

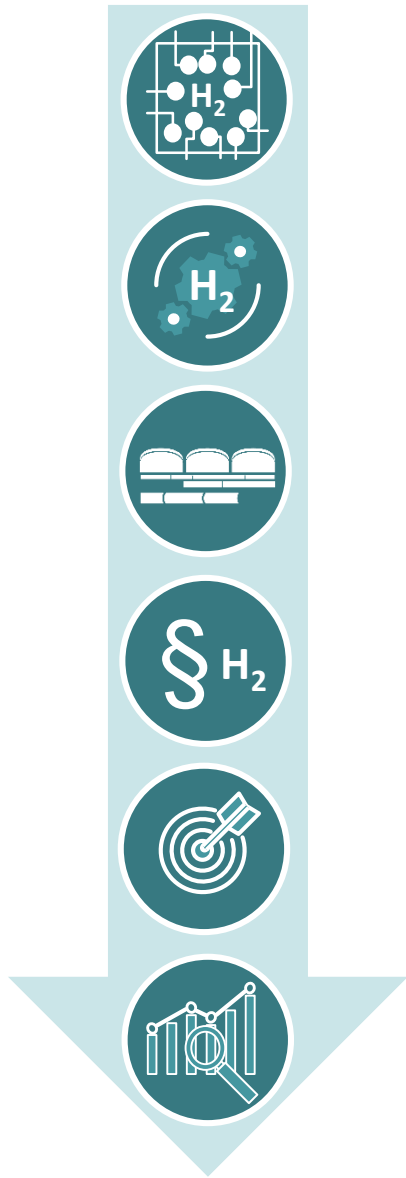


Bogotá
30.09.2022

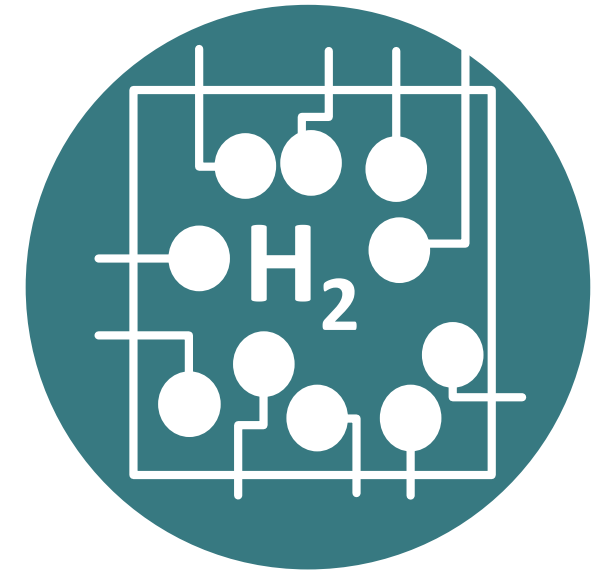
Green Hydrogen

Trends and Development in Germany and the European Union

Lucas Sens, Martin Kaltschmitt



1. Hydrogen in a Green Energy System
2. Hydrogen Applications
3. Hydrogen Infrastructure
4. Regulatory Framework
5. Hydrogen Projects
6. Hydrogen Ramp Up

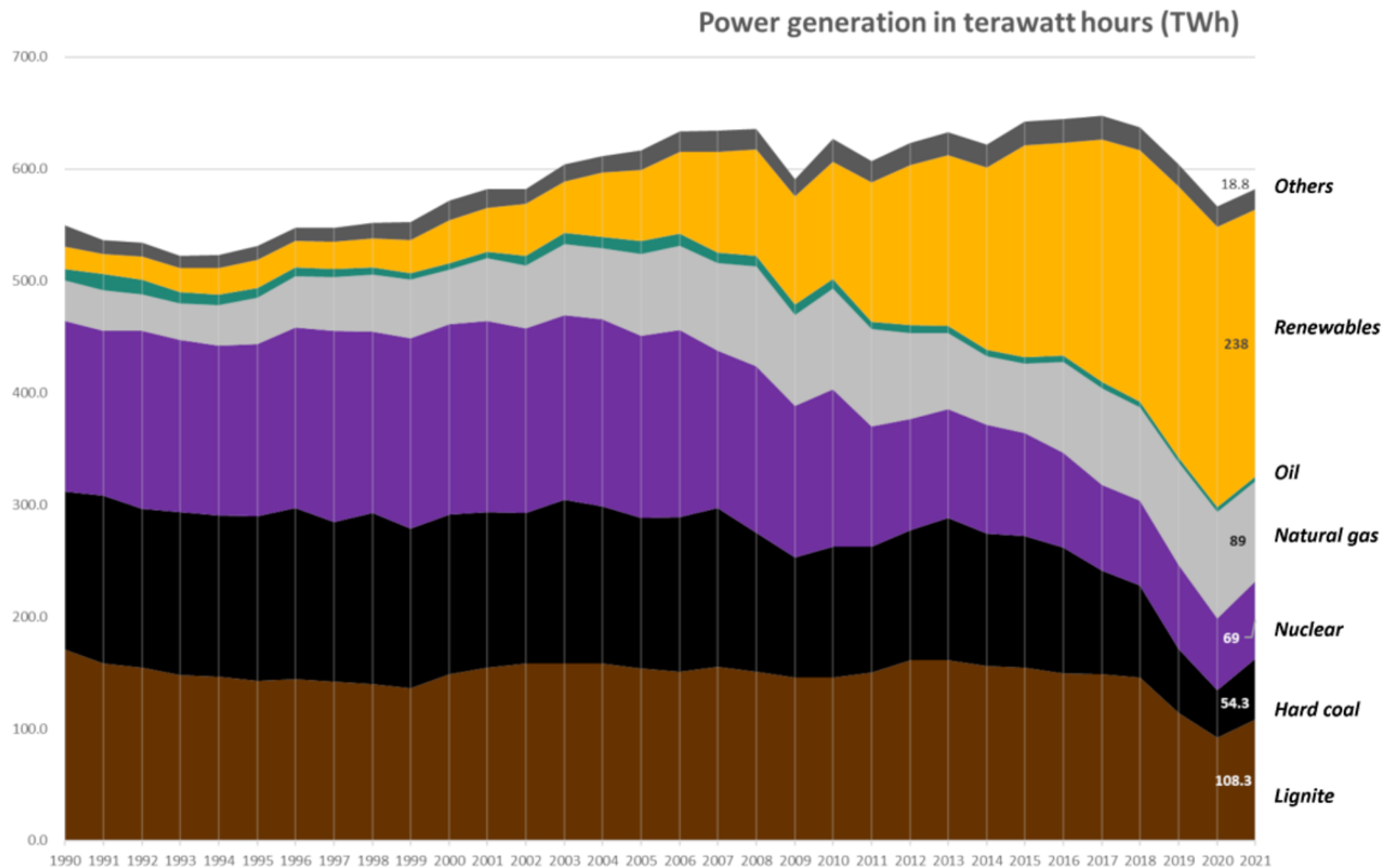


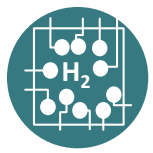
Why do we want green hydrogen?

1. Hydrogen in a Green Energy System

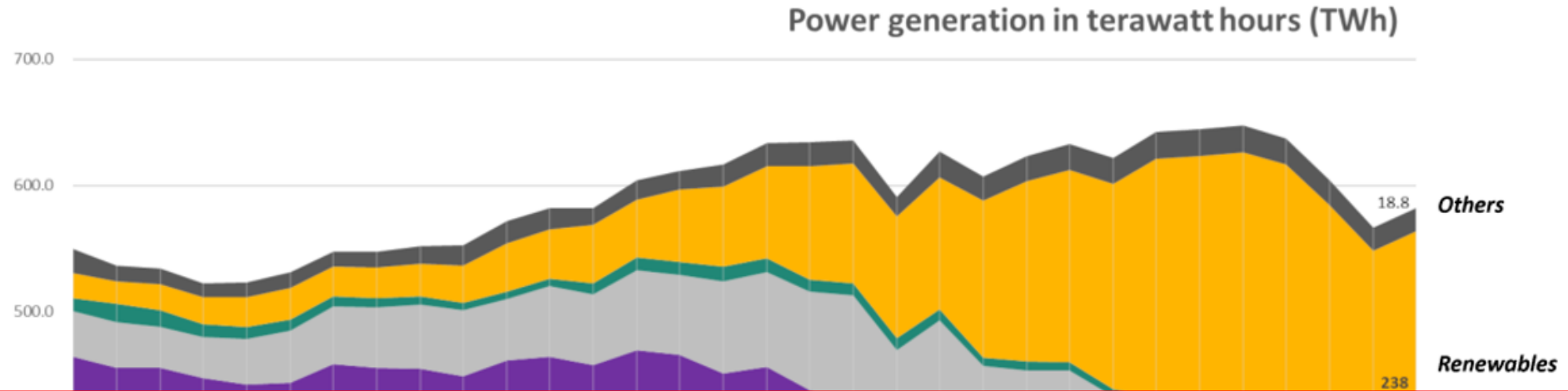


Power Generation in Germany

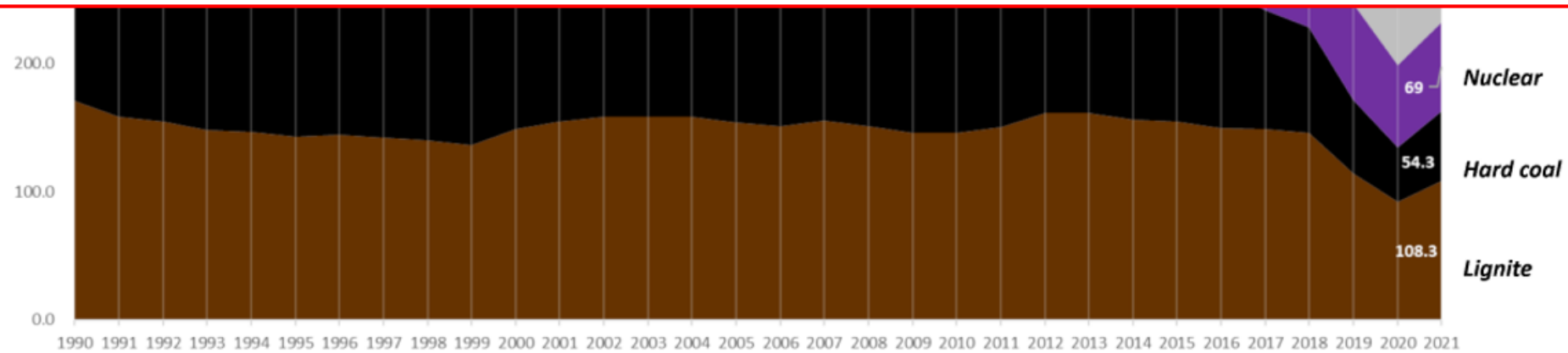


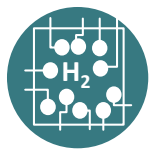


Power Generation in Germany



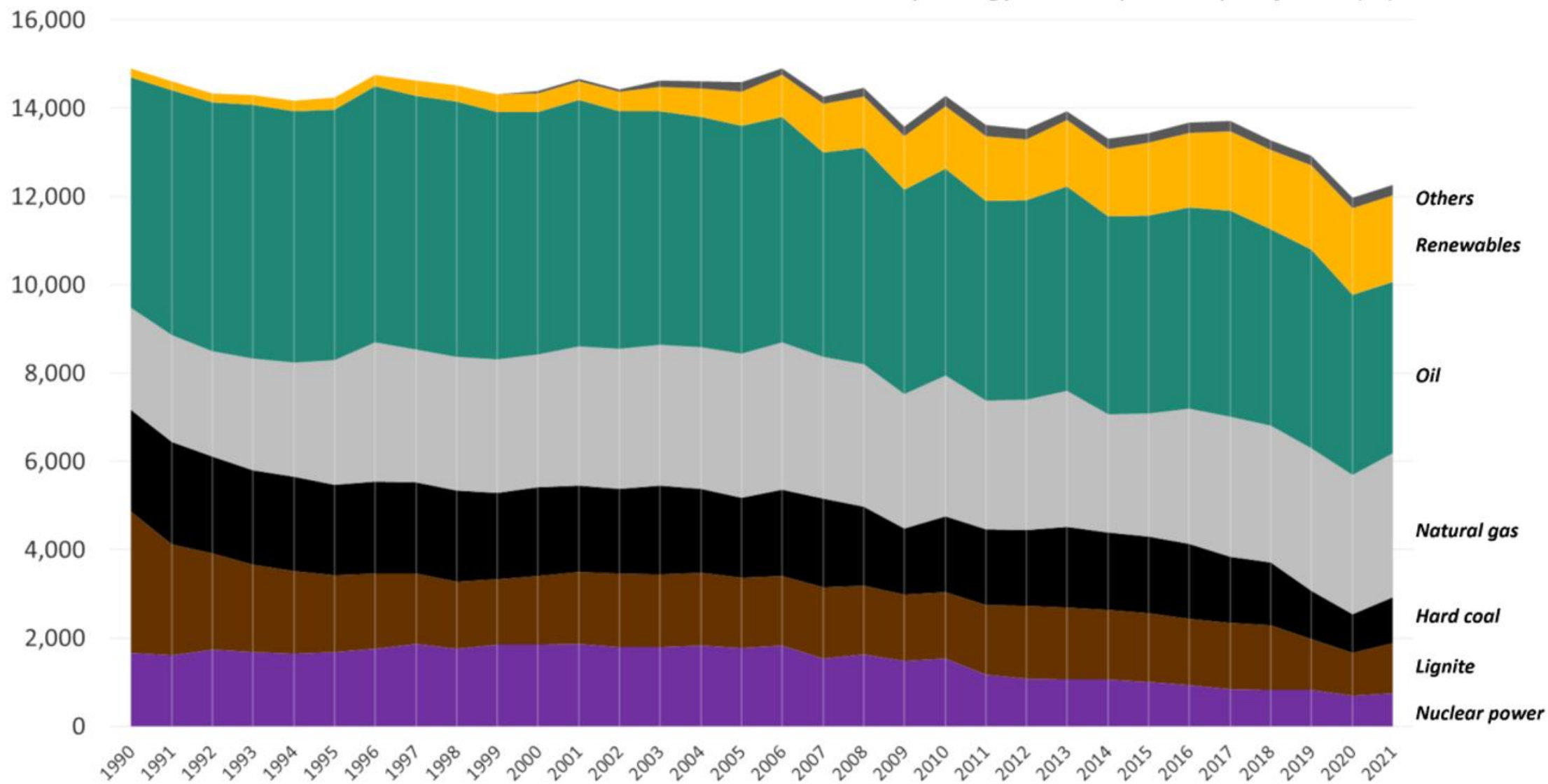
Share of renewable electricity at total power generation increased up to 50% in 2021





Primary Energy Consumption in Germany

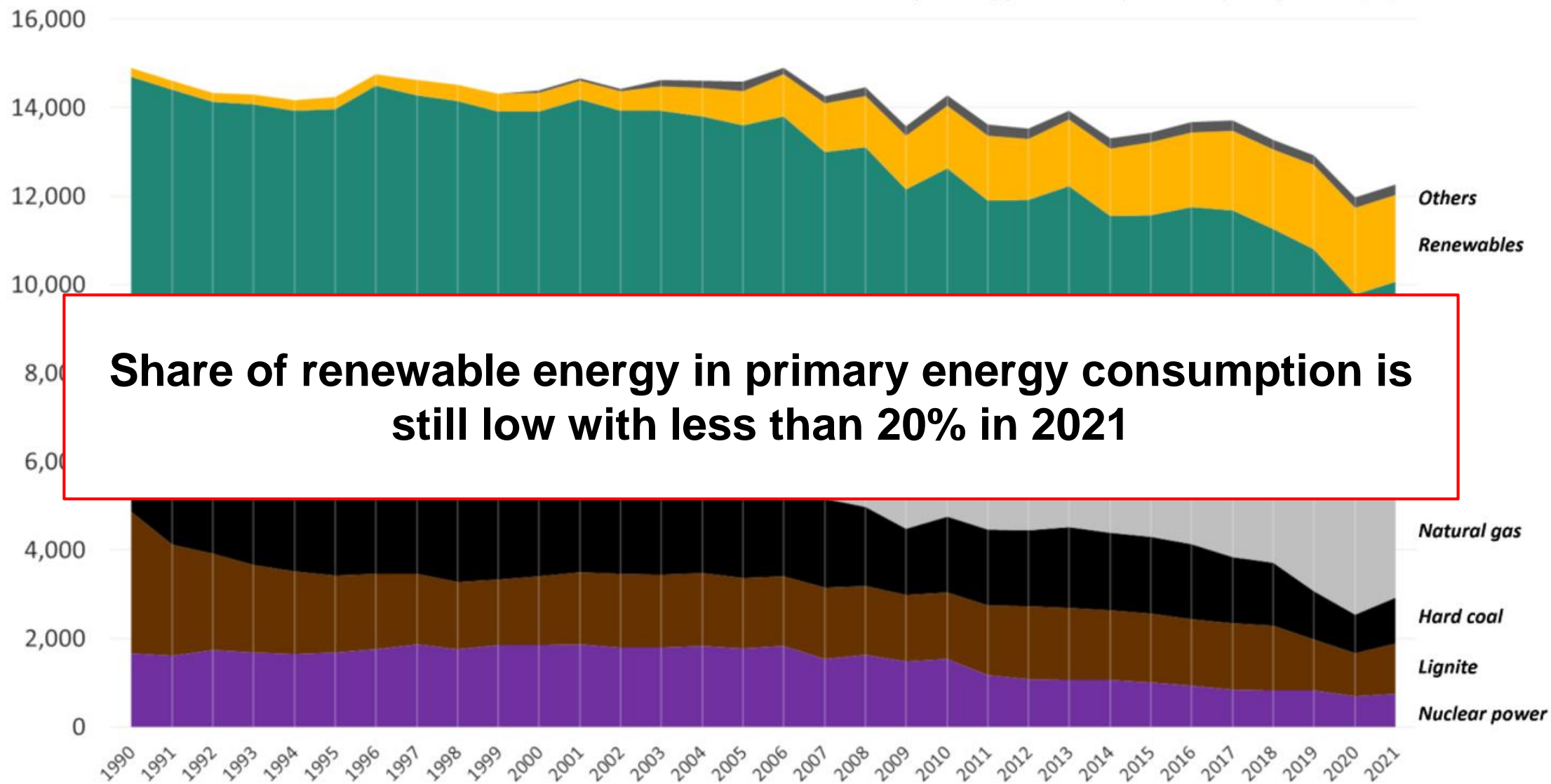
Primary energy consumption in petajoules (PJ)

