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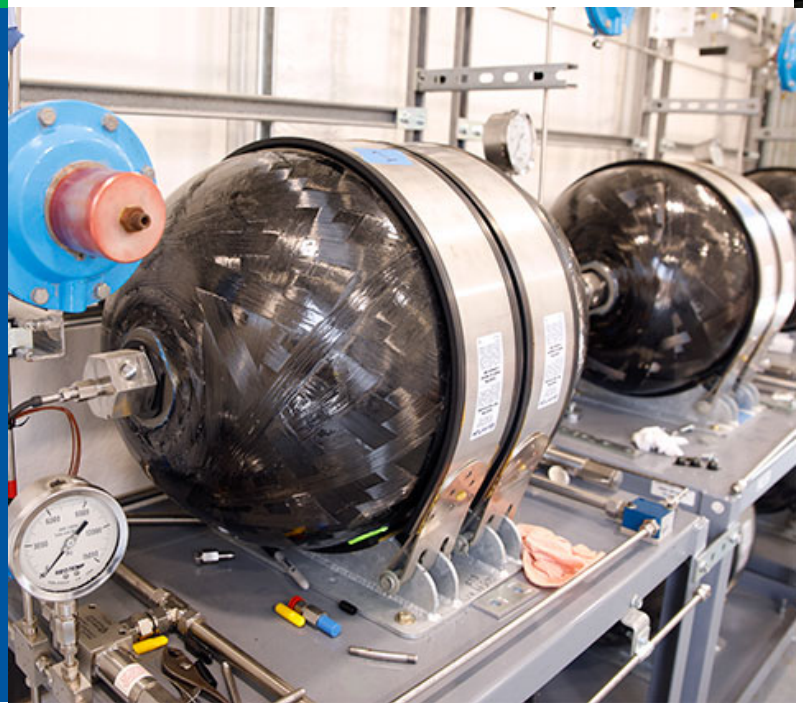
solutions that transform



HYDROGEN TECHNOLOGY CENTER

HyVelocity Hub

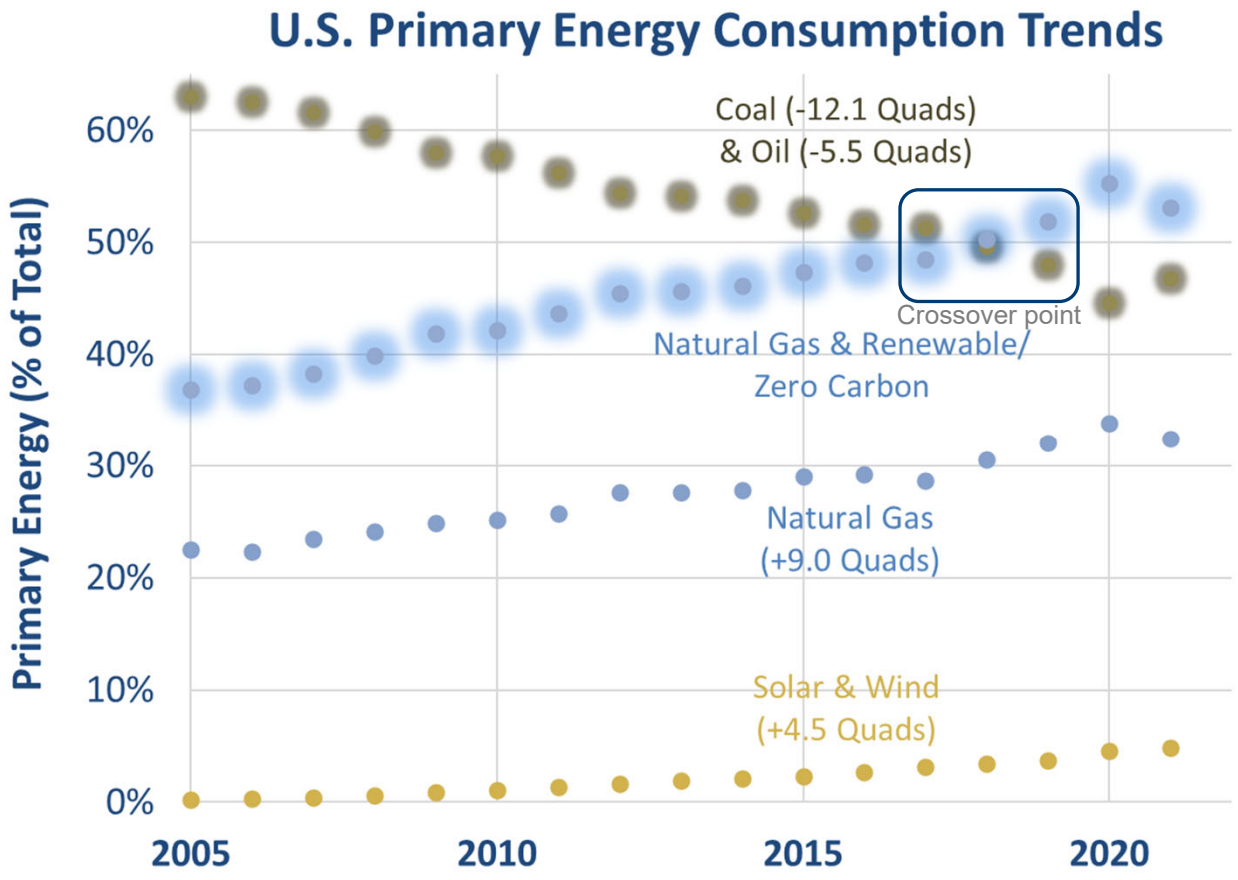
Hydrogen – What's Old is New Again

5-1-2024

Brian Weeks, Sr. Director R&D

GTI Energy

We Are Already 15 Years into the Energy Transition (Phase 1)



