Electrons, molecules, and uncertainty - what future are we planning for?

Agora Energiewende - Energy infrastructure for a net-zero future
19th September 2023

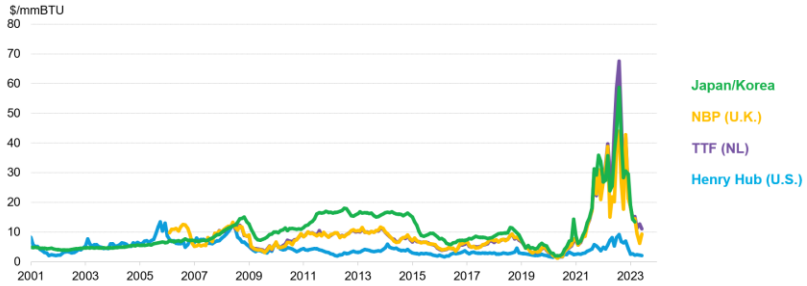
Michael Liebreich
Founder and CEO
Liebreich Associates

Bloomberg New Energy Finance

The 2020s in energy history

Liebreich Associates

The Great Energy Price Spike



Note: Data as of August 2023, monthly prices for 1M Forward contracts

Source: Liebreich Associates; Bloomberg

The Great Clean Energy Acceleration

Source: Liebreich Associates

Renewables expected to double

Liebreich Associates

“Renewables were already expanding quickly, but the global energy crisis has kicked them into an extraordinary new phase of even faster growth as countries seek to capitalise on their **energy security** benefits.

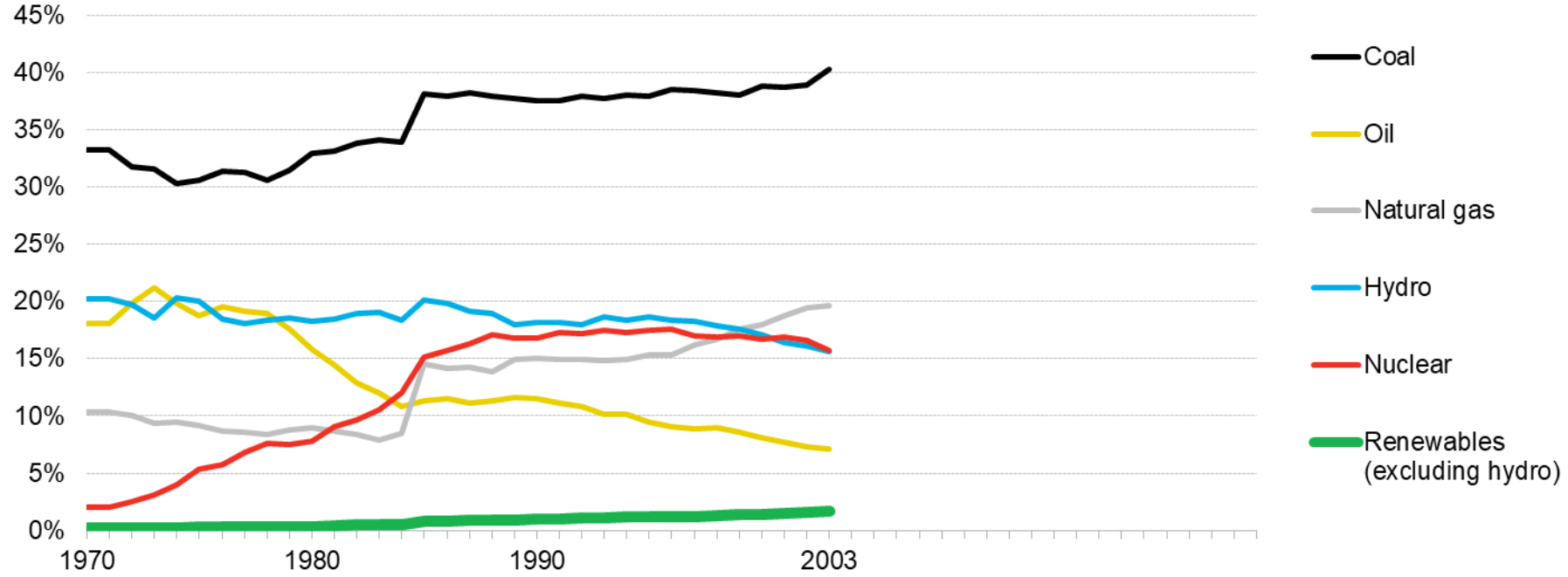
The world is set to add as much renewable power in the next 5 years as it did in the previous 20 years.”

Fatih Birol, Executive Director of the IEA

Image: Wikimedia Commons

Global share of power generation by source 1970 - 2003

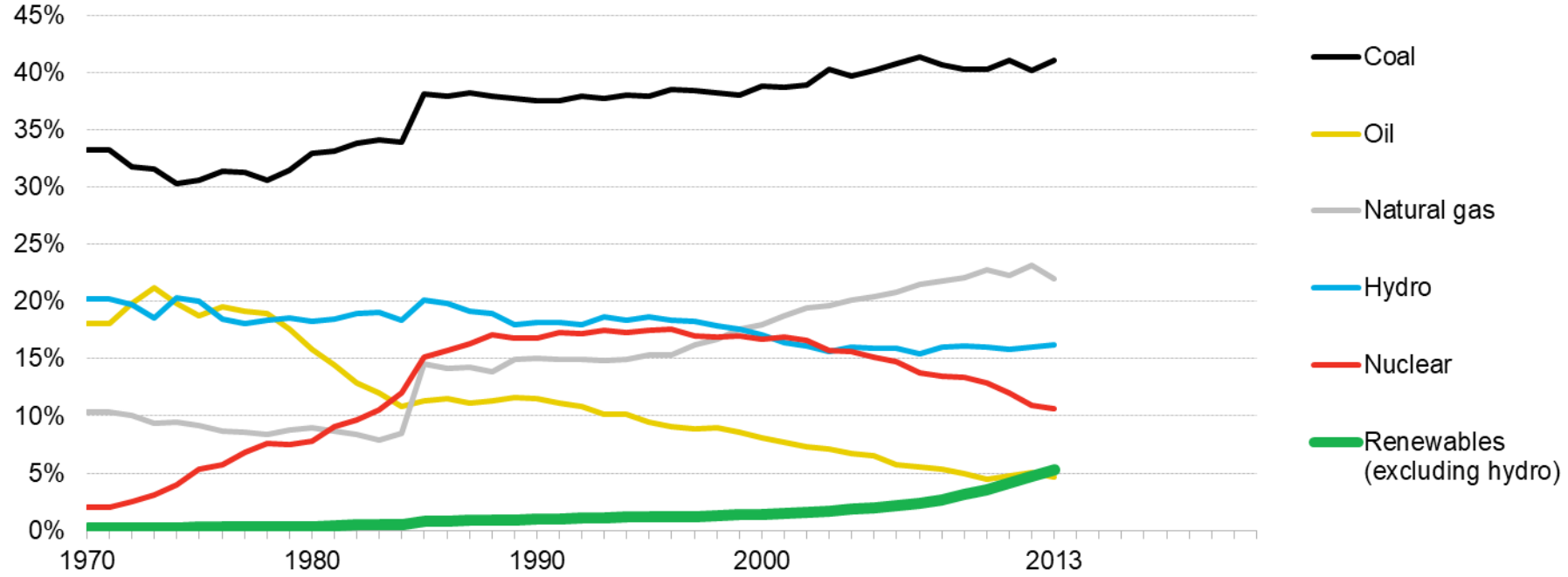
Liebreich Associates



Source: Liebreich Associates, IEA, BP, Energy Institute

Global share of power generation by source 1970 - 2013

Liebreich Associates



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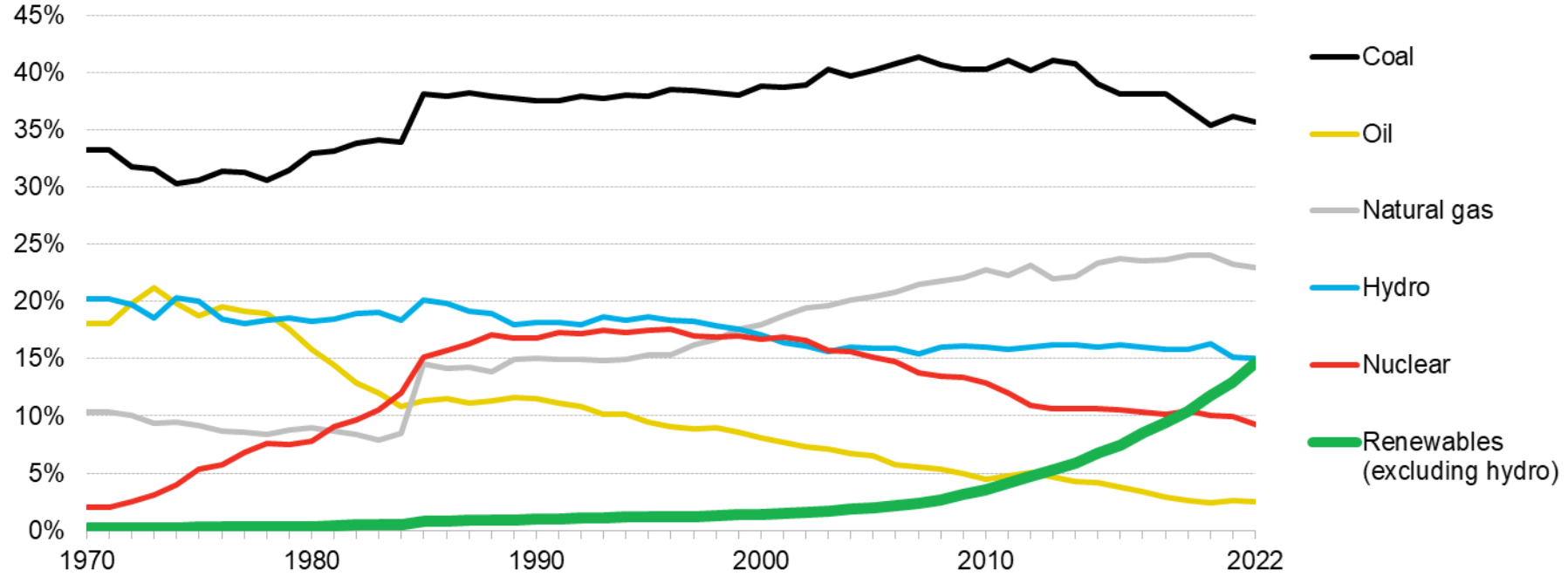
Global share of power generation by source 1970 - 2022