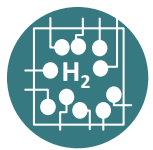




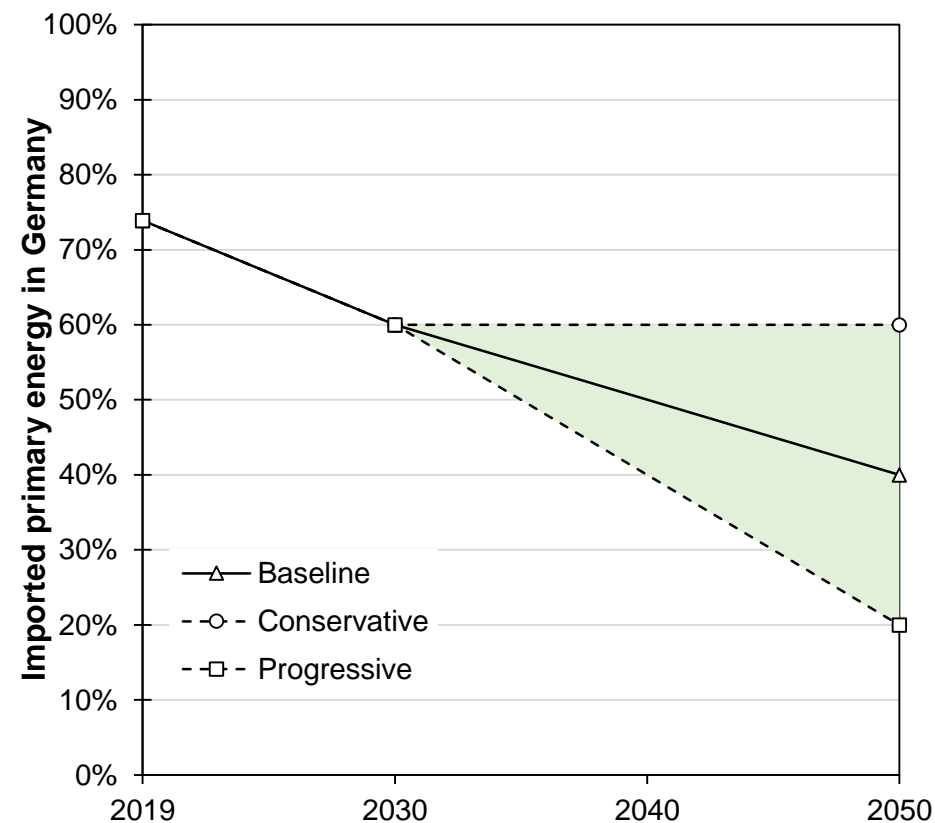
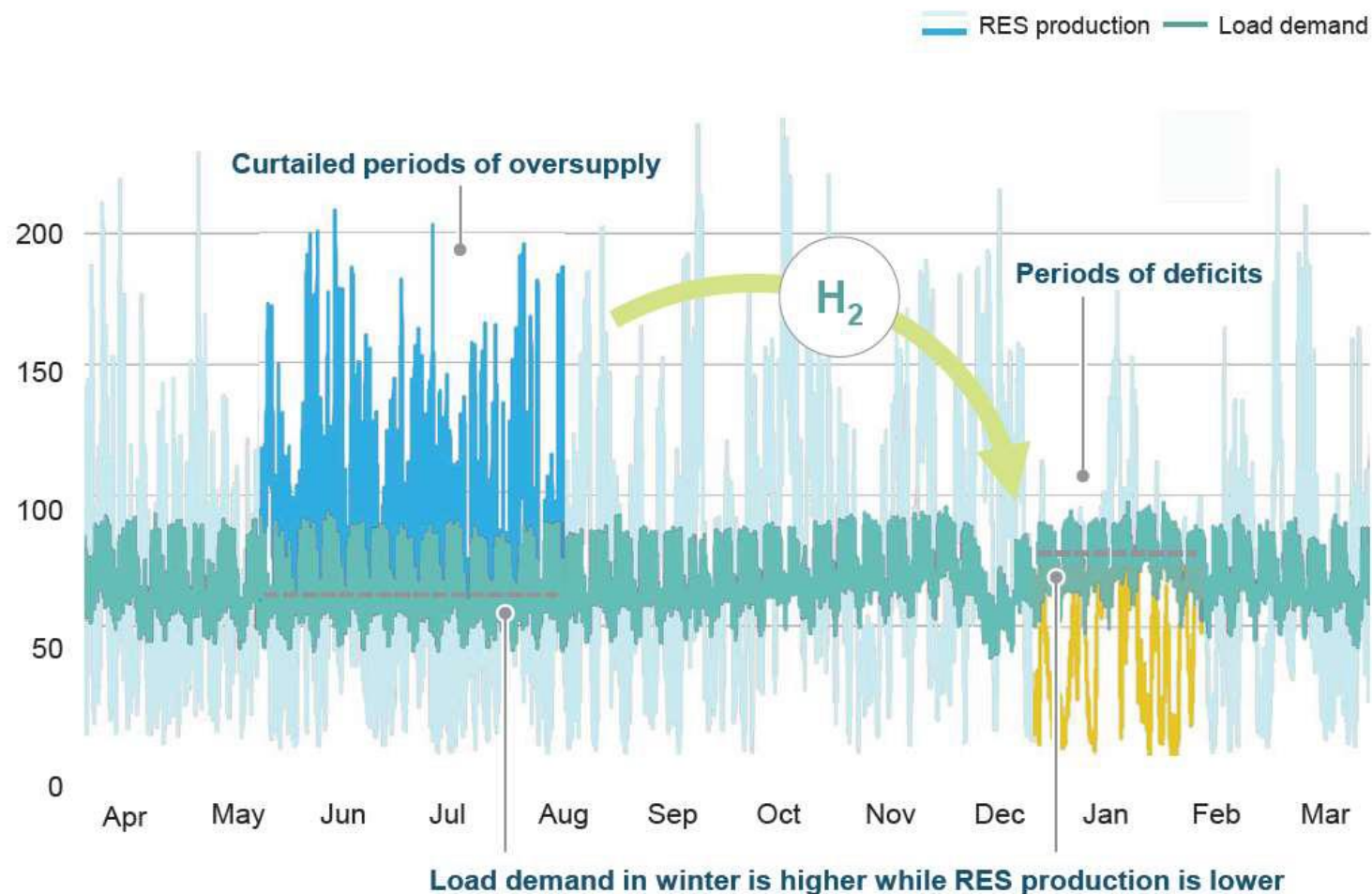
Primary Energy Consumption in Germany

Primary energy consumption in petajoules (PJ)

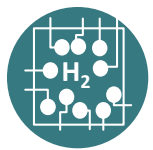




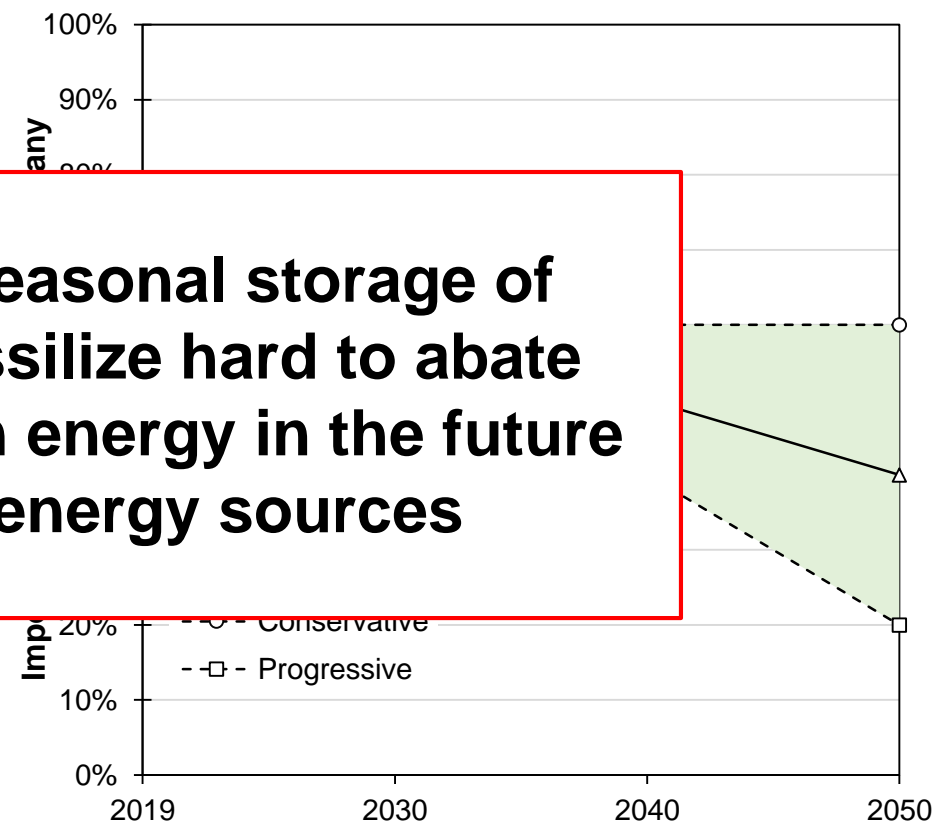
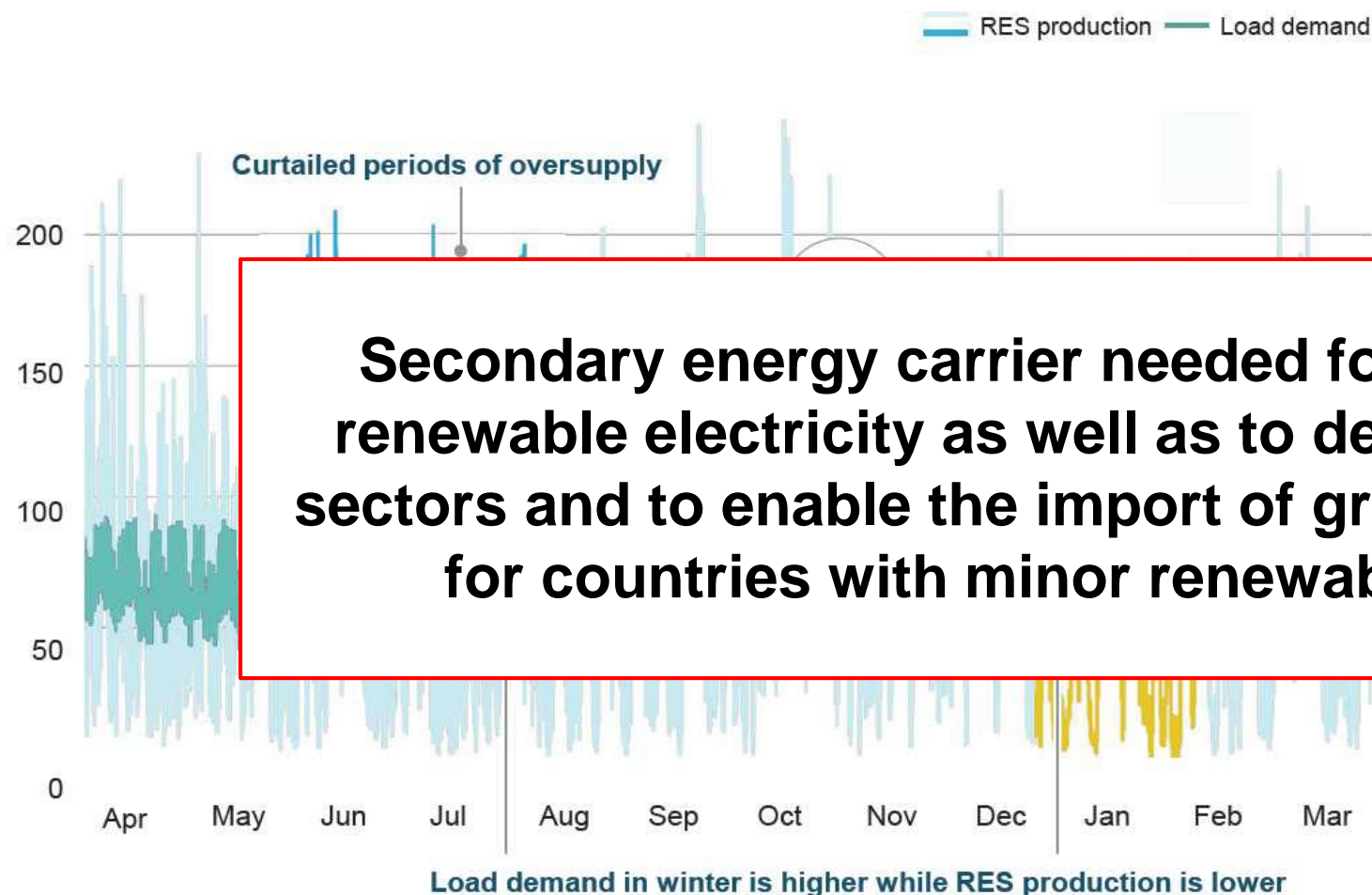
Seasonal Storage and Import Dependency



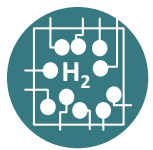
Source: EC 2050 scenario, McKinsey analysis



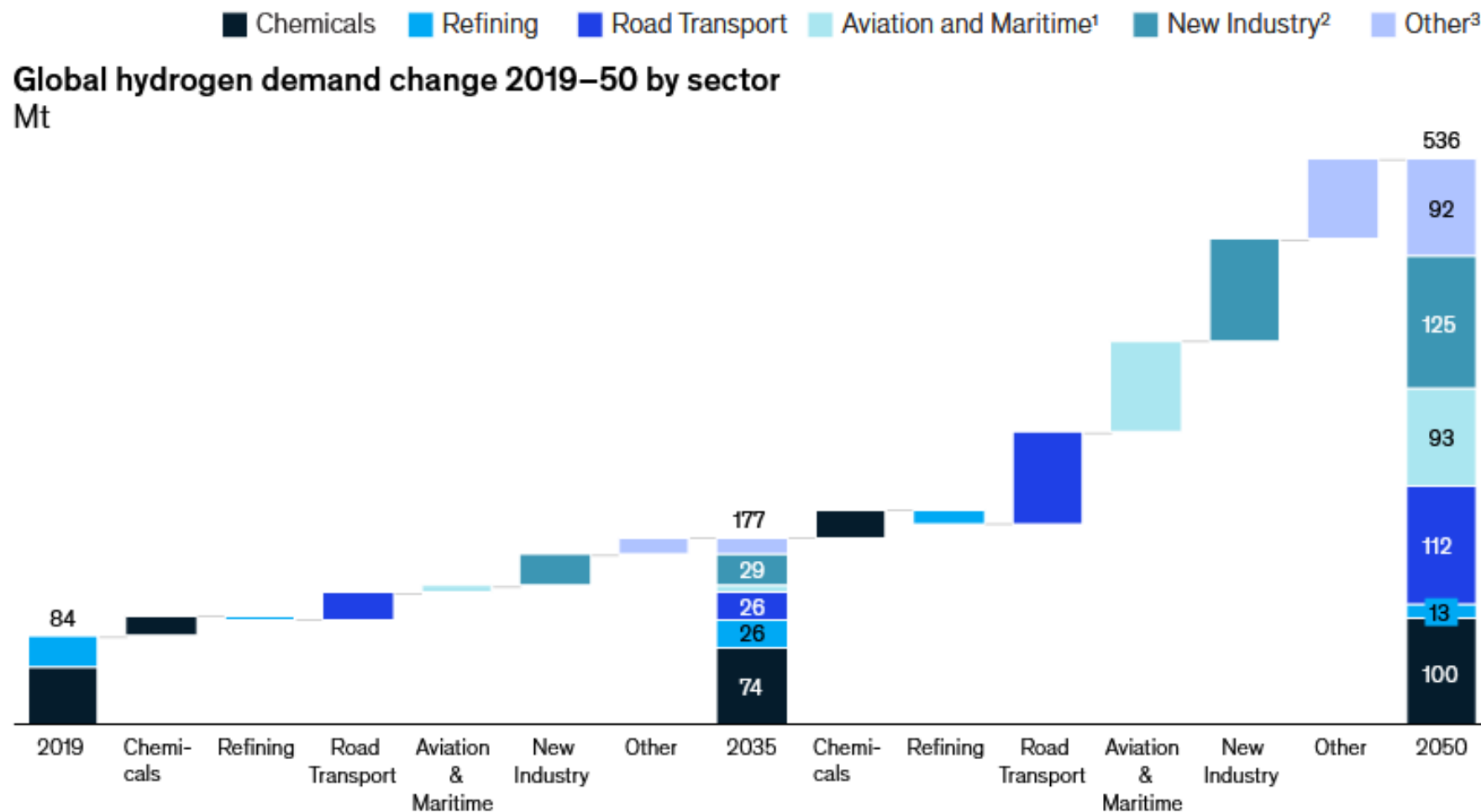
Seasonal Storage and Import Dependency



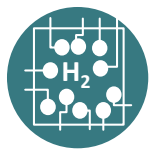
Source: EC 2050 scenario, McKinsey analysis



