Hydrogen

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INTRODUCTION

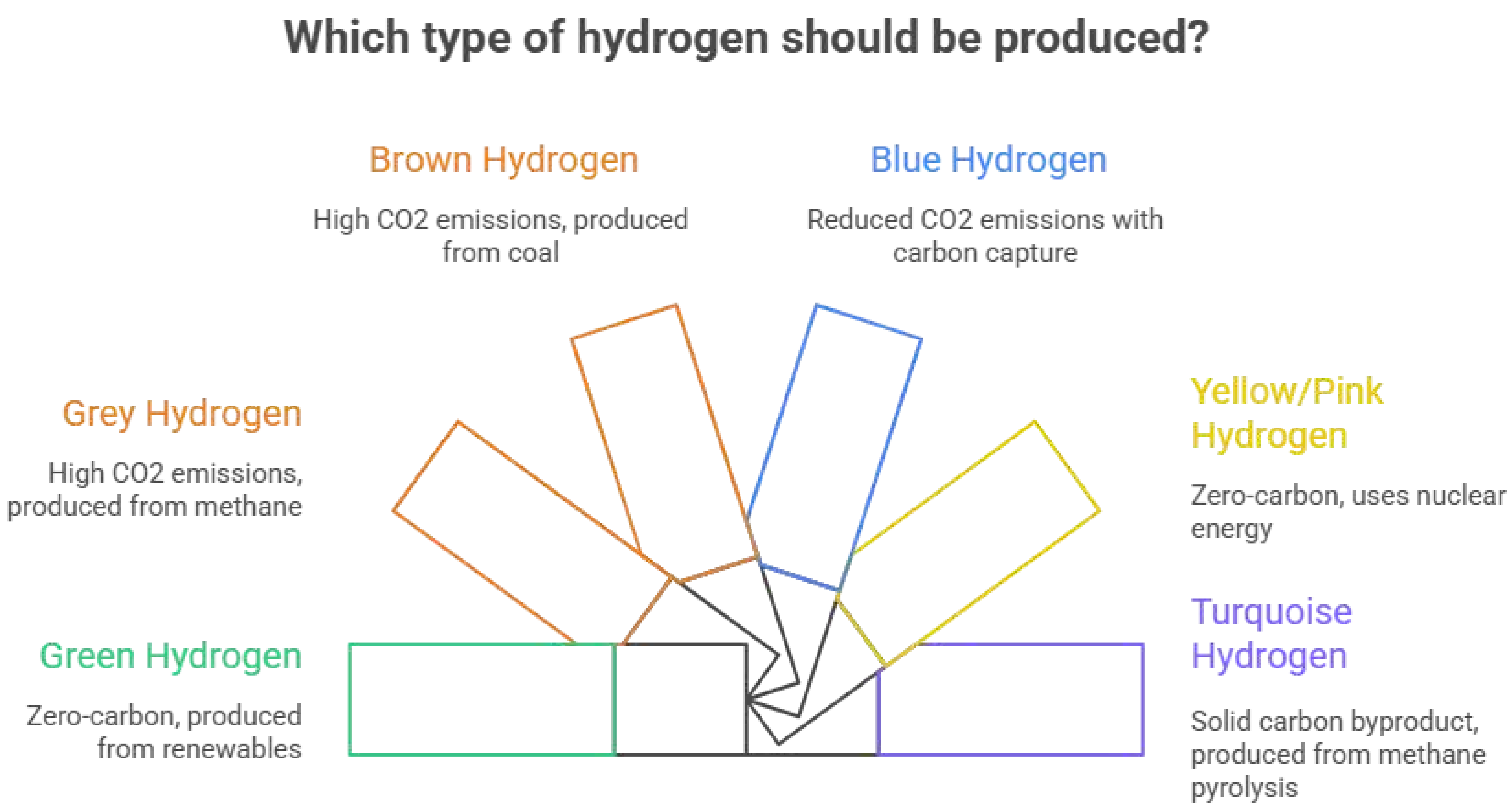
Energy forms the basis of human development. It spans usage from households to transport, industry, and cyber use. It is available in several forms: mechanical, chemical, thermal, and electrical.

Conventionally, global development rested on fossil fuels: coal, oil, and natural gas. While these have made industrial growth possible, their increasing environmental impact and finite supplies have quickened the pace toward renewable energy. Today, solar, wind, hydro, and geothermal sources are critical to addressing climate change, energy security, and resource depletion.

At the heart of the evolving energy landscape is innovation. Energy storage, smart grids, and hydrogen solutions are only some of the new technologies redefining how we produce and use energy, shaping our transition to a cleaner, more efficient, and sustainable world.

What is Hydrogen?

- Hydrogen is the lightest and most abundant element in the universe, making up nearly 75% of all matter.
- With an atomic number of 1, it consists of just one proton and is the simplest element known.
- Under standard conditions, hydrogen forms a diatomic molecule (H_2) two atoms bonded together.
- Because of its high energy content per kilogram, hydrogen is increasingly considered a promising clean energy carrier for future technologies.

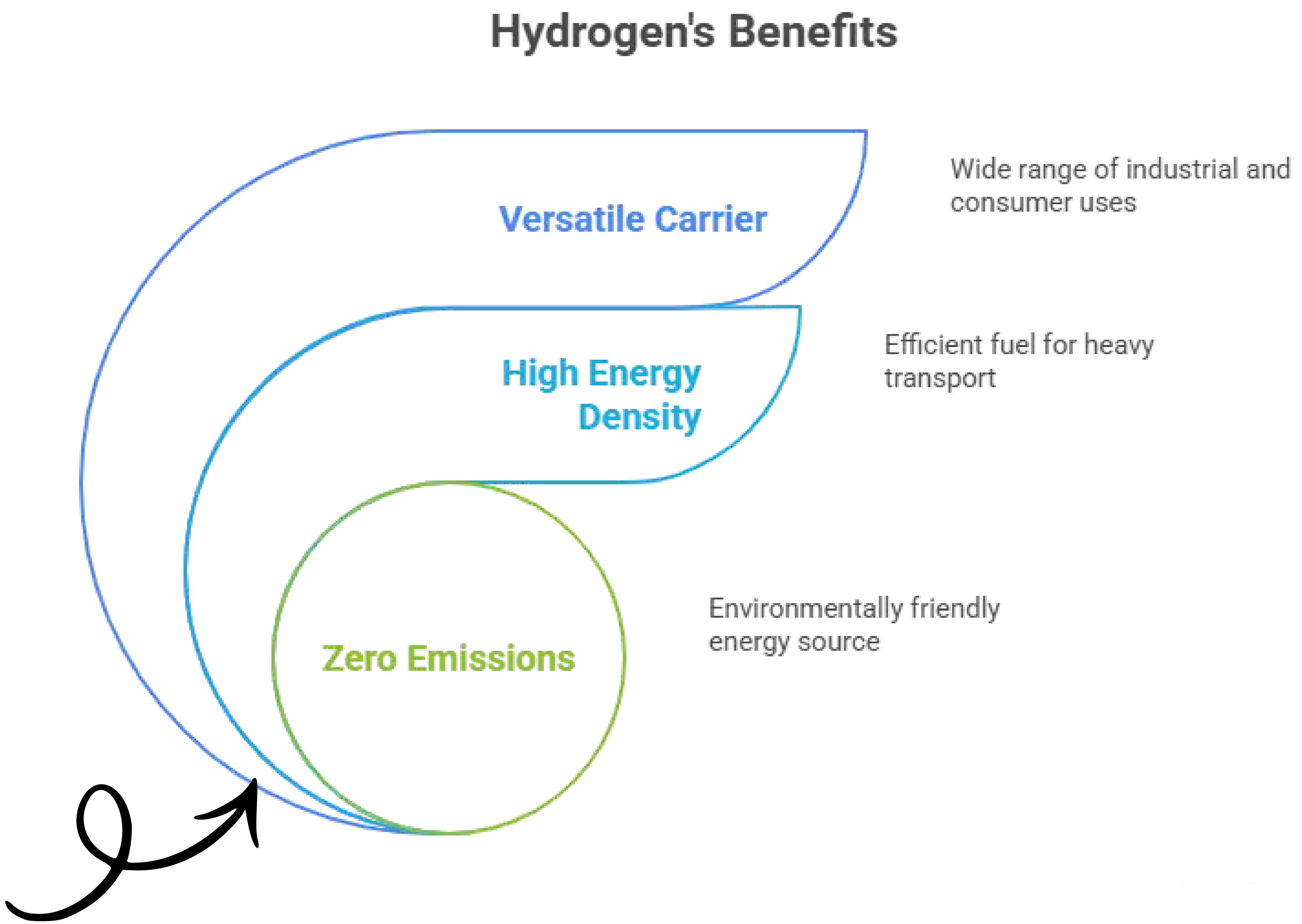


Types of Hydrogen

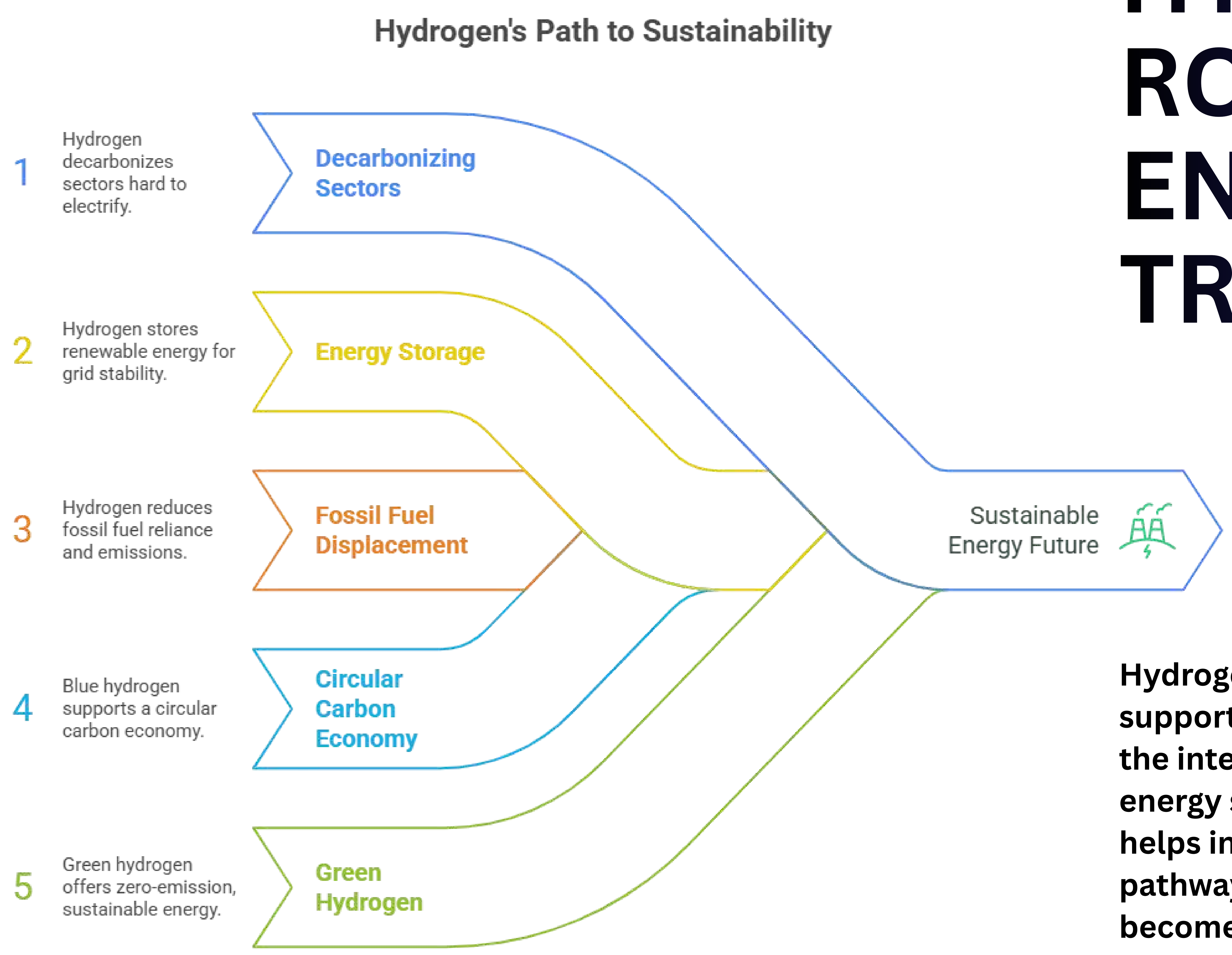
There Pros and cons

Hydrogen Why use it?

