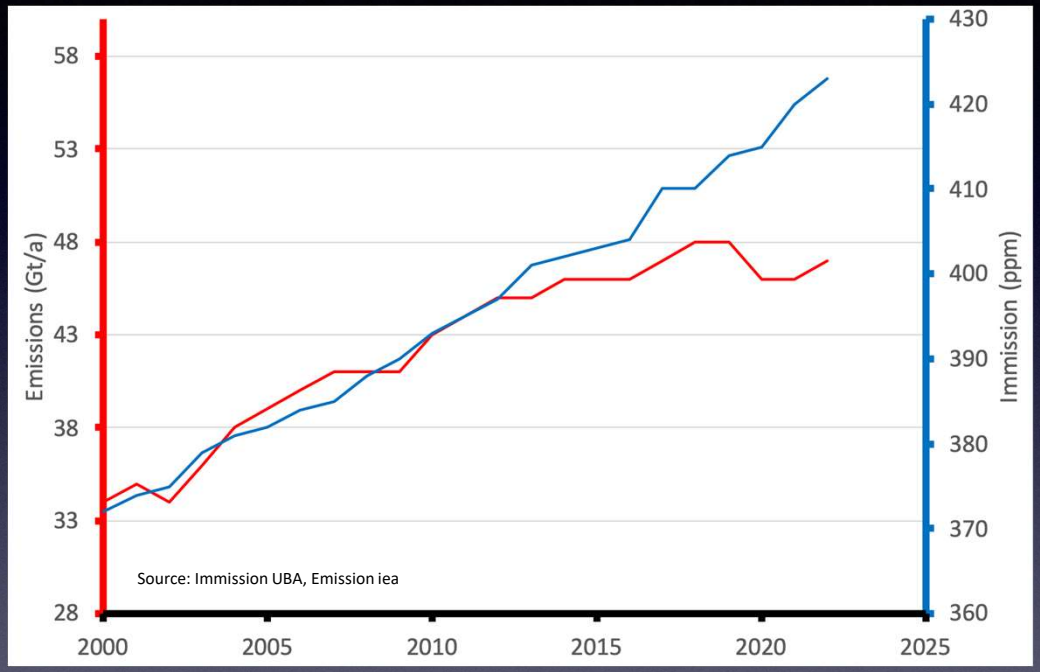
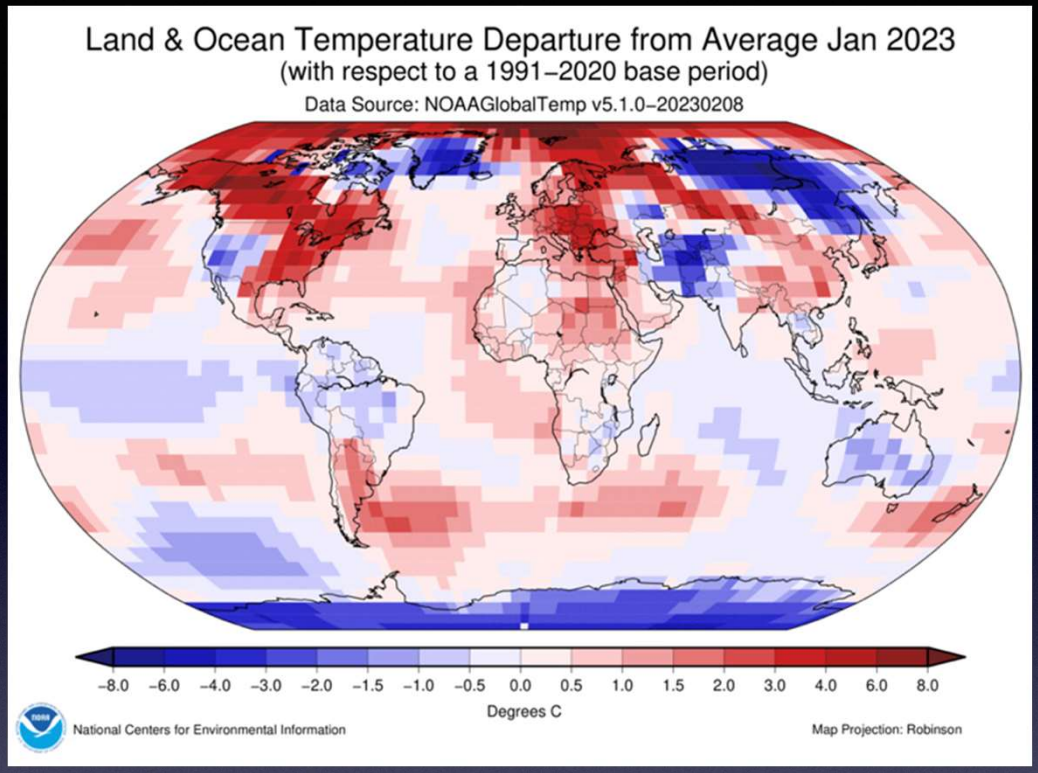
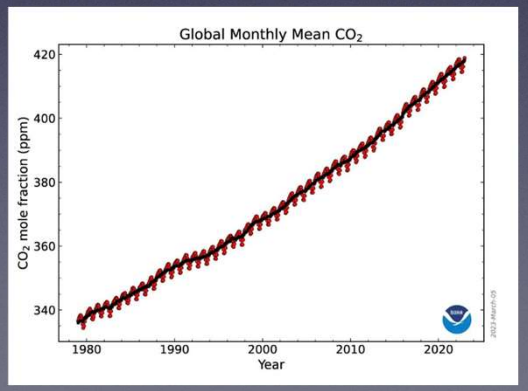

Emissions (Gt/a)
Immission (ppm)
58
53
48
43
38
33
28
430
420
410
400
390
380
370
360
2000
2005
2010
2015
2020
2025
Source: Immission UBA, Emission iea

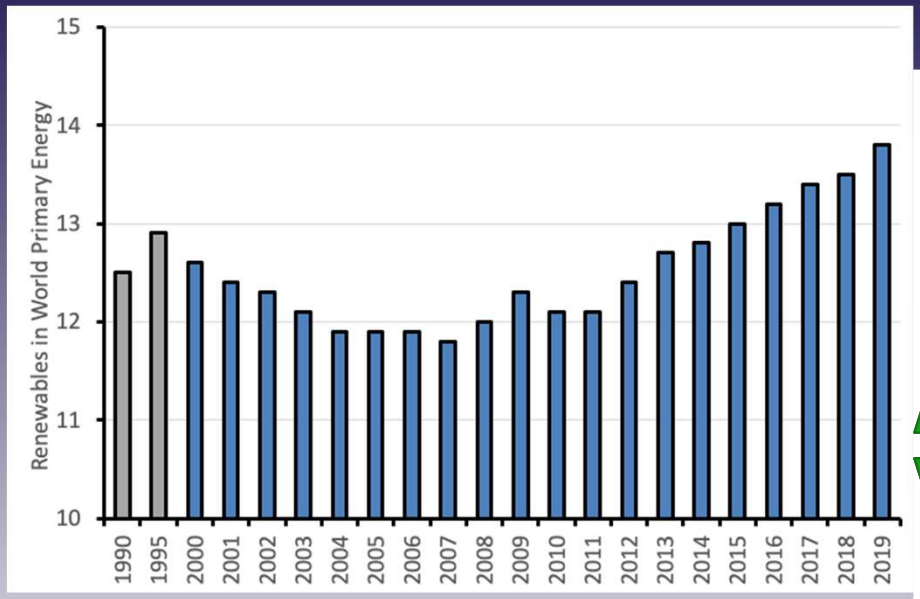

Land & Ocean Temperature Departure from Average Jan 2023
(with respect to a 1991–2020 base period)
Data Source: NOAAGlobalTemp v5.1.0–20230208
−8.0 −6.0 −4.0 −3.0 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 3.0 4.0 6.0 8.0
Degrees C
National Centers for Environmental Information
Map Projection: Robinson