Liebreich Associates



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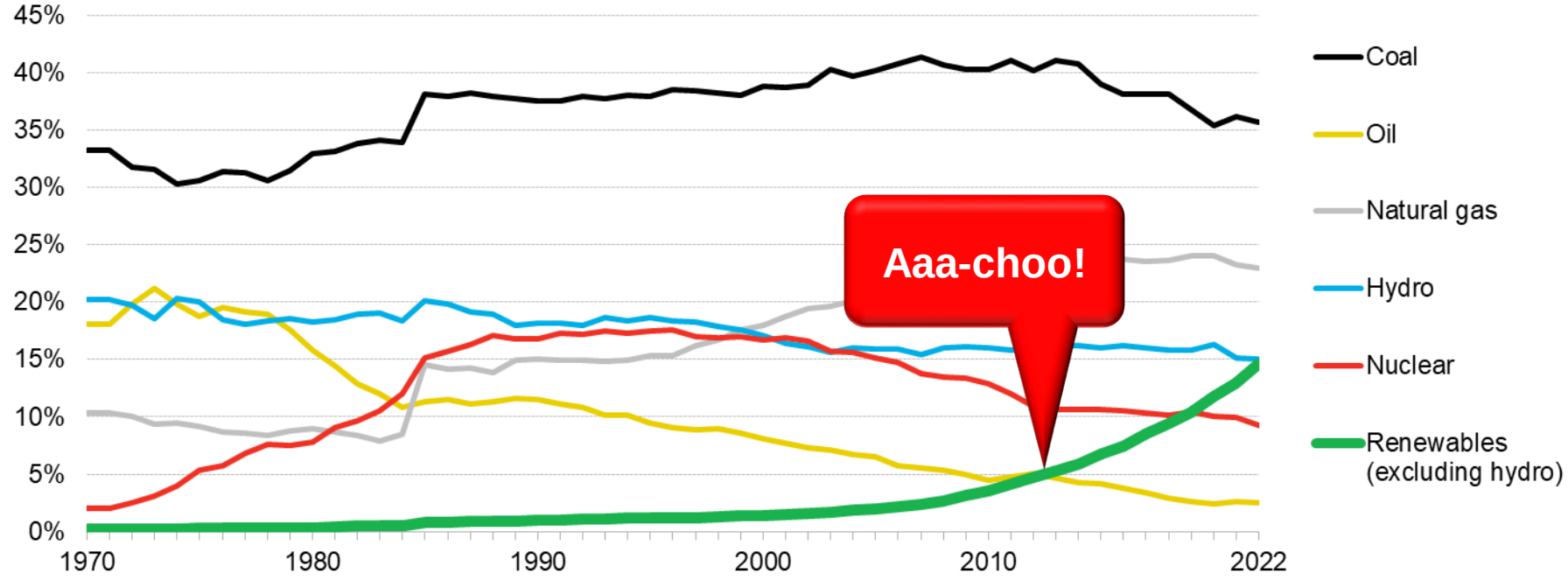
Global share of power generation by source 1970 - 2022

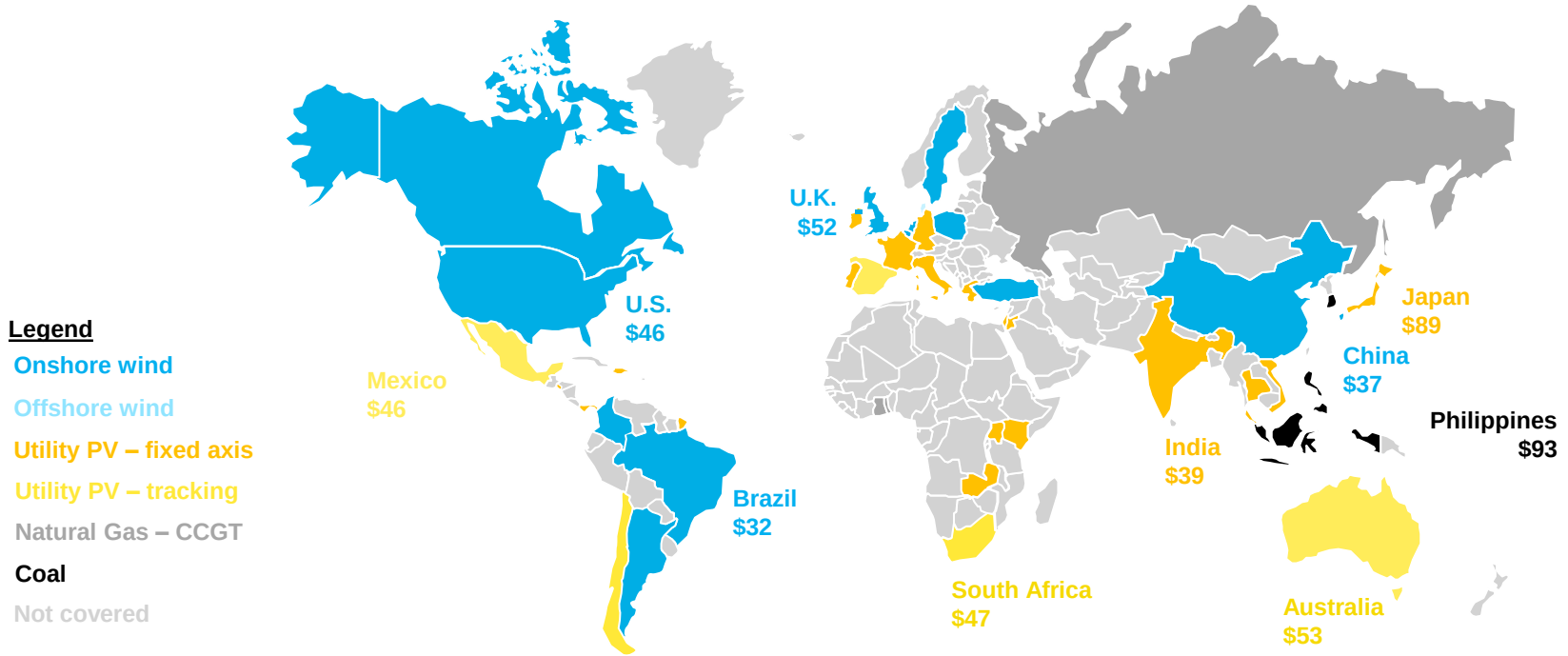
Liebreich Associates



Source: Liebreich Associates, IEA, BP, Energy Institute

Cheapest source of new build generation, 1H 2023

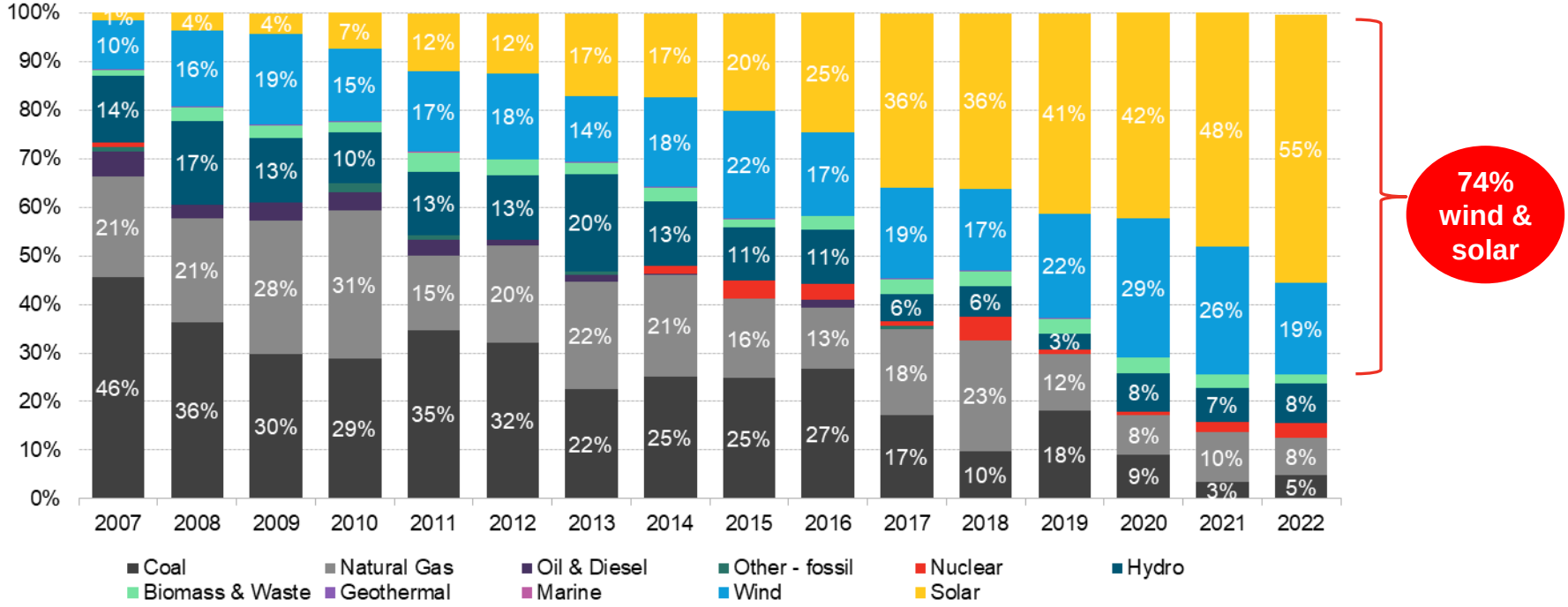
Liebreich Associates



Source: BloombergNEF, Liebreich Associates

Share of global capacity additions by technology

Liebreich Associates



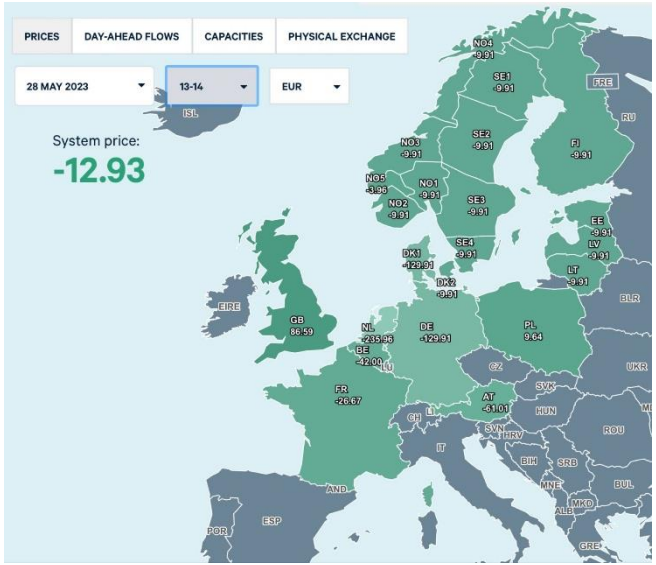
Global capacity additions excluding retirements