Hydrogen is widely regarded as a versatile and high-potential energy carrier, capable of powering multiple sectors while offering excellent energy density and zero emissions when used cleanly.



HYDROGEN'S ROLE IN THE ENERGY TRANSITION



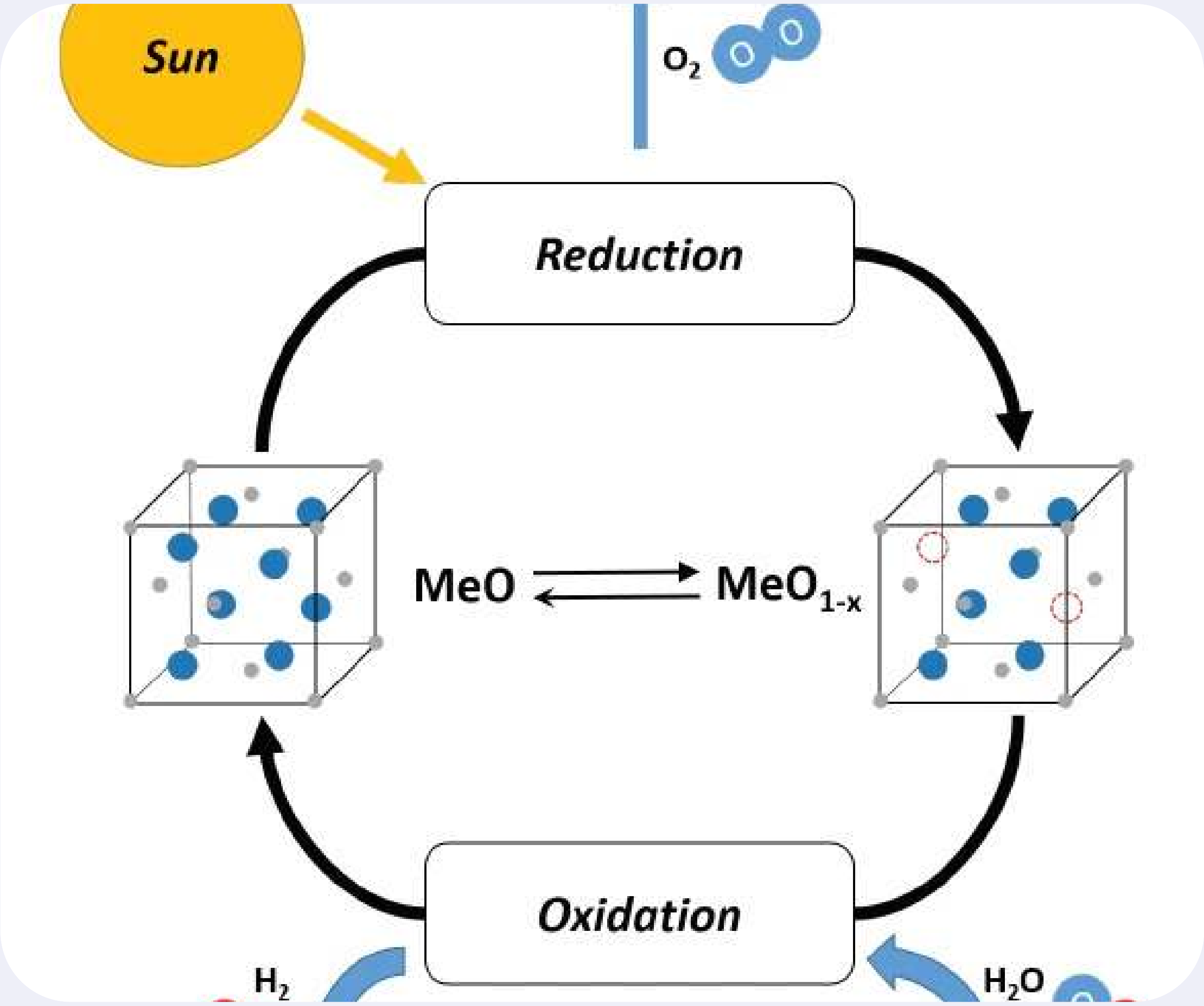
Hydrogen is central in the energy transition because it supports deep decarbonization in many sectors. It enables the integration of more renewables with large-scale energy storage, reduces dependence on fossil fuels, and helps in circular carbon strategies through blue hydrogen pathways. When made from renewables, green hydrogen becomes a fully zero-emission solution that will help hasten the shift to a sustainable energy future.

Production & Technologies

Hydrogen can be produced using a number of different processes.

Thermochemical processes

Thermochemical processes use heat to break down organic materials like biomass into simpler, more valuable products such as fuels and chemicals.



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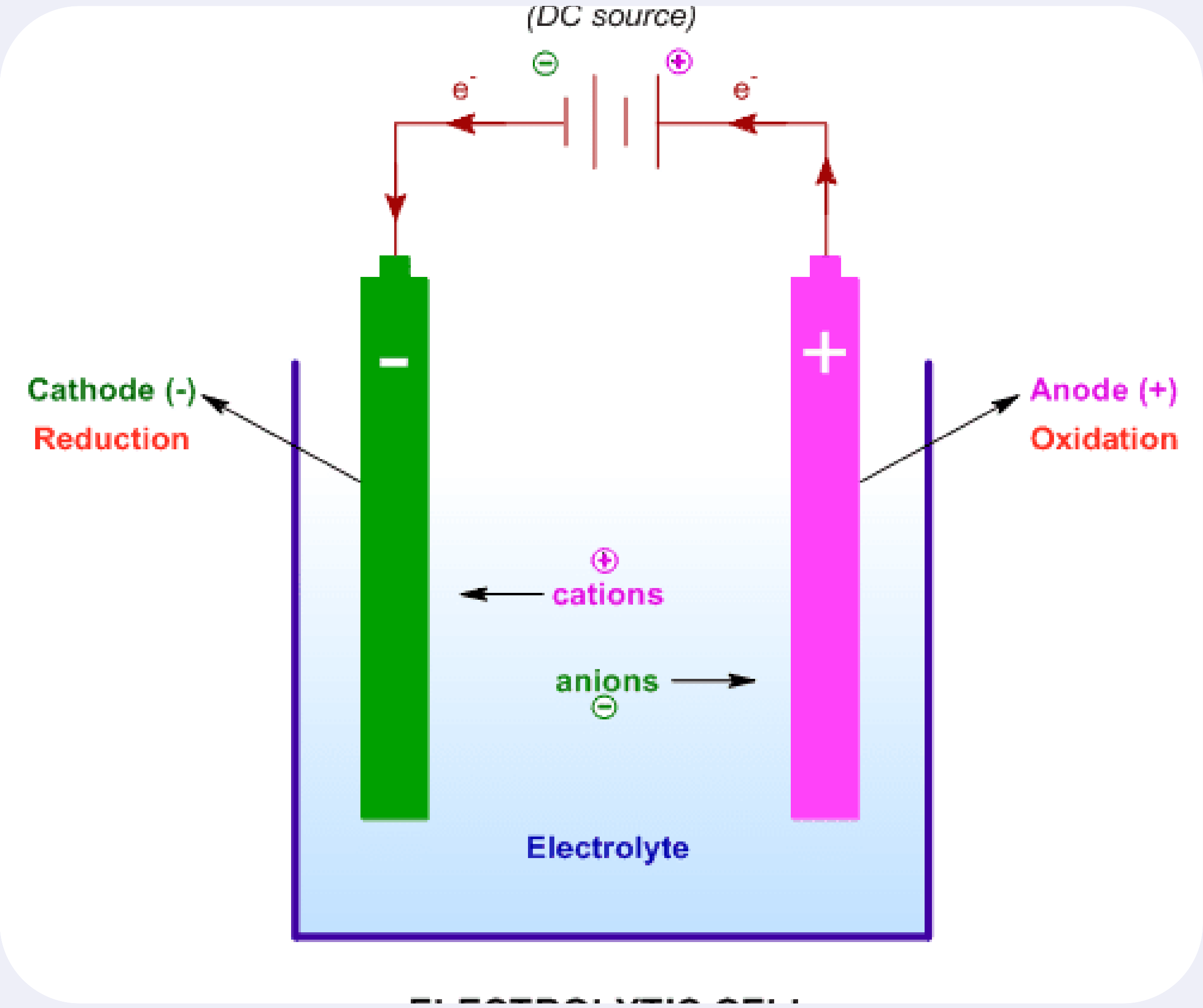
Electrolysis

Electrolysis is a process that splits hydrogen from water using an electric current.