Hydrogen Demand Projections



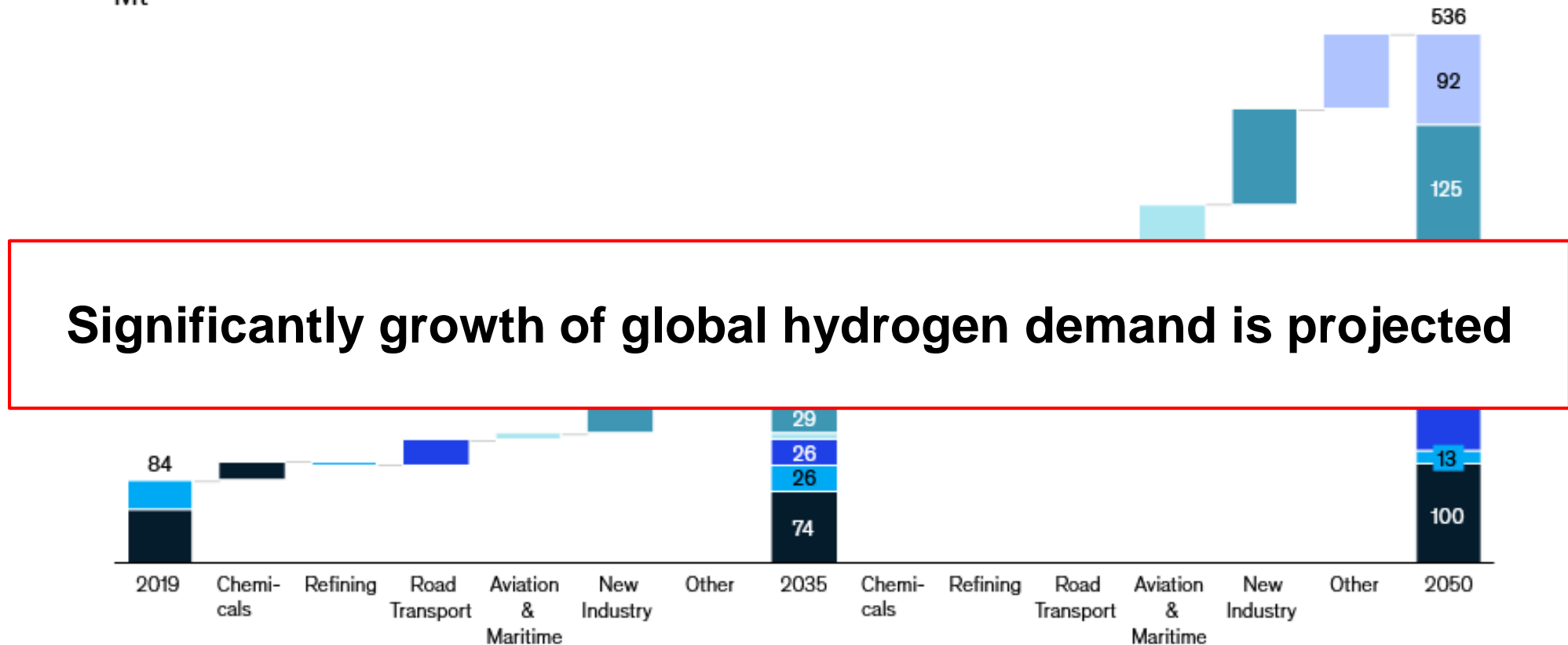
1. Aviation and maritime include direct use of hydrogen and hydrogen-derived syngases including kerosene, diesel, methanol, gasoline, and ammonia. The category also includes some hydrogen-derived syngases in road transport
2. New industry includes all new uses of hydrogen in industrial processes, eg, iron and steel production, whereas chemicals and refining are traditional hydrogen uses
3. Other includes buildings and electricity generation



Hydrogen Demand Projections

■ Chemicals ■ Refining ■ Road Transport ■ Aviation and Maritime¹ ■ New Industry² ■ Other³

Global hydrogen demand change 2019–50 by sector
Mt



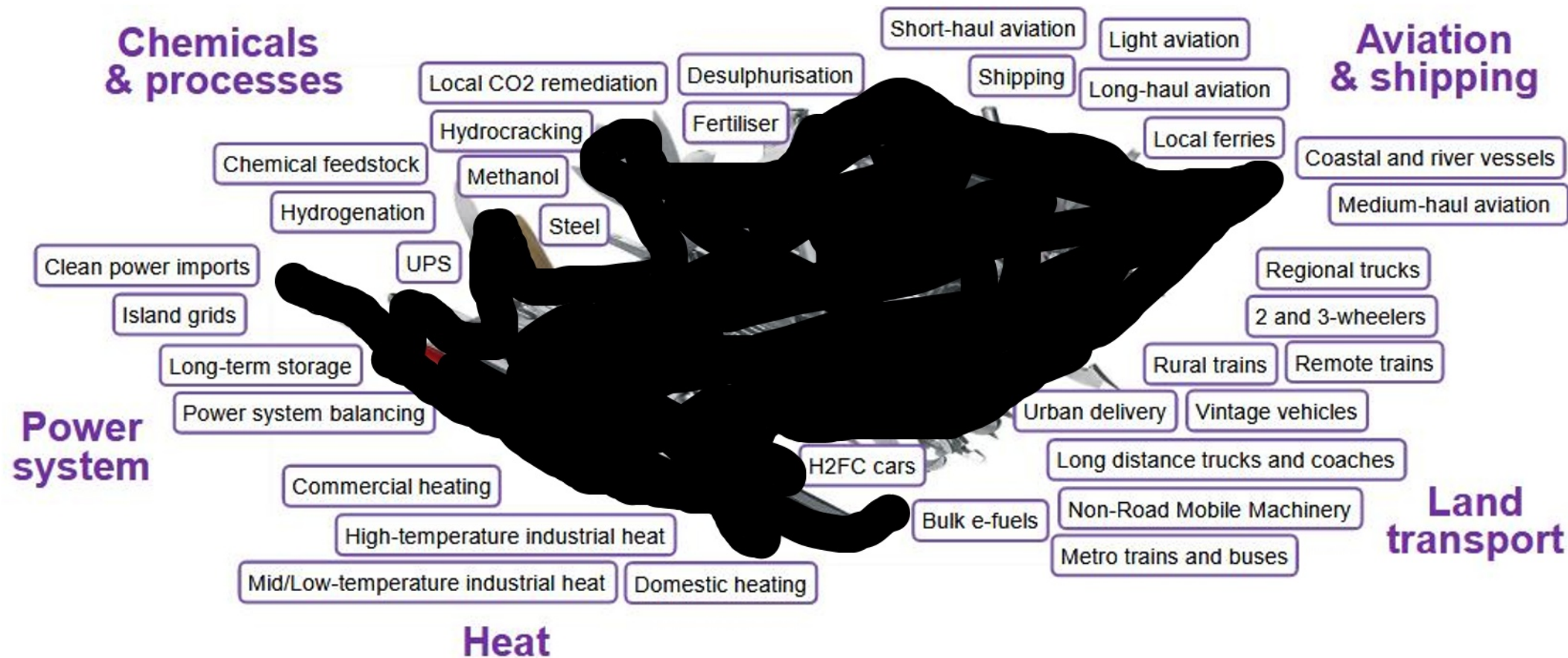
Significantly growth of global hydrogen demand is projected

1. Aviation and maritime include direct use of hydrogen and hydrogen-derived syngases including kerosene, diesel, methanol, gasoline, and ammonia. The category also includes some hydrogen-derived syngases in road transport
2. New industry includes all new uses of hydrogen in industrial processes, eg, iron and steel production, whereas chemicals and refining are traditional hydrogen uses
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Is hydrogen the Swiss-Knife for the energy transition?

