Towards a Responsible Transition

Voces con Energía
8th August 2024

Michael Liebreich
Founder and CEO
Liebreich Associates

Overview

Liebreich Associates

1. Global Trends

2. Hydrogen

3. Thoughts on Chile

Source: Liebreich Associates

The 2020s in energy history

Liebreich Associates

The Great
Price Spike

- Post-Covid recovery
- Quantitative tightening
- Russian invasion of Ukraine

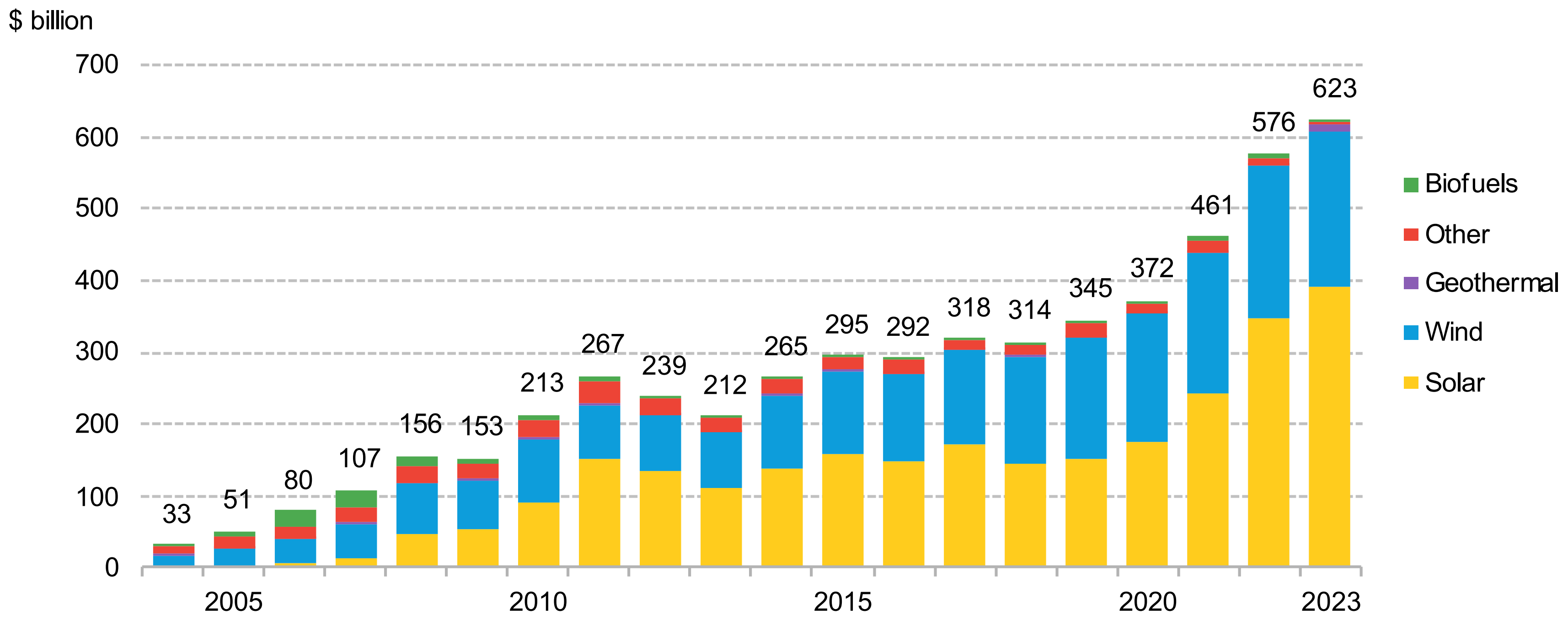
→

The Great
Clean Energy
Acceleration

Source: Liebreich Associates

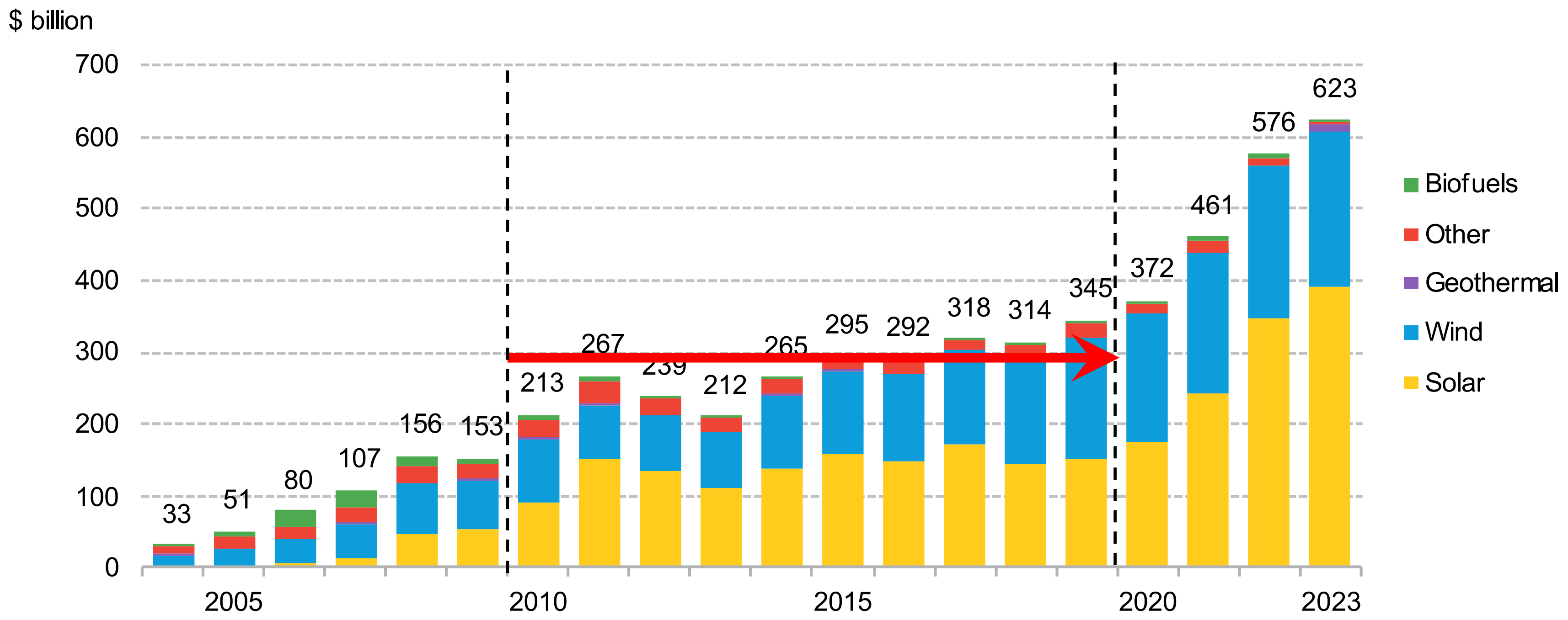
Global new investment in renewable energy by sector

Liebreich Associates



Source: BNEF Energy Transition Investment Trends 2023

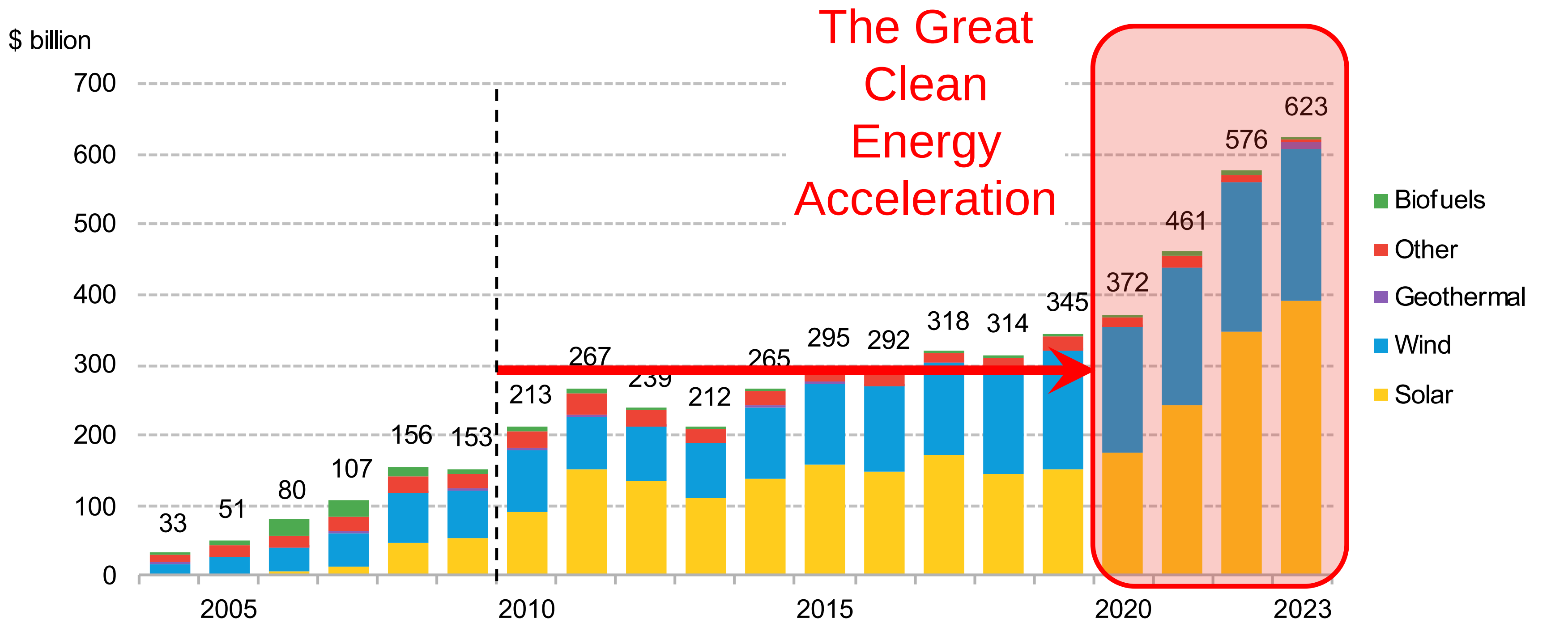
Global new investment in renewable energy by sector



Source: BNEF Energy Transition Investment Trends 2023

Global new investment in renewable energy by sector

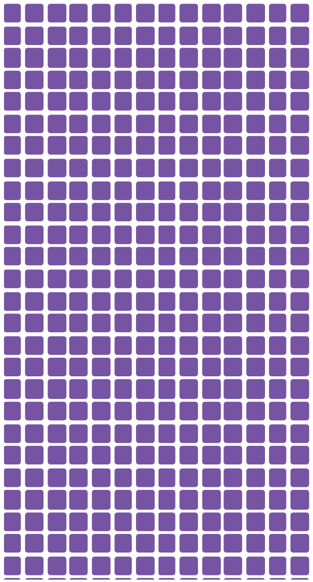
Liebreich Associates



Source: BNEF Energy Transition Investment Trends 2023

Great solar acceleration – time to install 1GW

Liebreich Associates



2004:
One year

Source: Kees van der Leun

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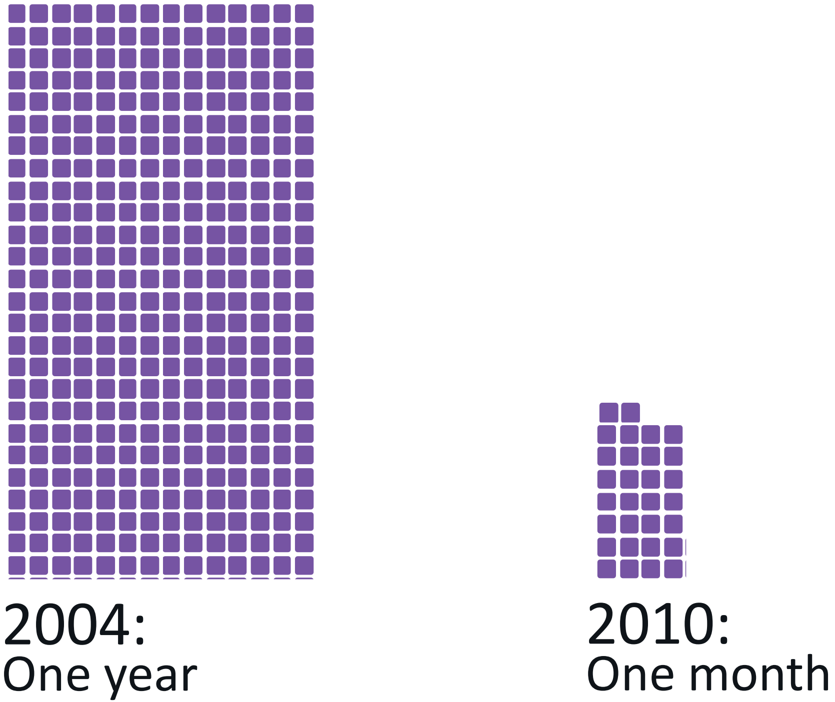

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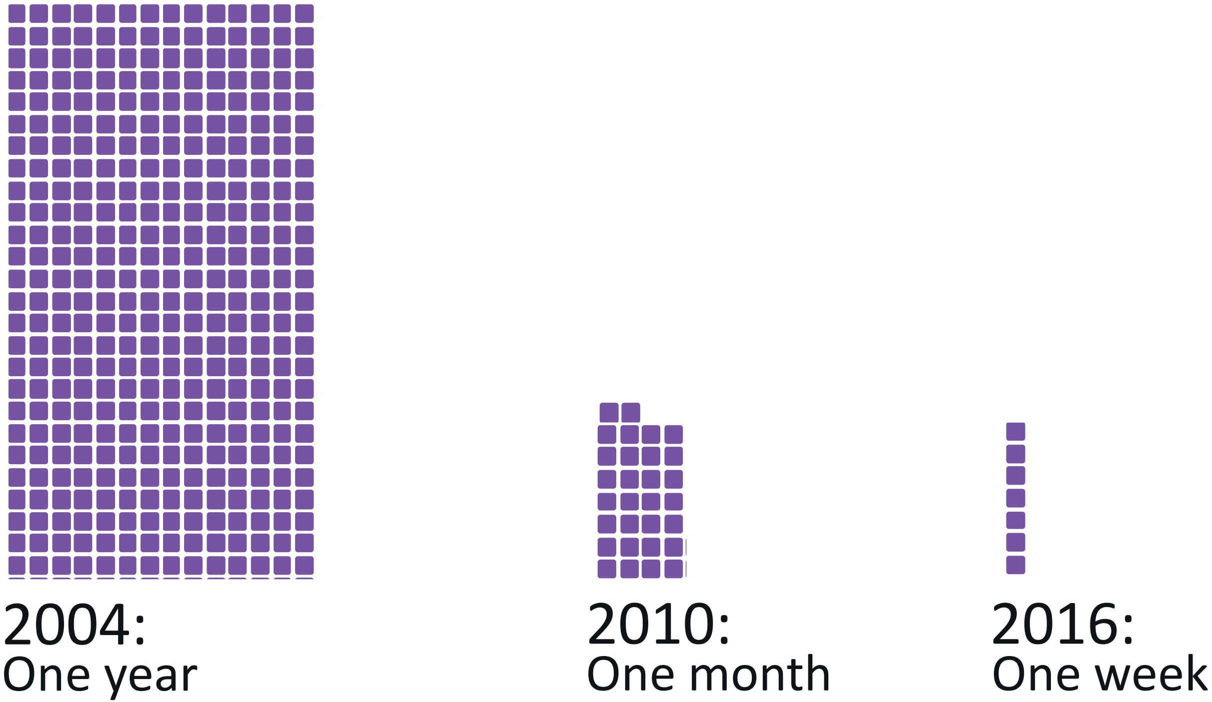

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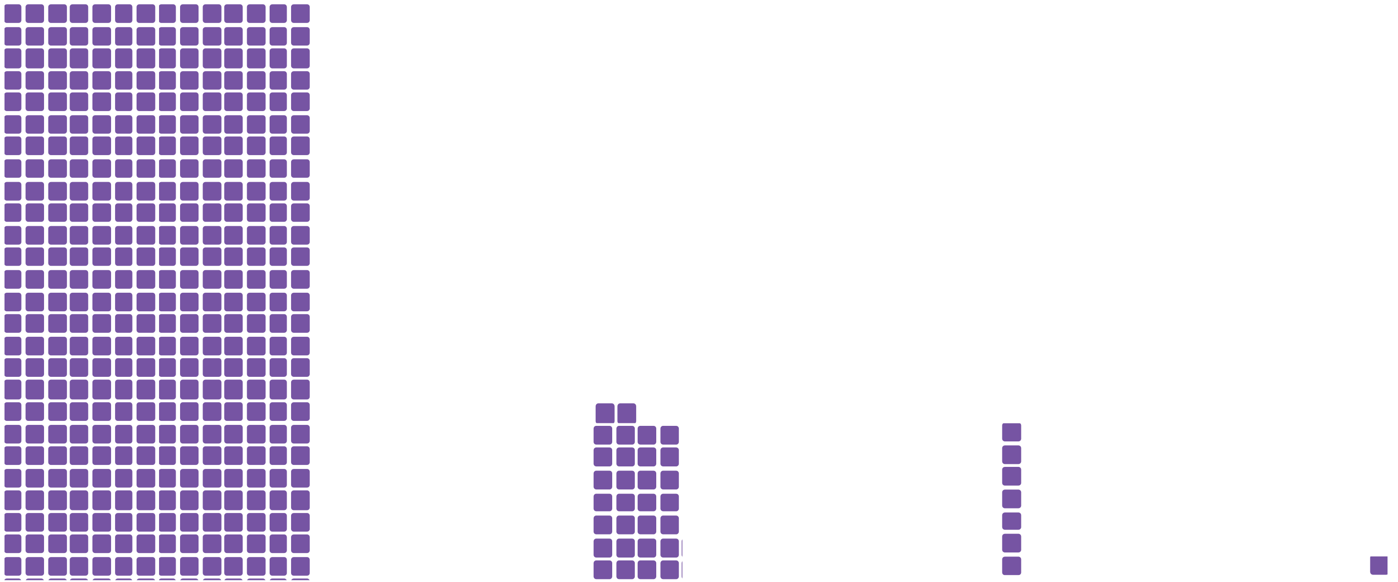


2004:
One year

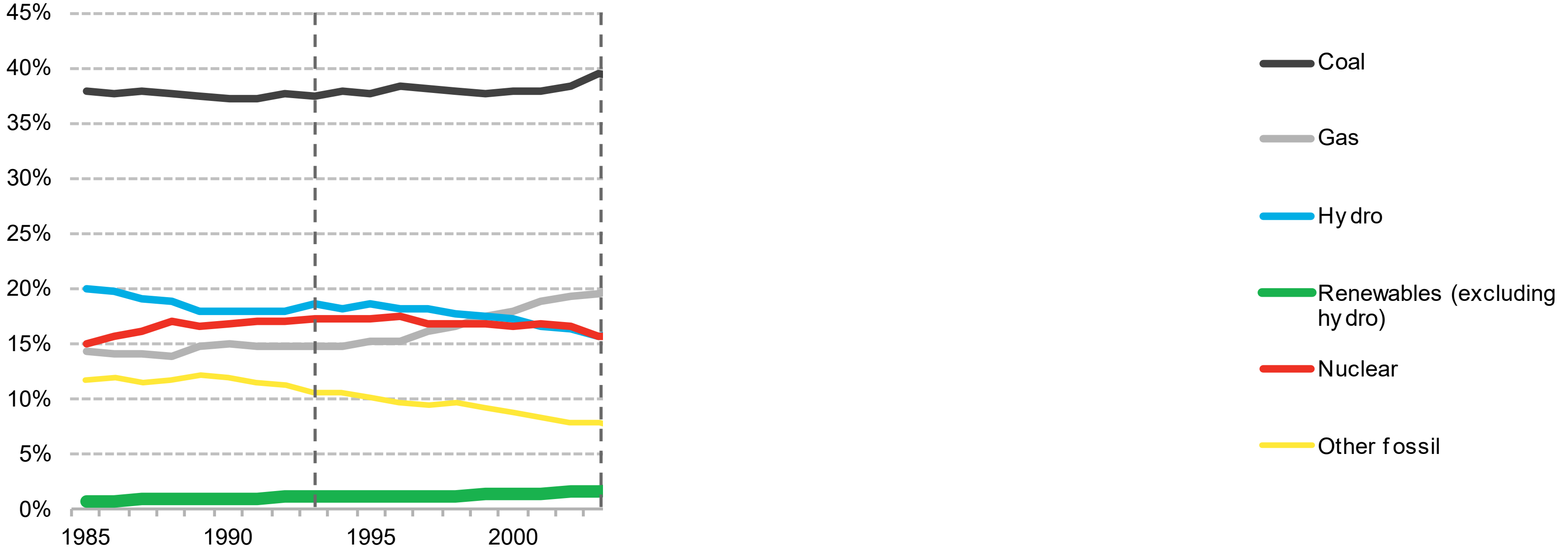
2010:
One month

2016:
One week

2023:
One day

Source: Kees van der Leun

Global share of power generation by source 1985 - 2023



Source: Ember, Energy Institute, Liebreich Associates

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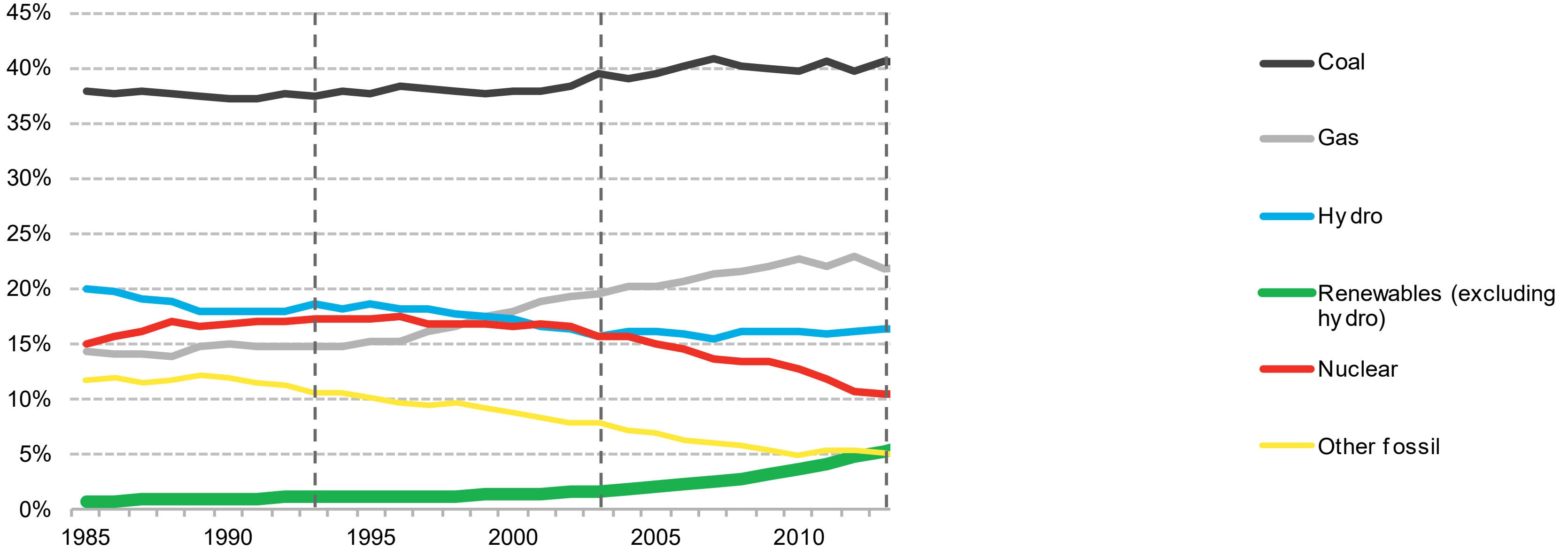