Chemical Reactions:

- Cathode reaction:

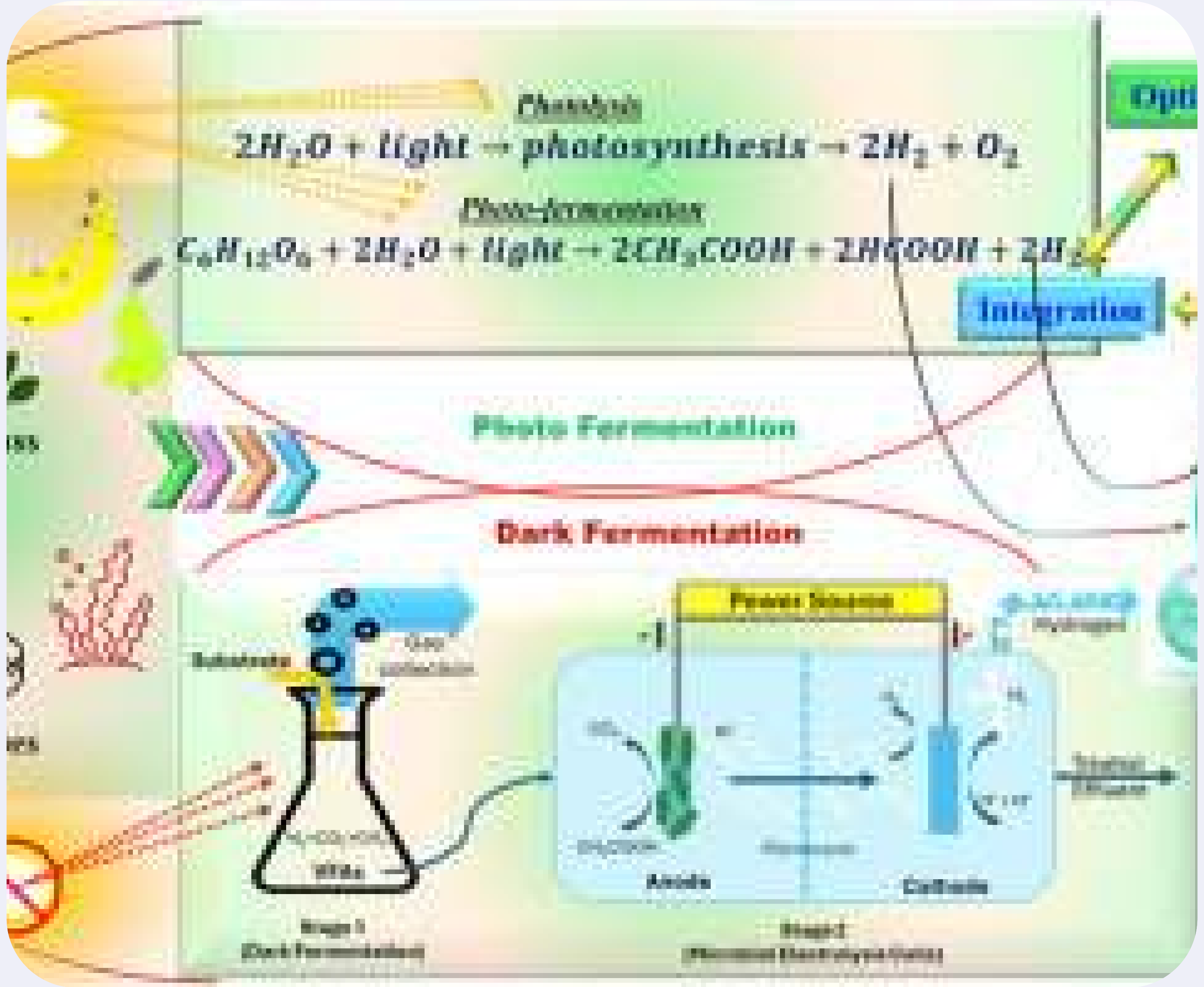
  $2H_2O_{(l)} + 2e^- \longrightarrow H_{2(g)} + 2OH_{(aq}$

- Anode reaction:

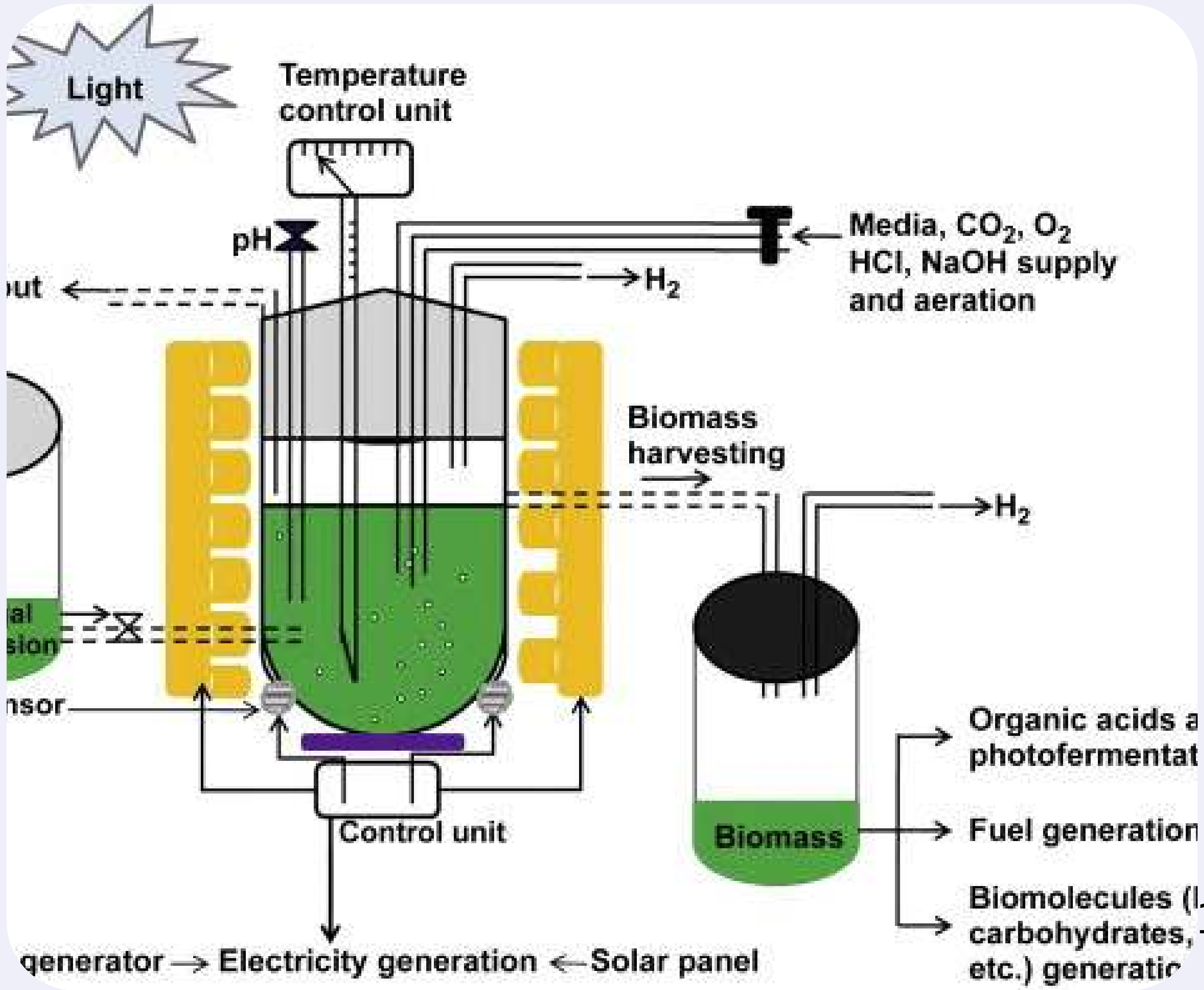
  $2H_2O_{(l)} \longrightarrow O_{2(g)} + 4H^+_{(aq)} + 4e^-$

Biological processes

MICROBIAL BIOMASS CONVERSION



PHOTOBIOLOGICAL HYDROGEN PRODUCTION



Stockage & transport

STORAGE OF HYDROGEN

Compressed Gas Storage

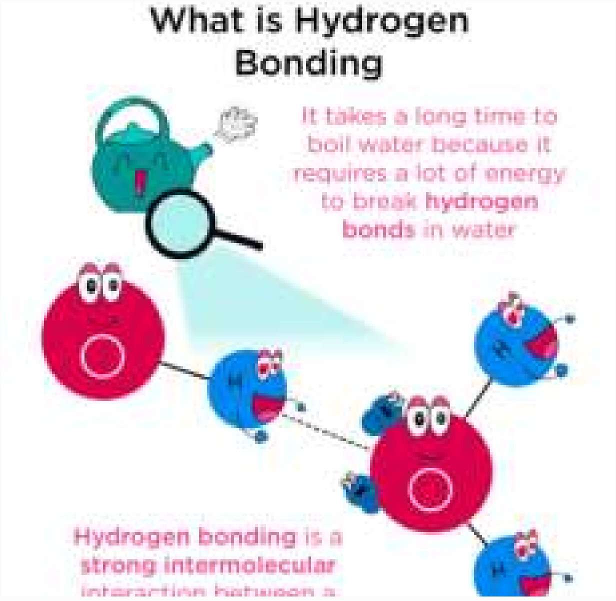
Hydrogen is stored at high pressures (typically 350–700 bar) in reinforced tanks. This method is widely used in fuel cell vehicles due to fast refueling, though it offers low volumetric energy density and requires strong, heavy containers.

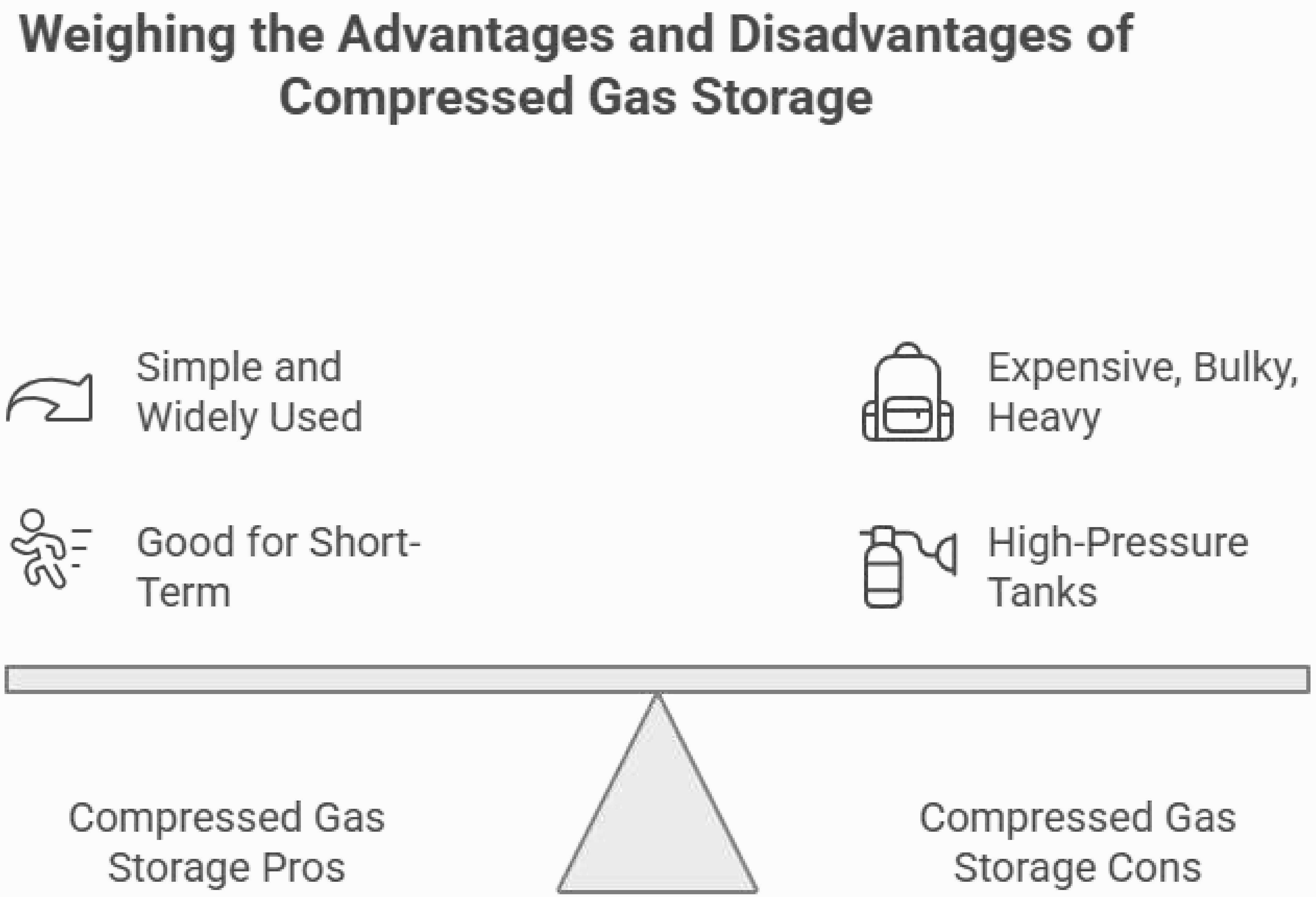
Liquid Hydrogen (Cryogenic)

Hydrogen is cooled to −253°C to become a cryogenic liquid. This increases its energy density by volume but requires insulated tanks and energy-intensive liquefaction. Used in aerospace and for long-range storage.