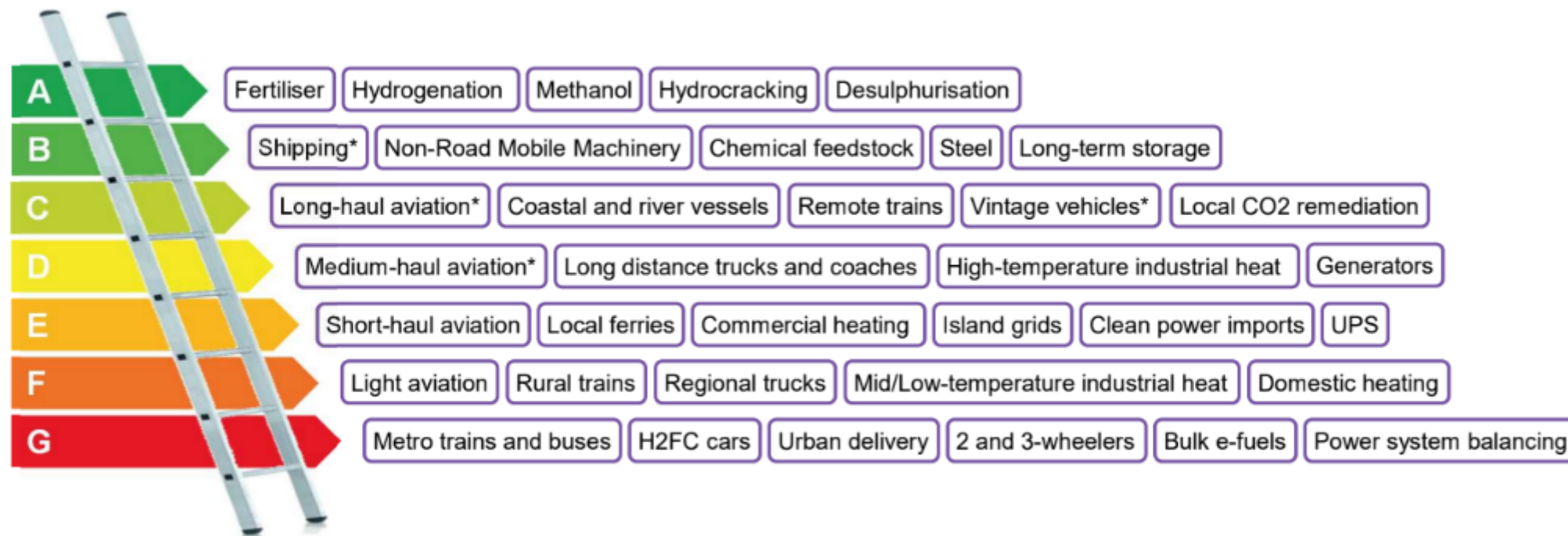
2. Hydrogen Applications



Green hydrogen has multiple cross sector application options



Unavoidable



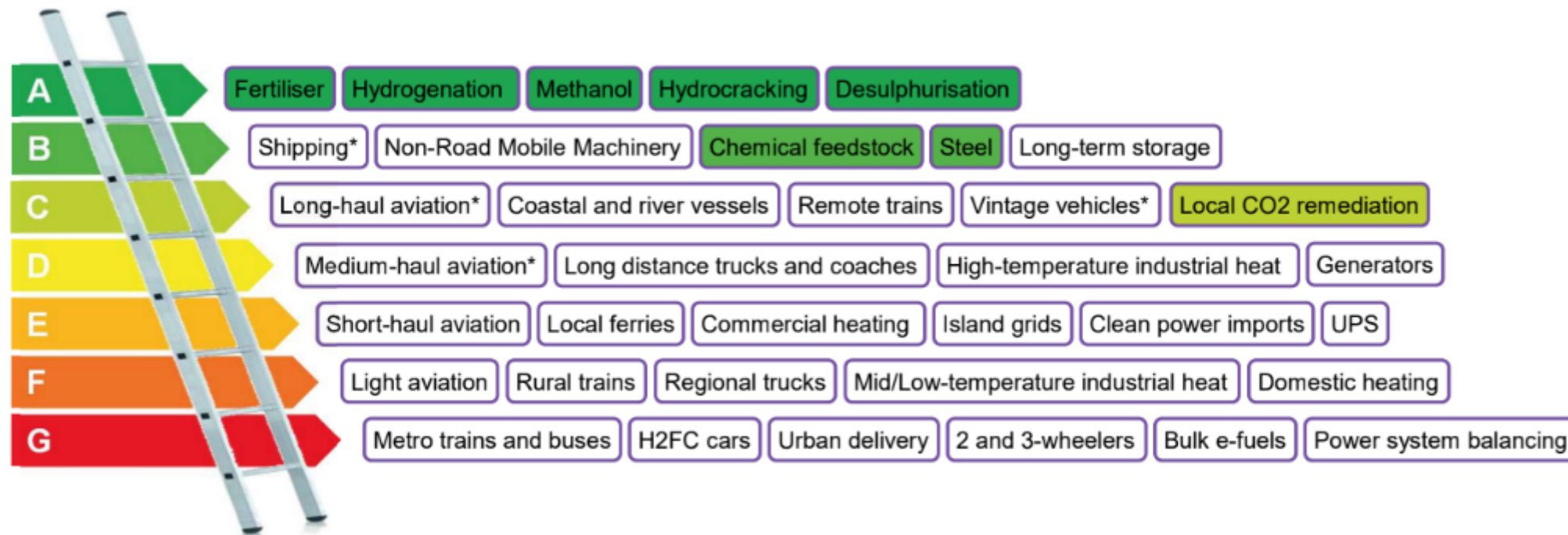
High competition

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



Green Hydrogen Ladder¹: Chemicals and Processes

Unavoidable



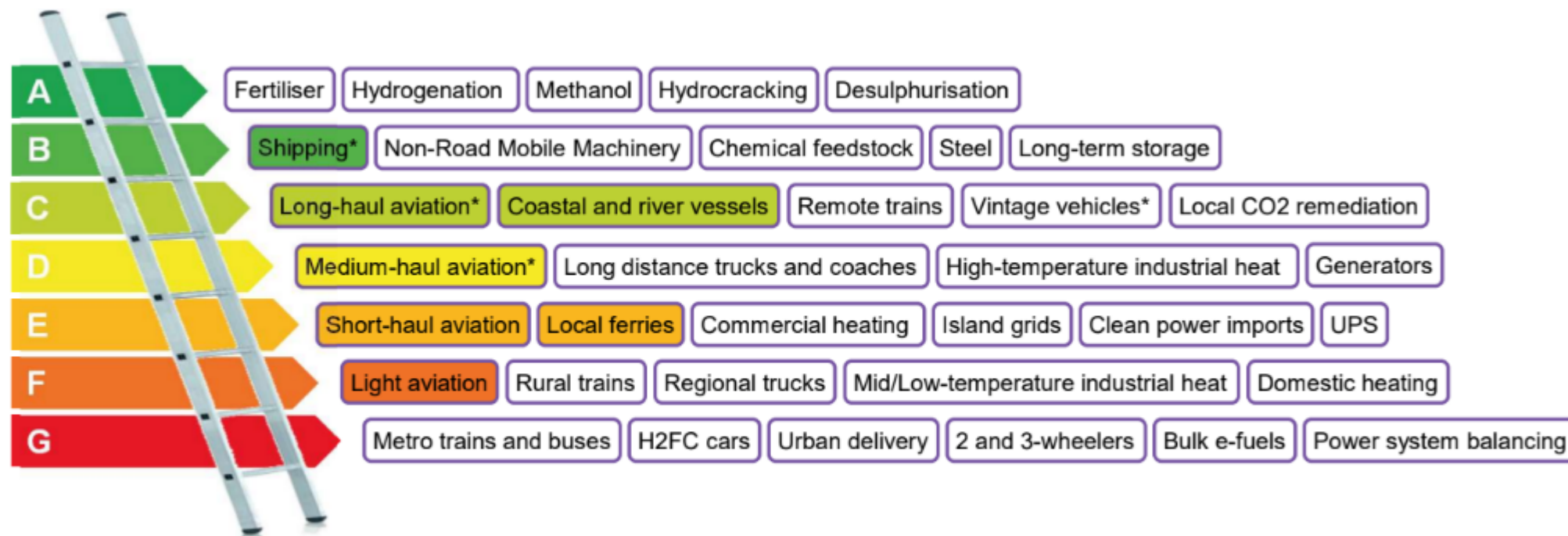
High competition

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



Green Hydrogen Ladder¹: Aviation and Shipping

Unavoidable



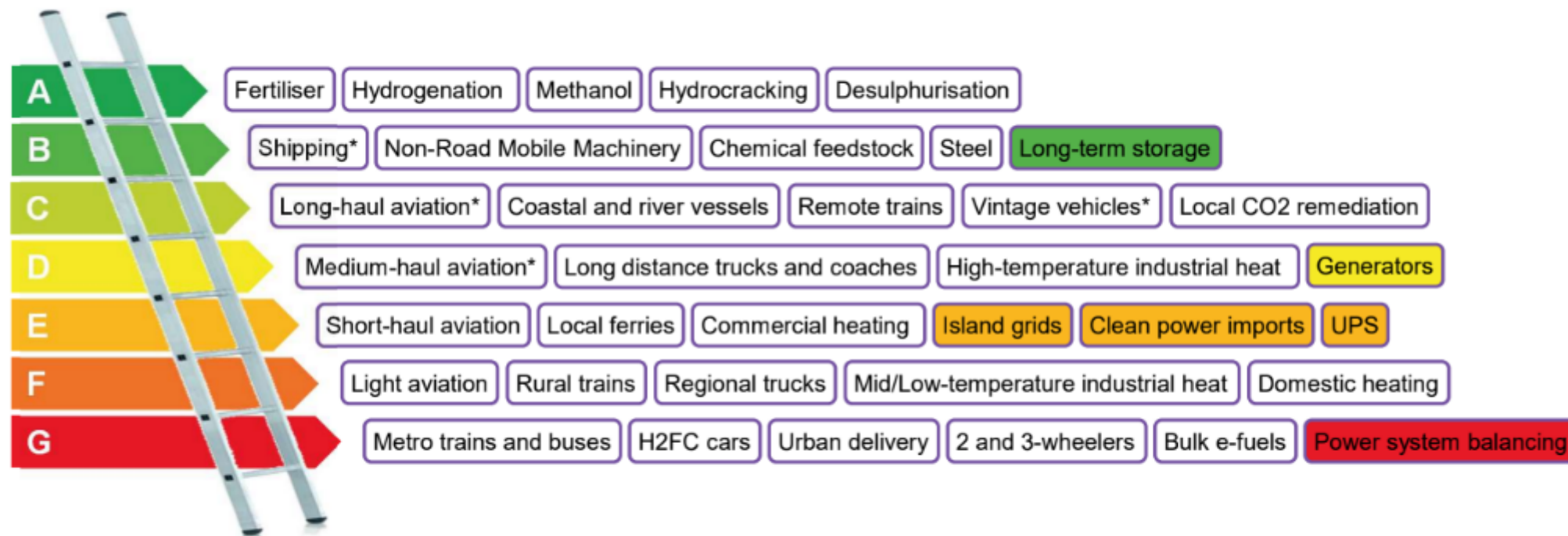
High competition

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



Green Hydrogen Ladder¹: Power System

Unavoidable



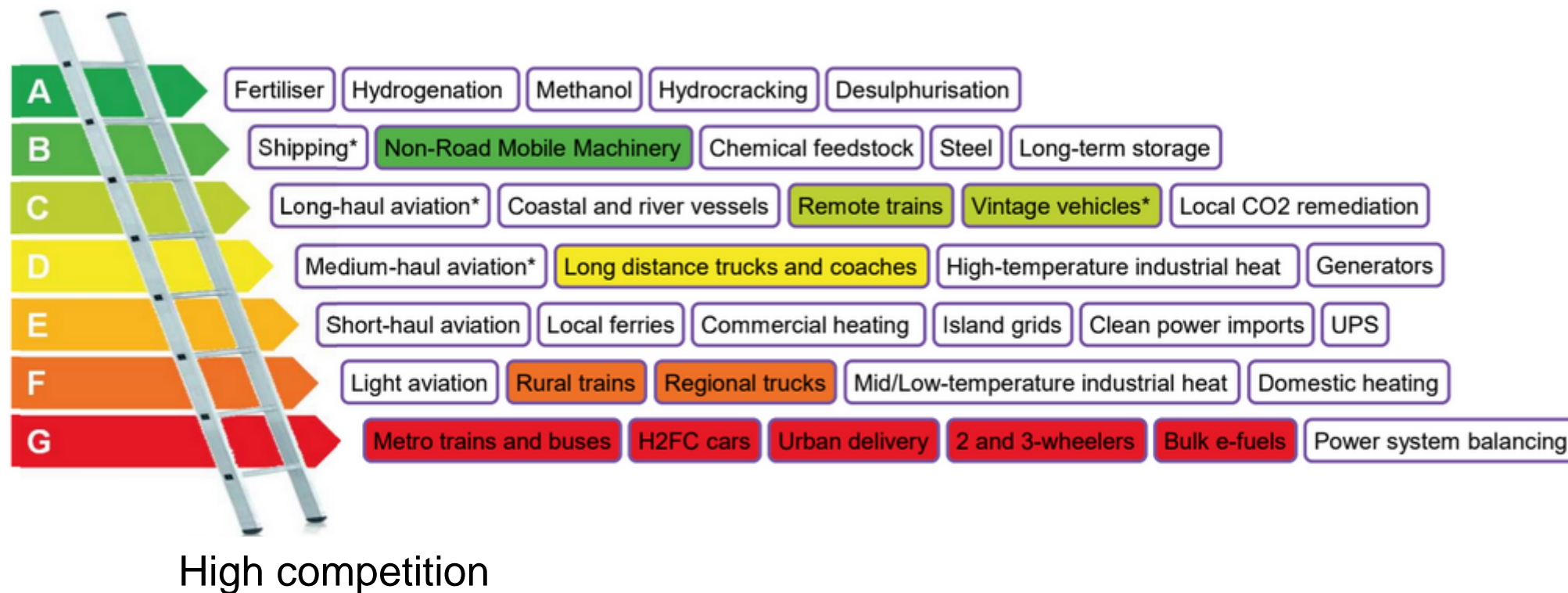
High competition

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



Green Hydrogen Ladder¹: Land Transportation

Unavoidable



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

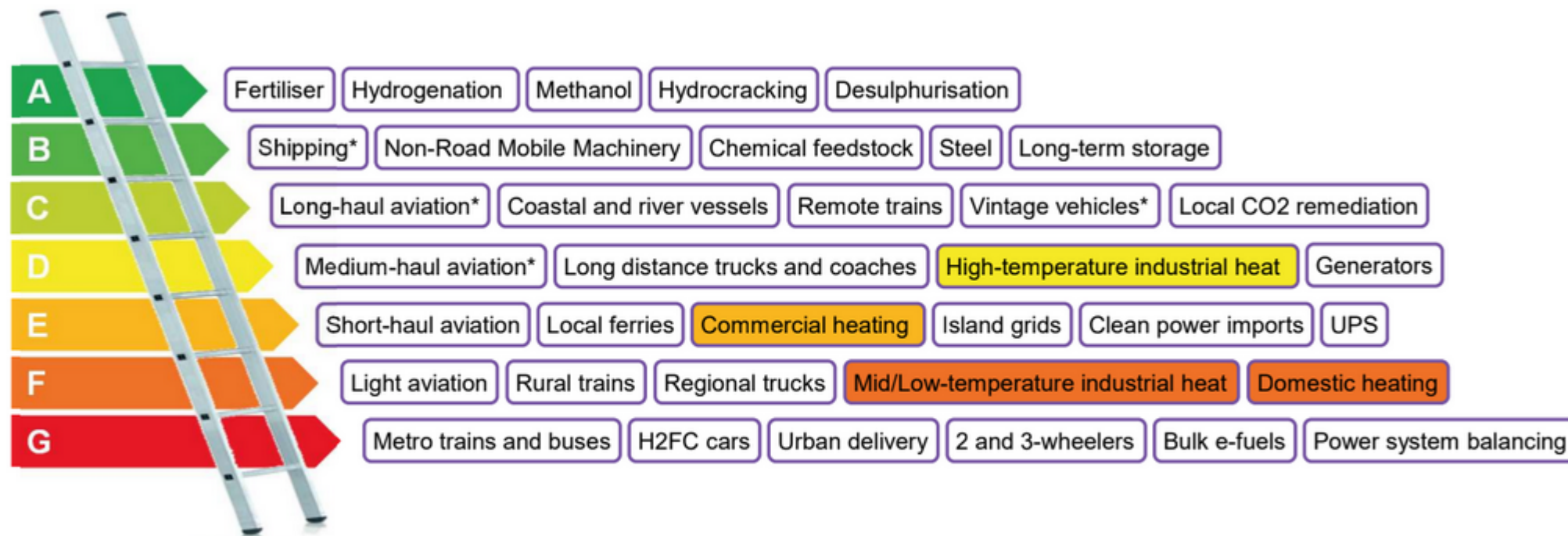


Due to very different conditions in Colombia than in Germany/EU (electricity grid, regulations, transport distances) the role of hydrogen in land transportation in Colombia is probably more important



Green Hydrogen Ladder¹: Heating

Unavoidable

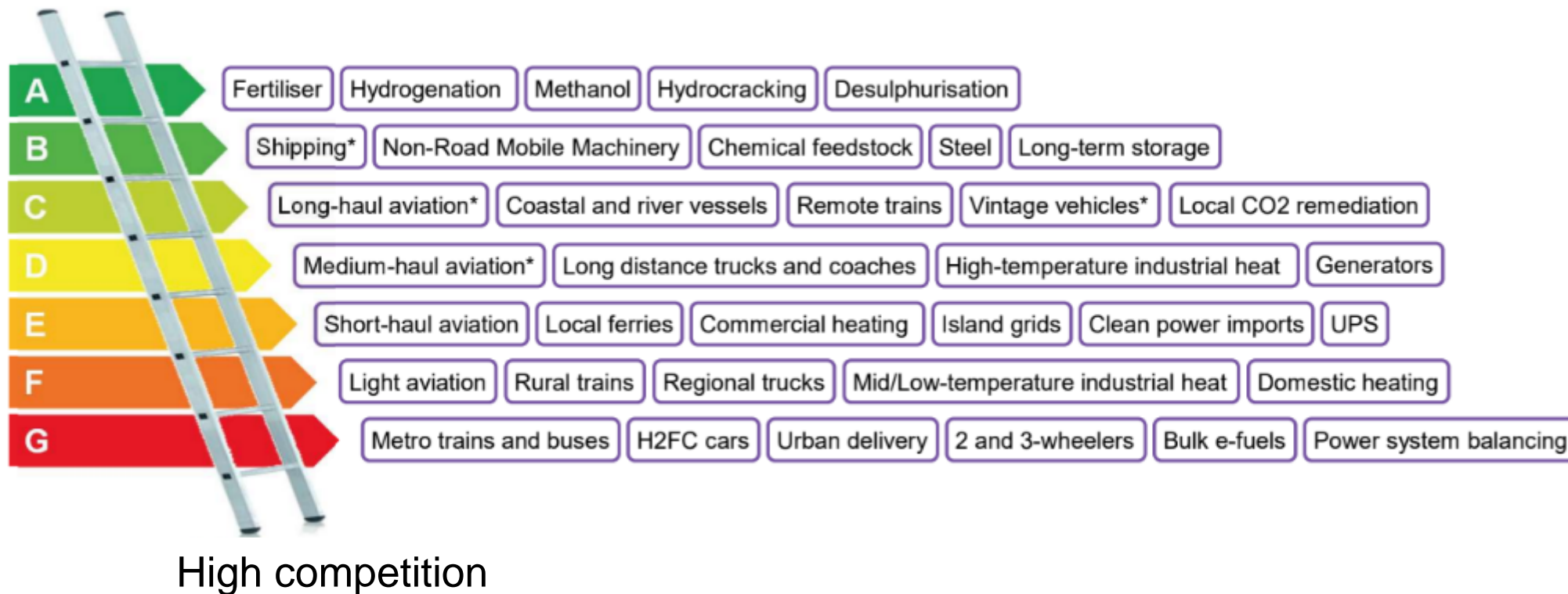


High competition

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



Unavoidable



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



Green hydrogen is a very promising energy carrier in many sectors but should not be used dogmatically if there are more promising options

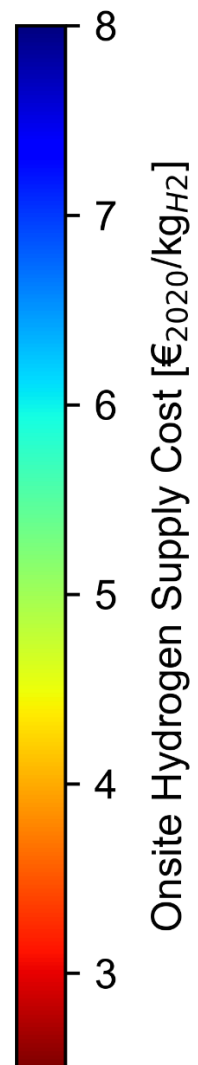
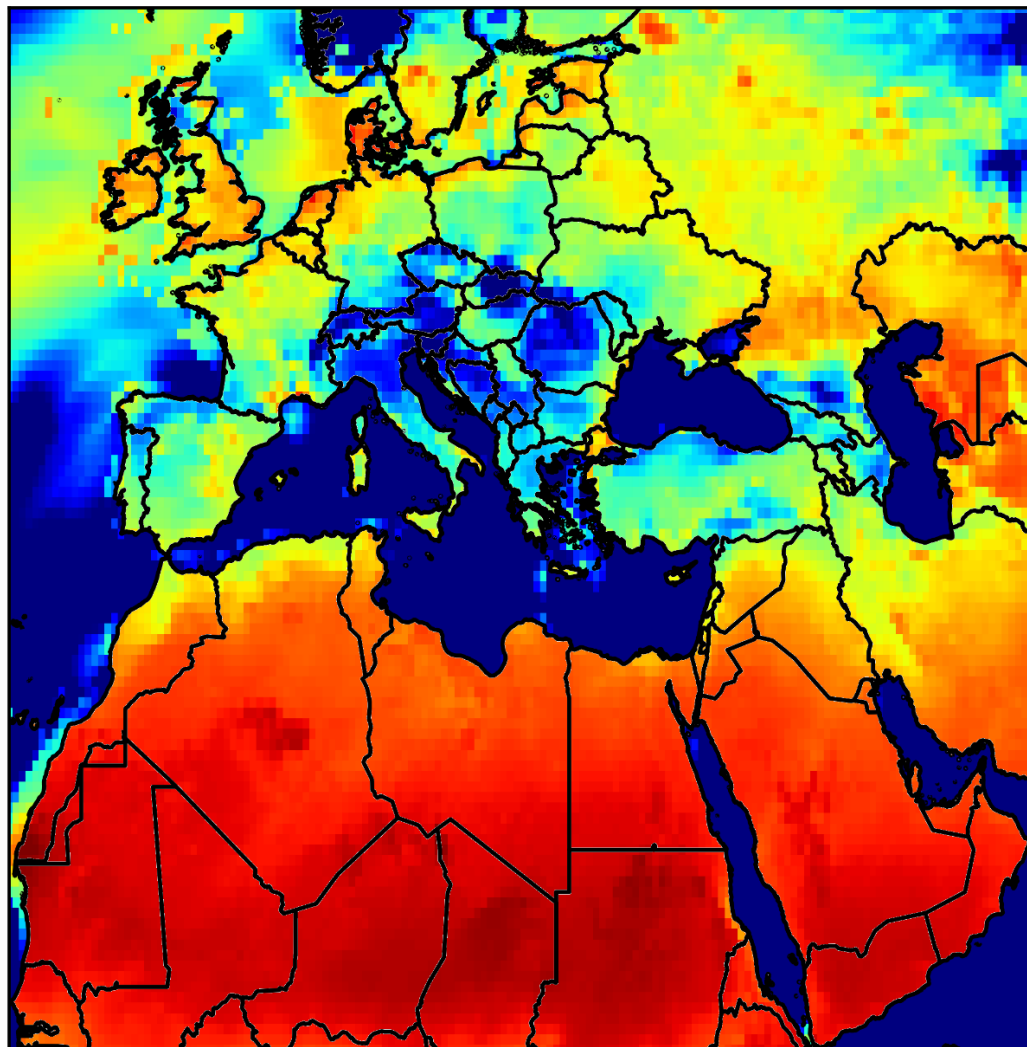


How will we transport and distribute hydrogen?