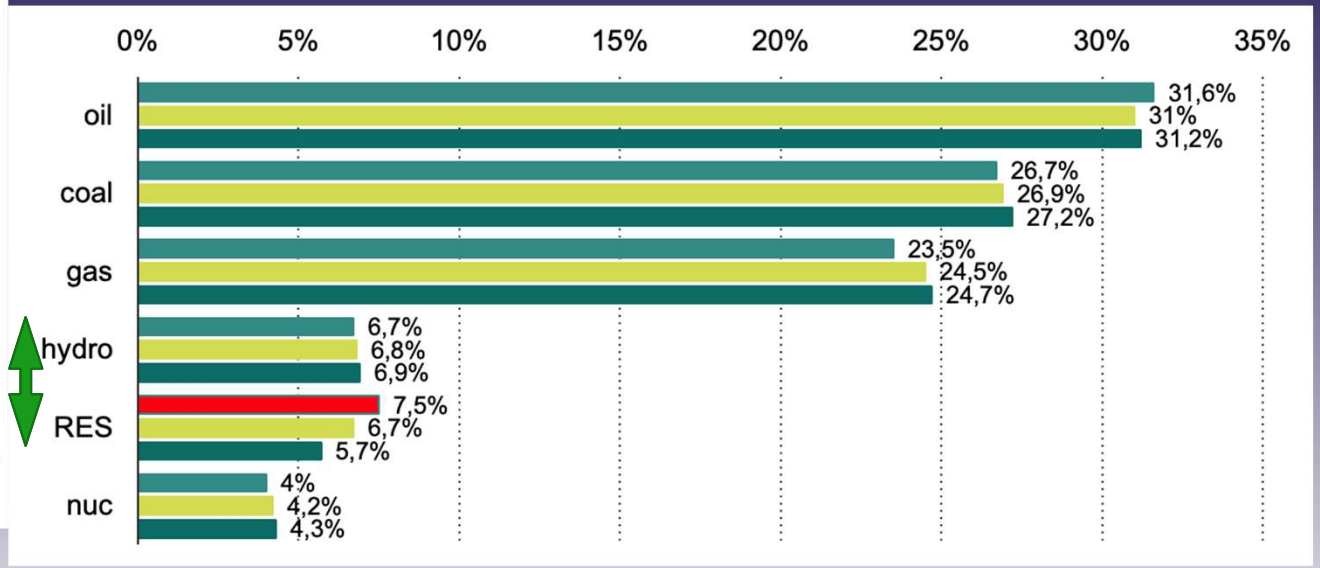

Global Monthly Mean CO_2
CO_2 mole fraction (ppm)
420
400
380
360
340
1980
1990
2000
2010
2020
Year

How to Replace Fossil by Renewable Energy
A Systemic and Global Approach

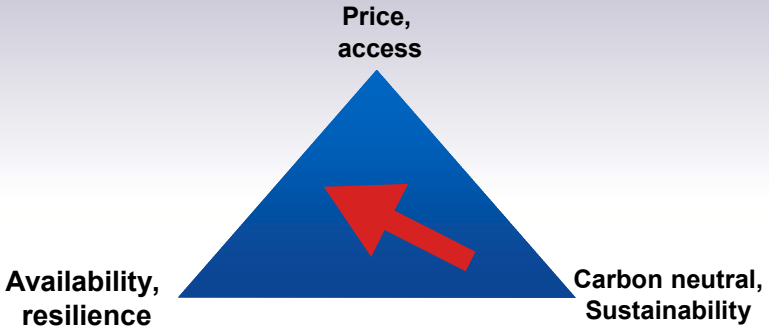
Robert Schlögl
Alexander von Humboldt Stiftung
Fritz-Haber-Institut der MPG
Department Interface Science

