Types Of Hydrogen Based On Production Pathways

→ Green Hydrogen: CI: 0 KgCo2e/KgH2
Produced via electrolysis using renewable energy (solar, wind, etc.). Zero-carbon process..

→ Blue Hydrogen: CI: 1.5-8 KgCo2e/KgH2
Produced via natural gas reforming with carbon capture and storage (CCS) to reduce emissions.

→ Grey Hydrogen: CI: 23-25 KgCo2e/KgH2
Produced via natural gas reforming without CCS, emitting CO2.

→ Turquoise Hydrogen: CI: 2-14 KgCo2e/KgH2
Produced via methane pyrolysis, yielding solid carbon as a byproduct.

→ Pink Hydrogen: CI: 0-1 KgCo2e/KgH2
Produced via electrolysis powered by nuclear energy.

→ Brown Hydrogen: CI: 16-20 KgCo2e/KgH2
Produced via natural gas reforming with carbon capture and storage (CCS) to reduce emissions.

→ Gold Hydrogen: CI: 1-3 KgCo2e/KgH2
Produced via natural gas reforming without CCS, emitting CO2.

Hydrogen Production Technologies

PEM (Proton Exchange Membrane):
High efficiency, expensive. **TRL: 8 ARL:7 Cost: $5-$6/KgH2**

Alkaline:
Lower cost, established technology. **TRL: 9 ARL:8 Cost: $5-$10/KgH2**

SOEC (Solid Oxide Electrolysis Cell):
High-temperature process, suitable for integration with waste heat. **TRL: 6 ARL: 5 Cost: $4-$8/KgH2**

Steam Methane Reforming (SMR):
Converts methane and steam to hydrogen; common but emits CO2. **TRL: 9 ARL: 8 Cost: $2-$3/KgH2**

Autothermal Reforming (ATR):
Similar to SMR but uses oxygen and allows easier integration with CCS. **TRL: 8 ARL: 7 Cost: $1-$2/KgH2**

Methane Pyrolysis:
Decomposes methane into hydrogen and solid carbon. **TRL: 6 ARL: 4 Cost: $1-$2/KgH2**

Biomass Gasification:
Renewable but feedstock dependent. **TRL: 6 ARL: 5 Cost: $1-$2/KgH2**

Photocatalytic Splitting:
Early Stage but promising for green hydrogen **TRL: 3 ARL:3 Cost: $10-$15/KgH2**

Nuclear-Thermal Hydrogen Production
Uses heat from nuclear reactors to drive water-splitting reactions **TRL: 6 ARL:5 Cost: $2-$4/KgH2**

Storage Methods

Compressed Gas:
Stored in high-pressure tanks (350–700 bar). **Cost $1M-$40M**

Liquid Hydrogen:
Cooled to -253°C; dense but energy-intensive. **Cost $50M-$80M**

Metal Hydrides:
Absorbed and released from metal alloys. **Cost $10M-$90M**

Ammonia (NH_3):
Hydrogen carrier; easier storage and transport. **Cost $30-$80M**

LOHCs
(Liquid Organic Hydrogen Carriers):
Hydrogen bound to liquid molecules for safer handling
Cost $5M-$50M

Applications

Energy Storage:
Stores excess renewable energy for grid balancing.

Fuel Cells:
Converts hydrogen to electricity (e.g., PEMFC, SOFC).

Transport: Hydrogen cars (FCEVs):
Toyota Mirai, Hyundai Nexo. Trucks, buses, trains, and aviation (hydrogen planes).

Industrial Uses:
Steel production (direct reduction of iron ore with hydrogen). Chemical manufacturing (ammonia, methanol).

Power Generation:
Hydrogen turbines in power plants. Blending hydrogen with natural gas.

Advantages

- Zero emissions when used in fuel cells.
- High energy density (3x gasoline by mass).
- Potential to decarbonize hard-to-abate sectors.

Challenges

Cost
Green hydrogen costs $3–7/kg; needs to drop below $2/kg for competitiveness.

Infrastructure
Limited refueling stations, transport, and storage facilities.

Energy Losses:
Conversion processes (e.g., electrolysis, compression) reduce efficiency.

Material Durability:
Hydrogen embrittlement in pipelines and storage tanks.

Transportation Options

Pipelines:
Existing natural gas pipelines can be retrofitted. **Cost: $50M-$500M**

Cryogenic Tanks:
For liquid hydrogen transport. **Cost:$10M-$150M**

Ammonia Shipping:
Ammonia as a carrier for hydrogen export. **Cost: $50M-$150M**

Key Policies and Incentives

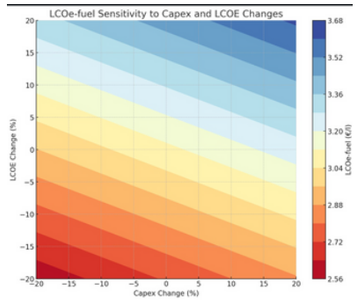
Inflation Reduction Act (IRA):
- Offers tax credits of up to $3/kg H_2 for green hydrogen production, depending on the carbon intensity (CI) of the hydrogen produced.
- Additional funding supports hydrogen hubs and infrastructure development.
- Focused on scaling green hydrogen and deploying CCS for blue hydrogen.

European Hydrogen Strategy
- Targets the production of 10 million tons of renewable hydrogen per year by 2030.
- Provides subsidies for electrolysis projects and funding for hydrogen infrastructure (e.g., refueling stations and hydrogen pipelines).
- Strong emphasis on cross-border cooperation and a hydrogen backbone for Europe.

Japan's Hydrogen Roadmap:
- Japan plans to import hydrogen as ammonia from countries like Australia to meet domestic energy needs.
- Targets 20% hydrogen blending in gas turbines by 2030 and substantial expansion of hydrogen refueling stations.

Metrics to Watch

Levelized Cost of Hydrogen (LCOE) and CAPEX/OPEX:



Production Cost:

- **Green:** $3-$7/Kg H2
- **Blue:** $2-$3/Kg H2
- **Grey:** $1-$2/Kg H2
- **Turquoise:** $3-$5/Kg H2
- **Pink:** $2-$5/Kg H2
- **Brown:** $1-$3/Kg H2
- **Gold:** $1-$5/Kg H2