Alternative fuels

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Alternative fuels: Biofuels and electrofuels

Biofuels	Conventional	Advanced
Electro fuels	**Without carbon**	**Containing carbon**
Gaseous	**Hydrogen gas (H_2)**	**Methane (CH_4)**
Liquids	**Ammonia (NH_3)***	**Alcohols (C_xH_yOH)** **Hydrocarbons (C_xH_y)**

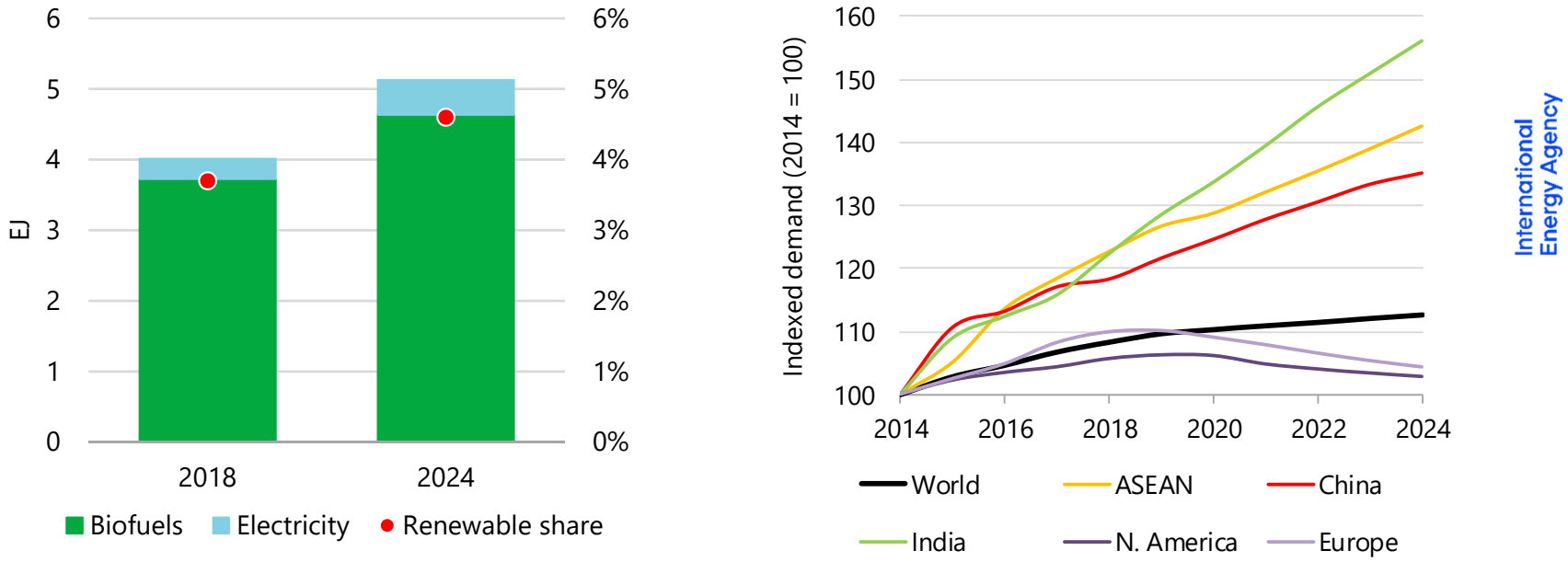
**NH3 is gaseous at normal temperature and pressure but easily handled as a liquid*

There is a great diversity of options for electro fuels, all based on hydrogen from electrolysis of water, which may correspond to different needs and uses

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Transport lags behind other sectors in harnessing renewable energy

Renewable energy in transport (left) and fossil transport fuel demand by country / region (right)

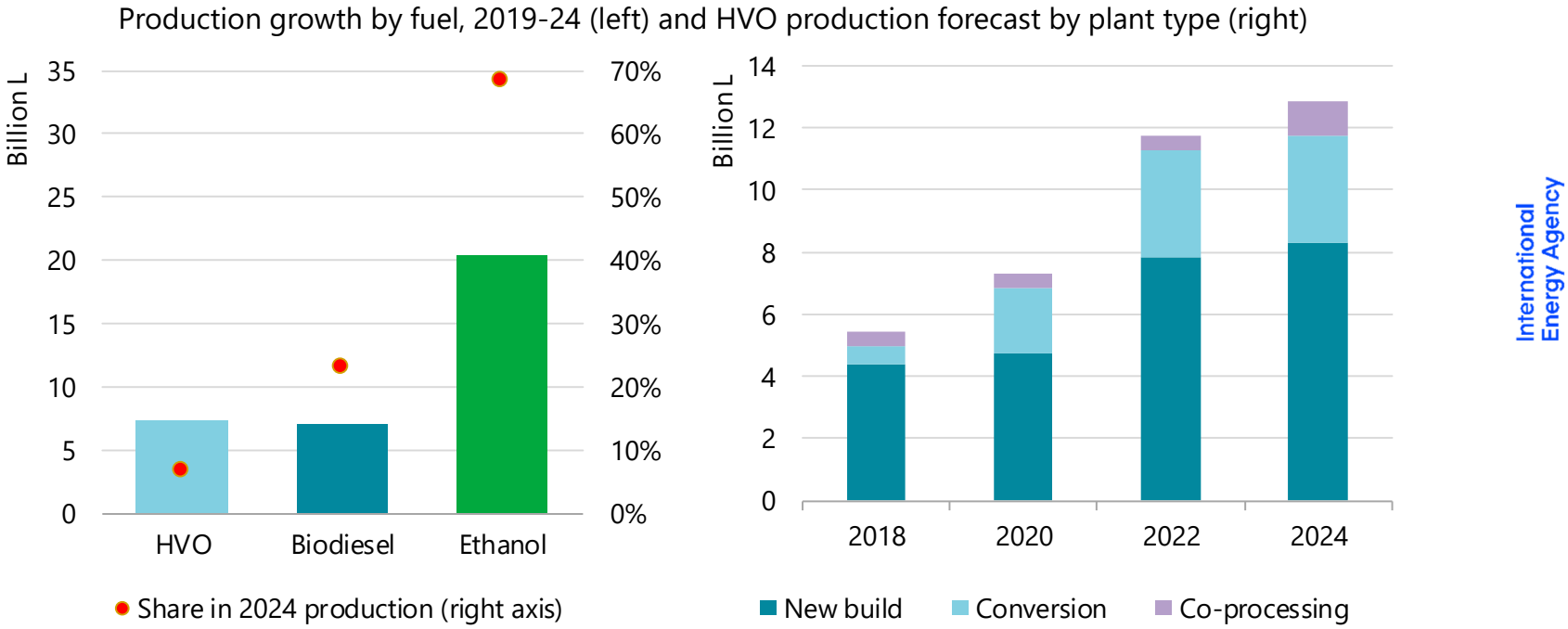


By 2024 renewable energy in transport remains below 5%, compared to 29% in the electricity sector.