Renewables in the World



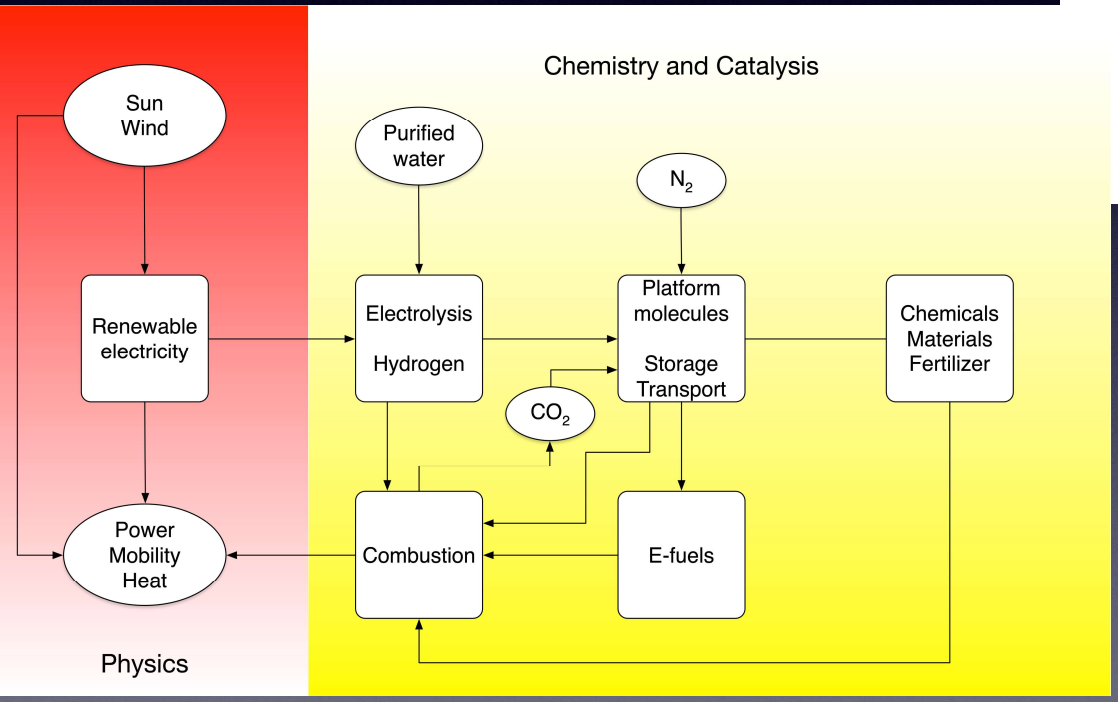


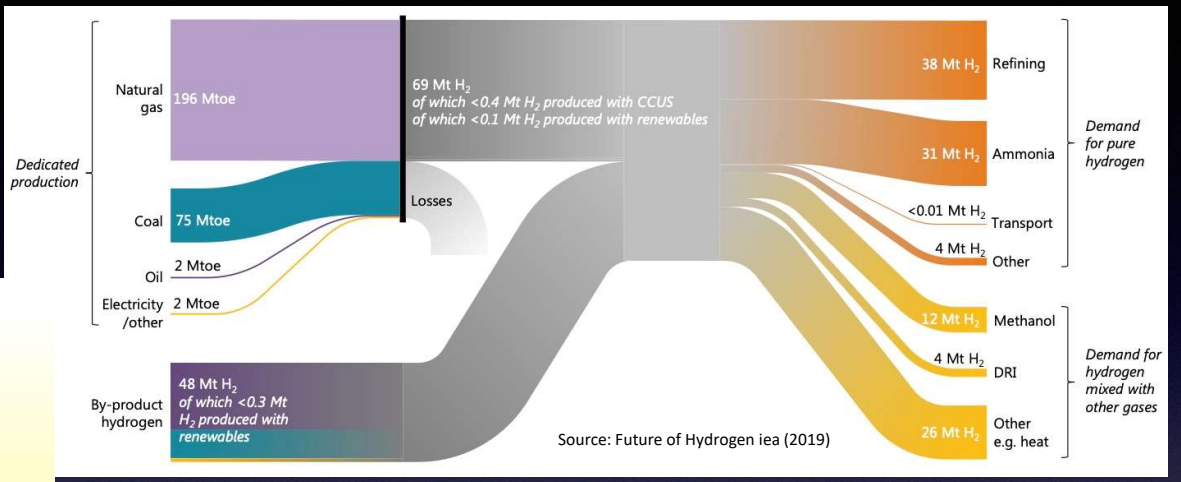
- Fraction still limited despite so many efforts
- Dimensional challenge
- Fossil will remain for a long time



From Diagnosis to Therapy: Dual Energy Systems

Works only as global concept
A strong European component helps resilience

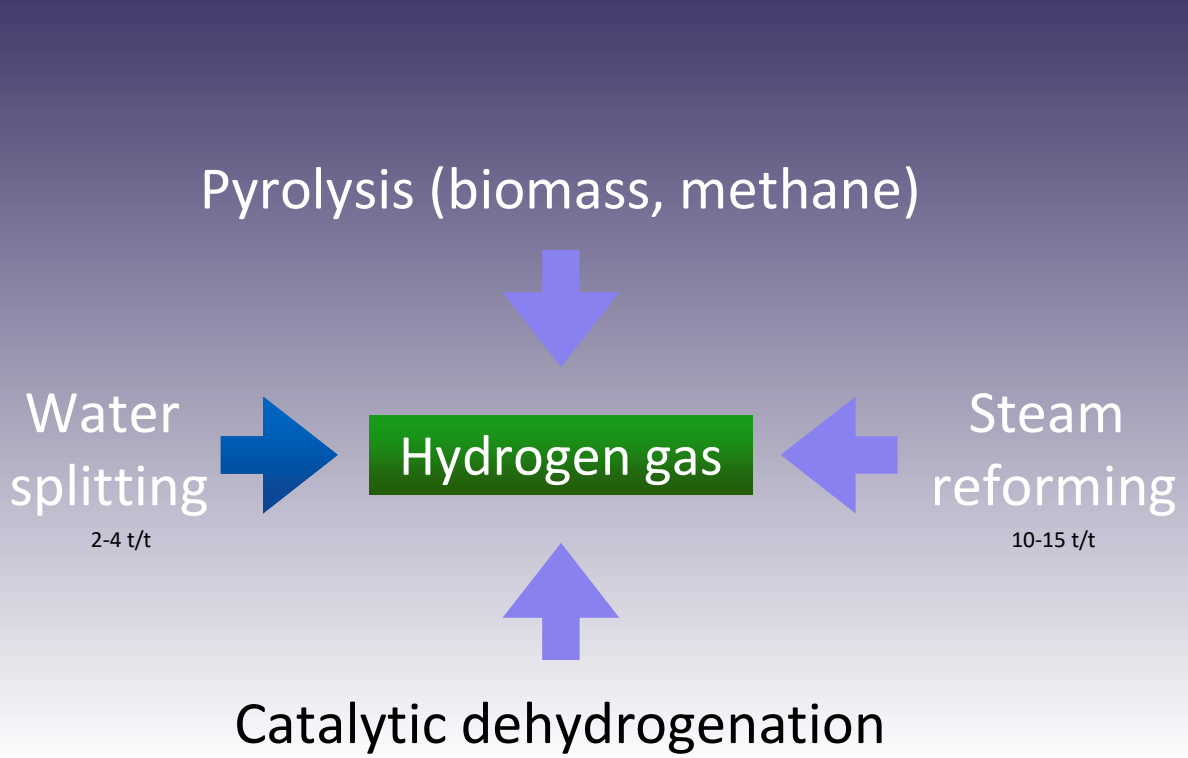


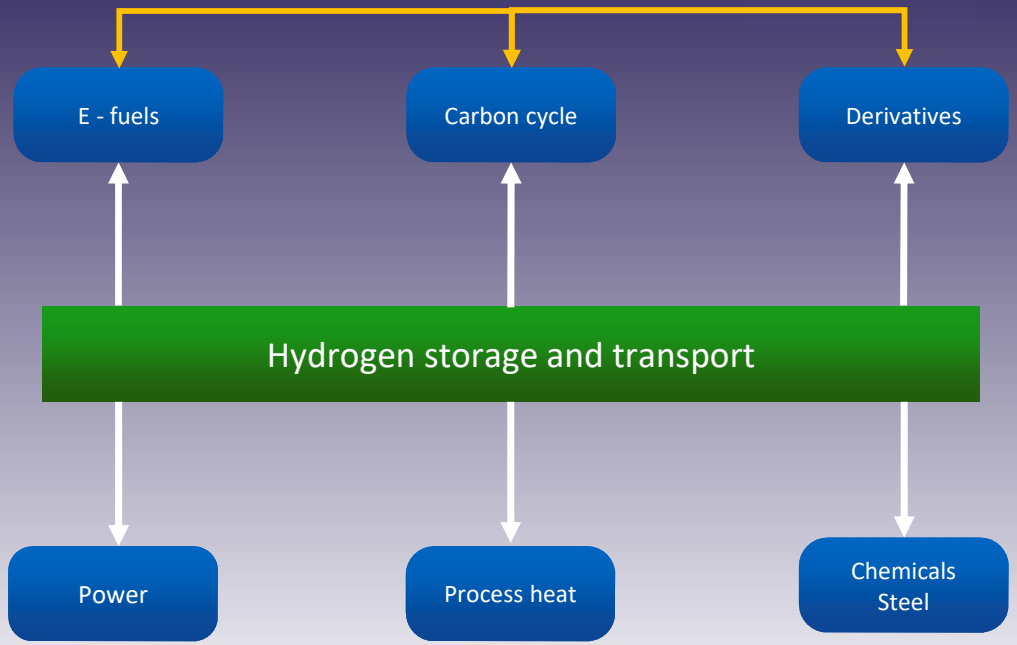


	H_2 content (Kg/m^3 liquid)
Hydrogen	70
Ammonia	120
Methane	107
Methanol	100
Isobutanol	110
Isoocatane	110

Source	Amount in TWy/a
Sun over land	23.000
Sun as PV	4.600
Wind	100
Biomass	5
Hydro	4