Source: BloombergNEF

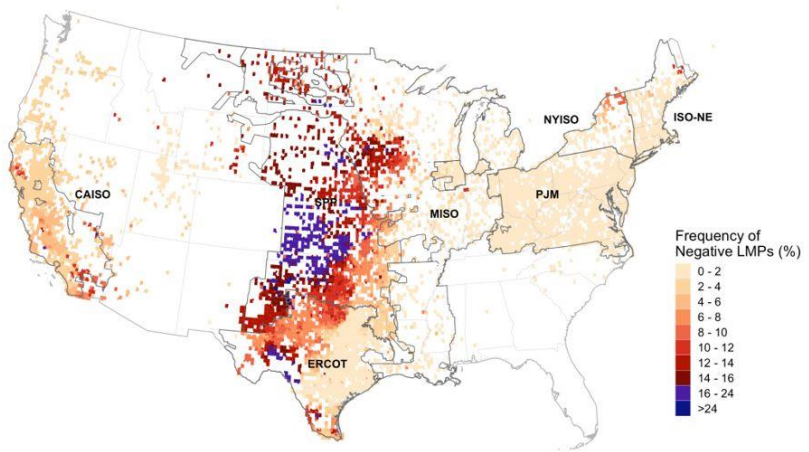
Negative wholesale electricity prices in the EU and US

Liebreich Associates

Europe wholesale spot prices, Whitsunday 2023



US wholesale pricing nodes, negative prices 2022



Sources: Gerard Reid, Ryan Wiser, Lawrence Berkeley National Lab

Solving for intermittency – the hunt is on

Liebreich Associates

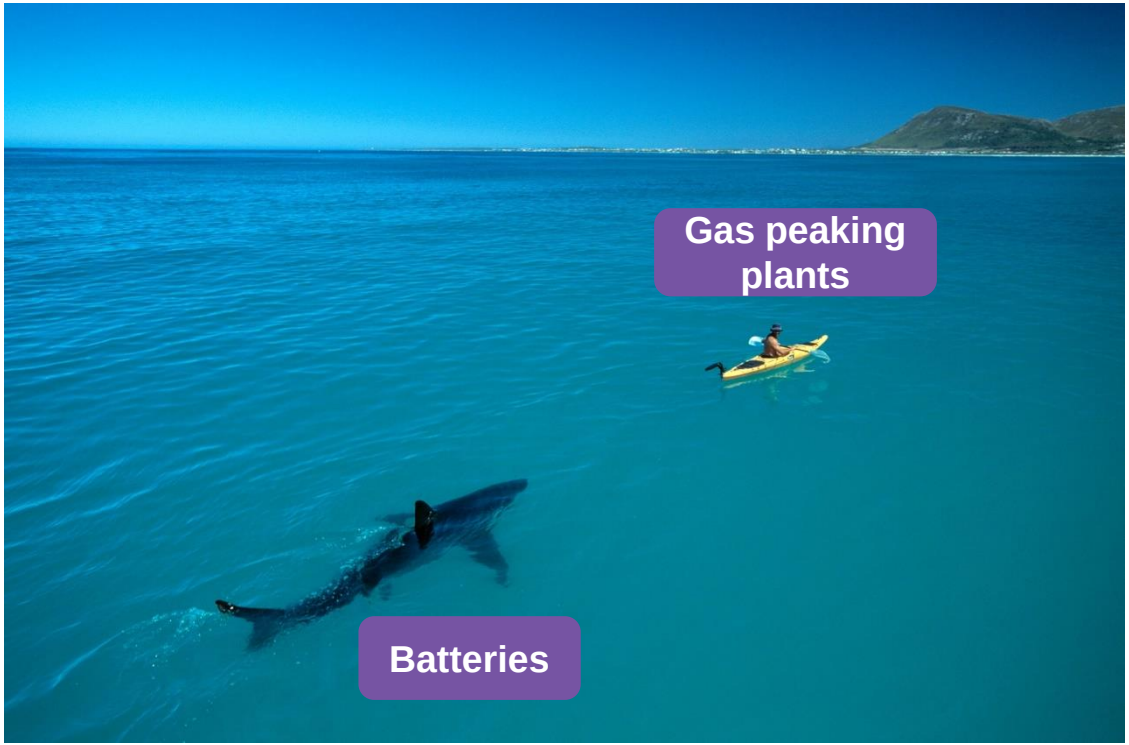


Image: Thomas P Peschak

Electrification of transport and heat

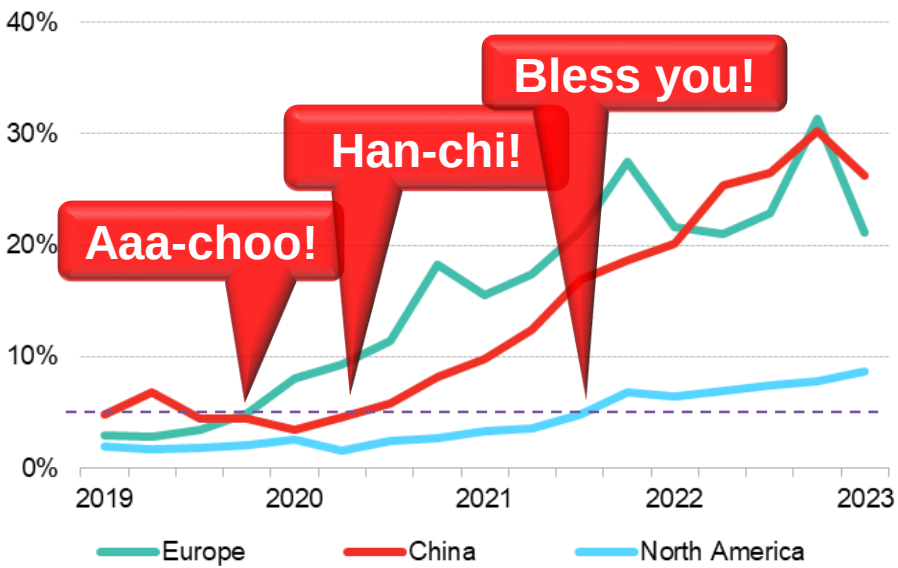
Liebreich Associates

Images: Rivian; Daikin

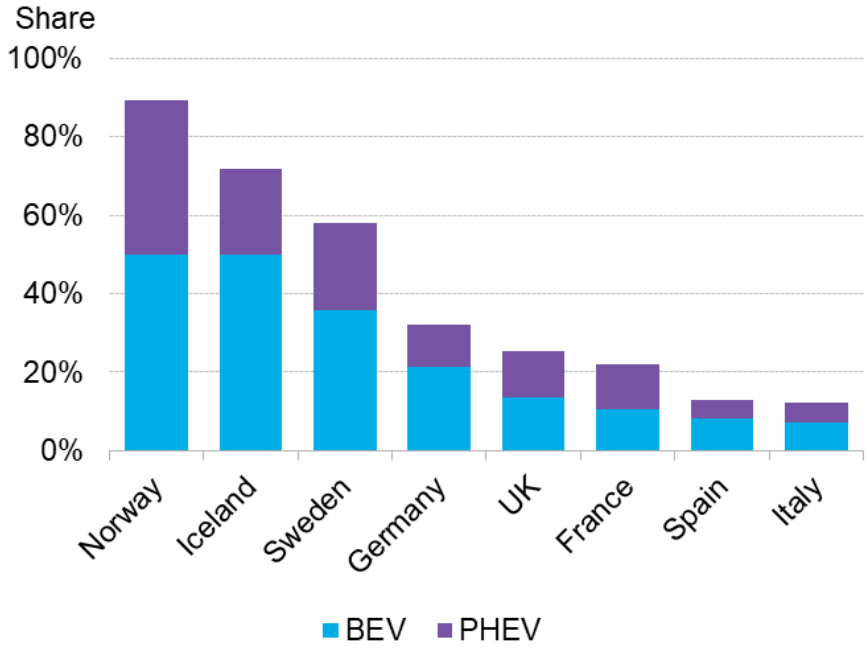
EV sales

Liebreich Associates

Global EV share of passenger vehicle sales



EV share of passenger vehicle sales in Europe

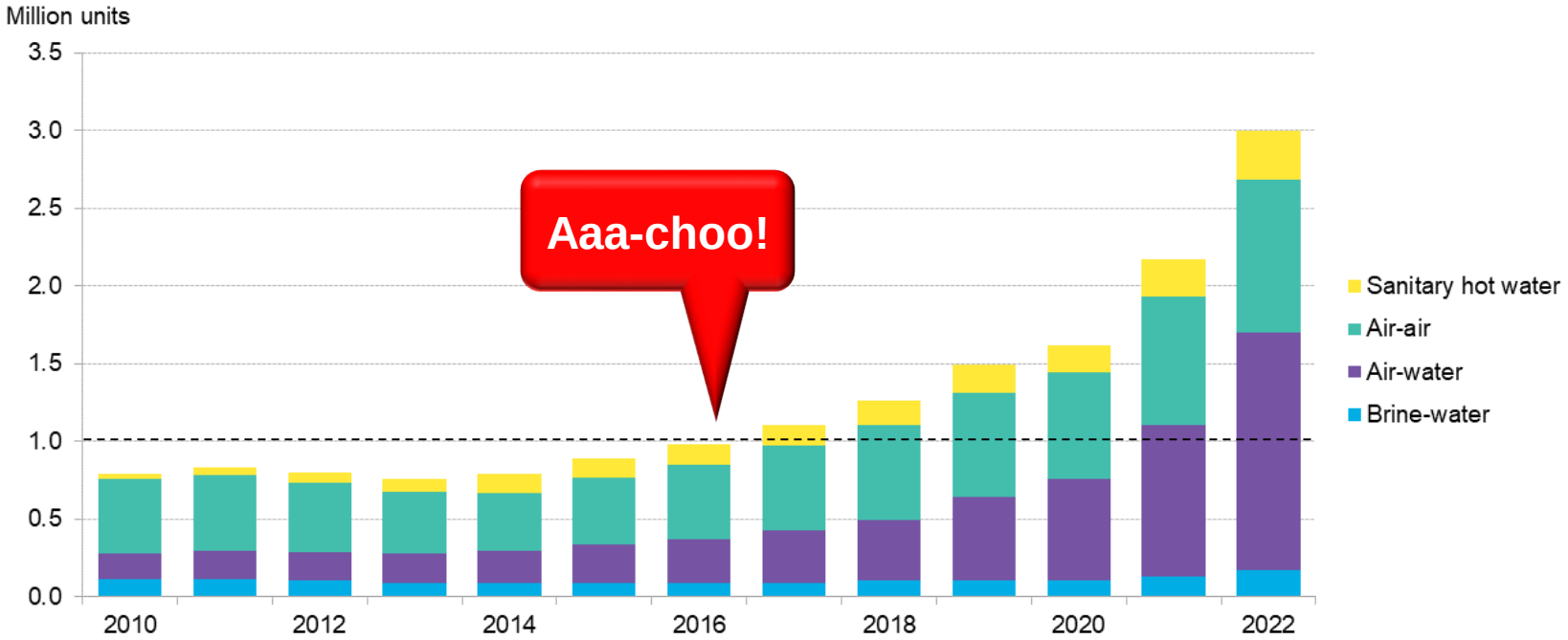


Note: Data as of Q2 2023

Source: BNEF

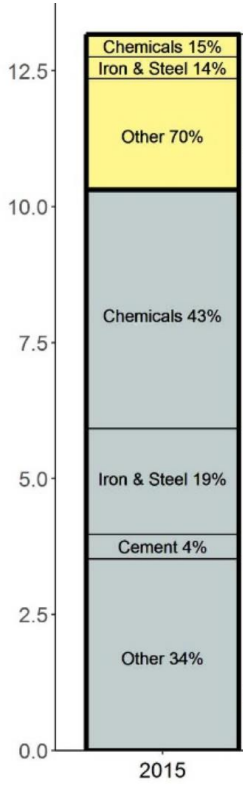
EU heat pump installations

Liebreich Associates



Source: EHPA

Industrial heat by power source (EJ)

