NREL
Transforming ENERGY

Hydrogen Systems Analysis

The Gulf Coast Hydrogen Ecosystem: Opportunities and Solutions

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April 17, 2024

NREL at-a-Glance

3,675

Workforce, including

211 postdoctoral researchers

152 graduate students

90 undergraduate students

World-class

facilities, renowned technology experts

More than 1000

Partnerships

with industry, academia, and government

Campus

operates as a living laboratory

~as of 9/30/2023

NREL Research Spans MAKE/MOVE/STORE/USE

Make

R&D on Advanced Production Technologies

Move

Infrastructure Research & Large Scale Demonstration and Deployment

Store

Hydrogen Storage Materials and Systems Research

Use

Hydrogen Penetration into Heavy-Duty Transportation Sector

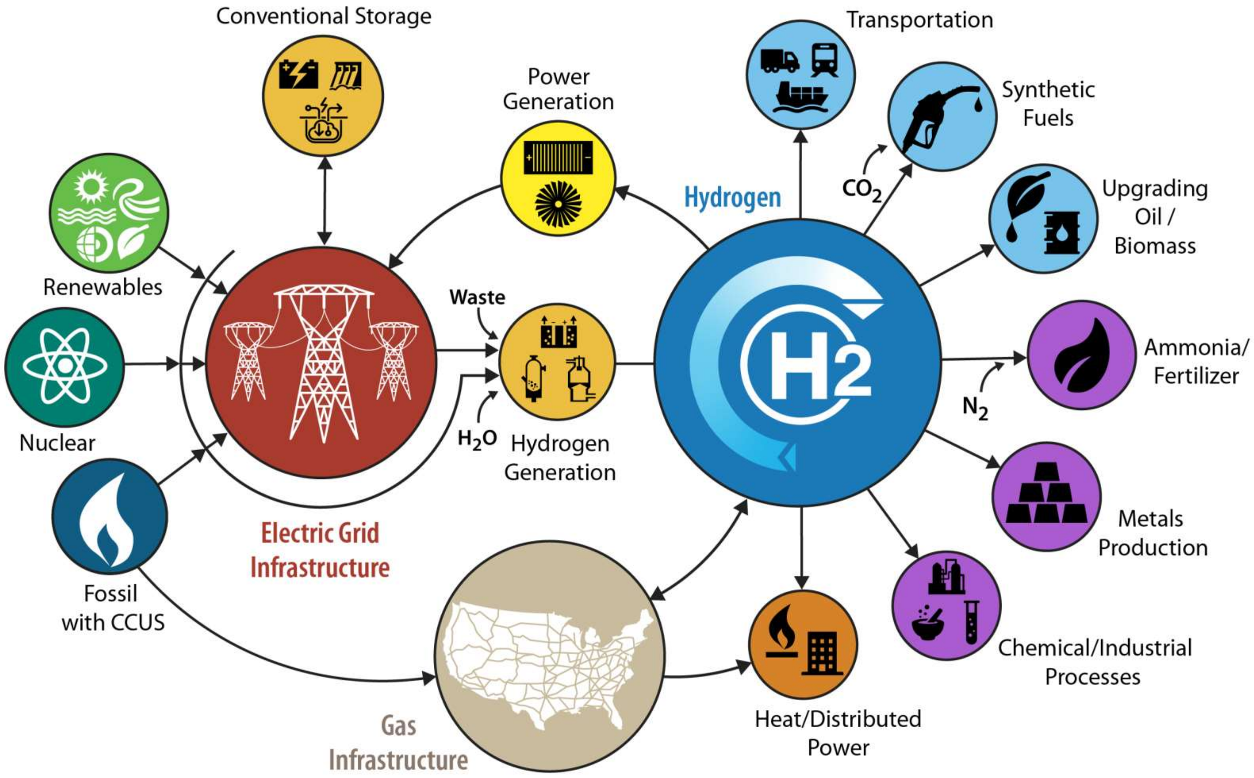
Expanding Low-Carbon Hydrogen Into New End-Use Cases

NREL's FCHT Program Strategy is on Accelerating Progress & Impact

Energy justice and American jobs are considerations that underly all these efforts.

H2@Scale

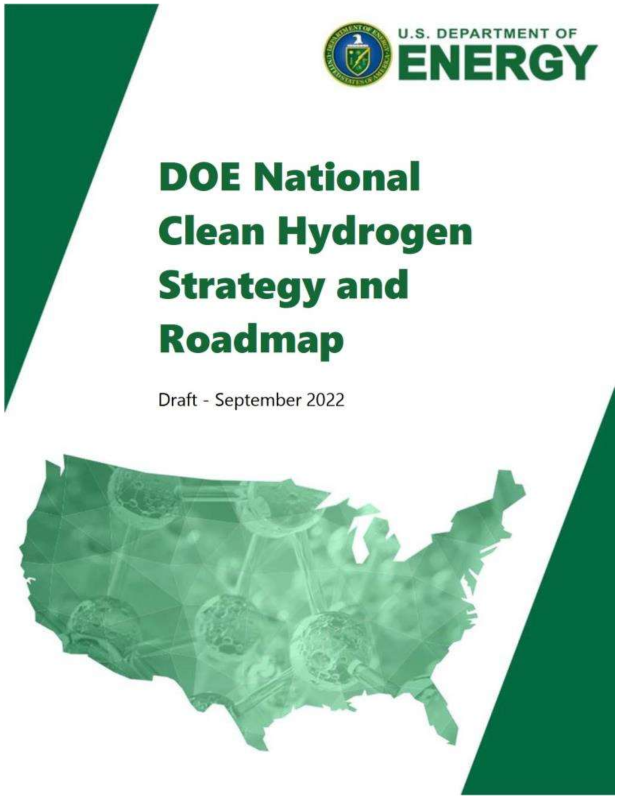
DOE initiative focusing on hydrogen as an energy intermediate.



https://www.energy.gov/eere/fuelcells/h2scale

U.S. Clean Hydrogen Strategy and Roadmap

"Snapshot of hydrogen production, transport, storage, and use in the United States today and the opportunity that clean hydrogen could provide in contributing to national goals across sectors."