Origin and Use of Hydrogen

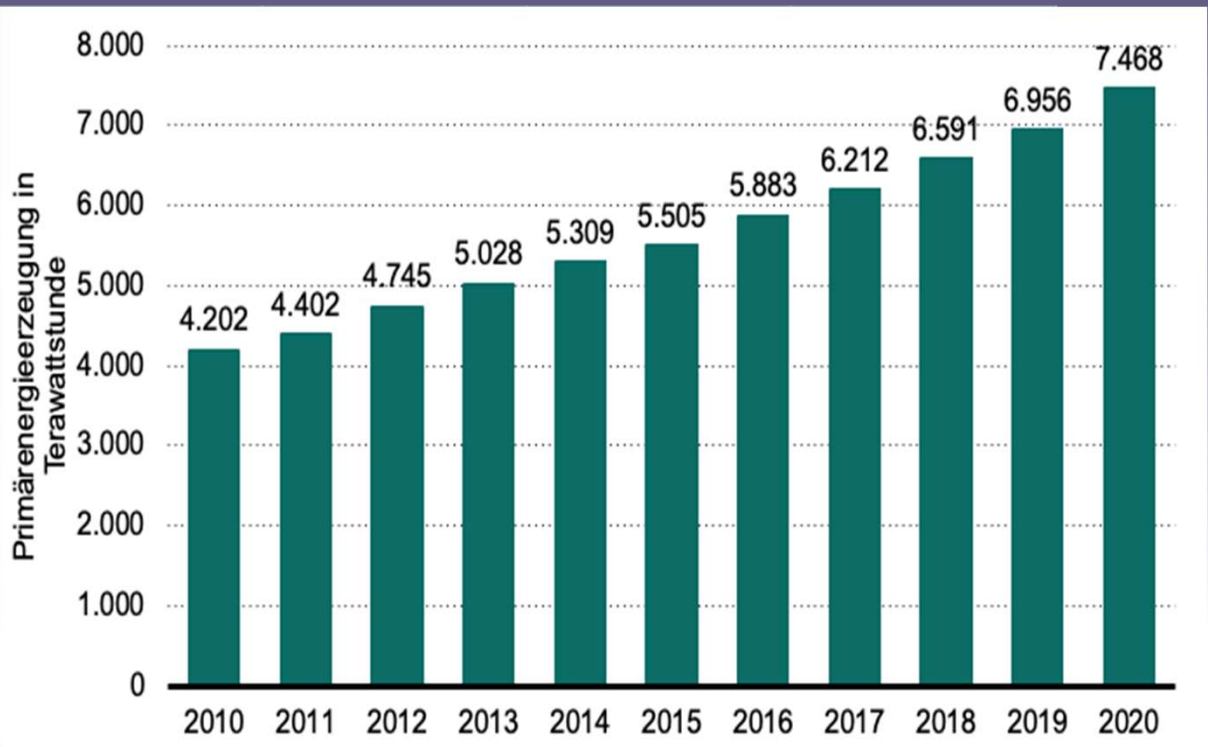




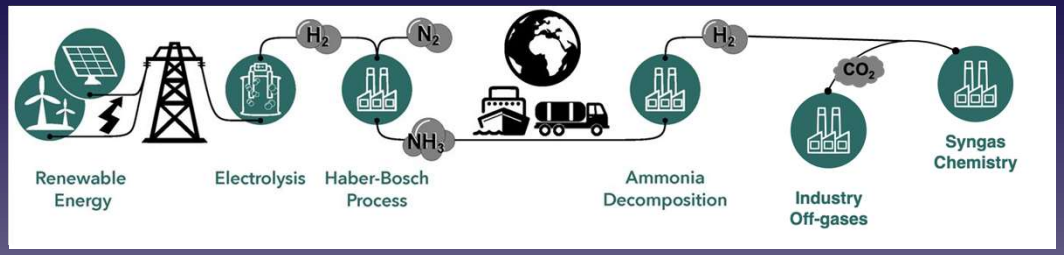
How much Hydrogen ?

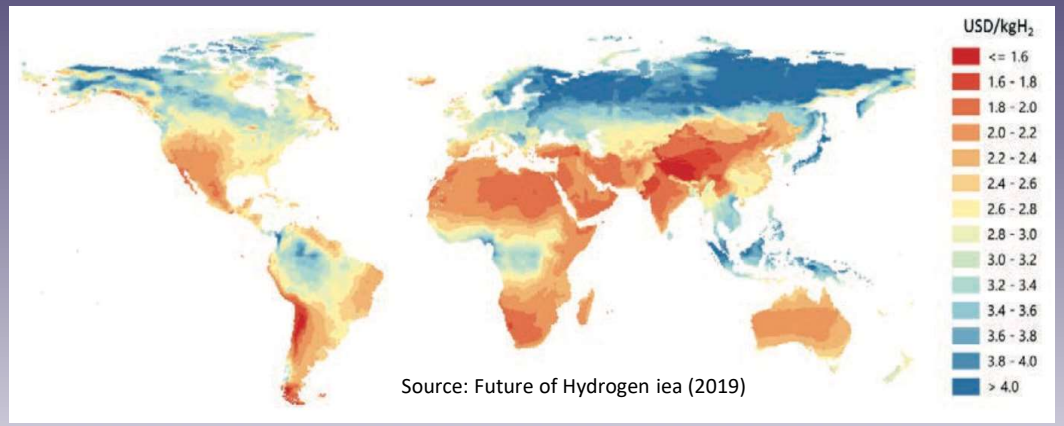
Annual lower estimate of hydrogen demand : amounts may be substantially larger as application scenarios may change with availability and price

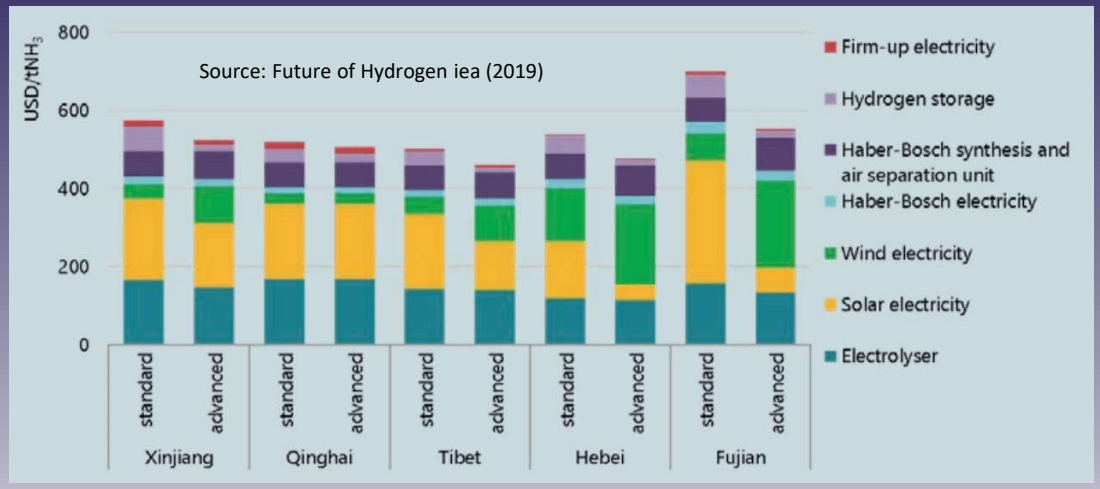
2021 Bp stat.rev.	Total (TWh)	RES + Hydro (TWh)
World	165.880	22.230
US	25.835	2.780
EU	16.667	3.056



Where from ?





