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CONGRESSIONAL BRIEFING
Green Hydrogen Briefing Series: Scaling Up Innovation to Drive Down Emissions

Wednesday, April 27, 2022

About EESI...

EESI
Environmental and Energy Study Institute

NON-PROFIT

Founded in 1984 by a bipartisan Congressional caucus as an independent (i.e., not federally-funded) non-profit organization

NON-PARTISAN

Source of non-partisan information on environmental, energy, and climate policies

DIRECT ASSISTANCE

In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop "on-bill financing" programs

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Focused on win-win solutions to make our energy, buildings, and transportation sectors sustainable, resilient, and more equitable

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Timely, objective coverage of environmental, clean energy, and climate change topics

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Wildfires - TBA

Extreme Heat - TBA

Scaling Up Innovation to Drive Down Emissions

Green Hydrogen – April 27

Direct Air Capture – May 25

Offshore Wind Energy - TBA

Electric Vehicle Charging - TBA

Green Hydrogen Briefing

April 27th 2022

What I'll cover today

- Hydrogen 101
- Cost
- U.S. policy landscape
- Green Hydrogen Catapult

“Hydrogen 101”

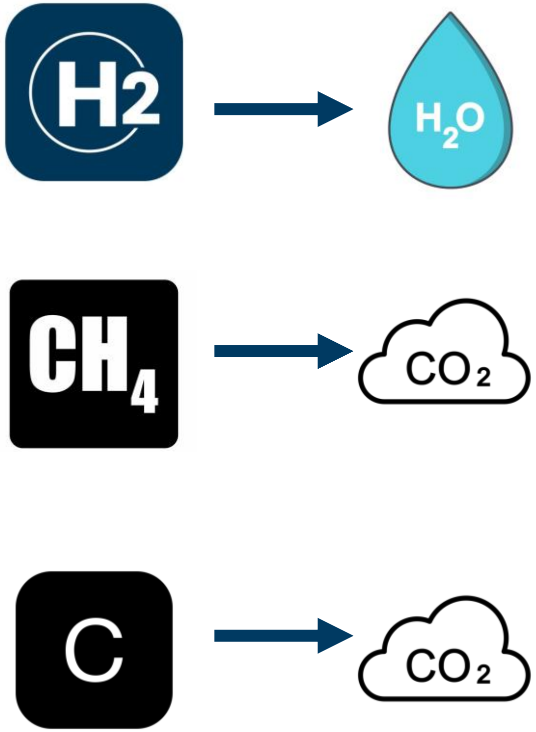
What is hydrogen?

A molecule…

Similar to fossil fuels…

- Combustion produces high temperatures
- It is energy dense
- It can be involved in chemical reactions

Unlike fossil fuels…



Giving it a unique role in net zero

- As a fuel where high temperatures are needed
- As a fuel where high energy density is needed
- As a chemical feedstock

What role will hydrogen play in achieving net zero?

1. Replace hydrogen in existing end uses

Fertilizer | Refining | Chemicals

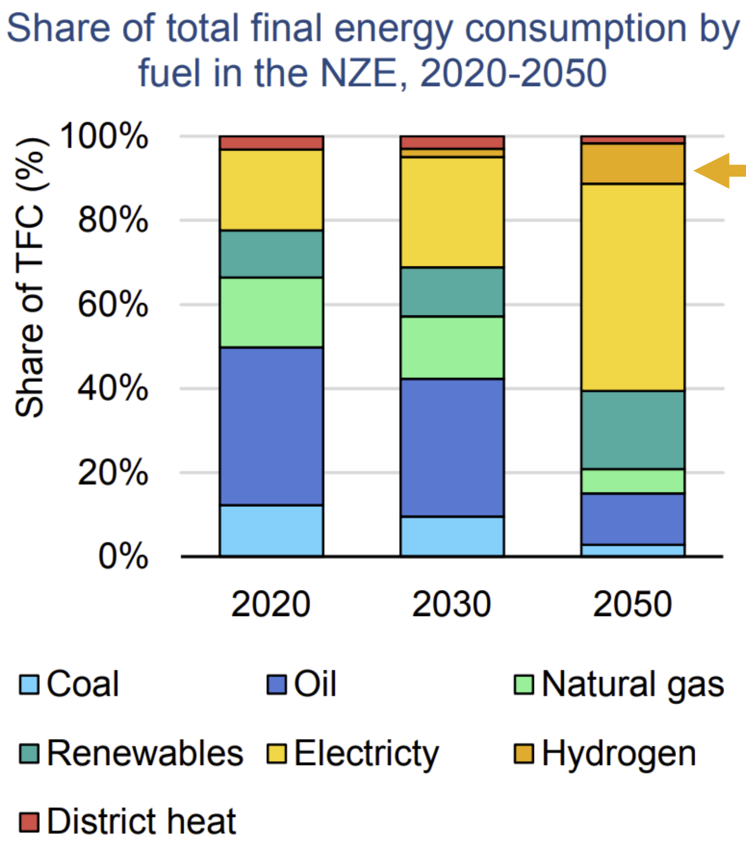
10 MMT H_2/yr → ~100 MMT CO_2/yr
(2% of total US emissions)

2. Replace fossil fuels in heavy industry & transport

Steel | Shipping | Trucking | Aviation

200-300 MMT CO_2/yr
(4-6% of total US emissions)

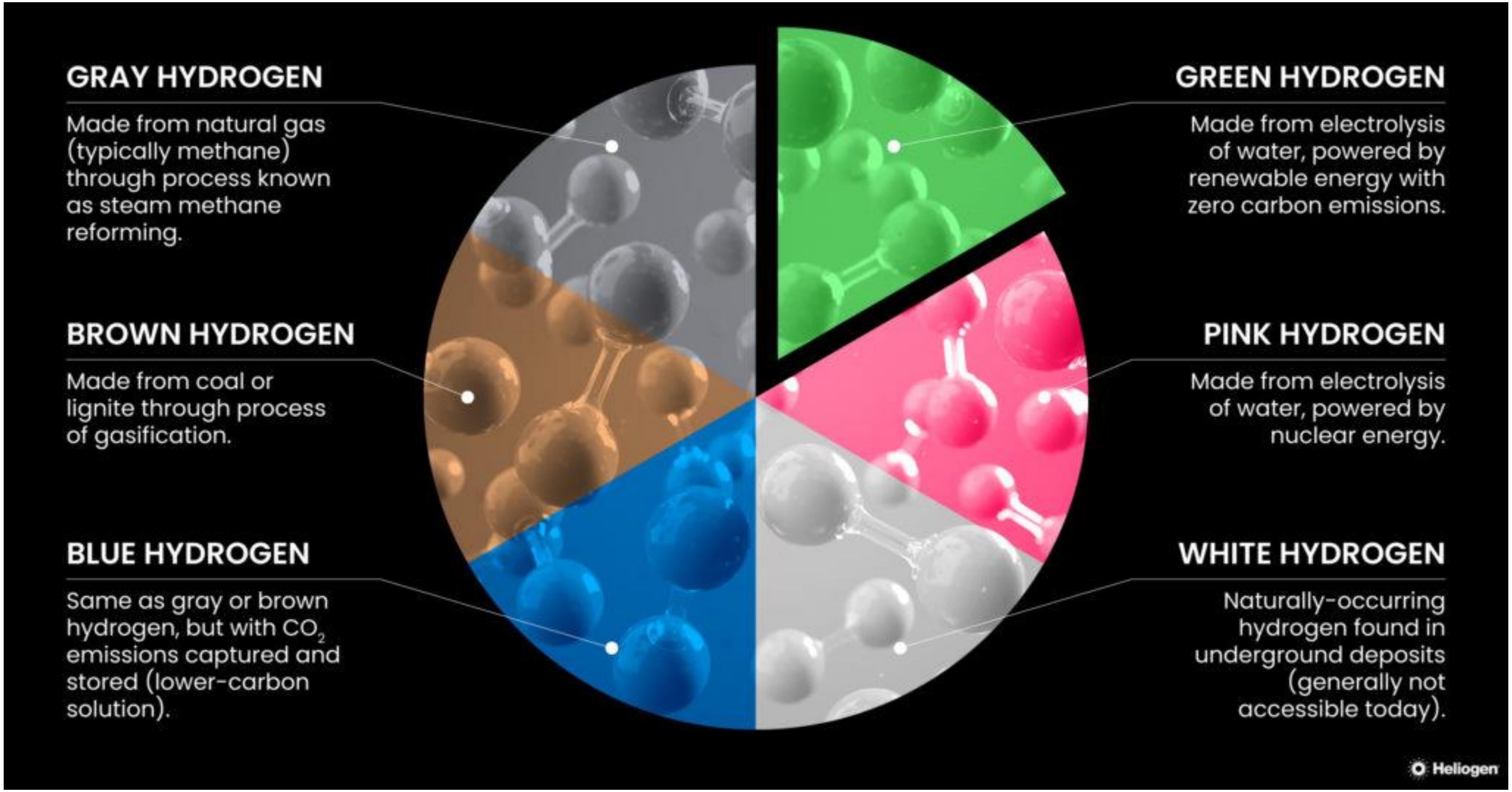
Hydrogen is vital for net zero, but is only one piece of the puzzle



