Production, transport, storage and economics of hydrogen

Leon Stille
Energy Delta Institute, part of New Energy Coalition
Hydrogen summer school

Energy Delta Institute

ENERGY DELTA INSTITUTE *Energy Business School*

´Being the transitional knowledge bridge between traditional and new energy actors´

- Business School founded 2001
- Part of New Energy Coalition
- Focus:
  - Open market programs, courses, incompany training and networking events
  - Yearly training of over 1000 energy professionals
  - Supported by (in-house) academia and expert lecturers
- 50 FTE (13FTE EDI), 6M revenue/yr

Leon Stille

General Manager Energy Delta Institute | Energy Transition | Innovation | Education | Hydrogen | CCUS | Green Gas | Speaker | Moderator

EU Energy system transformation

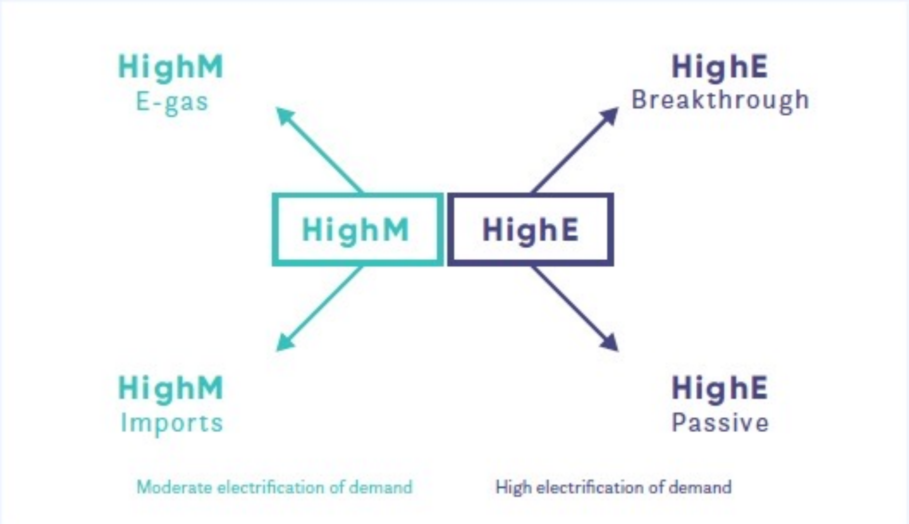


FIGURE 1: *Scenarios studied in this report*

Source: net zero 2050

How to further decarbonize?

Four scenario's:

- High molecules (renewable gas and fuels)
- High Molecules (import renewable gas and fuels)
- High electrons (breakthrough/smart)
- High electrons (passive/less smart)

Key Drivers for scenario choices

1. Economic
   - Cost and benefits
2. Social
   - Acceptance and disruption
3. Technical
   - Availability of (future) technology

EU Energy system greening

Greening so far

- Electricity mix
  - Renewable around 30%
  - Fossil around 45%
  - Nuclear 25%
- Fuels and solids
  - Renewables around 4%
  - Fossil 96%

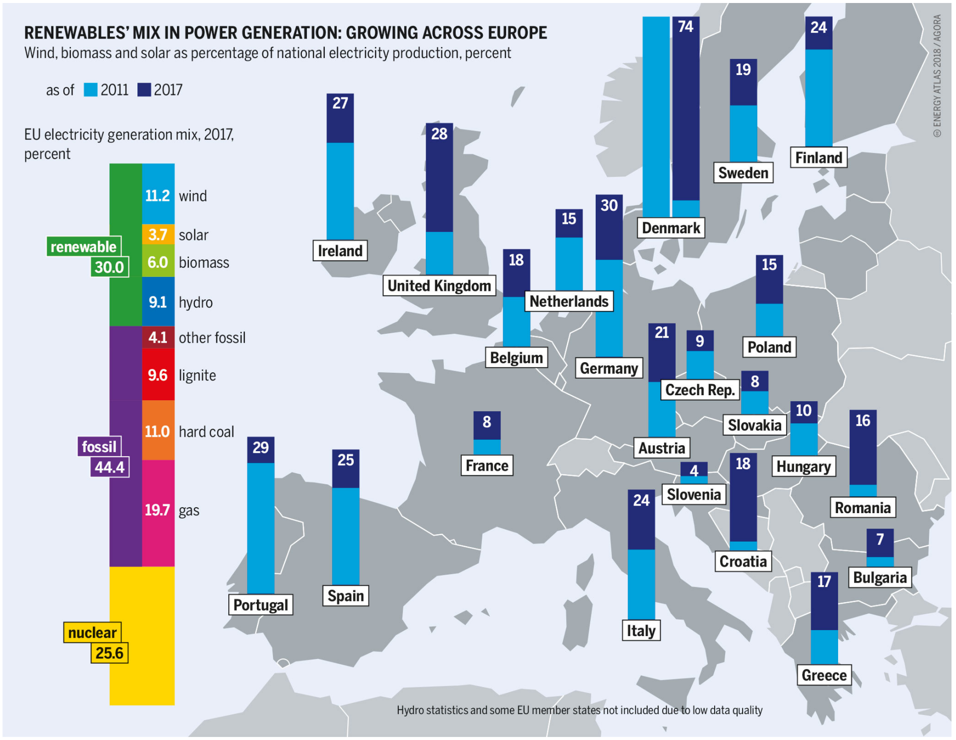
1000 billion euro
10 year time
0,5% EU economy