1 EJ = 23.9 Mtoe

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HVO output growth equal to that of biodiesel

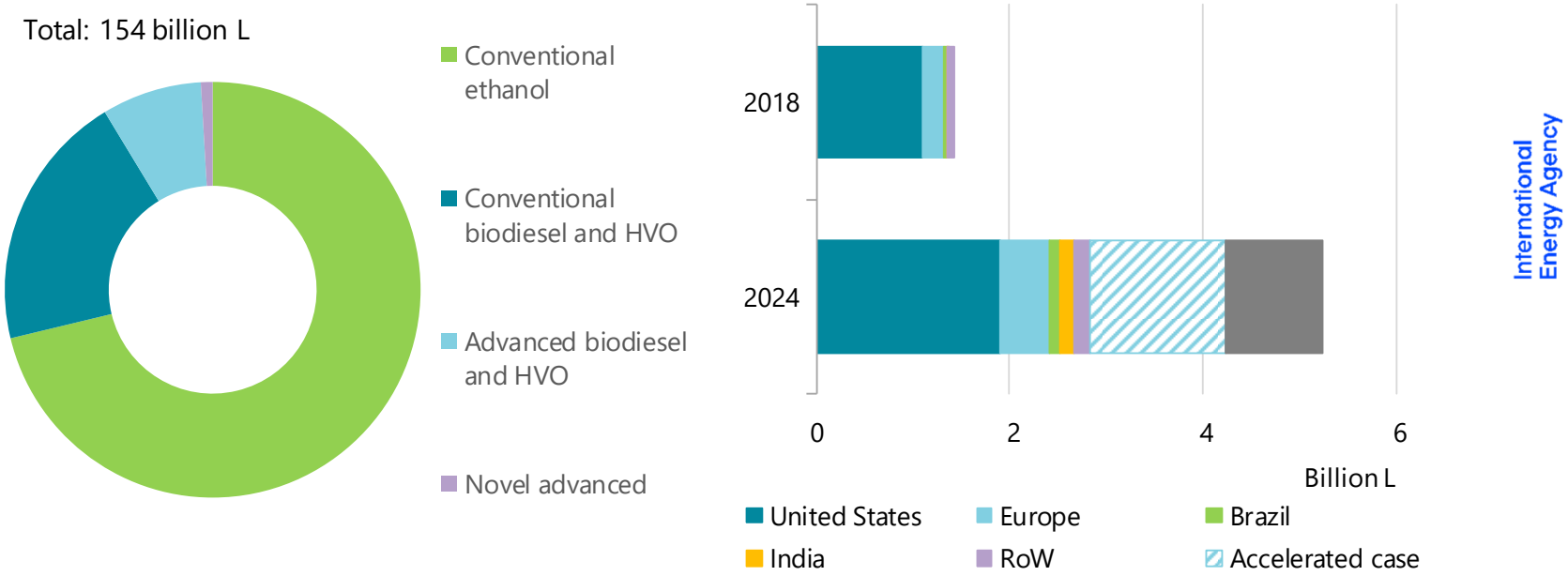


Around $5 billion of investment in new plants is anticipated, with HVO's 'drop-in' characteristics and valuable co-products (e.g. renewable propane and chemicals) supporting production growth.

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A stronger push of biofuel technology innovation needed

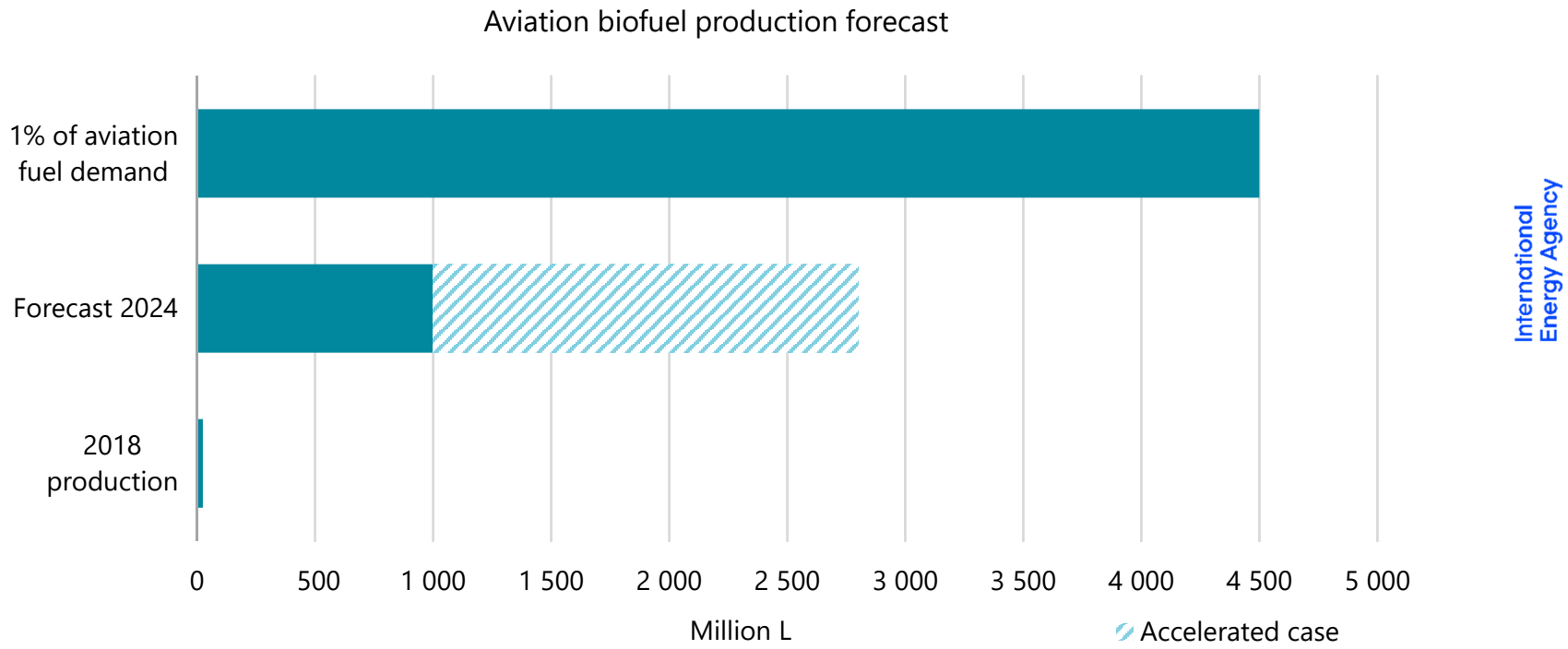
Biofuel production overview, 2018 (left), novel advanced biofuel production by country / region (right)



USA leads new biofuel technology development, but by 2024 these fuels only provide <2% of biofuel production as the high investment risk of moving from demo- to commercial-scale hampers growth.

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Aviation biofuels are on the runway, but have not yet taken off

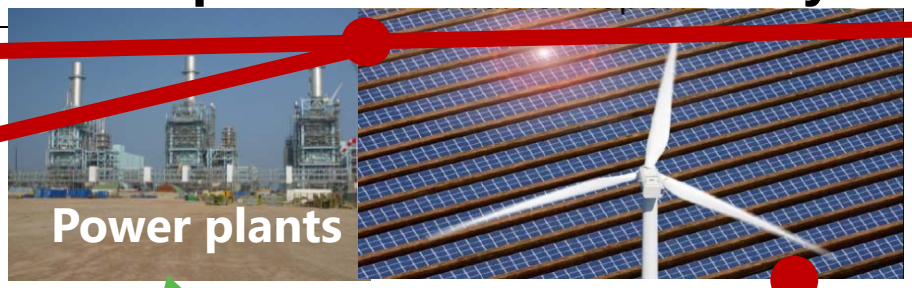


Between 1-3 billion L of aviation biofuel production anticipated by 2024, as several HVO plants plan to produce HEFA jet fuel. Higher costs than fossil jet fuel mean policy support is crucial to ensure demand.

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Renewable power can replace fossil fuels in many uses

Buildings
Heating
Cooking
Lighting



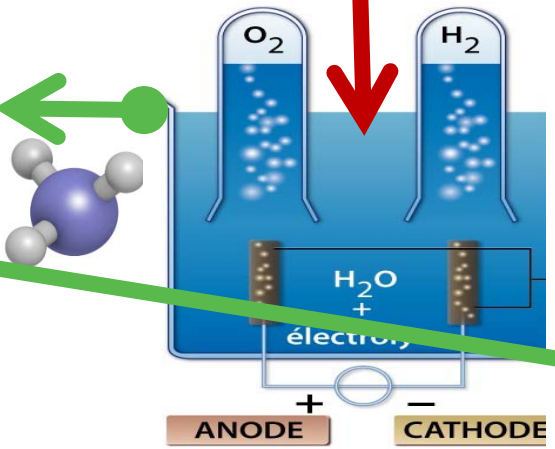
Industry
Steam
Force
Electrolysis

Feedstock, process agents, fuel

Transports
EVs
H-rich fuels







Beyond current uses, renewable electricity can replace fossil fuels in direct uses in buildings, industry and transports, directly or through electrochemistry/electrolysis

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Three ways of isolating hydrogen