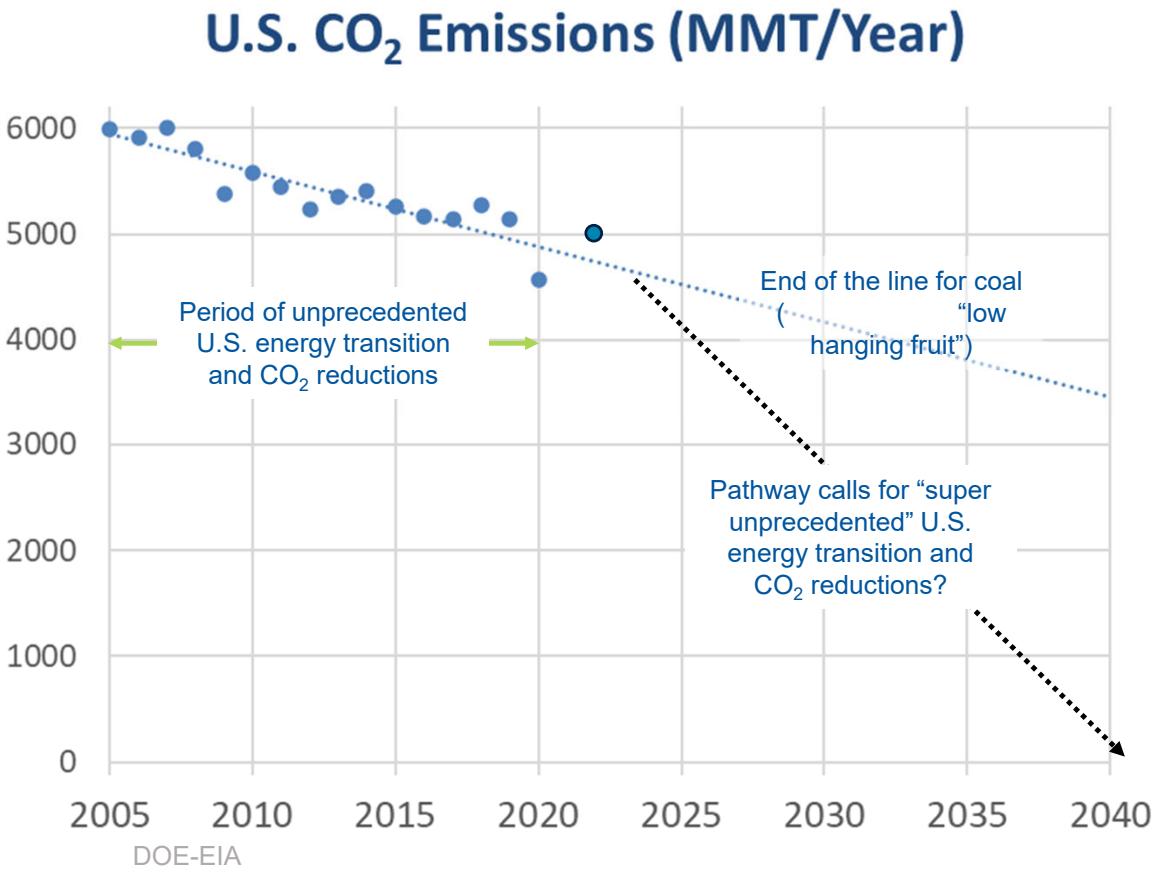
Source: DOE-EIA

U.S. Phase 1 Energy Transition began around 2007. Before then, fairly small changes took place in the overall energy mix.

Began with introduction of shale gas and expanded use of wind, solar, and biomass in our economy – displacing coal and oil.

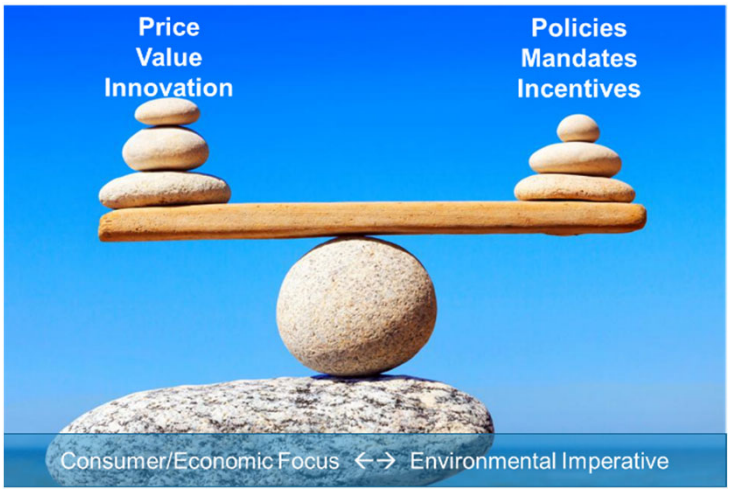
Very linear displacement
- Some flux during Covid
- 2021 price changes