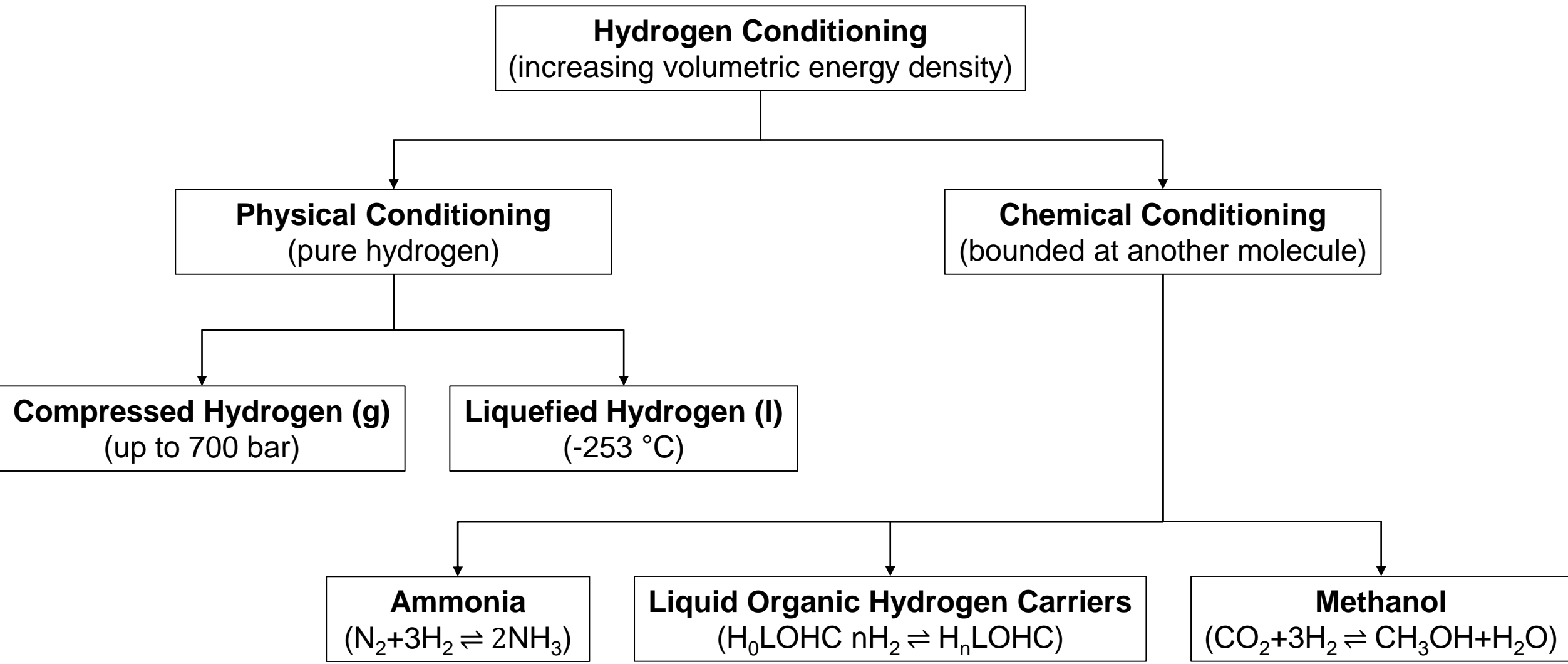
3. Hydrogen Infrastructure

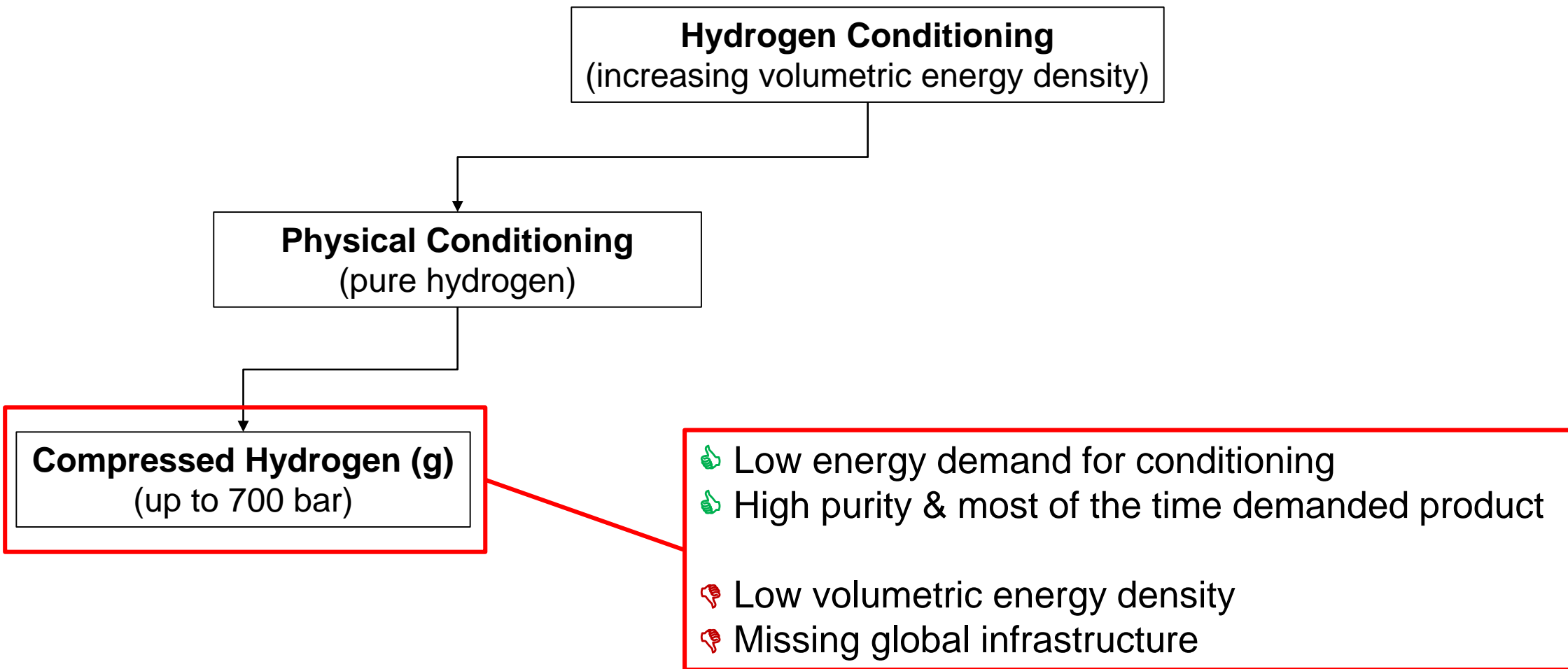


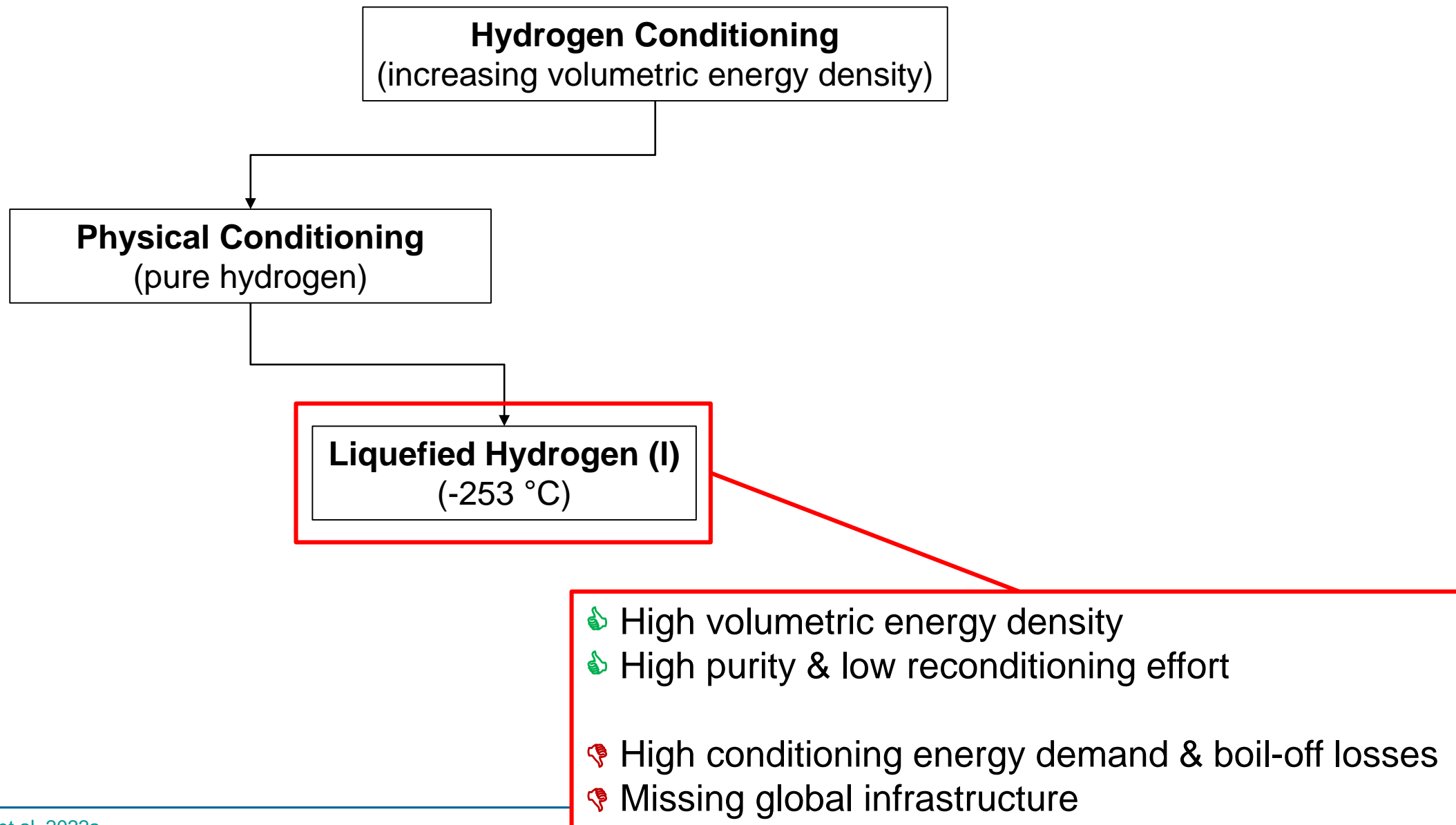
2035

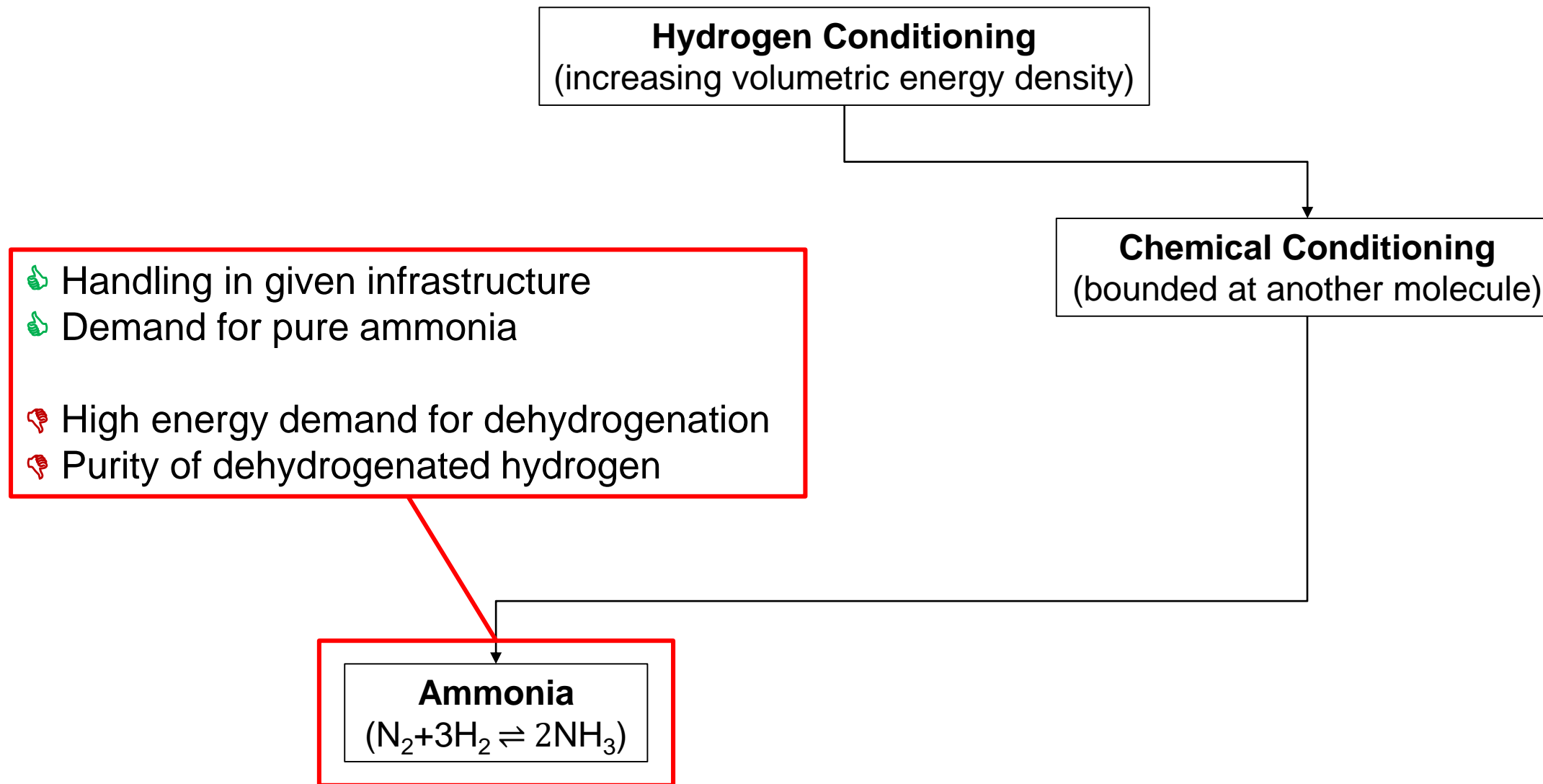


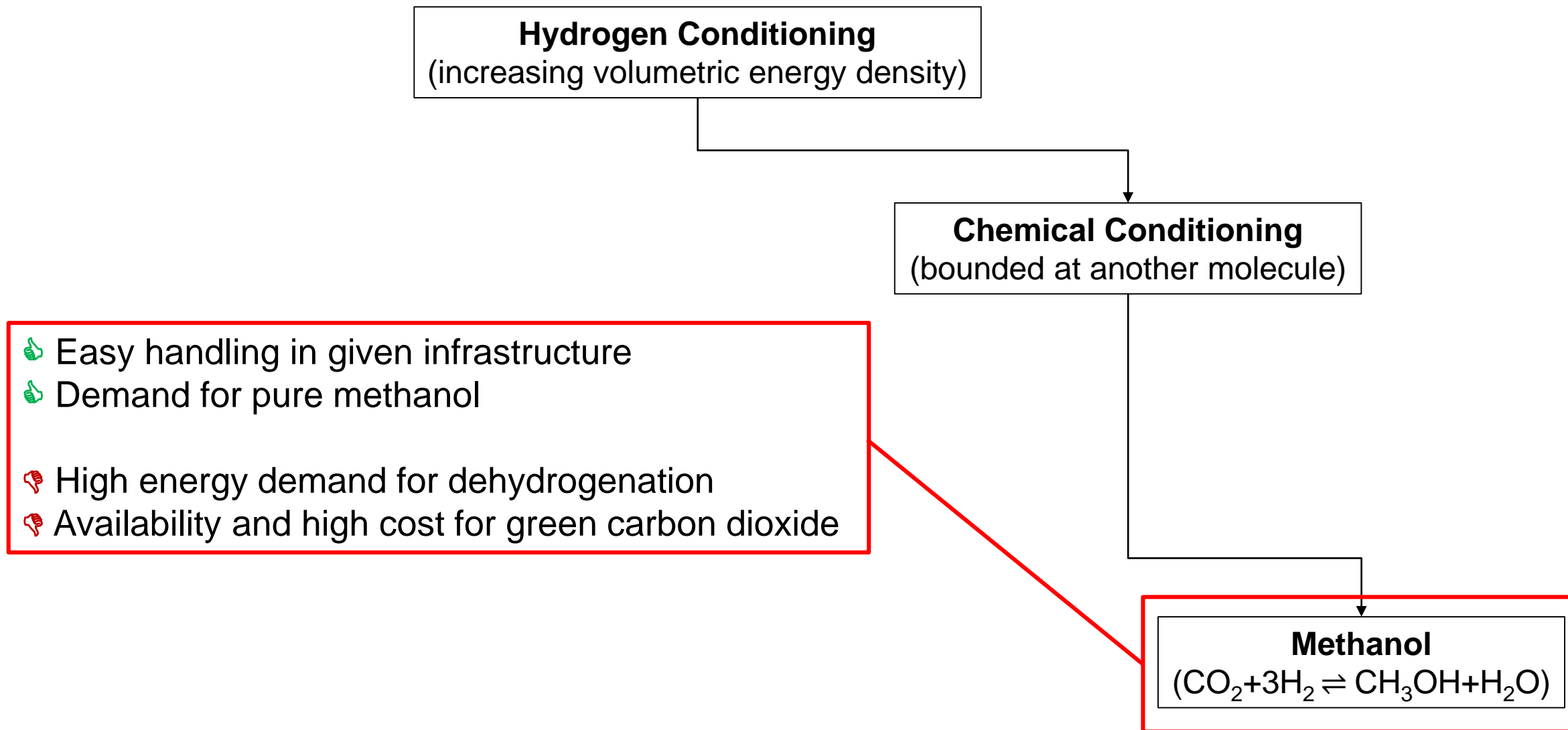
- Hydrogen production cost differ significantly between regions depending on the renewable energy resources
- Hydrogen transportation between regions is very likely
- Due to hydrogens low energy density at ambient conditions a conditioning is needed to increase the energy density