- Steam reforming of natural gas and partial oxidation of naphta and coal

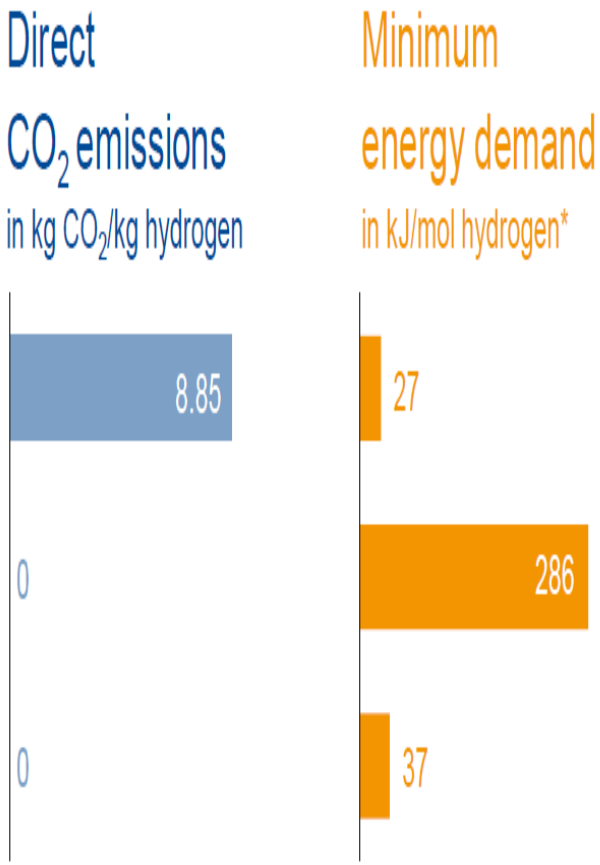
$$CH_4 + 2H_2O \xrightarrow[heat]{} CO_2 + 4H_2$$

- Electrolysis of water - with low-carbon electricity

$$2H_2O \xrightarrow[elec]{} O_2 + 2H_2$$

- Pyrolysis of methane

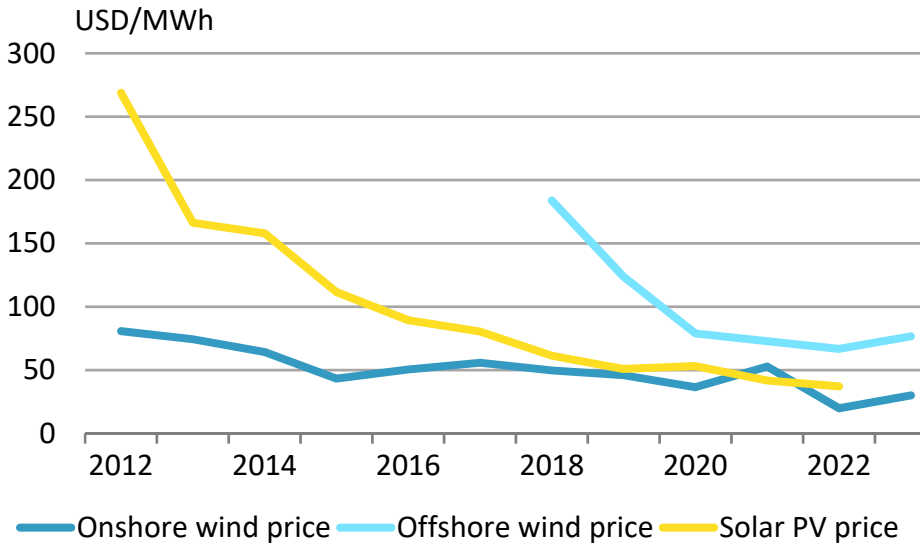
$$CH_4 \xrightarrow[elec]{} C + 2H_2$$



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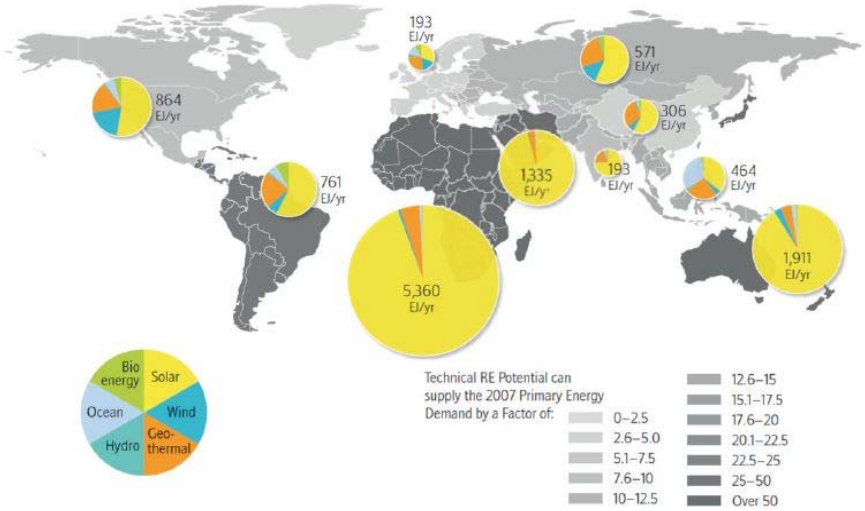
The emergence of low-cost renewable power is a game-changer

Average auction prices by commission dates



Source: IEA, Renewables 2017

Some areas have larger RE resources



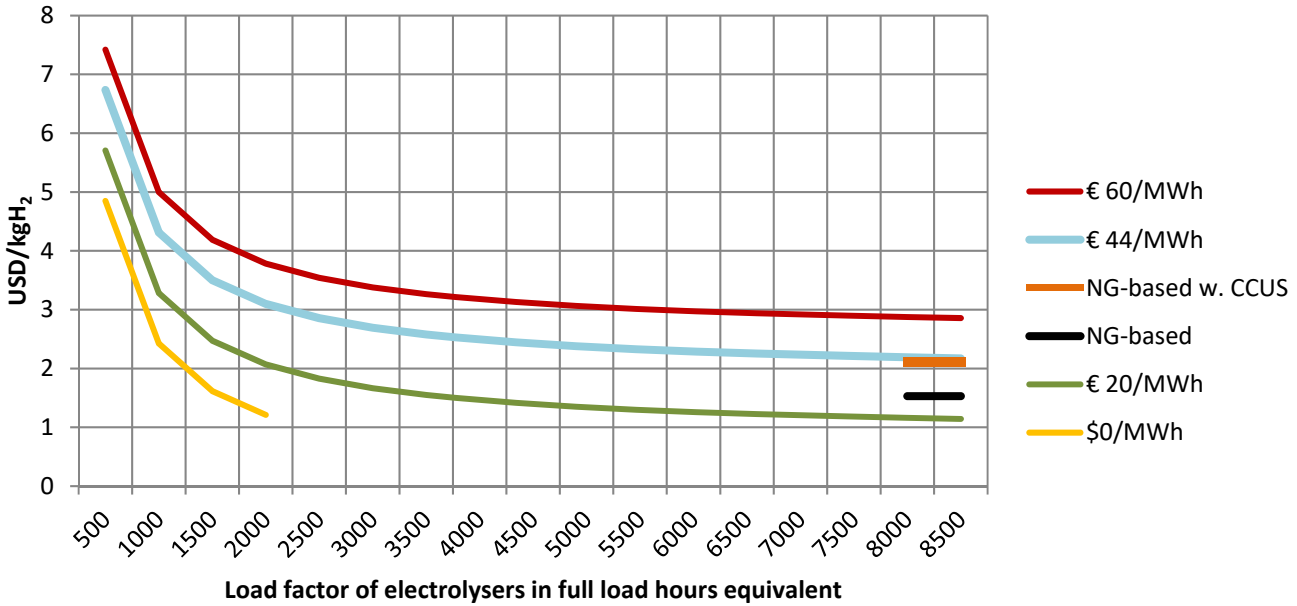
Source: IPCC 2012, Renewable Energy Sources and Climate Change Mitigation

Capacity factors of combined wind and solar power exceeds 50% in vast areas, often remote from large consumption centers, potentially delivering huge amounts of power at less than $30/MWh

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Green hydrogen from water electrolysis can compete…

