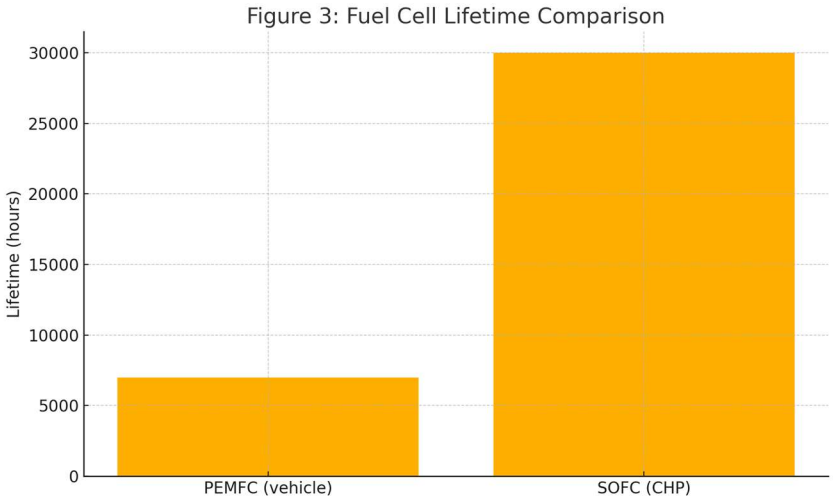
Lifetime comparison of PEMFC and SOFC systems.



Hydrogen Infrastructure and Global Strategies

Hydrogen has emerged as a cornerstone of clean energy systems due to its high energy content and zero-carbon combustion. As a secondary energy carrier, it allows for flexible storage and transportation of renewable energy. Unlike electricity, hydrogen can be stored in large quantities over long periods, making it crucial for seasonal storage and industrial use.

Hydrogen plays a transformative role in sectors that are hard to electrify, including long-haul transport, aviation, heavy industries like steel and cement, and large-scale power backup systems.

1. Hydrogen Pipelines and Distribution Networks

Hydrogen can be distributed in gaseous form via pipelines or in liquid form via trucks and ships. Distribution via pipelines is the most efficient for large volumes. Countries with existing natural gas infrastructure are exploring repurposing pipelines for hydrogen. However, hydrogen can cause embrittlement in metals and has high diffusivity, necessitating upgraded materials.

Dedicated hydrogen pipelines exist in the US (e.g., Gulf Coast H2 Pipeline), Germany, and the Netherlands. The EU's Hydrogen Backbone envisions 40,000 km by 2040, repurposing 69% of current gas pipelines. The system will connect industrial hubs, storage caverns, and import terminals.

2. Hydrogen Refueling Stations

Hydrogen refueling stations (HRS) are essential for the deployment of Fuel Cell Electric Vehicles (FCEVs). They include:

• Storage systems (compressed or liquid hydrogen)
• High-pressure compressors (350–700 bar)
• Pre-cooling units (-40°C for fast fueling)
• Dispensers with safety sensors

HRS can be either centralized (with bulk delivery) or decentralized (with on-site generation). On-site electrolysis allows remote locations to be served with green hydrogen. Global leaders in HRS deployment include:

- Japan: Over 160 stations supporting Toyota Mirai.
- Germany: H2Mobility aims for 400+ stations by 2025.
- USA: Primarily California with >50 HRS.

3. Green Hydrogen Economy

Green hydrogen is produced using renewable-powered electrolysis, unlike gray hydrogen (from natural gas) or blue hydrogen (with carbon capture). Producing 1 kg of hydrogen via electrolysis requires ~50–55 kWh of electricity.

Electrolyzer types:
• Alkaline (AEL): mature and cost-effective.
• PEM (Proton Exchange Membrane): fast response, compact design.
• Solid Oxide Electrolysis Cells (SOEC): high temperature, higher efficiency.

The cost of green hydrogen was ~4–6 $/kg in 2020. It is expected to fall below $2/kg by 2030 with scale-up and cheaper renewables.