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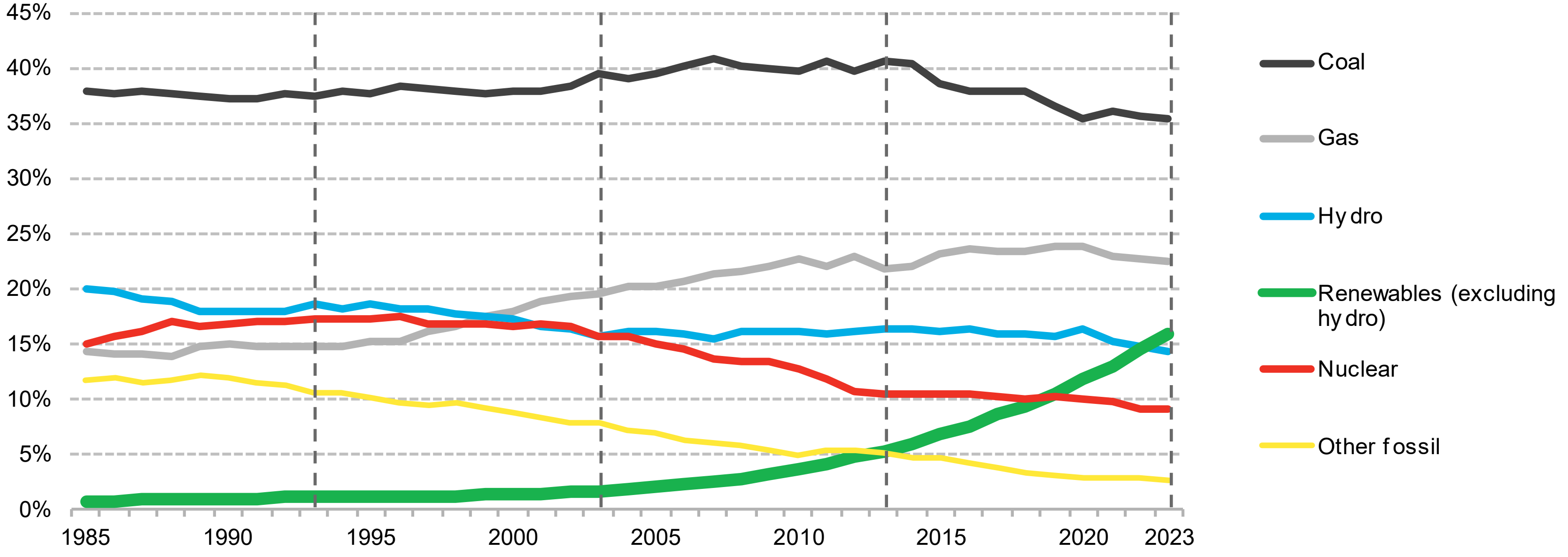


Source: Ember, Energy Institute, Liebreich Associates

COP 28 Dubai

Liebreich Associates

"Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030"

Sultan Al Jaber
COP28 President and CEO of ADNOC

Image: UNFCCC/COP28

Renewables expected to double

Liebreich Associates

"Under existing policies and market conditions, global renewable capacity is forecast to reach 7 300 GW by 2028. This growth trajectory would see global capacity increase to 2.5 times its current level by 2030"

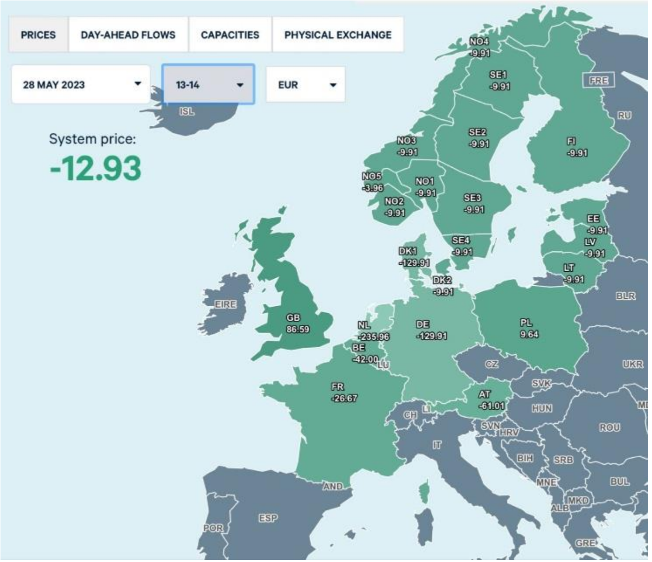
Fatih Birol
Executive Director of the IEA

Image: Wikimedia Commons

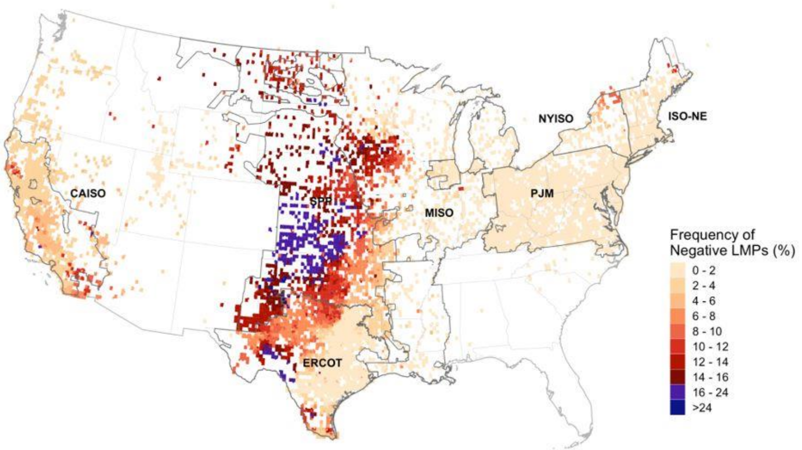
Negative prices in the EU and US

Liebreich Associates

Europe wholesale spot prices, Whitsunday 2023



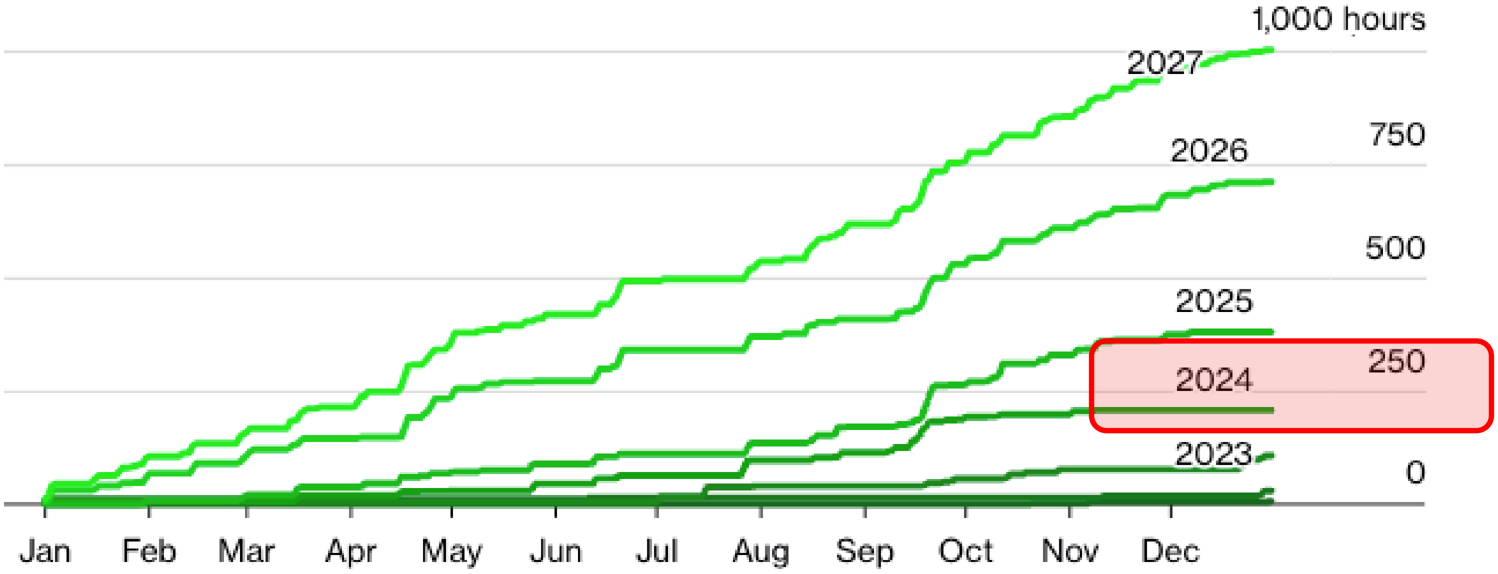
US wholesale pricing nodes, negative prices 2022



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

Hours of zero or negative power prices – UK

Liebreich Associates



Source: Modo

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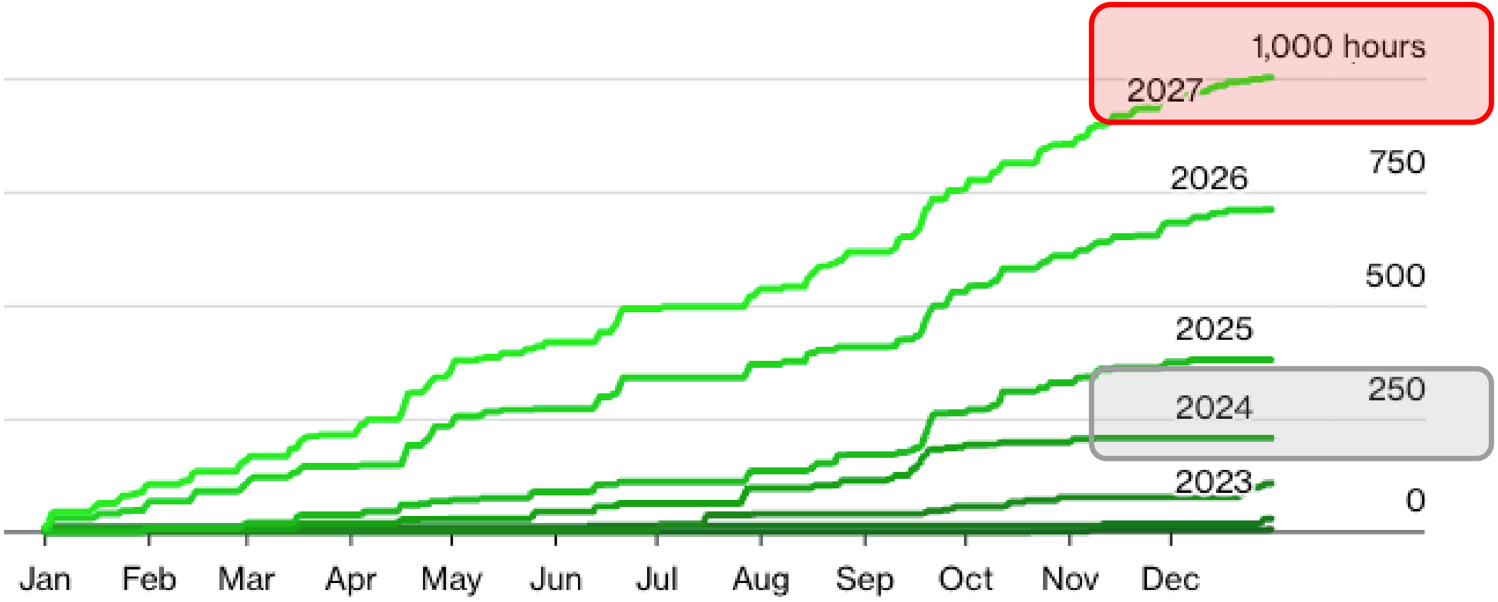
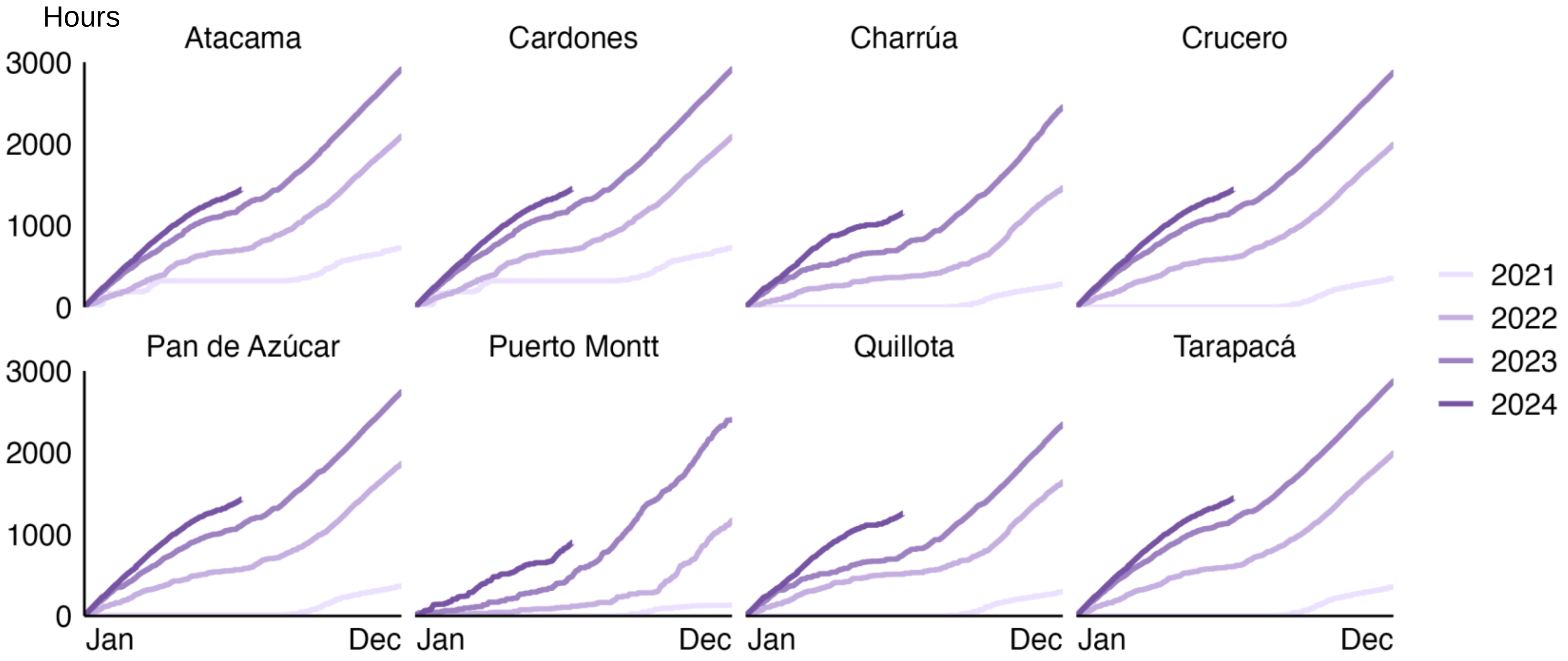


Source: Modo

Time of day mismatch - Zero price hours in Chile



Note: there are 8760 hours in a year

Source: CEN, Liebreich Associates

Keeping the lights on - the age of gas?

Liebreich Associates

Image: Thomas P Peschak

Keeping the lights on - the age of batteries

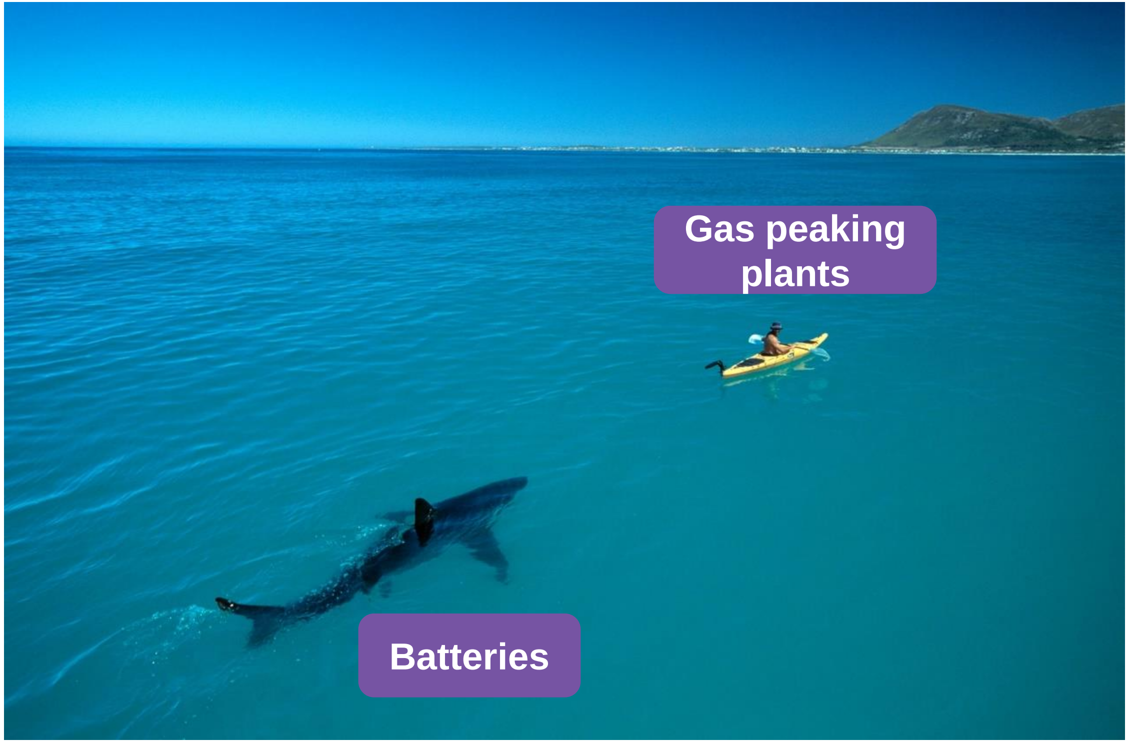
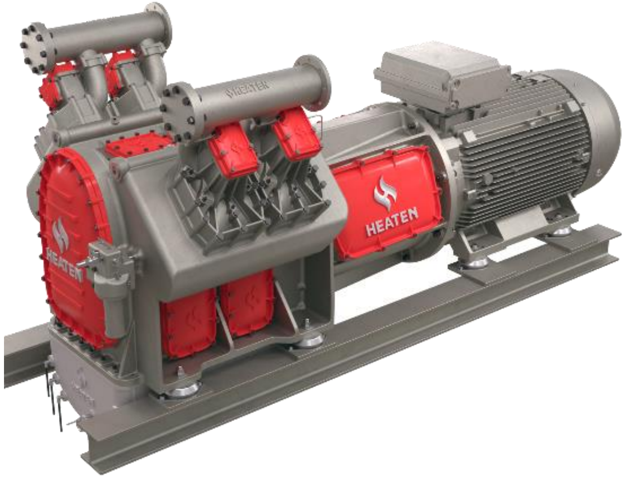


Image: Thomas P Peschak

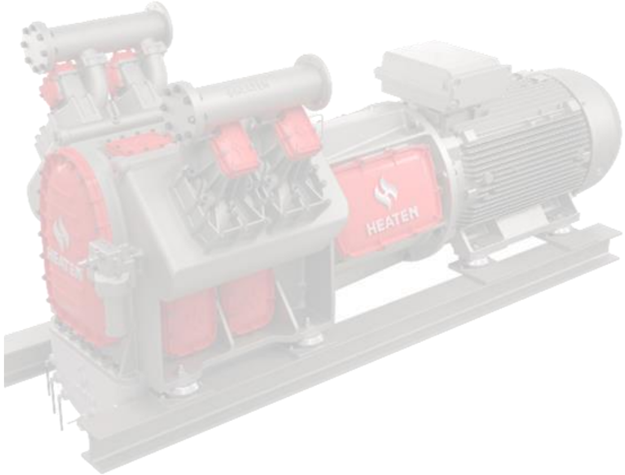
Keeping the lights on – the age of electrification