U.S. DEPARTMENT OF ENERGY

DOE National Clean Hydrogen Strategy and Roadmap

Draft - September 2022

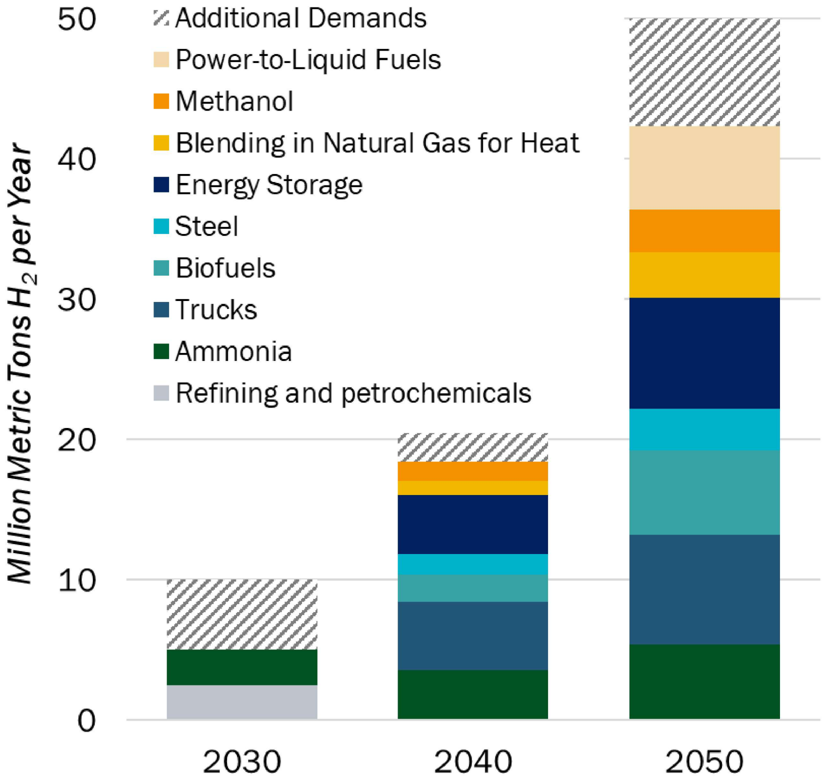
Identifies strategic opportunities for clean hydrogen

- 10 MMT/yr by 2030
- 20 MMT/yr by 2040
- 50 MMT/yr by 2050

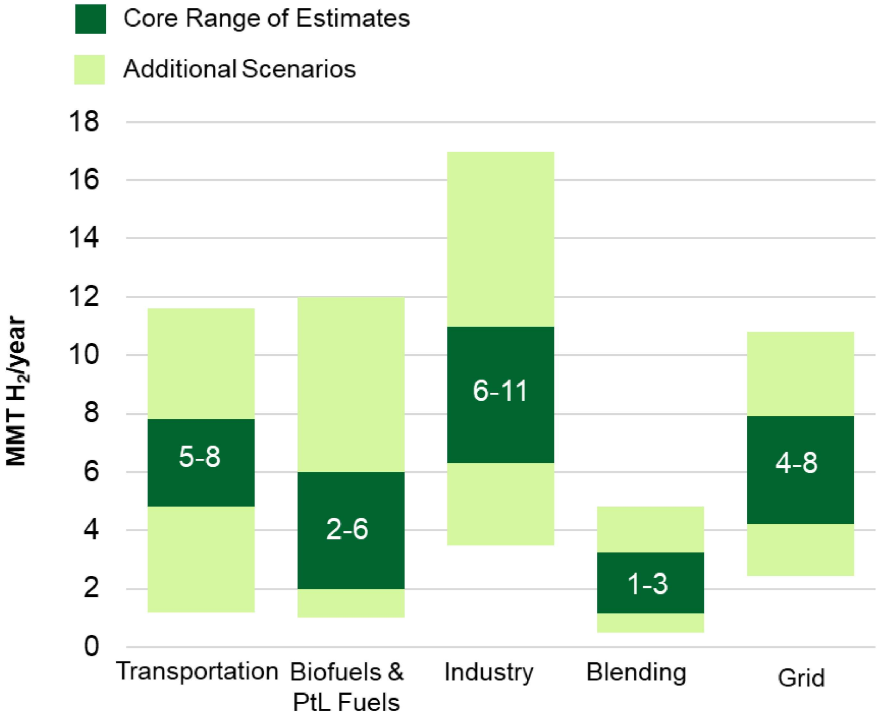
https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