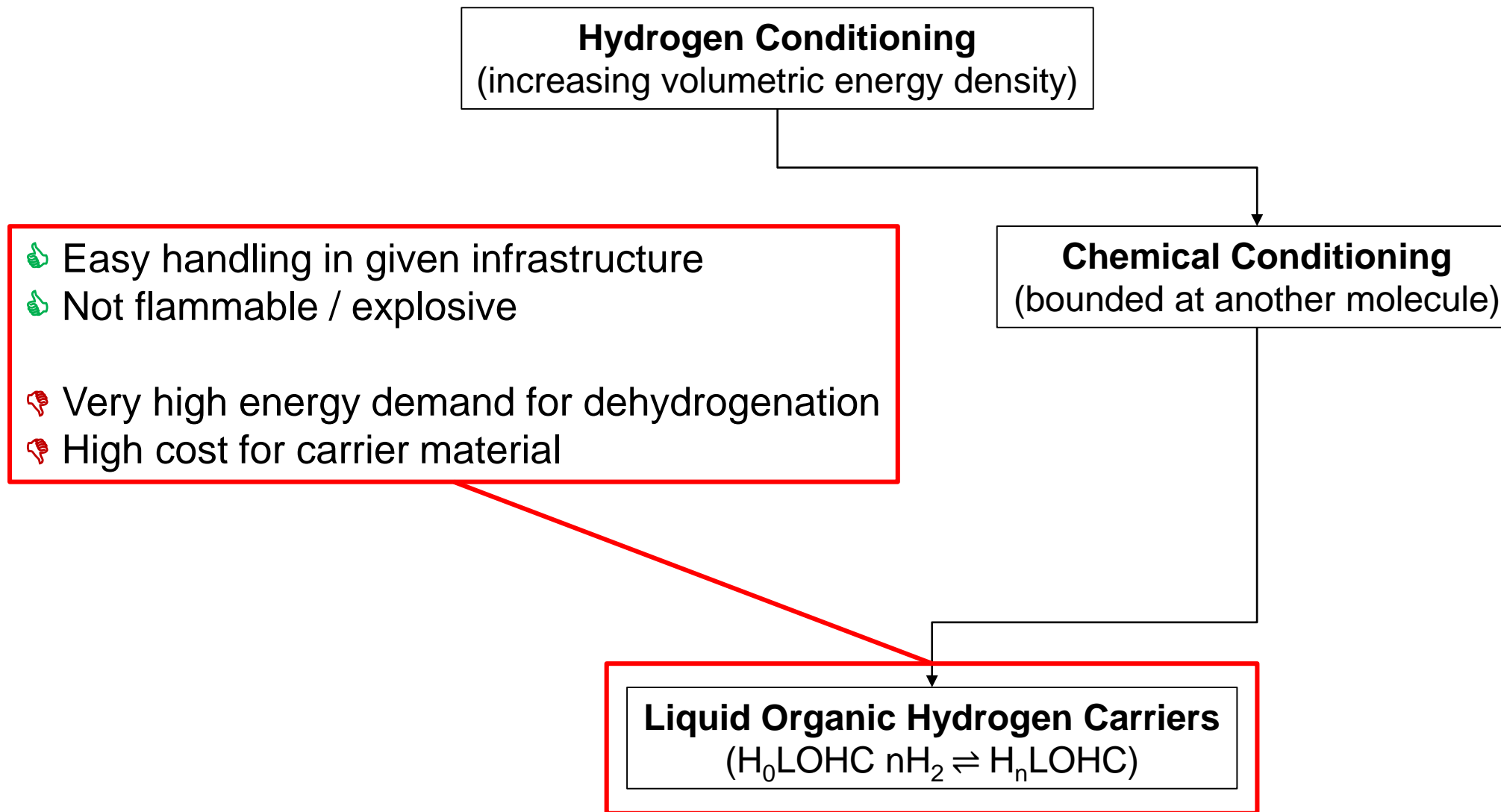


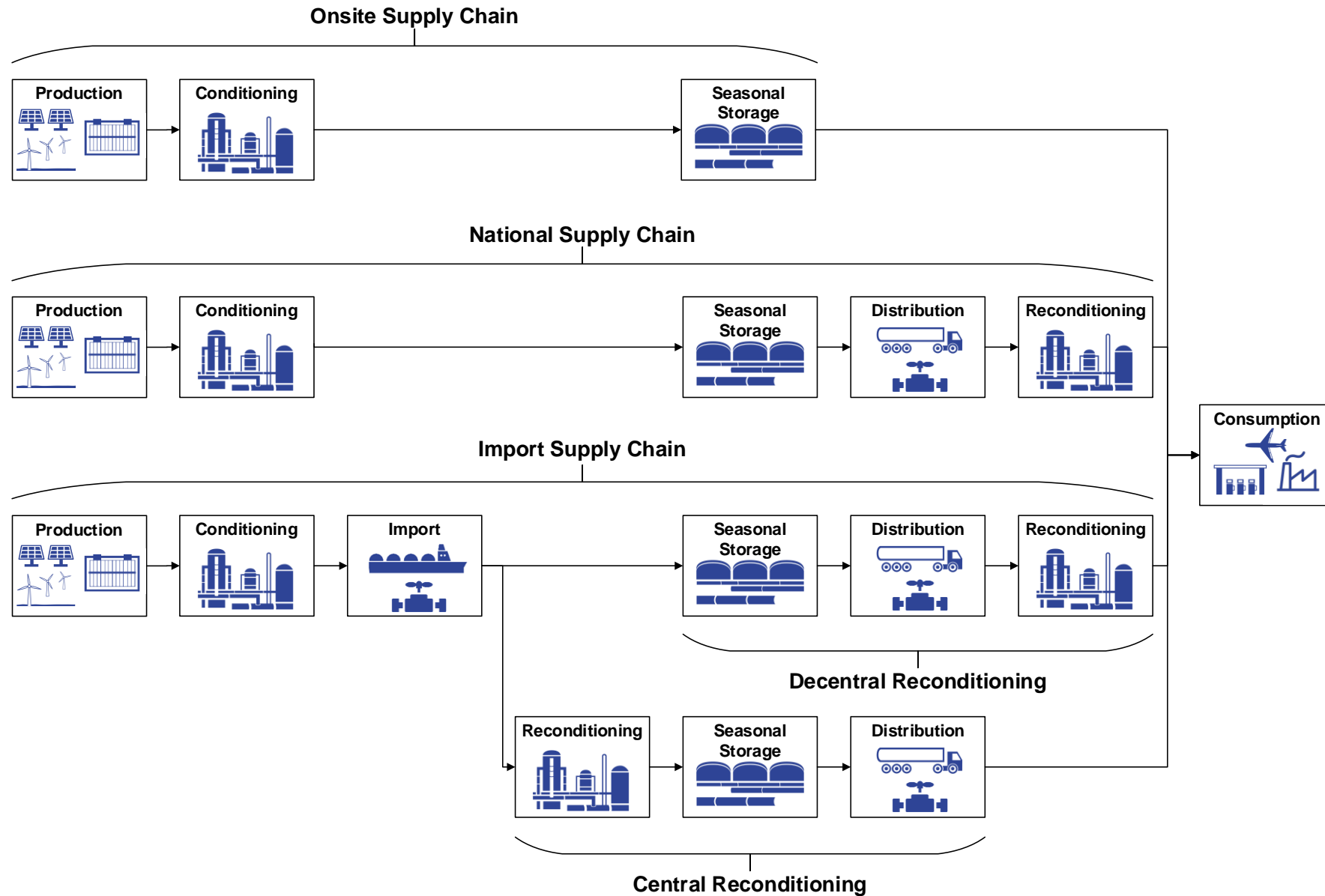




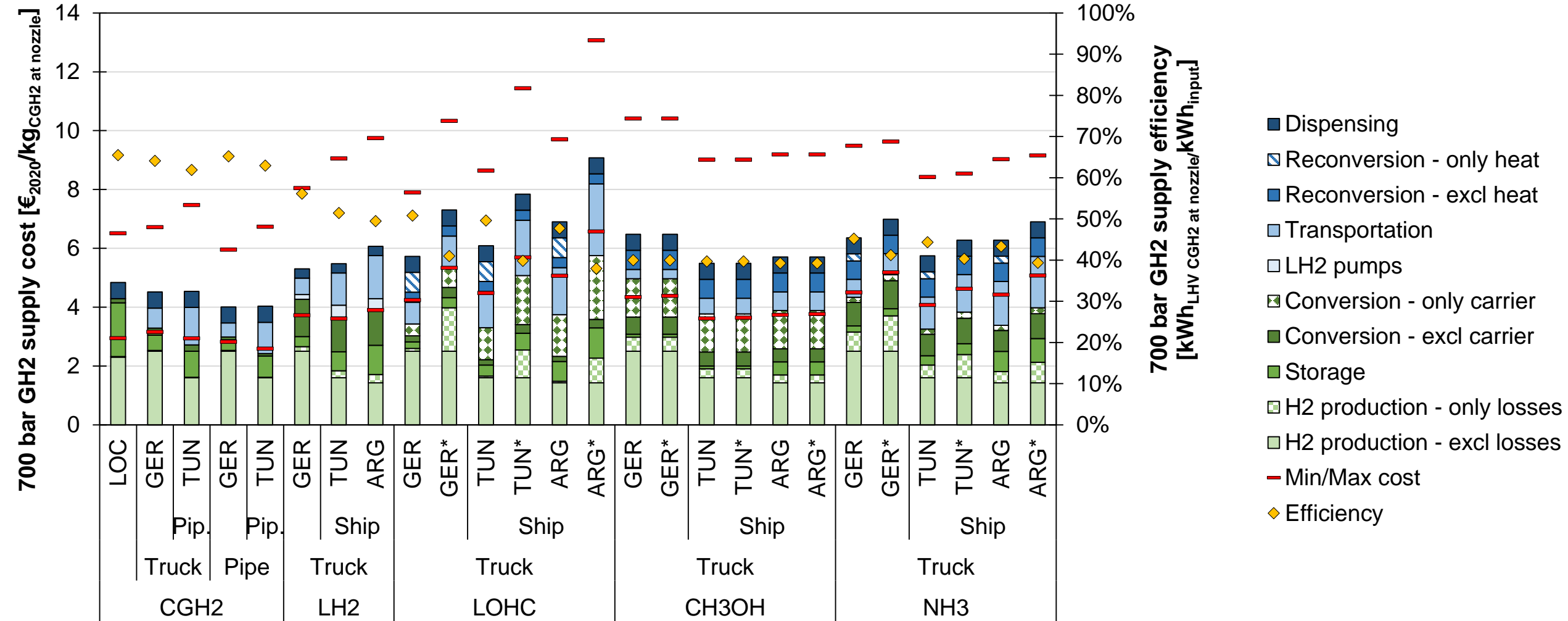






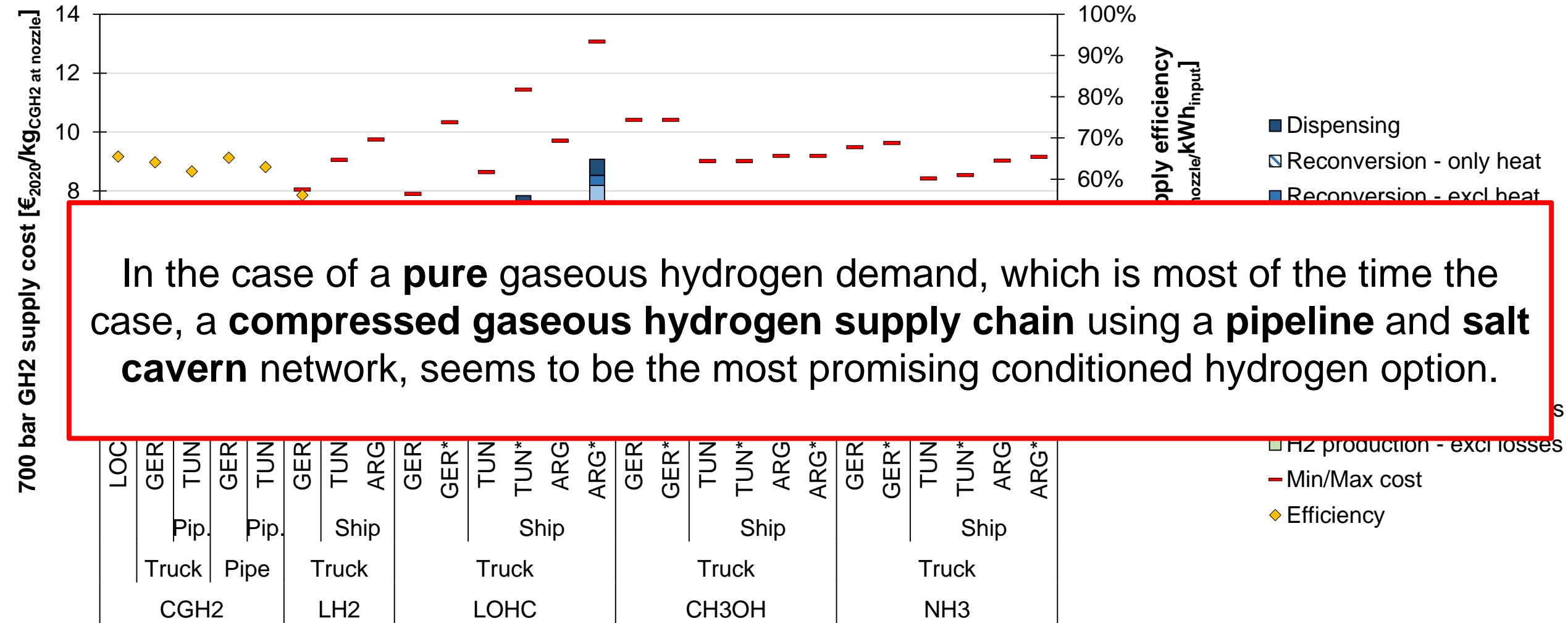


Hydrogen Supply Cost in 2050



(* = heat demand for the reconversion is supplied internally by using the needed energy fraction from the released hydrogen; ARG = hydrogen production in Argentina (Patagonia); CGH2 = compressed gaseous hydrogen supply chain; CH3OH = methanol supply chain; GER = centralized production in North Germany; LH2 = liquid hydrogen supply chain; LOC = local production directly at the airport in Central Germany; LOHC = liquid organic hydrogen carrier supply chain; NH3 = ammonia supply chain; Pip. = pipeline import; Pipe = pipeline distribution to filling station; Ship = ship import; TUN = hydrogen production in Tunisia; Truck = truck distribution to filling station

Hydrogen Supply Cost in 2050



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What will be the gold standard?

4. Regulatory Framework

- **Most important:**

- **Green H₂**: Electrolysis powered by renewable energy
- **Turquoise H₂**: Methane pyrolysis producing elementary carbon
- **Blue H₂**: Steam methane reformation with CCS
- **Grey H₂**: Steam methane reformation without CCS

- **Further:**

- **Brown H₂**: Coal gasification without CCS
- **Red H₂**: Electrolysis powered by nuclear energy
- **White H₂**: Naturally occurring geological hydrogen
- **Orange H₂**: Biomass or waste based production

Type of hydrogen which is probably promoted by the upcoming legal EU framework

TBD

- **Additionality:**
 - New renewable power generation is needed for new hydrogen projects
 - Installation of electrolyzer and renewable power within 36 months
 - Phase-in period until 2026
- **Temporal correlation:**
 - Hydrogen production occurring in the same hour than electricity generation from 2027 on
 - Until 2026 a monthly correspondence is sufficient
- **Exceptions:**
 - Electrolyzers supporting the integration of renewable power into the electricity system
 - Bidding zones where renewable power generation represents the dominant share of the power mix in the electricity system*

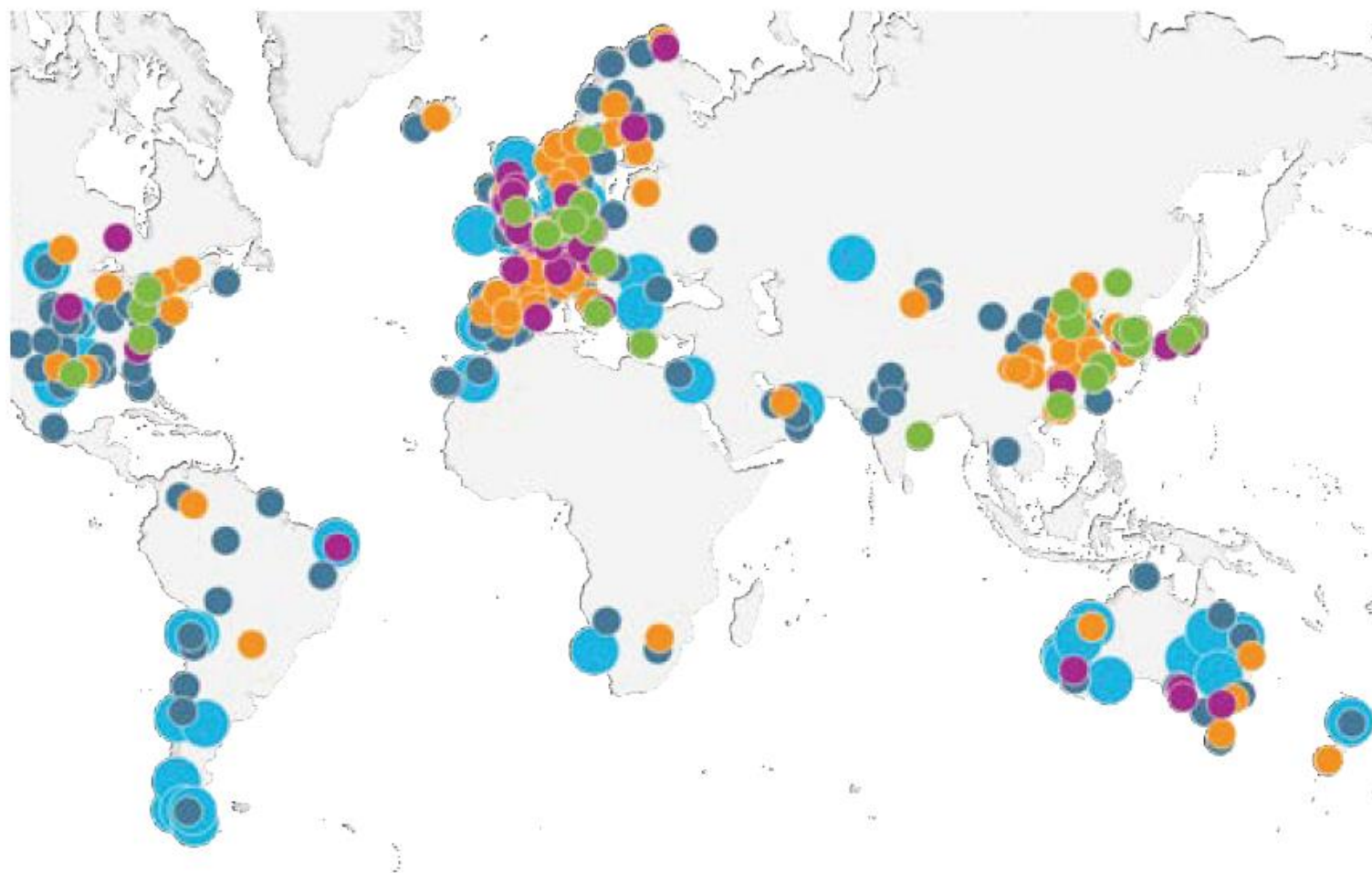


Only announcements or also final investment decisions?