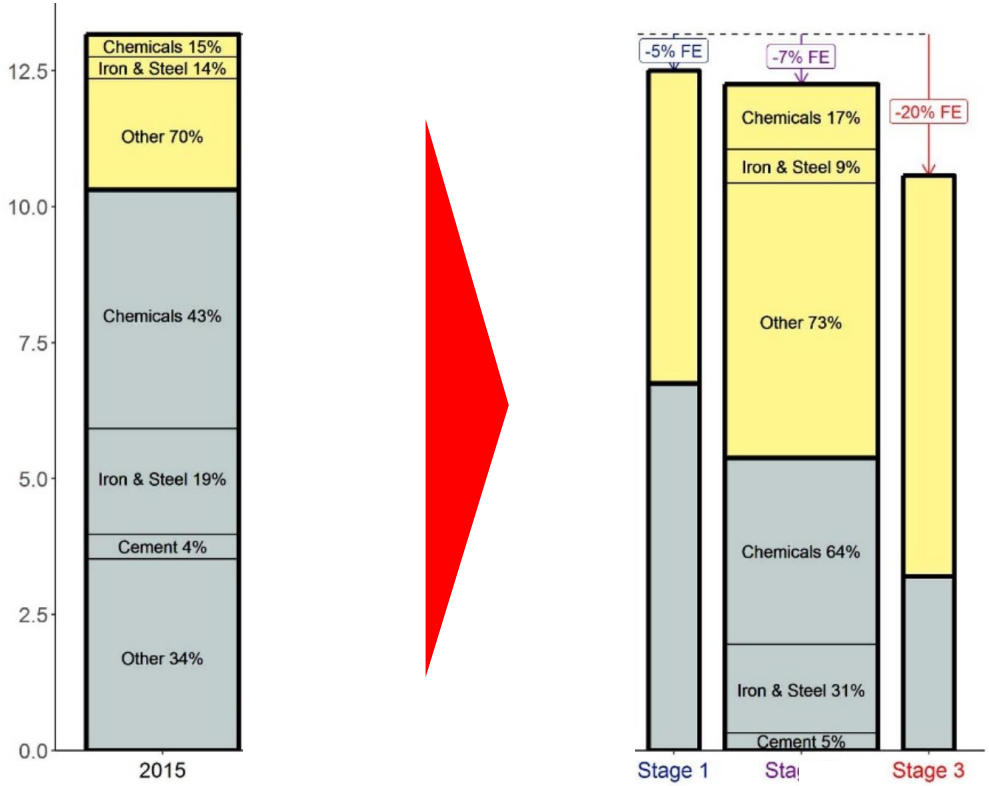


Electricity

Fossil fuel

Source: Madeddu et al 2019

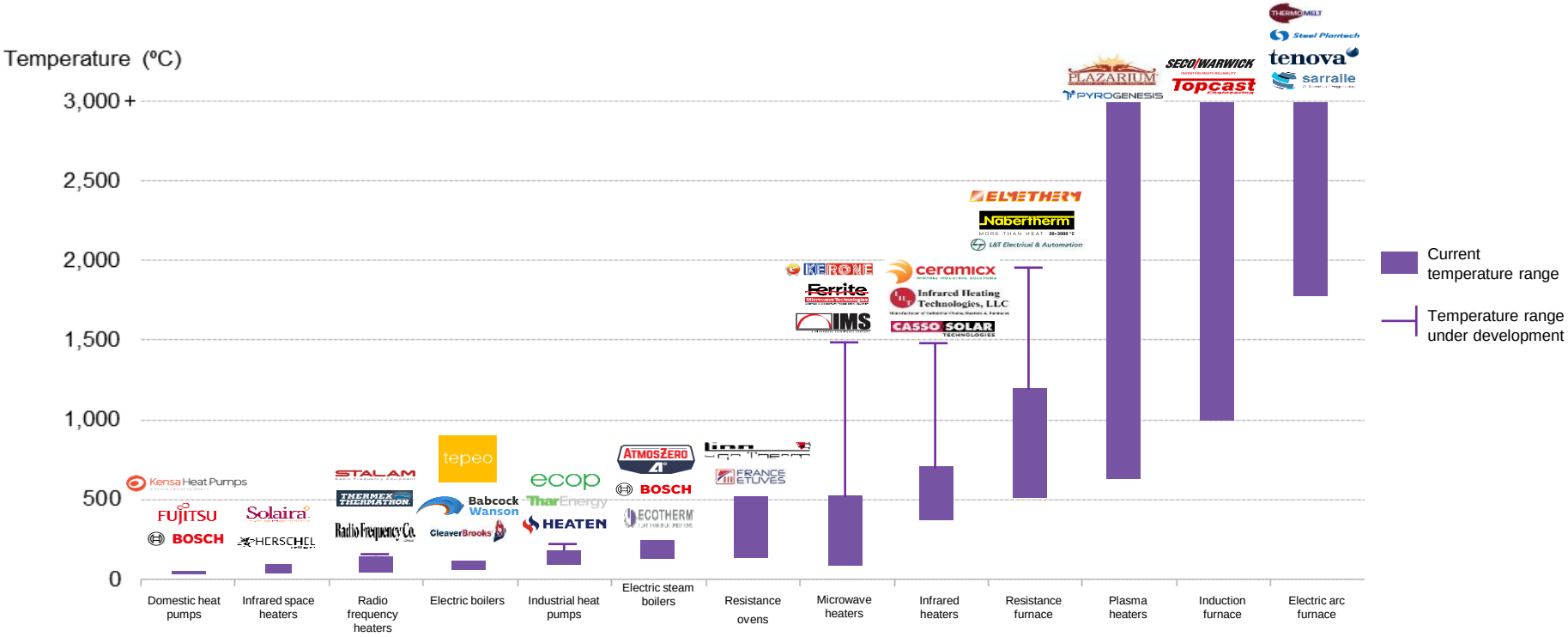
Industrial heat by power source (EJ)



Potential 78% reduction using mature technologies

Source: Madeddu et al 2019

Electrified heat technologies landscape

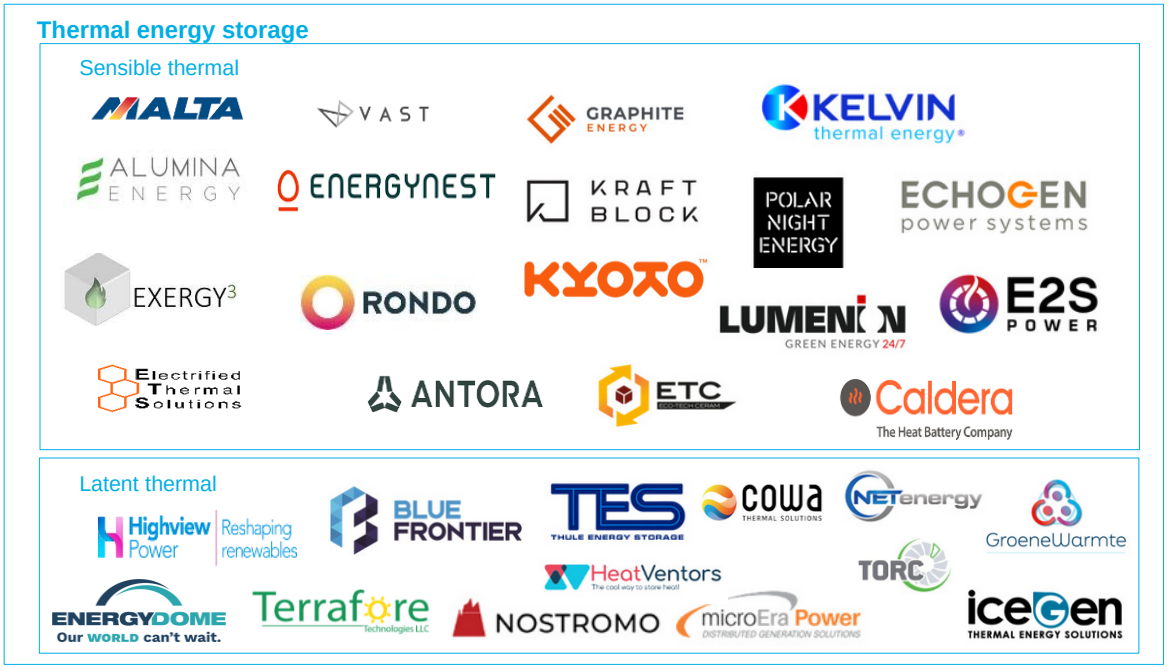


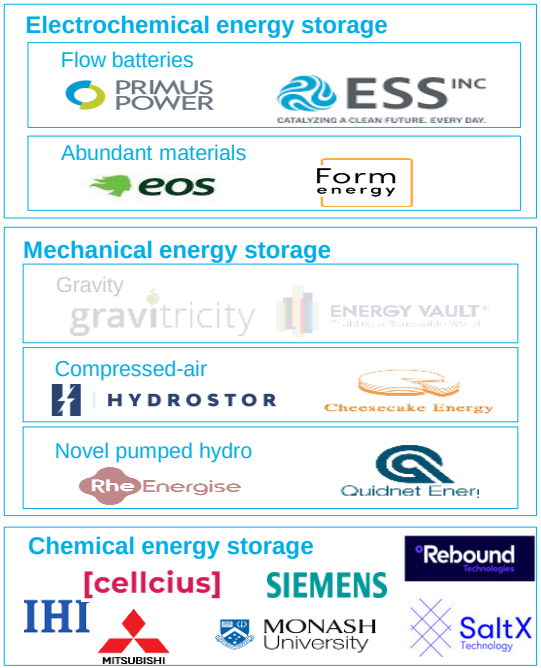
Note: List of companies is illustrative, not exhaustive.