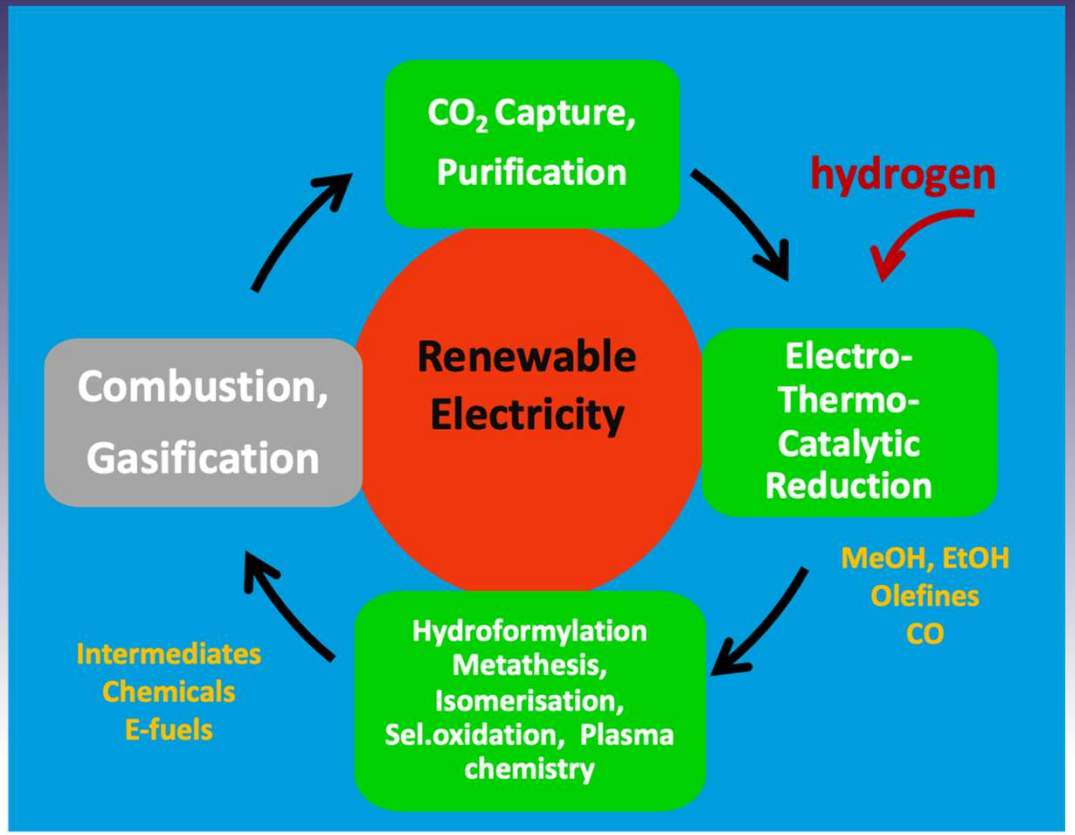


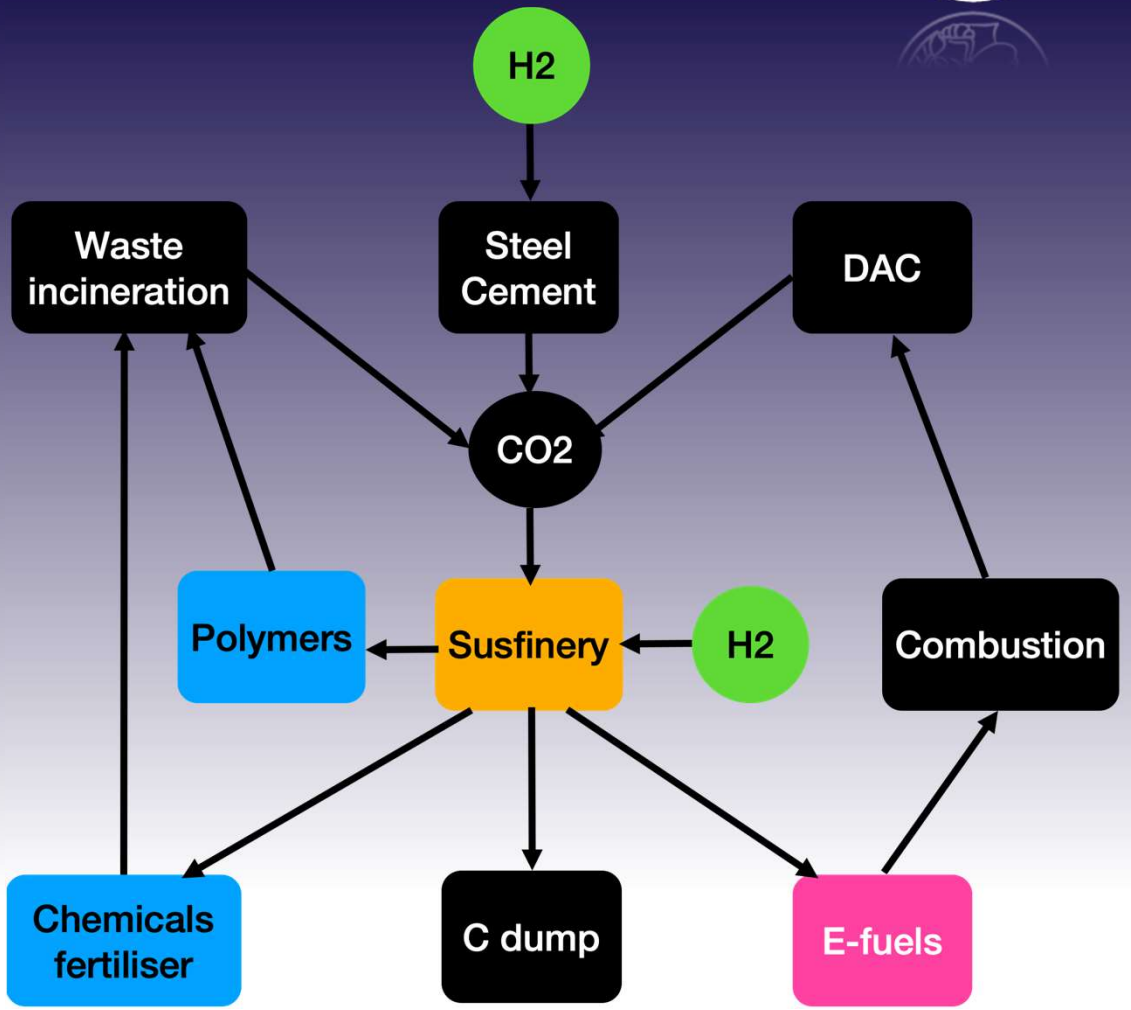
- Globally there are regions where hydrogen and derivative production is much favoured against strict local production
- A world market for „green“ energy carriers is emerging; resilience through diversification is critical
- Efficiency losses overcompensated by „unlimited“ availability
- Research can still reduce efficiency losses even when first gen technologies are in place

In Circular Economies Derivatives offer Advantages as Use and Transport can be Combined

	Derivative	Advantage	Disadvantage	Hurdle
1	Ammonia	High energy density Synthesis and transport 150 Mt/a technology, no regret as fertiliser needs	No self ignition (co-fuel), N_2O formation	Dehydrogenation technology, unexplored applications
2	Methanol	Platform chemicals, fuel, very cheap, 100 Mt/a technology, dynamical operation	Requires closed C cycle	_____
3	LOHC	Compatible with present oil transport infrastructure, high intrinsic safety	Low energy density (below 5wt%) Costly carrier	Reversibility of storage, energy integration at point of use
4	Oxygenates	Platform molecules, fuels, global transport infrastructure	Require closed C cycle	Synthesis technology not established
5	Methane	Exact replacement of present NG, transport and use infrastructure existing	Require closed C cycle, only for heating, difficult dehydrogenation	Immature synthesis technology, poor reputation