Material-Based Storage (Hydrides & Carriers)

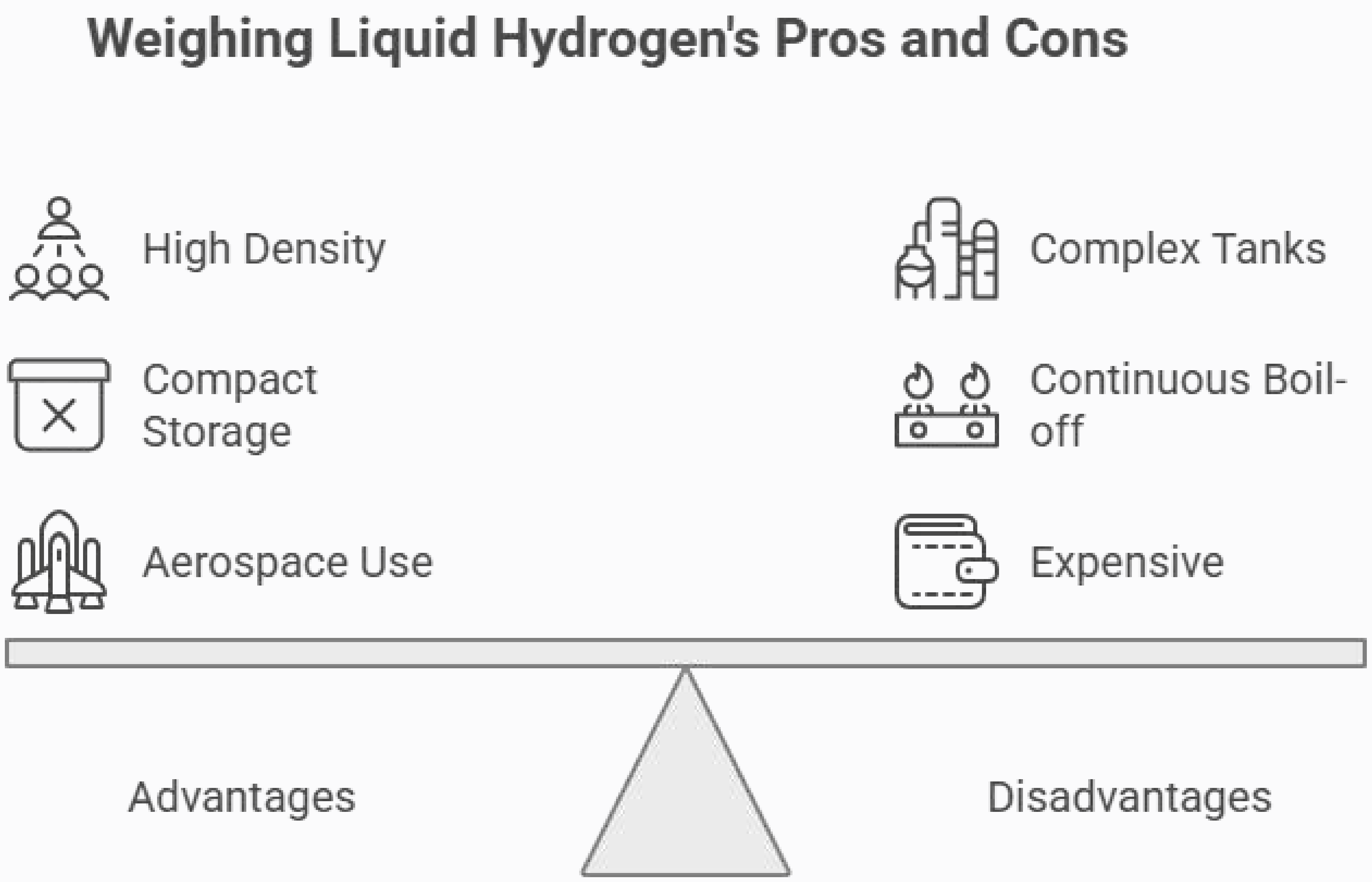
Hydrogen is stored by chemically bonding with metals or materials to form hydrides. This method offers compact, safe storage but requires heat to release the hydrogen, limiting rapid use and reducing overall efficiency.





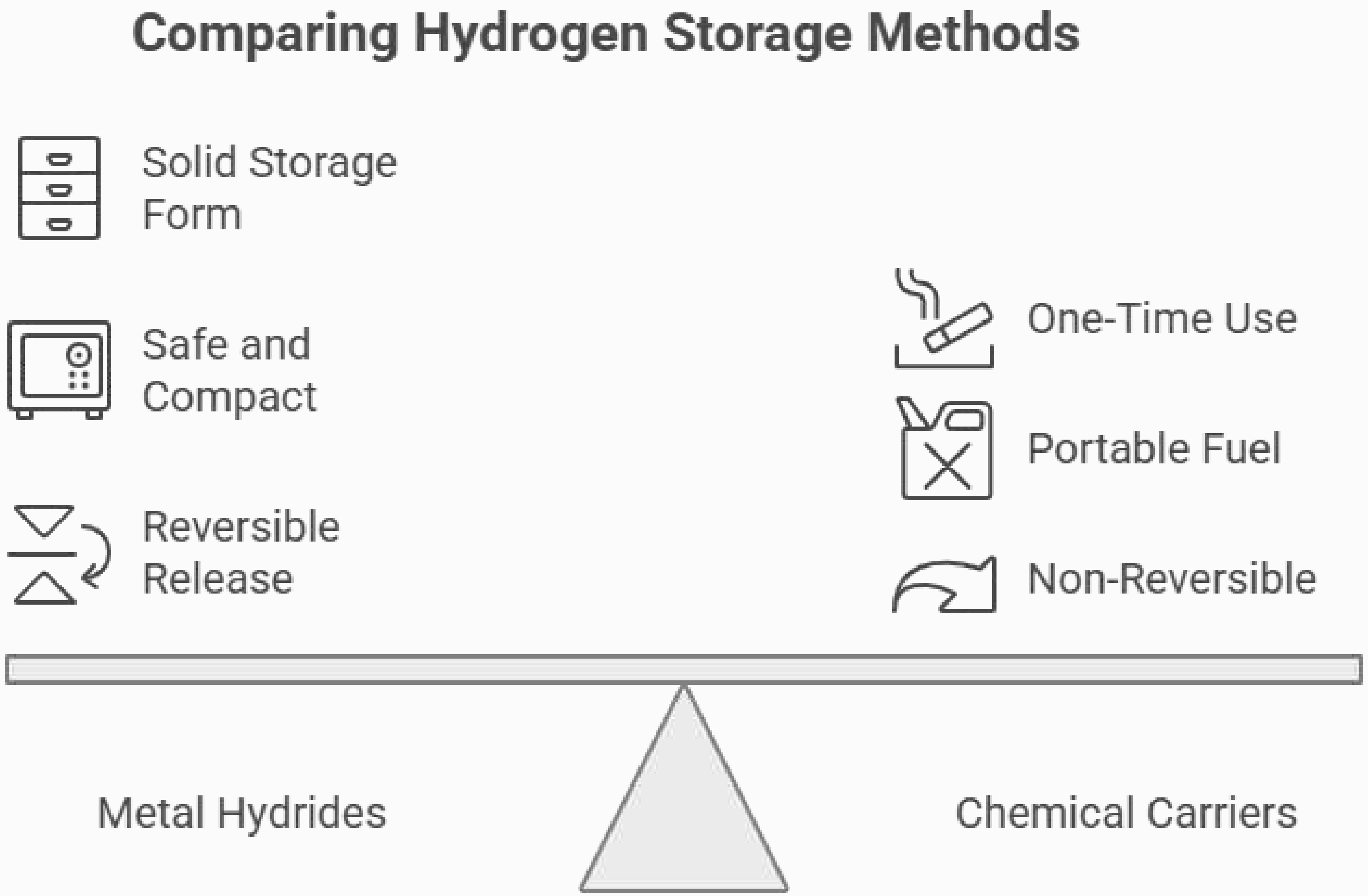
Compressed Gas Storage

Pros and Cons



Liquid Hydrogen (Cryogenic)

Pros and Cons



Material-Based Storage (Hydrides & Carriers)