Source: Liebreich Associates

Thermal stores and buffering technologies landscape

Liebreich Associates



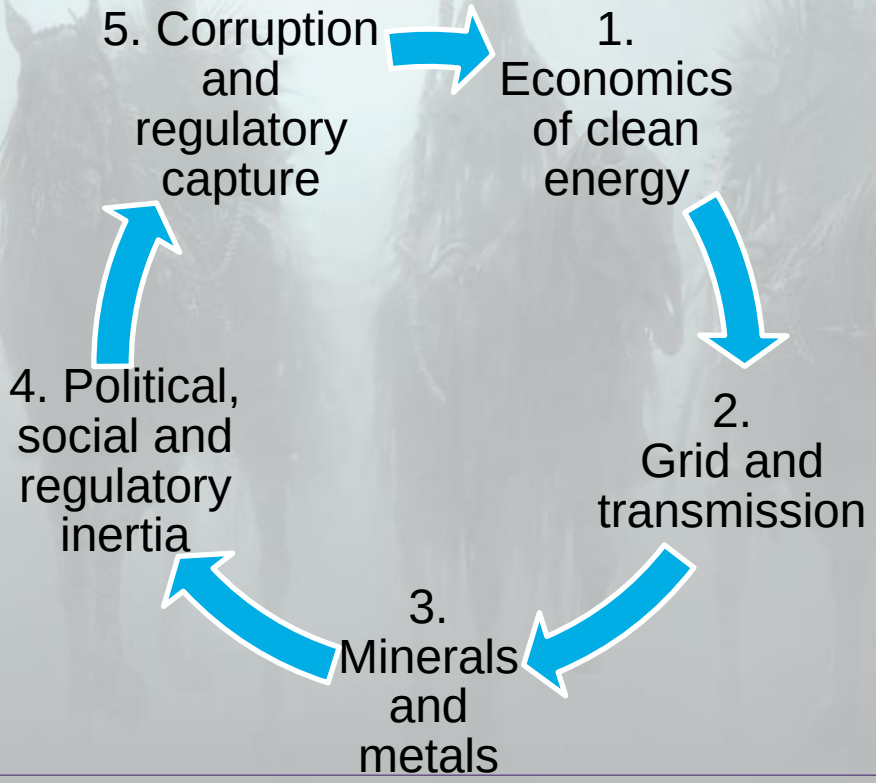


Note: List of companies is illustrative, not exhaustive.

Source: Liebreich Associates

Five Horsemen of the Net Zero Transition

Liebreich Associates



Source: Wikimedia Commons; Liebreich Associates

Hydrogen

Liebreich Associates

Image: Wikimedia Commons

Hydrogen economy

Liebreich Associates

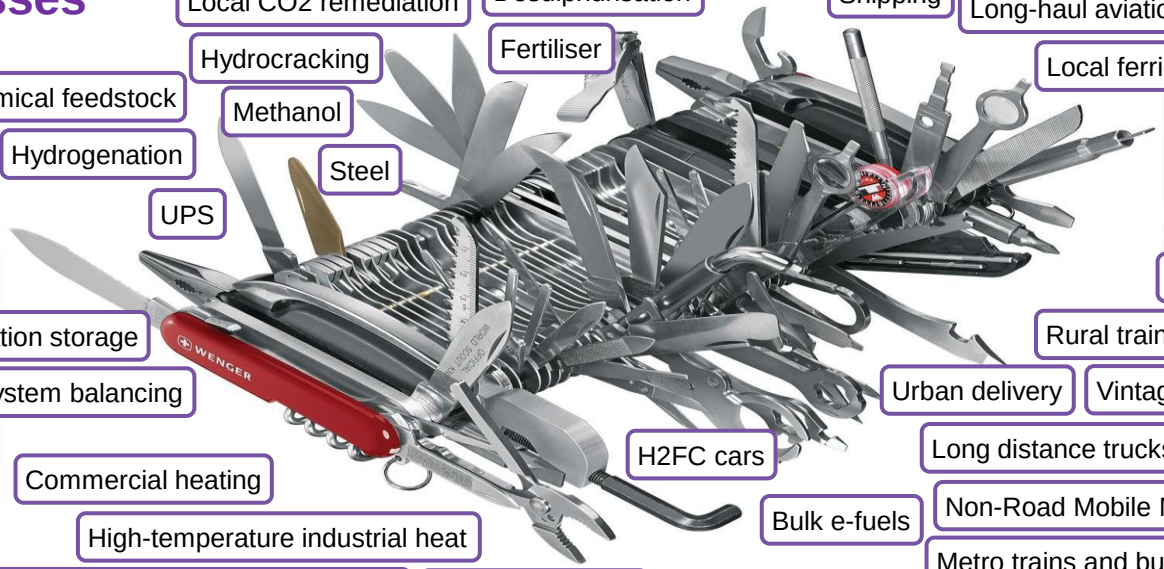
> Instead of the gas currently used for industry, heating and fuels, we will ensure hydrogen can be used – the gas of the future – and we will create a huge boom.

Olaf Scholz, German Chancellor
September 2022

Image: DW

Clean Hydrogen Swiss Army Knife

Liebreich Associates



Chemicals & processes

- Local CO2 remediation
- Desulphurisation
- Hydrocracking
- Fertiliser
- Chemical feedstock
- Methanol
- Hydrogenation
- Steel

Aviation & shipping

- Short-haul aviation
- Light aviation
- Shipping
- Long-haul aviation
- Local ferries
- Coastal and river vessels
- Medium-haul aviation

Power system

- Clean power imports
- UPS
- Island grids
- Generators
- Long-duration storage
- Power system balancing

Land transport

- Regional trucks
- 2 and 3-wheelers
- Rural trains
- Remote trains
- Urban delivery
- Vintage vehicles
- Long distance trucks and coaches
- H2FC cars
- Bulk e-fuels
- Non-Road Mobile Machinery
- Metro trains and buses

Heat

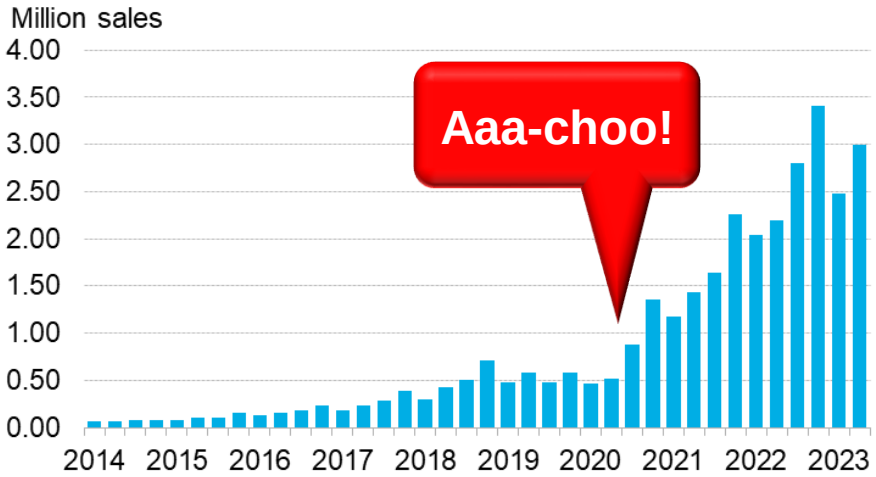
- Commercial heating
- High-temperature industrial heat
- Mid/Low-temperature industrial heat
- Domestic heating

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021.Concept credit: Adrian Hiel, Energy Cities. Image: Wenger (concept credit: Paul Martin). CC-BY 3.0

