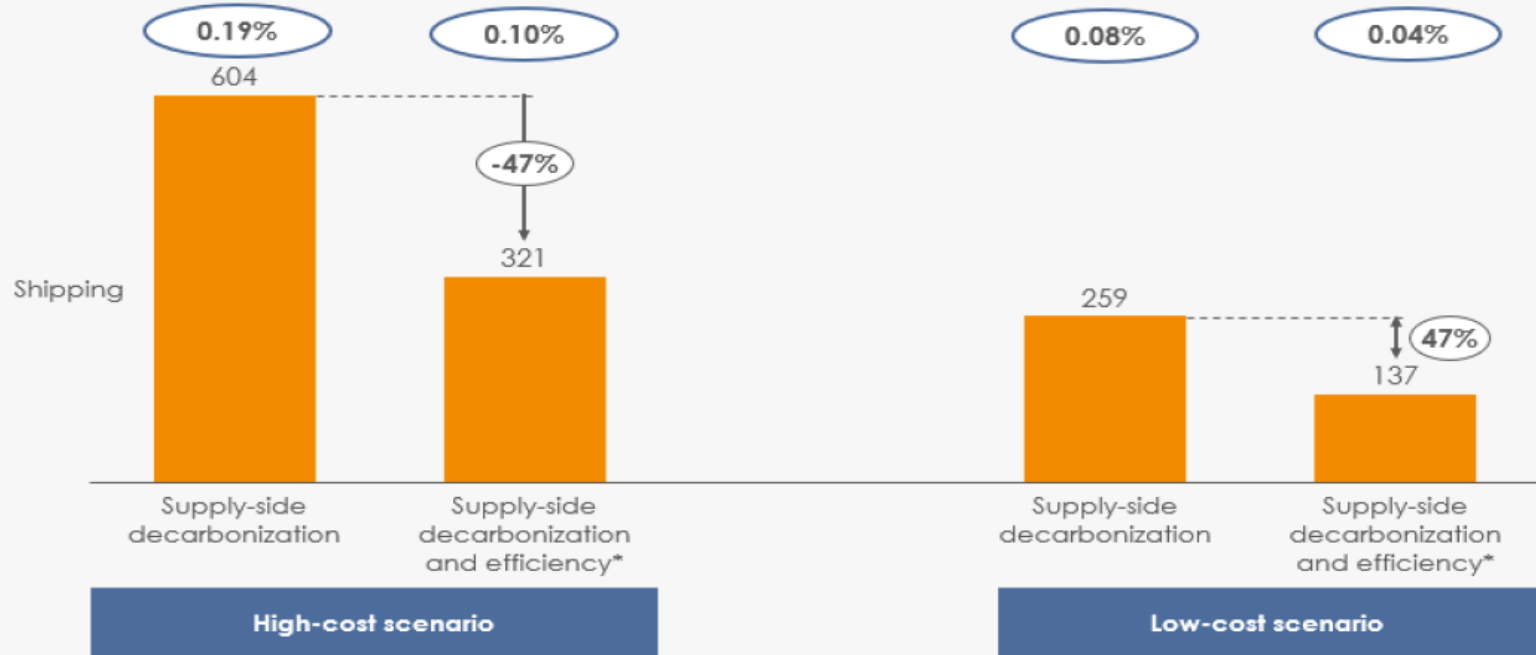
The world can afford the costs of decarbonisation

Total cost of decarbonization of shipping

Billion US\$ per year, 2050

X%

Share of global
projected GDP, 2050

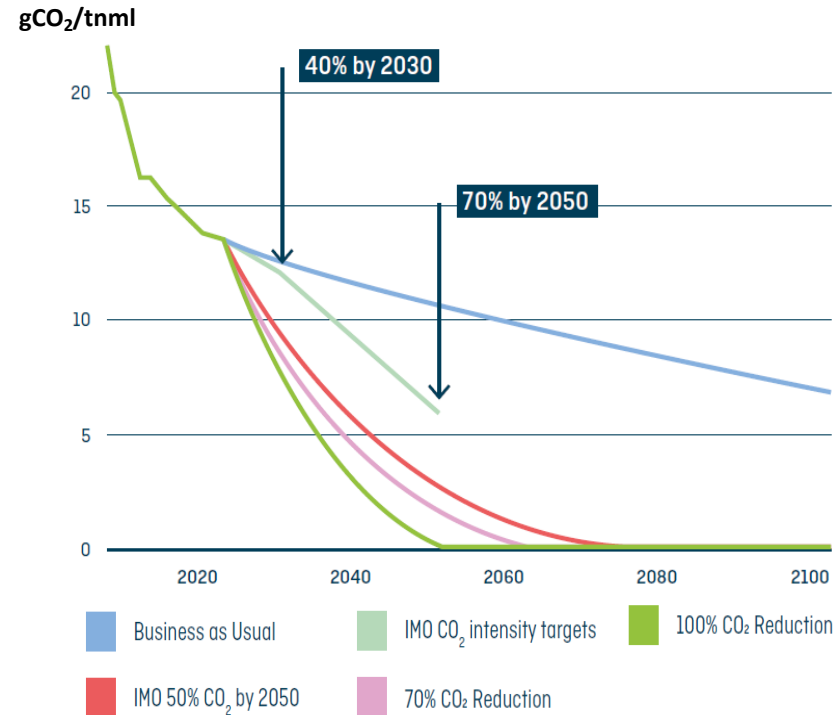


Efficiency improvements can halve the costs of decarbonisation via renewable fuels
Impacts of green international shipping on most good prices will be lower than 1%



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 CO₂ 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



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 than 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