Liebreich Associates



Images: Rivian; Daikin; Heaten

Keeping the lights on – electric transport

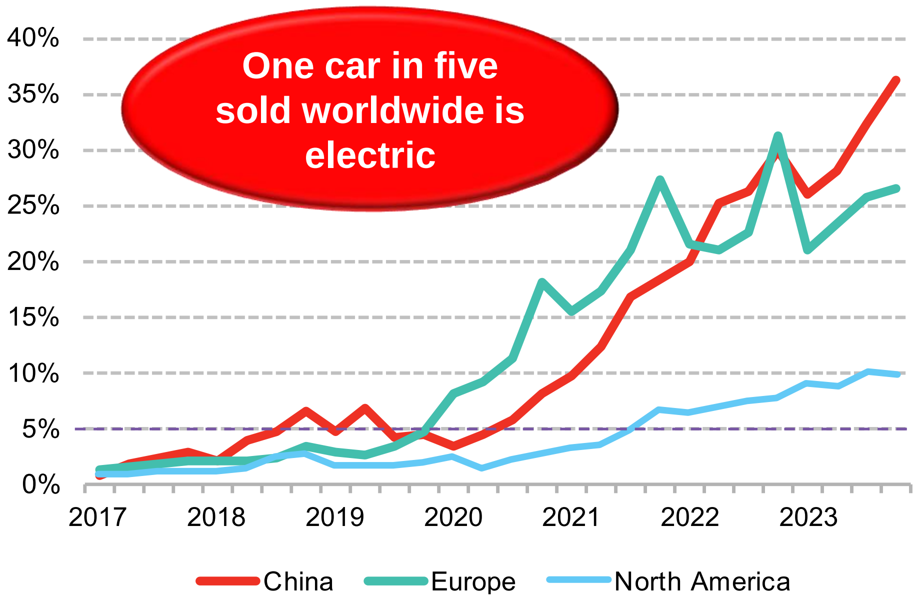


Images: Rivian; Daikin; Heaten

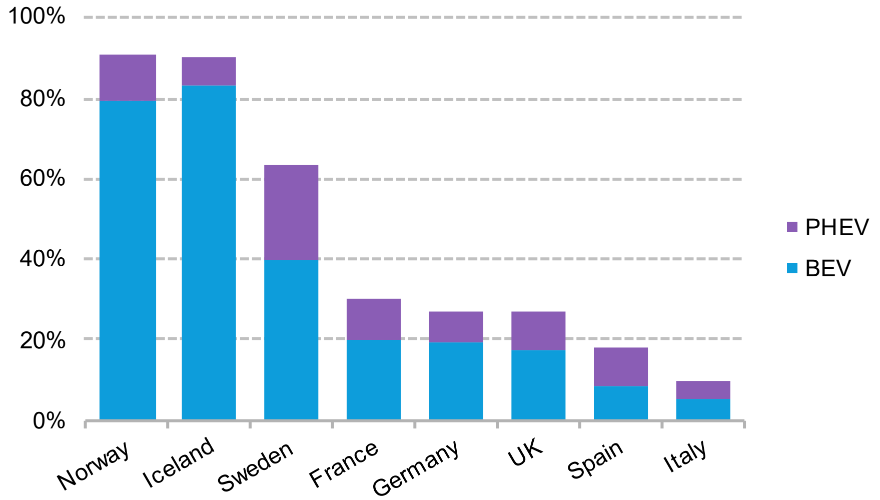
EV sales

Liebreich Associates

Global EV share of passenger vehicle sales



EV share of passenger vehicle sales in Europe

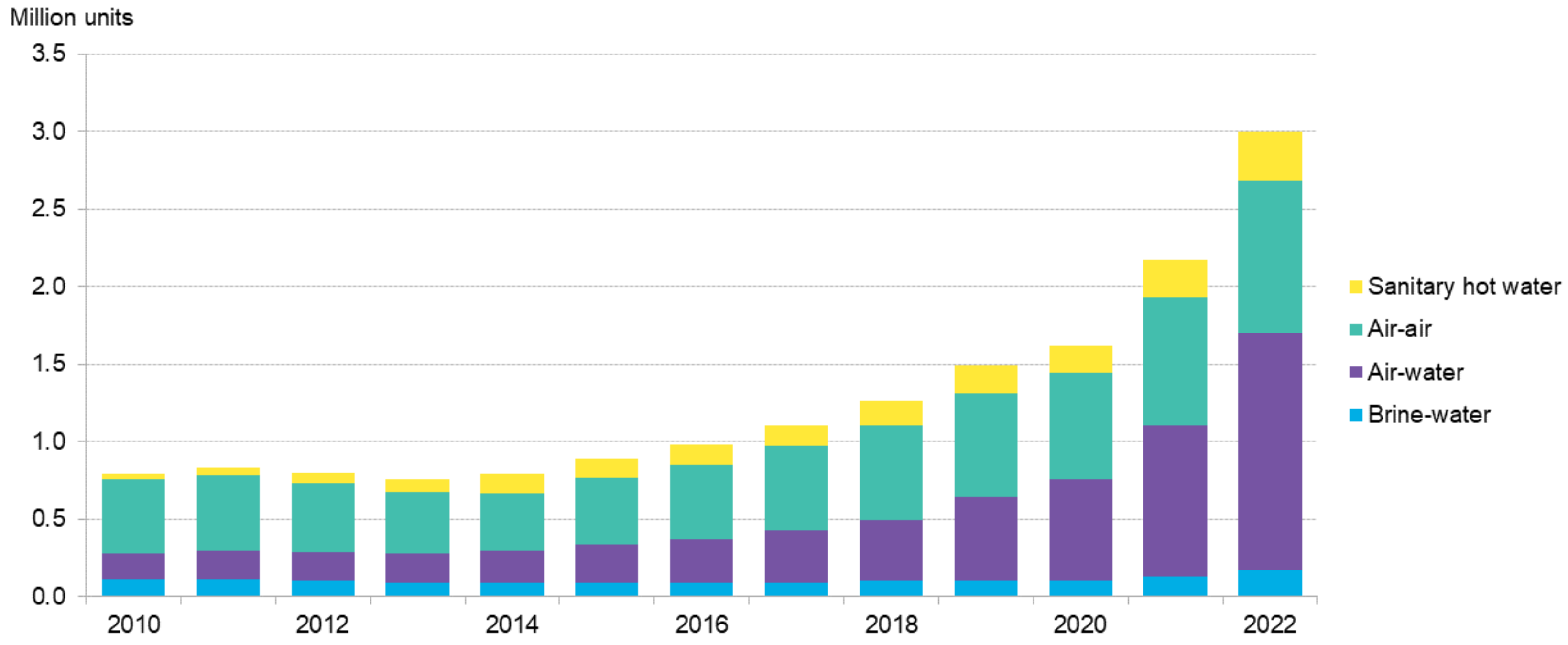


Note: Data as of Q1 2024

Source: BNEF

EU heat pump installations

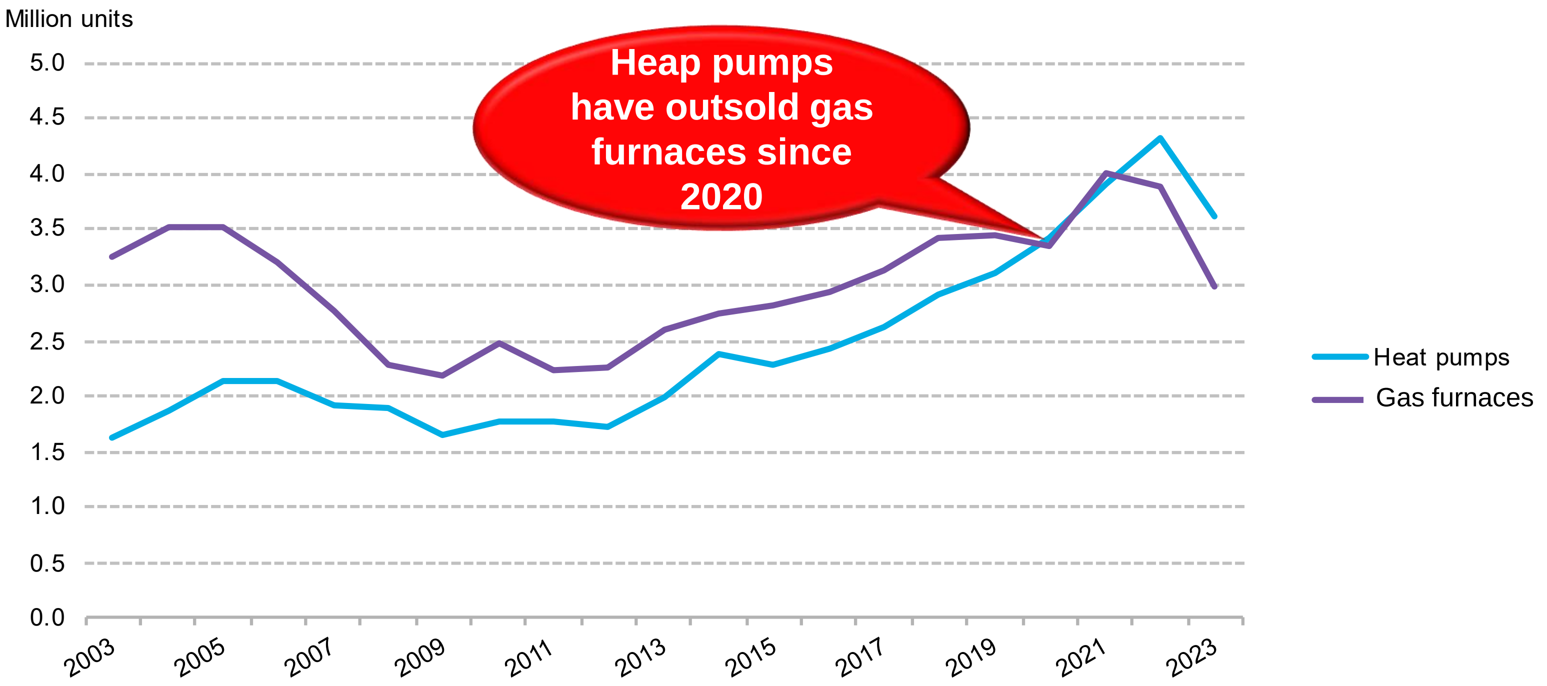
Liebreich Associates



Source: EHPA

US heat pump v. gas furnace sales

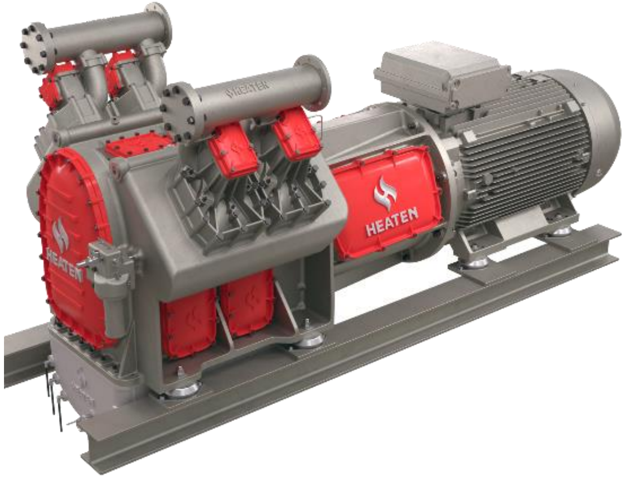
Liebreich Associates



Source: MIT Technology Review, Liebreich Associates

Keeping the lights on – industrial electrification

Liebreich Associates



Images: Rivian; Daikin; Heaten

Industrial heat pumps

Liebreich Associates

Up to 200C heat and steam

Also work for high-temperature district heat

Images: Heaten; Mitsubishi, Star Renewables

Wild card: data centres

Liebreich Associates

Image: FreePix, Liebreich Associates

Hydrogen

Liebreich Associates

Image: Wikimedia Commons

Hydrogen futurism – 1875

Liebreich Associates

> Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.

Jules Verne, Mysterious Island

Image: Wikimedia Commons

Clean Hydrogen Society

"Shifting to and developing a hydrogen society is critical for achieving decarbonization"

Japanese Prime Minister Fumio Kishida
19 April 2022, visiting liquid hydrogen terminal, Hyogo

Image: Nippon.com

Hydrogen economy

Liebreich Associates

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

Olaf Scholz, German Chancellor
September 2022

Image: DW

Clean Hydrogen Swiss Army Knife

Liebreich Associates

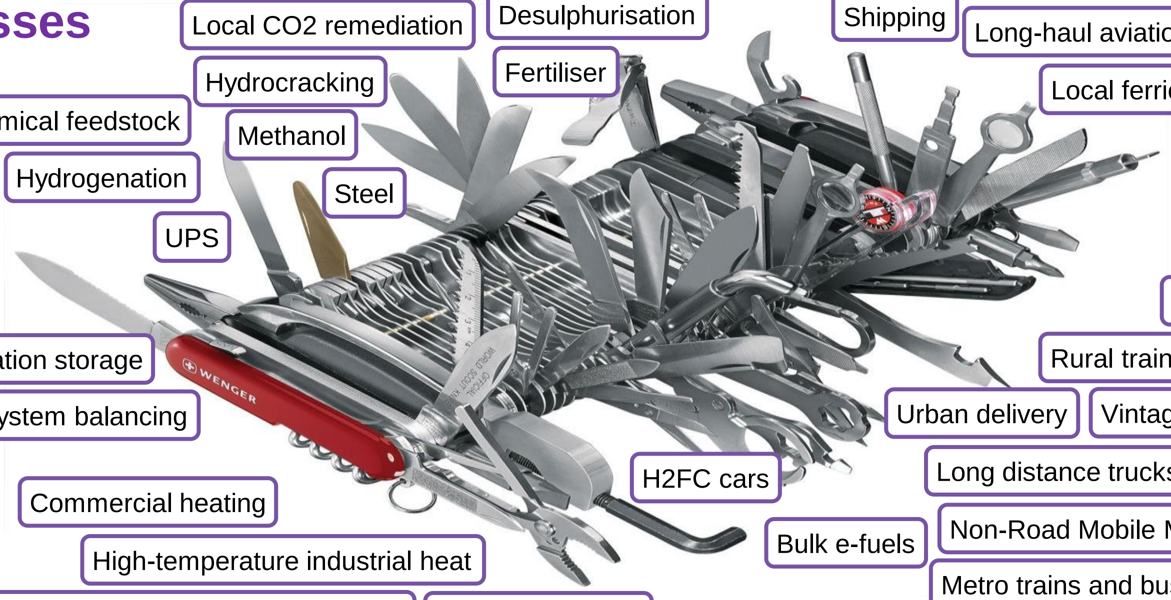
"Clean hydrogen is the "Swiss army knife" of zero-carbon technologies"

Jennifer Granholm, US Energy Secretary

Image: Wikimedia Commons

Clean Hydrogen Swiss Army Knife

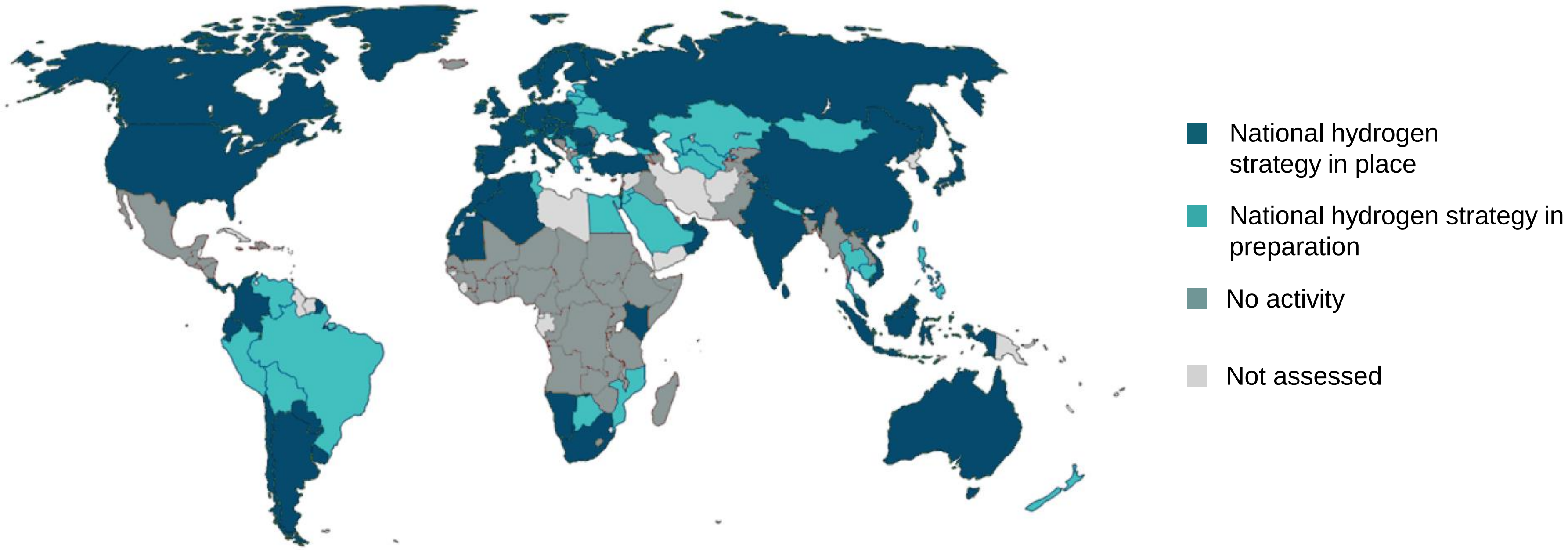
Liebreich Associates



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

Hydrogen strategies – 2024

Liebreich Associates

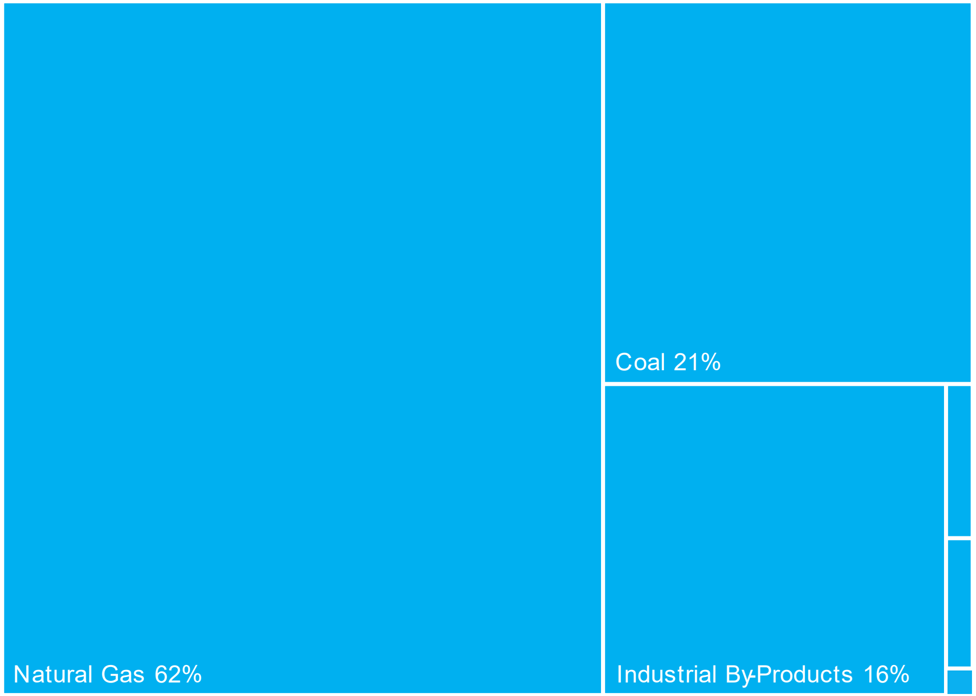


Source: BloombergNEF

150 years into hydrogen economy…

Liebreich Associates

100 million tons per year, $150 billion market



Source: IEA Global Hydrogen Review 2023

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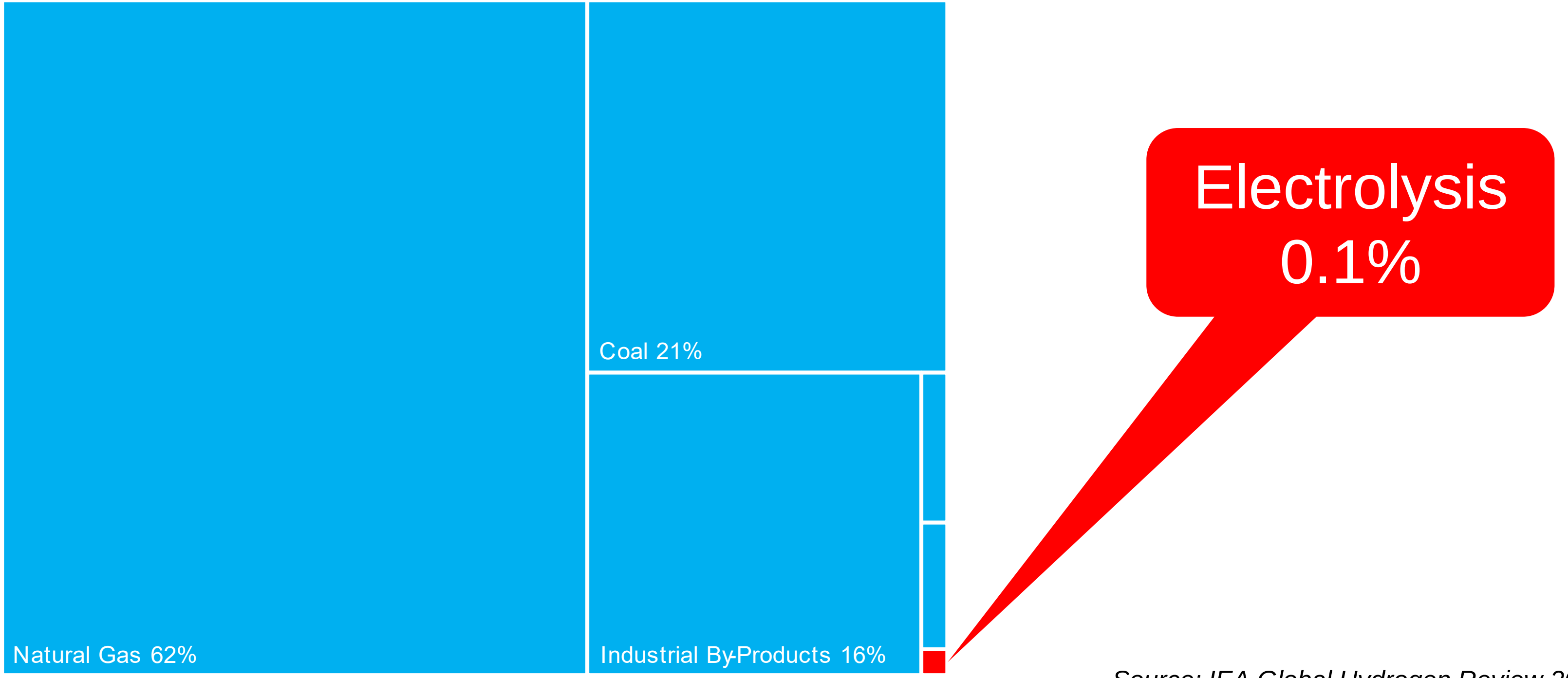
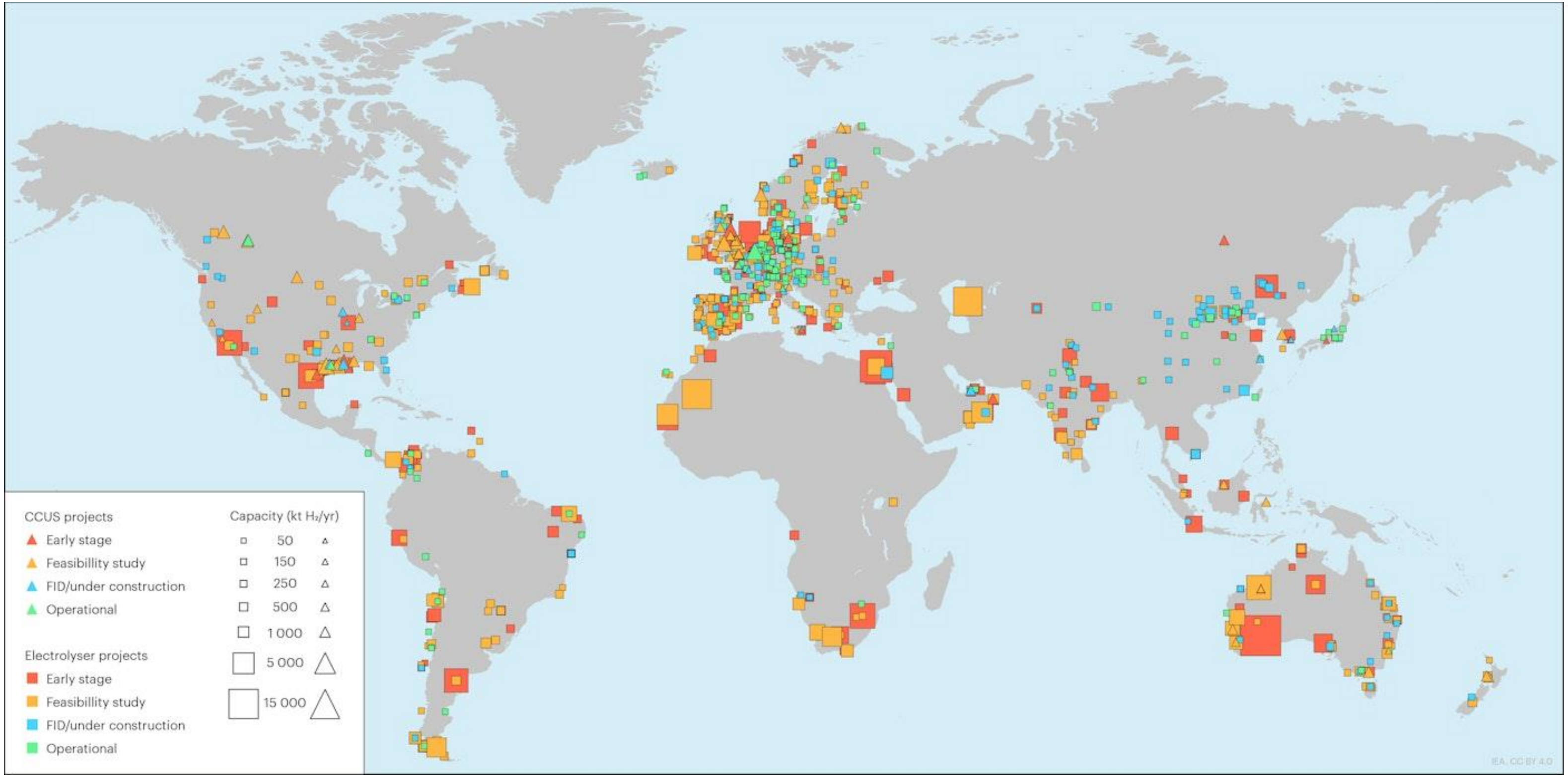