Strategic, High-Impact End Uses
Deployment Opportunities

Deployment Estimates across Applications

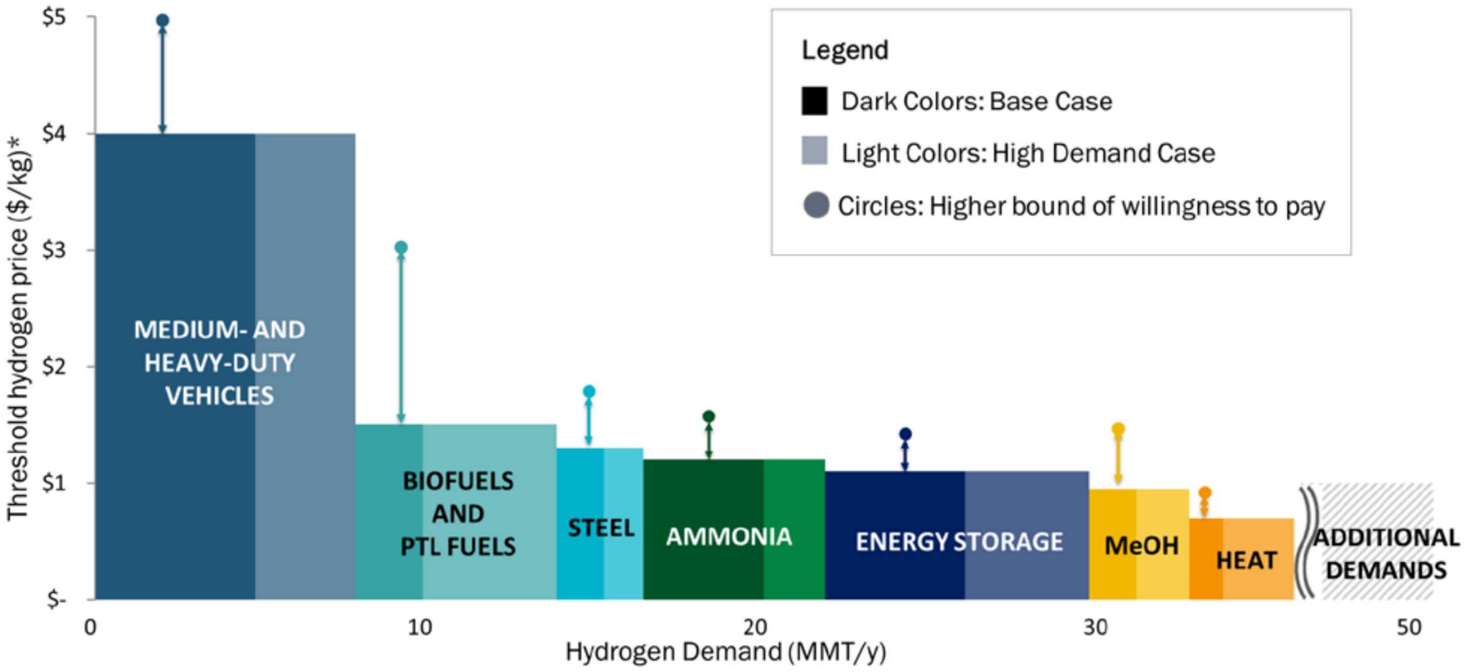


Deployment Estimate Ranges for 2050



https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

Economic Drivers for Hydrogen in Future Energy Systems



Estimates & Considerations

Hydrogen volumes dependent upon many variables

Key estimates

- Trucks: ≃ 10%-15% total energy
- Aviation: 100% sustainable aviation fuel using hydrogen
- Steelmaking: ≃ 10% using H_2
- Ammonia: 100%
- ≃50% of methanol
- Blends with natural gas for high-temperature heat
- Additional applications include stationary power, synfuels, and exports

*Price at point of use (includes production, delivery, and dispensing)

PTL: Power-to-Liquids
MeOH: Methanol

https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

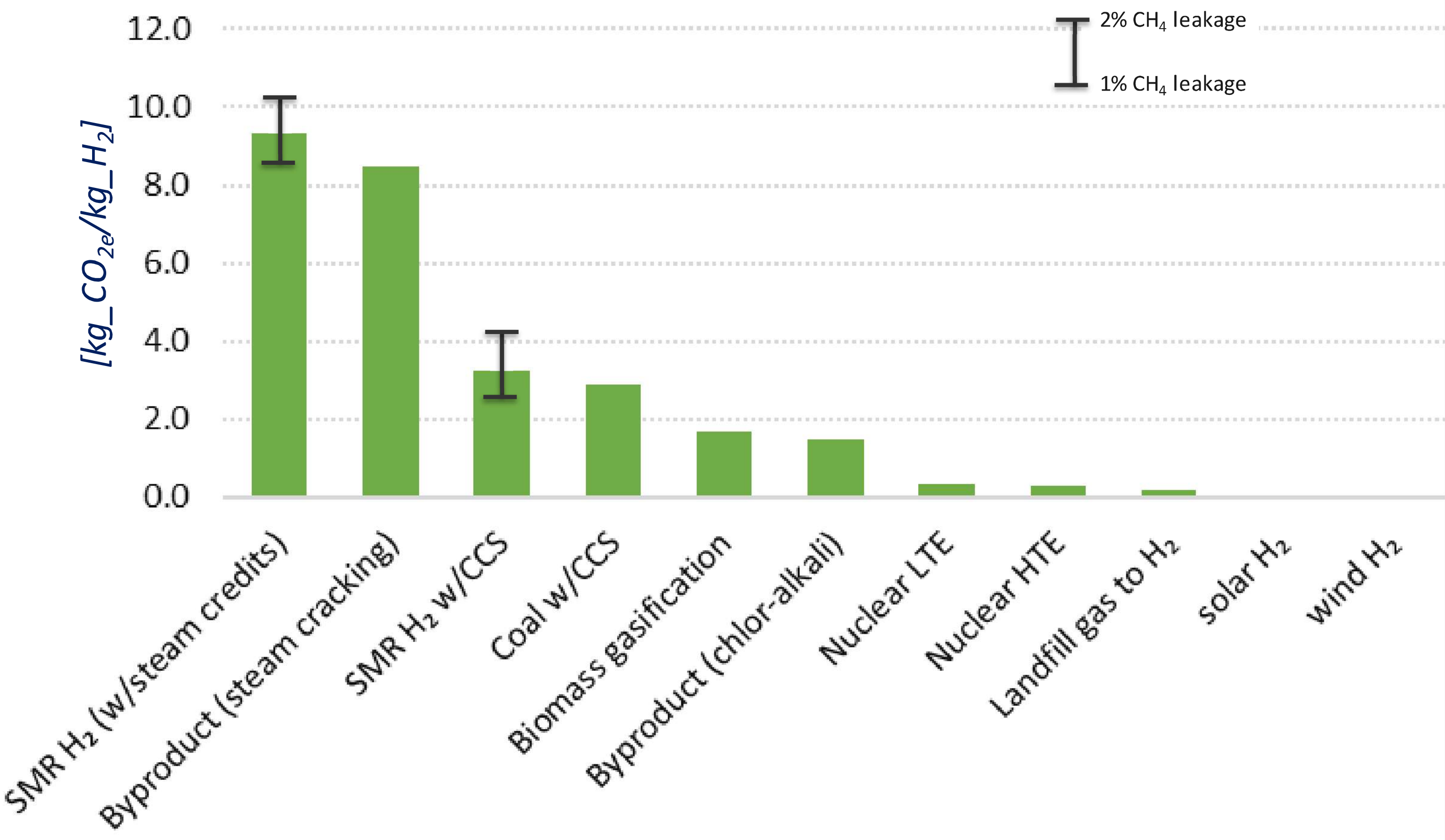
How Hydrogen is Often Identified – By Production Pathway via Colors