In total mix 2019

- 80% Fuel and gas, 20% Electricity

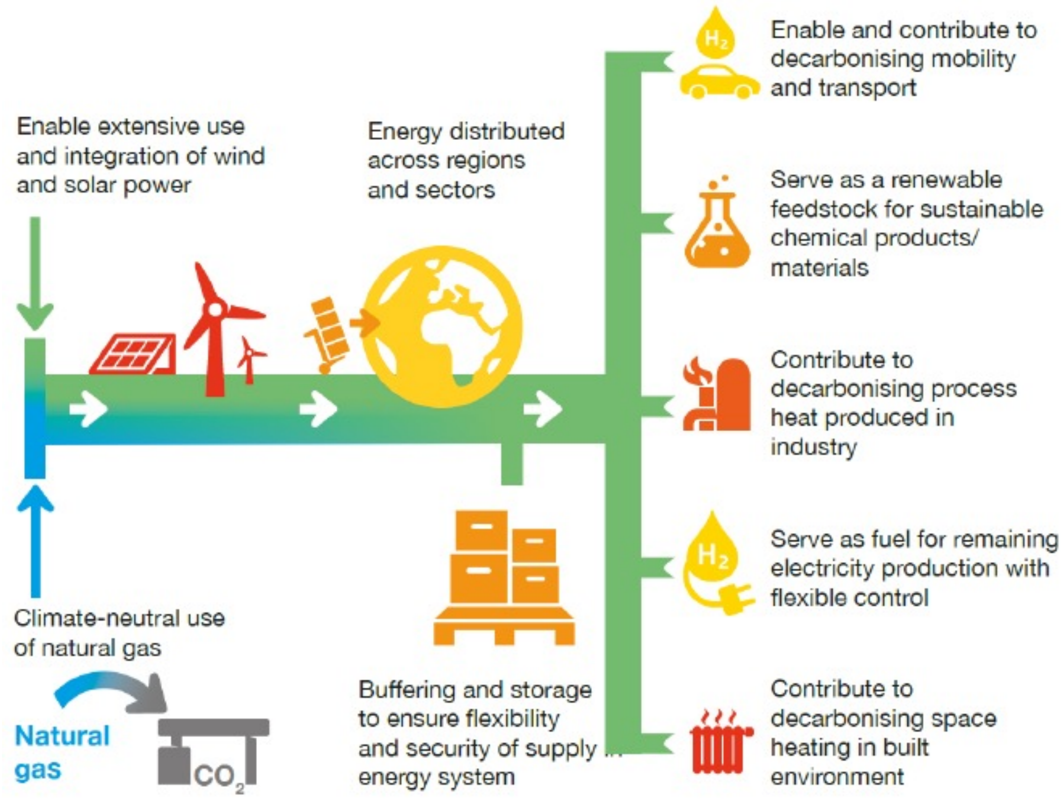
HOWEVER, 100% Renewable required 2050!

So the difference in the speed of greening between the electron and molecule part of the EU energy system is striking.