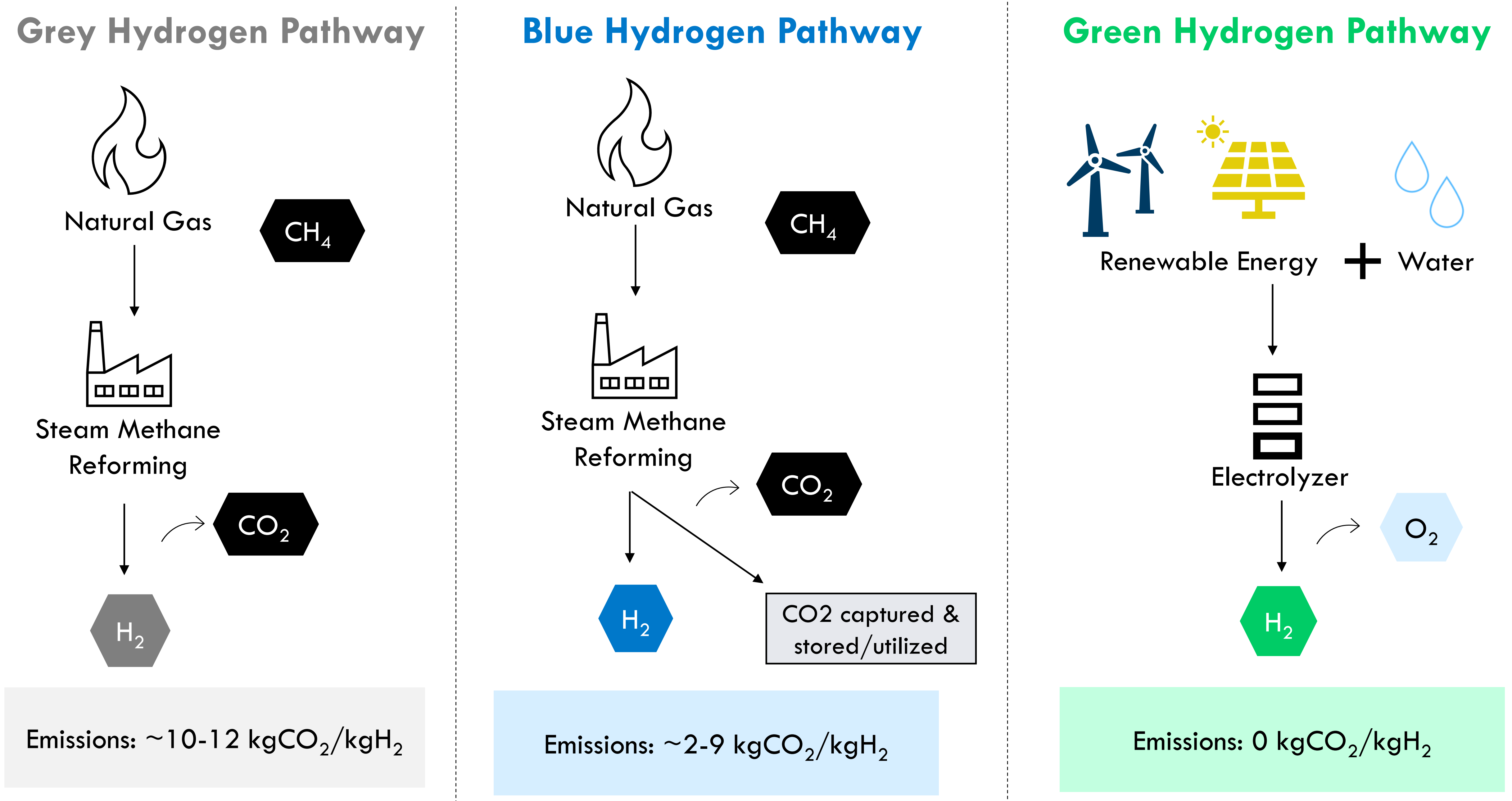
Hydrogen 10% in IEA's NZE scenario

Source: IEA, Global Hydrogen Review 2021, link

How is hydrogen produced?



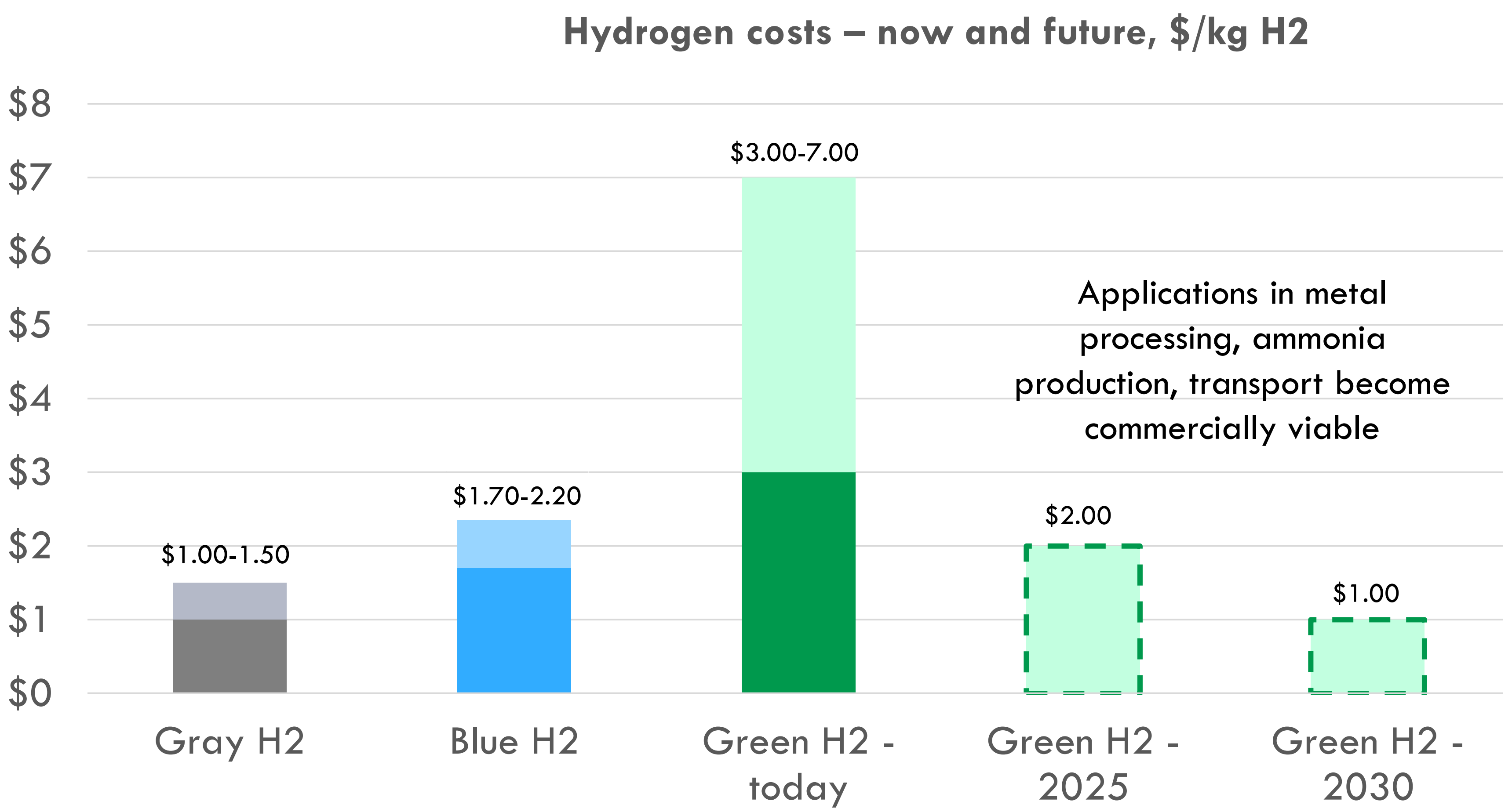
Source: Heliogen, link



Today's approximate values shown, emissions dependent on efficiency of capture, upstream emissions, electricity sourcing.
Capture rate used: 56-95%. Based on RMI analysis, the best blue (95% capture, 0.05% leakage) case still results in ~1.7kgCO2/kgH2 based on a typical grid emissions.

Cost

How much does hydrogen cost?



RMI – Energy. Transformed.

Source: RMI analysis; RFF analysis, link; DOE Hydrogen Shot; Carbon Brief / BloombergNEF, link

Why are green hydrogen costs expected to drop?

