The University of Texas at Austin
Cockrell School of Engineering

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HYDROGEN AND ITS ROLE IN INDUSTRIAL DECARBONIZATION

Industrial Processes Emissions Reduction (IPER) Technology Workshop

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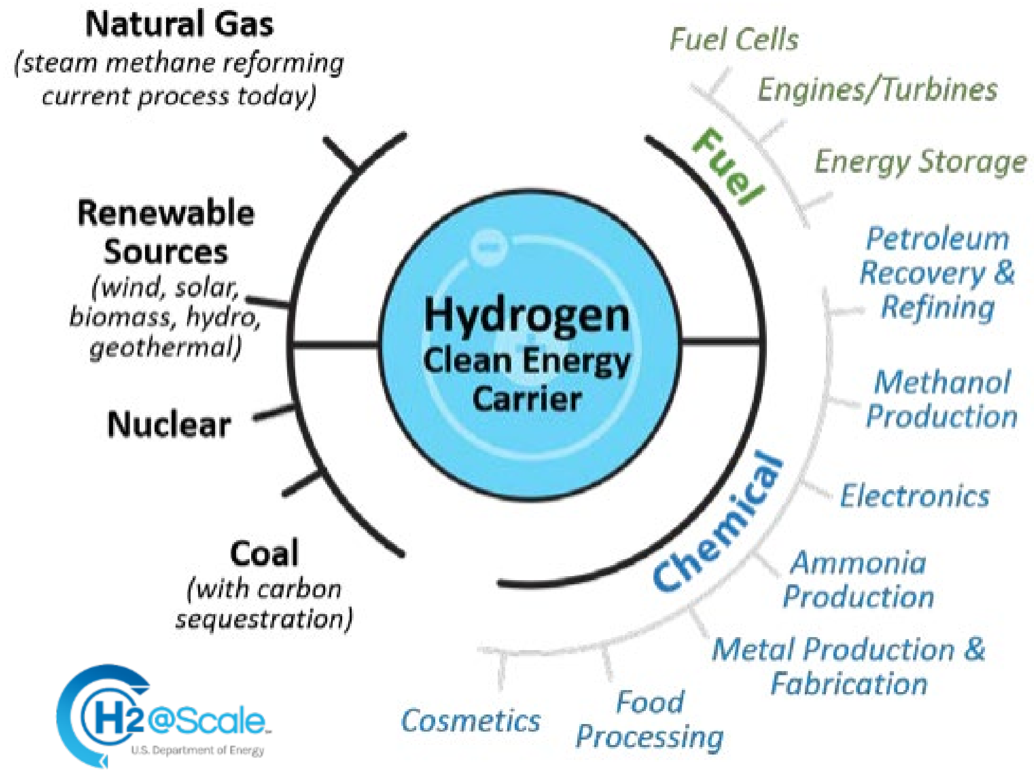
Michael Lewis

Hydrogen's Role in Industrial Decarbonization

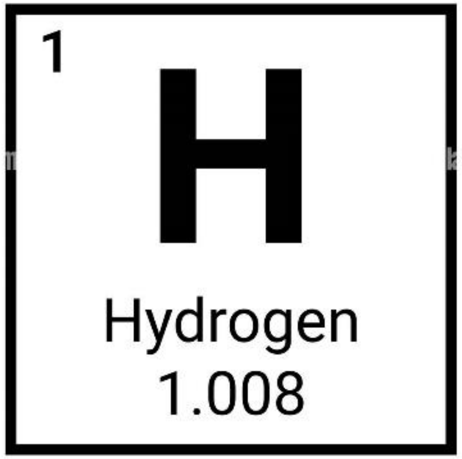
Hydrogen can enable U.S. energy security, resiliency, and economic prosperity, and is part of an "all of the above" energy strategy for these reasons:

1) Hydrogen can be produced from diverse domestic resources for use in multiple sectors, or for export.
2) Hydrogen is a critical feedstock for the entire chemicals industry, including liquid fuels.
3) Hydrogen can enable innovations in domestic industries, such as transportation (e.g., in vehicles, aviation, and marine applications) and iron making.
4) Hydrogen and fuel cells can enable zero or near zero emissions in transportation, stationary or remote power, and portable power applications.
5) Hydrogen can be used as a "responsive load" on the grid to enable grid stability and gigawatt-hour energy storage, and increase utilization of power generators, including nuclear, coal, natural gas, and renewables.



Source: https://www.energy.gov/sites/default/files/2020/07/f76/hfto-h2-at-scale-handout-2020.pdf

Hydrogen 1.01



- Most abundant element in the universe
- Present in common substances (water, sugar, methane)
- Very high energy by weight (3X more than gasoline)
- A versatile **clean energy carrier** with a wide rage of applications

Challenges

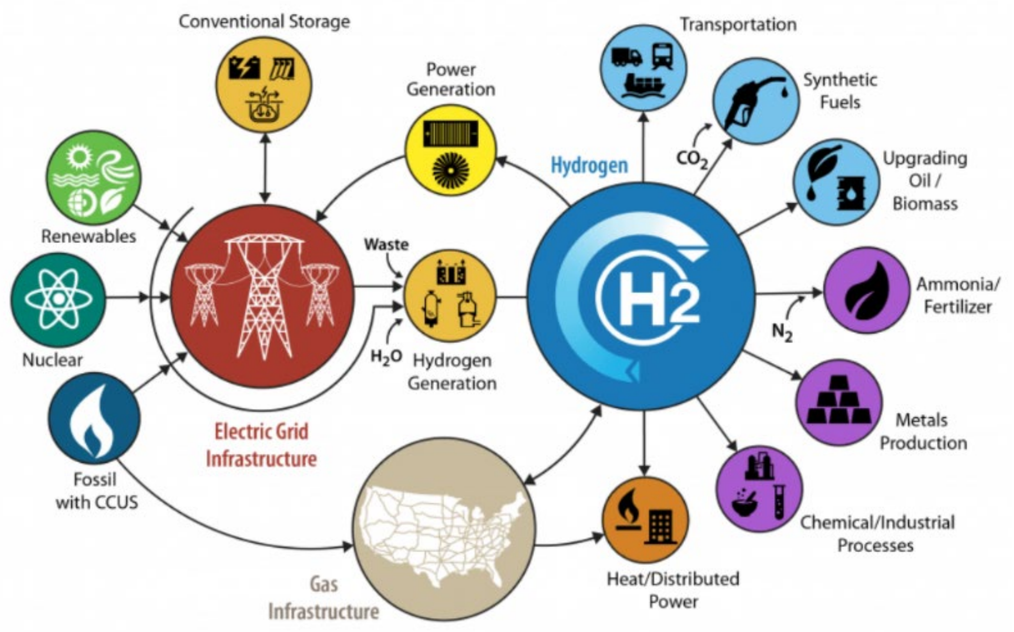
- Rarely found naturally, typically make from water or hydrocarbon sources
- Production, storage, and transport are all energy intensive due to poor volumetric density

How we will use and produce hydrogen is not without controversy

- Today costs are relatively high and infrastructure is limited
- Hydrogen emissions can prolong GHG in the atmosphere
- Water use is a local community issue