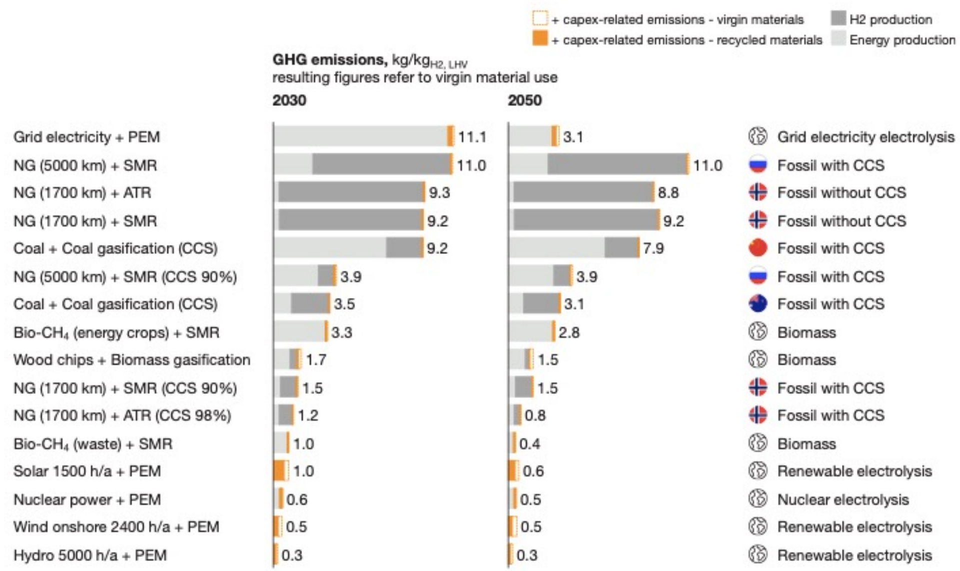
Source: energy atlas 2018

Decarbonization with hydrogen



McKinsey, 2019

Exhibit 1: Carbon-equivalent emissions by hydrogen production pathways, 2030 and 2050
(resulting figures refer to virgin material use); energy production refers to GHG emissions from the supply of the main input into the H_2 plant (natural gas, coal, electricity), while H_2 production refers to direct GHG emission of H_2 plant, including from plant auxiliary electricity use



Source: Hydrogen Council, LBST

[6] Reference: Amec Foster Wheeler; IEAGHG: Techno-Economics of Deploying CCS in a SMR Based Hydrogen Production using NG as Feedstock/Fuel; IEAGHG Technical Report, February 2017.

[7] Reference: Hydrogen Council: Path to Hydrogen Competitiveness: A Cost Perspective, 2020.

Colours of Hydrogen

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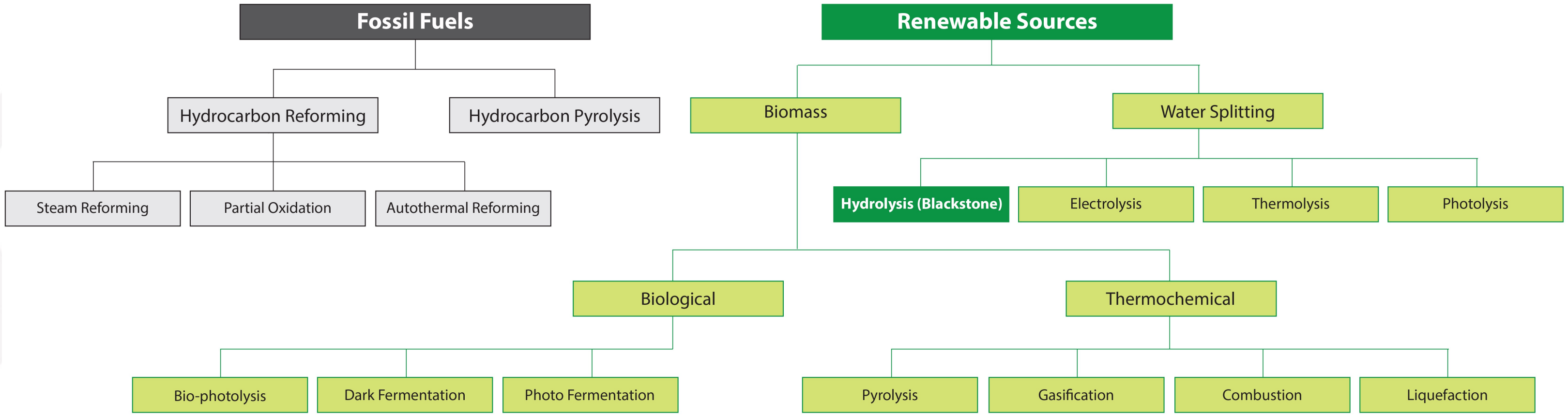
	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Hydrogen production methods