Source: IEA Global Hydrogen Review 2023

Global announced hydrogen projects

Liebreich Associates

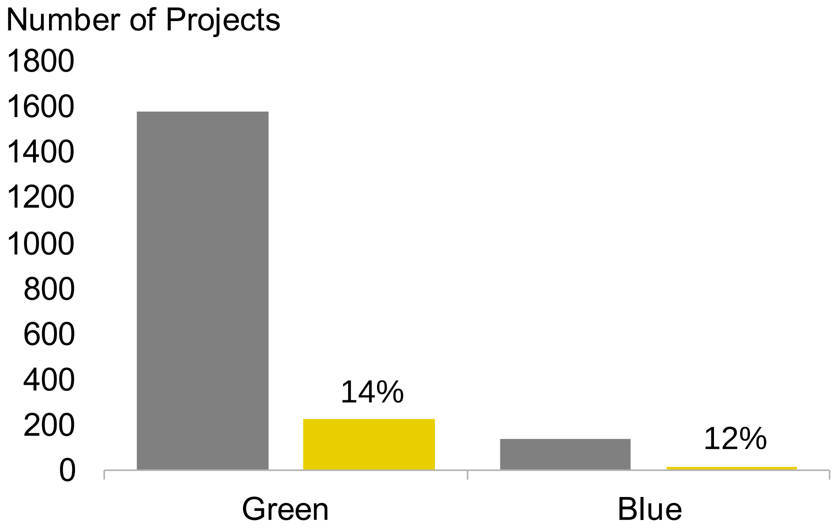


Source: IEA Hydrogen Review 2023

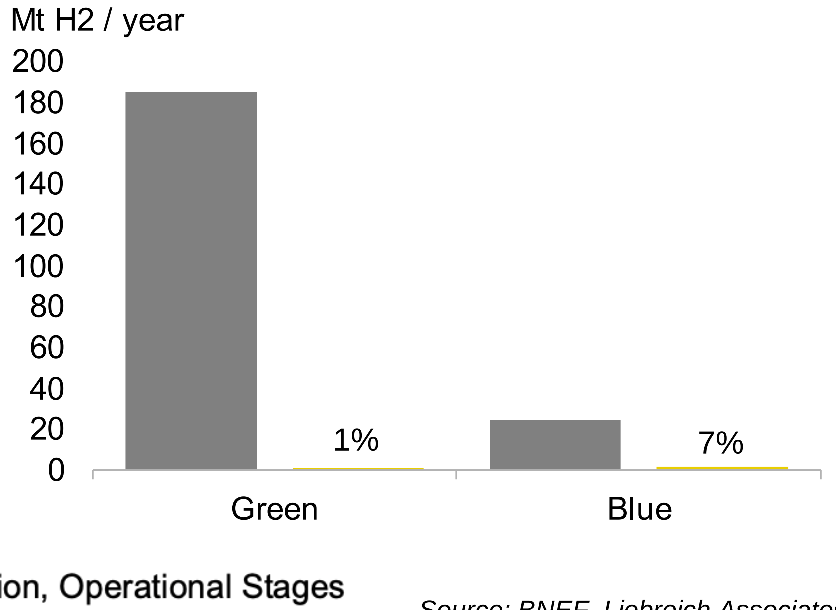
Clean hydrogen project status

Liebreich Associates

By number of projects

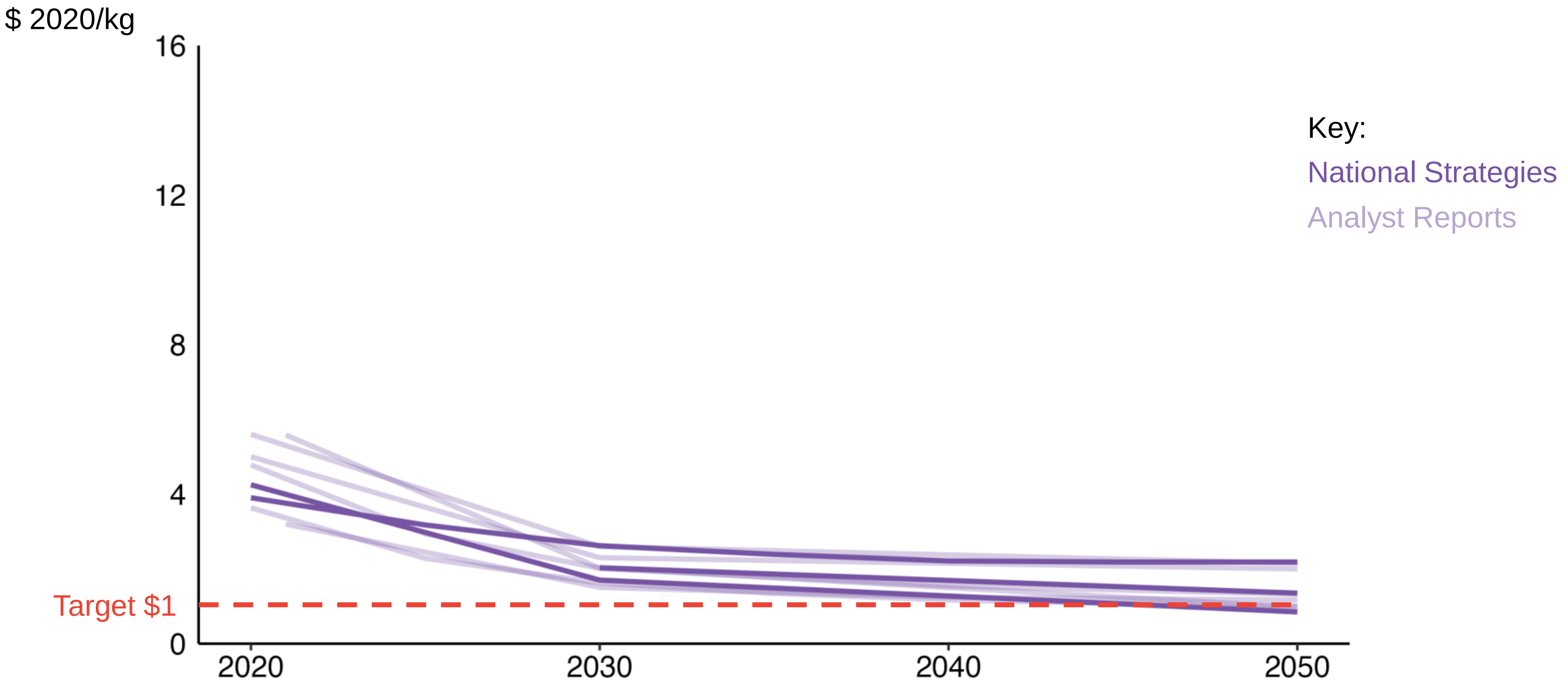


By production volume



Source: BNEF, Liebreich Associates

Green hydrogen cost: hydrogen strategies vs out-turn



Source: Various, Liebreich Associates

Green hydrogen cost: hydrogen strategies vs out-turn

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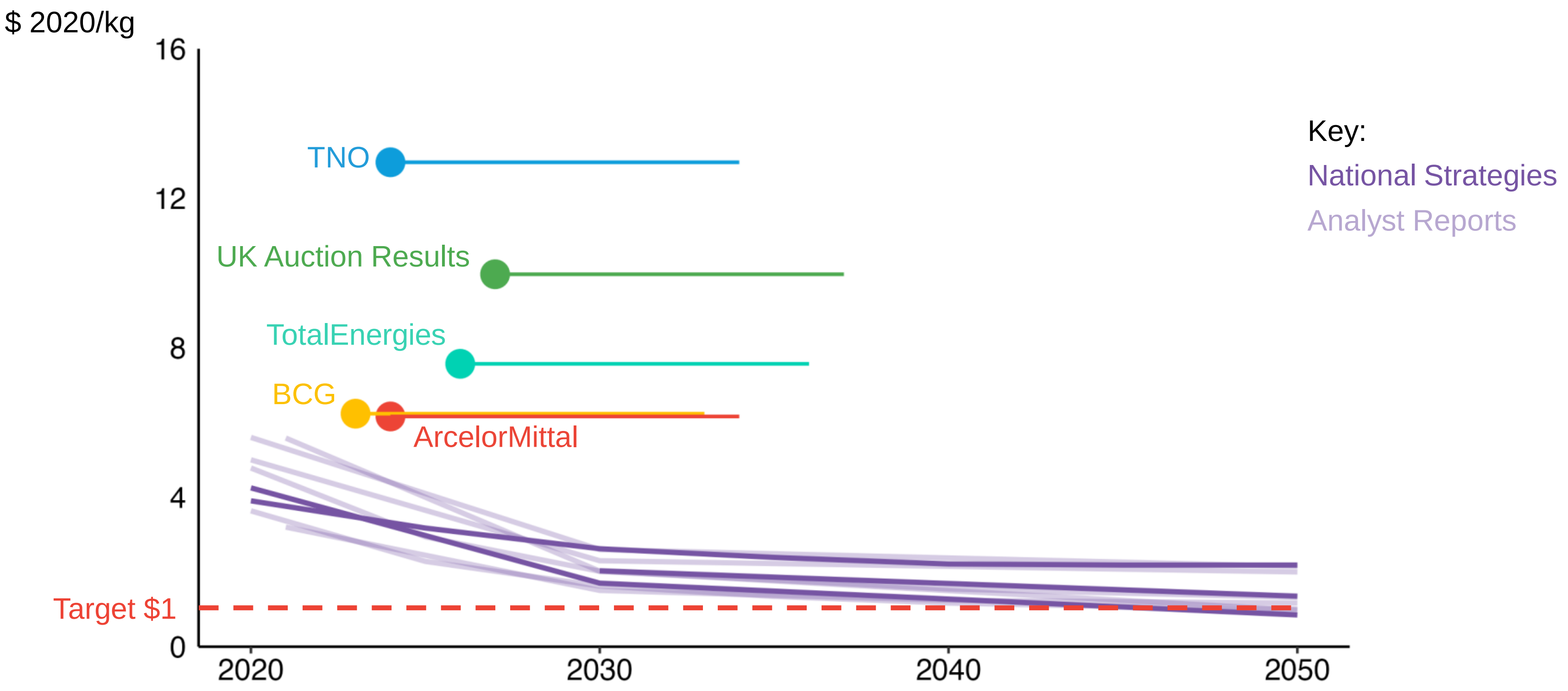
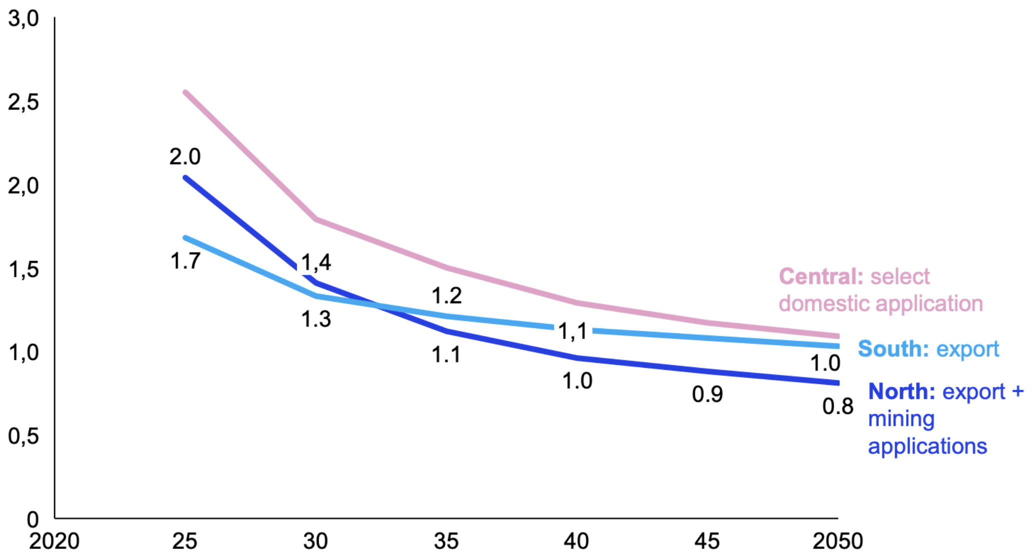


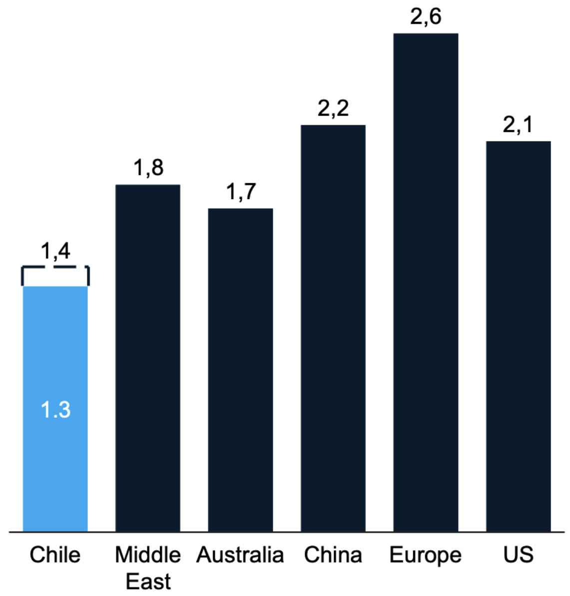
Source: Various, Liebreich Associates

The promise for Chile (2020)

Production cost curve for hydrogen by region,
Generation and Electrolyzer costs of LCOH, USD / kg H2



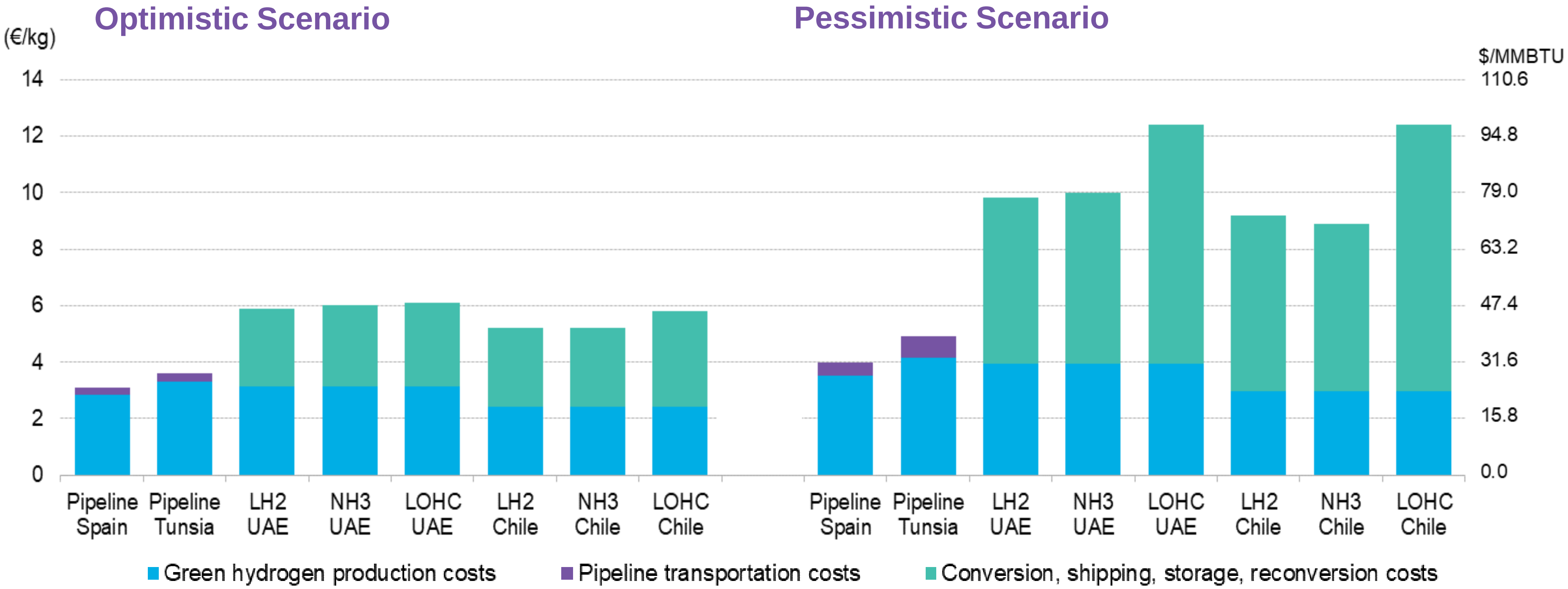
Comparison of production costs 2030
Generation and Electrolyzer costs of LCOH
USD / kg H2



Source: McKinsey & Co Chilean Clean Hydrogen Pathway

Cost of imported hydrogen, Austria/ Germany (2040)

Liebreich Associates



Note: Dutch TTF Natural gas prices as of Sept 2023.

Source: AIT, Bloomberg, Liebreich Associates

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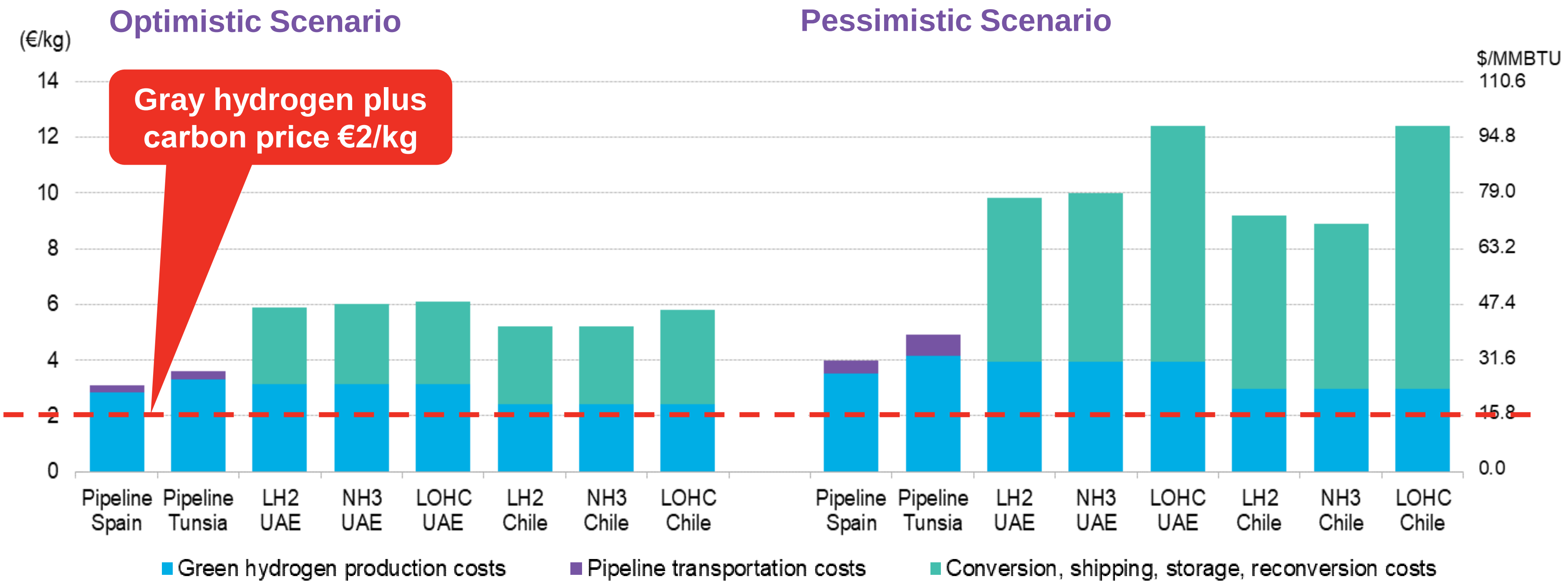

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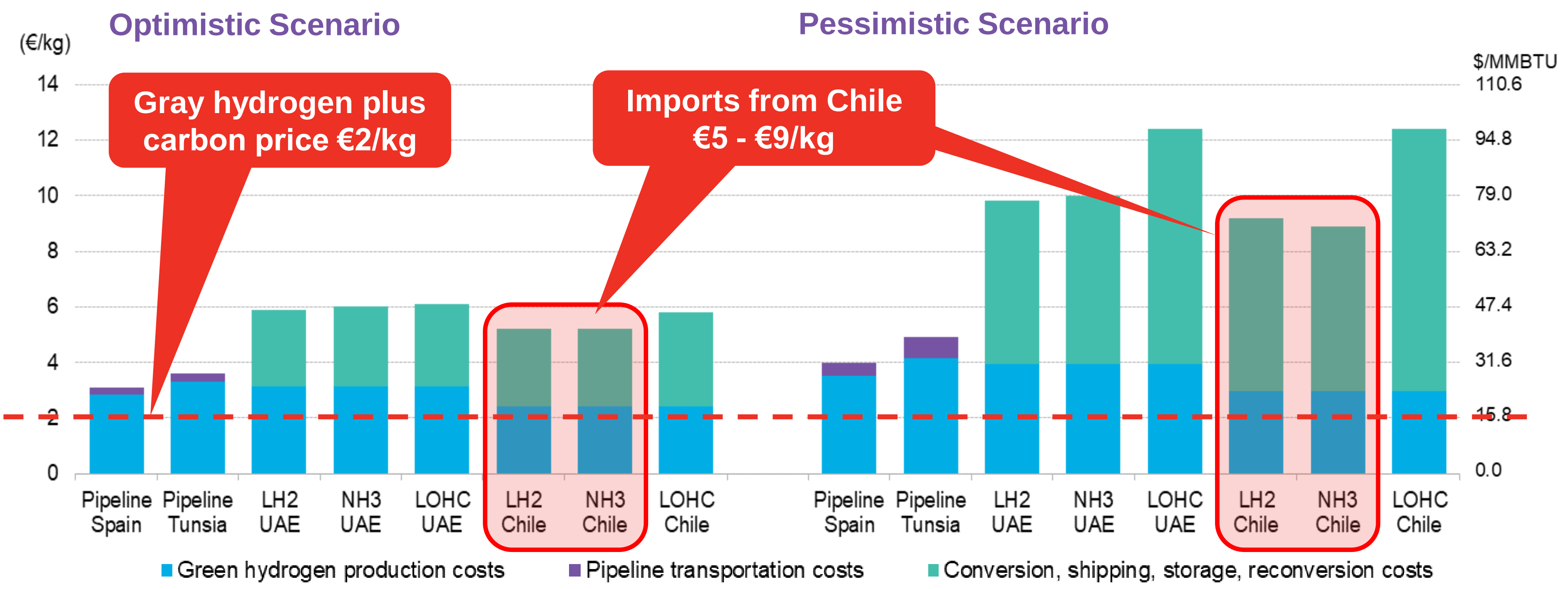