Cost of hydrogen from electrolysis for various electricity price and load factors vs. natural gas-based in Europe

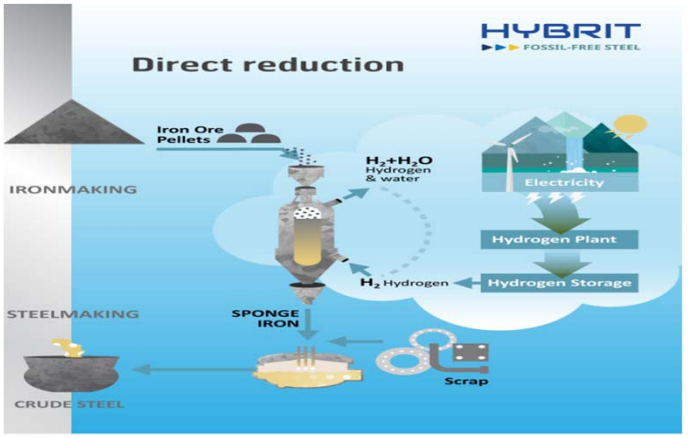


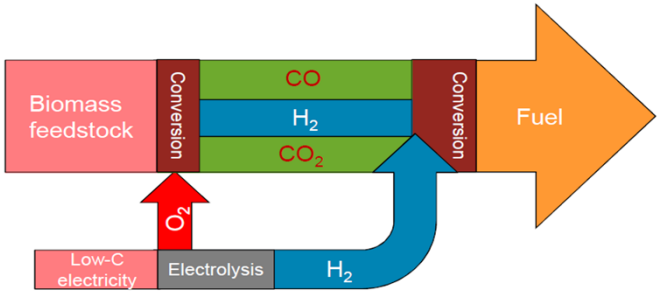
Beyond 20- 40% capacity factor the cost of electricity dominates the cost of hydrogen from electrolysis

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Most relevant areas for green hydrogen use

- Greening ammonia and methanol for their current industrial uses
- Refineries (to upgrade and clean fuels)
- Direct iron reduction in steelmaking
- H_2/NH_3 storable/shippable fuels in power systems
- Complementing direct electrification:
  - H_2/NH_3 as fuels (shipping, industrial furnaces)
  - H_2, CH_3OH and synthetic HCs as electro fuels
  - Sustainable if the carbon is taken from the air
  - Enhancing biofuels/biogas production

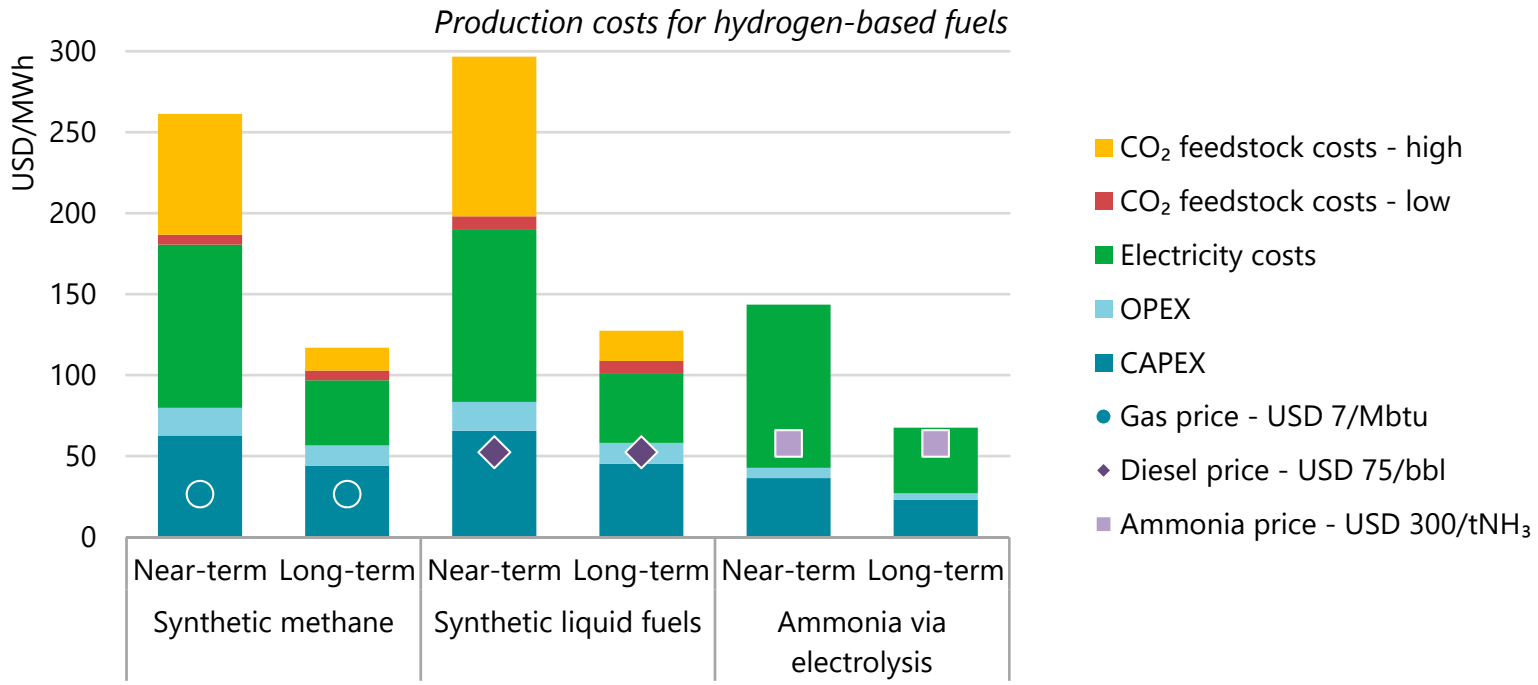




Renewable fuels and chemicals that are easy to ship and store will likely be traded from areas with vast resource to large consuming areas

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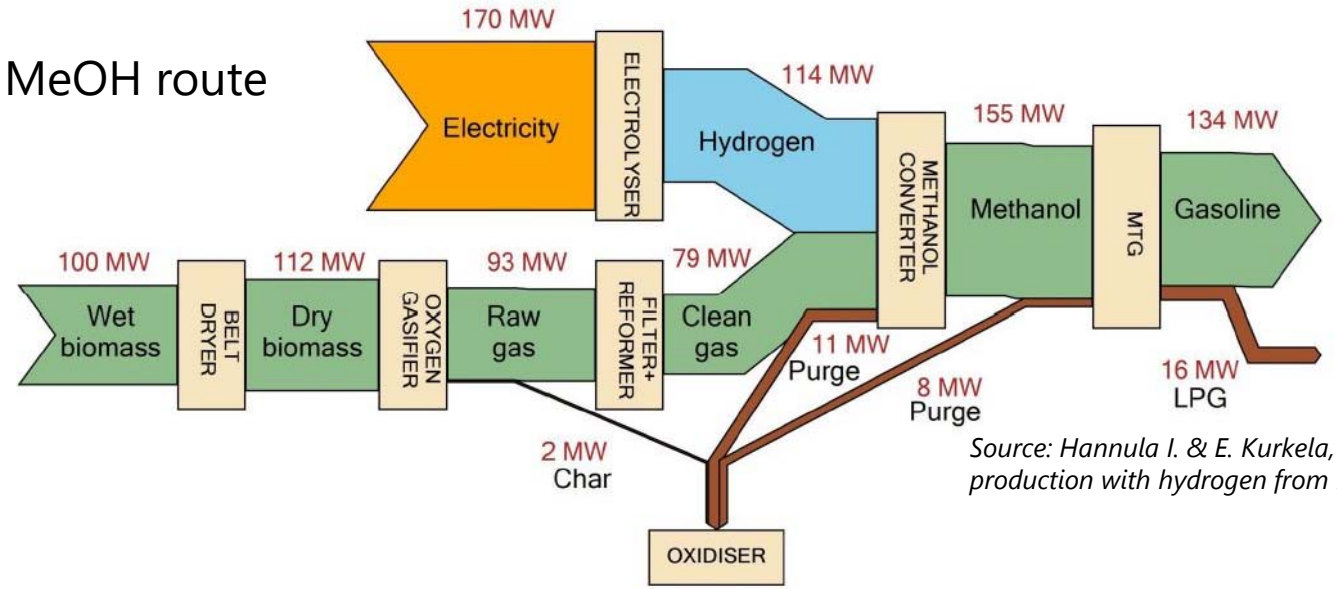
Synthetic methane, liquid hydrocarbons and ammonia