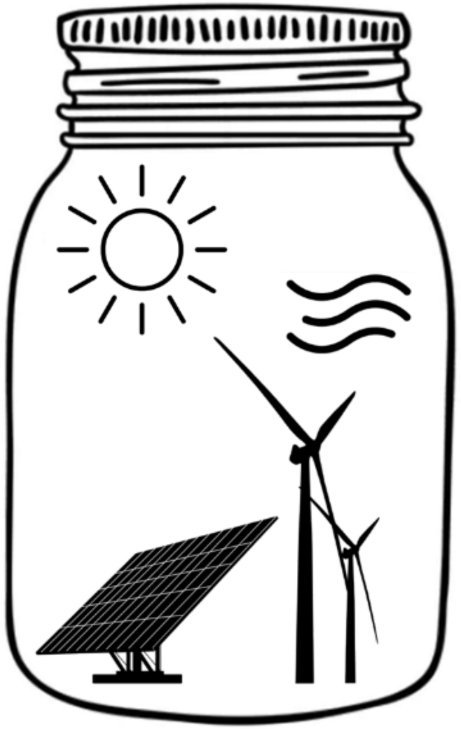
H2@Scale Vision and Opportunities

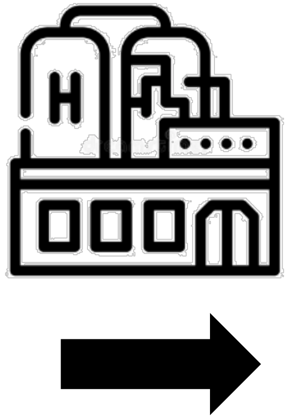
- Existing H2 applications well understood, but emerging and new applications still need research and commercial development
- Final 45V Clean Hydrogen Production Tax Credit (PTC) rules will be important
- Everything under that blue H_2 Circle is a challenge
- How do all these pieces fit and work together?
  - Grid resiliency, energy storage
  - Relationships between water, energy, and food, and communities
  - Carbon capture storage and use



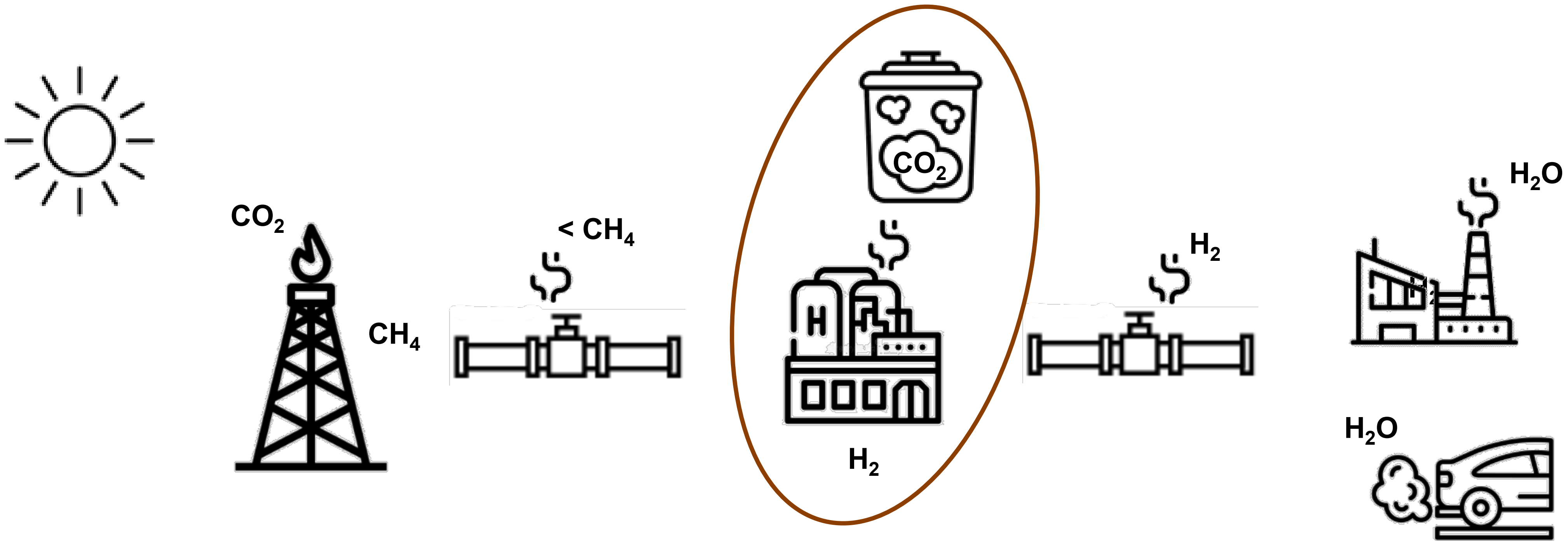
A Versatile Clean Energy Carrier – Sunlight in a Jar

How can we capture sunlight and wind at large scale and ship it around the world?





A Versatile Clean Energy Carrier - Hydrogen from Fossil Fuels



We can capture carbon with hydrogen production, and then clean hydrogen can be transported and used in numerous applications, thereby reducing emissions at many tailpipes and smokestacks around the world.

The Hydrogen Rainbow

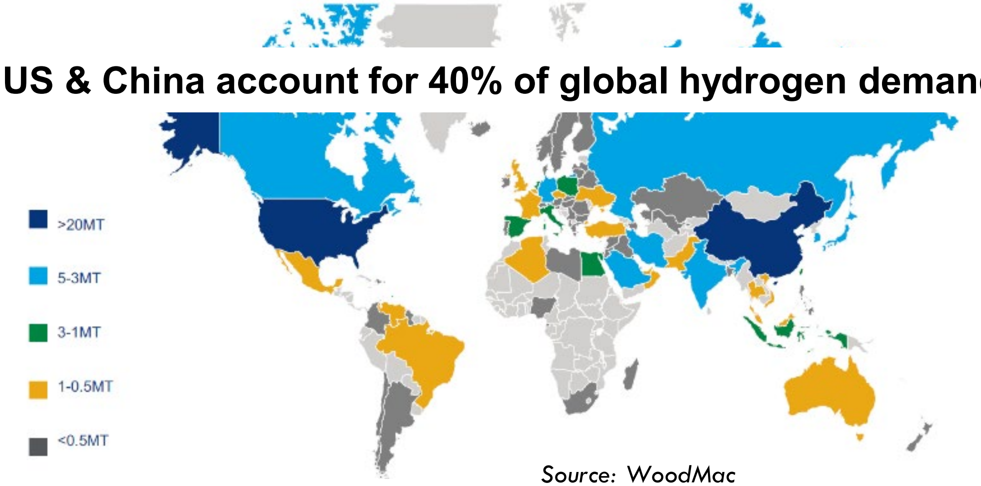
- There are many ways to produce Hydrogen.
- Historically, the production methods were referred to as “colors” of hydrogen
- Today, the shift is towards a carbon-intensity measure, no matter the production method
- However, colors are convenient when speaking broadly

Color	Technology	Feedstock / Energy Source	Relative GHG Footprint
White	N/A	Naturally occurring H2	Debatable
Grey	Natural gas reforming	Natural gas	High
Blue	Natural gas reforming + CCUS	Natural gas	Medium to Low
Green	Electrolysis	Renewable electricity (wind, solar, hydro, geothermal, etc)	Minimal
Turquoise	Pyrolysis	Natural gas	Solid carbon by product
Brown	Gasification	Brown coal (ignite)	High
Black	Gasification	Black coal	High
Pink	Electrolysis	Nuclear electricity	Minimal
Purple	Electrolysis	Nuclear heat and electricity	Minimal
Red	High-temp catalytic water splitting	Nuclear heat and electricity	Minimal
Yellow	Electrolysis	Solar electricity (Mixed grid?)	Medium

This is not an exhaustive list.