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Hydrogen's missing trillions

Liebreich Associates

Each million tons per year of hydrogen…

…equals one billion kg

Source: Liebreich Associates

Hydrogen's missing trillions

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Each million tons per year of hydrogen…
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So each dollar per kg of cost disadvantage…
…equals a billion dollars per year of missing money

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So each dollar per kg of cost disadvantage…
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But each project needs a fifteen-year offtake agreement…
…which requires $15 billion bankable subsidy or green premium

Source: Liebreich Associates

Hydrogen's missing trillions

Liebreich Associates

Each million tons per year of hydrogen…
…equals one billion kg

$3/kg cost gap
translates into
$45billion
of required subsidy
per million tons

So each dollar per kg of cost disadvantage…
…equals a billion dollars per year of missing money

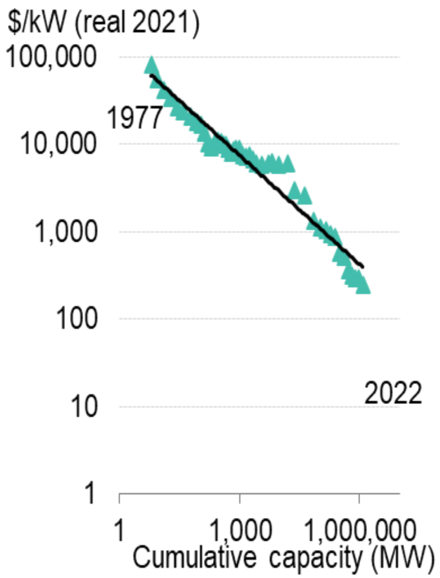
But each project needs a fifteen-year offtake agreement…
…which requires $15 billion bankable subsidy or green premium

Source: Liebreich Associates

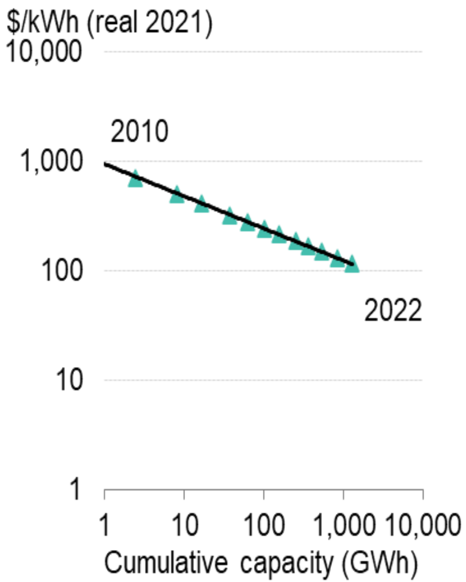
Experience curves

Liebreich Associates

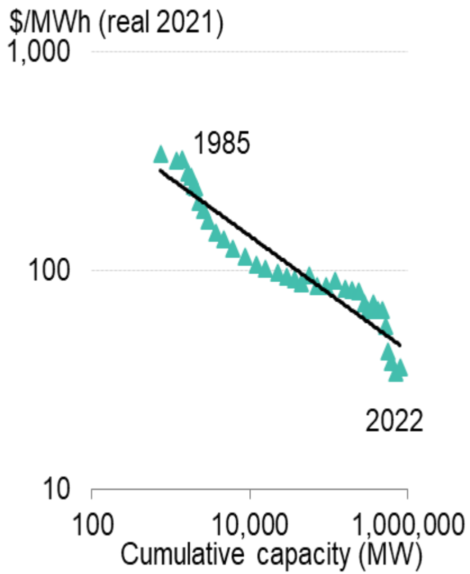
Solar Modules (28%)



Batteries (18%)



Wind (15%)



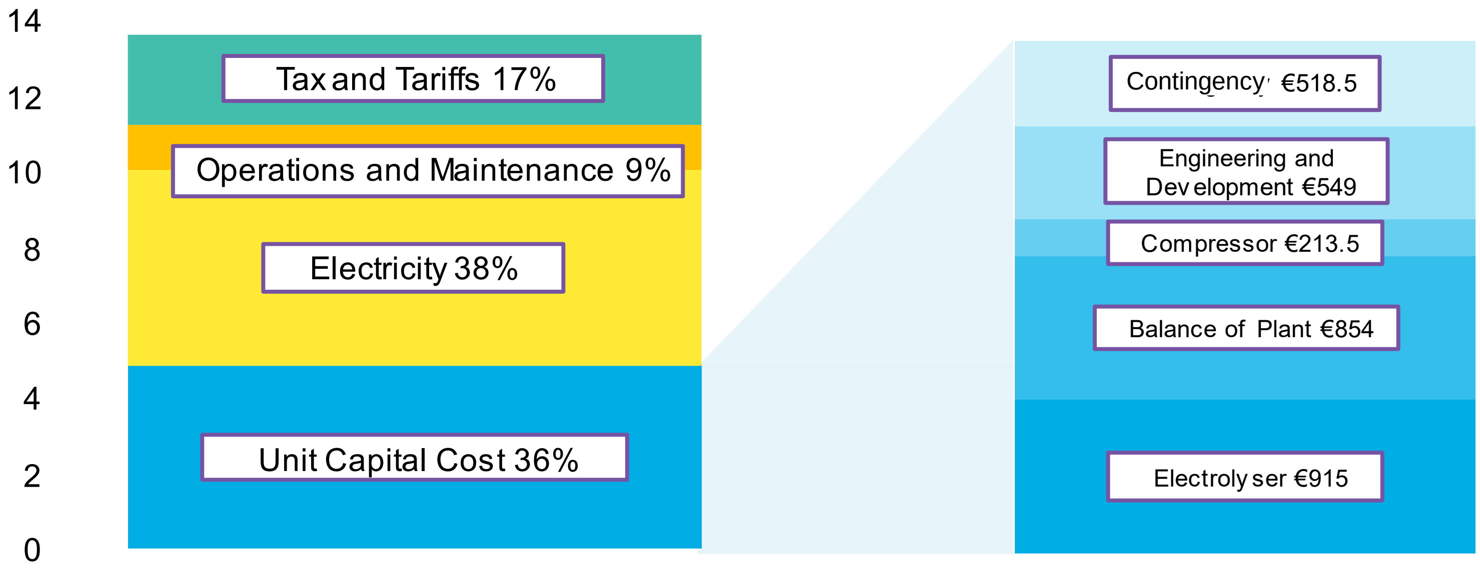
Source: Schmidt et al., BNEF, Liebreich Associates

Green Hydrogen – TNO Holland Cost Study

Liebreich Associates

Levelised Cost (€/kg)

Unit Capital Cost (€/kWe)

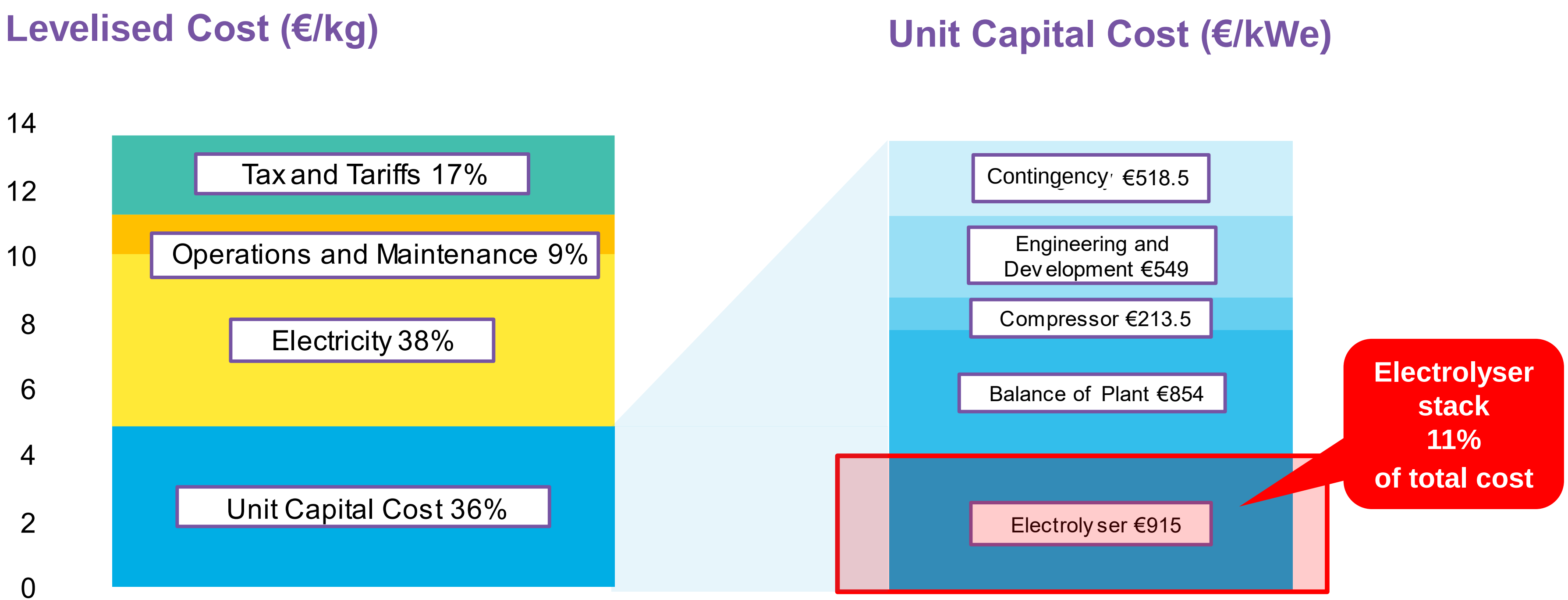


Note: Assumes 100 MWe alkaline/PEM electrolyser; 9.5% WACC; 4,800 FLH based on grid carbon intensity lower than SMR; €75/MWh electricity based on offshore wind

Source: TNO 2024, based on survey responses of current projects

Green Hydrogen – TNO Holland Cost Study

Liebreich Associates



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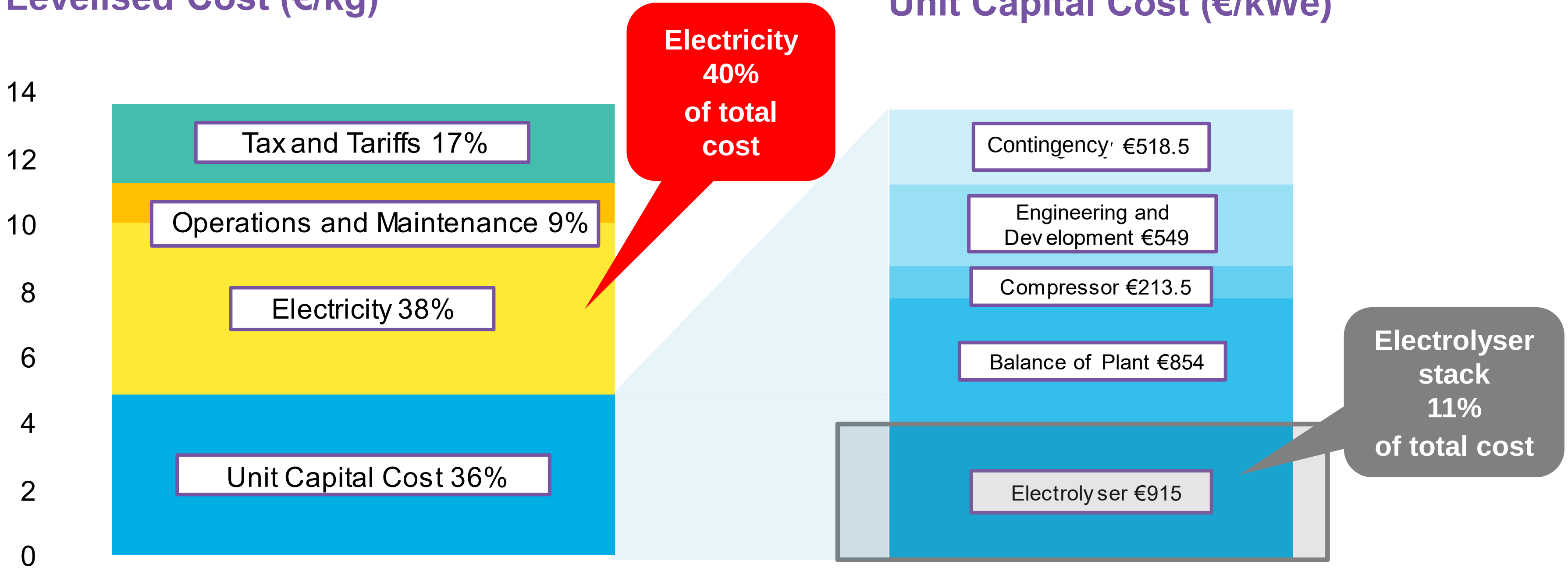

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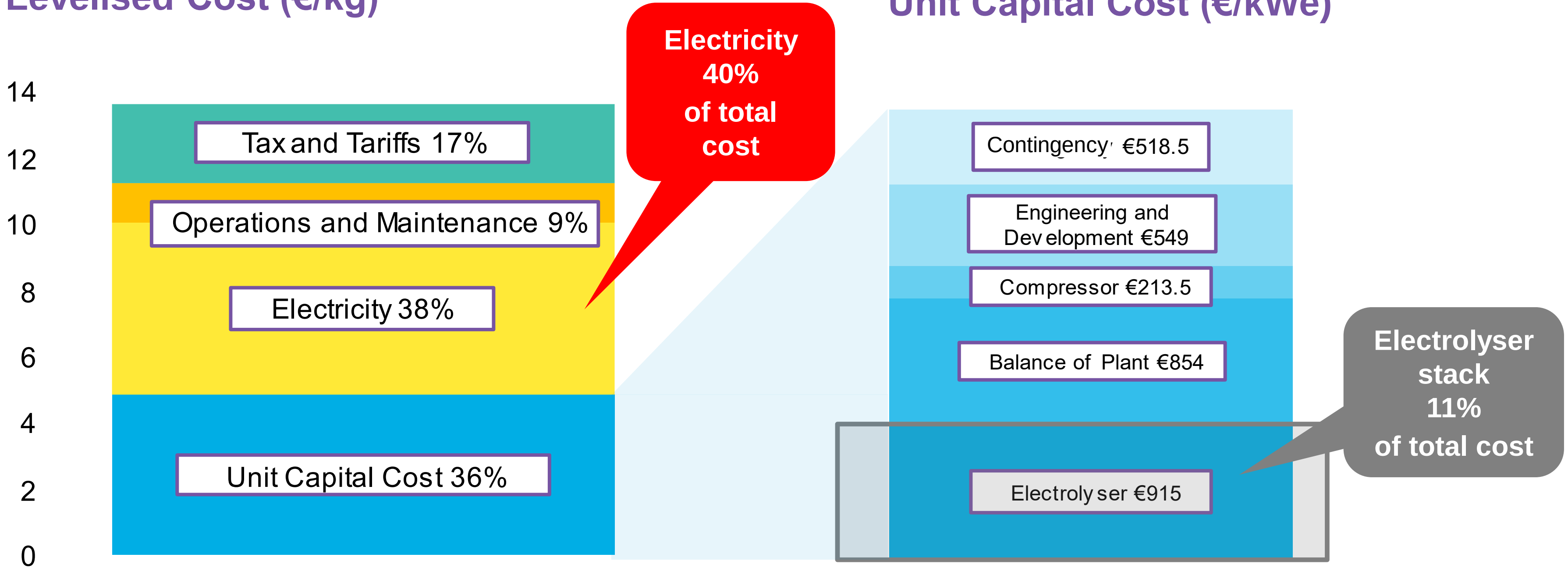

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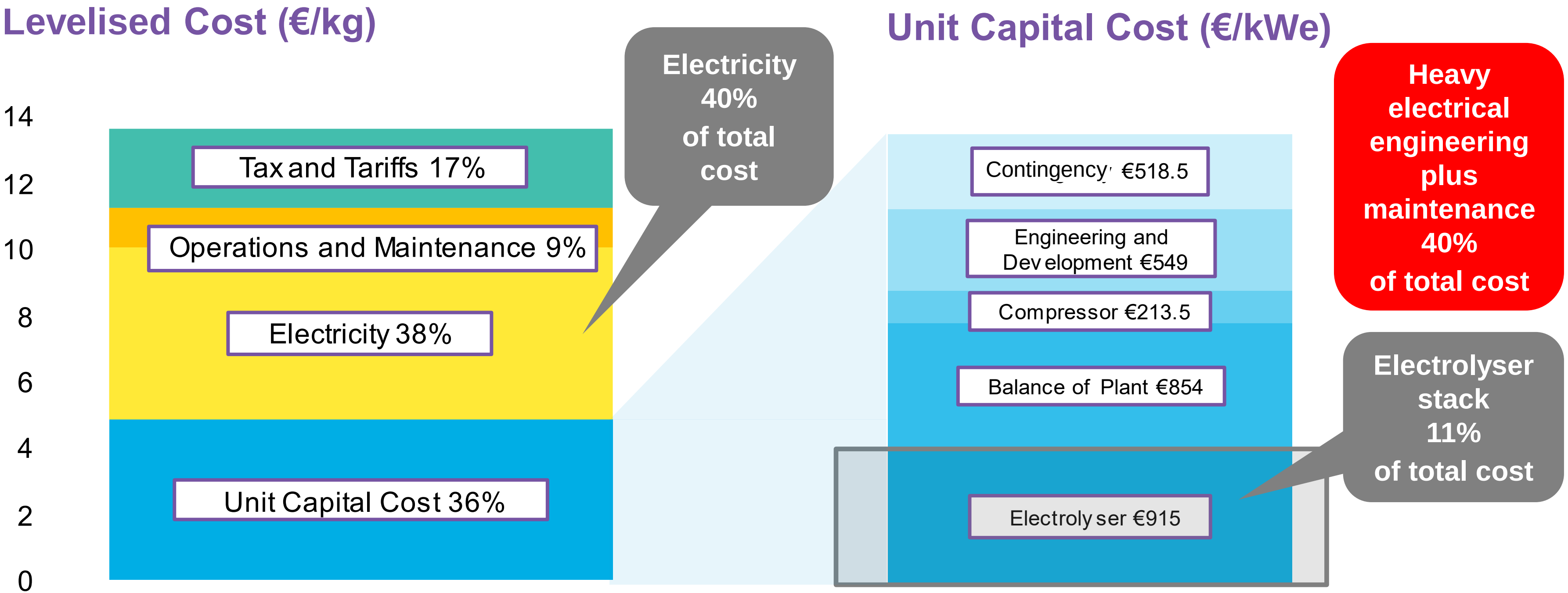

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Hydrogen challenges

Production → Transportation → Storage → Distribution → Use

- Expensive

Source: Liebreich Associates

Hydrogen challenges

Liebreich Associates

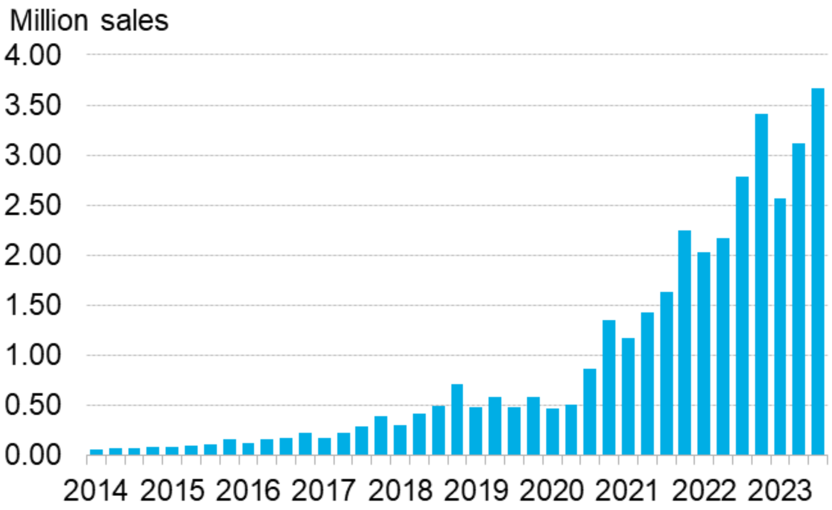
Production	Transportation	Storage	Distribution	Use
• Expensive	• Expensive (except by pipeline)	• Small-scale: expensive • Large-scale: unproven	• Expensive	• Existing uses: price-sensitive • New uses: expensive

Source: Liebreich Associates

Electric vs hydrogen car sales, global quarterly

Liebreich Associates

Battery electric vehicles (inc. PHEVs)