Each option will have a role, but ammonia is cheaper when it can be used directly

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Power & Biomass-to-Liquid: MeOH and FT routes



Source: Hannula I. & E. Kurkela, VTT, "Doubling of synthetic biofuel production with hydrogen from renewable energy", tcbiomass 2015

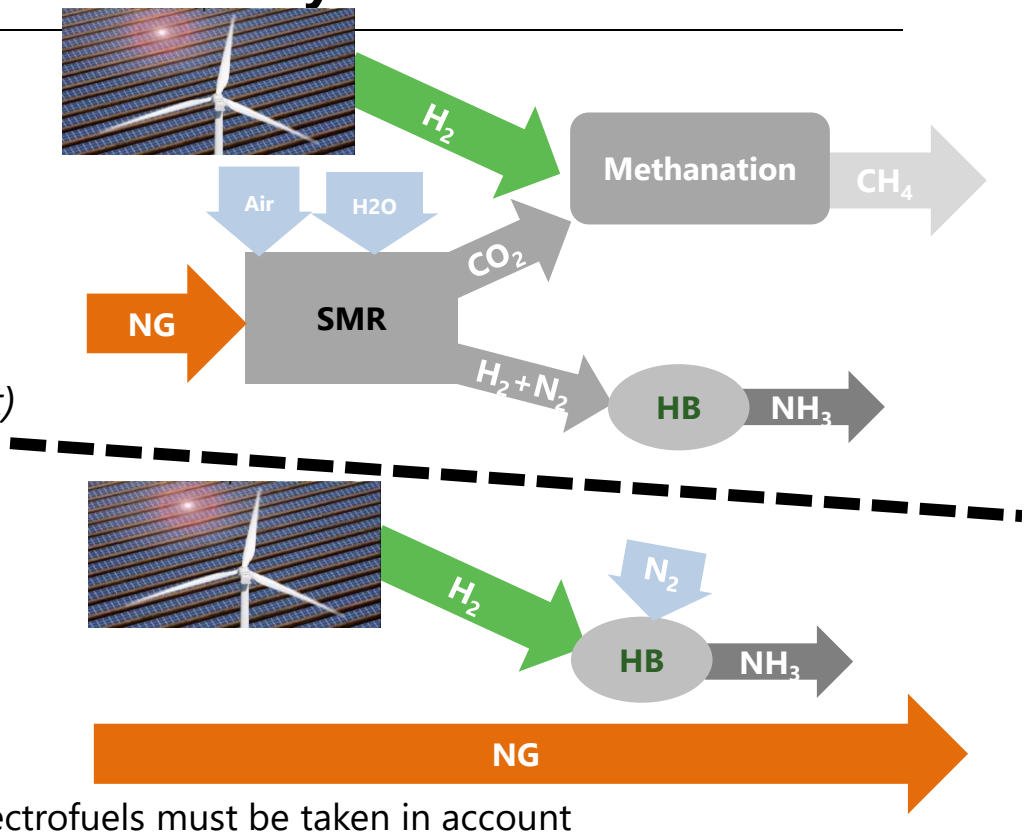
Fischer-Tropsch route	BtL	PBtL	PtL
X to liquid efficiency	36.3%	51.4%	50.6%
Carbon conversion	24.9%	97.7%	98%

Source: Albrecht, König, Baucks, Dietrich 2017, Fuel *194: 511-526*

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Sustainability issue: only carbon from air for synthetic HCs?

- Transition options:
  - Capture from plants running on fossils
  - *Real effectiveness must be analysed in comparing all other pathways*
  - *Risk of creating absurd situations*
  - *Fine if unavoidable emissions (e.g. cement)*
- Sustainable options:
  - Capture from a plant running on plants
  - Hydrogen-enhanced biofuel production
  - Direct air capture



Economic, environmental and social aspects of electrofuels must be taken in account

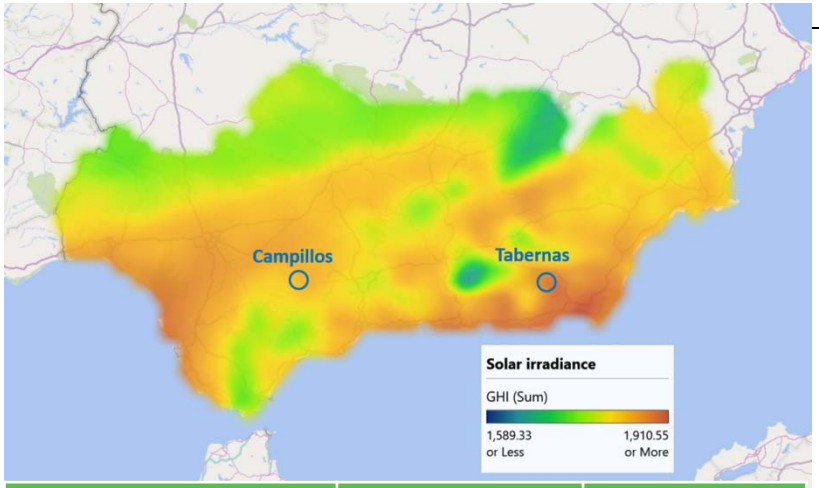
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Biomass use vs. DAC for electrofuels

- Assuming 100 EJ/y available biomass gives33 Ej as biofuels and ~4 Gt CO_2/y
- 4 Gt CO_2/y allows FT to deliver enough fuel/feedstock for aviation and petrochemicals
- Direct Air Capture is the other renewable CO_2 source
  - May be needed with storage to offset remaining CO_2 emissions and overshoot
  - Cost estimates from USD 30 to 1000/t CO_2, converging towards USD 100-200/t CO_2
  - 4 Gt CO_2/y DAC would require 1200 – 4000 TWh electricity, 20 EJ/y of (waste?) low-temp heat, significant amounts of water
- Extraction of CO_2 from seawater (together with H_2, metals?) a wild card…
- As long as there are concentrated CO_2 fluxes emitted to the atmosphere, from biofuel facilities or even from fossil origin, does it make sense to pay more for DAC?

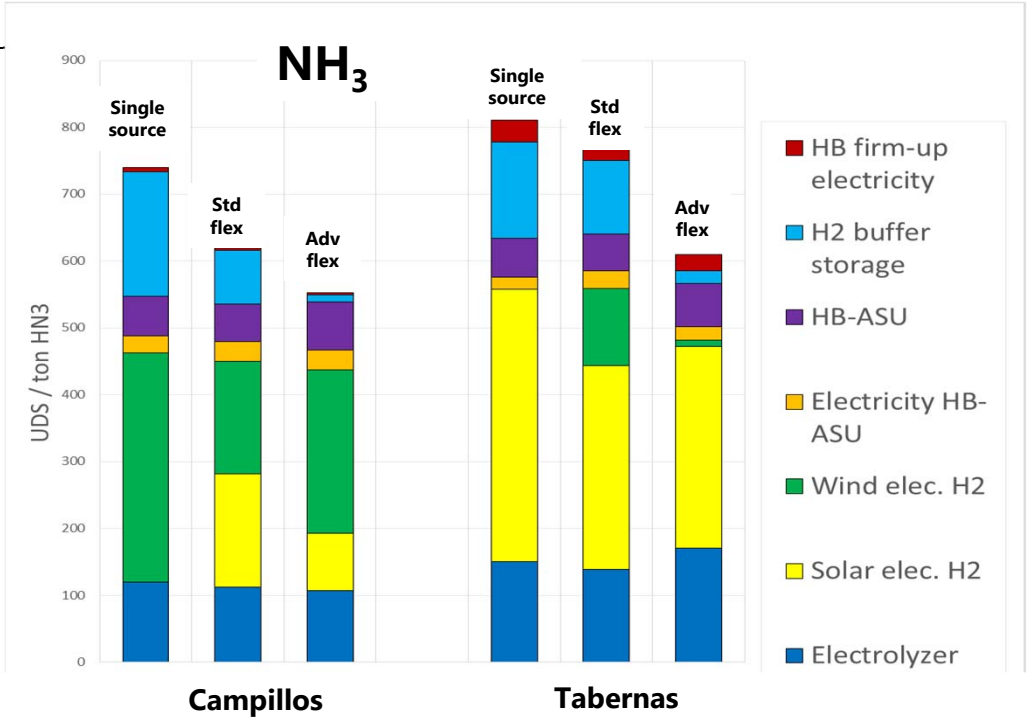
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Case study: costs of hydrogen and ammonia from PV and wind in Spain