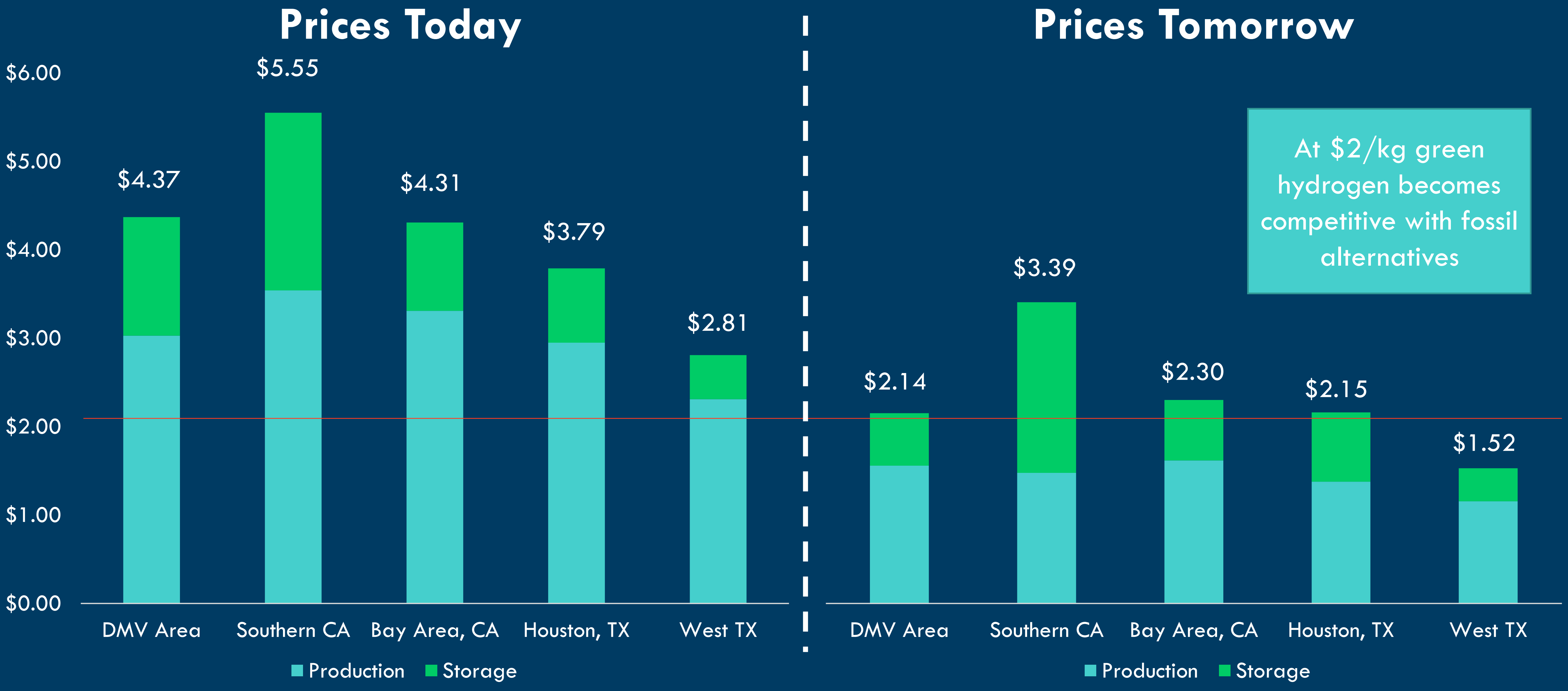
Today

- Renewables and electrolyzer are two Capex drivers
- Electrolyzers need high utilization due to Capex of ~$700/KW
- Combined wind and solar generation to improve renewable energy system availability

Tomorrow

- Improved manufacturing and system design drives electrolyzer Capex down to $200/KW
- Electrolyzer operation moves to capture generation, making utilization less critical
- Shift to use the least cost generation resource more heavily

Green hydrogen costs



Today assumes $700/kW electrolyzer capex, $800/kW solar capex, $1000/kW wind capex, and $516/kg hydrogen storage capex
Tomorrow assumes $200/kW electrolyzer capex, $500/kW solar capex, $800/kW wind capex, and $516/kg hydrogen storage capex

U.S. Policy Landscape

U.S. federal policy landscape

Opportunity unlocked

Bipartisan Infrastructure Law

- 4+ hydrogen hubs **($8bn)**
- RD&D **($1.5bn)**
- National strategy; clean hydrogen definition

Reconciliation

- Production incentive of \$3/kg for cleanest hydrogen; bringing renewable 'green' close to parity with fossil 'blue' and 'grey'

Sector-based proposals

Support for priority end-use sectors:

Fertilizer	Trucking
Shipping	H2 Distrib.

Notes

Requirements for:

- Feedstock diversity
- End use diversity
- Geographic diversity
- Max. employment

Tiered incentive:

- <0.45 $kgCO_2e/kgH_2$ = \$3
- <1.5 = \$1.00
- <2.5 = \$0.75
- <4 = \$0.60
- <6 = \$0.45

- \$500m for H2 equipment at ports and for shipping
- \$1.2b for H2 in industrial end use applications
- \$500m in grants/loans for H2 transport/ storage infra.

What's needed next?

The hydrogen economy needs local and state support to be successful

Prioritizing end uses – directing $$ toward high-value long-term uses

Integrated planning – considering system design including feedstocks

Permitting – siting and building necessary infrastructure

Safety and handling – updating regulations for new hydrogen industries

Standards/certification – verifying emissions of hydrogen production

Not exhaustive

U.S. state policy landscape

	Current	In development
States with hydrogen strategies and/or incentives:	• California (LCFS, ZEV targets) • Washington	• California • Colorado • Illinois (stalled) • New Mexico (stalled) • New York
States with interest in H2 hub funding	• Half of U.S. states have announced interest in H2 Hub funding: • AR, AZ, CA, CO, CT, IL, LA, MA, MS, NC, ND, NJ, NM, NY, OH, OK, OR, PA, SC, TX, UT, WA, WV, WY	

Green Hydrogen Catapult

Green Hydrogen Catapult

GHC is a private sector coalition, convened with the support of the UN High-Level Climate Champions and coordinated by RMI. It bring together the world's biggest green hydrogen project developers to drive down the production cost of green hydrogen.

Our members include ACWA Power, Arcelor Mittal, CWP Renewables, Fortescue Future Industries, H2 Green Steel, HyStor, Iberdrola, Mærsk Mc-Kinney Møller Institute for Zero Carbon Shipping, Ørsted, ReNew Power, Snam, and Yara.

Our Mission is to mobilize **80GW of green hydrogen capacity by mid-2026** to catalyze market growth, making possible a future where **green hydrogen is produced well below $2/kg.**

Our Approach is focused on 1) Developing "breakthrough" green hydrogen production solutions that can meet the cost target in many regions of the world, not just the most favorable, 2) Rally coordinated action in key sector supply chains 3) Equip policy makers with insights, targets, and policy options to drive down costs to stimulate market formation.

Taking action now is critical to meet out global climate targets. **Scaling Giga-Watts requires a whole system approach** that begins with designing-in the future, the GHC is helping to lead the way.

GHC areas of focus for 2022

Mobilize GW-scale Projects and Demand
Work with demand sectors to translate commitments to real projects

Hub Demand Aggregation in Key Regions (US, EU, Global South)

- Support operationalization of medium-term targets into near-term procurement
- Aggregate portfolios of projects into hydrogen clusters

Steel

- Domestic green production pathways
- Establish procurement coalitions

Shipping

- Green corridors
- Port infrastructure and value chains
- Book and claim system

Fertilizer

- Switch production assets to green H2
- Demand aggregation via certification and buyer schemes

Supercharge policy

- Support enabling policy to foster demand in select hubs
- Demand stimulation policy blueprints
- Support to develop global Green H2 Standard

Thank you!