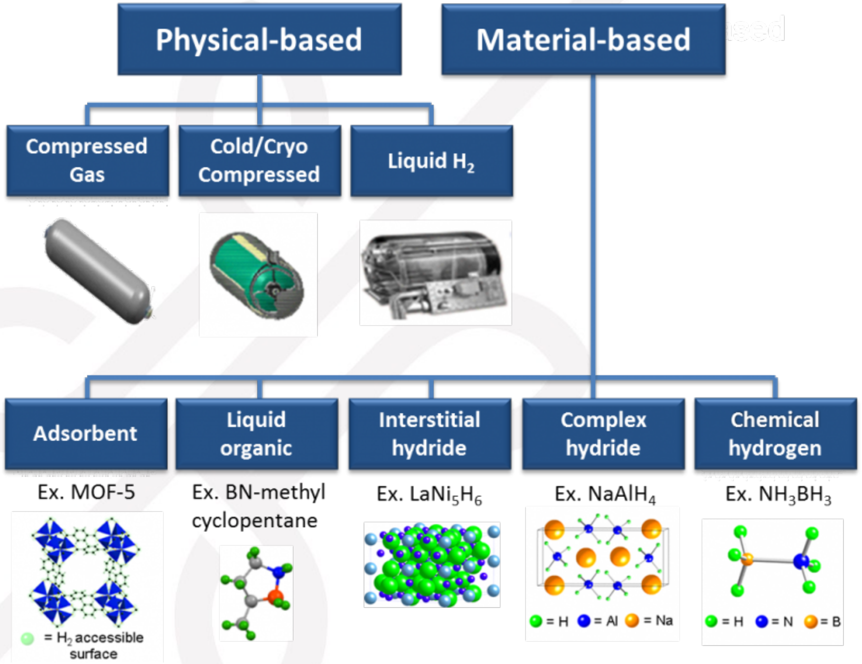
Technology	Feedstock	Efficiency	Maturity
Steam reforming	Hydrocarbons	70-85%	Commercial
Partial oxidation	Hydrocarbons	60-75%	Commercial
Autothermal reforming	Hydrocarbons	60-75%	Near term
Plasma reforming	Hydrocarbons	9-85%	Long term
Biomass gasification	Biomass	35-50%	Commercial
Aqueous phase reforming	Carbohydrates	35-55%	Med. Term
Electrolysis	H_2O + electricity	50-70%	Commercial
Photolysis	H_2O + sunlight	0.5%	Long term
Thermochemical water splitting	H_2O + heat	NA	Long term

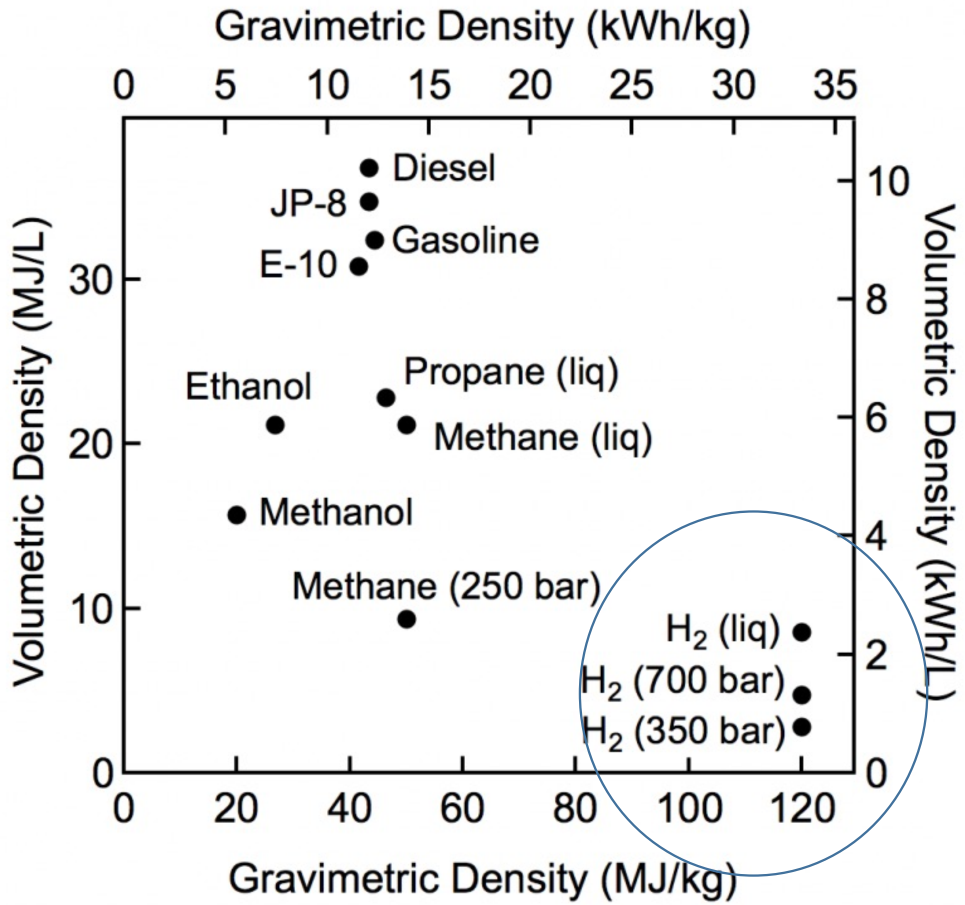
Note: hydrogen is not a source but an energy carrier.
Efficiency is important!