Hydrogen Production and Demand Today

US & China account for 40% of global hydrogen demand

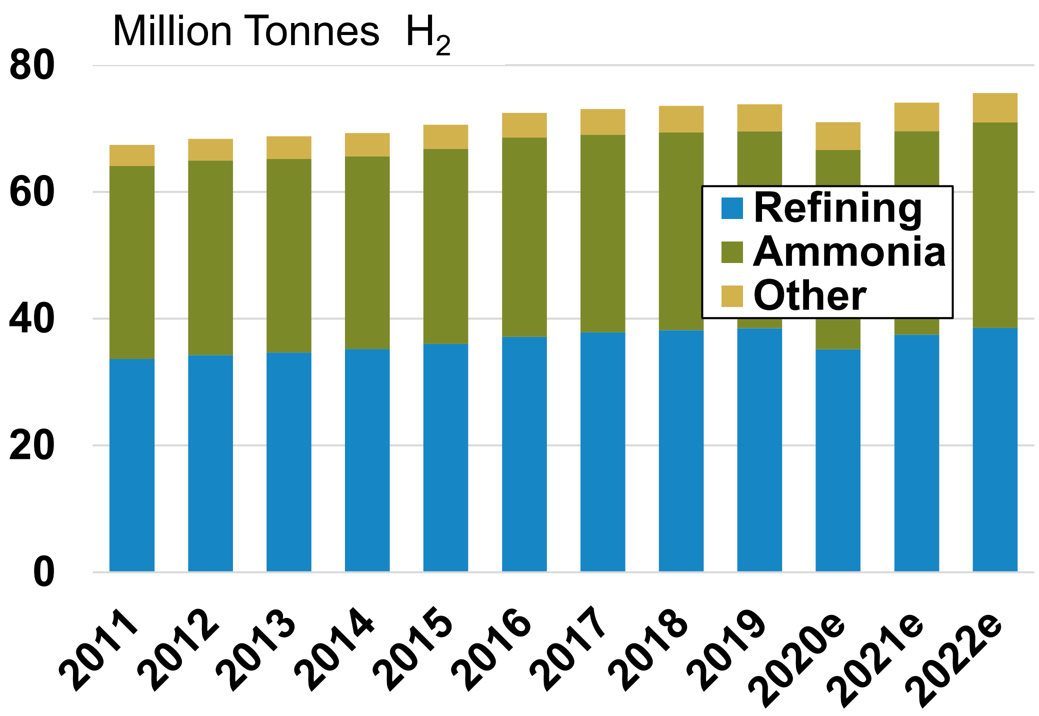


Source: WoodMac

U.S. annual hydrogen production
10 million metric tons

Largest Users in the U.S.			
Petroleum Processing	68%	Fertilizer Production	21%

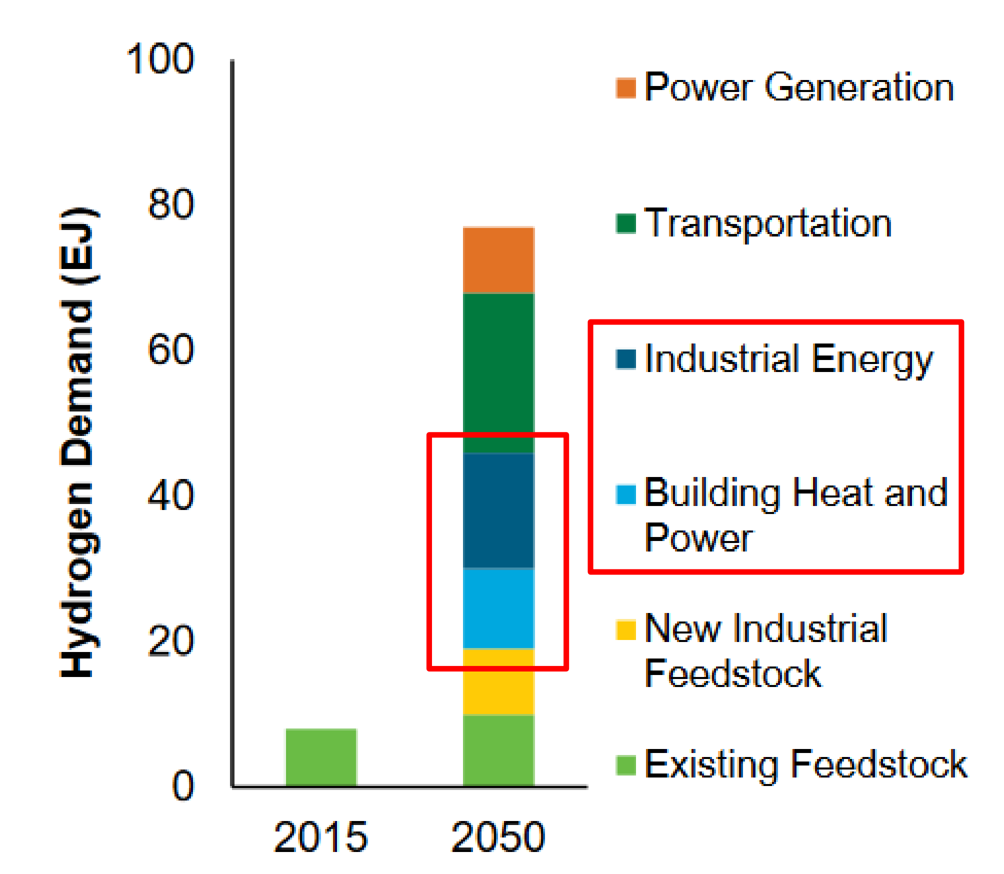
Global Pure H_2 Demand



Source: GTI, International Energy Agency

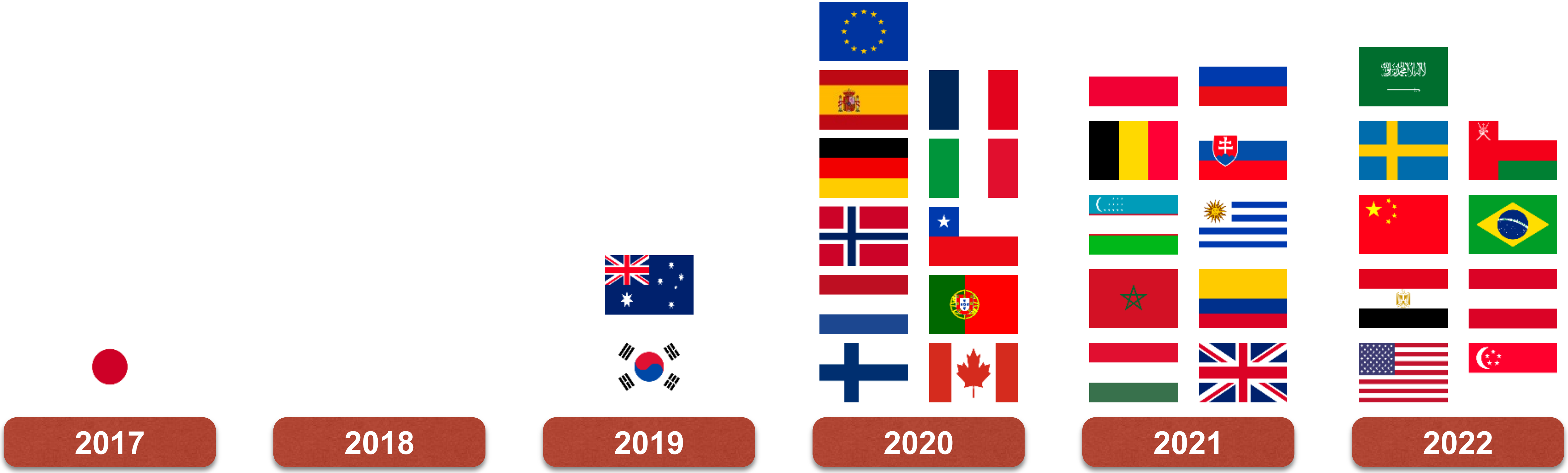
Why Now is an Exciting Time for Hydrogen