Color	Energy Source	Mode of Production
Green	Renewable energy	Water electrolysis
White	Natural geologic formations	Natural fracking
Yellow	Solar	Water electrolysis
No Color	Biomass	Gasification
Red	Nuclear	Catalytic splitting
Purple/Pink	Nuclear	Water electrolysis
Turquoise	Natural gas	Pyrolysis
Blue	Natural gas	Steam reforming + CCS
Gray	Natural gas	Steam reforming
Black/Brown	Coal (lignite and bituminous coal)	Gasification

Derived from: Parkinson, B., P. Balcombe, J.F. Spiers, A.D. Hawkes, and K. Hellgardt. 2018. "Levelized cost of CO2 mitigation from hydrogen production routes. *Energy & Environmental Science* 12: 19-40. https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee02079e and https://www.nrel.gov/docs/fy22osti/82554.pdf.

A Better Option to Identify Hydrogen – Greenhouse Gas (GHG) Emissions of Hydrogen Production

Actual emissions will vary by facility depending on system design and location



https://greet.es.anl.gov/files/hydrogenreport2022

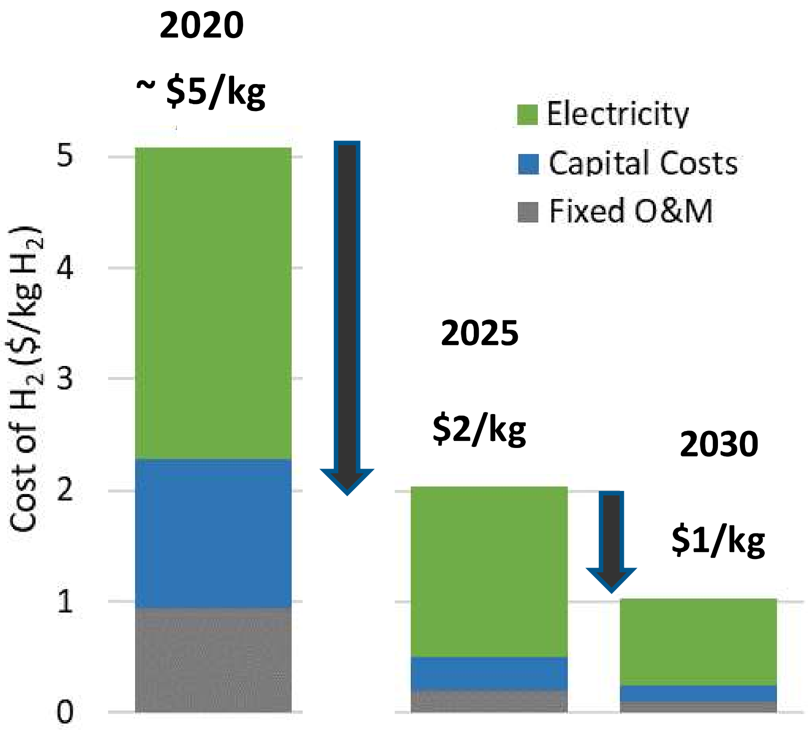
H_2 = Hydrogen
CH_4 = Methane
SMR= Steam Methane Reforming of Natural Gas;
CCS=Carbon Capture and Sequestration;
LTE=Low-Temp Electrolysis;
HTE=High-Temp Electrolysis;
LFG=Landfill Gas

Hydrogen Shot: "1 1 1"
$1 for 1 kg in 1 decade for clean hydrogen

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021

Example: Cost of Clean H_2 from Electrolysis



Electrolysis:

Reduce electricity cost from >$50/MWh to
  - $30/MWh (2025)
  - $20/MWh (2030)
- Reduce capital cost >80%
- Reduce operating & maintenance cost >90%

Bipartisan Infrastructure Law – $9.5B H2 Highlights

- $8B for at least 4 regional clean H2 Hubs
- $1B for electrolysis (and related H2) RD&D
- $0.5B for clean H2 technology mfg. & recycling R&D
- Aligns with H2 Shot priorities by directing work to reduce cost of clean H2 to $2/kg by 2026
- Requires developing a National H2 Strategy & Roadmap

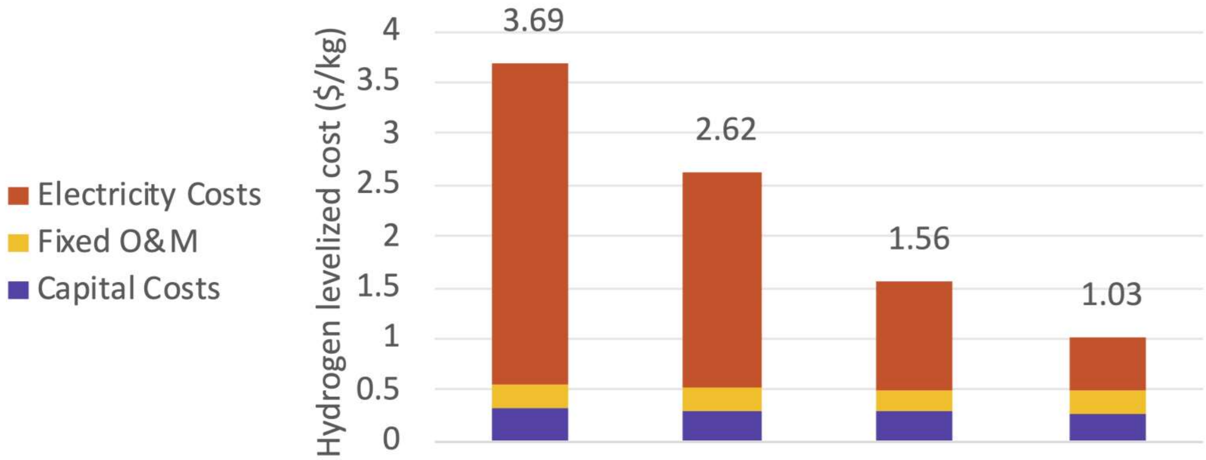
2020 Baseline: PEM low volume capital cost ~$1,500/kW, electricity at $50/MWh. Need less than $300/kW by 2025, less than $150/kW by 2030 (at scale)

(Adapted from multiple briefing slides from Sunita Satyapal, DOE's HFTO)

Electrolysis Economics are Driven by Electricity Prices

For electrolysis at scale, electricity prices are the largest component of the hydrogen production cost

Historically, electricity prices have been fixed in technoeconomic assessments (TEAs)