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

Based on a detailed hourly analysis



- 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

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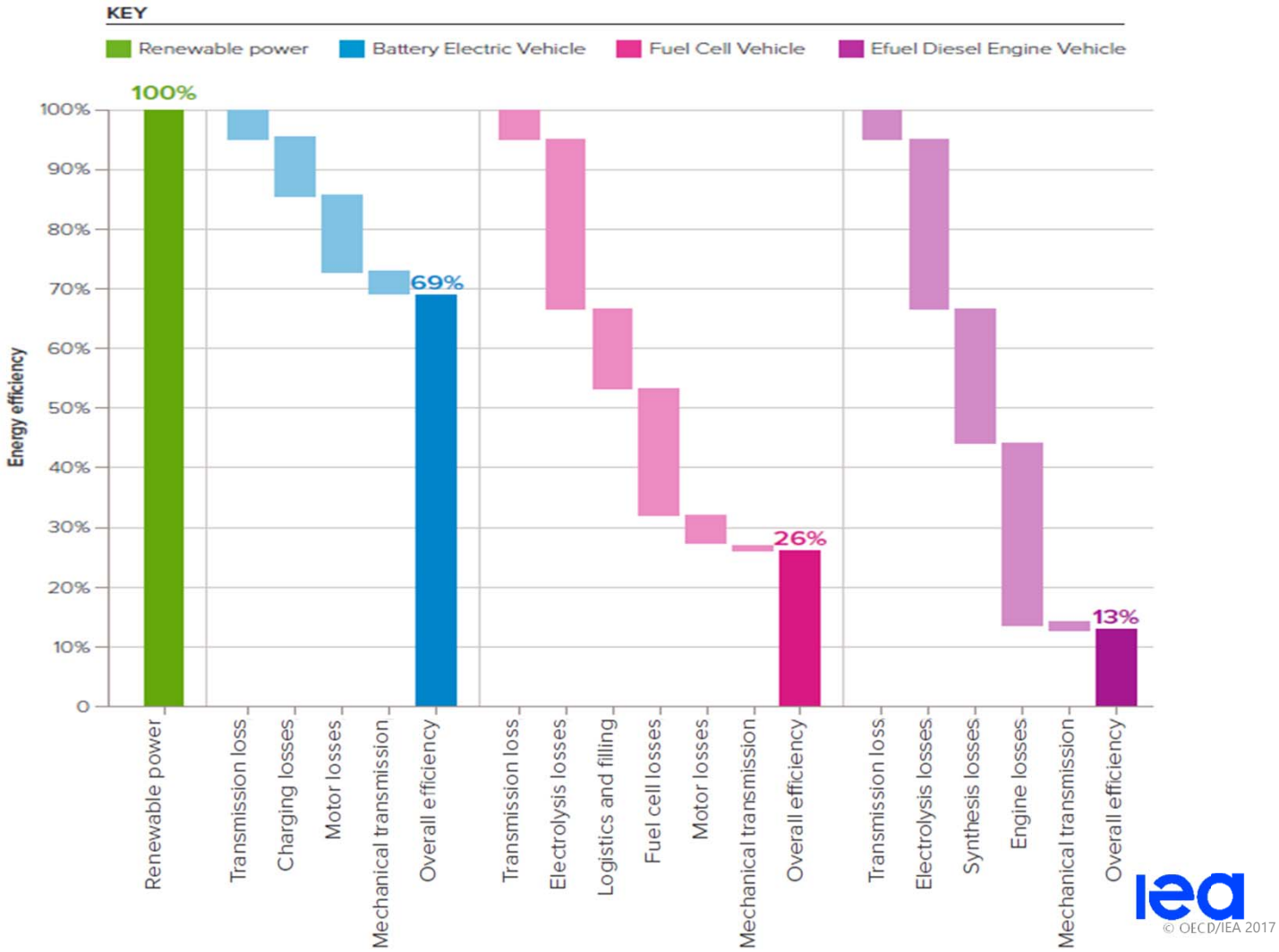
Costs and policy support

- Ammonia:
  - Modelling shows production today from solar and wind 500 USD/t in good resource areas
  - Production from gas and coal costs from USD 250 to 420/t, produces 2 – 4 t CO_2/t NH_3
- Methanol:
  - Some support for green methanol in the EU from biofuel mandates and in future RED II
  - US Renewable Fuel Standard (if extended or in conjunction with biofuel), LCFS in California
    - 45Q scheme supports DAC (USD 19 to 35/t CO_2)
- Synthetic hydrocarbons:
  - FT is capital intensive, not very flexible; FT fuels may cost several times more than fossils
  - One sector seems able to support the costs of technology deployment: aviation
    - A better policy option than taxation of air travel or jet fuel…
    - … which would require a global policy framework with incorporation mandates

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Direct electrification is much more efficient

Pathway efficiencies of low-carbon transport



Source: The Royal Society (2019), *Sustainable synthetic carbon based fuels for transport*, London, September

Electro fuels, from remote areas to long-haul transport

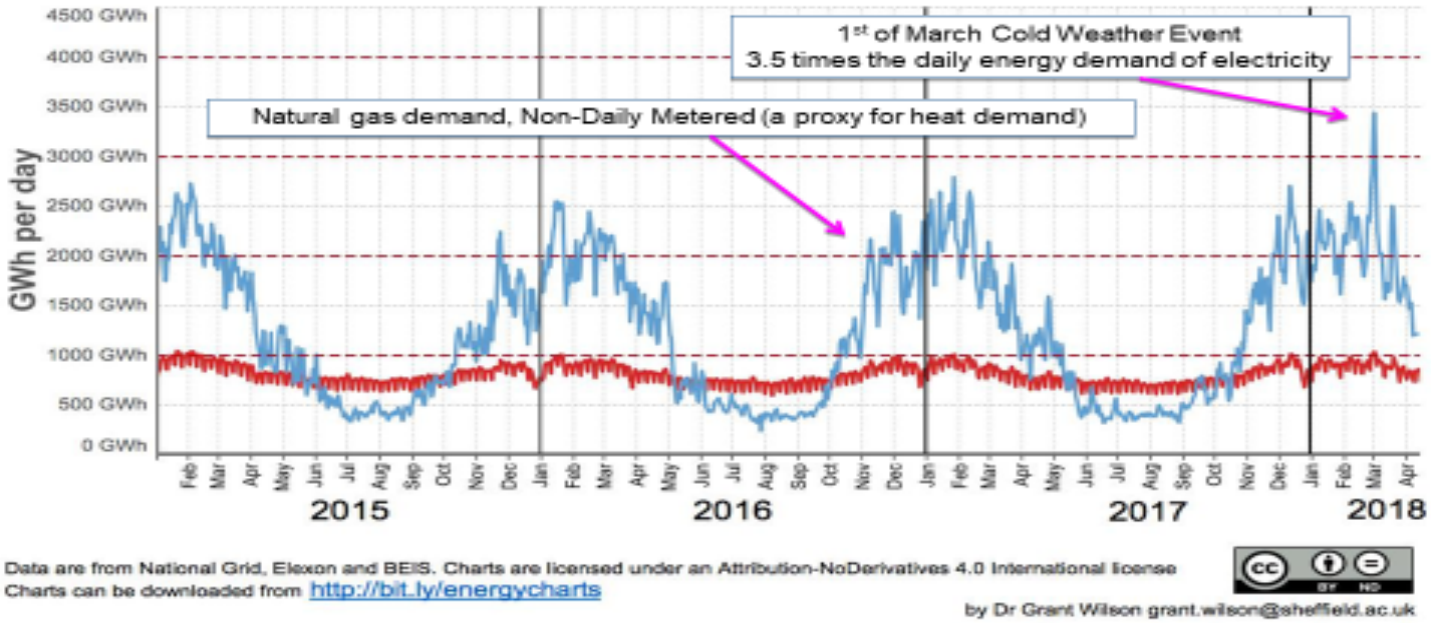
- Power sector, industry, aviation and shipping, some trucking need renewable, carbon-neutral electro fuels
- Sustainable biofuels can hardly provide them all
- Carbon-free H_2 gas and ammonia can deliver to maritime transportation, steelmaking…
- Biomass & Power to Liquid fuels can deliver to aviation
- Total electricity required for producing these fuels may exceed current global generation
  - EU potential for offshore wind @ 55-70€/MWh greater than current EU generation
  - However, direct electrification of industry, transport, heat is much more effective
  - Storable fuels/feedstocks should be produced in areas with vast stranded resources

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Electro fuels to complement electrification in buildings

Electricity and natural gas demand for heat in the U.K.