- New hydrogen markets are emerging
- International momentum is building to develop a hydrogen energy economy
- Department of Energy programs and goals
- U.S. Policy supporting hydrogen infrastructure and production



Source: "Hydrogen Scaling Up." Hydrogen Council. November 2017. http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

National Hydrogen Strategies



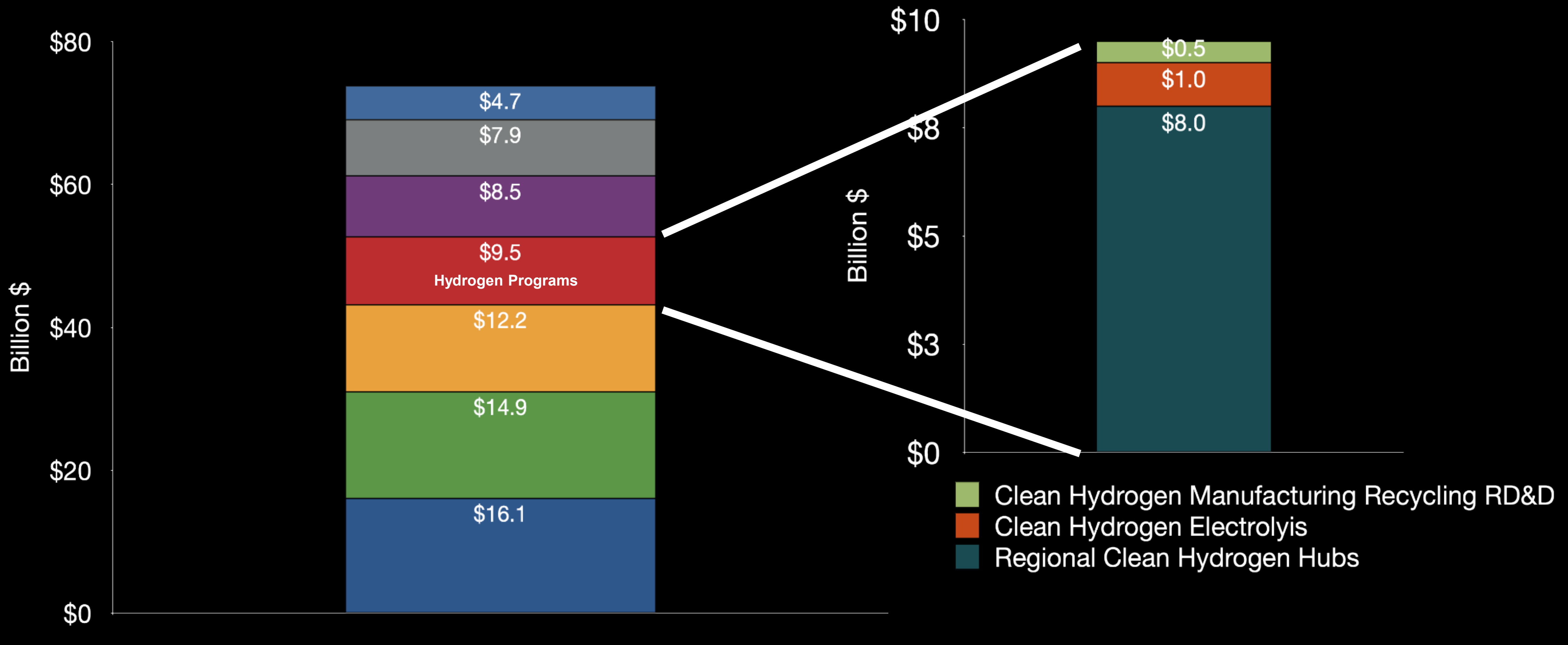
DOE low-carbon hydrogen cost targets

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

1 Dollar 1 Kilogram 1 Decade

- Launched in June 2021, the *Hydrogen Earthshot* sets a target to reduce the cost of clean hydrogen to $1/kg by 2032
- 80% cost reduction compared to current average cost of producing hydrogen from renewable energy ($5/kg)
- Modeled after the successful SunShot Initiative that drove cost declines in solar energy
- Other Energy Earthshot initiatives include: Long Duration Storage Shot, Carbon Negative Shot, Enhanced Geothermal Shot, Floating Offshore Wind Shot, and Industrial Heat Shot

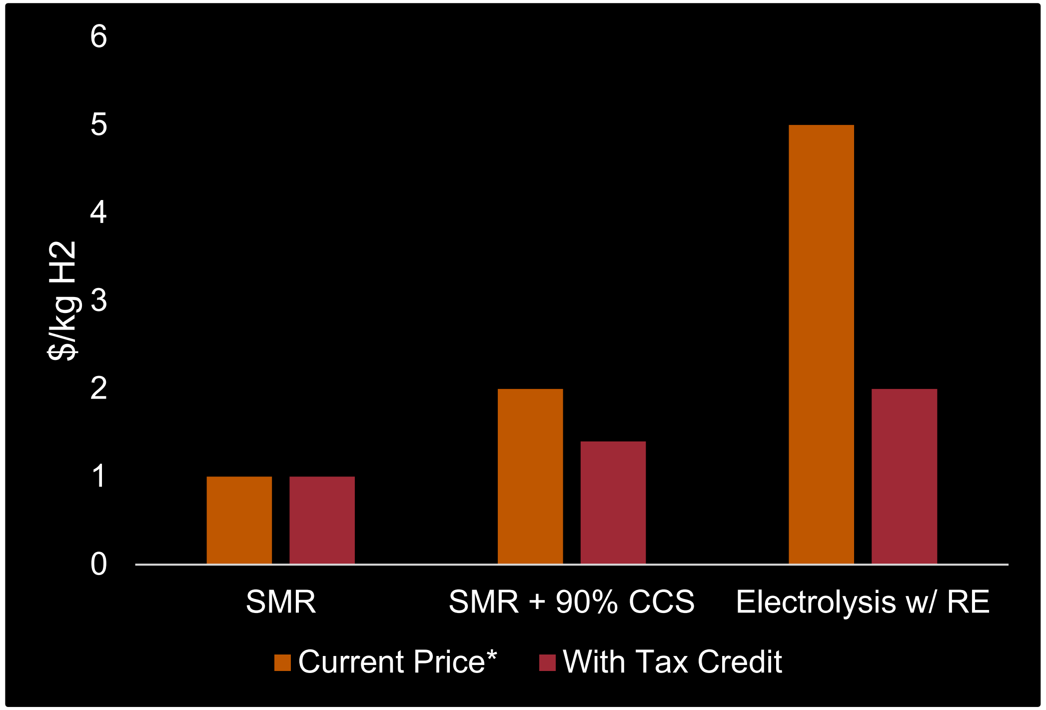
Infrastructure Investment and Jobs Act included $9.5 billion for hydrogen programs