Pros and Cons

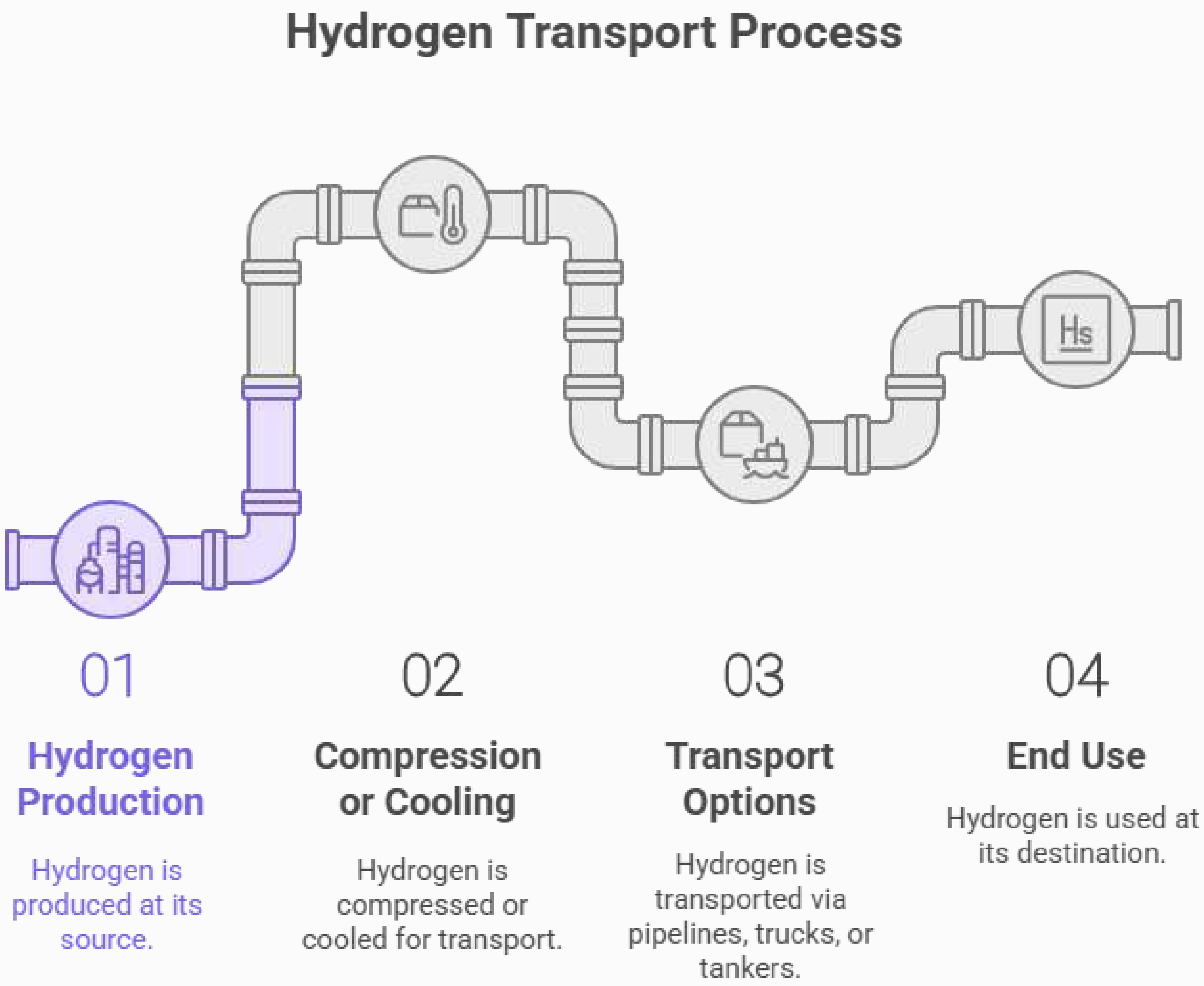
Transportation

Unlike electricity and other gas , hydrogen must be physically transported from its production site to where it is needed.
Due to its low volumetric density and very small molecular size, hydrogen presents unique challenges:

It tends to leak easily

It can cause embrittlement

Liquefaction (Energie Lost)



Transportation O Hydrogen

Tube Trailers

Hydrogen gas is compressed to 200–500 bar and loaded into long steel or composite tubes mounted on trucks.

Flexible and simple for small volumes.
Limited payload (usually <1 tonne per trailer), expensive per kg, and energy required for compression.

Cryogenic Liquid Trucks

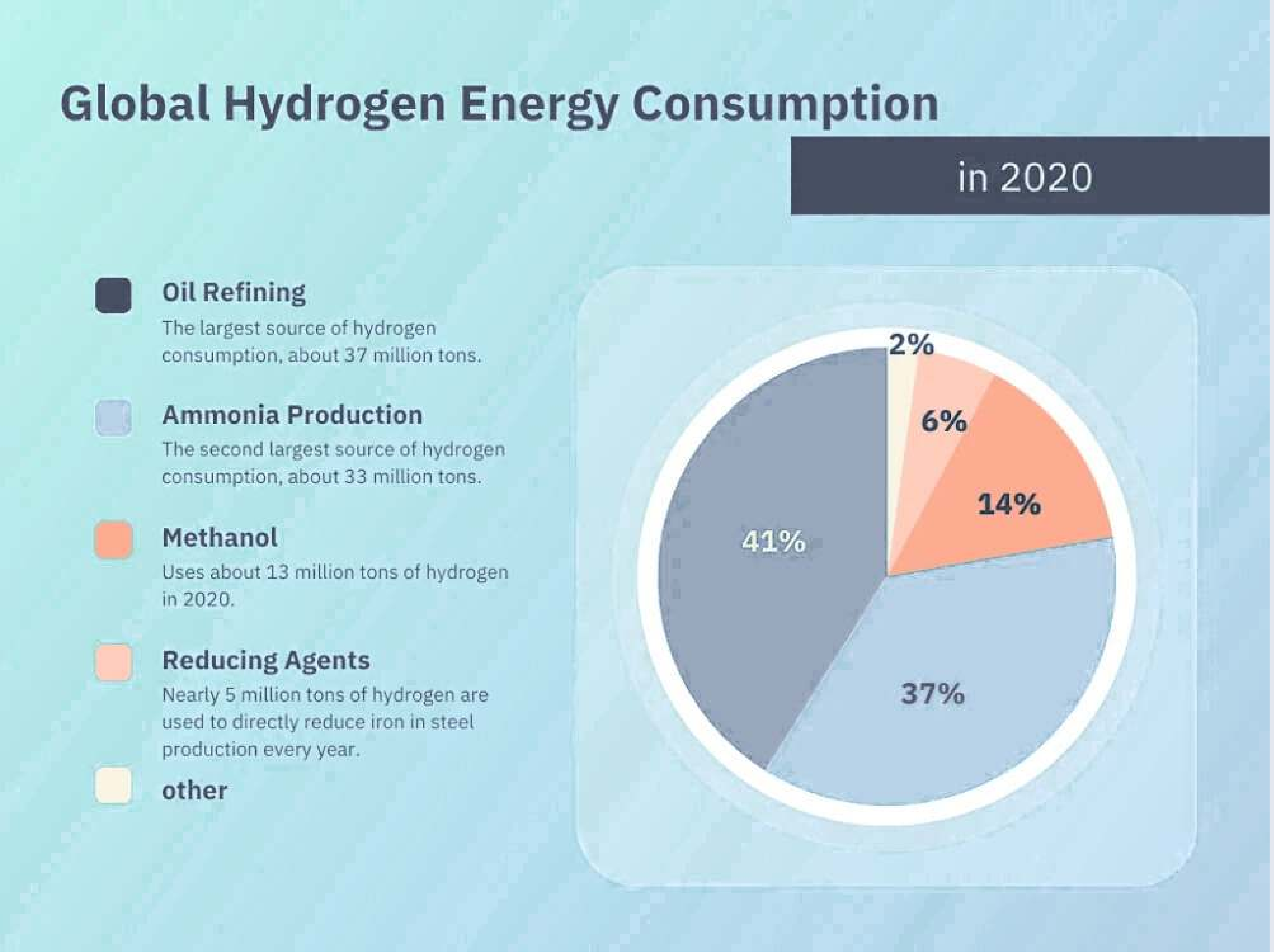
Hydrogen is cooled to −253°C and transported as a cryogenic liquid in insulated tankers
Higher volumetric density than gas; more efficient over distance.
Liquefaction uses ~30–40% of H_2's energy; boil-off losses occur over time; complex infrastructure.

Pipelines

Hydrogen flows through high-grade pipelines, similar to natural gas.
Regional supply to industrial clusters (refineries, steel plants)
Cost-effective and continuous for large volumes once built.

Global Production
&
Consumption Trends

Global Hydrogen Production Overview



Global hydrogen production

Hydrogen production reached almost 100 Mt in 2024

Top producers

China, USA, India, and EU.

Industrial use

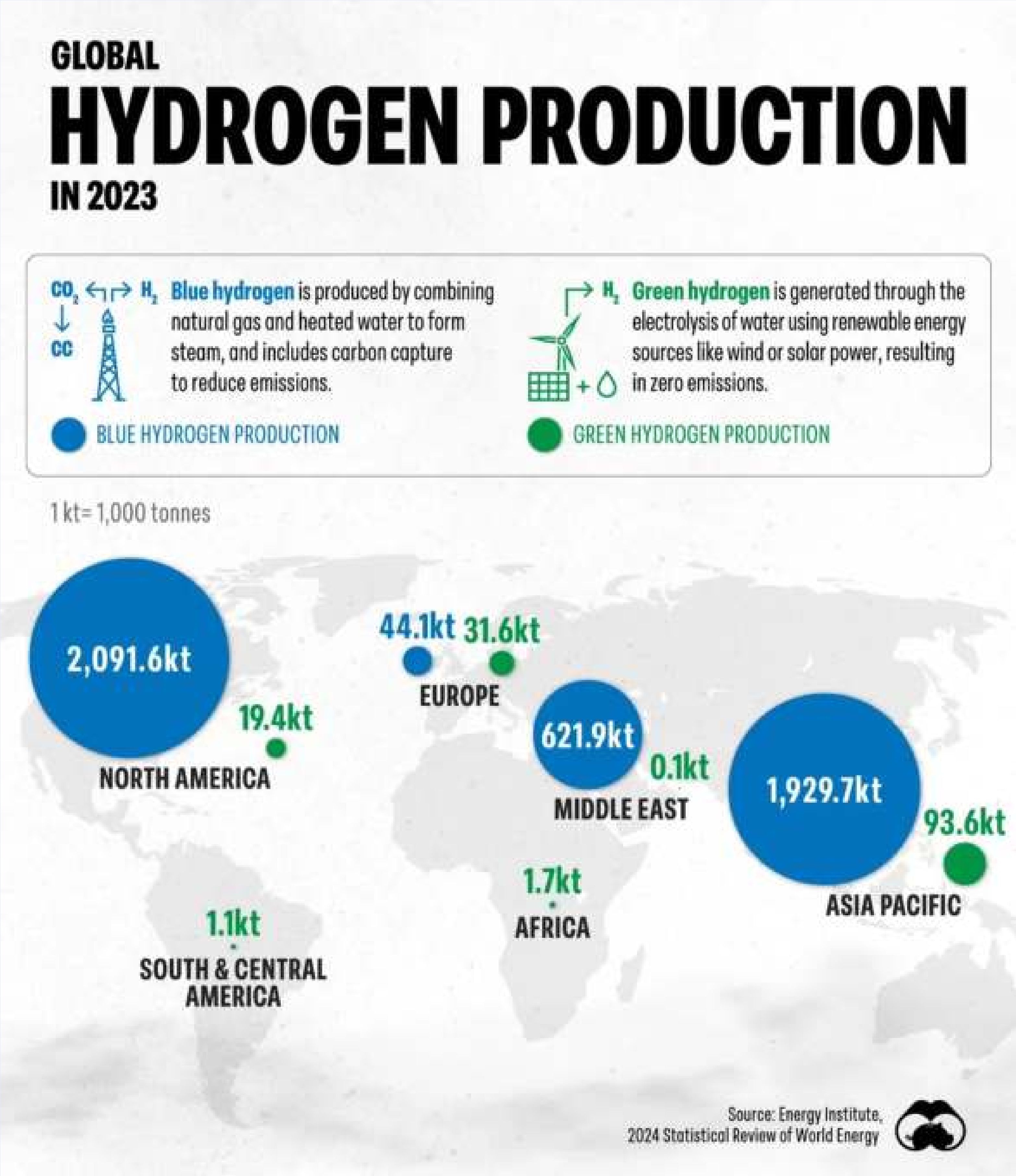
Refining (41%), ammonia (37%), methanol (14%), steel (5%), other: 3%