Setting the Stage for Hydrogen



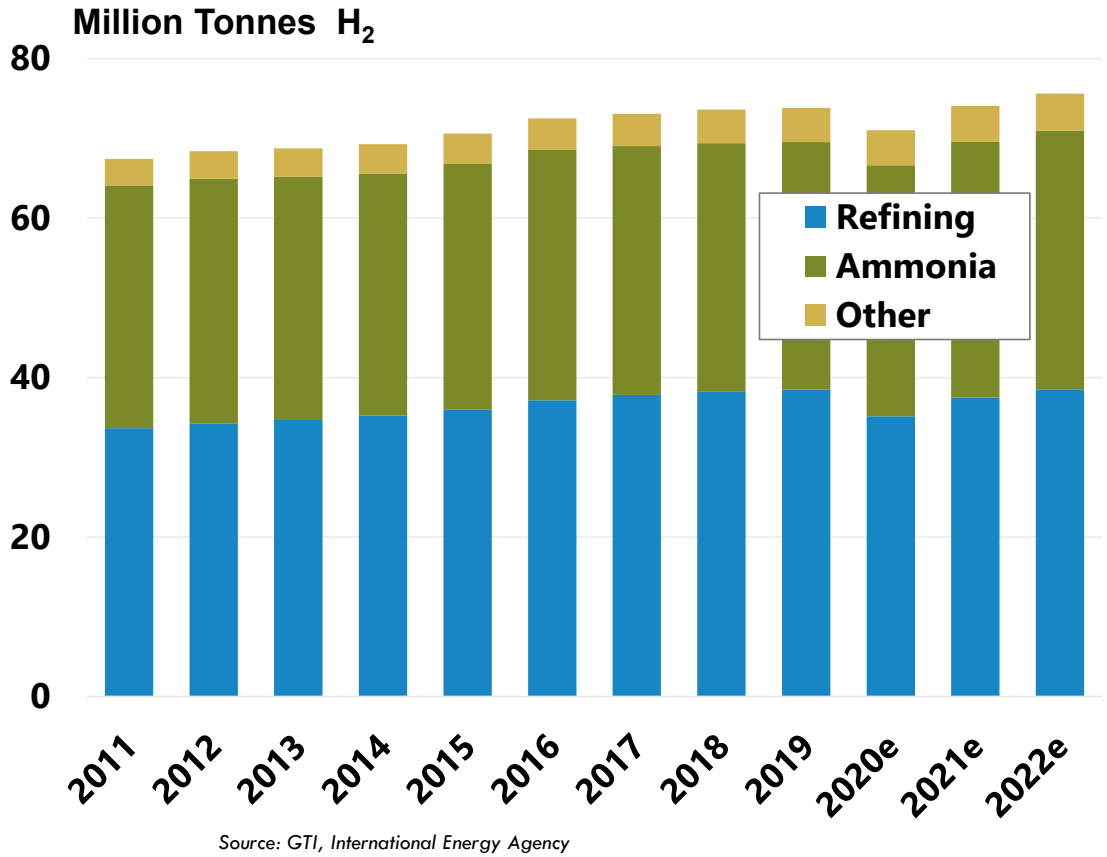
Most CO_2 emission reductions since 2005 due to shale gas cost-effectively displacing coal (and with minimal consumer energy cost impacts).

How do we achieve even greater rates of reduction after "low hanging fruit" is picked? What are the consumer energy cost and energy system implications?



Today's Hydrogen Demand

Global Pure H_2 Demand



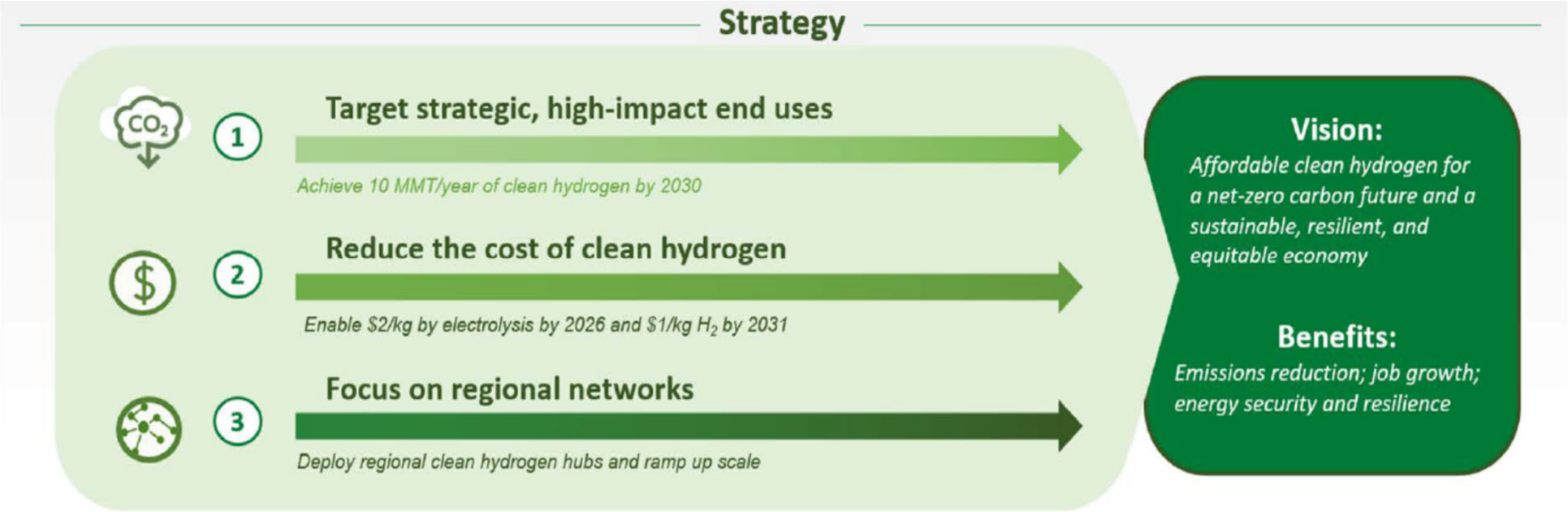
Source: GTI, International Energy Agency

- Today's hydrogen demand is dominated by two sectors: oil refining and ammonia production
- Hydrogen is used by refiners to reduce Sulphur content in oil products and upgrade low value products to higher value products
- Hydrogen is used in concert with atmospheric nitrogen to produce ammonia (NH_3)
  - Ammonia is a key feedstock for the production of fertilizer
- Nearly 100% of current demand with hydrogen from hydrocarbon fuels.