Electrification of heat can short term integration of renewables, but may aggravate the seasonal imbalance of the power demand. Green gases may be called to help

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Electro fuels to provide additional flexibility in power systems

- Interconnections and demand side response major flexibility options
- Pumped-storage hydropower and batteries excellent for short term storage
- Seasonnal storage needs chemical conversion
  To store 250 GWh over half a year:
  - Batteries cost 100 **bn $** (cost 400$/kWh)
  - Ammonia tanks cost 100 **M $** + combustion
  - Storing hydrogen gas cost-effectively requires availability of salt caverns

Power to power efficiencies

Fuel	PtP efficiency CO_2 from air	PtP efficiency CO_2 from fumes
CH_4	27%	31%
MeOH	27%	32%
DME	23%	28%
NH_3	35%	
NH3 PEM	*29%*	
NH3 SOEC	*39%*	

Hydrogen-based storage is less efficient than than battery and PSH, but it remains the most realistic option for long duration storage

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Where to start from?

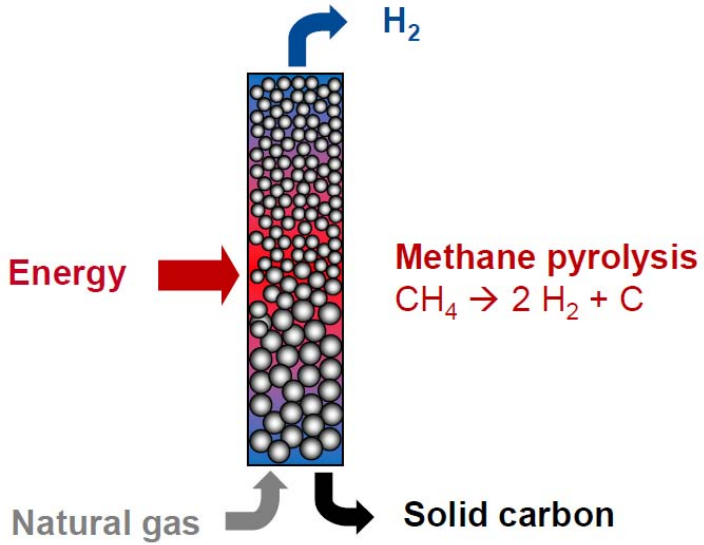
- Multiples drivers
  - In industry, greening H_2 uses and develop new ones, such as green steel
  - In transports, to fill the niches where direct electrification appears impossible
  - In buildings, to benefit from existing gas networks
  - In power systems, to provide additional flexibility options
  - As a way to harness cheap but stranded (remote) renewable resources
- Public support/decision needed for R, D&D, and infrastructure
  - Network effects and learning through mass deployment needed
  - Benefits of scale production vs. better adaptation to each sector needs
  - Thorough analyses can reduce the risks associated with "picking the winners"

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The value of methane pyrolysis

- Proven at commercial scale (*Kvaerner Hydrogen Plasma Black Reactor*, 1998-2007)
- Does not generate CO_2, a waste to store, but solid carbon, easier to valorise
  - Carbon black, graphene, fibers, tubes…
- Preserves stranded costs in natural gas production and transport infrastructures
  - CH4 easier to transport than H2, decarbonisation would likely take place close to consumption
- Allows to increase more rapidly the production of low-carbon hydrogen
- Monolith Materials is currently building a commercial plant in Nebraska
  - Plasma furnace developed at Mines Paristech

- TNO is developing its proprietary process
- BASF is building its third pilot plant



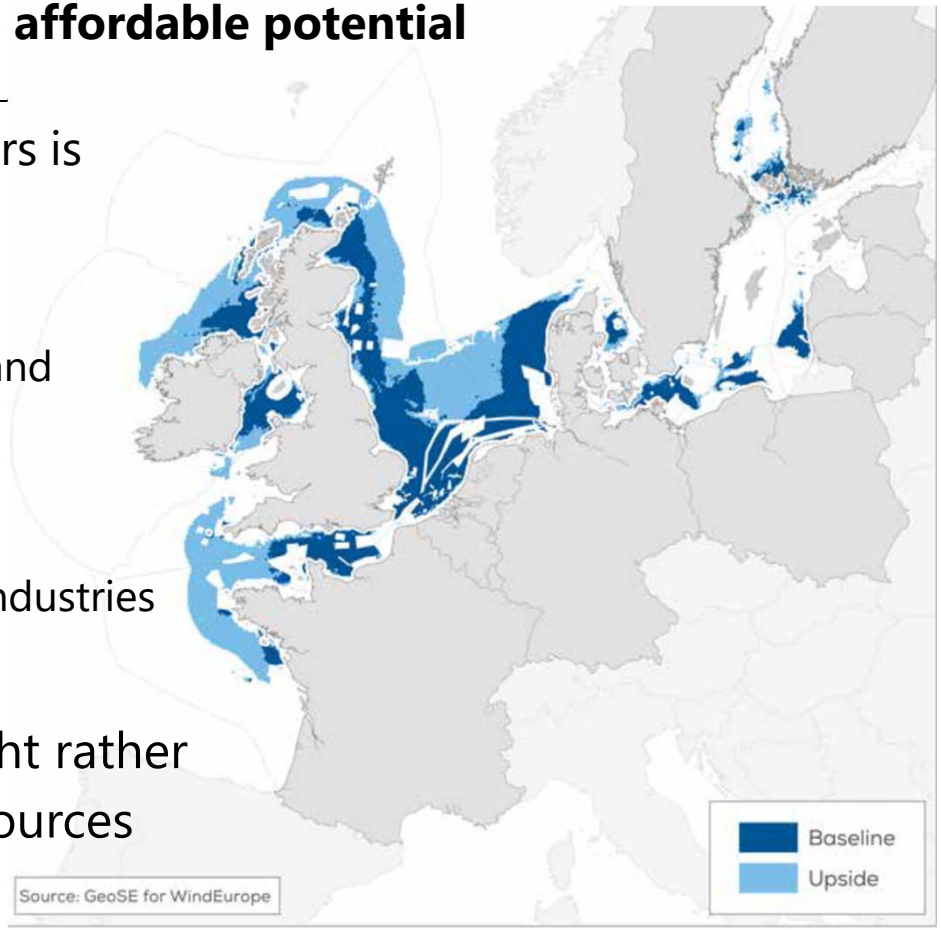
See Pöyry report *Hydrogen from natural gas – the key to deep decarbonisation*

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Offshore wind in Northern Europe: a large affordable potential

- Wind offshore potential in European waters is 2600 – 6000 TWh
  - @ € 55 to 70/MWh (*WindEurope*)
  - 80% to 180% of current EU electricity demand
  - Latest auctions in France: € 44/MWh
- Possible additional uses:
  - Electrification of buildings, transport, and industries
  - Production of hydrogen
- Storable/shippable fuels/feedstock might rather be imported from areas with better resources