Regional Trends

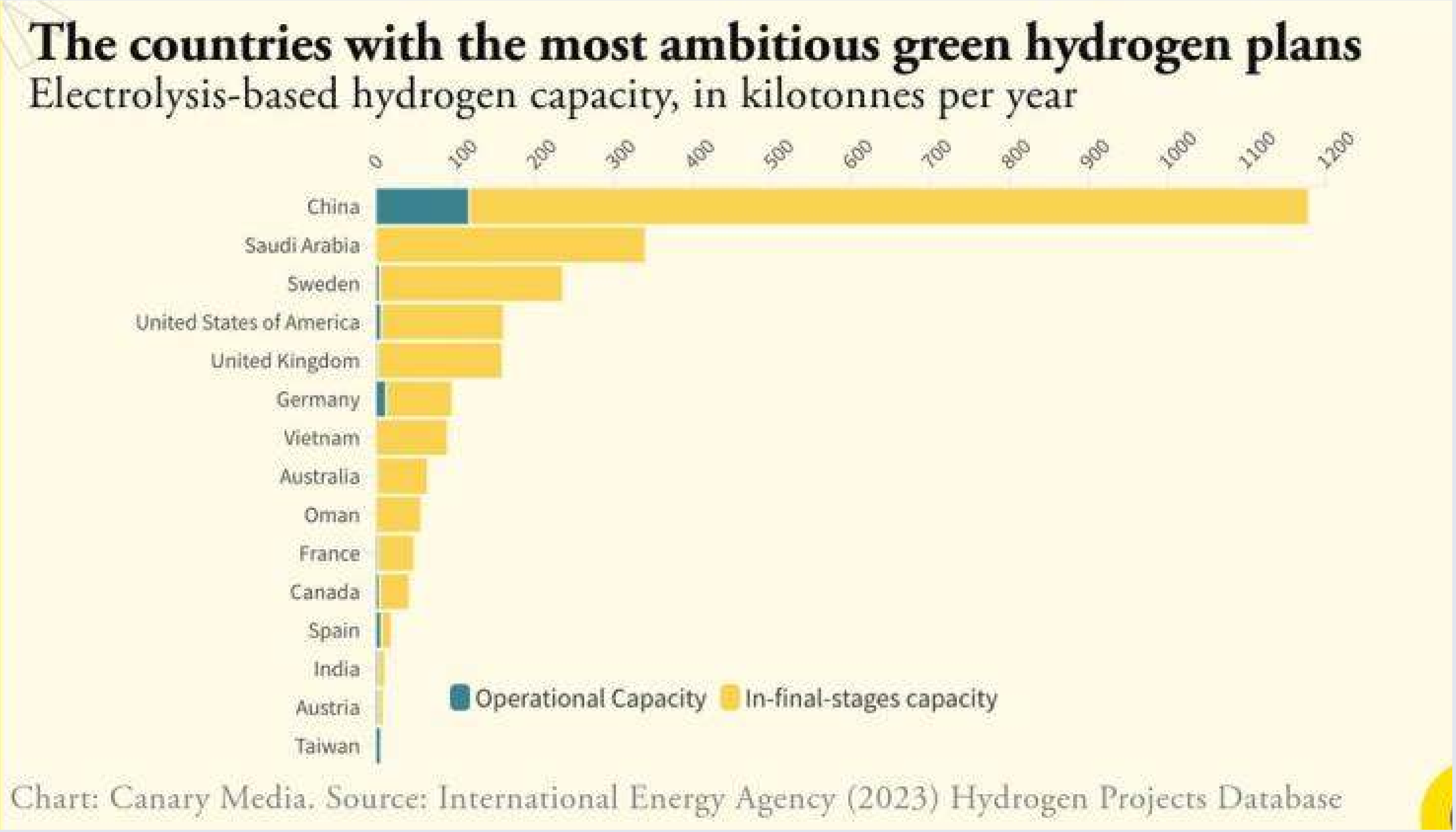
Asia leads in production and technology adoption.

In North America, focus is on blue hydrogen

The EU invests heavily in green hydrogen, with projects like the “Hydrogen Backbone” pipeline and



Regional Trends



Economic Outlook of the Hydrogen Sector

Economic Reality of Hydrogen

he idea of using hydrogen to store and transport renewable energy has been promoted as a major future solution.
However, the economic reality shows that this vision is struggling:

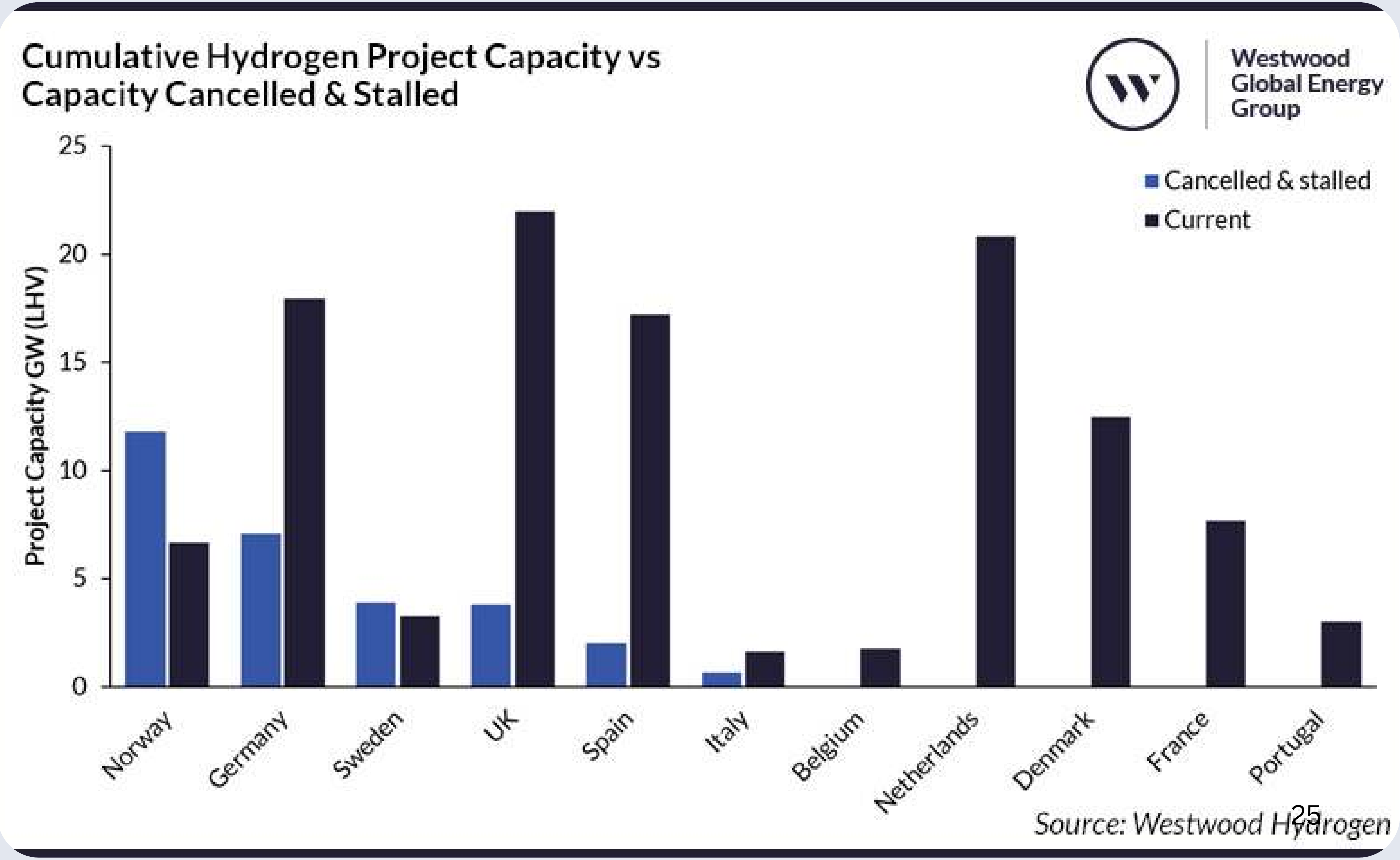
Investors are pulling out	**The stock value of major hydrogen companies has dropped significantly**	Augmentation des investissements

A fifth of projects lost

Hydrogen is central to Europe’s decarbonisation and net-zero goals

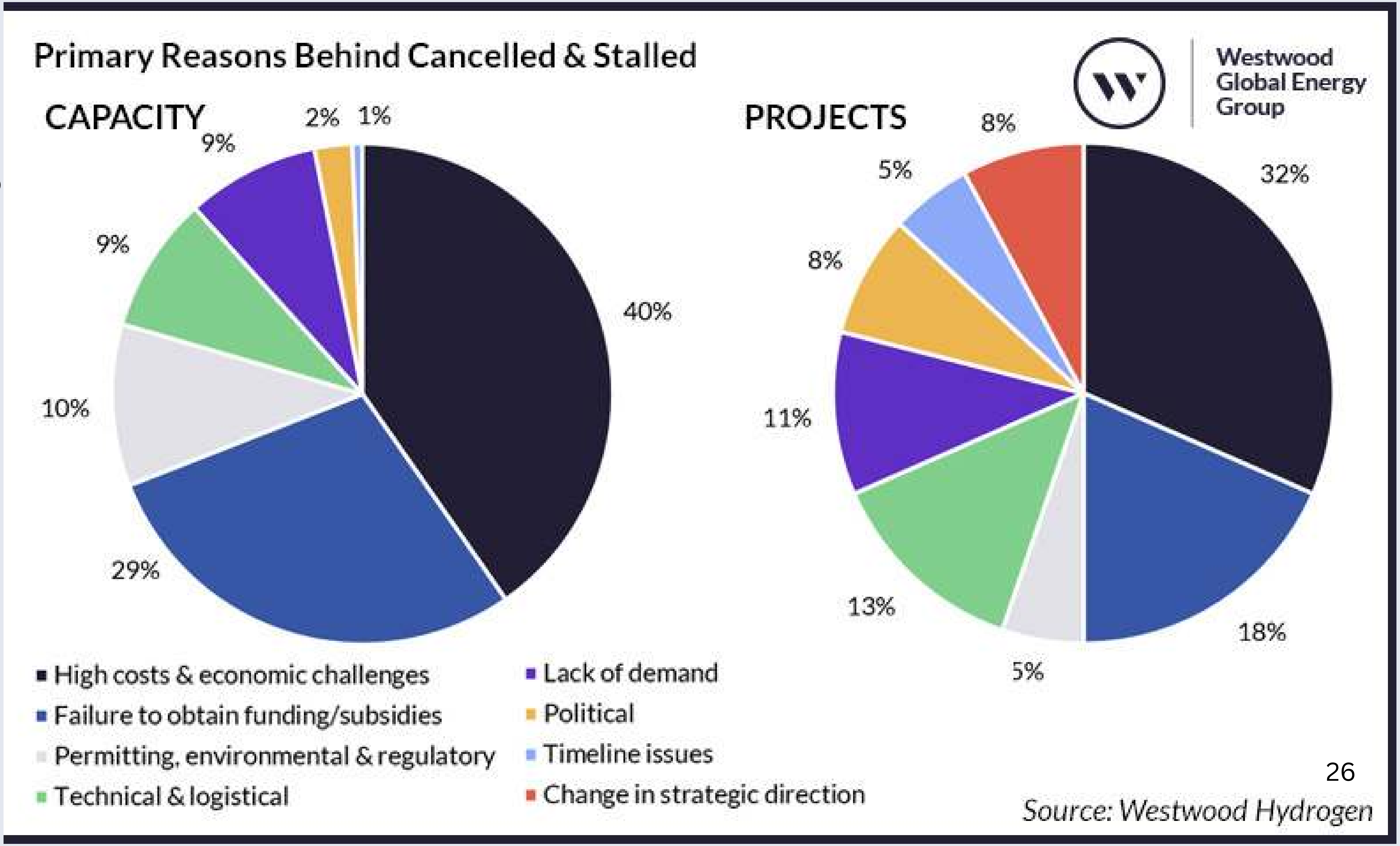
Despite strong support, the industry is facing challenges: 23 projects have been cancelled across 11 major European countries, impacting 29.2 GW 20% of the total pipeline