Hydrogen has many uses, but the vast majority is used for ammonia, refining, methanol, and chemicals

USE	Growth Rate to 2025	Current Use MM Metric tons/yr.	% of Total Demand	Outlook
Ammonia	3.1%	2.7	24%	Cheap natural gas supply in U.S. drives new ammonia capacity additions
Refining	1.5%	6.5	57%	Driven by continued global regulations toward low-sulfur fuels
Methanol	4.0%	1.6	14%	Methanol demand growing rapidly in China where it is used for fuel and for olefins Cheap natural gas in U.S. is driver for new methanol production
Metal processing	2.0%	0.2	2%	Welding, heat treatment of steel, glass production, Forming and blanketing of gas
Other (chemicals, glass, rocket fuel, electronics, etc.)	2.6%	0.4	3%	Cheap U.S. NGL's is driving new ethylene plants… leading to investments in derivative capacity such as resins and polymers that use hydrogen

U.S. National Clean Hydrogen Strategy



Source: US DOE AMR_2023

Federal Incentives for Clean Hydrogen

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Drivers to Enable Clean Hydrogen at Scale and Cross-Agency roles - Examples

Supply	Midstream	End Use Demand
Production Tax Credit 45V, 45Q (Treasury)	Fueling Corridor Grants (DOT/JO)	Vehicle Tax Credits, Clean Fuels Credits, 48C (Treasury)
Electrolyzer RD&D BIL (DOE)	Bipartisan PIPES Act NPRM (DOT PHMSA)	State Policies (ZEV Mandates, H2 PTC)[1]
Manufacturing Tax Credit 48C (Treasury/DOE)	Manufacturing Tax Credit 48C (Treasury/DOE)	Clean Power Rule NPRM (EPA)
Regional Clean H2 Hubs BIL (DOE)	Regional Clean H2 Hubs BIL (DOE)	Buy Clean Standards (EOP)
		Agency offtake (DOD, USPS, USDA, DOT, EPA, etc.)
		Regional Clean H2 Hubs BIL (DOE)

JO: Joint Office of Energy and Transportation; EOP: Executive Office of the President
NPRM: Notice of proposed rulemaking

1: ZEV Mandates see: https://www.c2es.org/document/us-state-clean-vehicle-policies-and-incentives/. Colorado's H2 PTC see: https://leg.colorado.gov/bills/hb23-1281.

Source: US DOE AMR_2023

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> The color scheme is not helpful in the sense that it's not getting to the key point, which is what are the environmental attributes of the hydrogen being produced… The key issue is there has to be a methodology for tracking and declaring the specific CO2 intensity of whatever hydrogen you're working with.

— Daryl Wilson, Executive Director, Hydrogen Council

Carbon Intensity of hydrogen has significant variability

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Risks of reliance on production technology to judge emissions:

- Fracture hydrogen markets along technology boundaries
- Locking in suboptimal systems
- Stifle innovation by boxing out alternatives
- Deeply inaccurate

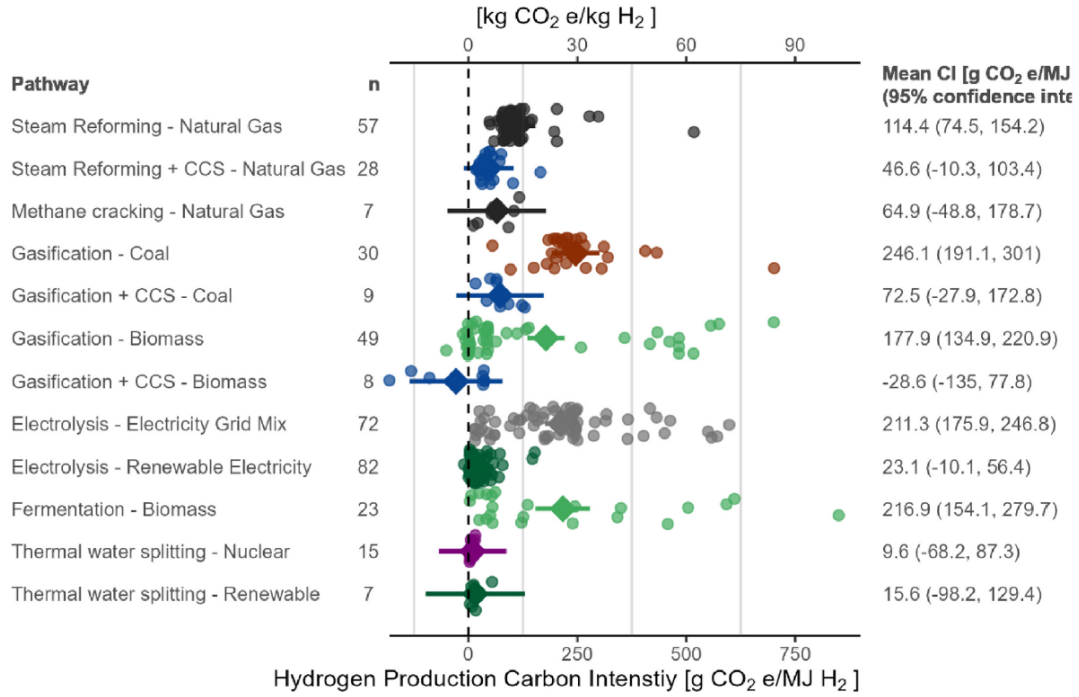


Fig. 2. Summary of the CI for the main Hydrogen production pathways. n = 387. The large diamond shows the average value with their respective 95% estimated confidence interval (for the mean) through a linear regression model using the hydrogen production pathways as categorical variables [121]. One CI for biomass gasification with a very high value of 1972 $gCO_2e/MJ\ H_2$ is omitted from the chart.