The new clean hydrogen production tax credit included in the *IRA* could make clean hydrogen competitive

Clean hydrogen PTC has a tiered credit value structure based on production emissions

Emissions Threshold	Credit Value (assumes 5x bonus)
>= 2.5 kg CO_{2e}/kgH_2 & < 4 kg CO_{2e}/kg H_2	\$0.60/kg H_2
>= 1.5 kg CO_{2e}/kgH_2 & < 2.5 kg CO_{2e}/kg H_2	\$0.75/kg H_2
>= 0.45 kg CO_{2e}/kgH_2 & < 1.5 kg CO_{2e}/kg H_2	\$1.00/kg H_2
< 0.45 kg CO_{2e}/kg H_2	\$3.00/kg H_2



*Approximate prices of current production methods to demonstrate impact of tax credit

- Proposed rules published in Dec 2023
- Public comment period ended in Feb 2024

Regional Clean Hydrogen Hub Program

Production

At least one from…

Renewable energy

Nuclear energy

Fossil fuels

End Use

At least one in…

Residential and commercial heating

Electric power generation

Transportation

Industrial sector

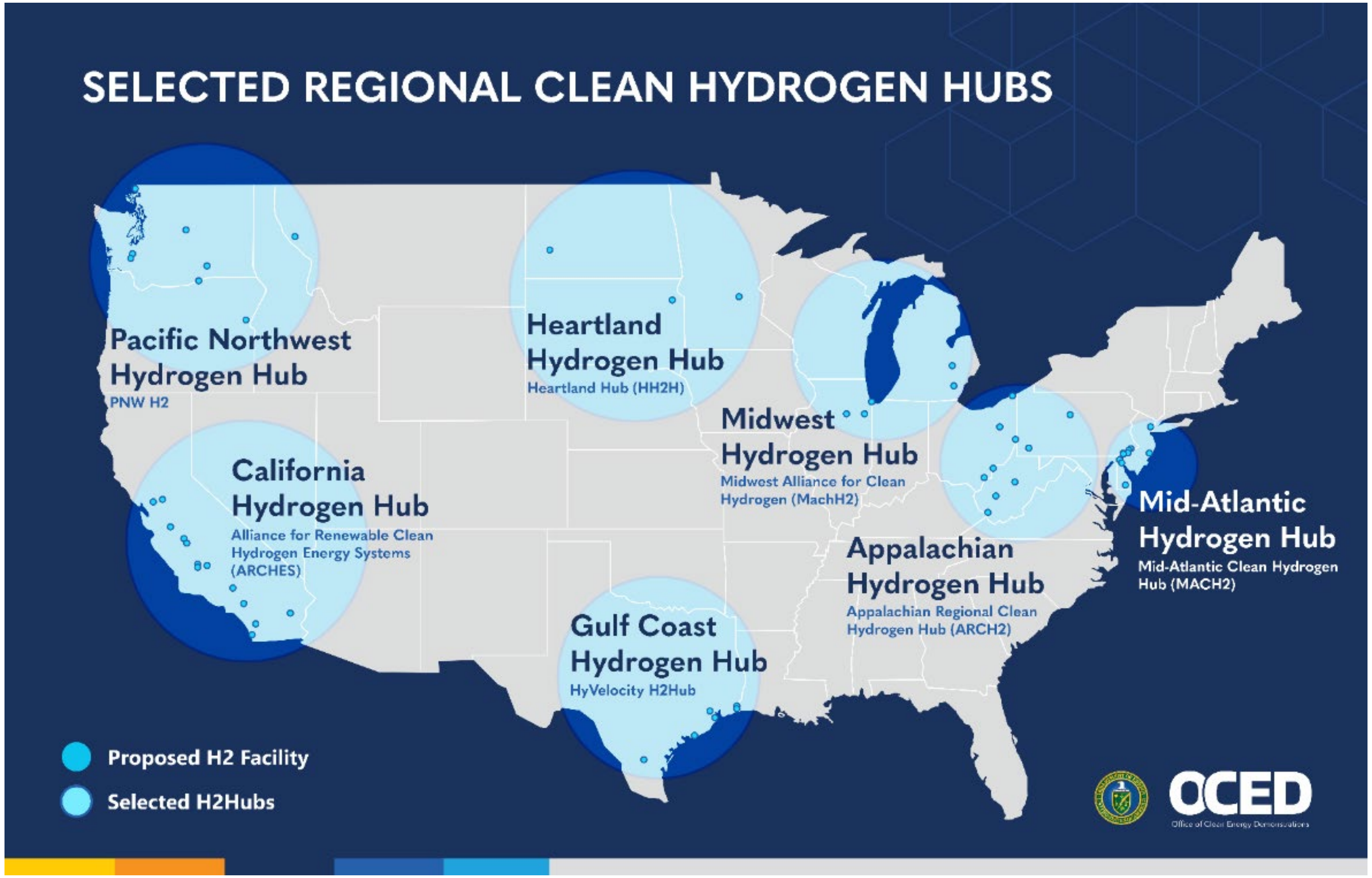
Geography

Each in different regions of the US

At least two in…

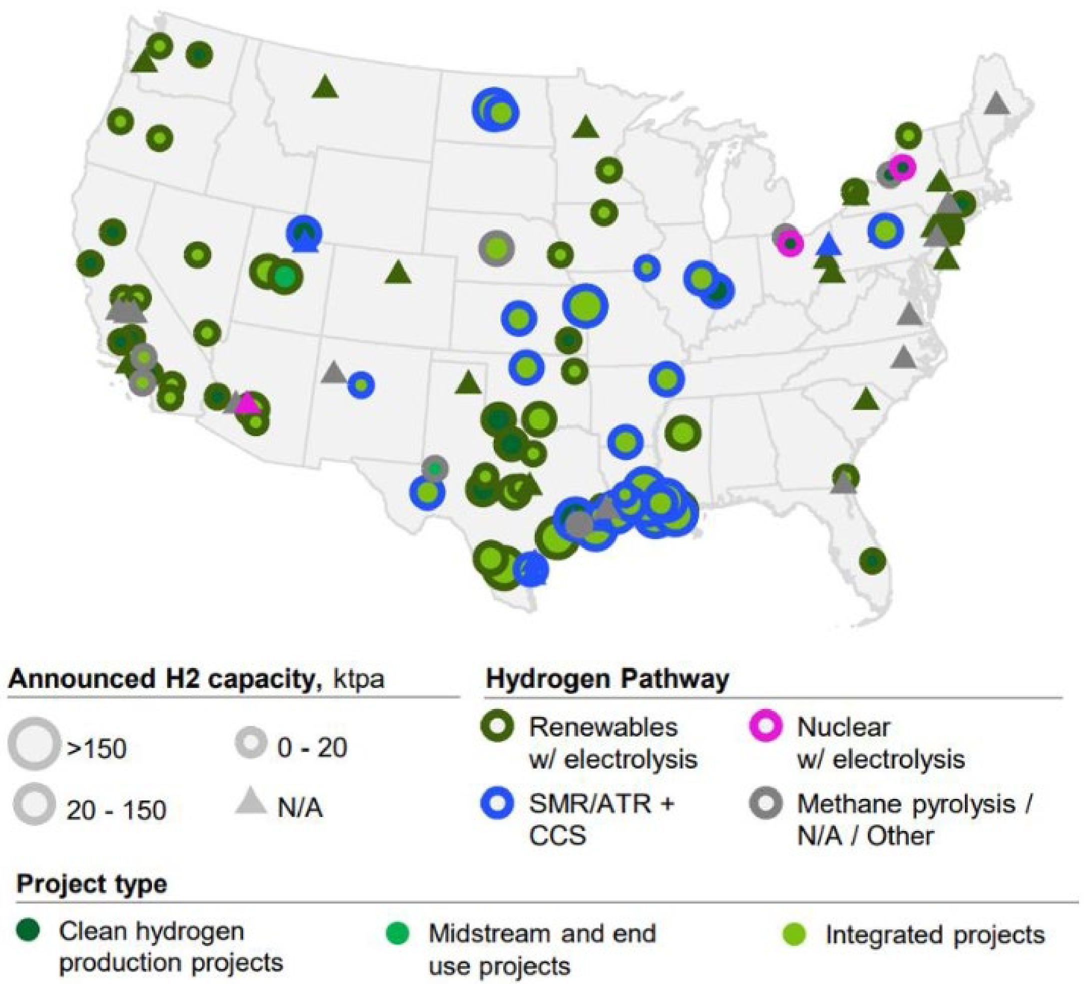
Natural gas producing regions

Selected Regional Clean Hydrogen Hubs



- >300,000 direct jobs
- Reduce emissions by 25 MMT of CO_2/year

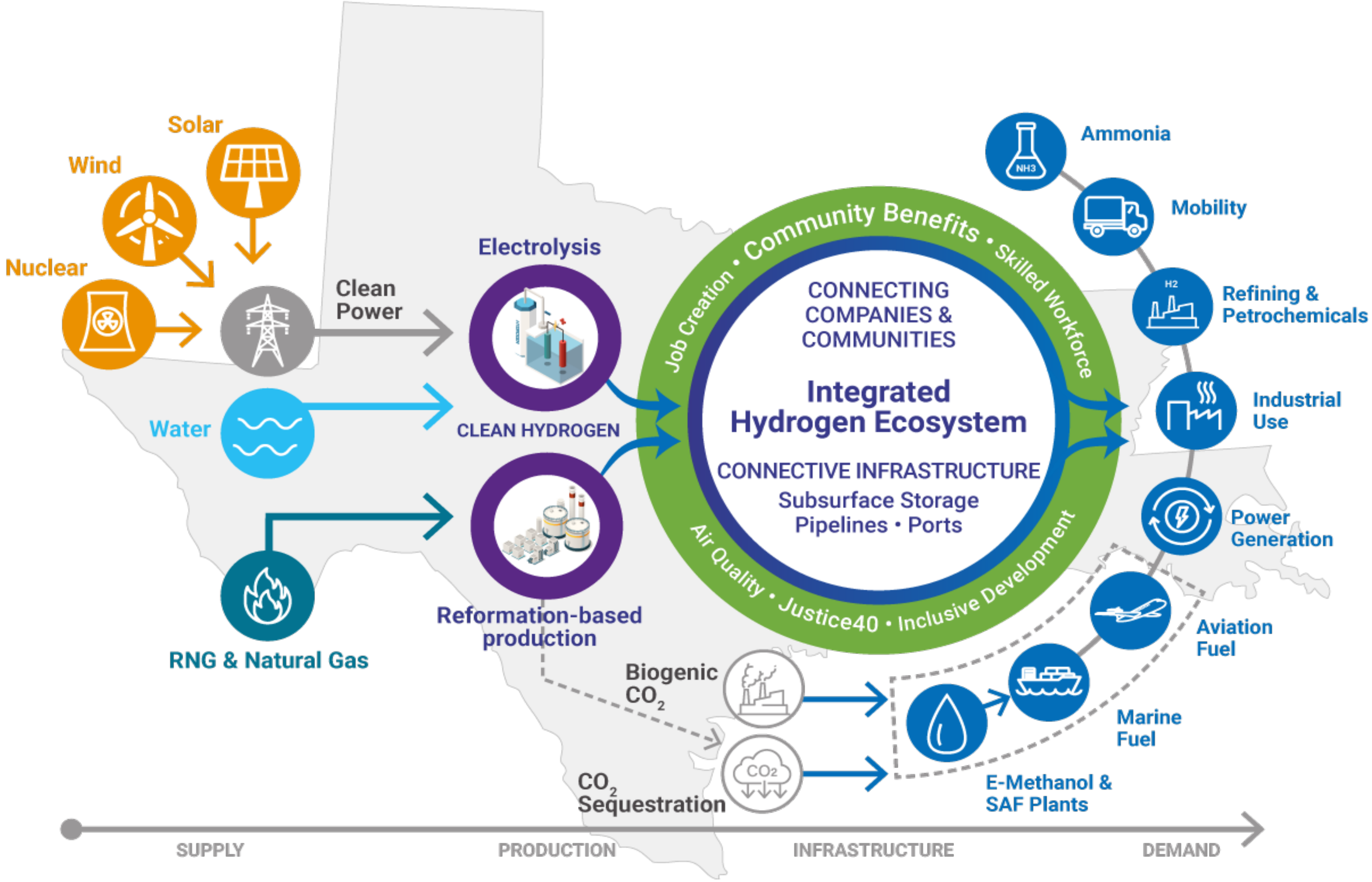
Publicly announced clean hydrogen production



As of EOY 2022, with total production potential of 12 MMT/year.