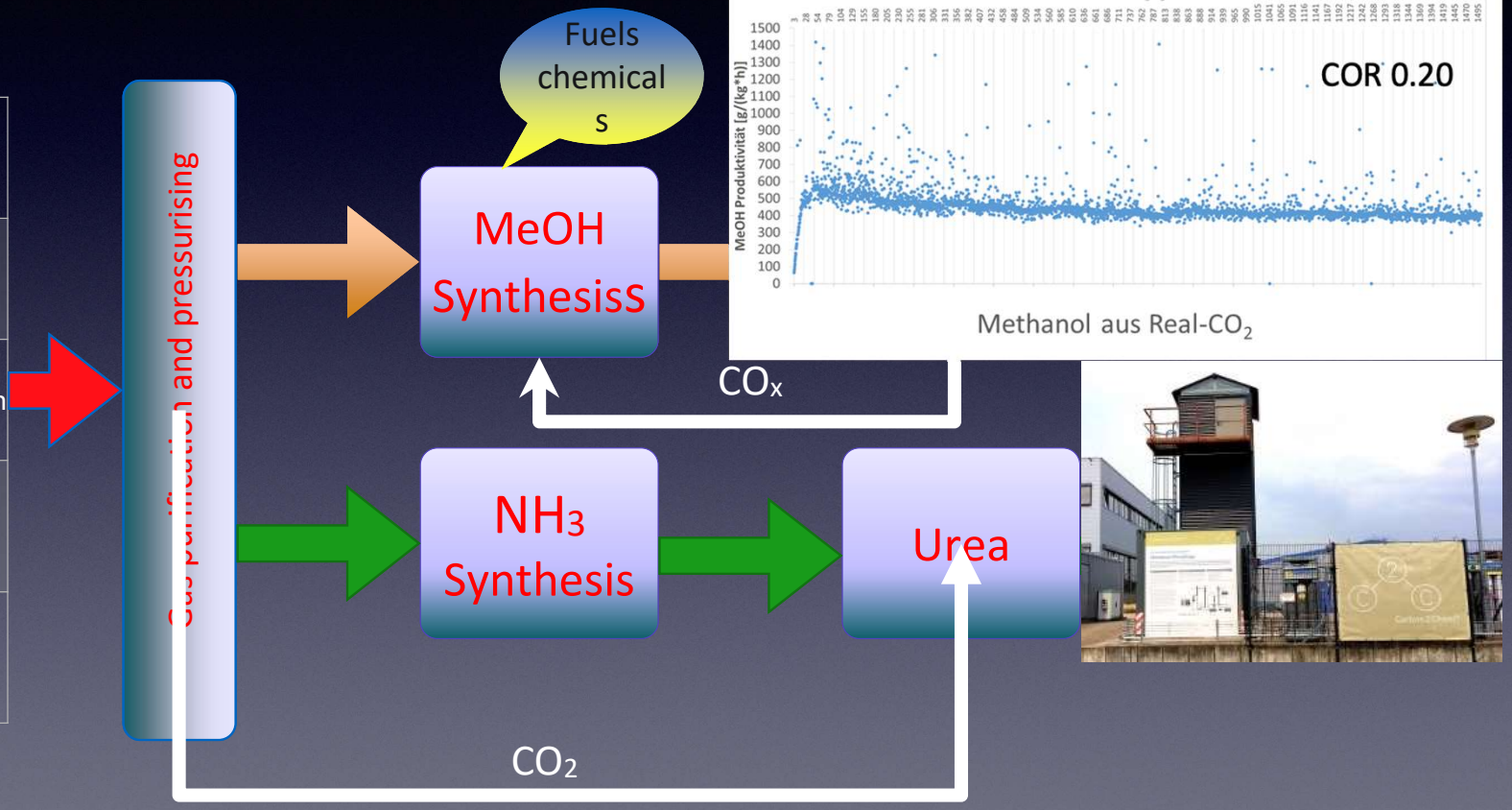
Carbon Cycle: Copy Nature



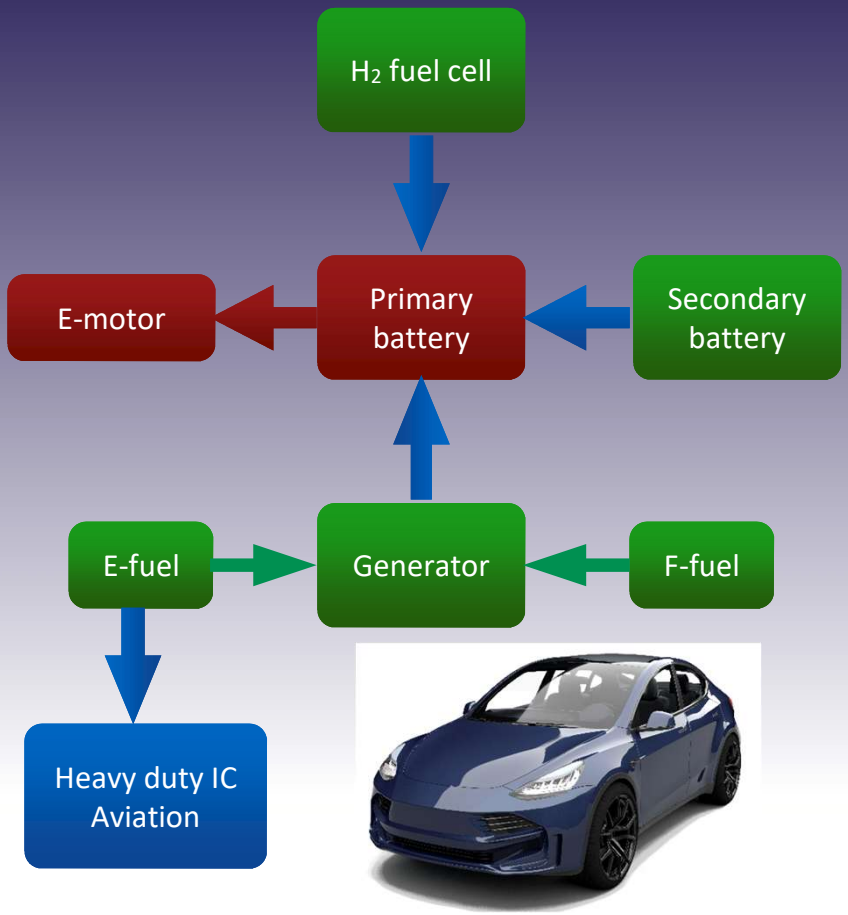


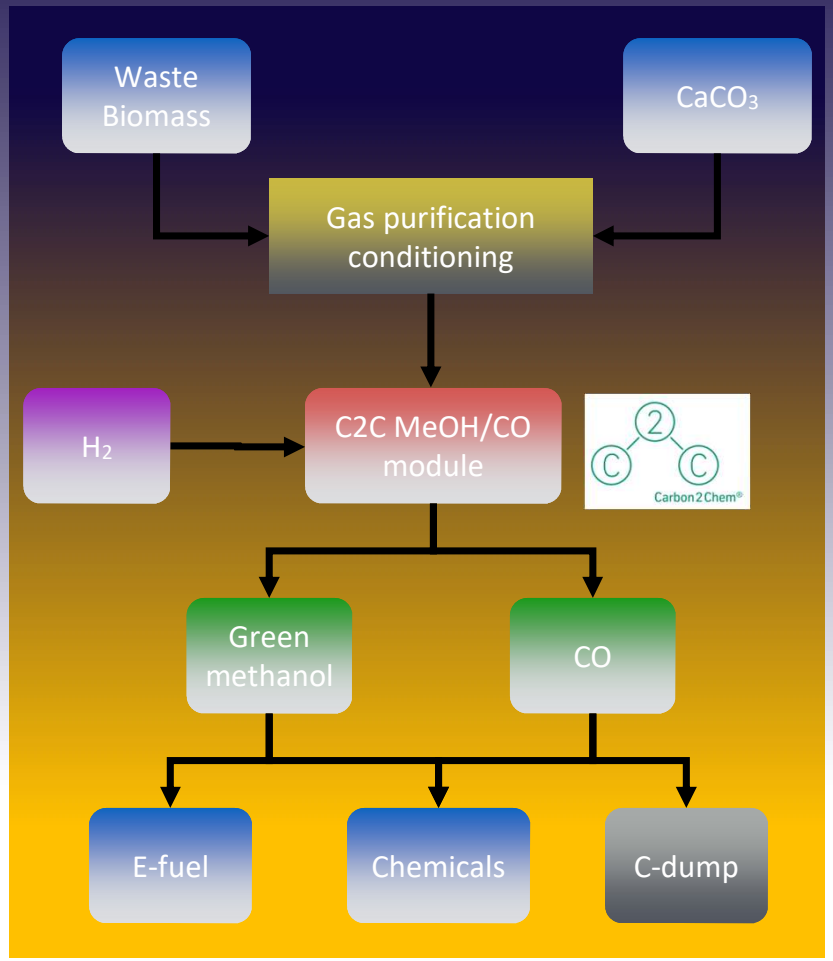
Real example: C2C Project

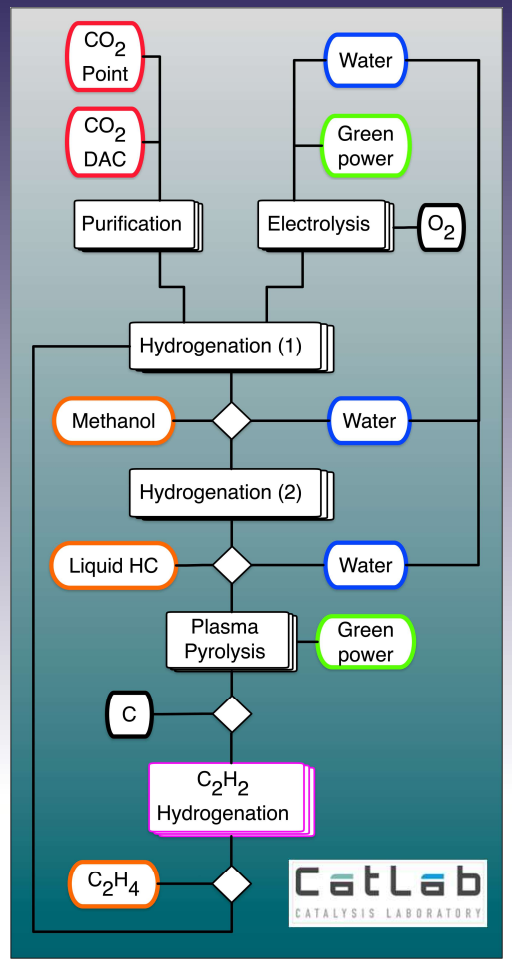
0,89	BFG Blast furnace gas
0,20	BOFG Basic oxygen furnace gas
0,1-1,0	DRI Direct reduction gas
1,0	Waste Waste incineration flue gas
0,9-1,0	Cement Lime and cement calcination gas



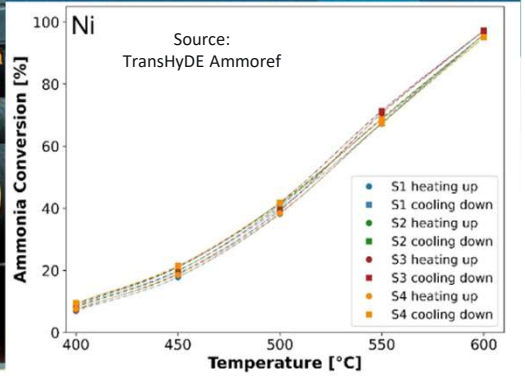
CCU Technologies; only with ample Hydrogen



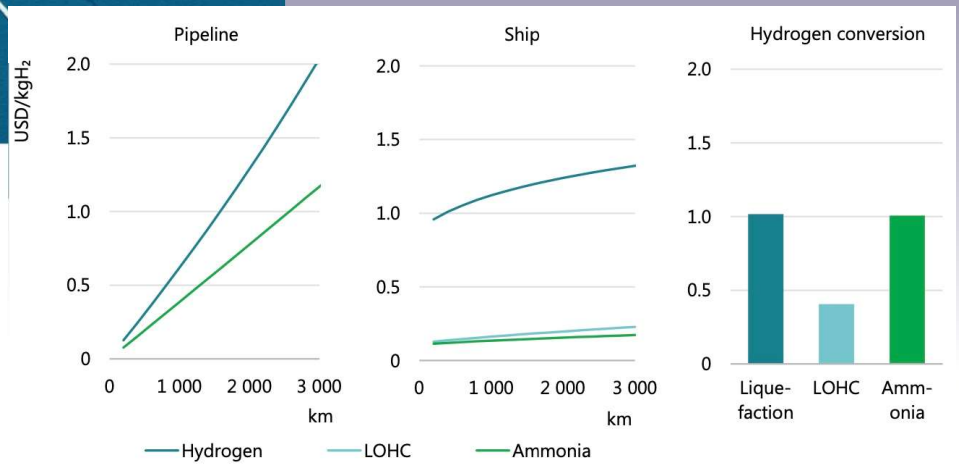