Questions or feedback welcome

Alexa Thompson: athompson@rmi.org

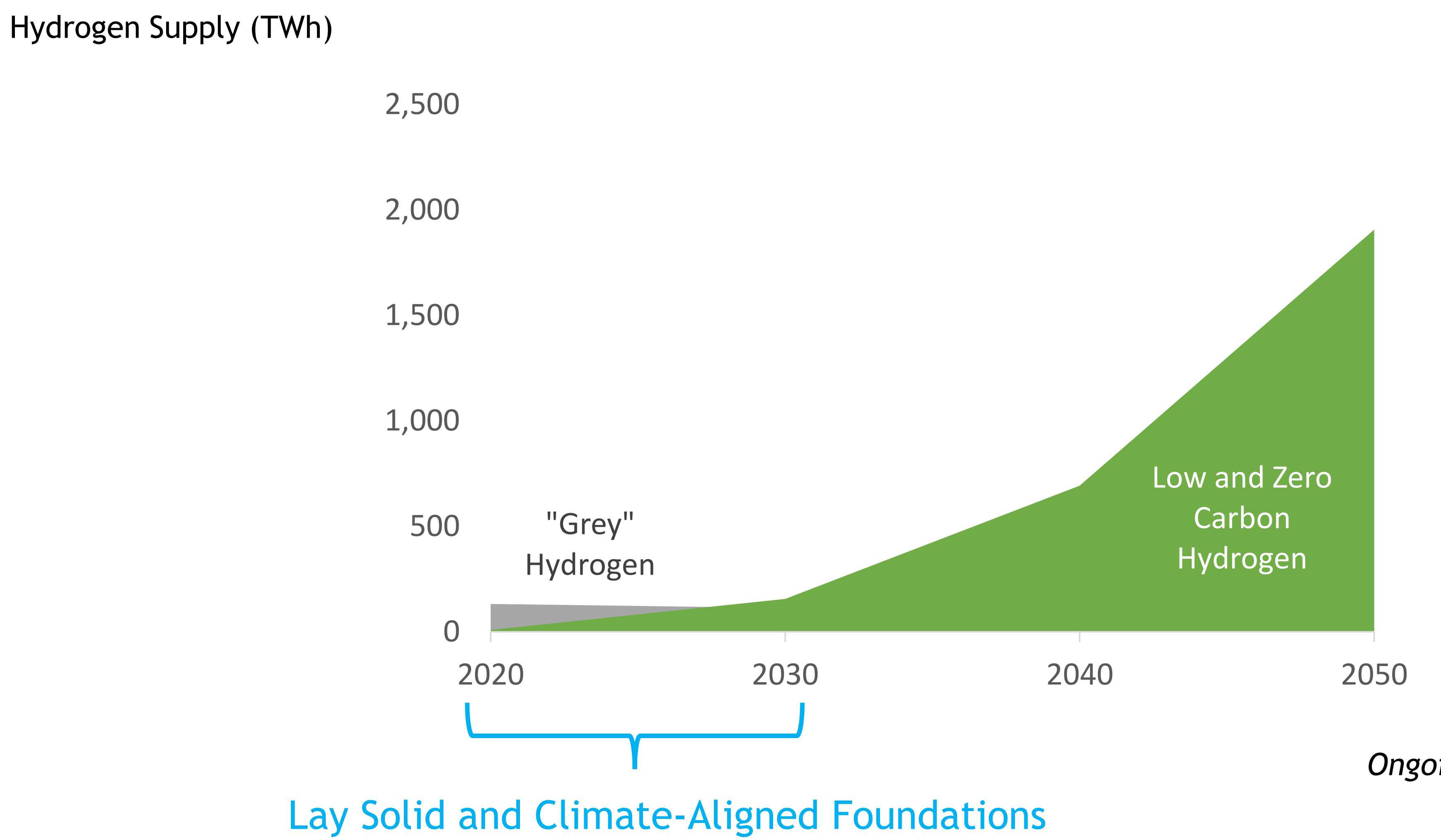
Scaling Up Clean Hydrogen In a Climate-Aligned and No-Regrets Manner

EESI Congressional Briefing

NRDC

April 2022

In Pathways to Net-Zero, Clean Hydrogen Production Ramps Up After 2030



Ongoing NRDC Net-Zero Analysis;
Preliminary Results

Bring it Back to the Holistic Picture: This is Not About Hydrogen

Hydrogen scale-up should not be for hydrogen's sake;

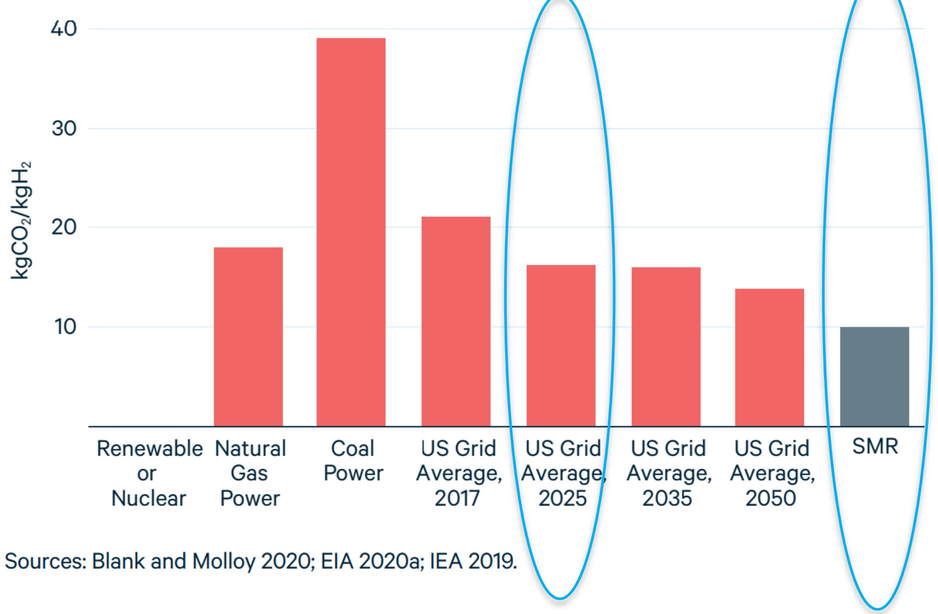
Hydrogen deployment should be done with a view to support the most affordable, efficient and community-safe transition to a clean economy.

Hydrogen Production is Energy Intensive and Can Be Highly Emitting Absent Policies and Regulations

The Department of
Ecology & Evolutionary Biology

Prof Howarth provideds view of 'blue' hydrogen; may be worse than gas or coal

Figure 3. CO_2 Emissions from Electrolysis, by Power Source



Sources: Blank and Molloy 2020; EIA 2020a; IEA 2019.

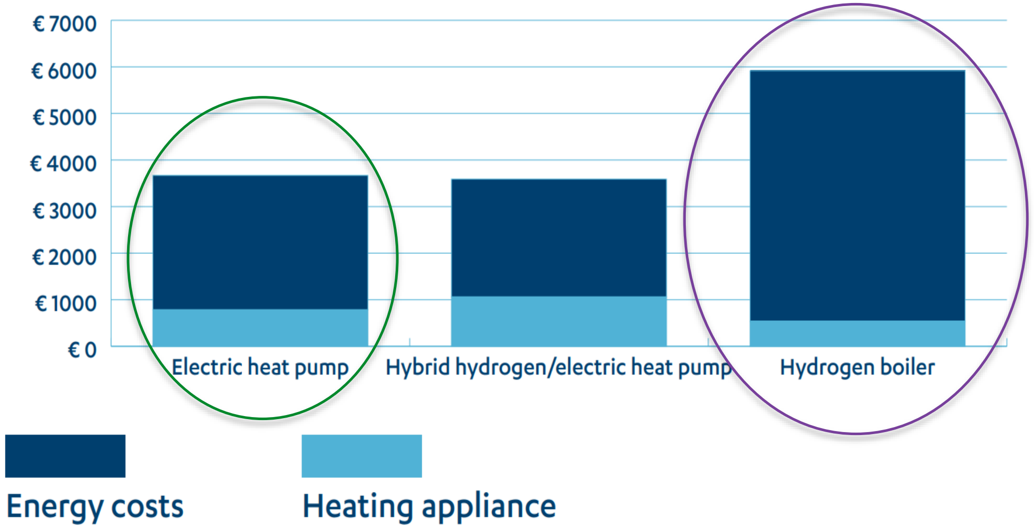
Hydrogen Use is Generally Inefficient; Indiscriminate Deployment Can Increase Costs

Green hydrogen takes over five times more energy to produce heat compared to electrification

Number of wind turbines needed to cover heating demand in the UK where one symbol = 1,500 turbines

Source: Energy Monitor analysis of Committee on Climate Change and Renewable UK figures. This is illustrative for the UK assuming all gas used for heating is substituted with green hydrogen or using heat pumps. In reality not only wind power would be used to provide the electricity.

Annual cost of heating a single family home in Poland in the period 2025-2040 with different heating systems



Source: Goodbye gas: heat pumps will be the cheapest green heating option for consumers; BEUC, The European Consumer Organisation

Hydrogen Leakage Can Have Detrimental Climate Consequences

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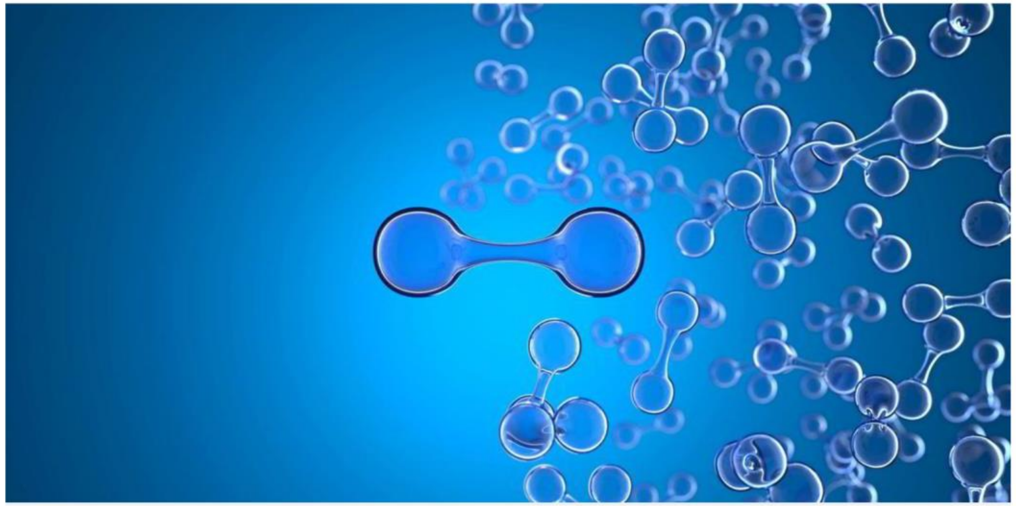
Our Work Get Involved About

Home › News and blogs › EDF Voices blog › For hydrogen to be a climate ...