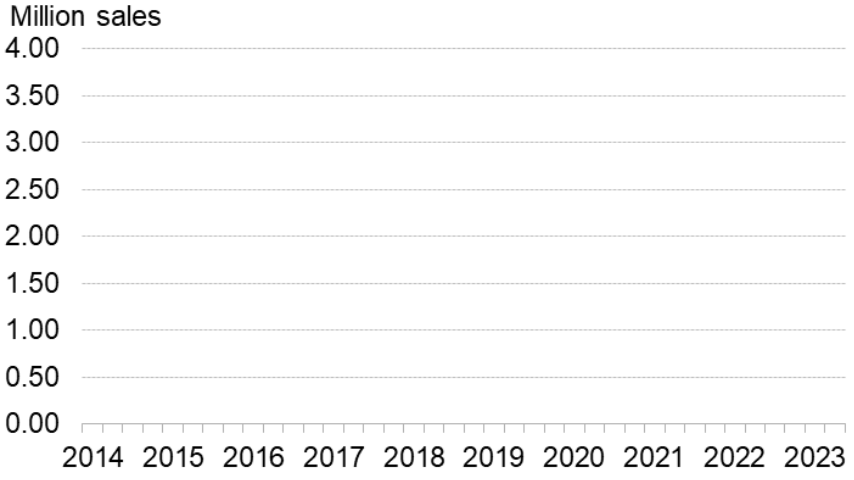
Global BEV vs. FCV sales quarterly

Liebreich Associates

Battery electric vehicles



Fuel cell vehicles



Note: Includes BEV sales include PHEVs

Source: BloombergNEF

Hydrogen vs BEV platforms

Liebreich Associates

H2FC drive train

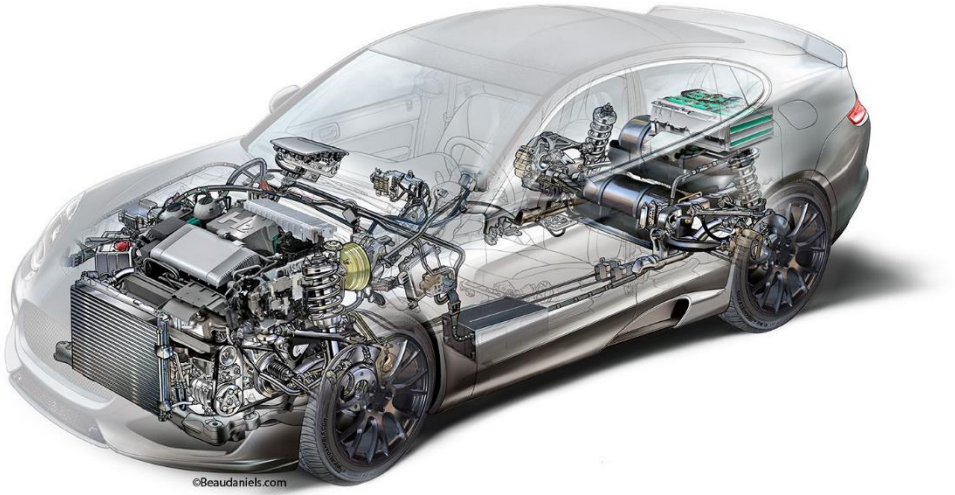


Image: Beaudaniels.com

Image: SNECI

Hydrogen vs BEV platforms

Liebreich Associates

H2FC drive train

~30% wind-to-wheel efficiency

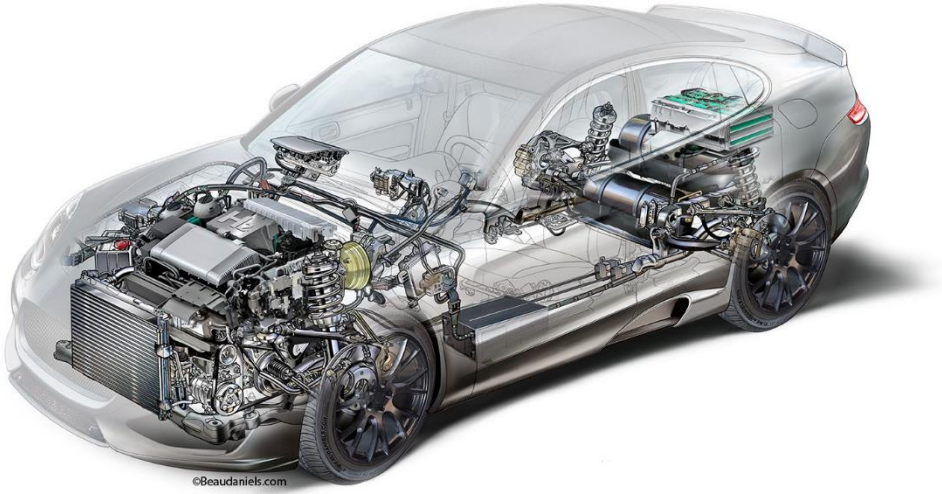


Image: Beaudaniels.com

BEV drive train

~80% wind-to-wheel efficiency

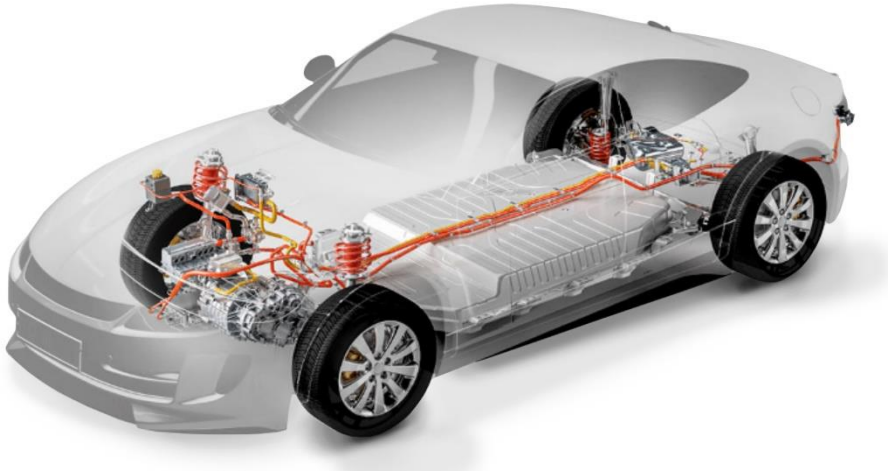


Image: SNECI

How it started… how it's going

Liebreich Associates

May 2021

Everfuel
@EverfuelEU

Follow

Today, we launch our #H2 #station #rollout plan for #Denmark with an ambition of deploying 19 #fueling sites for #zero #emission #transport by end of 2023. This completes our Scandinavian green #hydrogen fueling strategy for #trucks, #buses and #cars in Sweden, Norway and Denmark

September 2023

All hydrogen stations in Denmark close

"We cannot justify throwing more money at subsidizing hydrogen alone," states Everfuel's director, who however does not want to kill the future of hydrogen in passenger cars.

Photo: Everfuel

Source: Everfuel, Twitter

Hydrogen buses – Montpellier experience

Liebreich Associates

> Hydrogen buses were €150,000-200,000 more expensive to buy than their electric counterparts.
>
> Operation of the hydrogen buses would cost €3m per year, compared to €500,000 with electric ones — or €0.95 per km versus €0.15.

Julie Frêche, VP Transport
Montpellier Méditerranée Métropole
Speaking to La Tribune

Image: Van Hool

Hydrogen trains – Lower Saxony 2023

Liebreich Associates

> **The basis for the purchase of the new battery-powered is market research into alternative drives, which LNVG carried out.**
>
> **In particular, trains with hydrogen drives and batteries were considered. Result: battery trains are cheaper to operate.**

Ministry for Economic Affairs, Transport, Building and Digitisation – Lower Saxony

Image: Reuters

Zero-carbon forklift trucks

Liebreich Associates

Hydrogen fork lift truck

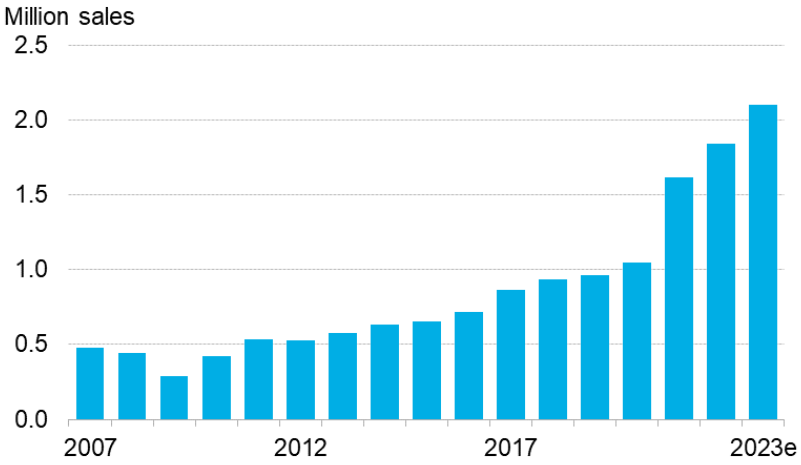
Battery electric fork lift truck

Images: Toyota

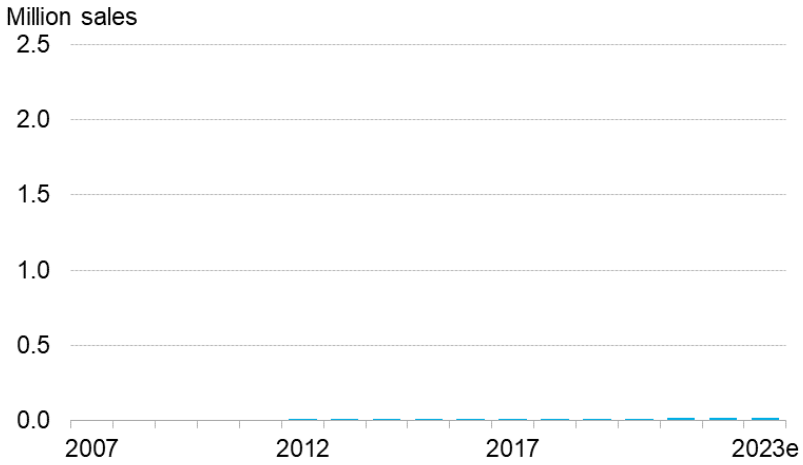
Electric and hydrogen forklift sales

Liebreich Associates

Electric



Hydrogen



Note: 2023 sales are estimated

Source: Liebreich Associates; various

E-Fuels for electromobility

Liebreich Associates

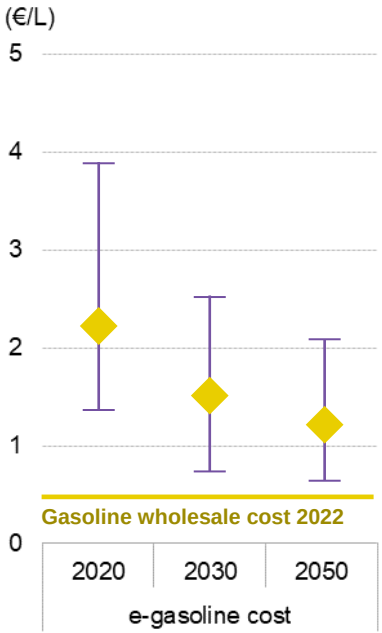
> We need e-fuels to achieve our climate protection goals. Electricity-based synthetic fuels are an important and necessary addition to electromobility.

Volker Wissing (FDP)
German Minister of Digital Affairs and Transport

Image: Wikimedia Commons

Levelised production cost of e-fuels in EU

Liebreich Associates

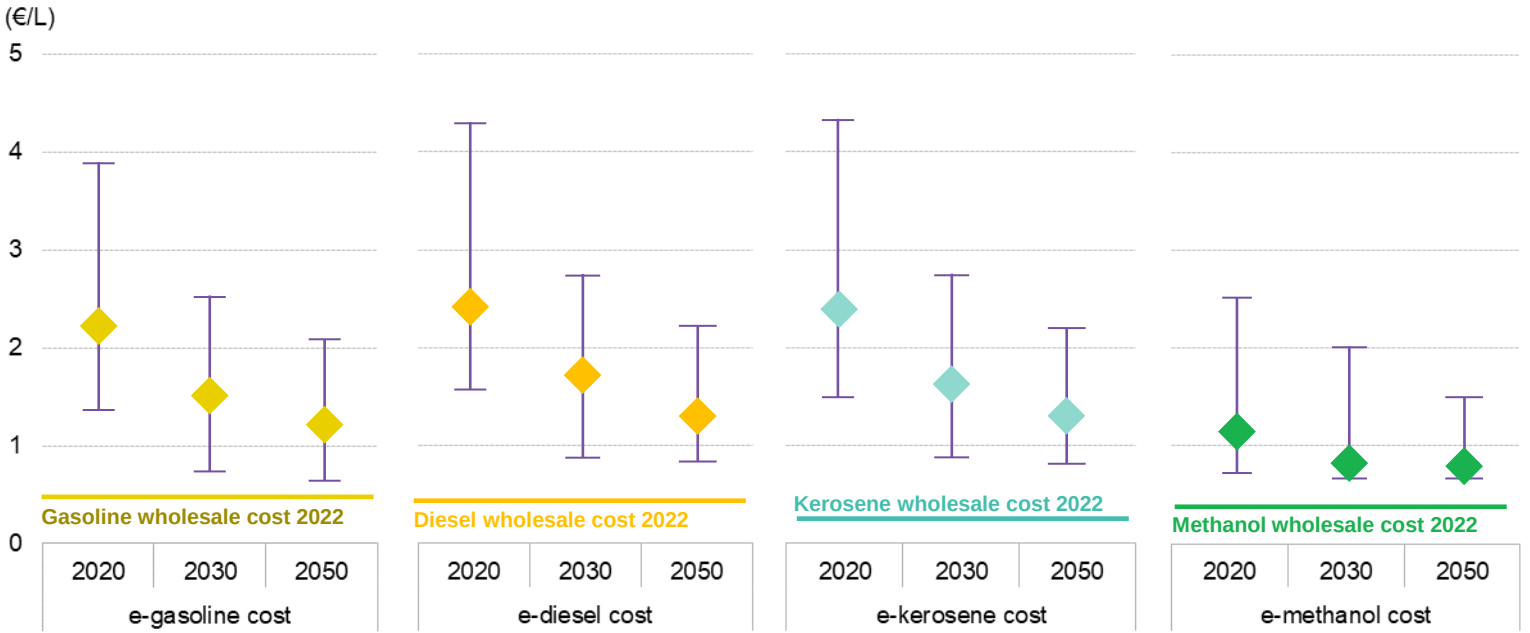


Note: Cost of e-fuels are distributed by energy percentage from Fischer-Tropsch synthesis. FT efficiency of 73%. Fuel prices as of Sept 2023.