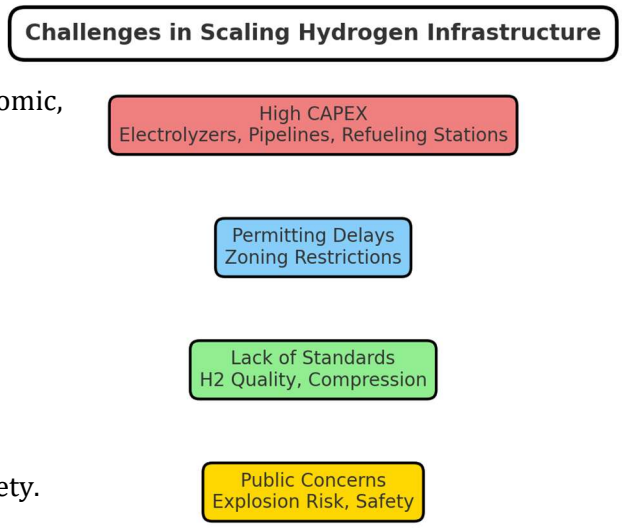
5. National Hydrogen Strategies

• Japan: Focus on import-based hydrogen economy; uses ships to bring liquid hydrogen from Australia. Target: 3 Mt H2/year by 2030.

• Germany: Focus on green hydrogen production and cross-border trade within Europe. €9 billion investment includes 5 GW domestic electrolysis.

• USA: The Hydrogen Energy Earthshot aims for '1 1 1' – $1 per 1 kg in 1 decade. DOE supports regional clean hydrogen hubs (H2Hubs). Emphasis on innovation, job creation, and emissions reduction.

6. Challenges in Infrastructure Scaling



Scaling hydrogen infrastructure faces technical, economic, and regulatory challenges:
• High CAPEX for electrolyzers, pipelines, and refueling stations.
• Permitting delays and zoning restrictions.
• Lack of harmonized standards for H2 quality and compression.
• Public concerns over explosion risk and storage safety.

Solutions involve regulatory reforms, international certification schemes, public-private partnerships, and robust R&D investment.

7. International Collaborations & Future Outlook

Global efforts are coordinated by platforms such as:
• Hydrogen Council: 140+ companies across the value chain.
• Mission Innovation Hydrogen Valley Platform: funding regional hubs.
• IEA & IRENA: Provide roadmaps and analysis for policy support.

Future scenarios involve:
• Hydrogen trade routes (Australia to Japan, North Africa to EU).
• Hydrogen derivatives (e-fuels, ammonia).
• Full integration with renewable grids and storage systems.

Hydrogen will be a cornerstone in achieving Net-Zero goals by 2050.

Figures

Figure 1: Hydrogen stations in leading countries.

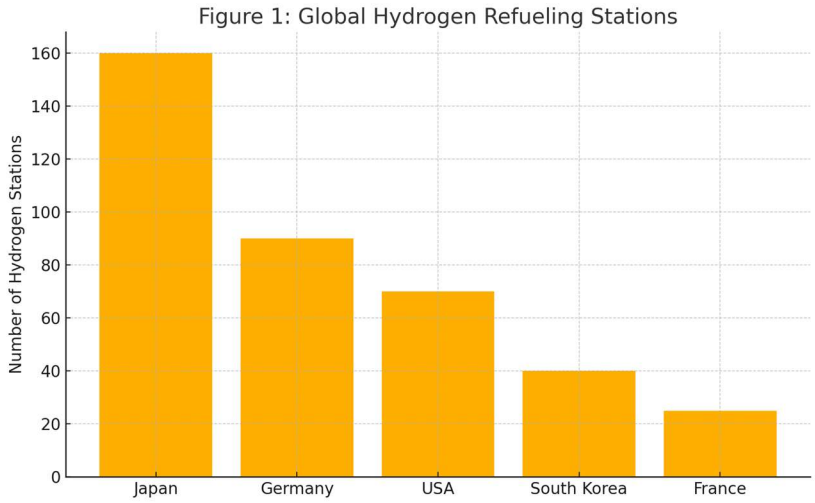


Figure 2: Growth of hydrogen pipeline infrastructure in the EU.