For hydrogen to be a climate solution, leaks must be tackled



Hydrogen 'twice as powerful a greenhouse gas as previously thought': UK government study

Report highlights importance of preventing leakage from future H2 infrastructure

8 April 2022 14:43 GMT *UPDATED 11 April 2022 9:46 GMT*

By **Leigh Collins**

CLIMATE-ALIGNED AND NO-REGRETS SCALE

Rigorous and Climate-Aligned “Clean” Hydrogen Production Standards

- Rigorous accounting of GHGs arising both at the site of hydrogen production and upstream of production;
- Rigorous verification mechanisms
- Low limit on GHG emissions, ensuring deployment of only the lowest-emitting and climate-aligned hydrogen resources.

- DOE and EPA “Clean” Hydrogen Standard (IIJA)
- States “Clean Hydrogen” Standards

Focus on No-Regrets and Targeted Demand Creation

- Rigorous evaluation of hydrogen's highest-value applications, those aligned with the most efficient pathways to net-zero GHGs by 2050;
- Target:
  - Existing hydrogen users (refineries, fertilizer plants)
  - New hard-to-abate applications where hydrogen is projected to be a major climate solution (steel, maritime shipping)

- DOE Hydrogen Hubs
- Public procurement standards ("green" steel)
- Minimum quotas for clean hydrogen in existing hydrogen uses and hard-to-abate applications (e.g., European Commission, Germany, Spain, India)
- Better DOE RDD&D prioritization to advance hydrogen use in priority, hard-to-abate sectors where its use remains pre-commercial (steel, maritime shipping, aviation)

Caution and Further Reflection Concerning Hydrogen Transport Infrastructure

- Significant uncertainties relating to the costs and implications of the widespread repurposing of natural gas pipelines to hydrogen as well as building new hydrogen pipelines;
- Hydrogen leakage risks are likely high during transport

- Advance hydrogen use in clusters/hubs to minimize hydrogen transport infrastructure
- Scientific and transparent assessments of the future hydrogen landscape and need (or lack thereof) of extensive pipeline infrastructure (DOE and academia)
- DOE and global RD&D concerning hydrogen leakage detection and repair, and development of leakage measurement, verification and reporting protocols

Robust and Proactive Outreach to Labor and Environmental Justice Groups

- Equity considerations – both health and labor– permeate the hydrogen space;
- Hydrogen production and use can produce high levels of air pollution (NOx emissions when combusted)
- Some hydrogen applications may have safety risks that require further assessment and solution development

- Proactive and meaningful engagement with EJ and labor communities
- High labor standards across the hydrogen value chain and workforce training programs
- Rigorous and strict health and safety standards for all hydrogen use cases

THANK YOU

H2NEW Hydrogen from Next-generation Electrolyzers of Water

U.S. DEPARTMENT OF ENERGY

Hydrogen's Big Shot : Where we are and where we are going

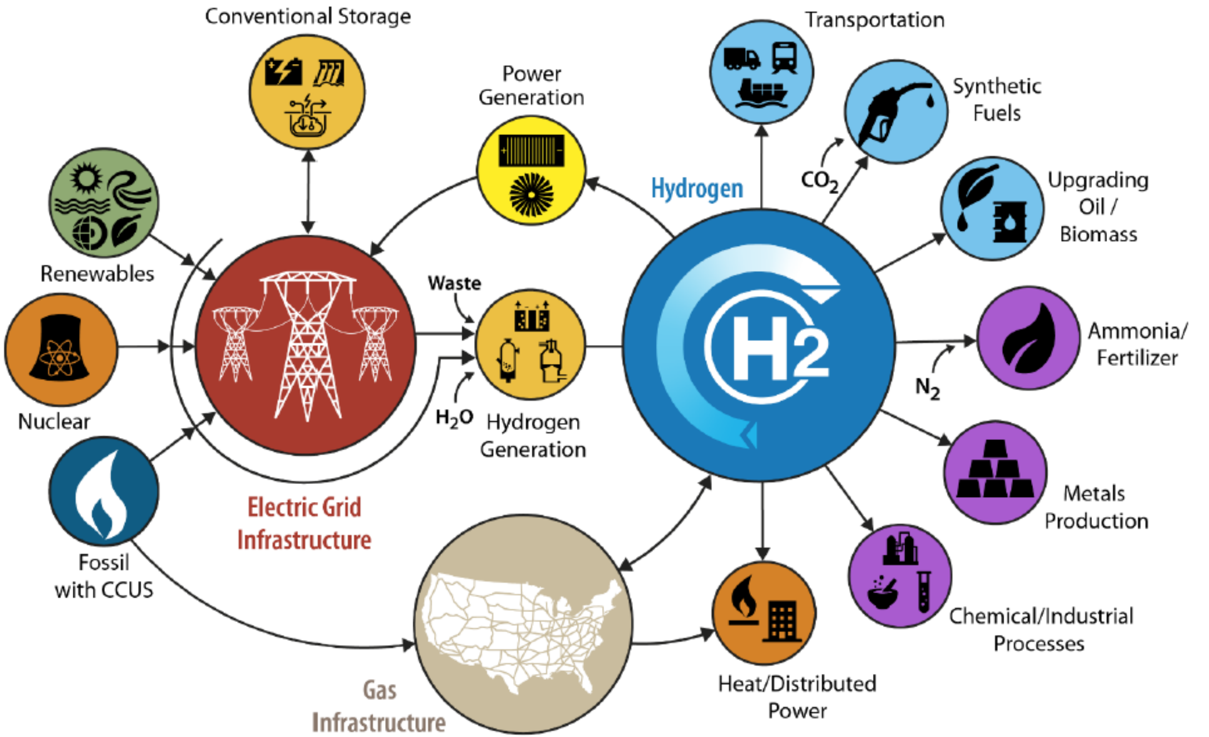
Bryan Pivovar, National Renewable Energy Laboratory (NREL)

Date: 4/27/22

EESI Briefing

NREL Transforming ENERGY | INL Idaho National Laboratory | Argonne NATIONAL LABORATORY | BERKELEY LAB Bringing Science Solutions to the World | Lawrence Livermore National Laboratory | Los Alamos NATIONAL LABORATORY EST. 1943 | NATIONAL ENERGY TECHNOLOGY LABORATORY | OAK RIDGE National Laboratory | Pacific Northwest NATIONAL LABORATORY

H2@Scale



Illustrative example, not comprehensive

https://www.energy.gov/eere/fuelcells/h2-scale

H2@Scale

- Attributes
  - Cross-sectoral and temporal energy impact
  - Clean, efficient end use
- Benefits
  - Economic factors (jobs, GDP)
  - Enhanced Security (energy, manufacturing)
  - Environmental Benefits (air, water)
    - GHG
    - Local criteria pollutants

Getting all these benefits in a single energy system significantly enhances value proposition.

Improving the economics of H2@Scale

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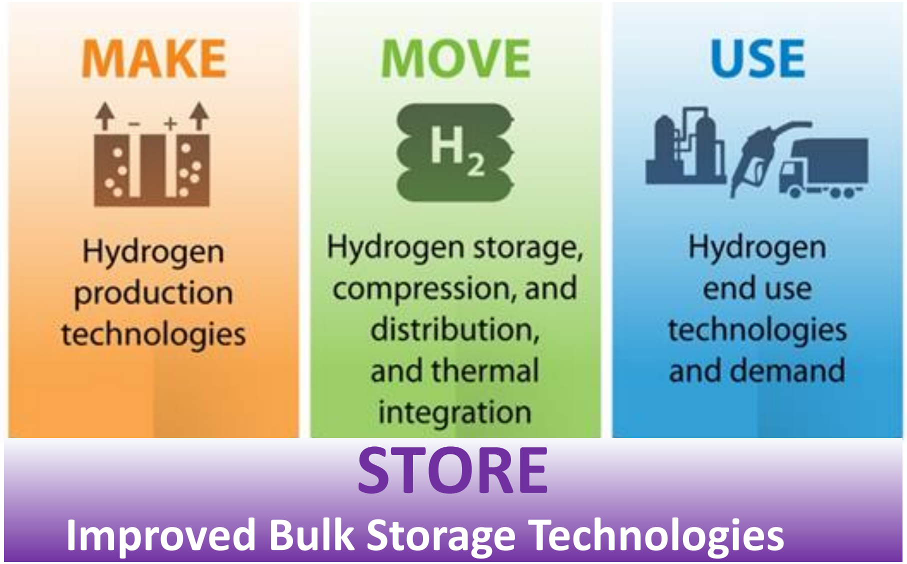
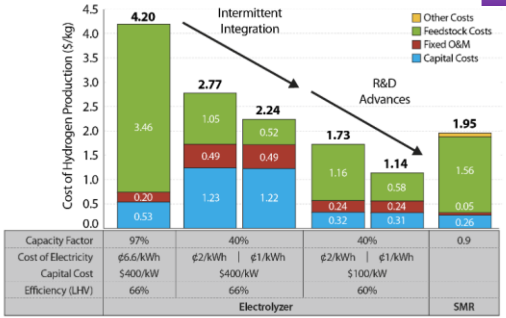
Early-stage research is required to evolve and de-risk the technologies.