Current pipeline capacity across Europe is 111.5 GW (LHV), supported by major funding programs like IPCEI (€18.9B) and the EU Innovation Fund (€4.8B), along with national schemes



Primary Reasons Behind Cancelled & Stalled Capacity/Projects

Nearly 80% of cancelled hydrogen capacity is due to purely economic factors (Costs + Funding + Demand)t



Australia: Green Hydrogen Project Abandoned

One of Australia's biggest energy companies has pulled out of plans to build the country's largest green hydrogen plant.

Origin Energy withdraws from the Hunter Valley Hydrogen Hub, initially planned to produce 5,500 tonnes of hydrogen per year from renewable energy.

This decision represents a setback for Australia's green hydrogen ambitions.

Air Products Pulls Out of Green Hydrogen JV Project in Texas

- Air Products has given up on its USD 4.5-billion green hydrogen joint venture in Texas with AES Corporation.
- The project never reached a final investment decision (FID) and the development rights were sold to the partner
- Reason for abandonment: the project did not meet the company’s criteria, such as having an anchor customer and 75% load on existing facilities

Economic Roadblocks Slowing the Hydrogen Industry

High Production Costs

- Green hydrogen requires expensive infrastructure (electrolysers,pipelines, CCS).
- Total project costs often reach tens of billions, making profitability uncertain.

Difficulty Securing Funding

- Developers struggle to obtain the necessary capital or navigate complex funding schemes.
- Even promising projects fail due to unclear or insufficient financial support.

Lack of Market Demand

- Few buyers are currently willing to purchase green hydrogen or derivatives (e.g., green ammonia) at high prices.
- Without long-term offtake agreements, investors cannot justify moving forward.

Global Hydrogen Policies & Strategies

Global Hydrogen Policies & Strategies

Hydrogen policies and strategies are essential because hydrogen is not yet competitive on its own.

Governments and regions use targets, subsidies, regulations, and alliances to make low-carbon or green hydrogen viable and to align it with their climate and industrial goals.

Why policy is needed?

What policies usually do?

Why policies are needed

Cost & Market Barriers

-Green hydrogen is not yet cost-competitive, requiring subsidies to close the price gap.

-Grey hydrogen dominates today because fossil fuels remain artificially cheap.

-Private sector hesitates due to uncertain long-term demand.

Infrastructure Needs

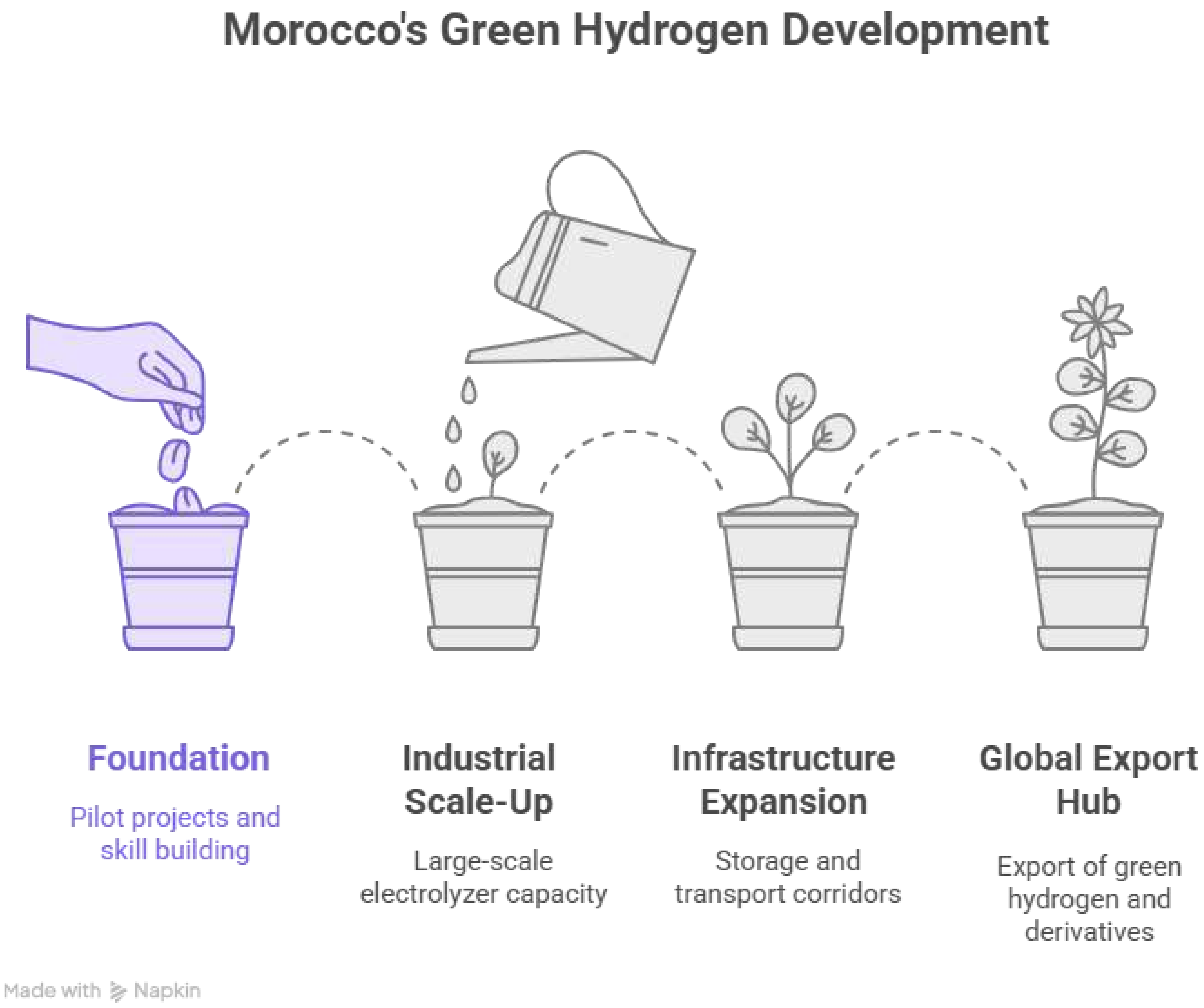
Massive infrastructure is required: pipelines, storage sites, terminals, refueling networks

No hydrogen market can emerge without coordinated national and regional planning.

Standards & Regulation

Governments must define safety standards, certification of green hydrogen, and market rules

International alignment is needed for cross-border hydrogen trade.



Morocco's Policies & Strategy for Green Hydrogen

Morocco aims to become a global leader in green hydrogen, leveraging its strong solar and wind resources.
Hydrogen is integrated into the national energy transition, industrial competitiveness, and export strategy.

Geopolitics of Hydrogen

Strategic Competition

Race for technology leadership

The U.S., EU, Japan, and China compete for leadership in electrolyzer and fuel cell manufacturing

Resource security

China currently dominates the electrolyzer market (50%+), raising dependency concerns for others

Industrial policy rivalry

Access to critical minerals (platinum, iridium) is becoming a geopolitical factor.

Risks and Tensions

Energy nationalism

Developing nations risk being used as low-cost producers without local benefits

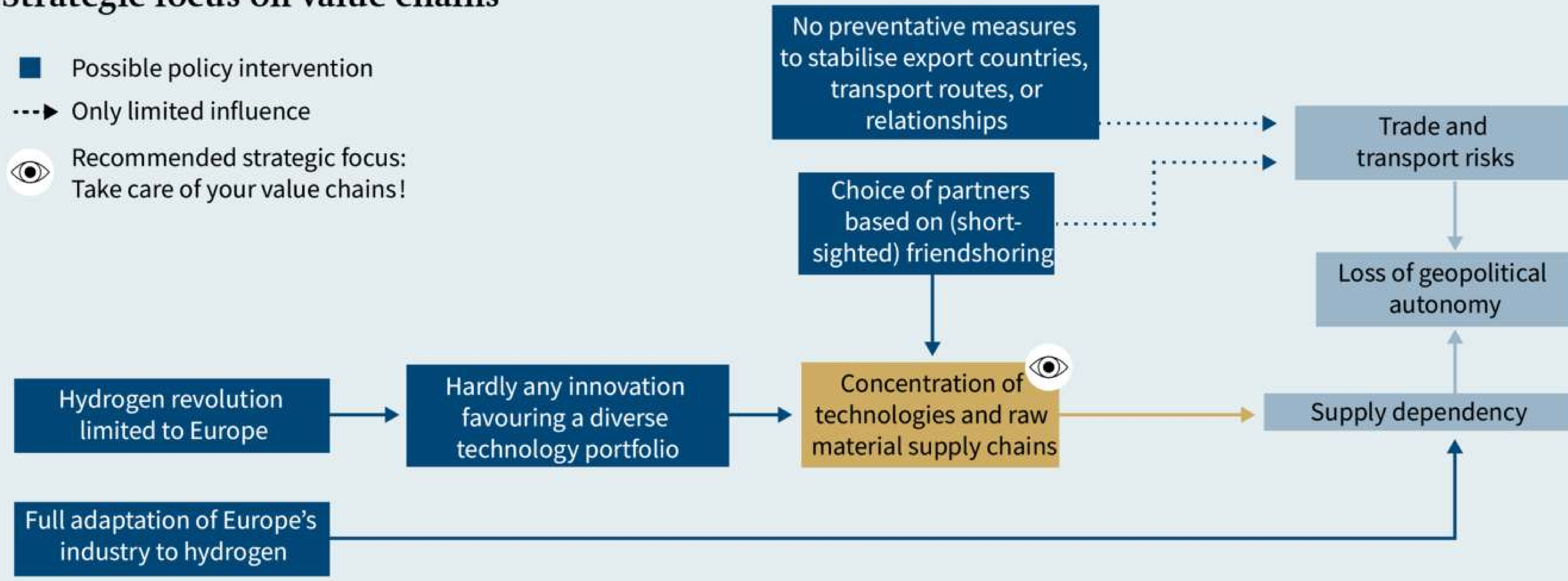
Green colonialism debate

National subsidies and export restrictions could spark trade tensions

Unequal access to technology

Equitable technology transfer and partnerships will be crucial to avoid new inequalities

Impact chain for “Hydrogen (In)Dependence” scenario: Strategic focus on value chains



Source: Scenarios “The Geopolitics of Hydrogen”

Applications & Case Studies of Hydrogen

MAJOR APPLICATIONS OF HYDROGEN

Transportatio n

Decarbonizing heavy transport (trucks, buses, trains, maritime, aviation) & light-duty vehicles.