Source chart: P. Nikolaidis and A. Poullikkas (2017), "A comparative overview of hydrogen production processes," 67 *Renewable and Sustainable Energy Reviews*, 597–611.
Source table: http://article.sapub.org/10.5923.c.chemistry.201501.06.html

Hydrogen transport and storage

How is hydrogen stored?





Hydrogen transport and storage

Power *Unavoidable physical losses*

BritNed

- 260 km
- € 600 mio
- 1 GW capacity
- € 230/kW/100 km

Gas *Leak-free: no losses*

bbl company

- 230 km
- € 500 mio
- 20 GW capacity
- € 11/kW/100 km

Nord Stream

- € 9/kW/100 km

Offshore wind farms at GW scale: the combination of local conversion of power to hydrogen + a pipeline system may well be cheaper than a GW scale cable….certainly when current gas infrastructure is used.

Hydrogen transport and storage

Cavern

Volume

- 1 cavern with 1 mln m^3 of hydrogen equals 240,000 MWh (= 6,100 tons H_2)

Equivalents

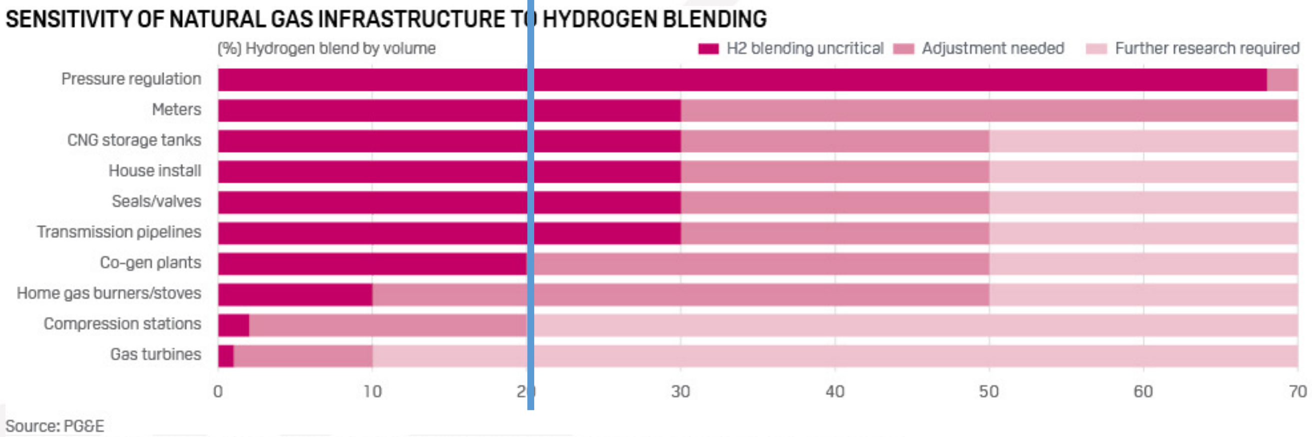
- 24 mln power walls (10 KWh, Tesla)
- 2400 of the largest batteries in the world (100 MWh, Tesla)