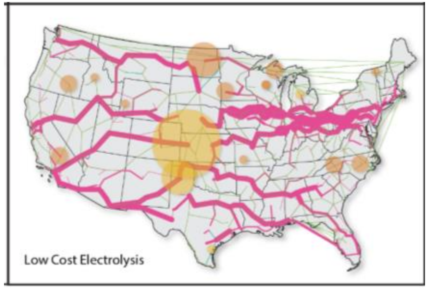


Preliminary

Use	Potential MMT/yr
Refineries & CPI	8
Metals	12
Ammonia	4
Synthetic Chemicals	14
Biofuels	1
Natural Gas	10
Light Duty Vehicles	57
Other Transport	17
Electricity Storage	28
Total	**151**

Decreasing cost of H_2 production





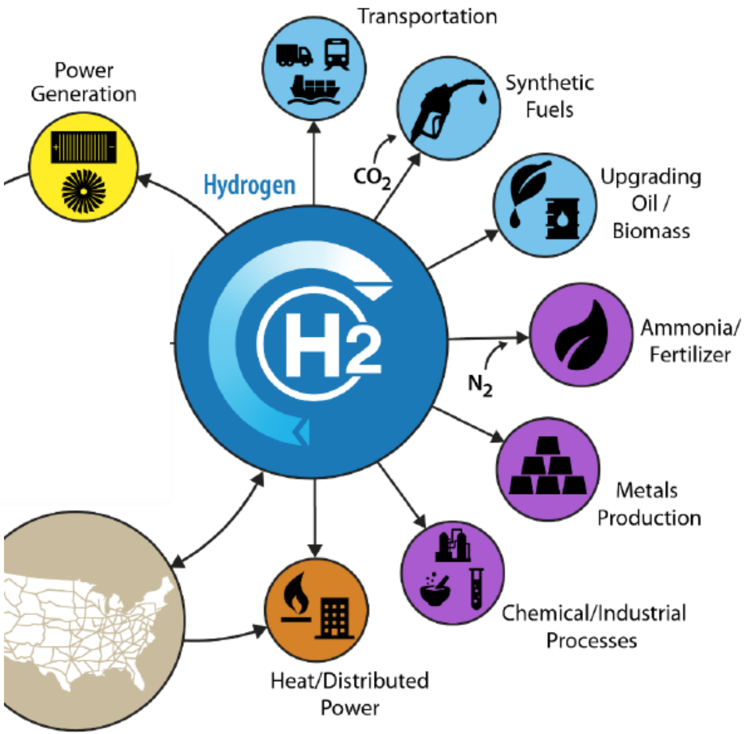
Optimizing H_2 storage and distribution

Leveraging of national laboratories' early-stage R&D capabilities needed to develop affordable technologies for production, delivery, and end use applications.

https://www.hydrogen.energy.gov/pdfs/review18/tv045_ruth_2018_o.pdf

Use

Use



https://www.energy.gov/eere/fuelcells/h2-scale

https://www.nrel.gov/docs/fy21osti/77610.pdf

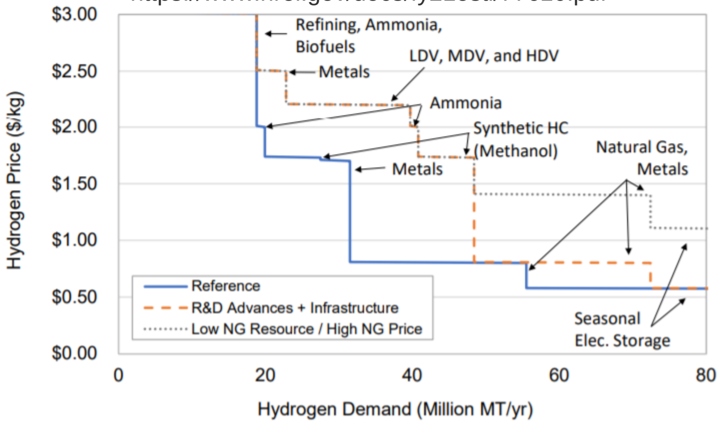


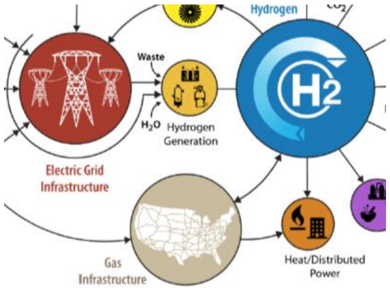
Figure 24. Aggregated demand curves for H2@Scale scenarios

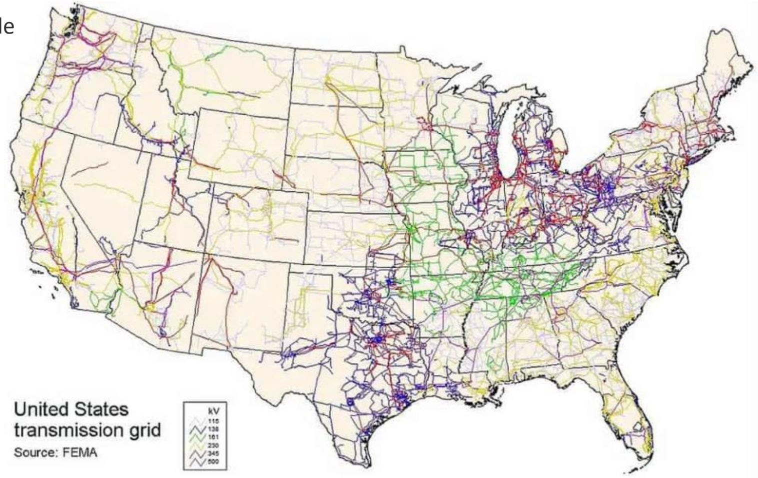
- Transportation and Industry are strongest economic sectors (also difficult to decarbonize)
- Difficult or impossible to fully electrify
- Many of the processes are or could be electrochemical
- R&D needs are significant
  - Fuel Cells (M2FCT), NH3, Steel, burners/turbines

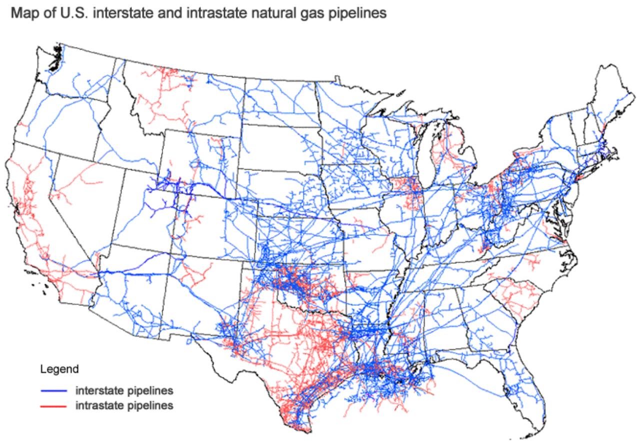
Move/Store

Energy Transmission Infrastructure

https://www.energy.gov/eere/fuelcells/h2-scale



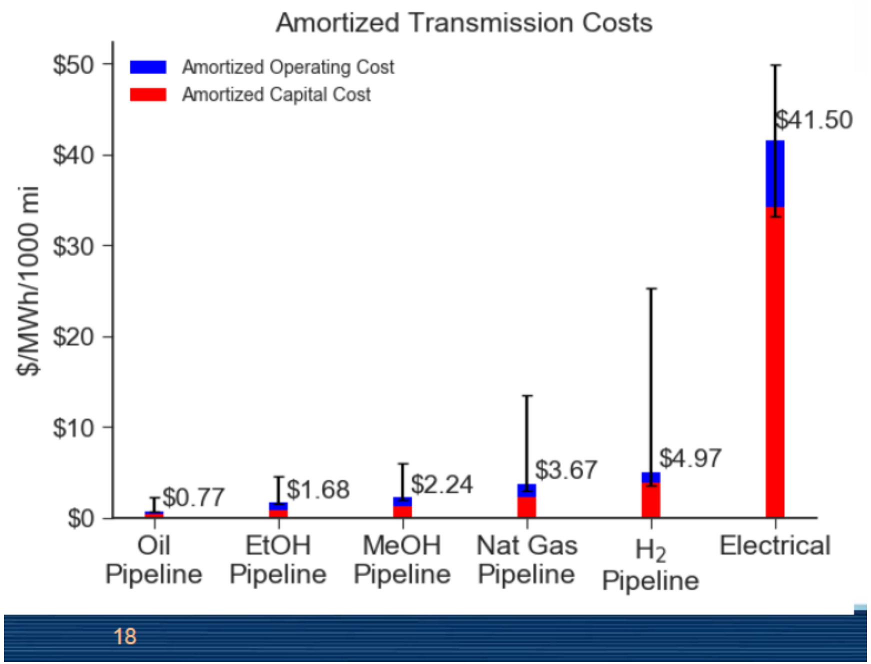




Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

- Hydrogen has a very limited infrastructure (due to scale and selective use).
  - Current H2 prices dominated by storage and distribution (LDV CA)
- Electricity and natural gas have extensive infrastructural investments.
- Similar maps, much different energy/cost, permitting challenges
- Hydrogen pipeline analogous to natural gas