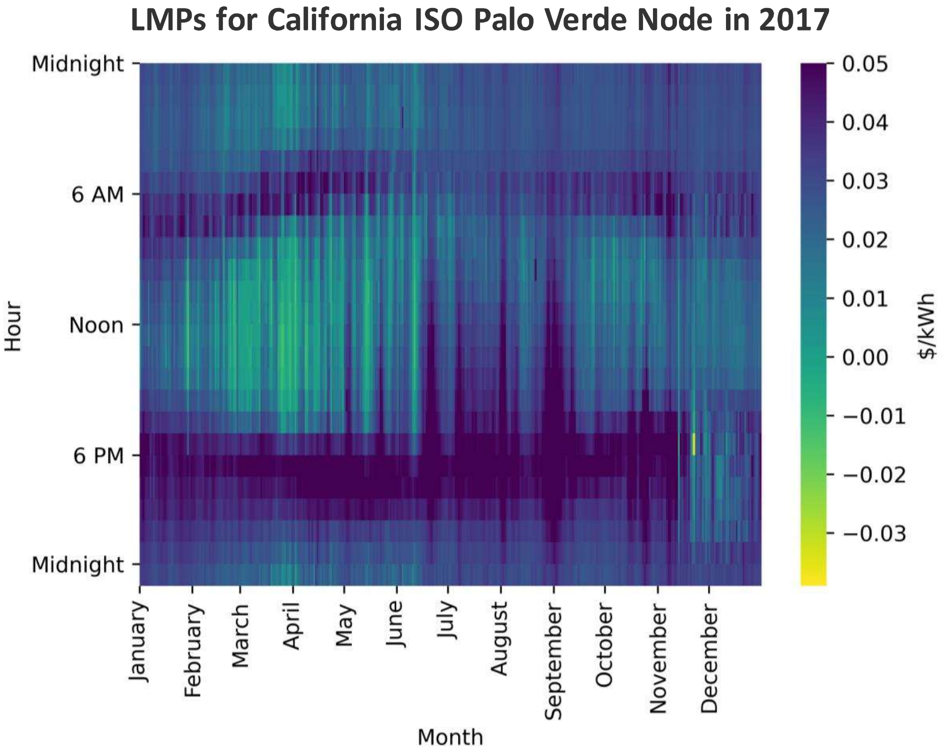


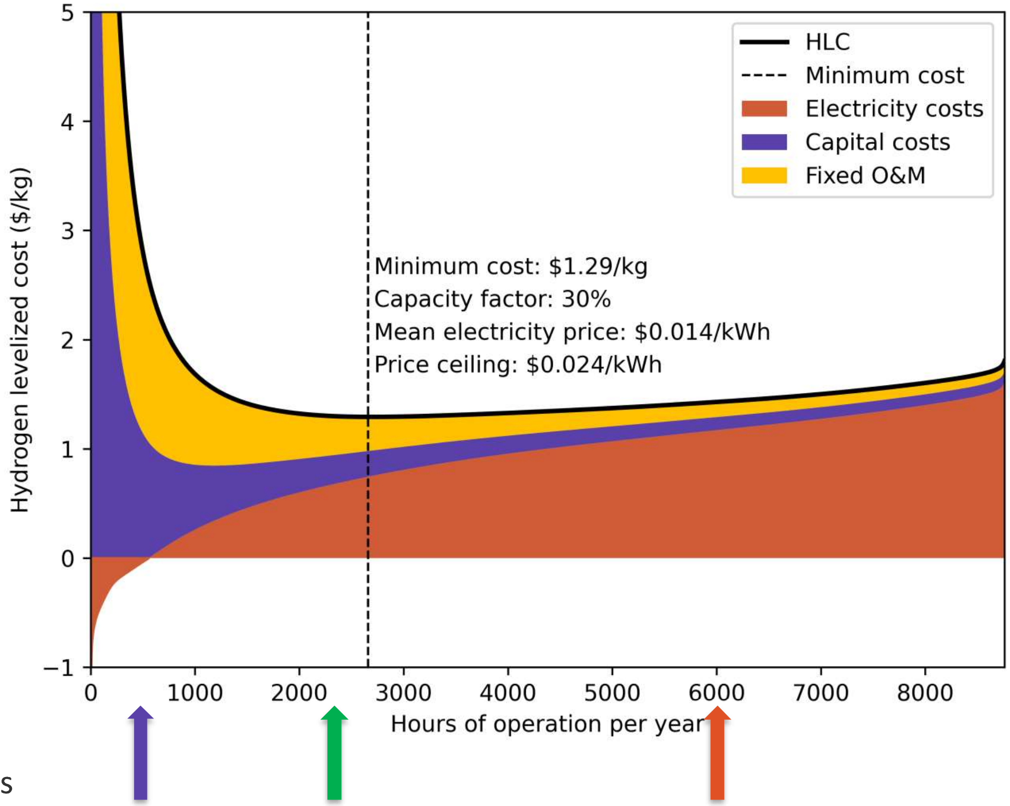
Electricity price	$0.06/kWh	$0.04/kWh	$0.02/kWh	$0.01/kWh
Capital cost	$400/kW	$400/kW	$400/kW	$400/kW
Capacity factor	97%	97%	97%	97%

H2A Future Central case. 51.3 kWh/kg system efficiency. Capital costs are total system purchase cost.

Badgett, A., Ruth, M. and Pivovar, B. (2022) 'Chapter 10 - Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis', in Smolinka, T. and Garche, J. (eds) *Electrochemical Power Sources: Fundamentals, Systems, and Applications* Elsevier, pp. 327–364.

Electricity supply and operating strategies





High cost of capital

Minimized costs

High mean electricity prices

- Low system capital costs can enable operation at low capacity factors
- Operating only when electricity prices are low minimizes production costs, but system cycles on and off frequently

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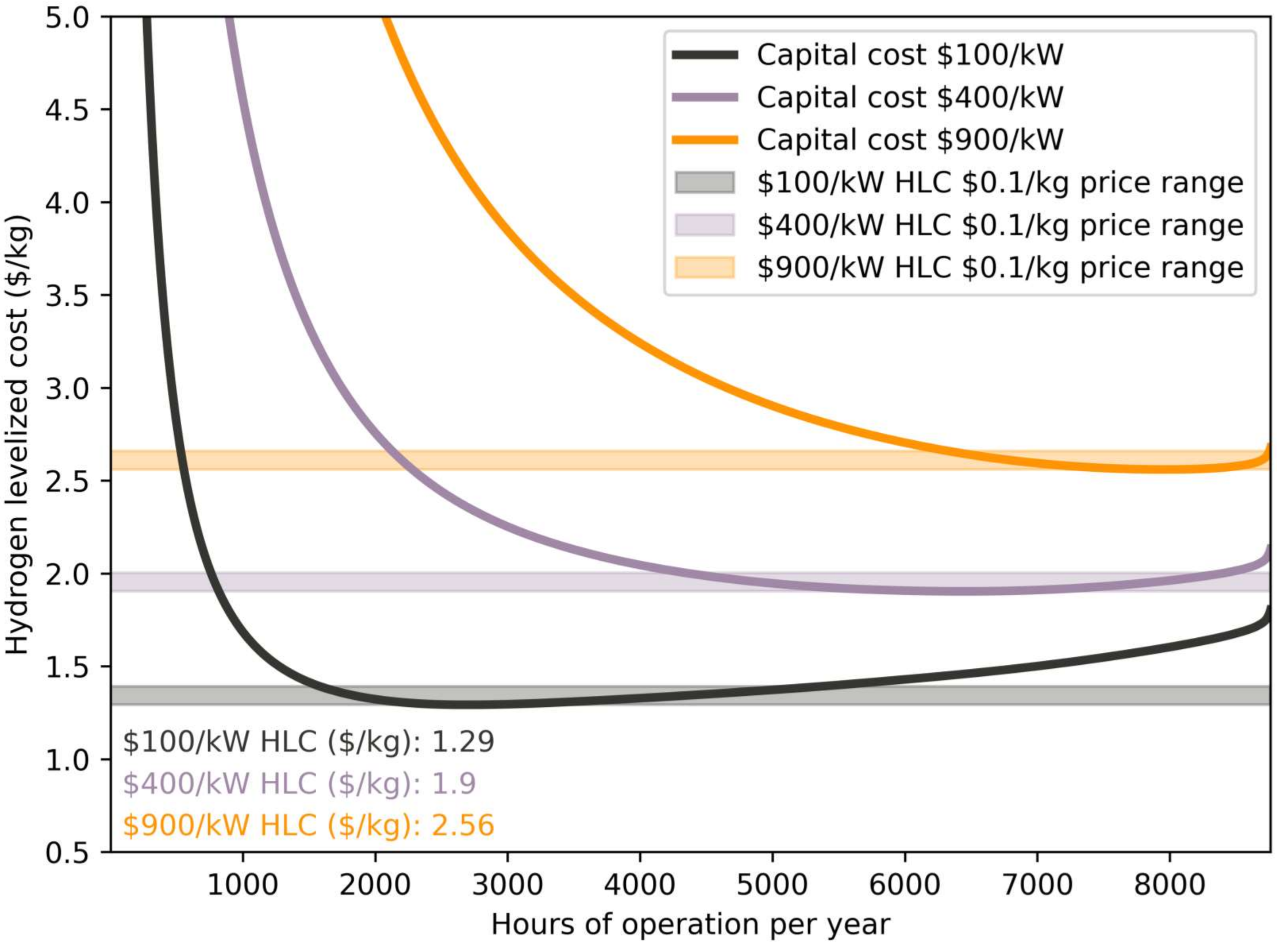
H2A Future Central case. 51.3 kWh/kg system efficiency. $100/kW total system purchase cost. Palo Verde LMPs.