Source: BloombergNEF; Liebreich Associates

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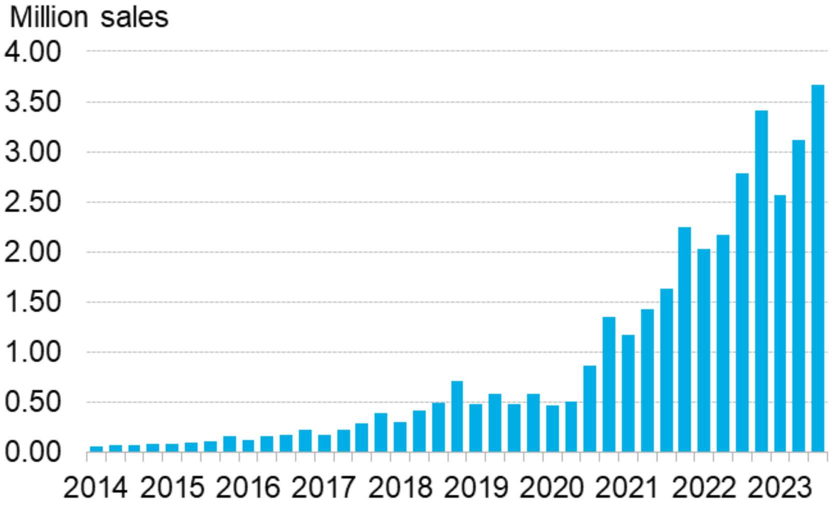
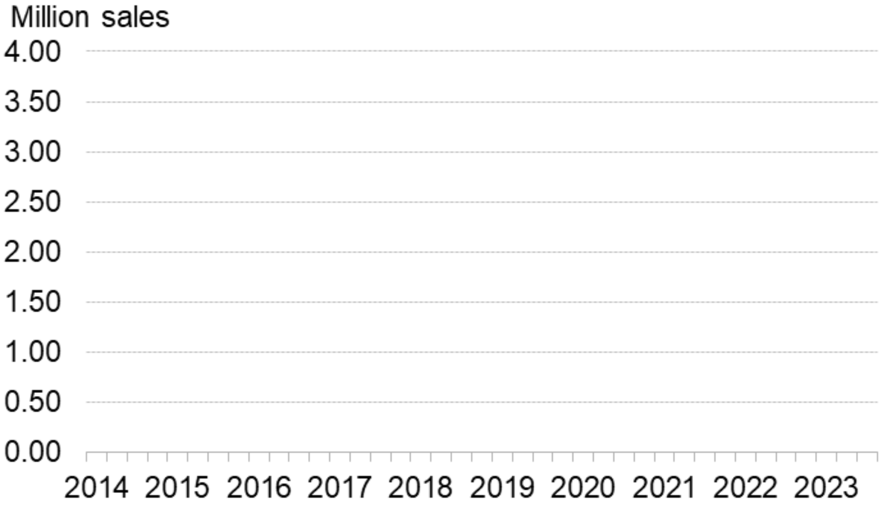


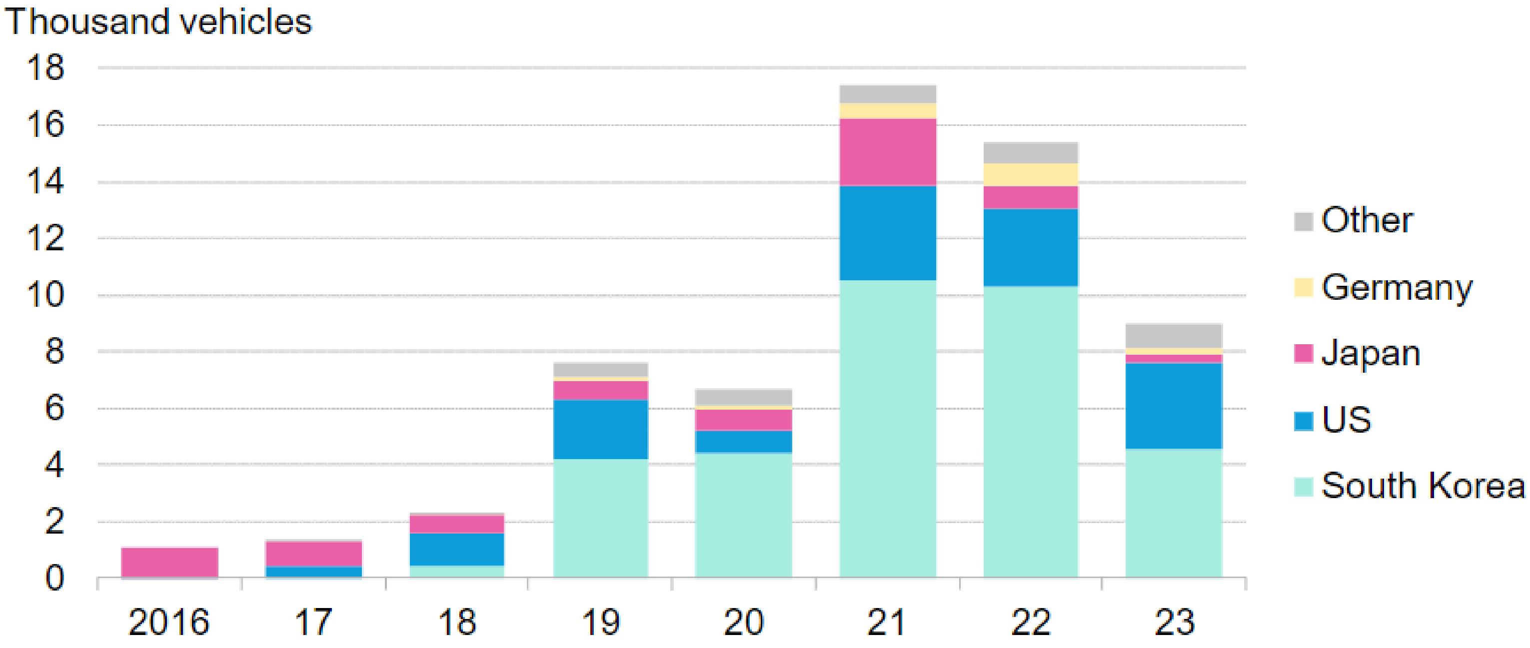
Hydrogen fuel cell vehicles



Source: BloombergNEF; Liebreich Associates

Passenger fuel cell vehicle sales

Liebreich Associates



Source: BloombergNEF; Marklines; Ferrari

Passenger fuel cell vehicle sales

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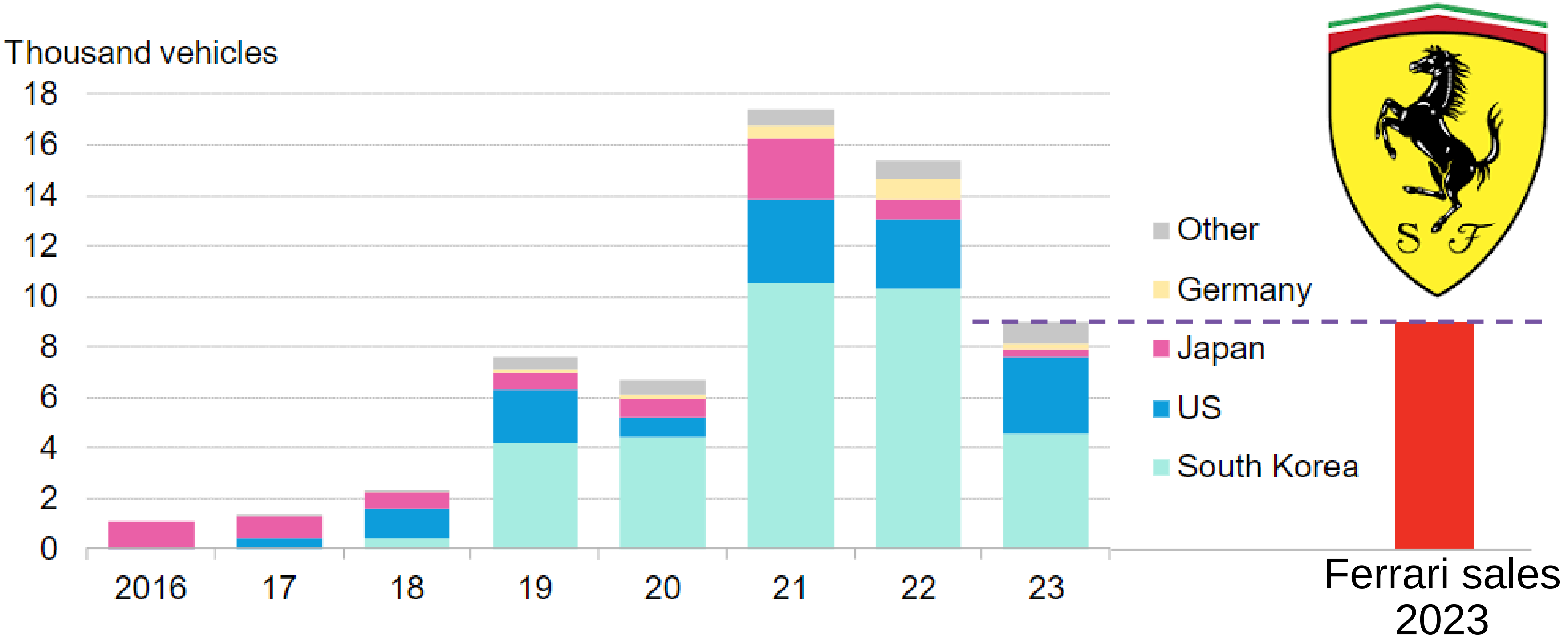


Source: BloombergNEF; Marklines; Ferrari

How it started… how it's going – H2 buses

Liebreich Associates

December 2019

A French town has become the first to launch a fleet of public transit buses powered by hydrogen fuel.

Hydrogen transit buses have entered service in Pau, a town in France located on the northern end of the Pyrenees Mountains. The fleet of buses powered by this clean fuel is the first in the world.

The total fleet consists of eight hydrogen buses.

November 2023

French city that pioneered hydrogen buses will opt for battery-electric in future due to ongoing problems and high costs

Source: Hydrogen Fuel News, Hydrogen Insight

How it started… how it’s going – H2 trains

Liebreich Associates

August 2022

Germany inaugurates world’s first hydrogen-powered train fleet

A fleet of 14 trains powered entirely by hydrogen is launched in Germany’s Lower Saxony state.

A fleet of 14 trains were provided by French industrial giant Alstom [Alstom handout/EPA]

24 Aug 2022

August 2023

No more hydrogen trains | Rail company that launched world's first H2 line last year opts for all-electric future

State-owned LNVG to buy 102 battery trains and 27 catenary-connected models in order to phase out diesel, says Lower Saxony government

Source: Al Jazeera, Hydrogen Insight

Hydrogen and heavy goods vehicles

Liebreich Associates

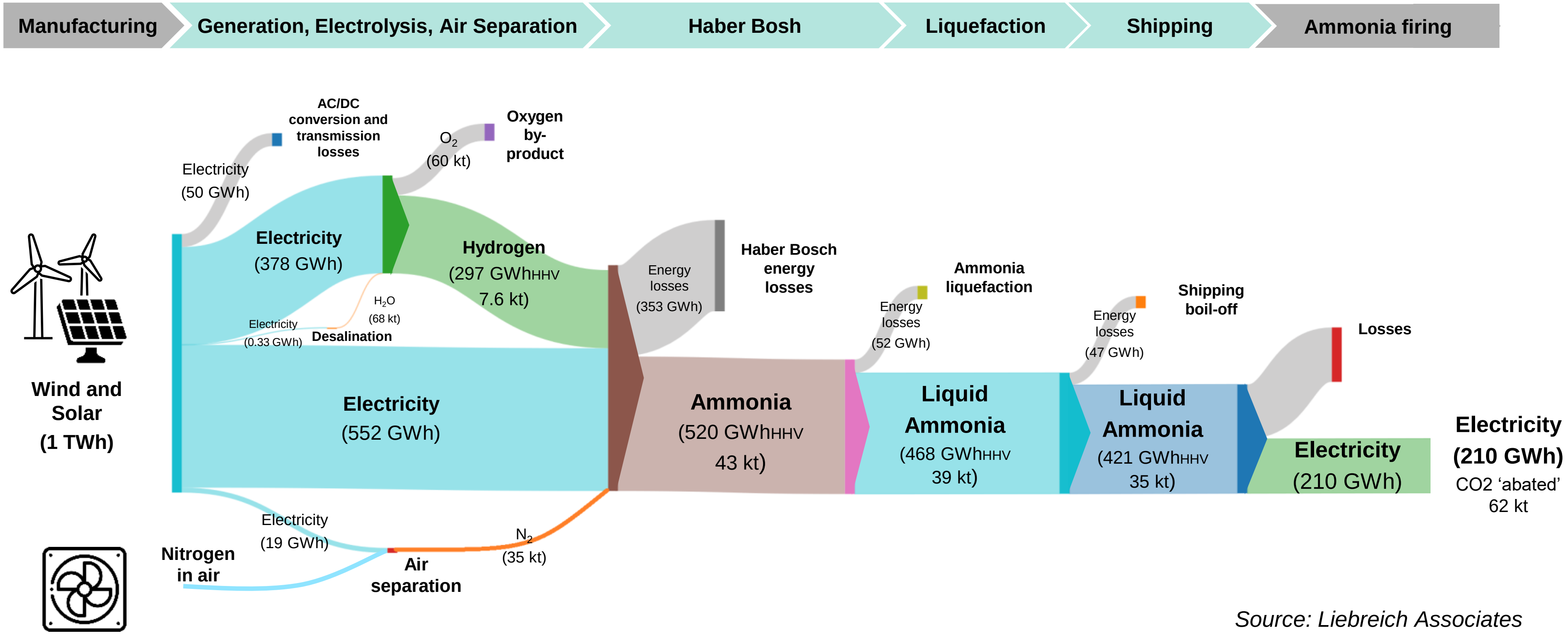
We decided to invest in a European network of hydrogen filling stations for HGVs, but I’m not sure we got it right. I think electricity is going to carry the day because of progress on batteries and light vehicles.

Patrick Pouyanné
CEO Total Energies

Image: Wikimedia Commons

Imported green ammonia electricity generation efficiency (Energy balance)

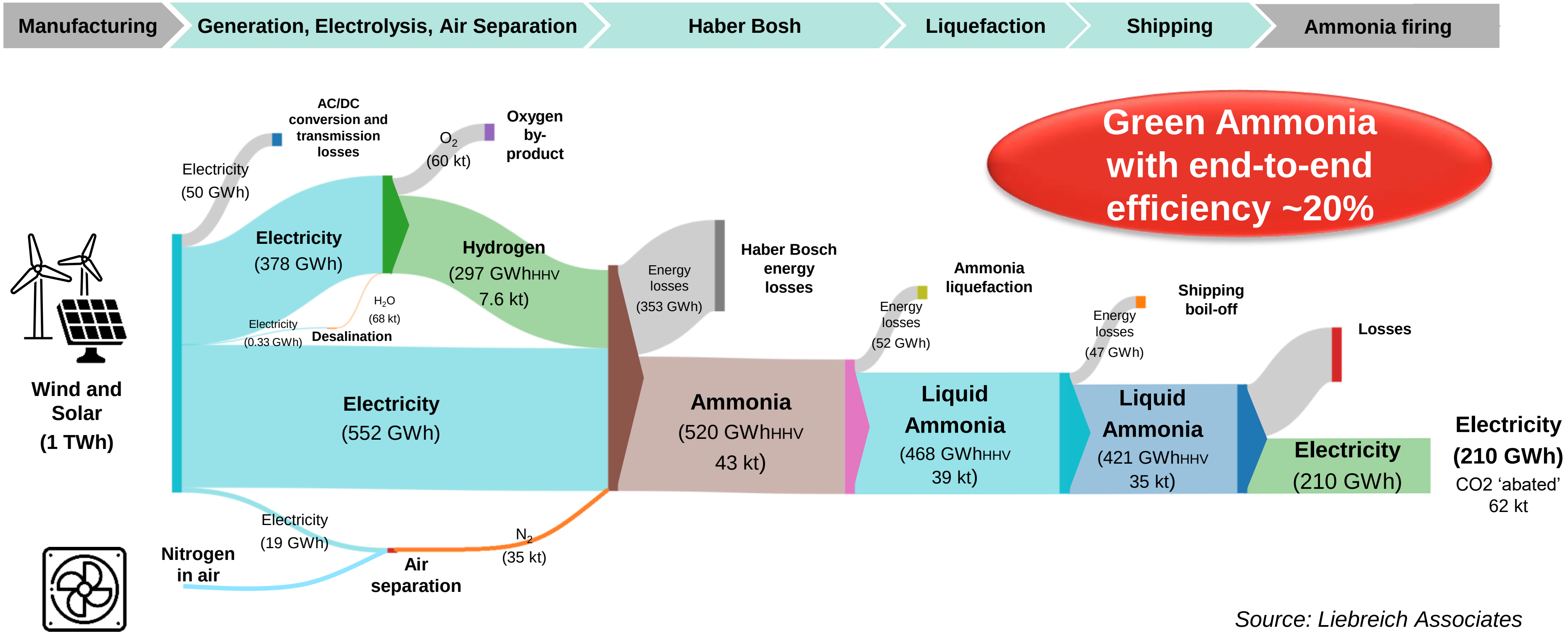
Liebreich Associates



Source: Liebreich Associates

Imported green ammonia electricity generation efficiency (Energy balance)

Liebreich Associates



Source: Liebreich Associates

Hydrogen aviation: the figures for Chile

Liebreich Associates

Image: Vinci

Jet fuel use 2022	1.3 million tonnes
Equivalent hydrogen demand	480,000 tonnes
Energy content	16.1 TWh
Equivalent to 24/7 power	1.8 GW
Liquefaction losses	1.0 GW
Production losses	0.5 GW
Total power demand	**3.3 GW**

- **50% of Chile's total power production**
- **Liquefaction must be at airports**
- **Or via 285 liquid hydrogen deliveries per day**

Source: GlobalEconomy; Liebreich Associates

Hydrogen storage options (long-duration)

Liebreich Associates

Hydrogen gas

e-Methanol

e-Methane

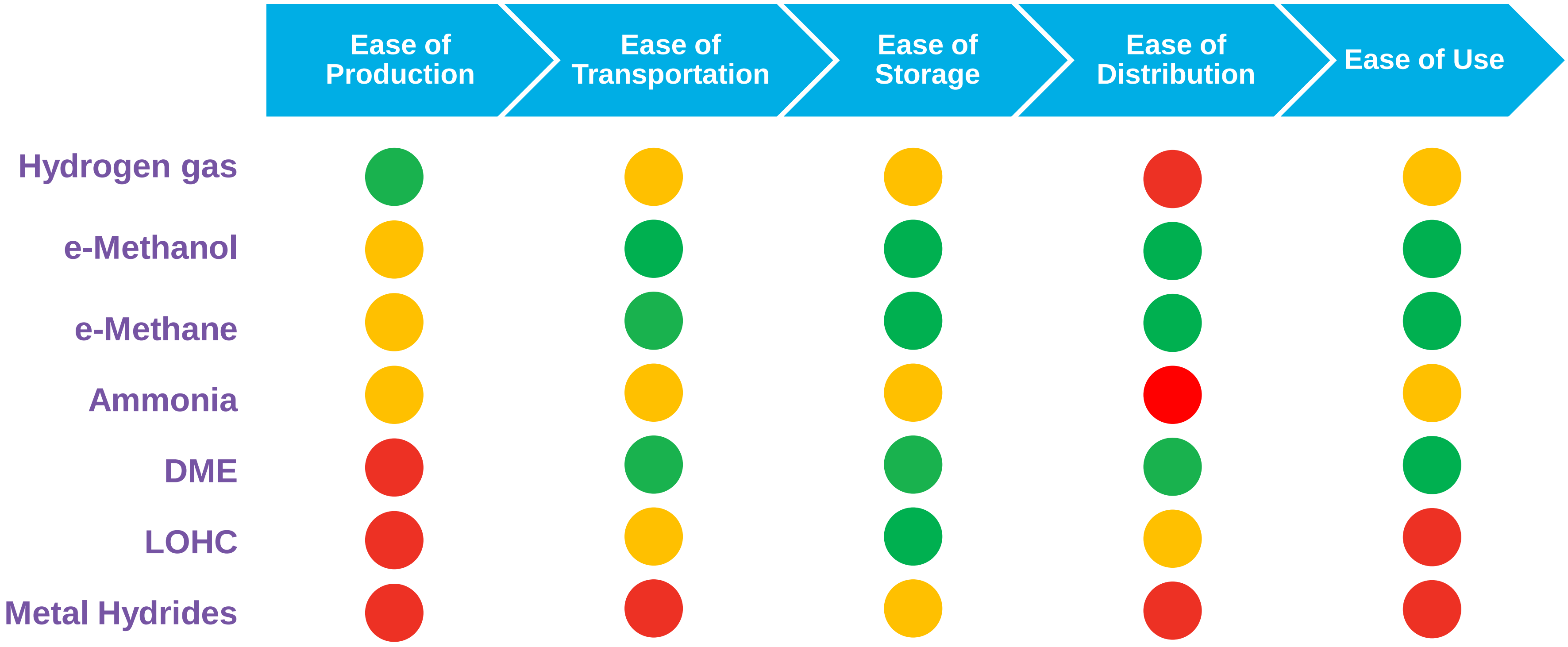
Ammonia

DME

LOHC

Metal Hydrides

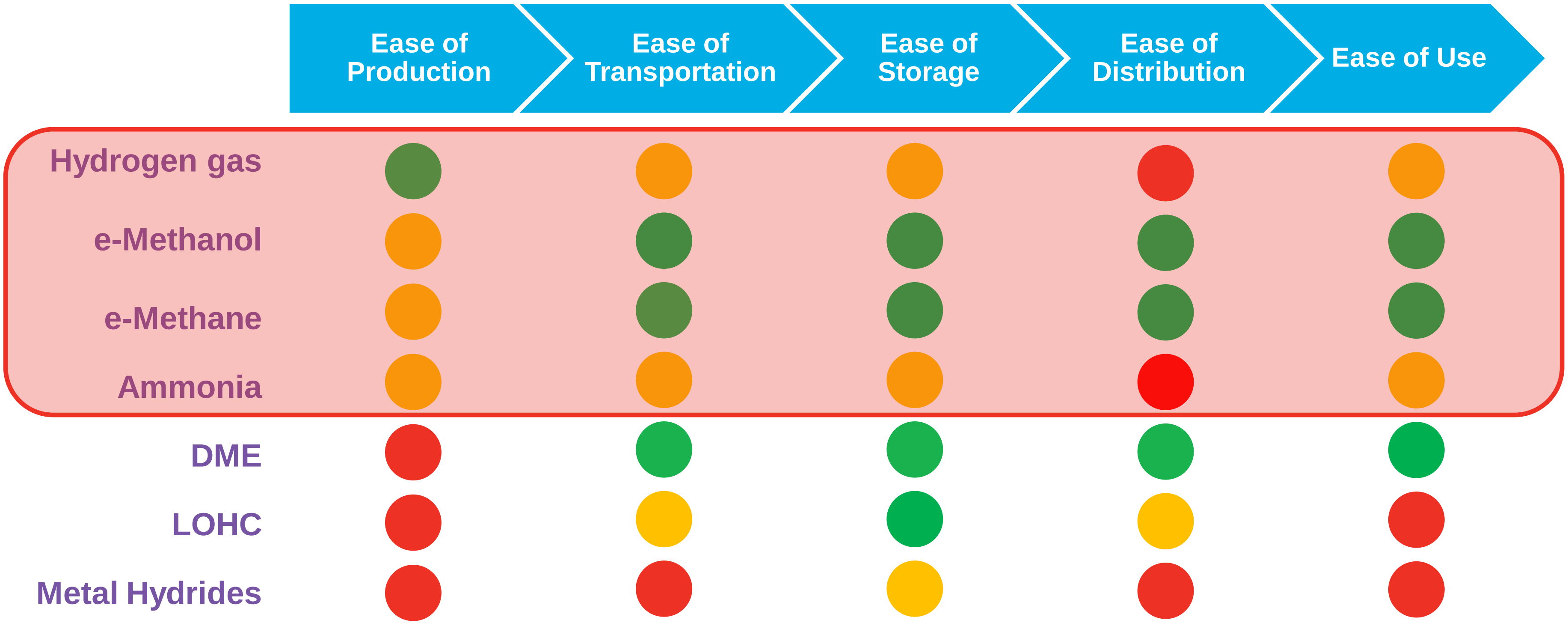
Hydrogen storage options (long-duration)