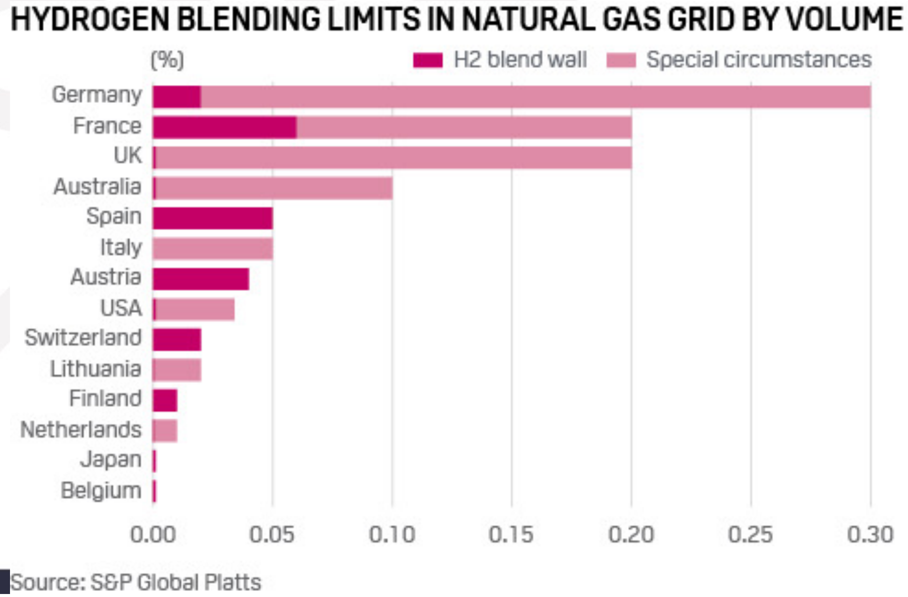
Experience

- H_2 storage in caverns is existing technology
- Many years of experience in the UK and US

Battery

Hydrogen infrastructure re use





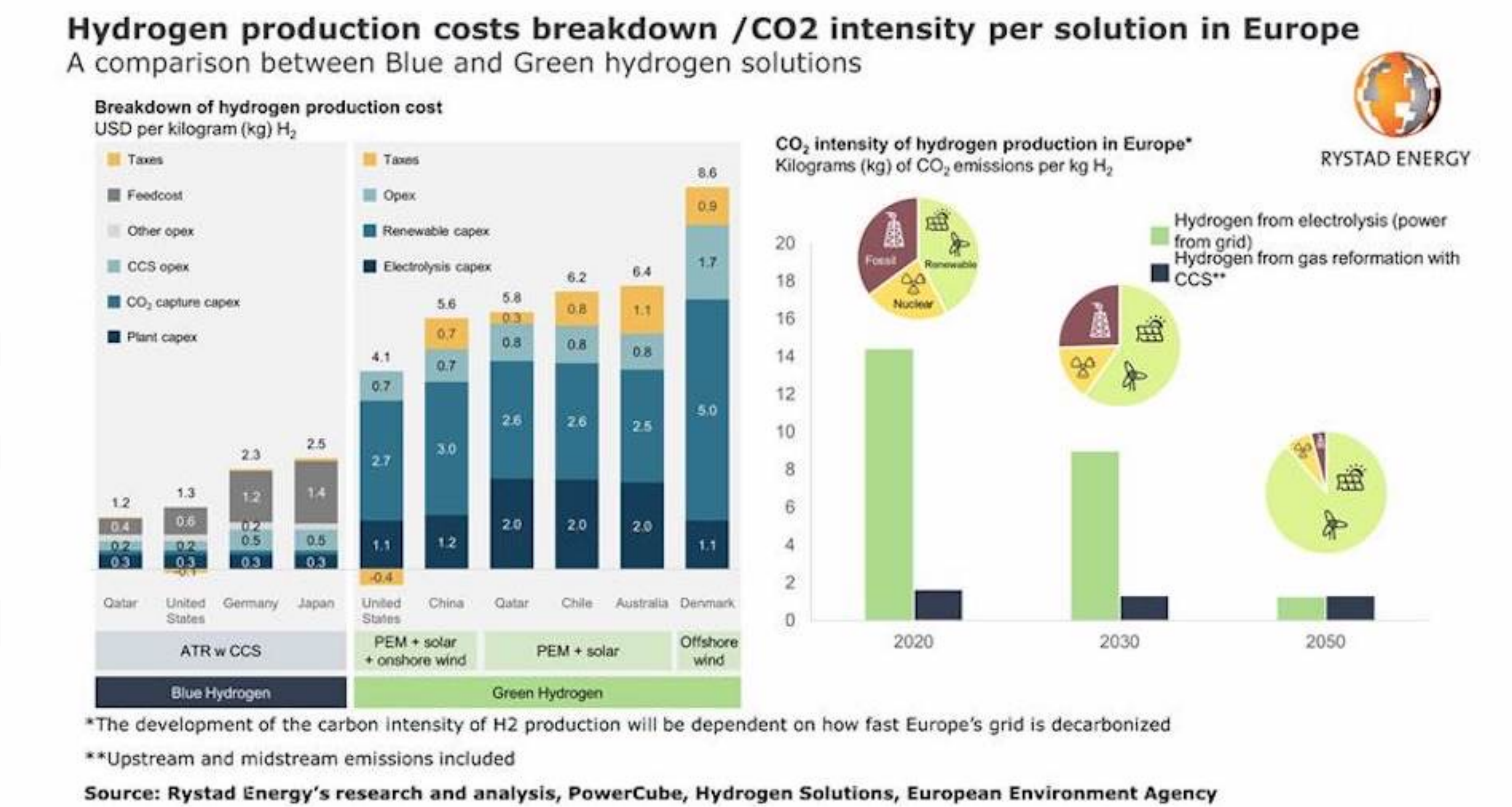
Pro's:

- Displaces fossil fuels (Natural gas)
- Enables re use of existing infrastructure
- Minimal adjustments required for end users currently using NG
- Kickstart hydrogen economy--> quick roll out possible

Con's:

- Significant adjustments are still required for infrastructure parts
- Hydrogen has lower energy density so CO2 reduction by volume is low
- Overall transport efficiency is low (different from economic efficiency)
- Regulatory challenge

Hydrogen economics



1 euro/kg
8 euro/MMBtu

Current gas price around 12 euro/MMBtu

Hydrogen economics- learning rates

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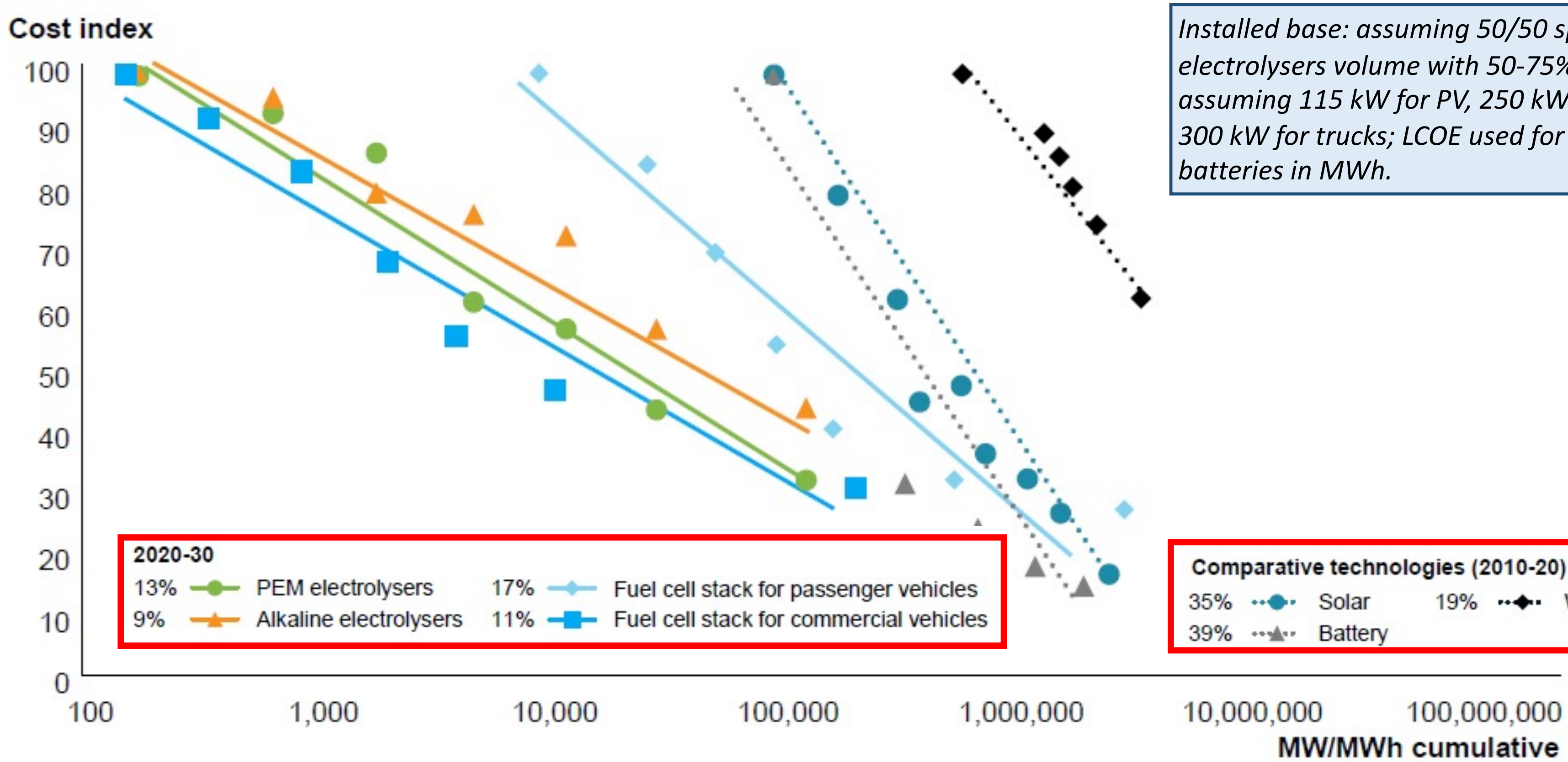