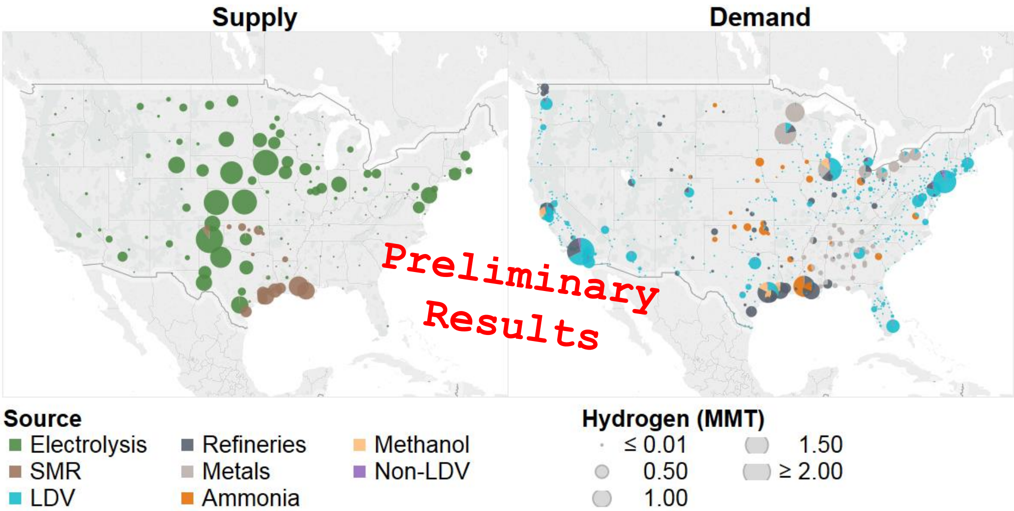
Natural gas as the nearest H2 parallel

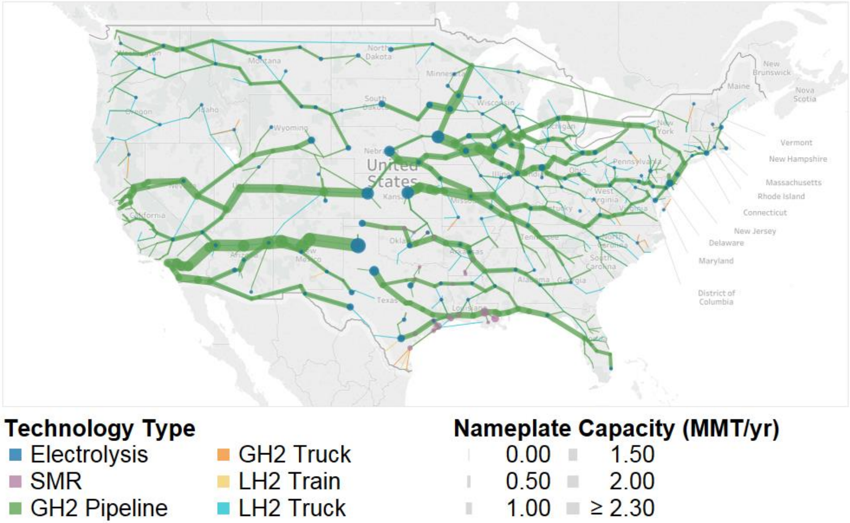


- Hydrogen perhaps ~30% move expensive to move than natural gas.
- ~1/3rd volumetric energy density, ~1/3rd viscosity.
- Additional materials compatibility limitations
- Particularly relevant at large scales and long distances

https://www.hydrogen.energy.gov/pdfs/review18/pd102_james_2018_p.pdf

Location of Generation vs. Demand





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- Similar maps, much different energy/cost, permitting challenges
- Hydrogen pipeline analogous to natural gas

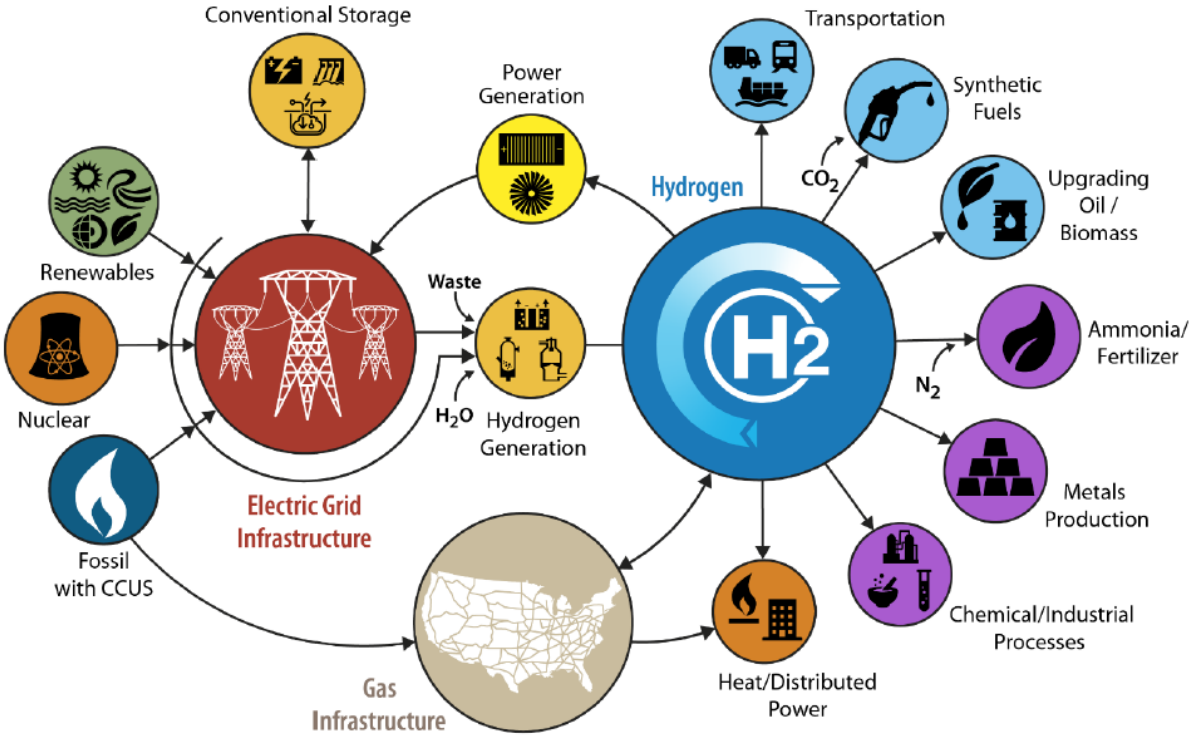
https://www.hydrogen.energy.gov/pdfs/review18/tv045_ruth_2018_o.pdf

Select Store/Move Needs

- Bulk storage, liquefaction workshops
  - Subsurface, surface
  - Liquefaction, boil off, shipping, cryo
- Pipeline R&D
  - H2 only
  - HYBLEND
  - Conversion of existing NG infrastructure
- Compression (incl. electrochemical compression/separation)
- Hydrogen Storage Materials
- Dispensing (HD)

Make

H2NEW connection to H2@Scale



Illustrative example, not comprehensive

https://www.energy.gov/eere/fuelcells/h2-scale

- Making H2 is the inherently obvious, first step to spur the wide-ranging benefits of the H2@Scale vision.
- Electrolysis has most competitive economics and balances increasing renewable generation challenges.