Sources: Liebreich Associates

Hydrogen storage options (long-duration)

Liebreich Associates



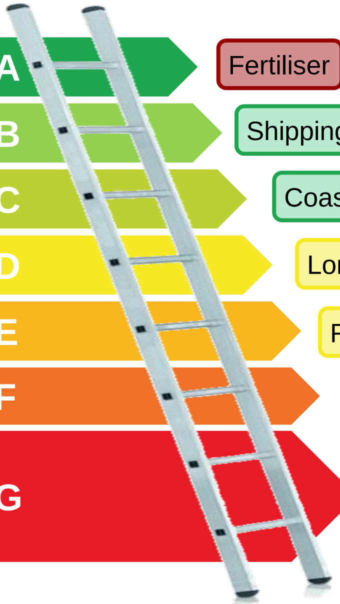
Sources: Liebreich Associates

Hydrogen Ladder 5.0

Liebreich Associates

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

Unavoidable



- **A**: Fertiliser | Hydrogenation | Methanol | Hydrocracking | Desulphurisation
- **B**: Shipping* | Jet Aviation** | Chemical Feedstock | Steel | Long Duration Grid Balancing
- **C**: Coastal and river vessels | Non-Road Mobile Machinery | Vintage and Muscle Cars** | Biogas Upgrading
- **D**: Long Distance Trucks and Coaches | High-Temperature Industrial Heat | Generators
- **E**: Regional Trucks | Commercial Heating*** | Island Grids | Short Duration Grid Balancing
- **F**: Light Aviation | Remote and Rural Trains | Local Ferries | Light trucks | Bulk Power Imports | UPS
- **G**: Metro Trains and Buses | Urban Delivery and Taxis | 2 and 3-Wheelers | Cars | Bulk e-Fuels | Mid/Low-Temperature Industrial Heat | Domestic Heating | Power Generation Using Non-Stored Hydrogen

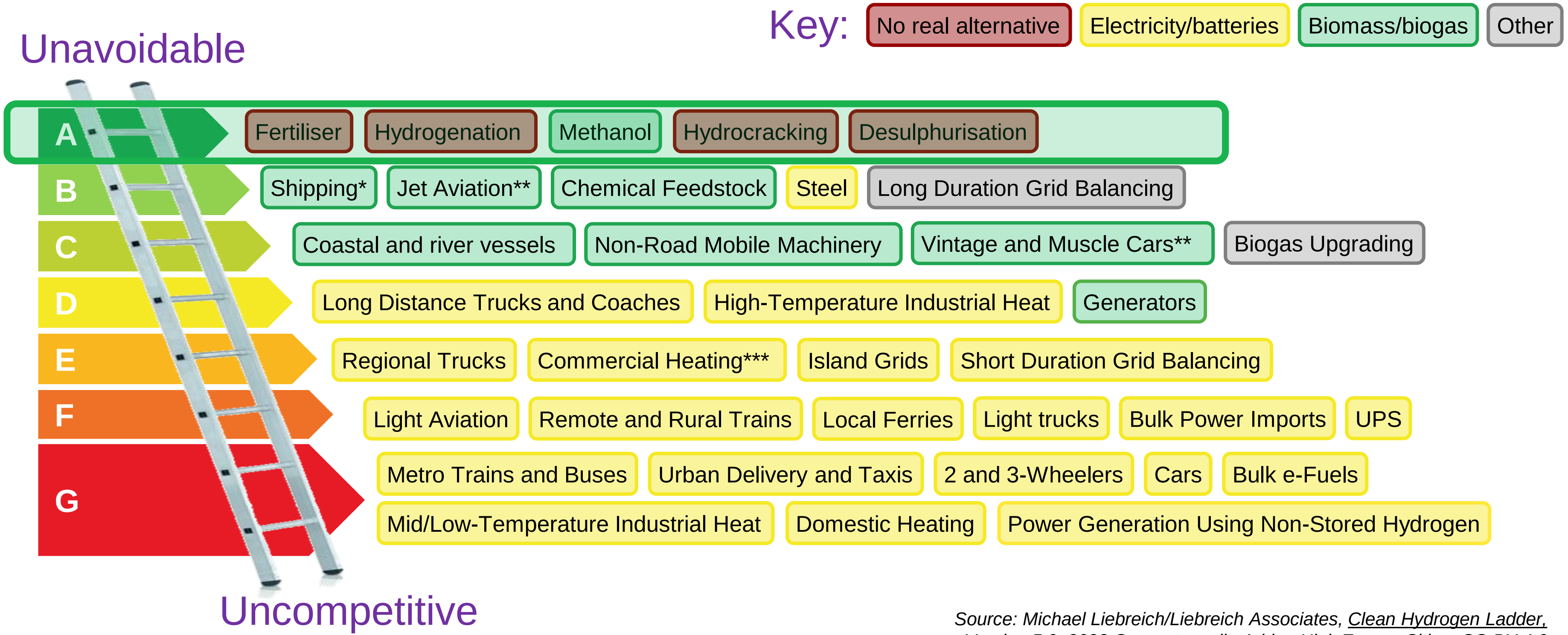
Uncompetitive

**As ammonia or methanol   **As e-fuel or PBTL   ***As hybrid system*

Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 5.0, 2023. Concept credit: Adrian Hiel, Energy Cities.

Hydrogen Ladder 5.0

Liebreich Associates



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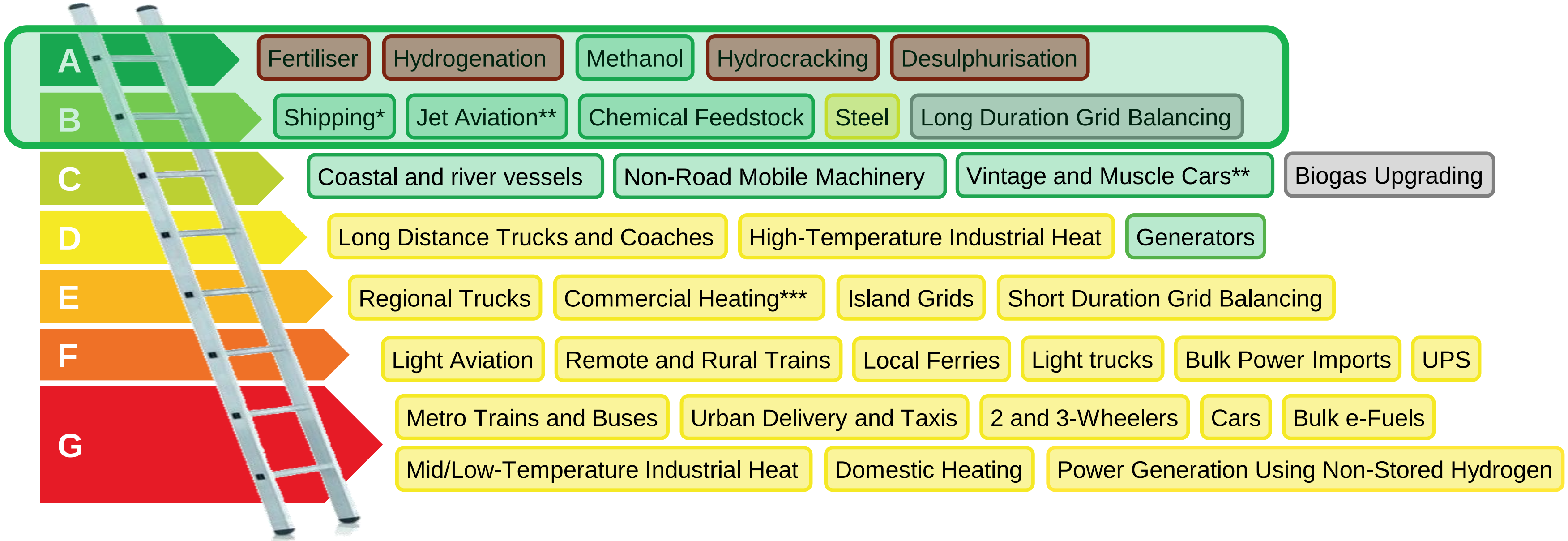

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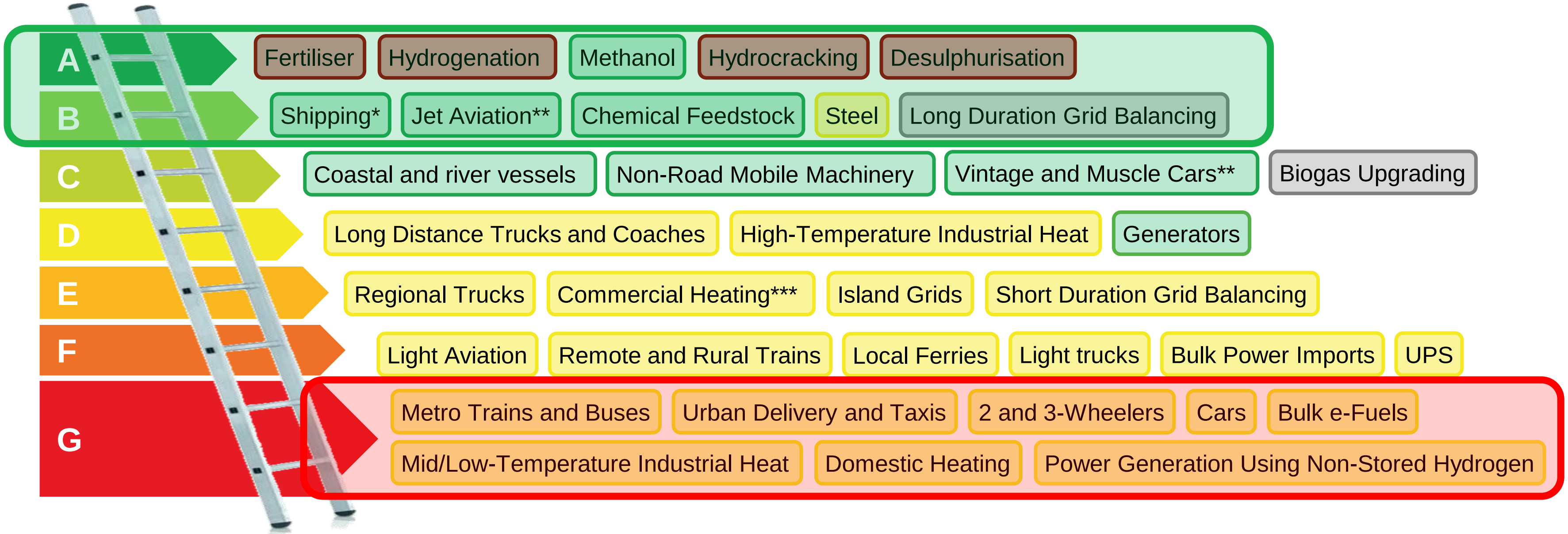

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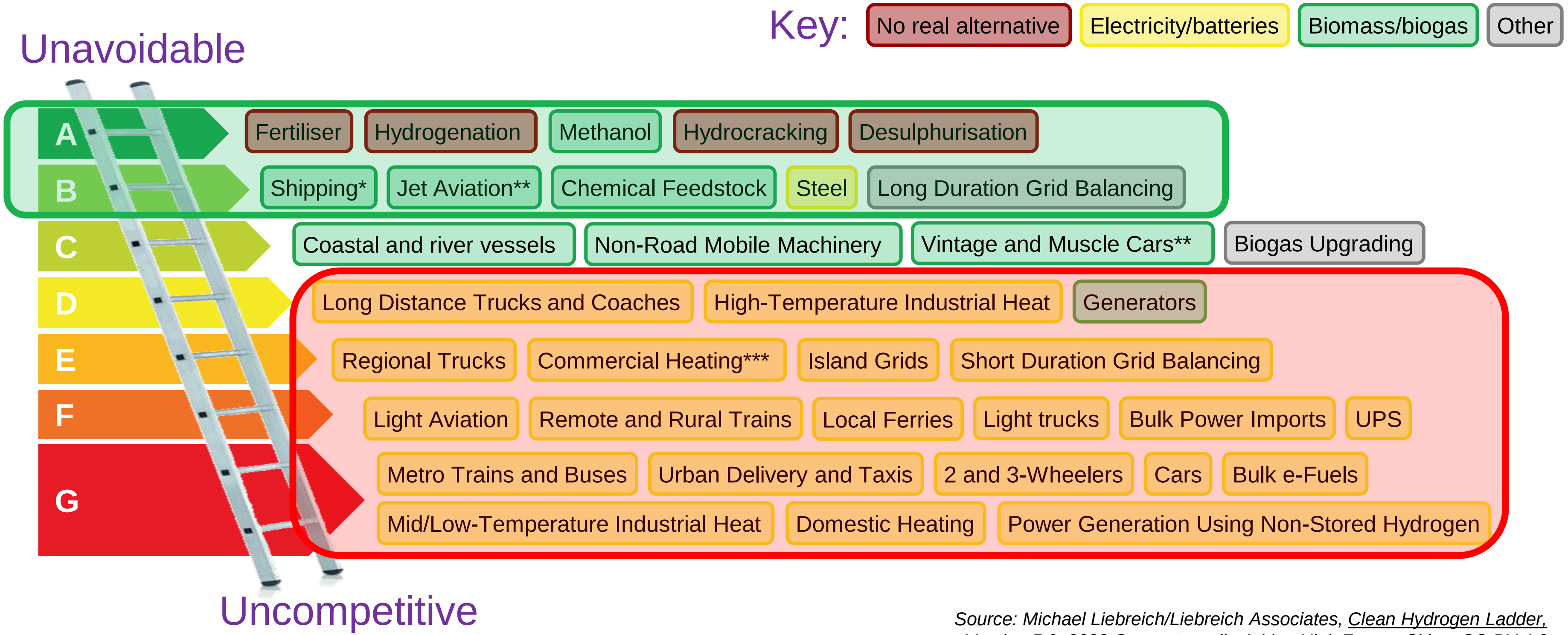


*As ammonia or methanol **As e-fuel or PBTL ***As hybrid system

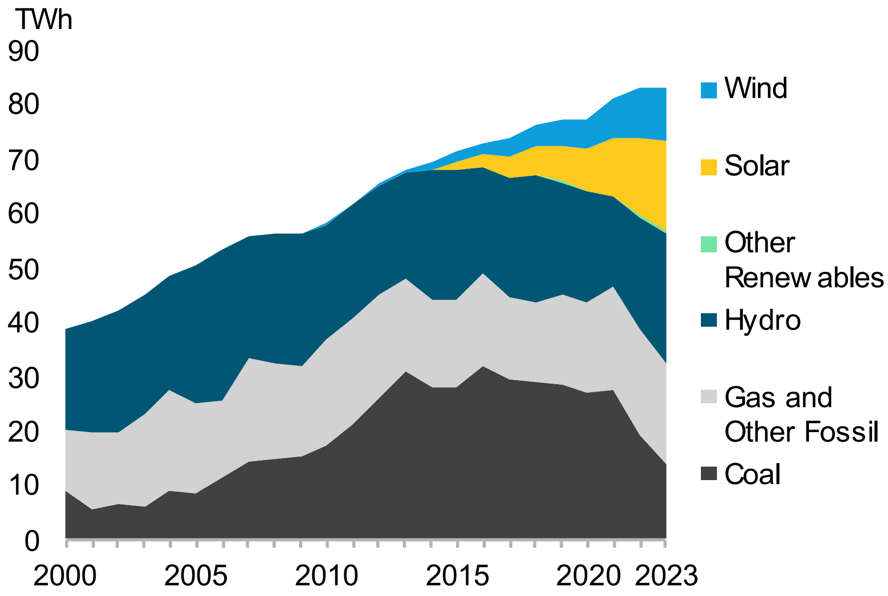
Source: Michael Liebreich/Liebreich Associates, Clean Hydrogen Ladder, Version 5.0, 2023. Concept credit: Adrian Hiel, Energy Cities. CC-BY 4.0

Chile – postcard from the future?

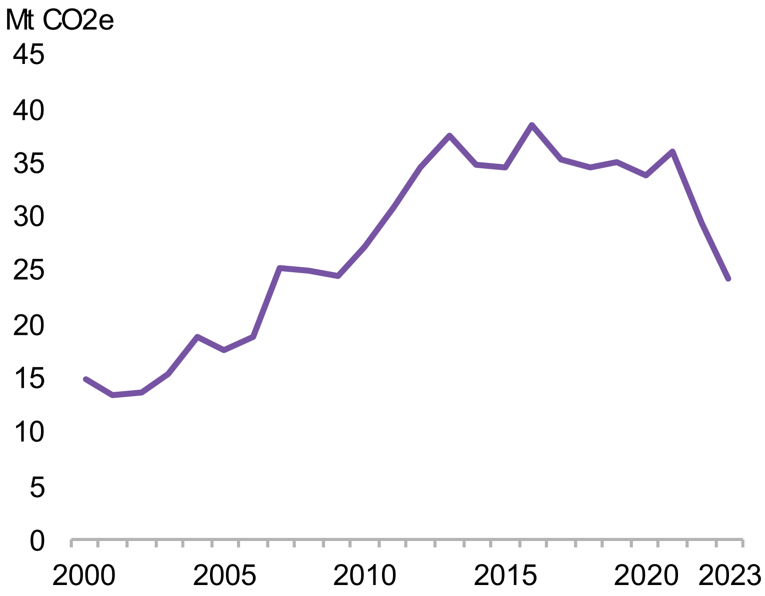
Electricity in Chile 2000-2023

Liebreich Associates

Power mix



Emissions



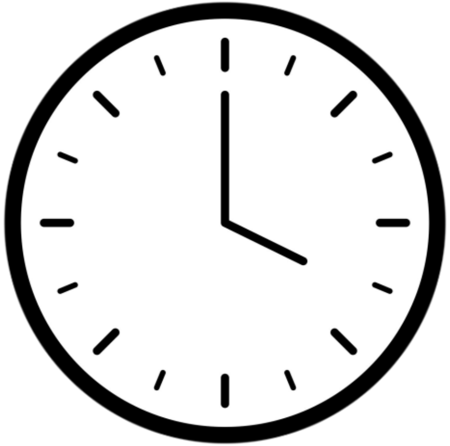
Source: Ember, Liebreich Associates

Three great renewable energy mismatches

Liebreich Associates

Location

Time of day



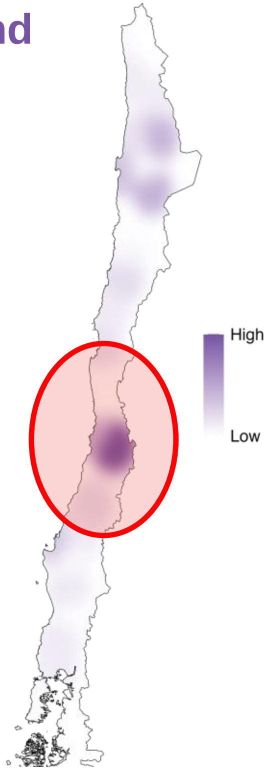
Season

Images: Freepik (juicy_fish, rawpixel.com)

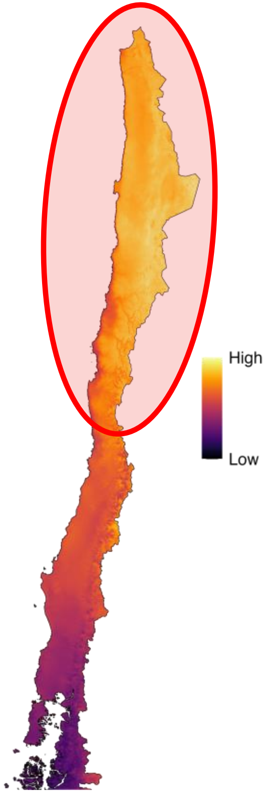
Locational mismatch

Liebreich Associates

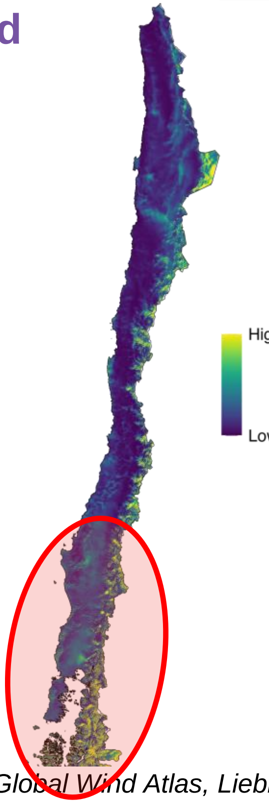
Demand



Solar



Wind



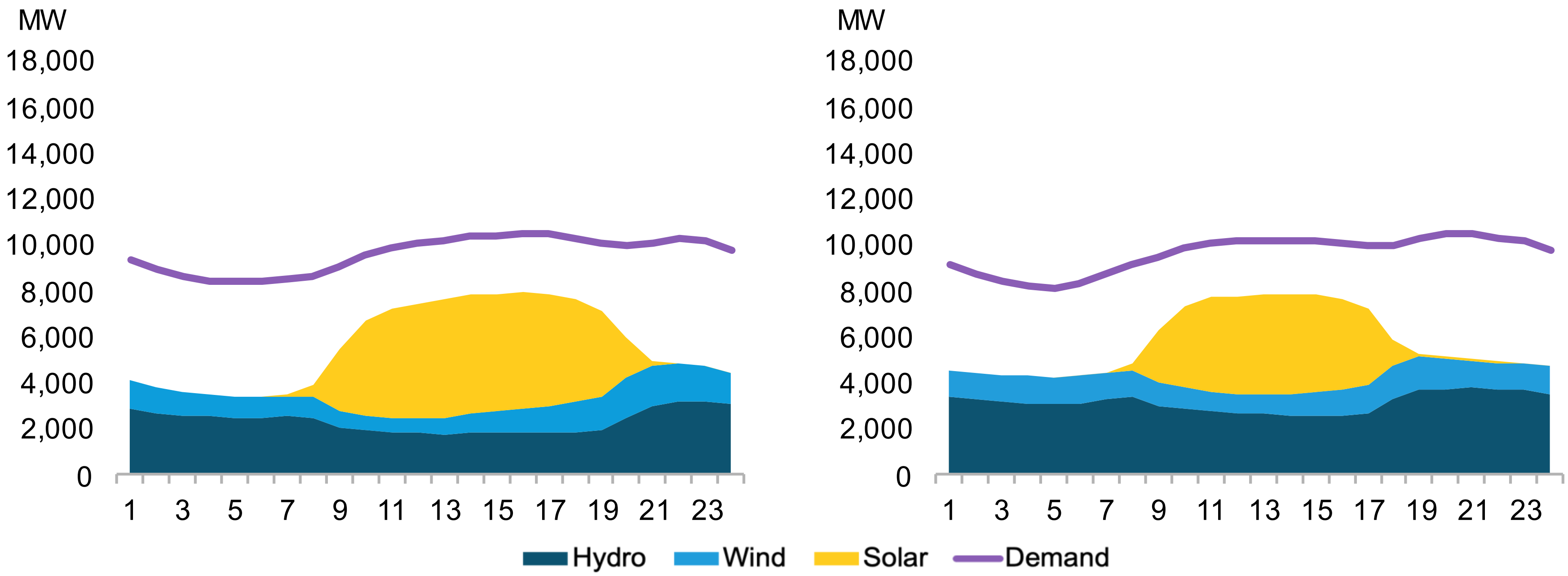
Source: CEN, Global Solar Atlas, Global Wind Atlas, Liebreich Associates