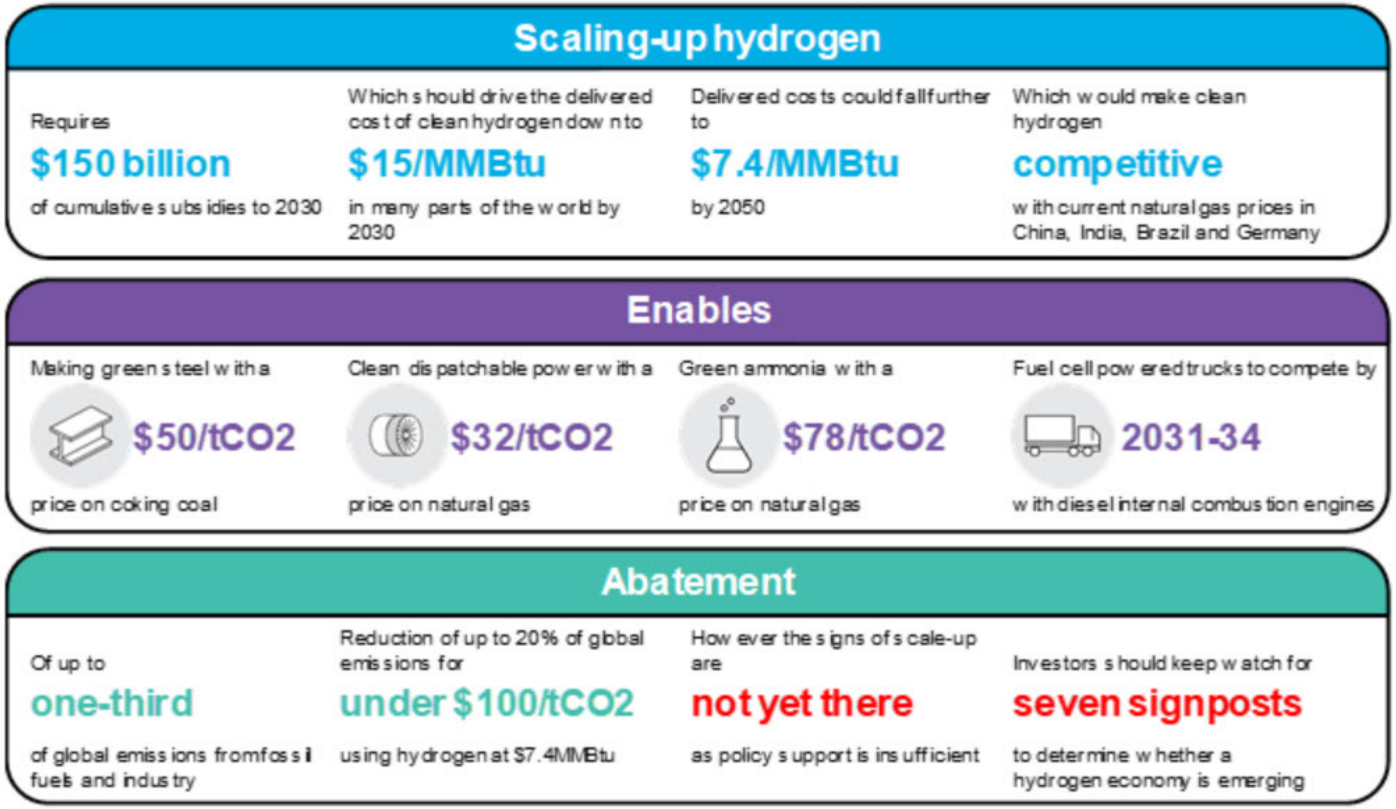
Installed base: assuming 50/50 split of electrolysers volume with 50-75% utilisation; assuming 115 kW for PV, 250 kW for buses and 300 kW for trucks; LCOE used for solar cost; batteries in MWh.

Capex development of selected technologies over total cumulative production, indexed to 2020 values (2010 for comparative technologies).

Source: Hydrogen Council, Path-to-Hydrogen-Competitiveness _Full-Study-1 2019
https://hydrogencouncil.com/en/path-to-hydrogen-competitiveness-a-cost-perspective/

Hydrogen economics

Figure 1: Summary of the economics of a hydrogen economy



Source: BloombergNEF. Note: Clean hydrogen refers to both renewable and low-carbon hydrogen (from fossil fuels with CCS). Abatement cost with hydrogen at $1/kg (7.4/MMBtu).

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Thank you!

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