Infrastructure and Import



Connected to German national start grid? Ready for several media including CO_2?



Source: Future of Hydrogen iea (2019)

Albert Einstein

We cannot solve our problems with the same thinking we used when we created them

We develop the means to transform the energy system

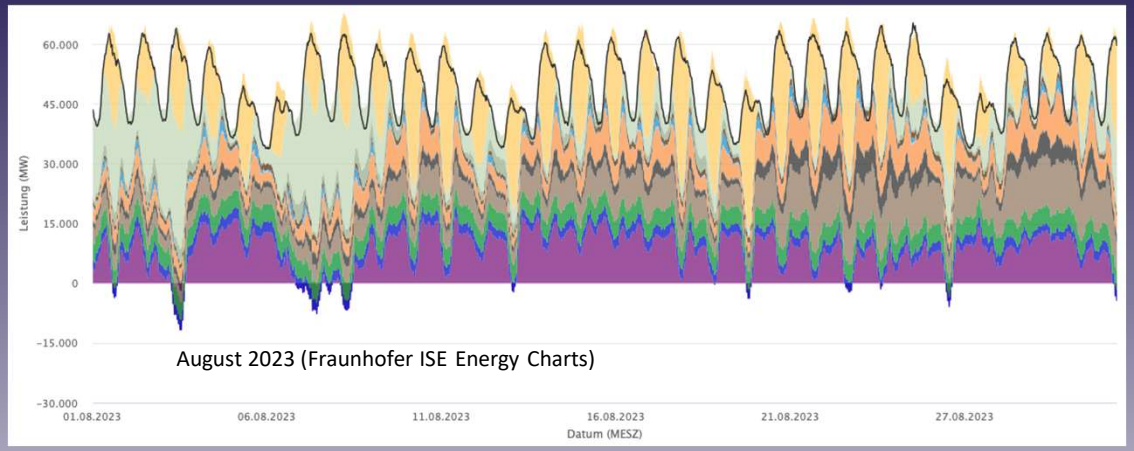
Fast is reliable, rigorous and resilient; if steady, no showstoppers in sight

Systemic and global concepts are needed: co-operation between nations and companies