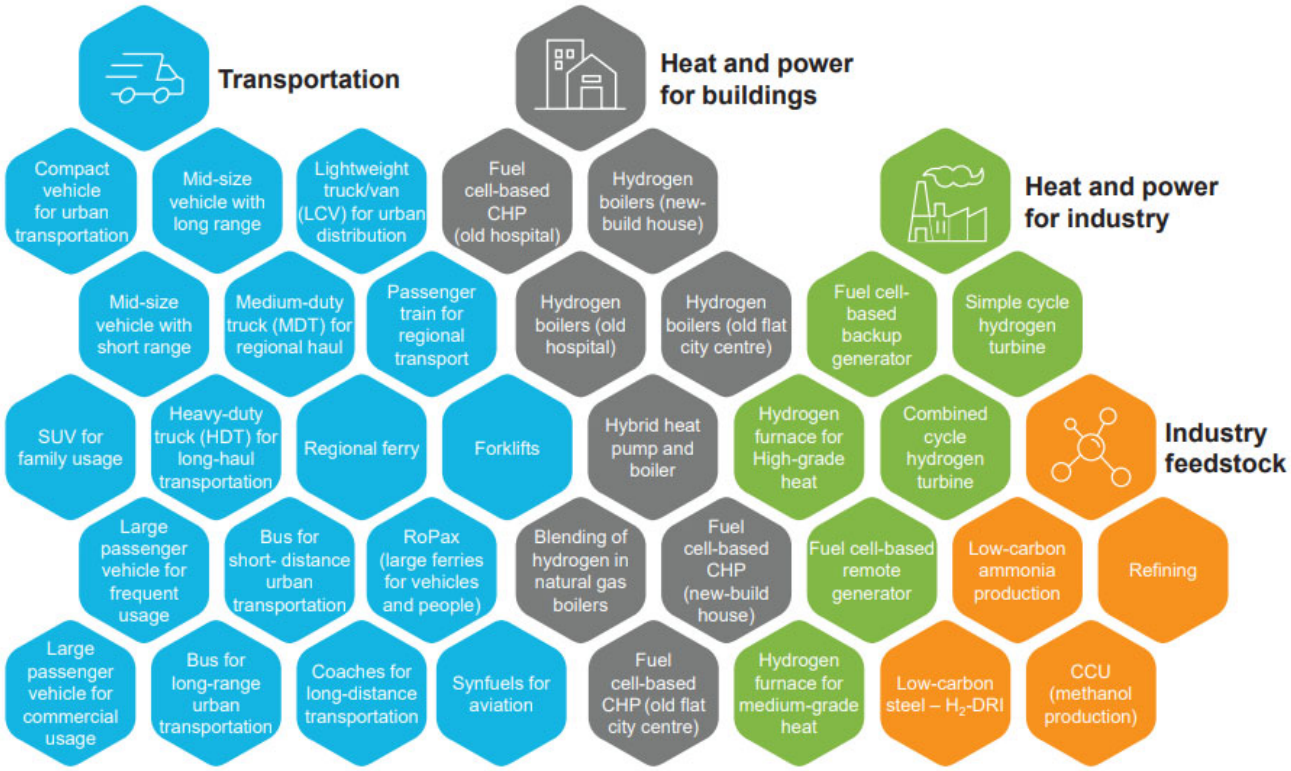
Source: Busch, Pablo et.al.

Moving Beyond Existing H_2 Demand

Hydrogen can be used to reduce emissions in many hard-to-abate sectors

Despite current limitations in use cases, hydrogen could be an economically viable solution across the energy landscape, including:

- Land Transport
- Marine Transport
- Aviation
- Steel Production
- Industrial Heat
- Power Generation
  - Long Duration Power Storage
- Natural Gas Pipeline Blending



Source: Hydrogen Council, 2020

Decarbonizing ammonia production will unlock its potential as a hydrogen vector

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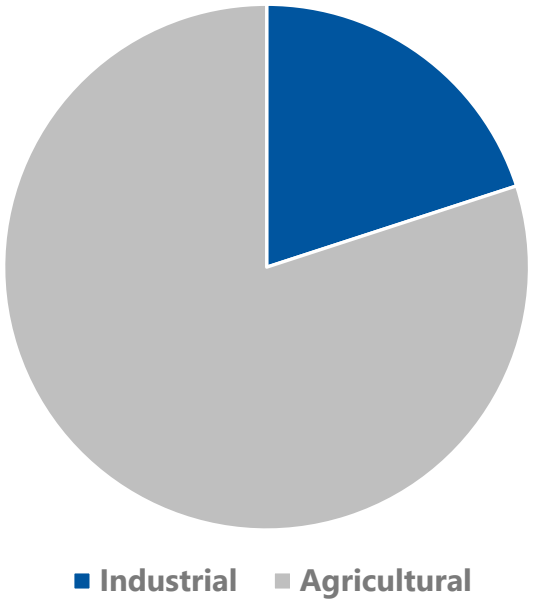
Ammonia production contributes roughly 2% of global emissions, accounting for approximately 0.5 gigatons (Gt) of CO_2 emitted annually.

Globally, 65% of ammonia production comes from natural gas. Outside China, over 95% of ammonia production is from natural gas.

Potential new applications for ammonia in a decarbonized economy:

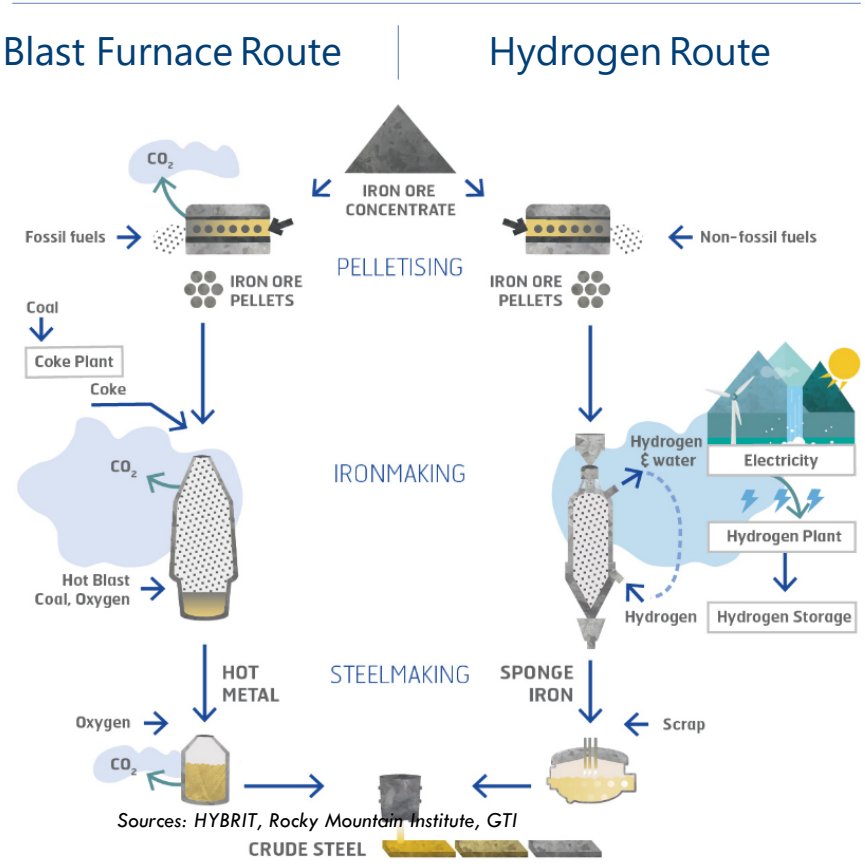
- Maritime fuel
- Low-carbon power generation fuel
- Hydrogen transportation vector (hydrogen carrier)

Global Ammonia Demand (2019)



Source: Hydrogen Council 2021

Hydrogen in Steel



Sources: HYBRIT, Rocky Mountain Institute, GTI

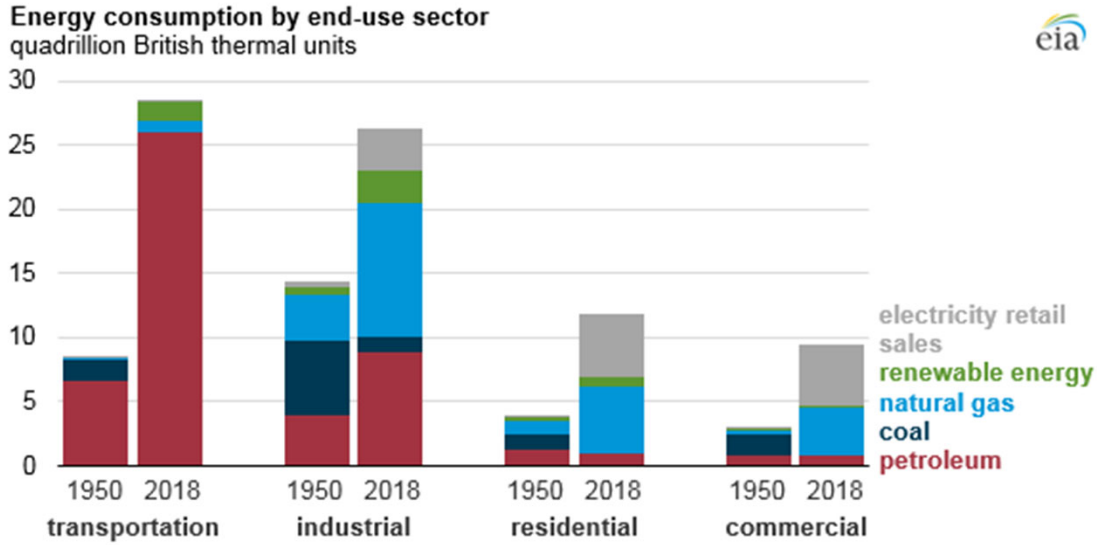
Demand for scrap-based **recycled steel** is anticipated to **increase significantly** through mid-century

Hydrogen can be used to achieve **significant emissions reductions** vs traditional blast furnace steel

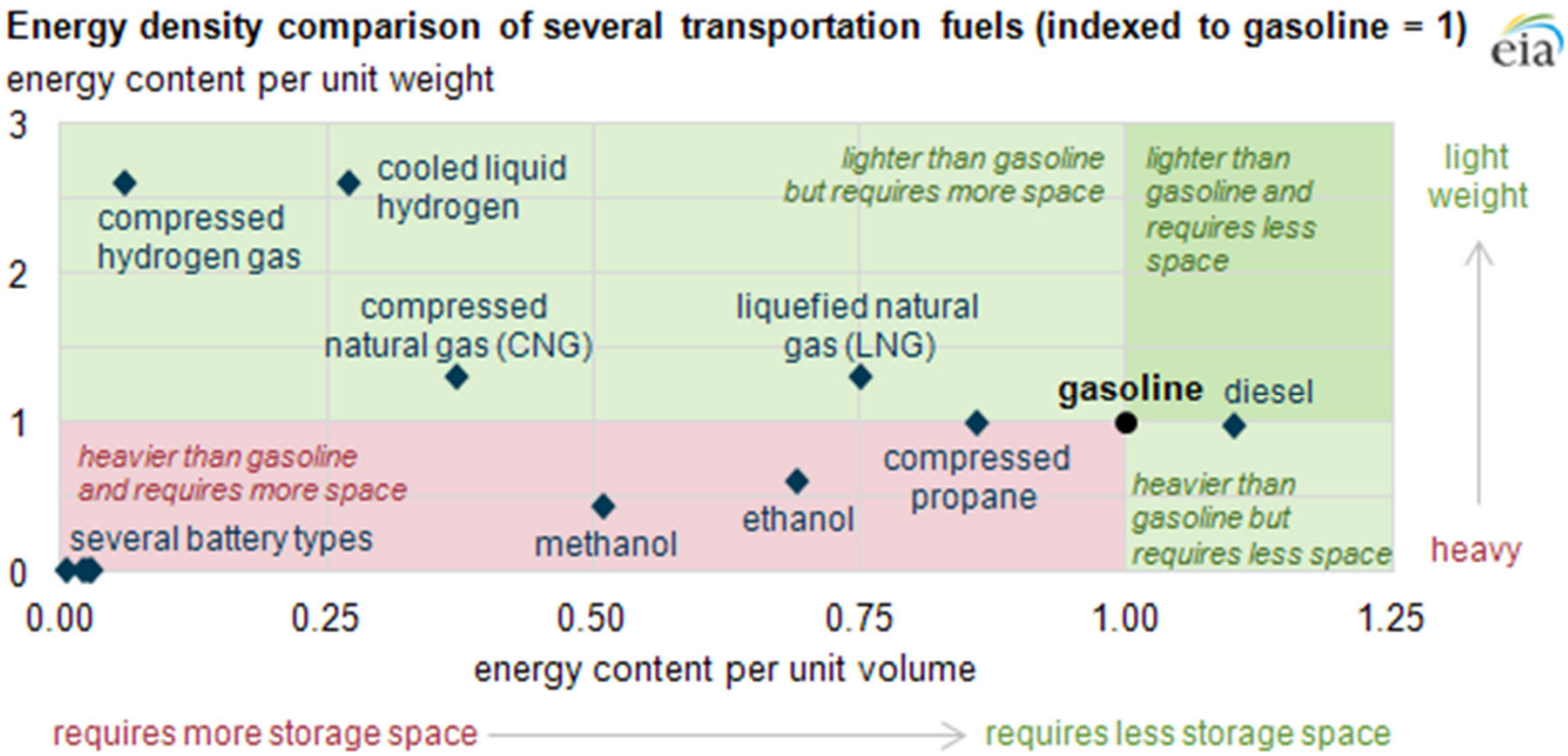
Steelmaking is a particularly difficult application for electrification, making hydrogen a candidate for decarbonization solutions.