https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf

HyVelocity: Envisioned Clean Hydrogen Ecosystem

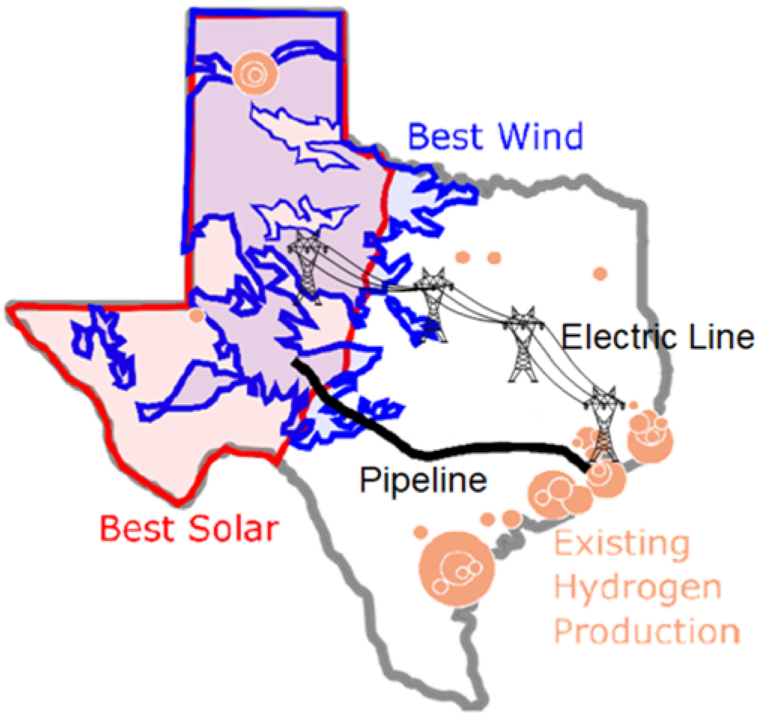


Announced Clean Hydrogen Projects in TX and LA

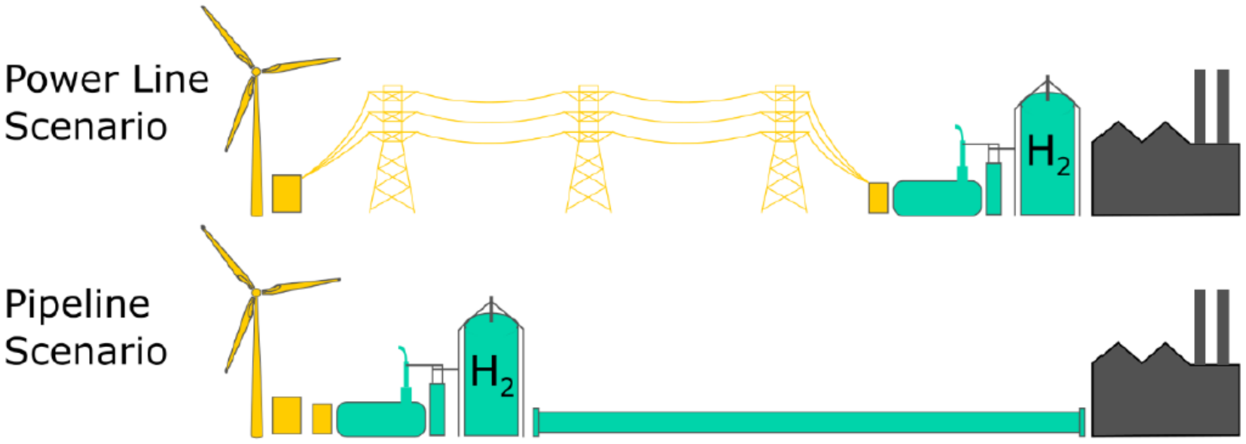
Source: Center for Houston's Future

Industrial Hydrogen Use Considerations and Examples

Renewable Energy is Often Not located With Demand



Two pathways to convert wind energy into hydrogen for the end user

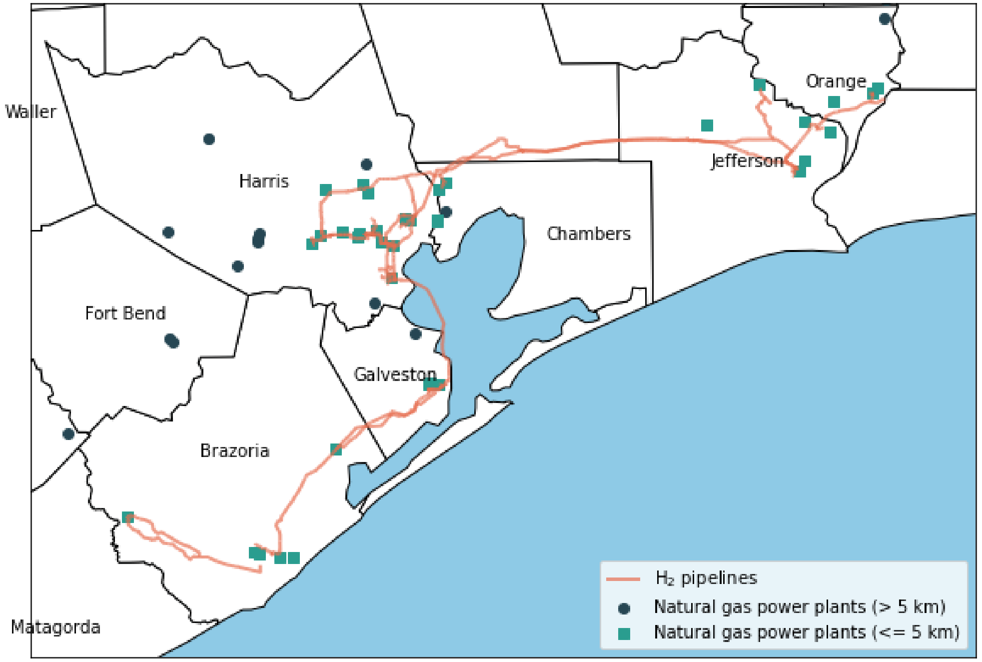


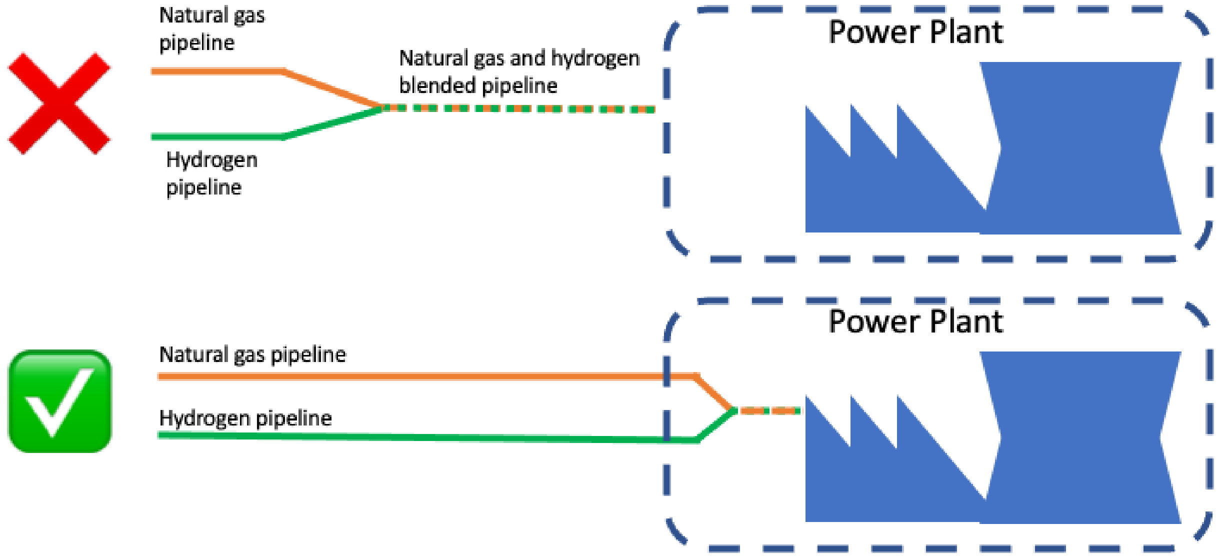
- Hydrogen pipeline pathway is about 3X more cost effective than electrical transmission lines
  - A single pipeline vs **Five high voltage** electric transmission corridors