Pathways to Reduce the Cost of Electrolytic H_2

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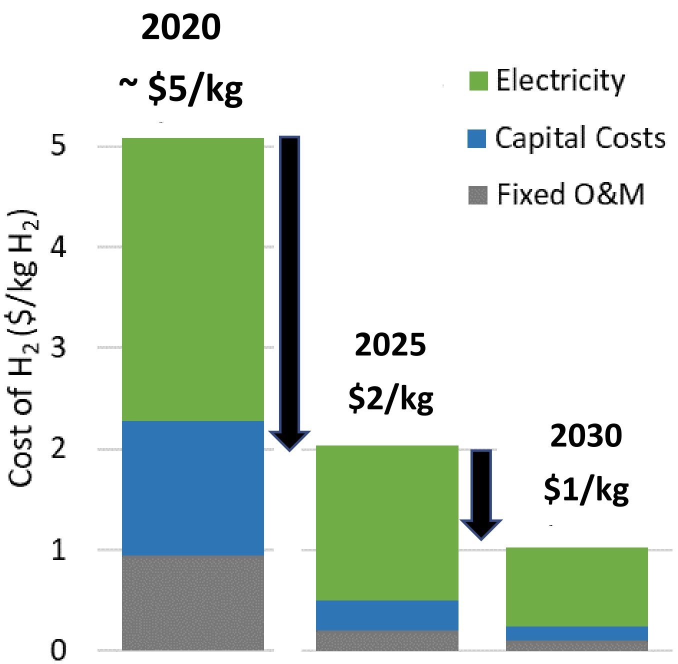
Cost Reduction of Clean Electrolytic H_2



Key enablers for lower cost electrolytic H_2:

- Low-cost electricity
- High electrical efficiency
- Low-cost capital expense
- Increased durability/lifetime
- Low-cost manufacturing processes
- Manufacturing at MW-scale

Electrolyzer goals for 2025	Unit	PEM	SOEC
Higher electrical efficiency	% (LHV)	≥ 70	≥ 98
Lower stack costs	$/kW	≤ 100	≤ 100
Increased durability	hours	80,000	60,000
Lower system CAPEX	$/kW	≤ 250	≤ 300

https://www.hydrogen.energy.gov/pdfs/review21/plenary7_stetson_2021_o.pdf

Electrolyzers by Type

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Type	Pros	Cons
Alkaline	Well established, lower capital cost, more materials choices at high pH, high manufacturing readiness, can leverage established supply chains, demonstrated in larger capacity	Corrosive liquid electrolyte used, higher ohmic drop, lack of differential pressure operation, shunt currents, limited intermittency capabilities, efficiency
Polymer Electrolyte Membrane	Low ohmic losses/high power density operation, differential pressure operation, DI water only operation, leverages PEM fuel cell development and supply chain, load following capability	Requires expensive materials (Ti, Ir, Pt, perfluorinated polymers), lower manufacturing and technology readiness, efficiency
Solid Oxide	High efficiency, low-cost materials, integration with continuous high temperature electricity sources (e.g., nuclear energy), leverages SOFC development and supply chain, differential pressure operation	High temperature materials challenges, limited intermittency capabilities, thermal integration, lower manufacturing and technology readiness, steam conversion and separation challenges

Low Temperature ($0 - 200^oC$) (Alkaline, Polymer Electrolyte Membrane)

High Temperature ($>500^oC$) (Solid Oxide)

Badgett, Ruth and Pivovar, "Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis," accepted 2021.

H2NEW : H2 from Next-generation Electrolyzers of Water

H2NEW
U.S. DEPARTMENT OF ENERGY

A comprehensive, concerted effort focused on overcoming technical barriers to enable affordable, reliable & efficient electrolyzers to achieve <$2/kg H_2

- Launching in Q1 FY21
- Both low- and high-temperature electrolyzers
- $50M over 5 years

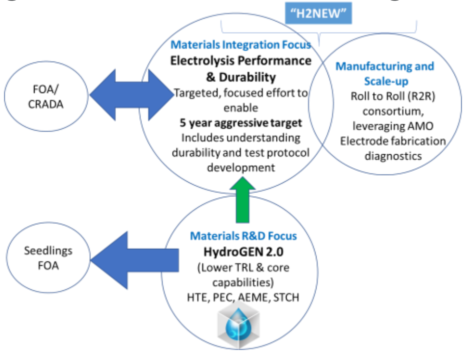
National Lab Consortium Team

NREL – National Renewable Energy Laboratory
INL – Idaho National Laboratory
Argonne National Laboratory
Berkeley Lab
Pacific Northwest National Laboratory
Los Alamos National Laboratory
Lawrence Livermore National Laboratory
Oak Ridge National Laboratory
NETL – National Energy Technology Laboratory

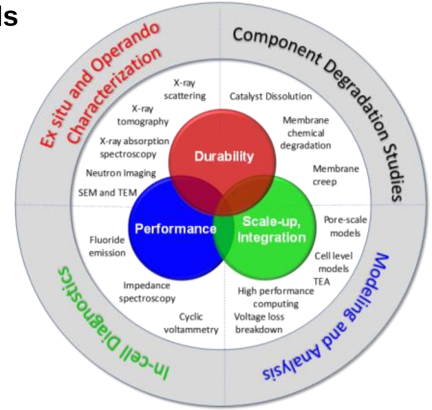
Clear, well-defined stack metrics to guide efforts.

Draft Electrolyzer Stack Goals by 2025		
	LTE PEM	HTE
Capital Cost	$100/kW	$100/kW
Elect. Efficiency (LHV)	70% at 3 A/cm²	98% at 1.5 A/cm²
Lifetime	80,000 hr	60,000 hr

The focus is not new materials but addressing components, materials integration, and manufacturing R&D



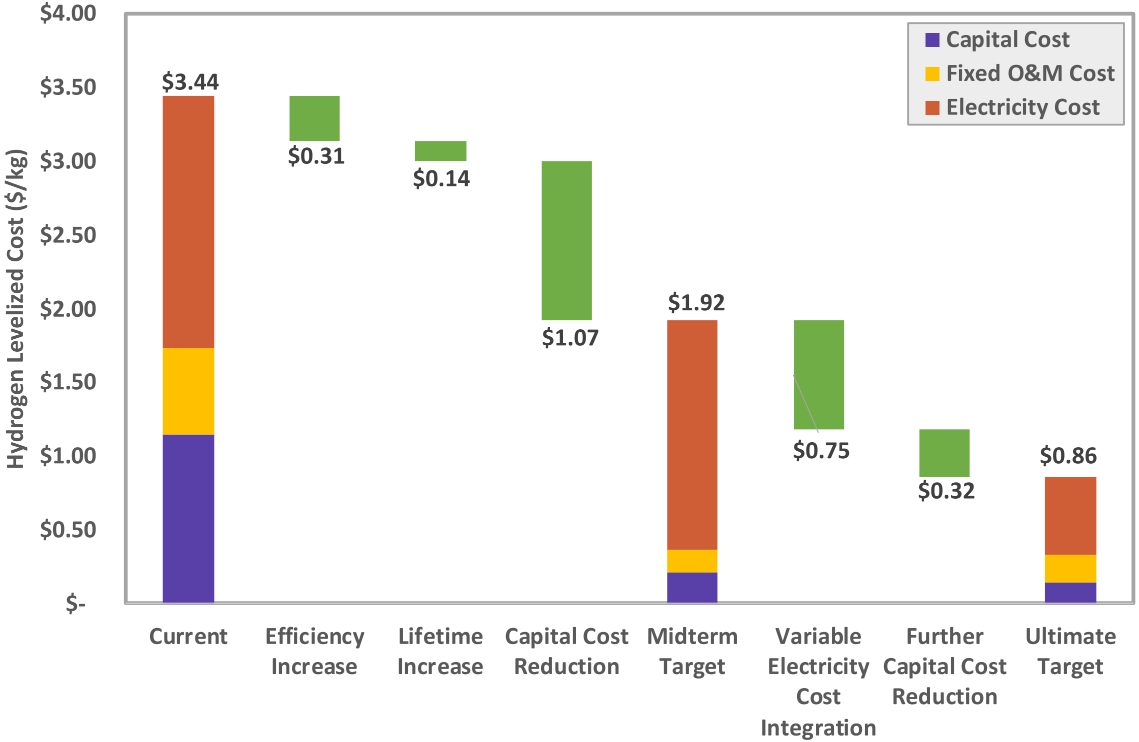
Utilize combination of world-class experimental, analytical, and modeling tools



Durability/lifetime is most critical, initial, primary focus of H2NEW

- Limited fundamental knowledge of degradation mechanisms.
- Lack of understanding on how to effectively accelerate degradation processes.
- Develop and validate methods and tests to accelerate identified degradation processes to be able to evaluate durability in a matter of weeks or months instead of years.
- National labs are ideal for this critical work due to existing capabilities and expertise combined with the ability to freely share research findings.

Relevance: Hydrogen Levelized Cost (PEM Centric)



Select pathway to $2/kg and $1/kg identified.

Much of HLC gains possible through greatly decreasing capital costs and enabling lower cost electricity through variable operation.

These advances can't come with compromised durability or efficiency, so all three areas are linked.

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