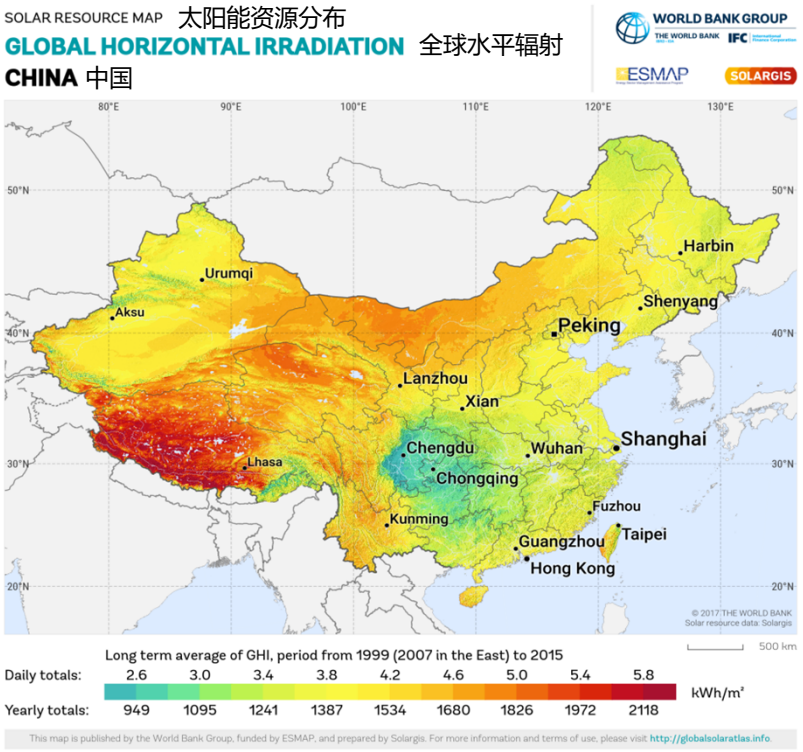
More: https://bit.ly/2XlR1Mn

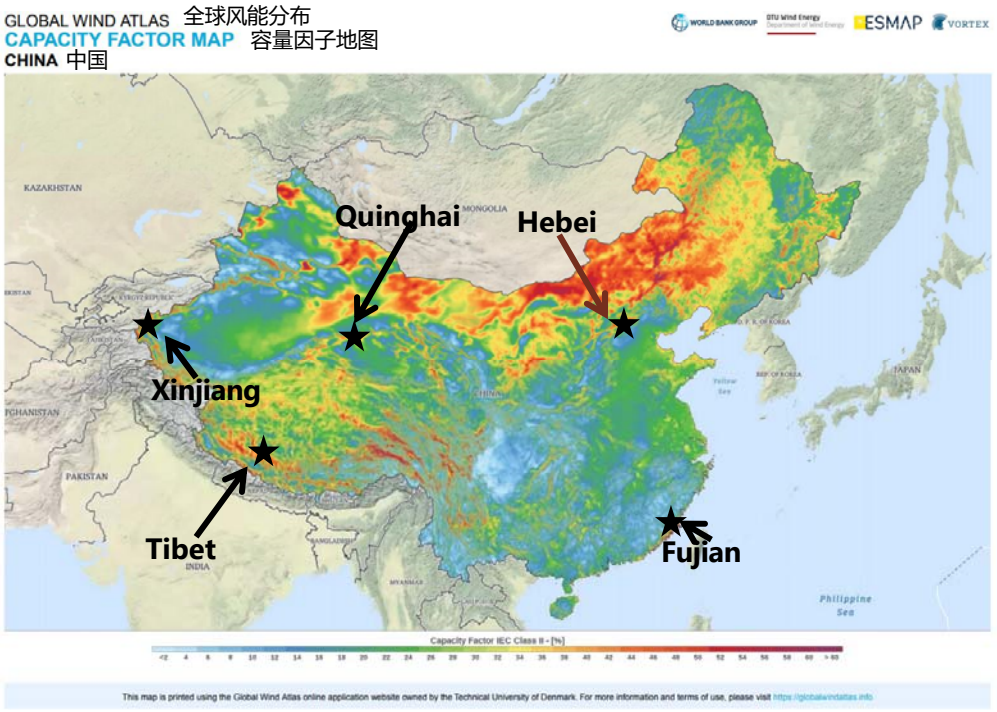


Source: Hundleby and Freeman (2017)

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China is blessed with immense solar and wind resources 中国拥有丰富的太阳能和风能资源

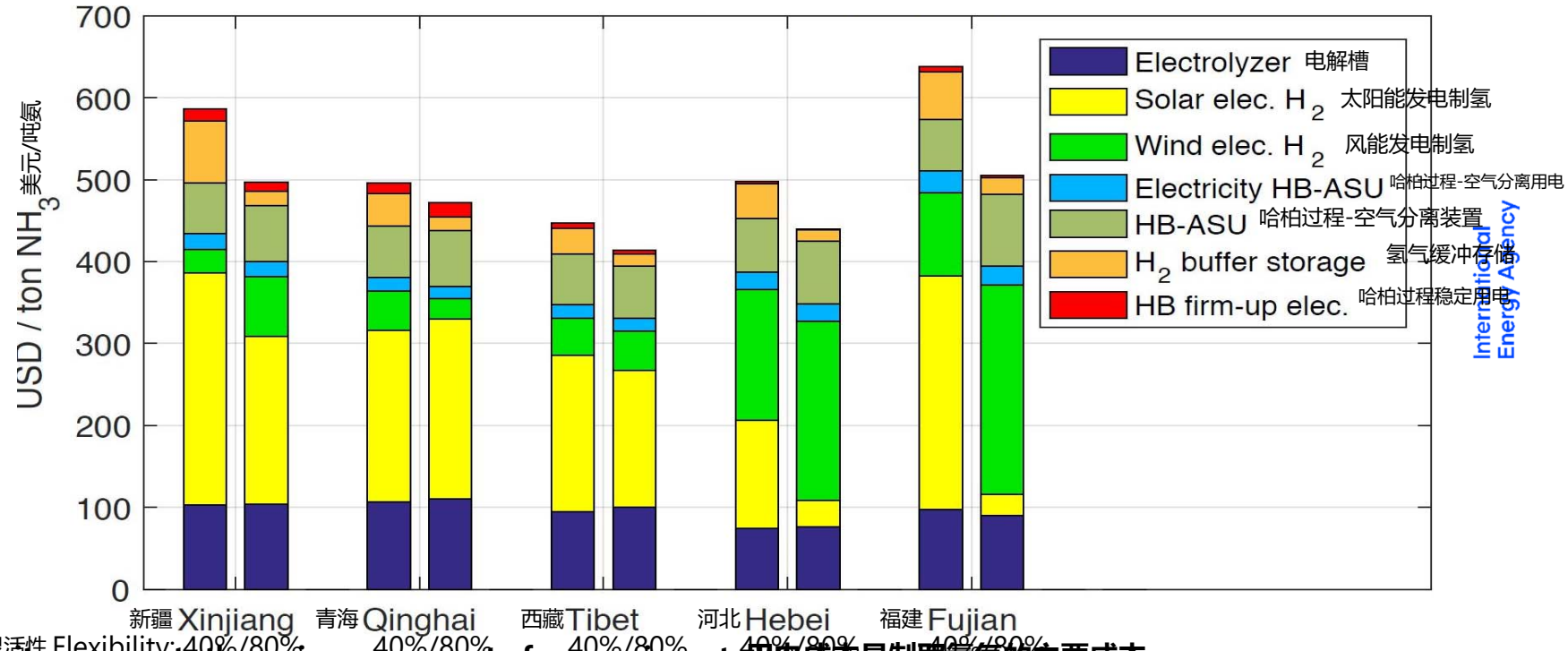




North and West China have the best solar and wind resources 中国北部和西部拥有最丰富的太阳能和风能资源

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Levelised cost of ammonia from solar and wind 太阳能和风能制氨平准化成本



Electricity represents the major component of ammonia cost. 用电成本是制取氨气的主要成本

Solar dominates in Qinghai, wind dominates in Hebei, Tibet uses a more even mix. 青海主要使用太阳能，河北主要使用风能，对于西藏两者相对平均。

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