5. Hydrogen Projects

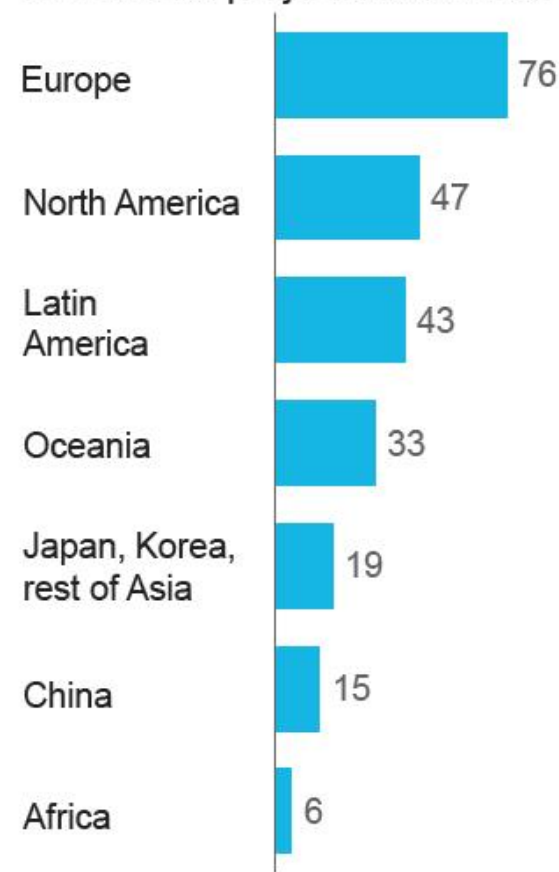


Announced Hydrogen Projects



USD 240bn

investments required for announced projects until 2030



of projects

51
Giga-scale production

262
Large-scale industrial use

128
Transport

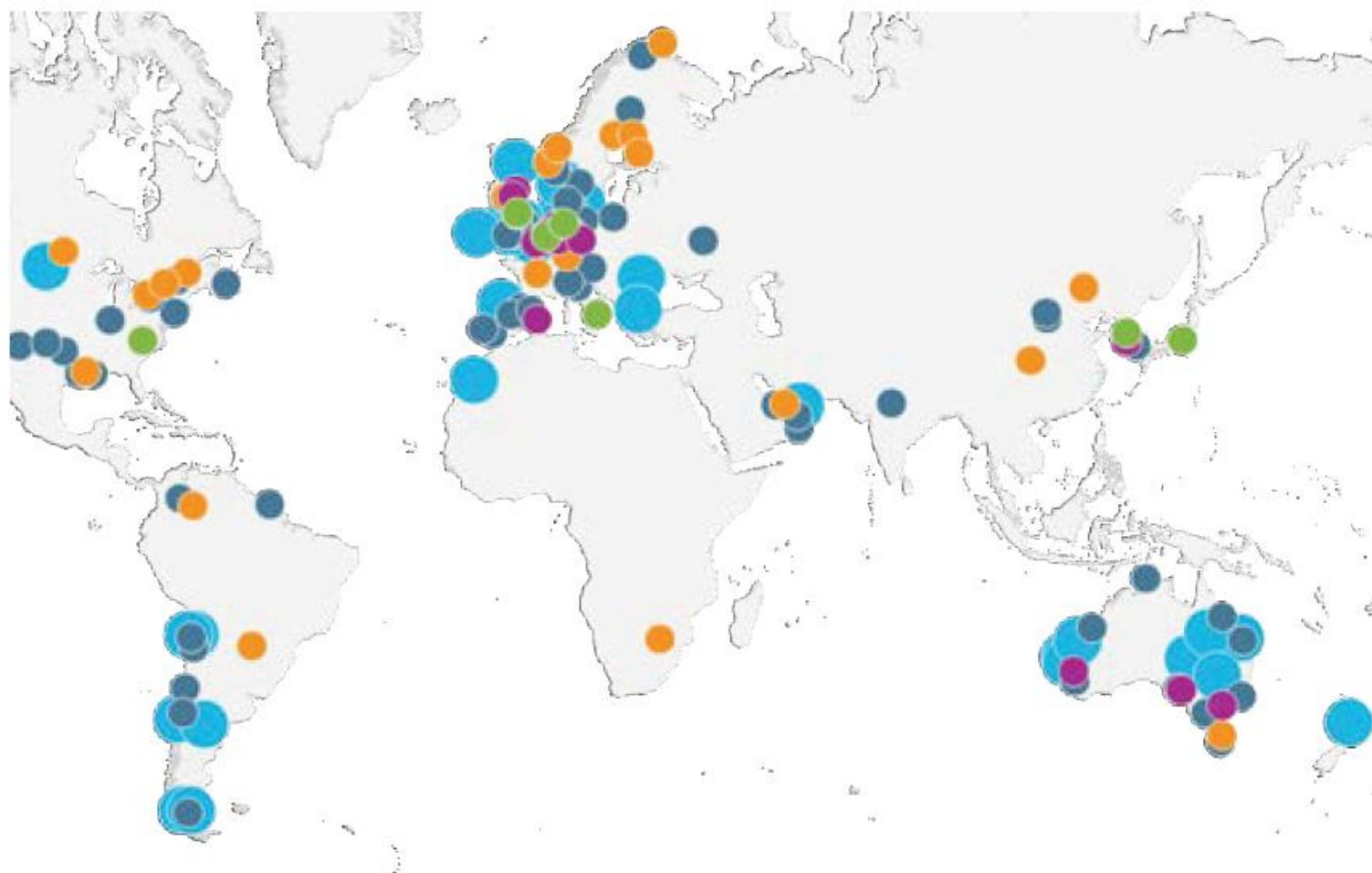
53
Integrated H₂ economy

40
Infrastructure projects

➔ In 2022 around \$ 2,400bn have been invested in the global energy sector

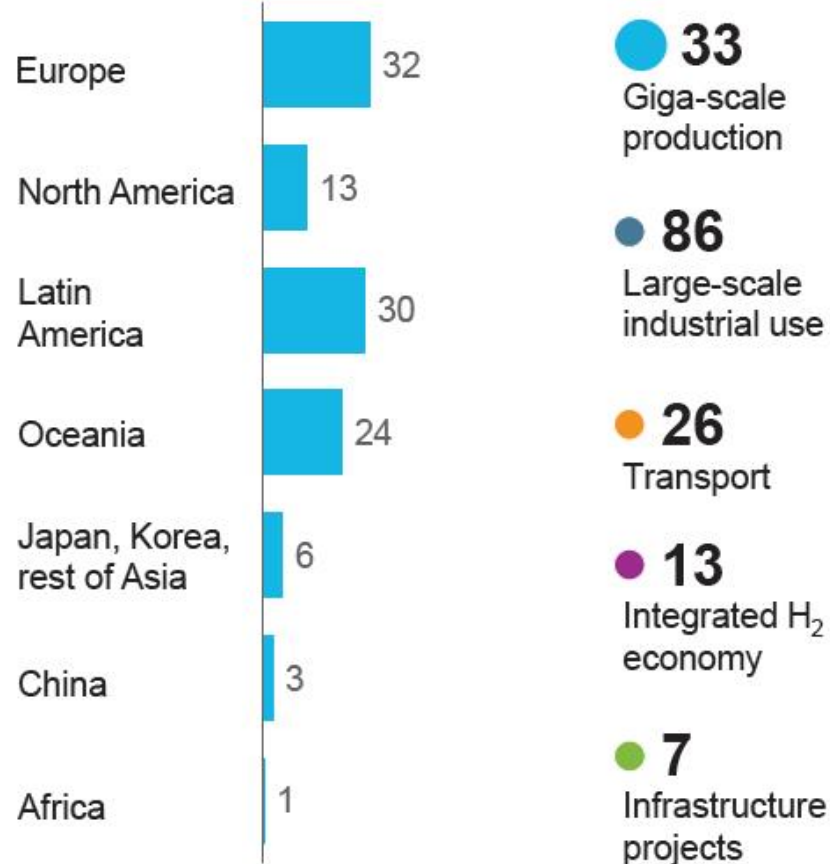


Hydrogen Projects Undergoing Feasibility Studies



USD 109bn

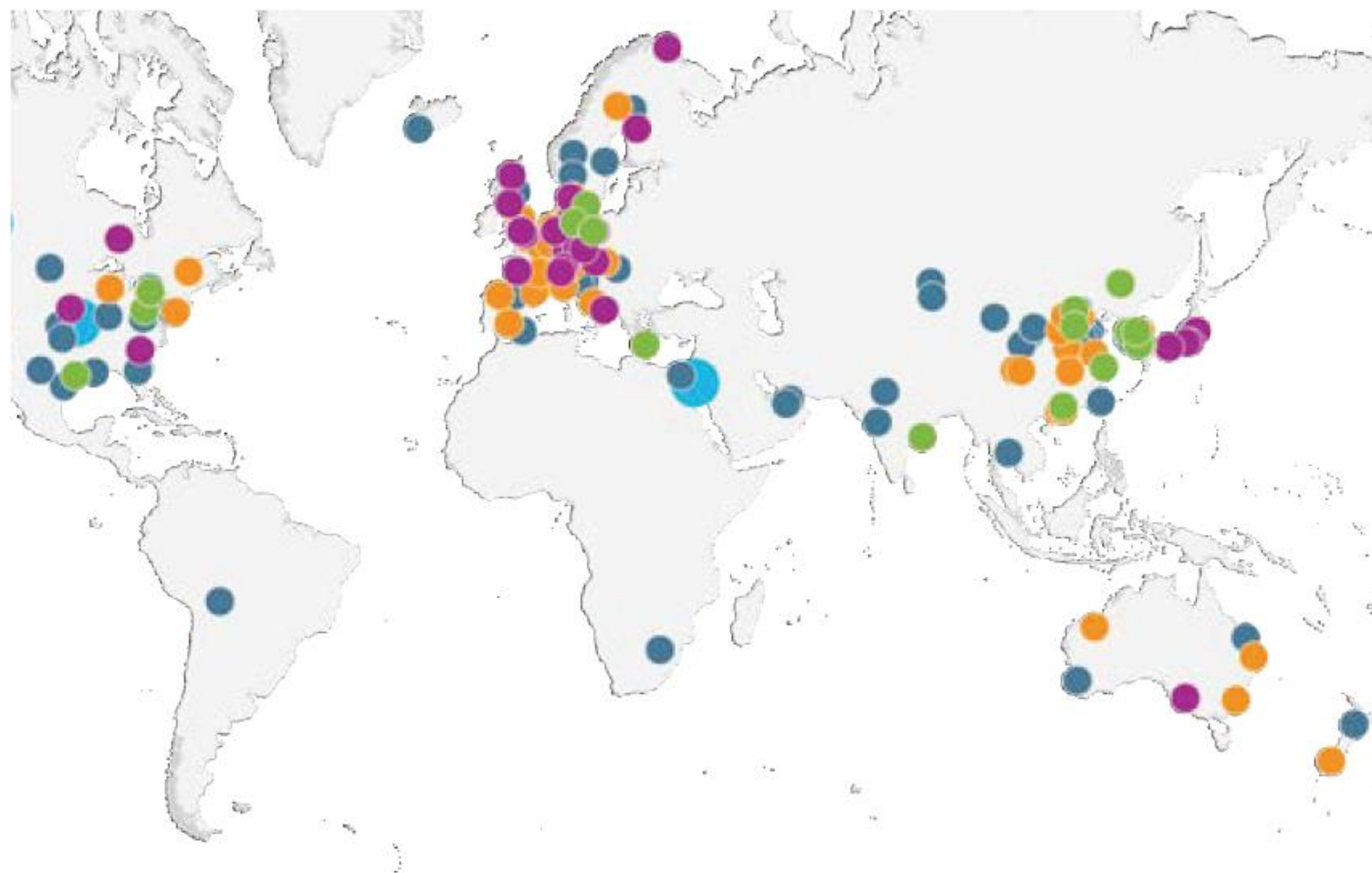
investments until 2030,
related to projects in planning



➔ **Around 45% is undergoing feasibility studies**

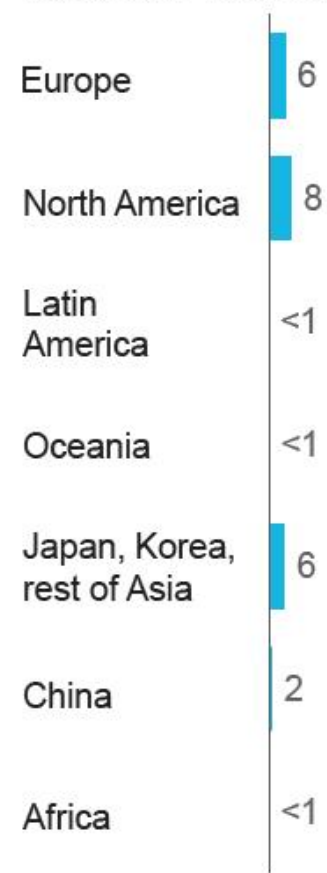


Hydrogen Projects Achieved Final Investment Decisions



USD 22bn

investments until 2030,
related to committed projects



of projects

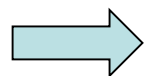
3
Giga-scale production

77
Large-scale industrial use

61
Transport

29
Integrated H₂ economy

19
Infrastructure projects



But less than 10% as achieved a final investment decision



Hamburg Green Hydrogen Hub (Germany)

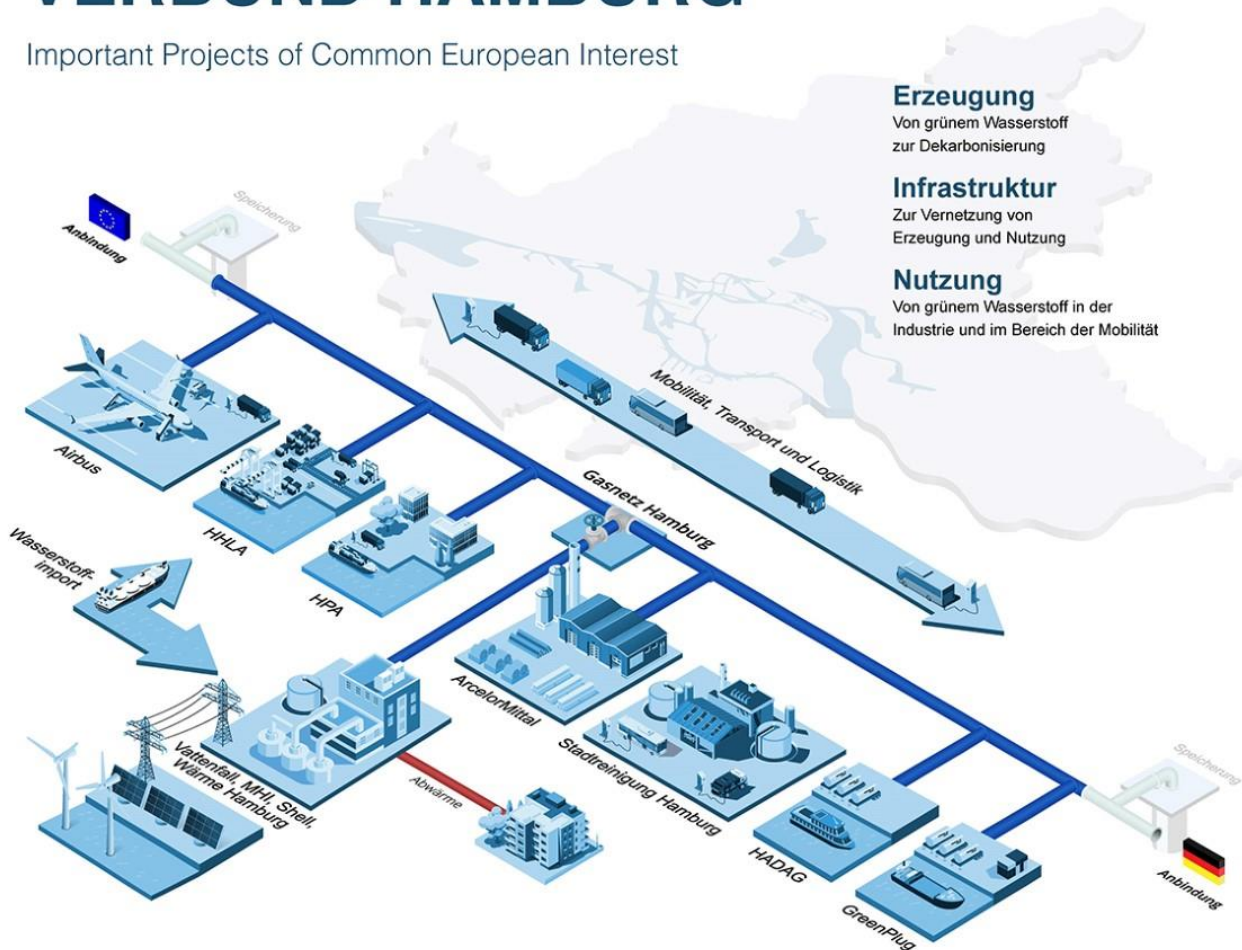


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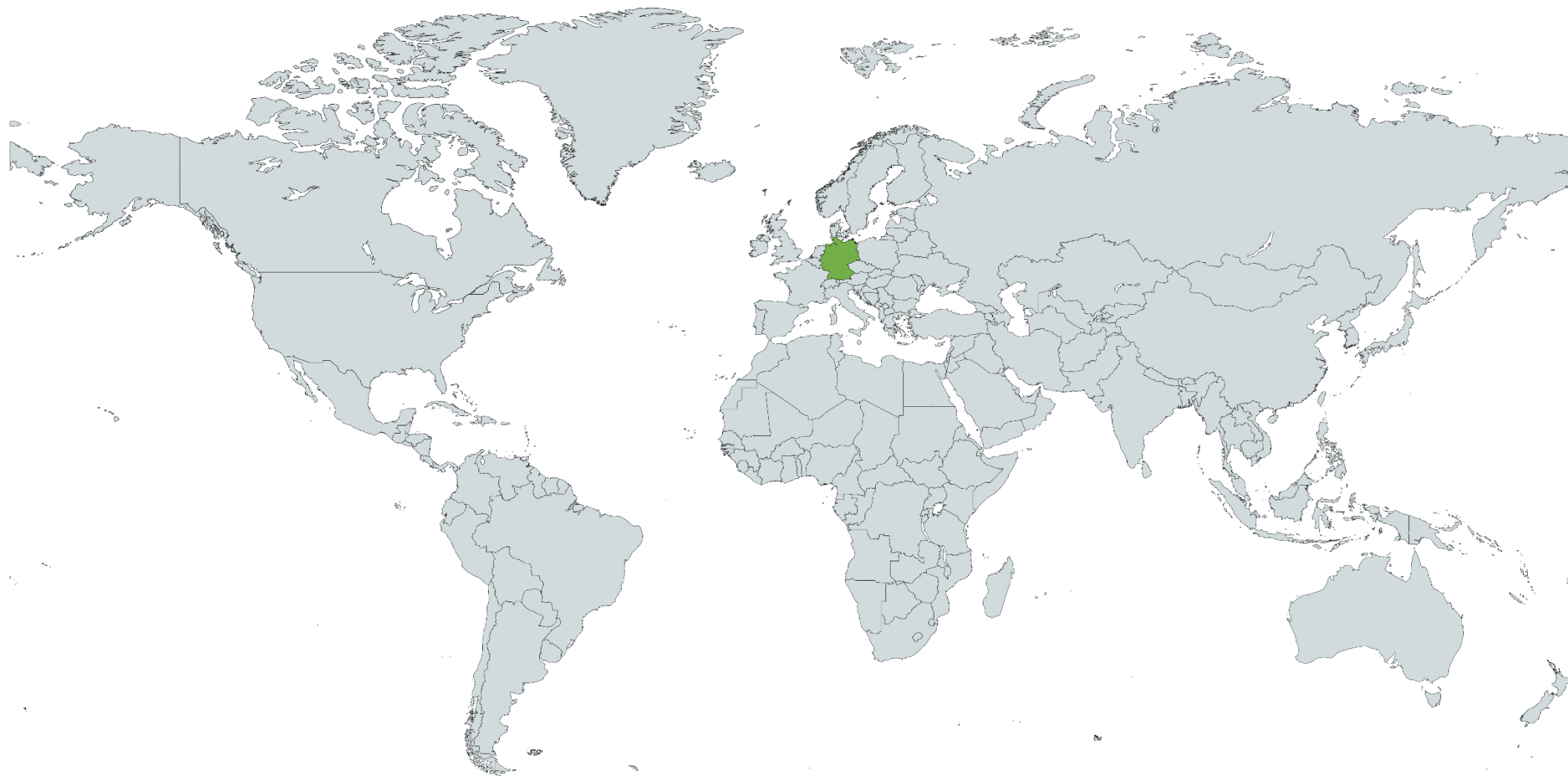