Power Plants Located Near H2 Pipelines

- Large potential for CO_2 emissions reductions, even at just 5% blends
  - In Houston area, 1.8 million metric tons CO_2 per year (~ 400,000 cars)
- Proposed or existing policies, if adapted for H2, would enable blending

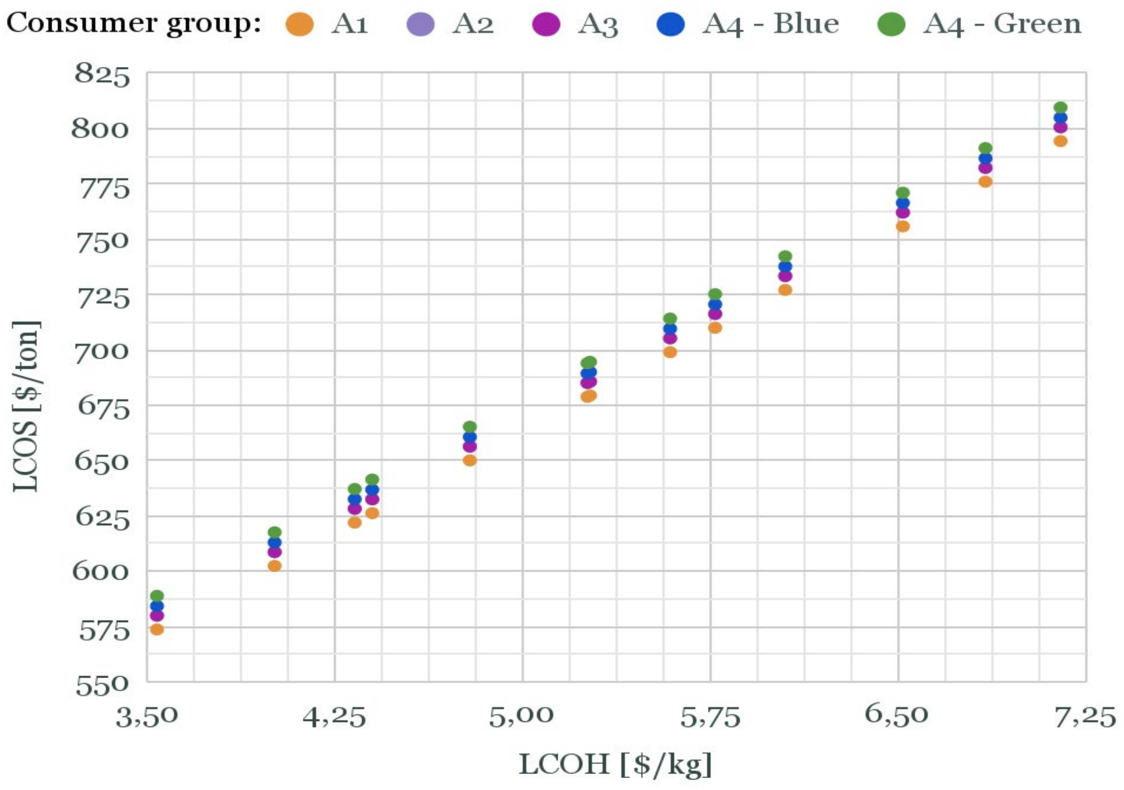
Texas Gulf Coast natural gas power plants in relation to existing H_2 pipelines





Steel Industry Example – 30% of Industrial GHG Emissions

- Case Study performed for Brazilian Market using local renewable energy resources for hydrogen production
- Traditional steel manufacturing results in a cost of $450-650/ton and 1.87 tons CO_2 per ton of steel.
- Using Hydrogen Direct Reduction of Iron and Electric Arc Furnaces with renewable energy, emissions are reduced to 0.05 ton CO_2 per ton steel.
- Cost of producing steel in this manner is estimated to be $575-800/ton for Brazilian markets



H2@UT - https://sites.utexas.edu/h2/

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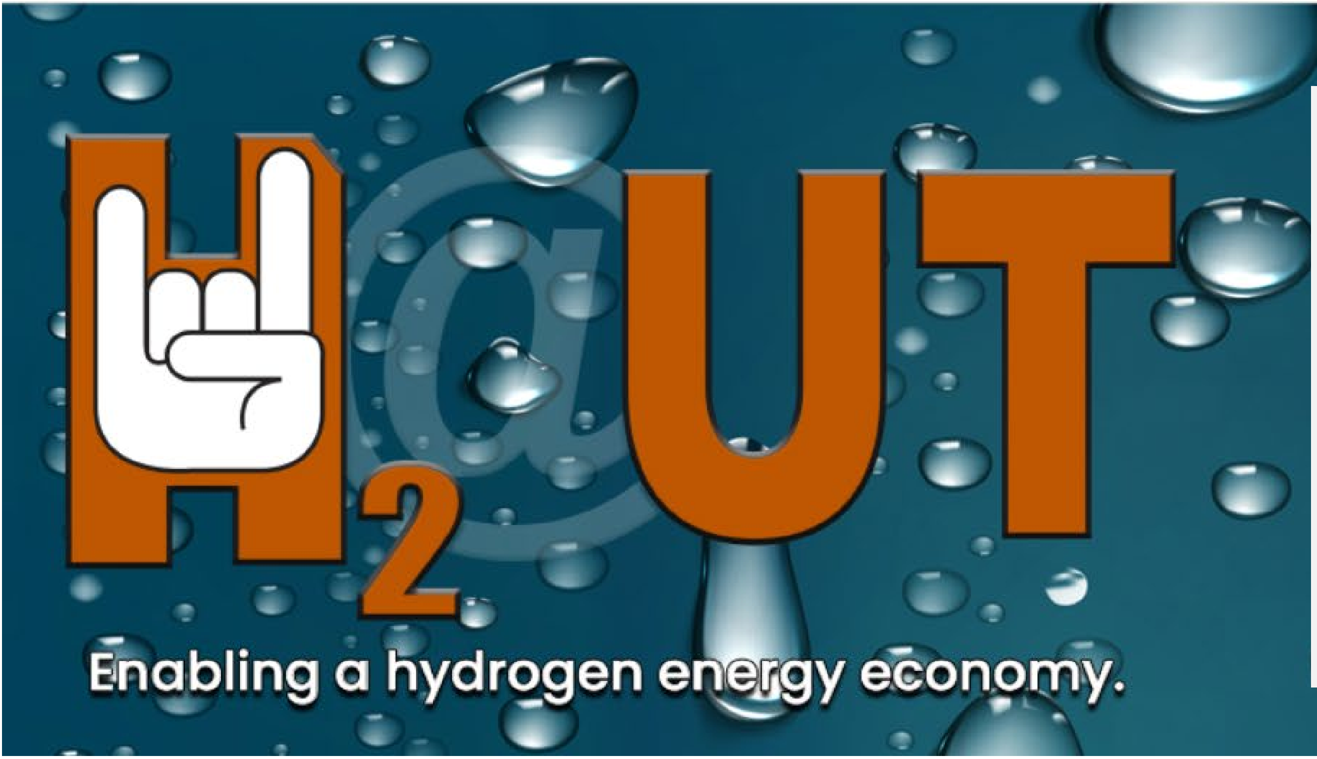

UT has about 80 researchers working across the entire field of hydrogen production, storage, transmission, and use

- Providing information to industry and government supporting prudent decisions to guide the growth of the hydrogen economy
- Educating students who will lead future hydrogen growth

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