Sources: ICCT (2022), Transport & Environment (2023), Concawe (2022), Bloomberg, Liebreich Associates

Levelised production cost of e-fuels in EU

Liebreich Associates



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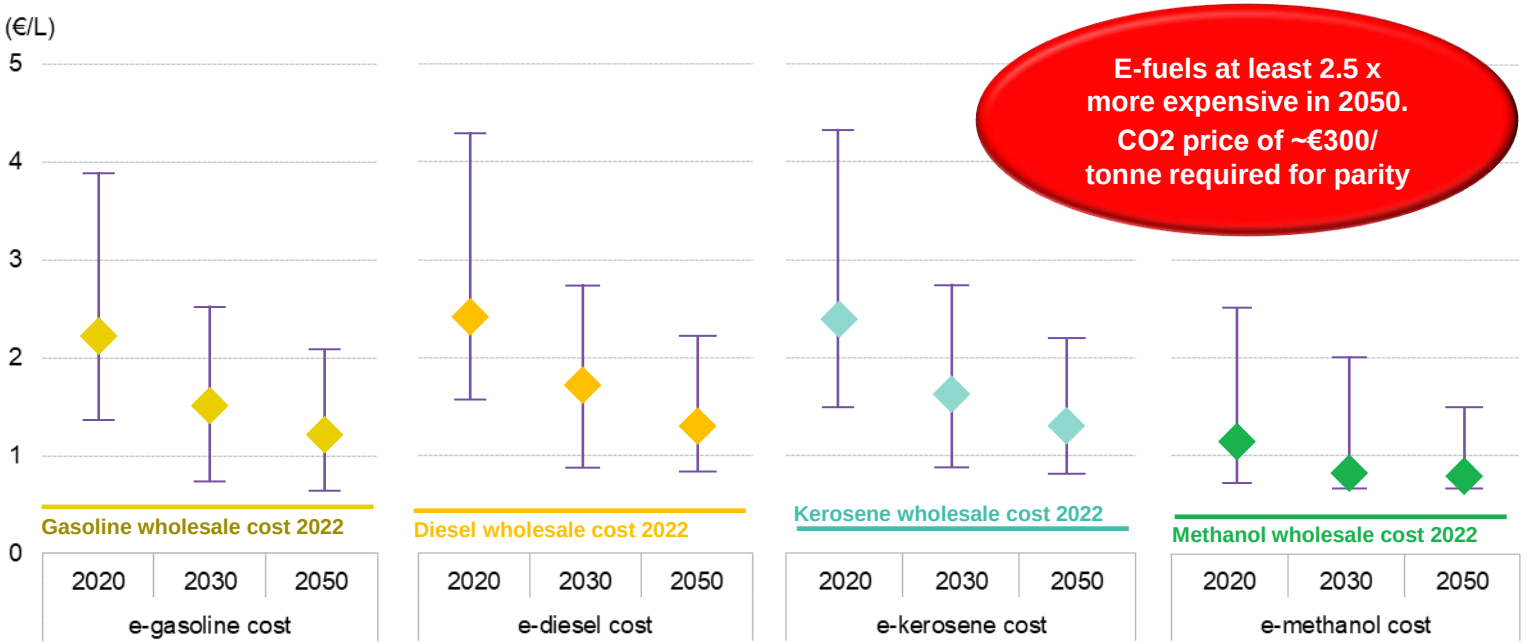

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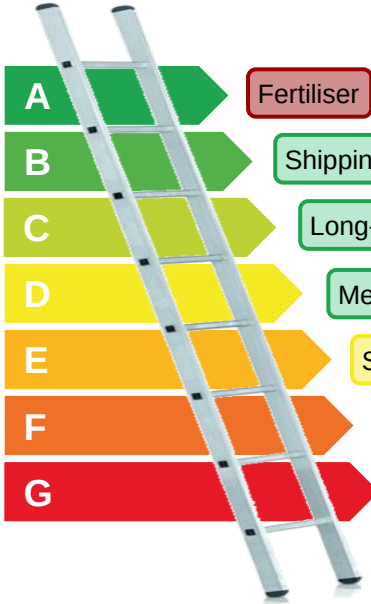
Clean Hydrogen Ladder: Competing technologies

Liebreich Associates

Unavoidable

Key: No real alternative | Electricity/batteries | Biomass/biogas | Other



A	Fertiliser	Hydrogenation	Methanol	Hydrocracking	Desulphurisation	
B	Shipping*	Non-Road Mobile Machinery	Chemical feedstock	Steel	Long duration storage	
C	Long-haul aviation*	Remote trains	Coastal and river vessels	Vintage vehicles*	Local CO2 remediation	
D	Medium-haul aviation*	Long distance trucks and coaches	High-temperature industrial heat	Generators		
E	Short-haul aviation	Local ferries	Commercial heating	Island grids	Clean power imports	UPS
F	Light aviation	Rural trains	Regional trucks	Mid/Low-temperature industrial heat	Domestic heating	
G	Metro trains and buses	H2FC cars	Urban delivery	2 and 3-wheelers	Bulk e-fuels	Power system balancing

Uncompetitive

** Most likely via ammonia or e-fuel rather than H2 gas or liquid*

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021.Concept credit: Adrian Hiel, Energy Cities. CC-BY 3.0

Hydrogen economics

Note: Pink hydrogen includes nuclear and geothermal Sources: BloombergNEF, Lucid Catalyst, Hydrogen Council, IRENA, IEA, ETC, Liebreich Associates

NEOM Green Hydrogen/Ammonia Project

Liebreich Associates

Cost: SAR 31.5 Billion ($USD 8.4 Billion)

Renewable generation: 4 GW

Announced commissioning year: 2026

H2 production: 0.22 Million tonnes/year

Ammonia production: 1.24 Million tonnes/year

0.2% of current global hydrogen demand
0.7% of current global ammonia demand

Image: NEOM

Source: NEOM, GlobalData, Liebreich Associates

Clean Hydrogen Ladder: Competing technologies

Liebreich Associates

Unavoidable

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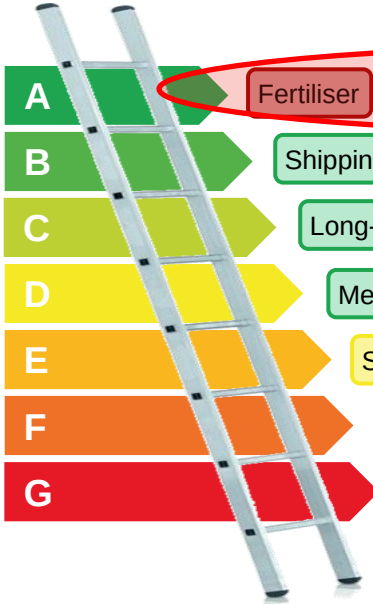

A: Fertiliser | Hydrogenation | Methanol | Hydrocracking | Desulphurisation

94MT = 143% of all existing wind & solar

B: Shipping* | Non-Road Mobile Machinery | Chemical feedstock | Steel | Long duration storage

C: Long-haul aviation* | Remote trains | Coastal and river vessels | Vintage vehicles* | Local CO2 remediation

D: Medium-haul aviation* | Long distance trucks and coaches | High-temperature industrial heat | Generators

E: Short-haul aviation | Local ferries | Commercial heating | Island grids | Clean power imports | UPS

F: Light aviation | Rural trains | Regional trucks | Mid/Low-temperature industrial heat | Domestic heating

G: Metro trains and buses | H2FC cars | Urban delivery | 2 and 3-wheelers | Bulk e-fuels | Power system balancing

Uncompetitive

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Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021.Concept credit: Adrian Hiel, Energy Cities. CC-BY 3.0

Clean Hydrogen Ladder: Competing technologies

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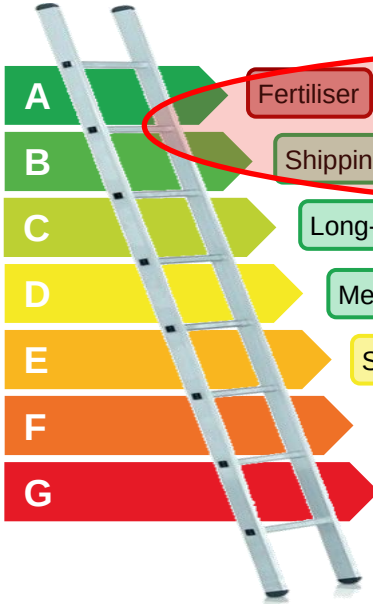

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550% of all existing wind & solar

Uncompetitive

** Most likely via ammonia or e-fuel rather than H2 gas or liquid*

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 4.1, 2021.Concept credit: Adrian Hiel, Energy Cities. CC-BY 3.0

Hydrogen shipping vs LNG – some physics

Liebreich Associates

LNG Carrier
Q-Max Mozah

Volume:	266,000 cbm
Volumetric density:	22.2 MJ/litre
Total load:	5.9 x 10^15 J
Temperature:	-162 C
Liquefaction losses:	10%
Boil-off:	0.1% per day

Hydrogen carrier
Suiso Frontier

0.2% of the energy carried by a Q-Max

Volume:	1,250 cbm
Volumetric density:	8.5 MJ/litre
Total load:	1.1 x 10^13 J
Temperature:	-253 C
Liquefaction losses:	33%
Boil-off:	1% per day

Images: Qatar Gas, Kawasaki Heavy Industries, MHI Source: Liebreich Associates

Electricity imports – hydrogen, ammonia, HVDC

Liebreich Associates

Power – hydrogen – power

5x as many ships as LNG

Electrolysis efficiency:	80%
Liquefaction efficiency	67%
Transport efficiency:	80%
Generation efficiency:	60%
Total Efficiency:	**26%**

Power – ammonia – power

Easier – but even less efficient

Electrolysis efficiency:	80%
Haber Bosch efficiency:	70%
Liquefaction efficiency	90%
Transport efficiency:	90%
Generation efficiency:	50%
Total efficiency:	**23%**

HVDC

3.2 x as efficient

Conversion efficiency to HVDC:	97%
Transport efficiency (3% loss per 1000km)	88%
Conversion efficiency HVDC to grid:	97%
Total efficiency:	**82%**