WASSERSTOFF- VERBUND HAMBURG

Important Projects of Common European Interest



- Aiming for a local **hydrogen hub** covering production, infrastructure & consumption
- Construction of a local **hydrogen pipeline network of 40 km** starting in 2023, connecting industrial costumers with a 100 MW electrolysis
- Hydrogen **import terminal** planned
- **End use of hydrogen** in industry, logistics, trucks, ships & aviation aimed



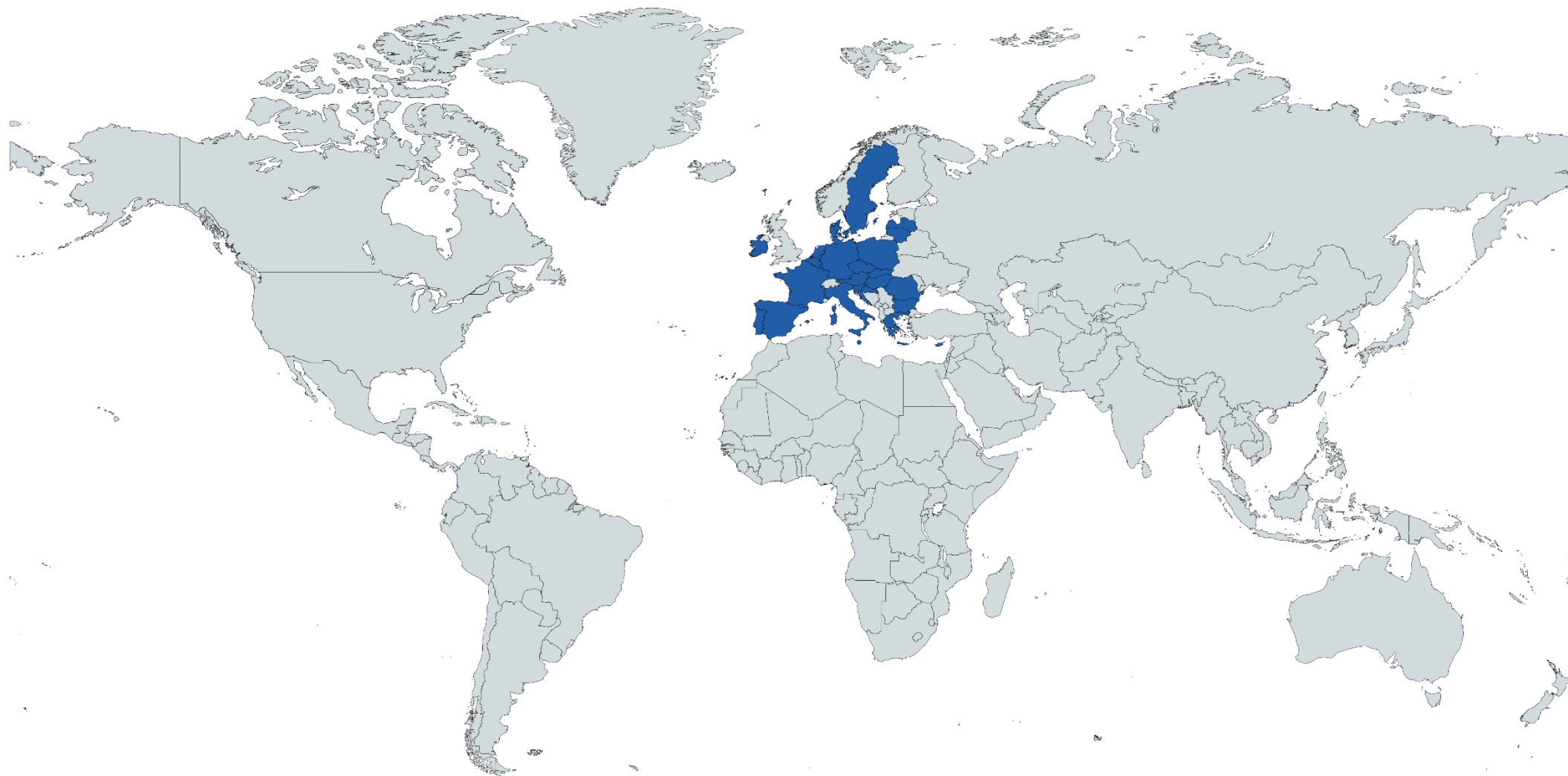
Created with mapchart.net



- National Hydrogen Strategy set **10 GW electrolyzer** capacity installed in Germany as a target for 2030
- Germany is looking for international (import) **hydrogen partnerships**
- € 700m for **lighthouse hydrogen projects**:
 - Upscaling and mass production of electrolyzers (H2Giga)
 - Offshore hydrogen generation without grid connection (H2Mare)
 - Technologies for the transport of hydrogen (TransHyDE)
- **€ 8bn state aid** to trigger € 33bn investment for 50 projects including 2 GW electrolyzer capacity and 1,700 km hydrogen pipelines



Hydrogen in the European Union



Created with mapchart.net

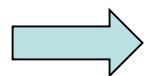
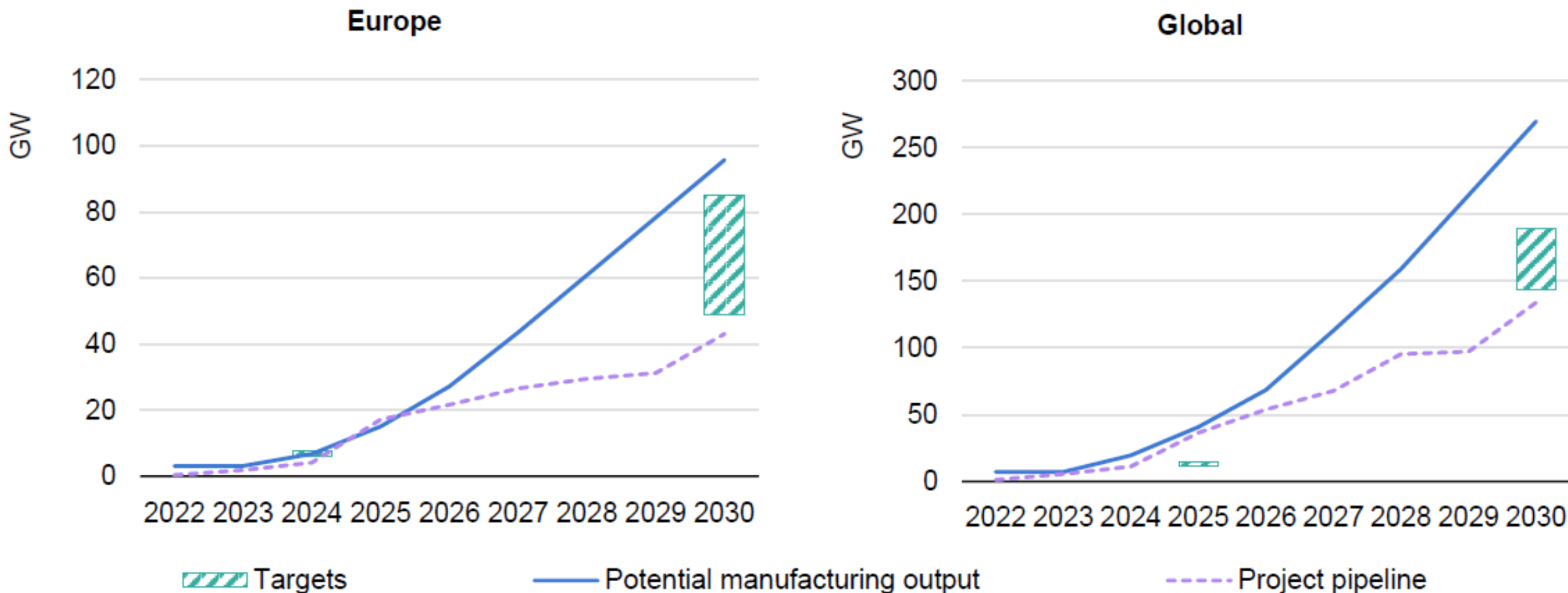


- The „REPowerEU“ program sets a target of **10m tons** of green hydrogen **domestically** by 2030 and **importing** additional **10m tons**
- **€ 225bn*** is already available in loans for the REPower EU programm
- **€ 20bn*** are proposed to make available as funds
- Further up to **€ 40bn*** are planned to provide in addition
- First round of hydrogen **IPCEI unlocks € 5.4bn state aid** for 35 companies unlocking an additional **€ 8.8bn** in private investments



Eleetrolyzer Production Capacities

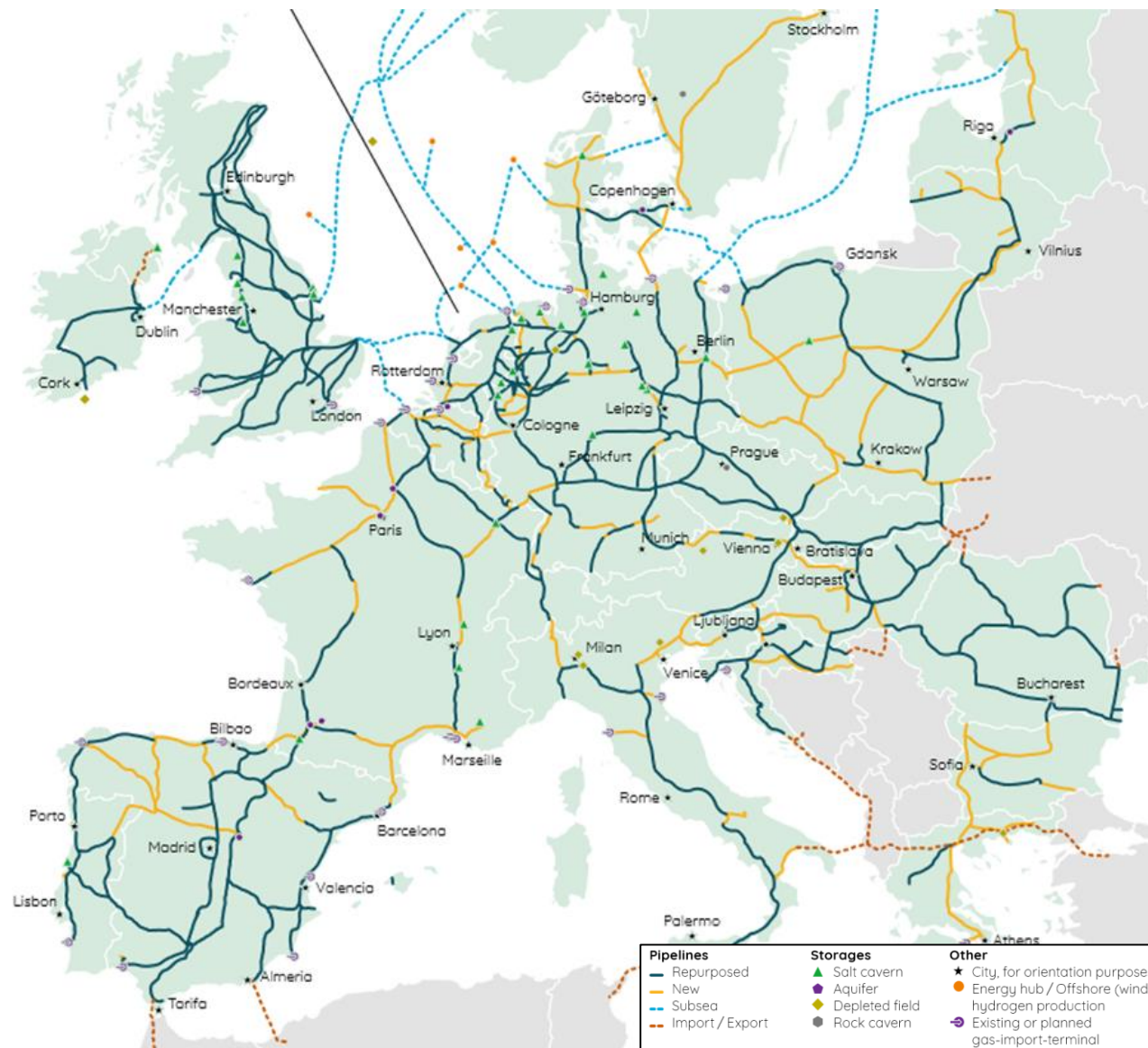
Electrolyser project pipeline, manufacturing output and targets in Europe and globally, 2022-2030



Around one third of the global electrolyzer production capacity is expected in Europe



European Hydrogen Backbone



- **53,000 km** of hydrogen backbone pipelines
- **€ 80 to 143bn** investment needed
- **60% repurposed** natural gas pipelines and **40% new** hydrogen pipelines
- **€ 0.1 to 0.2** per kg of hydrogen when transporting over 1,000 km



Which challenges are we facing and how can we solve them?

6. Hydrogen Ramp Up



- Enable **demand visibility** and **regulatory certainty** by adopting legally binding measures
- **Fast-track access** to public funding for hydrogen projects
- Ensure **international coordination** and support credible **common standards** and robust tradable certification systems
- Build up the needed **renewable power** and electrolyzer capacities



- Double auction model enables **price security** for supply and demand side and therefore investment security
- Based on a mechanism in analogy to the Contracts for Difference approach, the **difference between supply prices** (production and transport) and **demand prices** will be **compensated** by using grant funding from the German government
- Long-term purchase contracts (10 a) on the supply side and short-term sales contracts on the demand side (both **competition-based bidding**)
- Initially granted with € 900m funding but is expected to reach **at least € 5bn** to provide sufficient security in Germany

Thank you for your Attention!

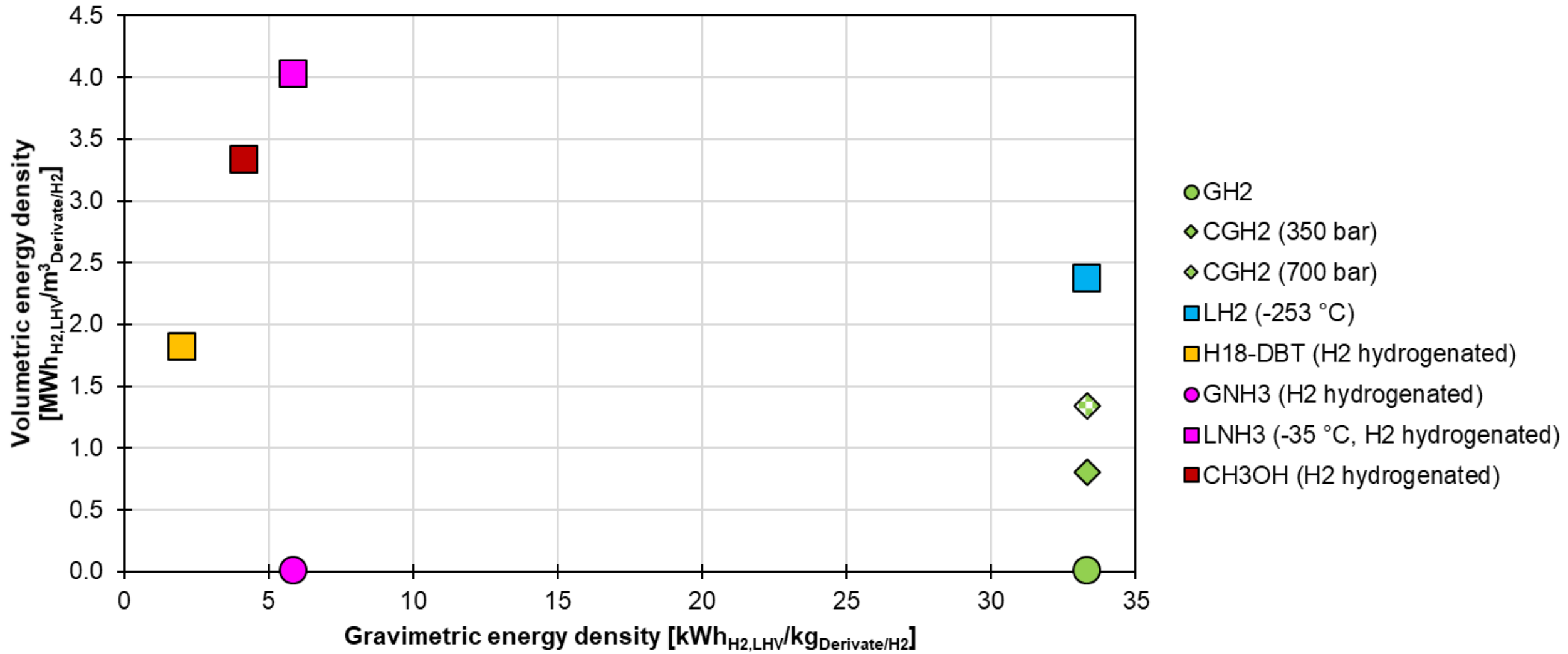
Questions and Discussion

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Eißendorfer Str. 40, D-21073 Hamburg
www.tuhh.de/iue

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Conditioned Hydrogen Options



Onsite Hydrogen Supply Cost in Colombia