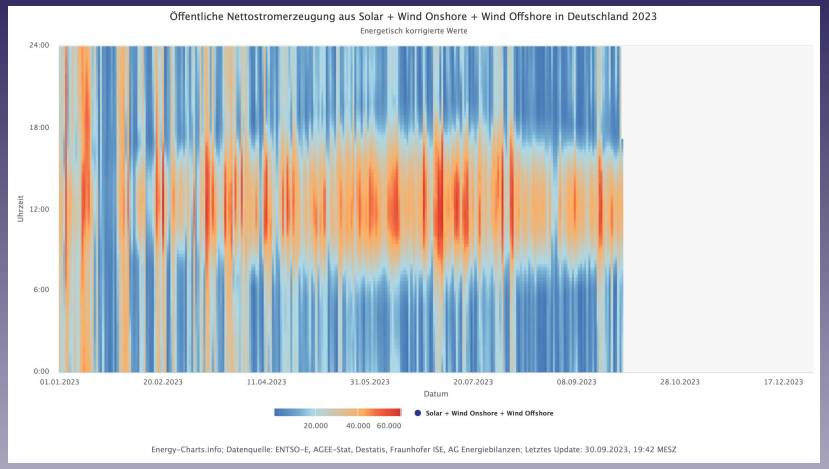
We can and should transform our energy systems into a sustainable future

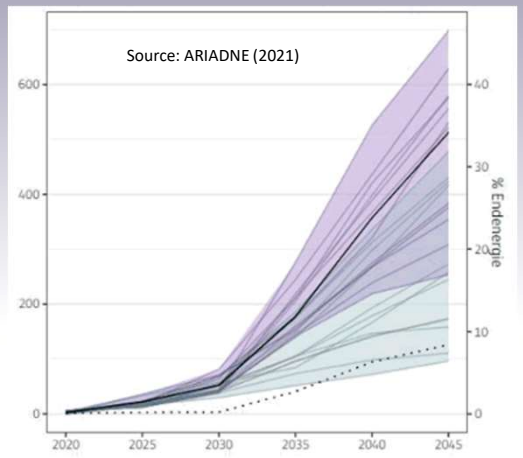
Thank you for the kind attention

Power and Hydrogen in Germany



August 2023 (Fraunhofer ISE Energy Charts)



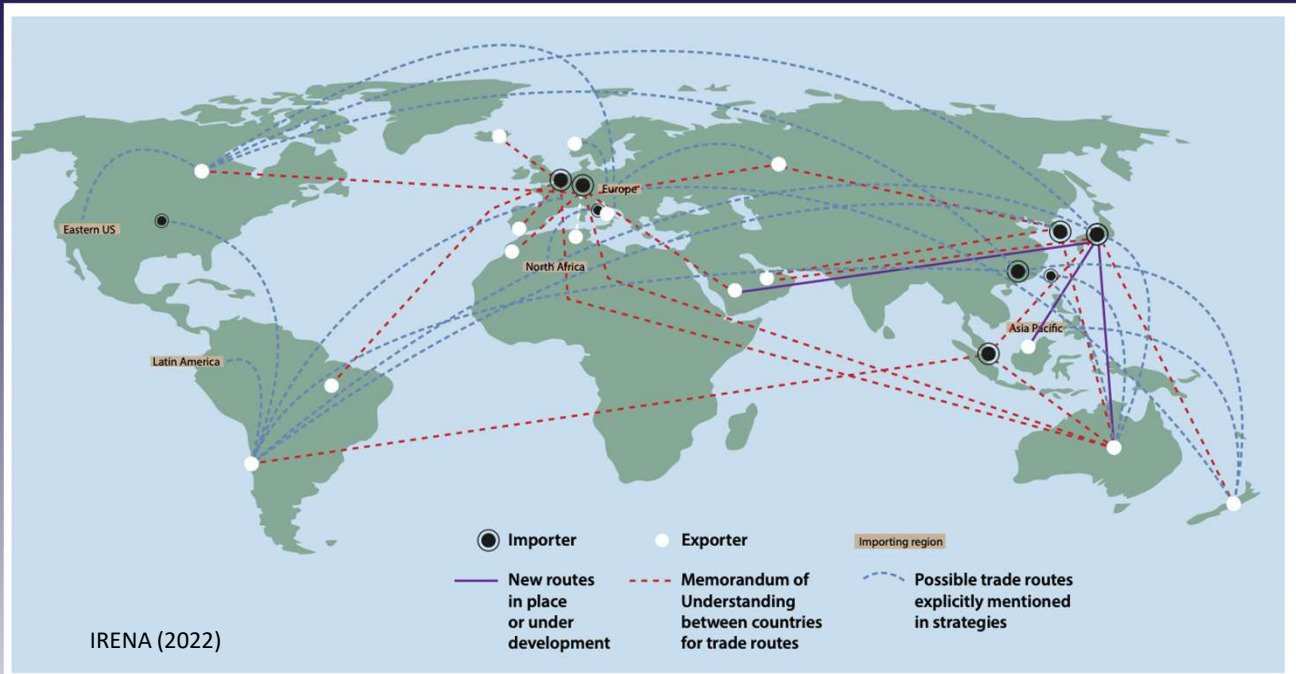


Consumer (2020)	TWh	Mt H_2
EU 27	12328	310
DE total	2500	62
DE industry	1085	27
DE studies	700	18
NWS domestic	60	1,8

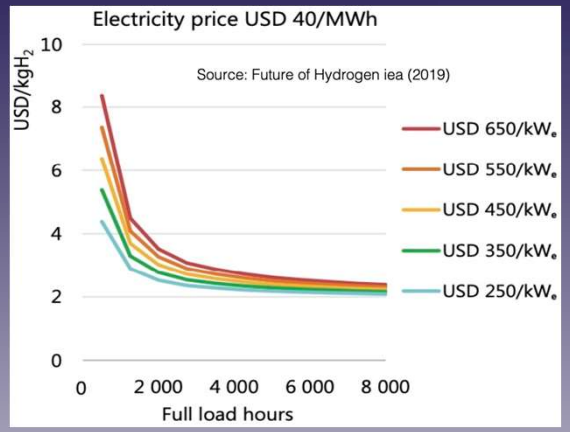
Long term storage by hydrogen for cost reasons more than anticipated

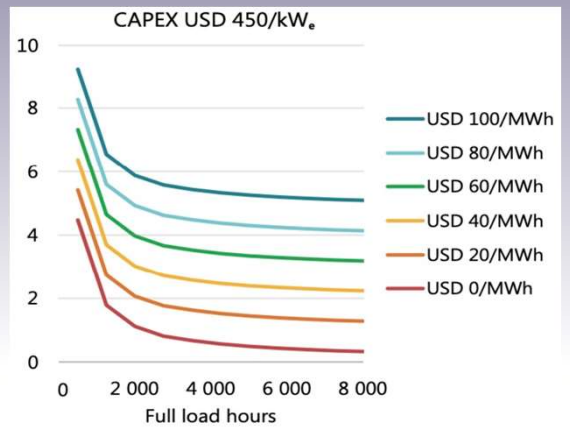
Hydrogen use in addition to power also in industrial heat generation and in chemicals and material production required

Global Development



IRENA (2022)





NH_3	CH_3OH	LOHC	CH_4	LH_2	
6,10	9,84	7,35	13,90	6,6	Kg H_2
0,95	1,07	——	1,75	——	Kg carrier

acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN
BDI Bundesverband der Deutschen Industrie e.V.
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Delivery in DE in € Including CO_2 capture