Capital Costs Influence Shape and Minima of Hydrogen Levelized Cost (HLC) Curves

Curves at low capital costs are:

- Lower cost
- Flatter
- Optimum at lower capacity factor



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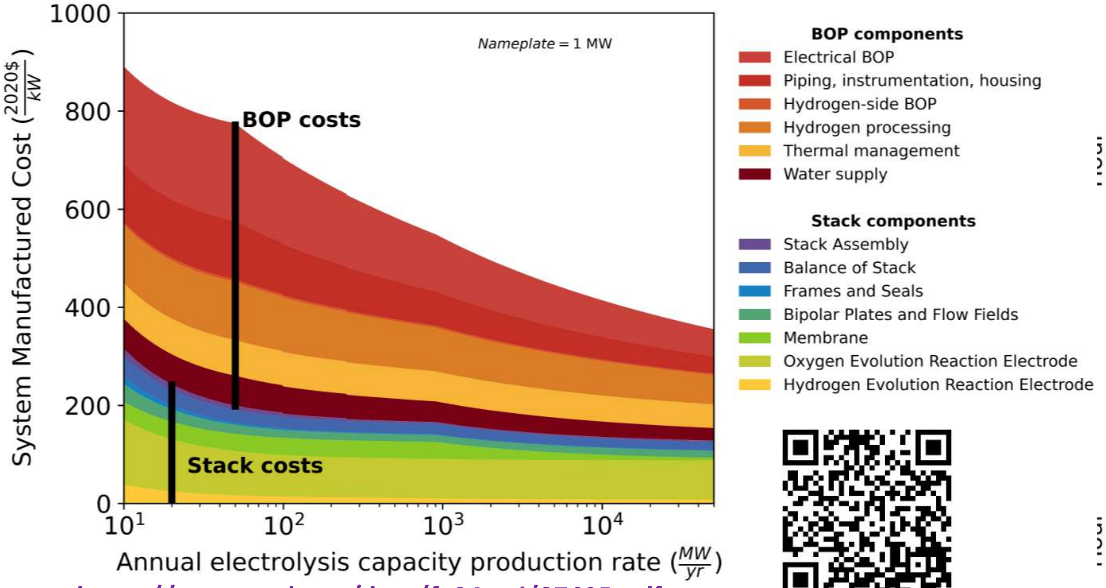
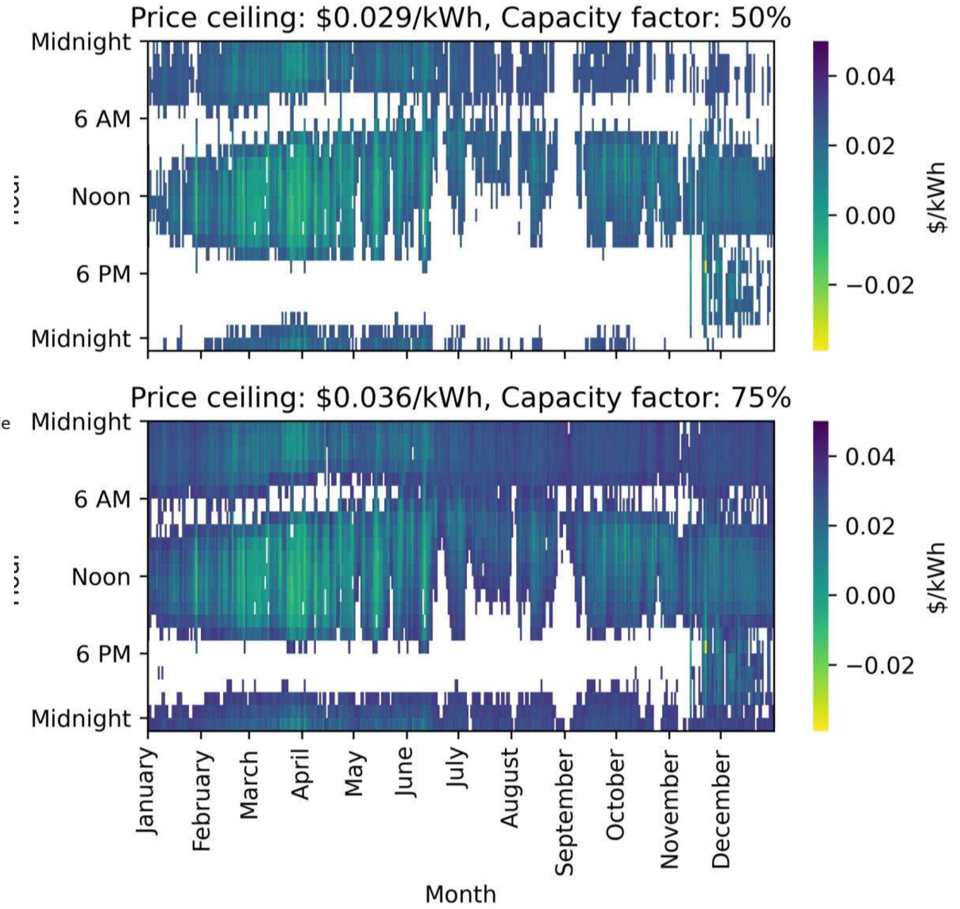
Economies of Production can Reduce Polymer Electrolytic Membrane (PEM) Electrolysis Capital Costs