Transportation Sector – Current Market

- Transportation is least diverse energy sector
  - Costs still drive market choices – at scale
  - Environmental concerns and solutions are increasing
  - 28 Quads (28 TCF) per year
- Advancements for alternative fuels are critical to meet goals
  - Natural Gas (including RNG)
  - Electricity (and Hybrids)
  - Propane
  - Hydrogen



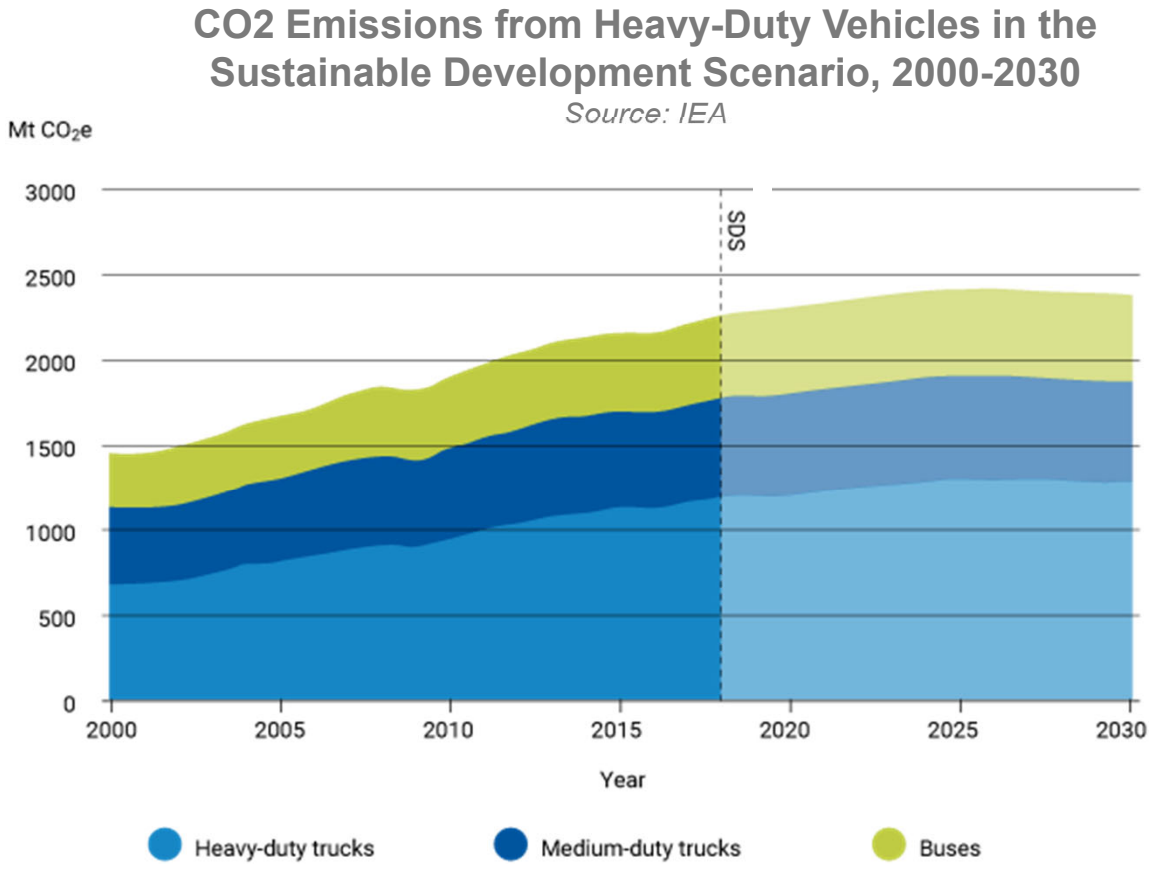
Clean Fuel trade-offs begin with Energy Density