Time of day mismatch

Liebreich Associates

Summer

Winter



Notes: Data is average generation at each hour per season in 2023

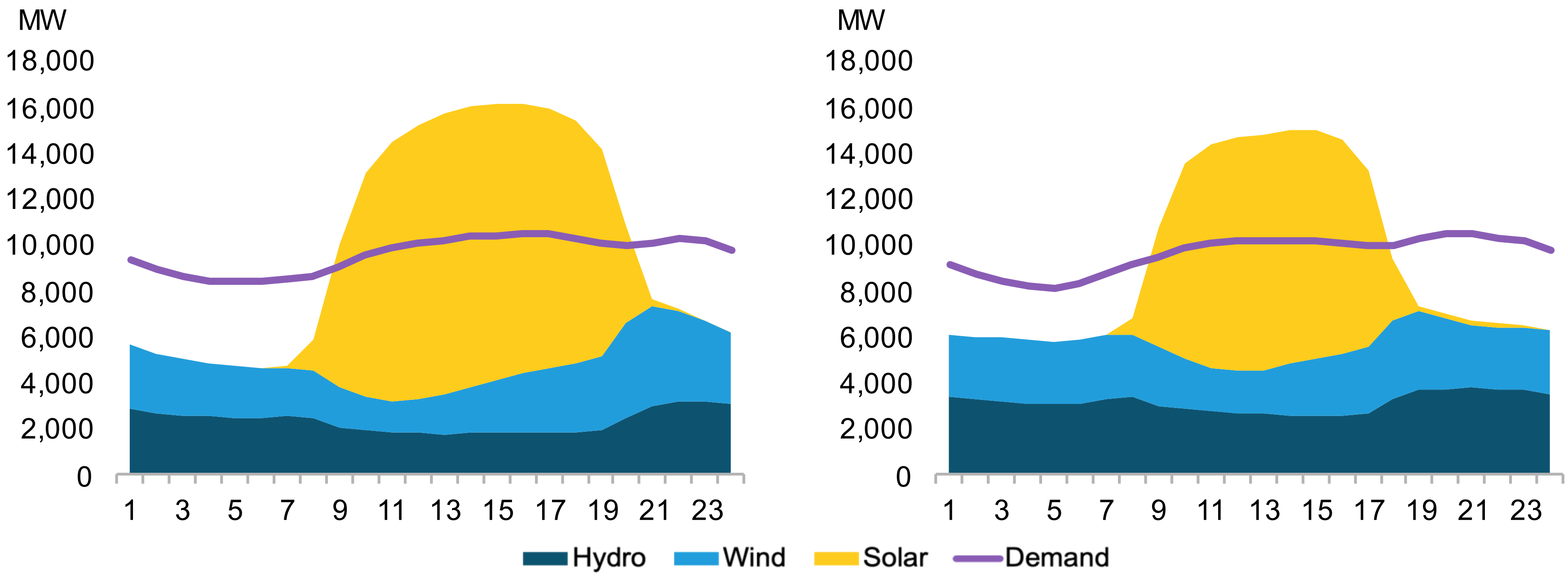
Source: CEN, Liebreich Associates

Time of day mismatch – future

Liebreich
Associates

Summer

Winter

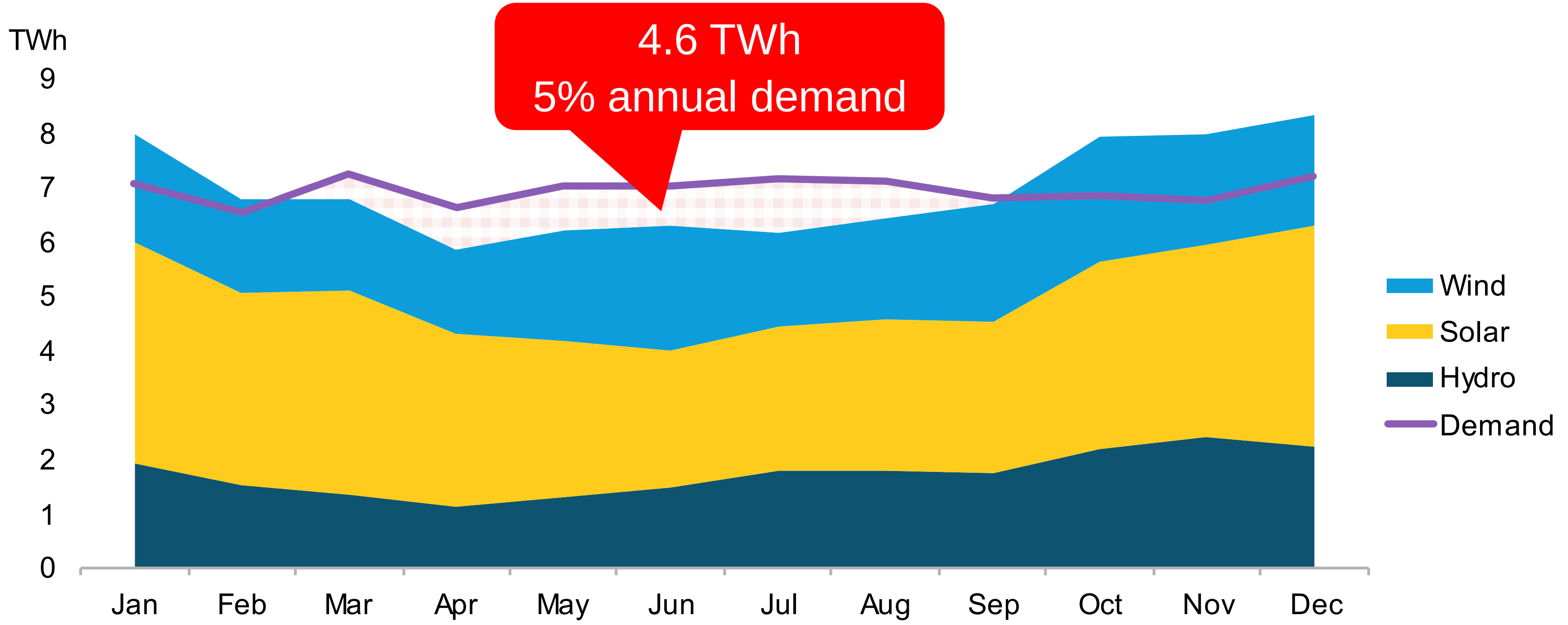


Notes: Wind and solar are scaled up to meet aggregate demand across the year

Source: CEN, Liebreich Associates

Seasonal mismatch

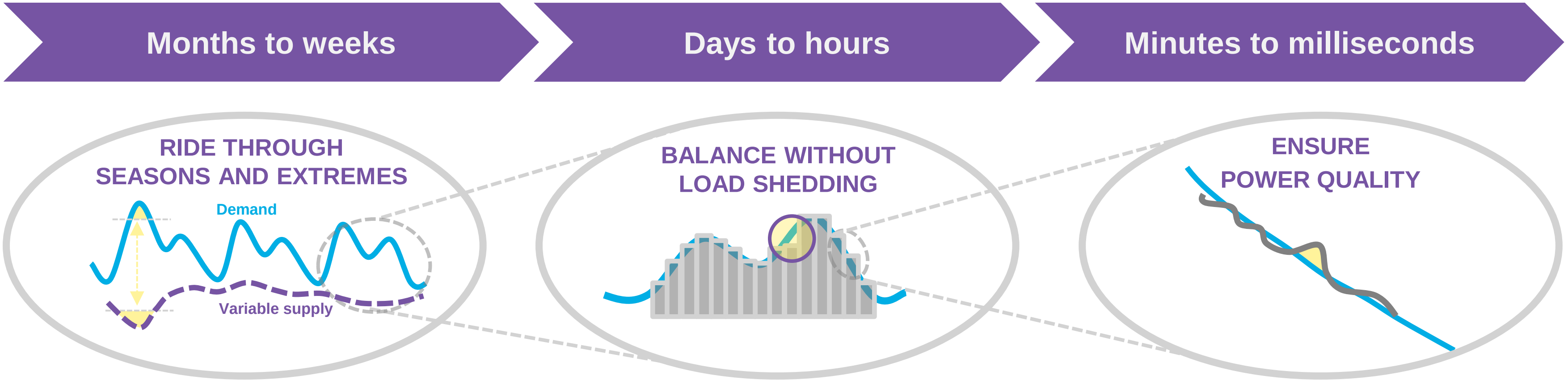
Liebreich Associates



Note: Wind, solar and demand are 2023 data, hydro uses an average of 2016-2023 for a more representative shape. Wind and solar are scaled to meet aggregate demand

Source: Ember, Liebreich Associates

Towards an affordable, resilient, clean grid

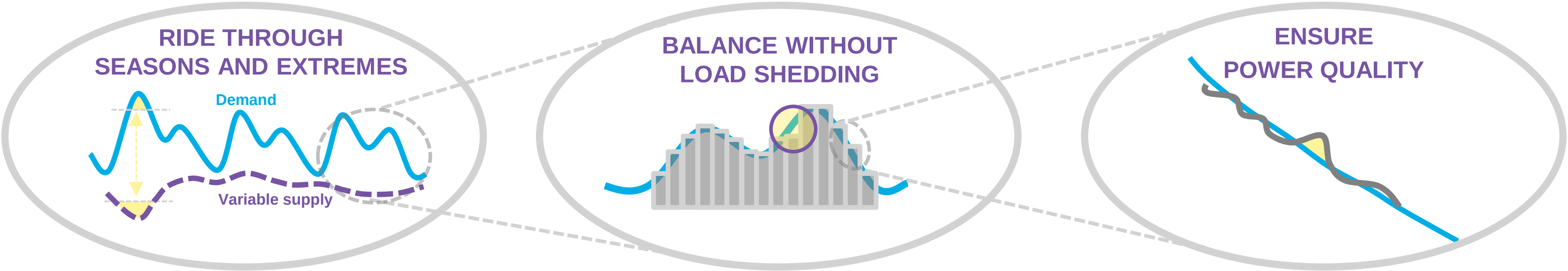


Source: Liebreich Associates

Towards an affordable, resilient, clean grid

Liebreich Associates

Months to weeks | Days to hours | Minutes to milliseconds



Current Plan:

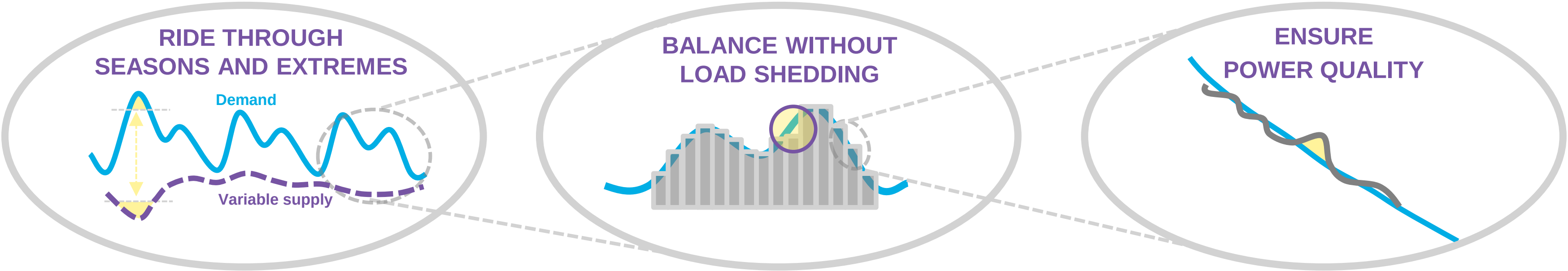
- Over-capacity
- Pumped storage
- Battery storage
- Smart charging
- Demand response

Source: Liebreich Associates

Towards an affordable, resilient, clean grid

Liebreich Associates

Months to weeks | Days to hours | Minutes to milliseconds



Current Plan: Over-capacity | Pumped storage | Battery storage | Smart charging | Demand response

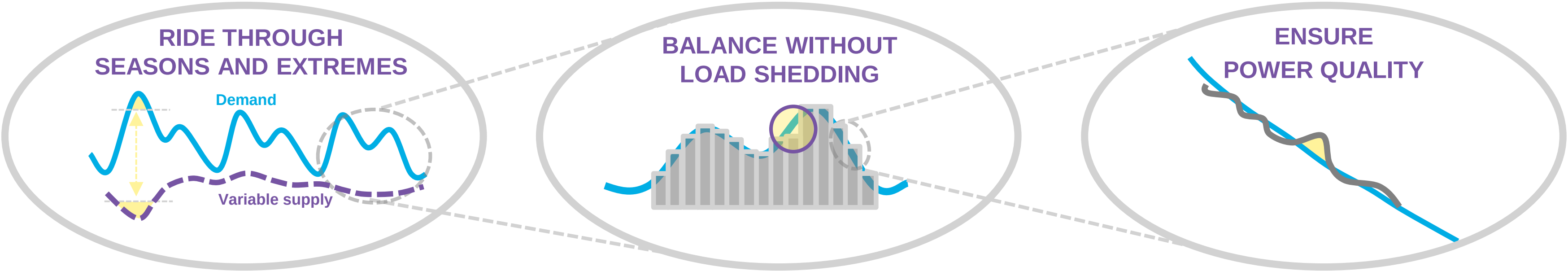
Needed: (Bio)gas peaking plants | Hydrogen, ammonia or methanol storage | Smart electric heat | Synchronous condensers

Source: Liebreich Associates

Towards an affordable, resilient, clean grid

Liebreich Associates

Months to weeks | Days to hours | Minutes to milliseconds



Current Plan: Over-capacity | Pumped storage | Battery storage | Smart charging | Demand response

Needed: (Bio)gas peaking plants | Hydrogen, ammonia or methanol storage | Smart electric heat | Synchronous condensers

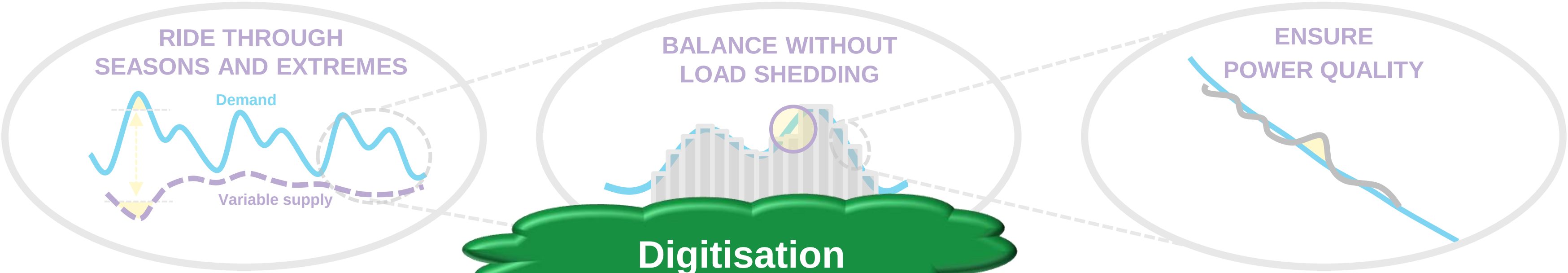
Maybe: Nuclear SMR | Gas with CCS | High-Temp Thermal storage | Advanced geothermal | Flow batteries | Liquid air storage | Vehicle to grid

Source: Liebreich Associates

Towards an affordable, resilient, clean grid

Liebreich Associates

Months to weeks → Days to hours → Minutes to milliseconds



Digitisation

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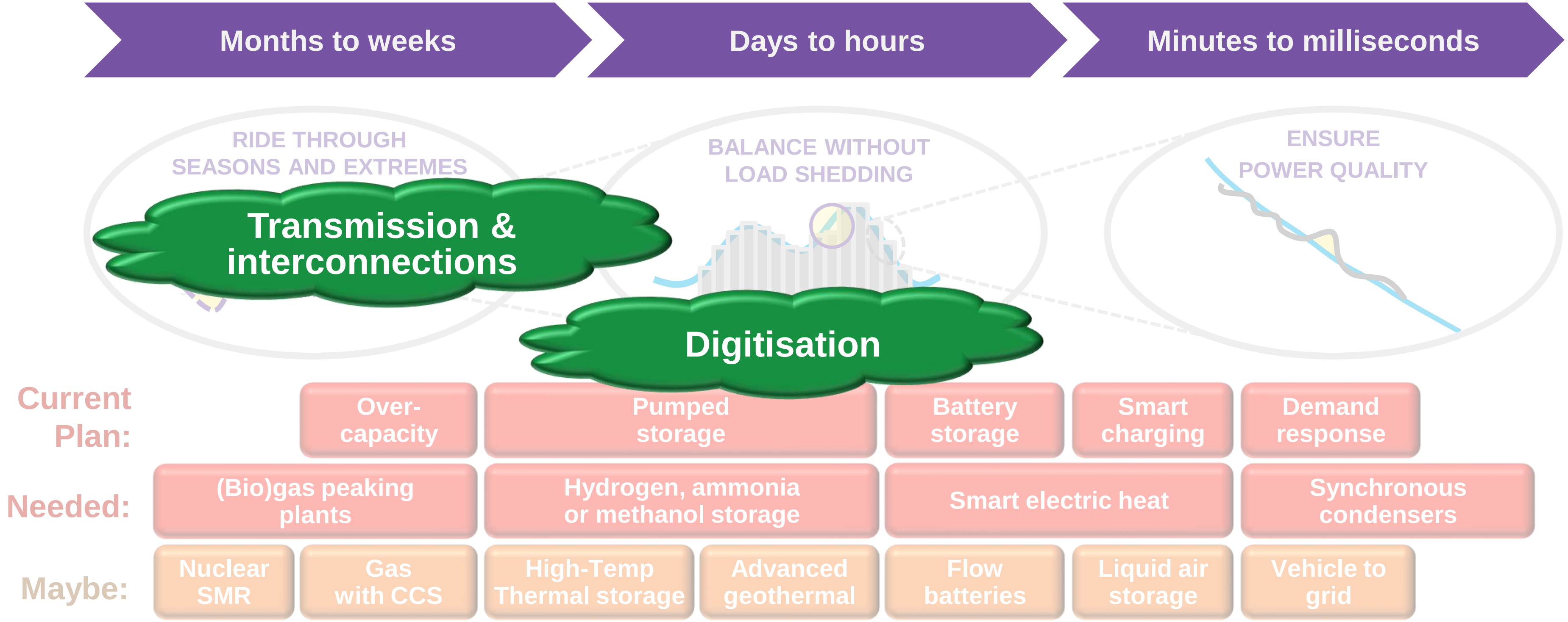
Towards an affordable, resilient, clean grid

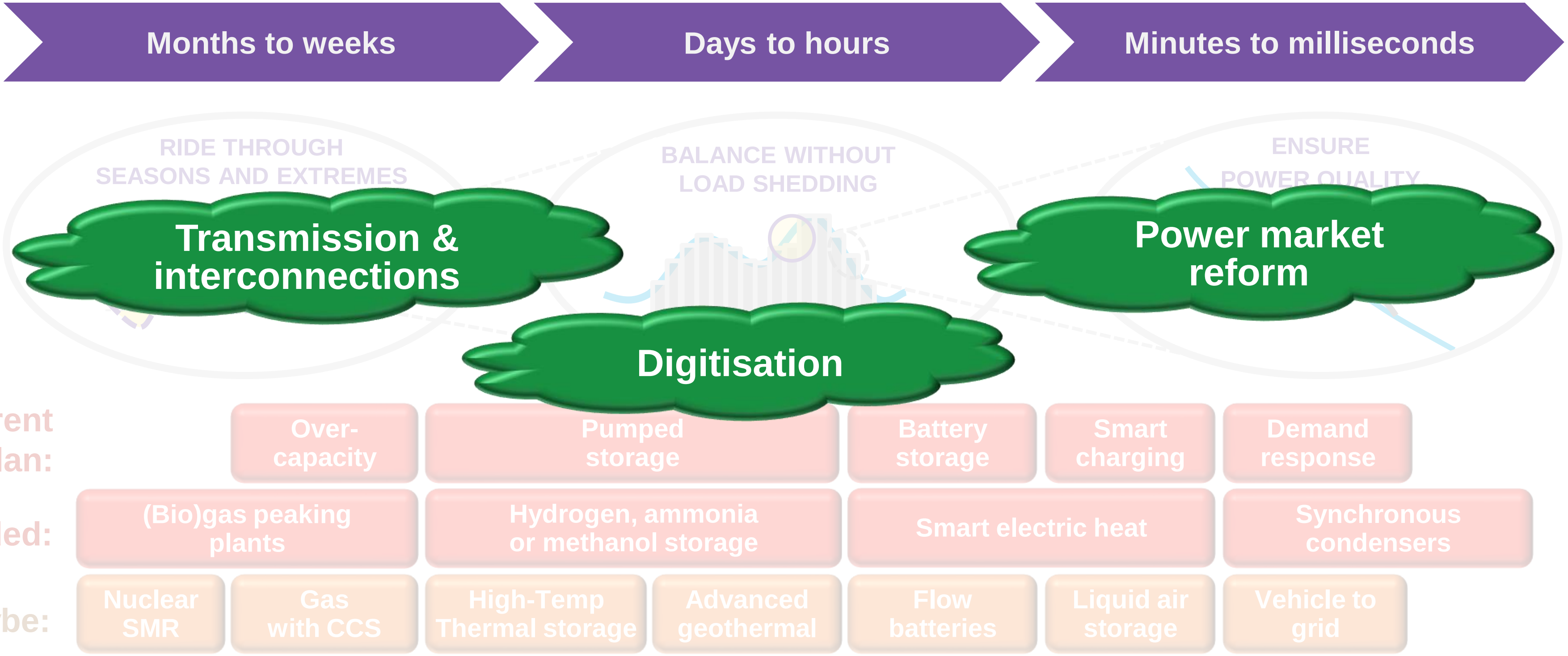
Liebreich Associates



Source: Liebreich Associates

Towards an affordable, resilient, clean grid

Liebreich Associates



Source: Liebreich Associates

Thanks!

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