https://www.nrel.gov/docs/fy24osti/87625.pdf

- NREL completed a manufactured cost analysis for a current state-of-the-art (2022) electrolyzer stack
- Electrolyzer system capacity scaling, reduced catalyst loading and increased current density can lower capital cost further though the latter two approaches affect system performance
- Future low-cost electrolyzers must also be durable and efficient over dynamic operating cycles



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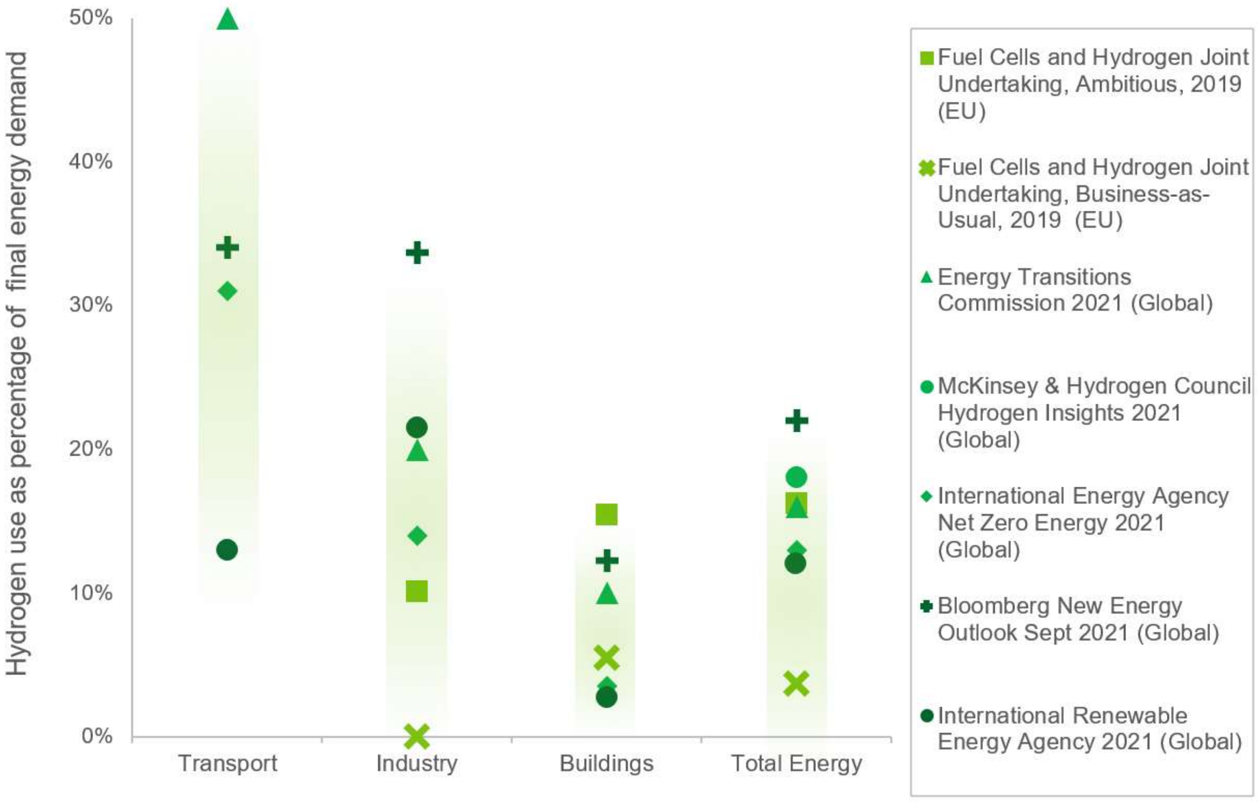
Conclusion: Hydrogen Has the Potential to be a Key Energy Intermediate in a Decarbonized Energy System

Multiple enablers will likely be involved in meeting that potential:

- Application technology development and scaling
- Production technology development and scaling
- Initial economic opportunities that can network and scale



Total Energy includes transport, industry, buildings, and power sector uses

https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

Thank you

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