Heavy Industry

Producing green steel, ammonia, cement, and high-temperature heat.

Buildings & Heating

Producing green steel, ammonia, cement, and high-temperature heat.

Power Generation & Storage

Long-term energy storage, grid balancing, hydrogen turbines.

NEOM Green

Hydrogen Project – Saudi Arabia

- One of the world’s largest green hydrogen projects.
- Uses massive solar + wind capacity to produce green ammonia.
- Aim: export to global markets (especially Asia).
- Shows how renewable-rich regions can scale H_2 production.

Japan – Hydrogen in Transport and Energy

- Japan pioneers hydrogen mobility (Toyota Mirai, H_2 buses).
- Hydrogen used for power generation and residential fuel cells.
- Shows early adoption of hydrogen across multiple sectors.

Germany – Hydrogen in Steelmaking

(HYBRIT / SALCOS)

- Projects to replace coal in steel production using green hydrogen.
- Goal: near-zero-carbon steel.
- Shows hydrogen as a key solution for hard-to-abate industries

Environmental and energy challenges

Energy challenges

High production costs

Hydrogen production costs, especially for green hydrogen, remain higher than fossil fuels.

Costly infrastructure

Developing production plants requires substantial investment.

Complex storage and transportation

Hydrogen’s low volumetric energy density requires high pressure or cryogenic storage, making transport challenging.

Energy challenges

High production costs

It emits large amounts of CO_2, which fails to meet climate goals.

Blue hydrogen

It reduces emissions, but still depends on fossil resources, and carbon capture is never 100% effective.

Green hydrogen

Clean, but highly energy-intensive and requires large amounts of water, which can be problematic in waterscarce regions

Future Outlook and Strategic Perspectives

Global Outlook for Hydrogen Deployment

- **Rapid scale-up expected by 2030** :

Hydrogen demand could reach 175–200 Mt/year by 2050, compared to ~95 Mt in 2023. Growth will be driven by industry, transport, and power balancing.

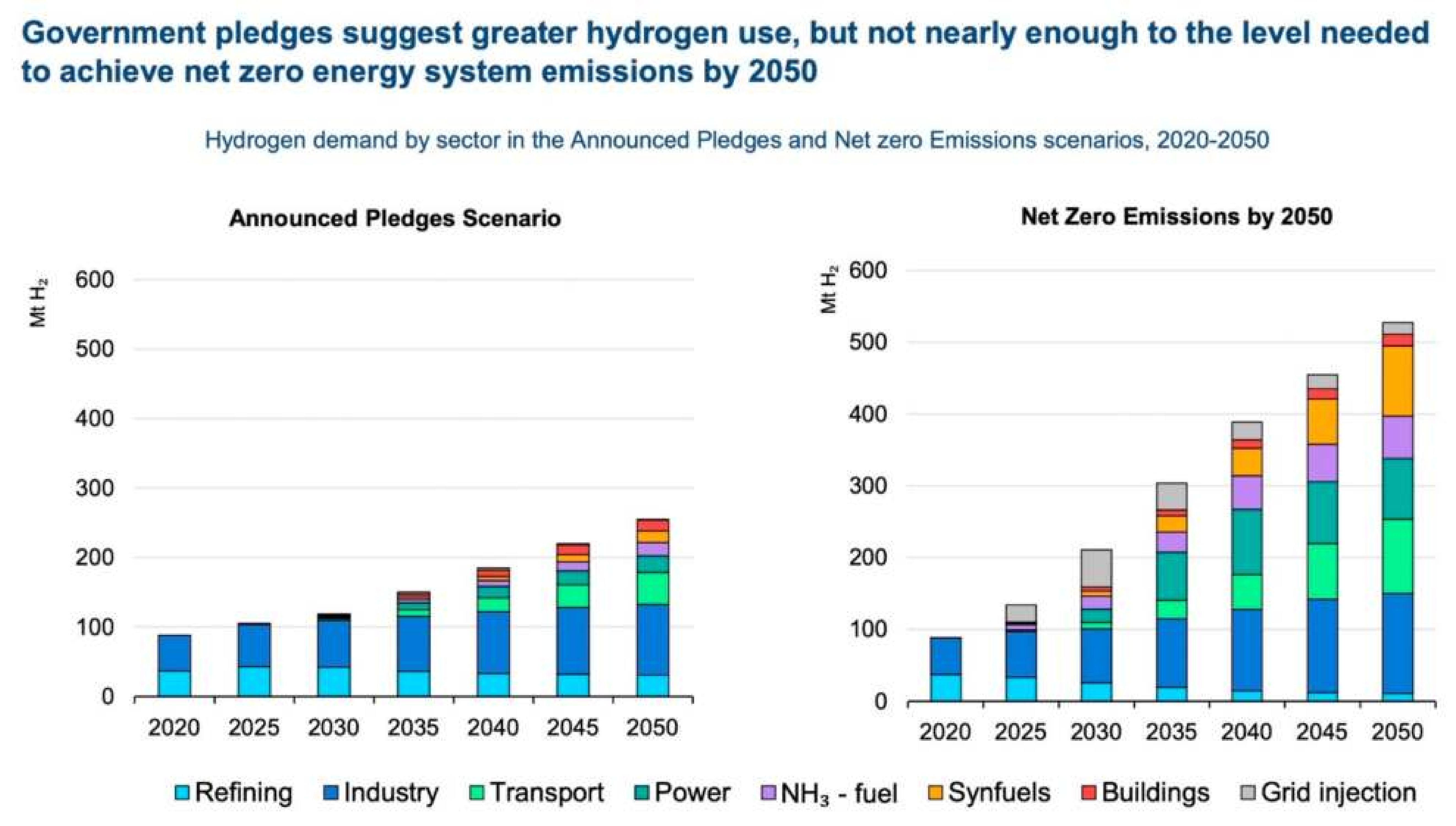
- **Cost reductions from technology learning :**

Electrolyser CAPEX expected to fall 50–70% by 2030, enabling green H_2 price convergence with grey hydrogen in regions with cheap renewables.

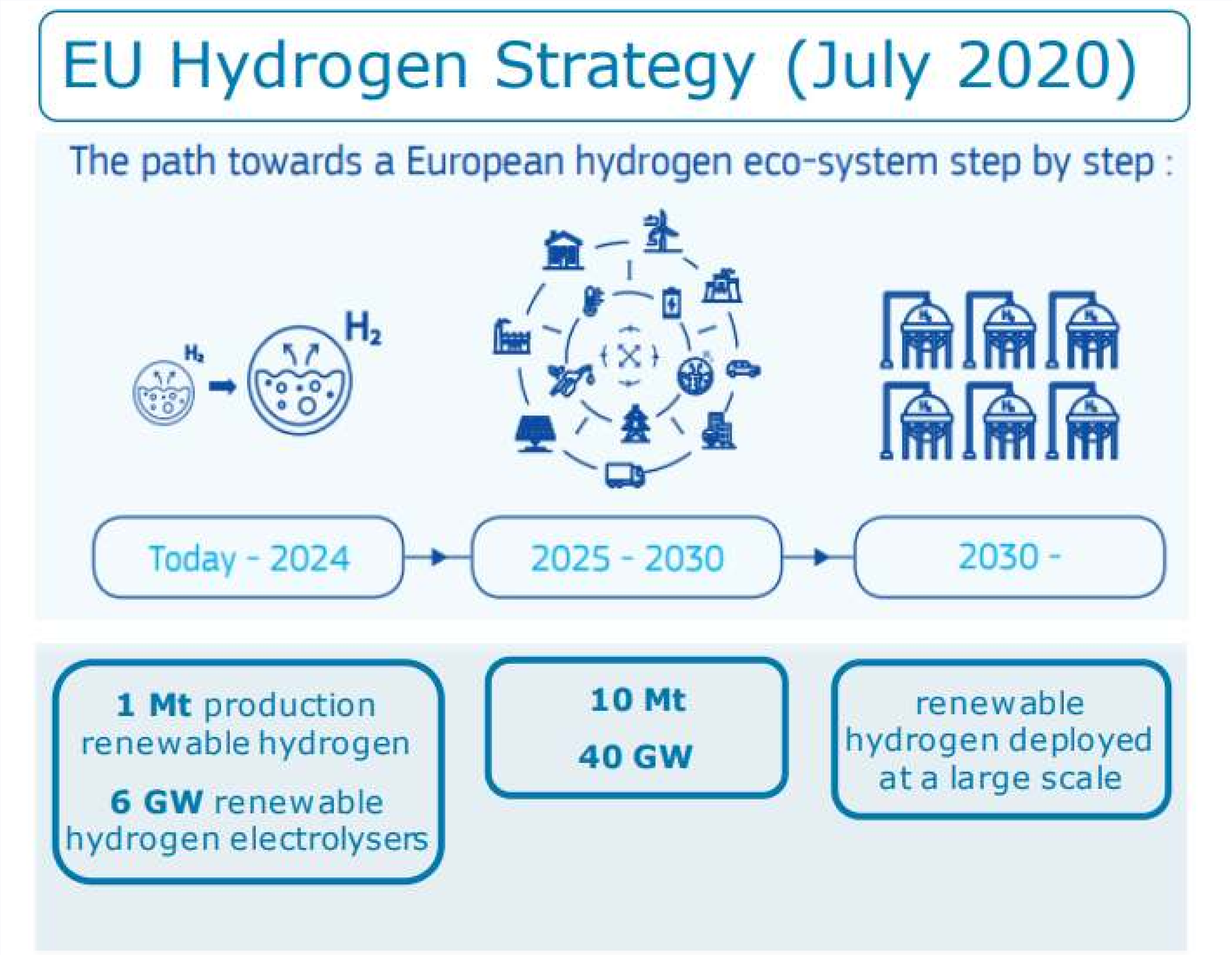
- **Shift from pilot projects to large-scale hydrogen valleys :**

Over 70 “hydrogen valleys” already planned worldwide, acting as regional integrated ecosystems.

Global Outlook for Hydrogen Deployment



Growth of Green Hydrogen



Conclusion

Hydrogen stands at the intersection of science, engineering, and global energy strategy.
As the **most abundant element**, its fundamental atomic properties translate into high versatility, enabling production, storage, and use across sectors.

While challenges remain cost of production, infrastructure, safety standards ongoing innovations in green hydrogen, fuel cells, and renewable integration position hydrogen as a critical component of tomorrow's energy systems.

It **will not replace all existing sources**, but it will **complement them** where electrification is difficult, especially in industry, mobility, and large-scale energy storage.
Hydrogen is therefore not only a chemical element but a pathway toward a cleaner, more resilient, and technologically advanced energy future.

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