Images: Kawasaki Heavy Industries; NYK; Suncable Source: Liebreich Associates

Low carbon hydrogen hubs

Hydrogen industrial hub

Liebreich Associates

Europe - other

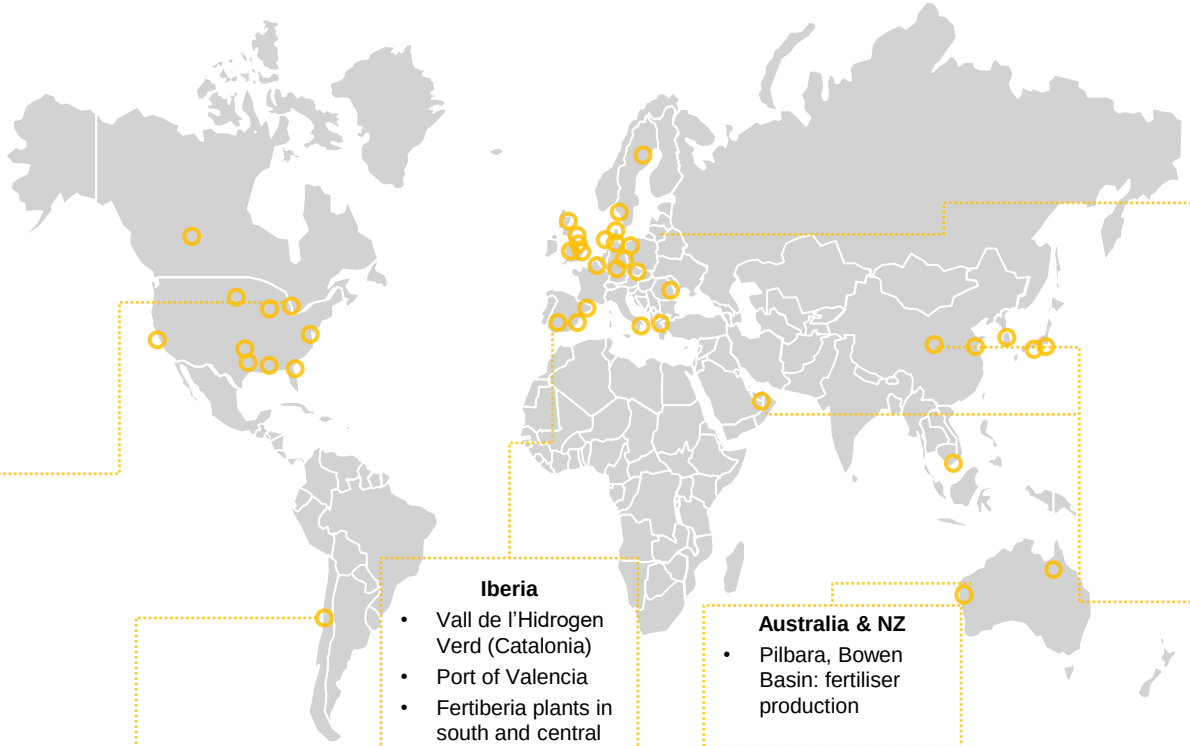
- Steelmaking: Lulea, Duigsburg, Dunkirk, SALCOS,GravitHy
- Refineries in Lingen, Heide, Saras, Schwechat
- Copenhagen
- Western Macedonia

North America:

- Gron Fuel
- Port of Corpus Christi
- Hydrogen City
- Port of Long Beach
- Suncor Edmonton Refinery
- Mississippi Clean Hydrogen Hub
- HIF USA
- Great Plains Hydrogen Hub

Latin America

- Mejillones: HyEx mining explosives



Iberia

- Vall de l'Hidrogen Verd (Catalonia)
- Port of Valencia
- Fertiberia plants in south and central Spain

Australia & NZ

- Pilbara, Bowen Basin: fertiliser production

North Sea:

- NorthH2
- Port of Antwerp
- Port of Rotterdam
- North Holland
- ZeroCarbon Humber
- HyNet NorthWest
- Teesside
- Aberdeen
- Cromarty Firth
- AquaVentus
- Freeport East
- Grangemouth
- Fawley

Gulf & Asia:

- Hebei province Duqm refinery
- Port of Onahama-Kobe Area
- Ulsan
- Datong
- H2Biscus Malaysia

Sources: Projects' pages, press releases, Liebreich Associates

Low carbon hydrogen hubs

Hydrogen industrial hub
Green hydrogen giga-project

Liebreich Associates

Europe - other

- Steelmaking: Lulea, Duigsburg, Dunkirk, SALCOS,GravitHy
- Refineries in Lingen, Heide, Saras, Schwechat
- Copenhagen
- Western Macedonia

North America:

- Gron Fuel
- Port of Corpus Christi
- Hydrogen City
- Port of Long Beach
- Suncor Edmonton Refinery
- Mississippi Clean Hydrogen Hub
- HIF USA
- Great Plains Hydrogen Hub

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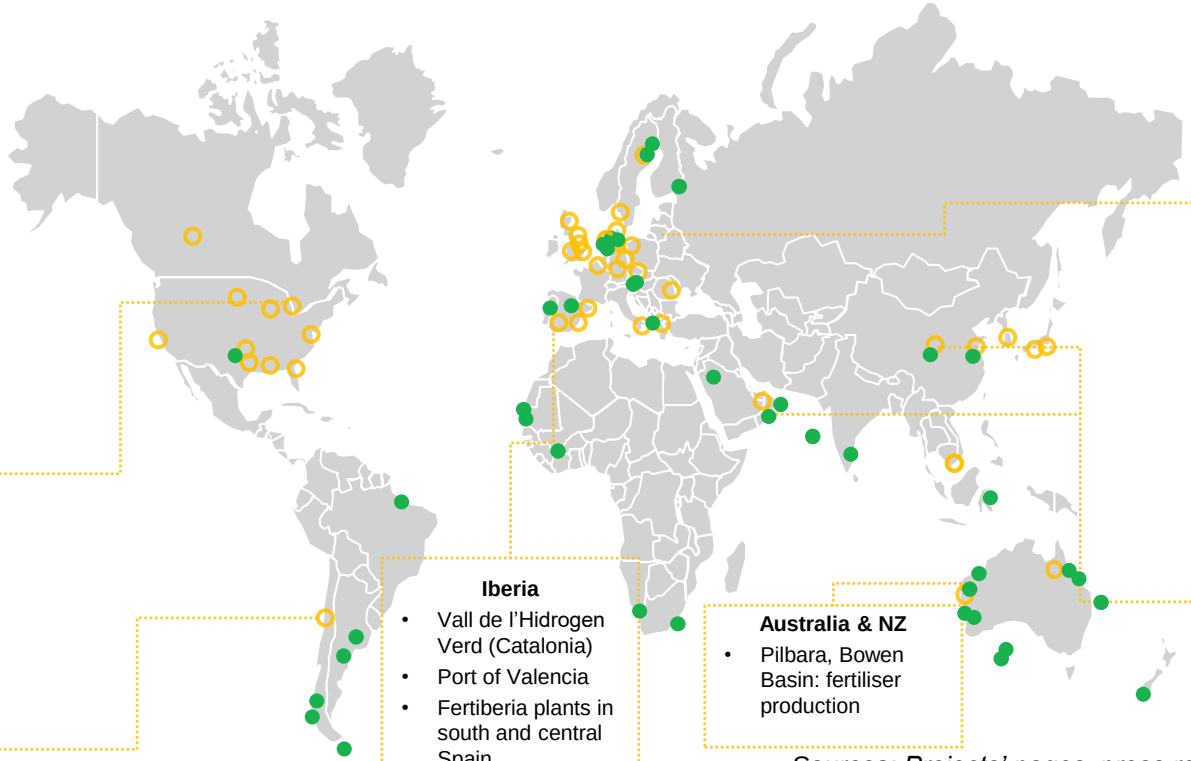

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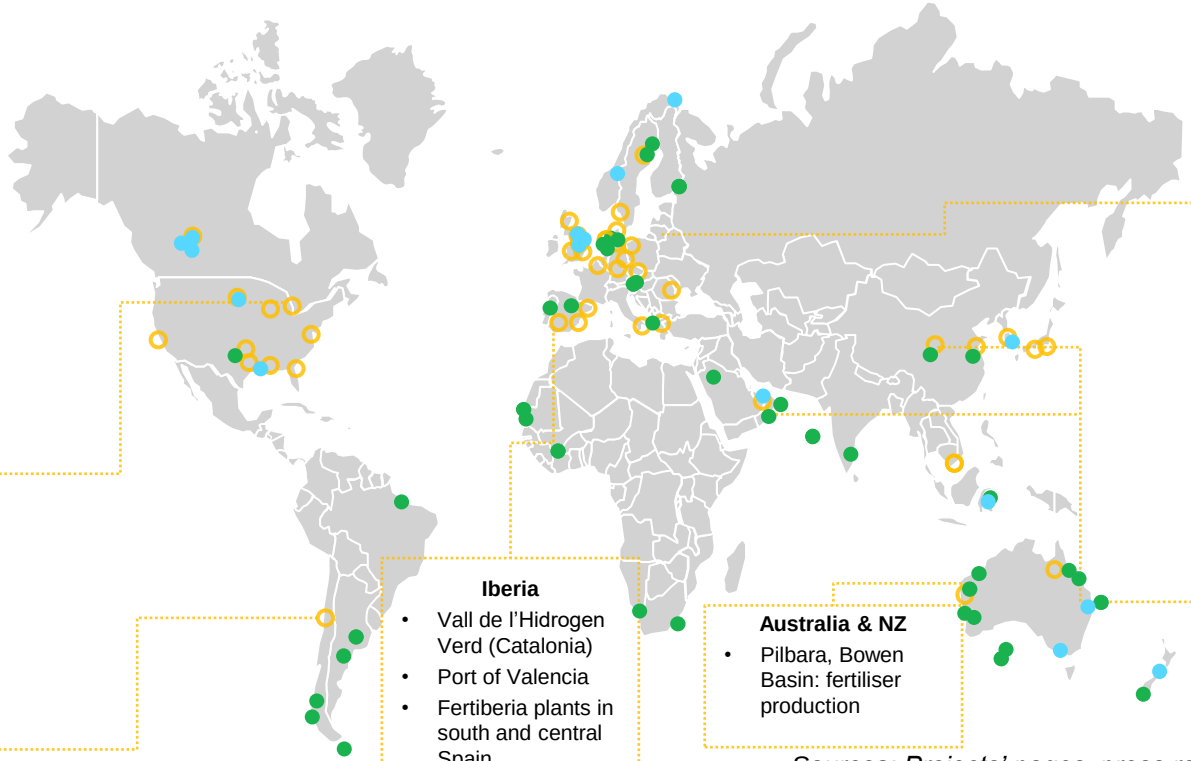

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Thanks!

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