Why Focus on Heavy Duty Vehicles

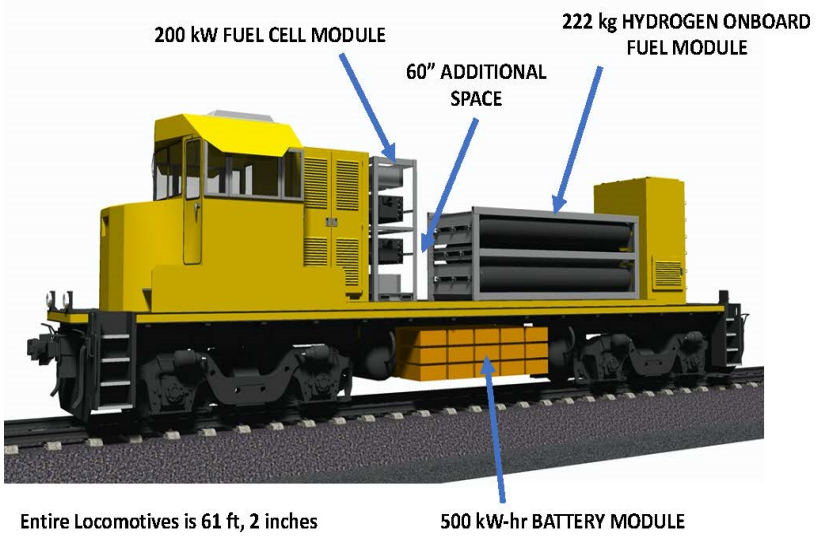
Commercial, heavy-duty transport remains **challenging to decarbonize** cost effectively.

- HD Vehicles Transport 80% of Goods in the US
- HD Vehicles represent 4% of vehicle traffic but consume 20% of fuel
- Routes and fuel logistics are predictable.

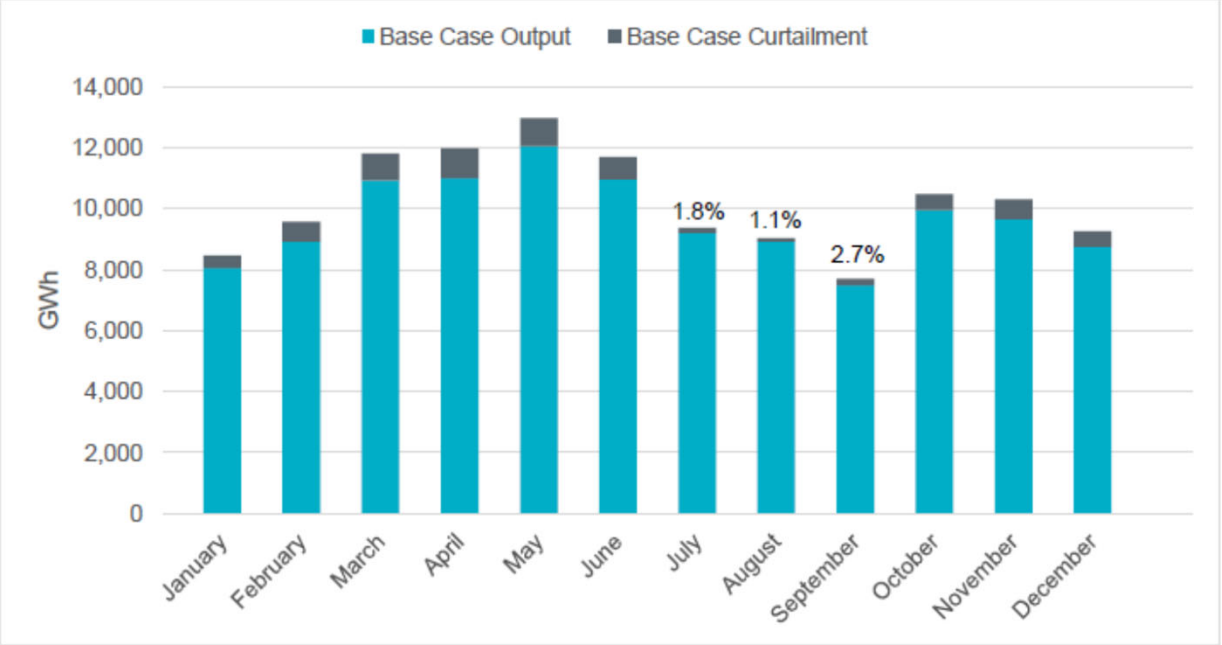


Off-Road Transportation Markets

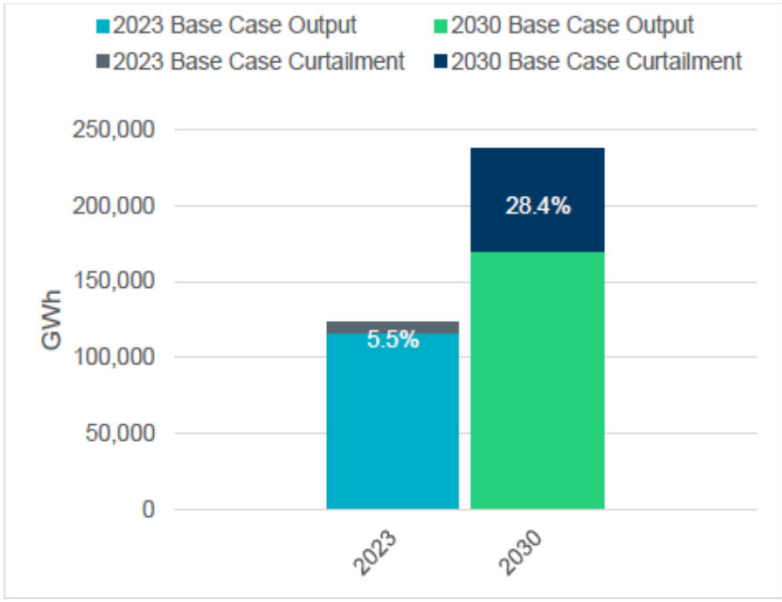
- Rail
  - –Fuel Cell Trains in Europe with activities in California focused on switch yard/ports
- Marine – 180+ LNG ships operating – 80+ on order (DNV GL)
  - –Environmental drivers – IMO 2020
  - –Water-Go Ferry – Hydrogen ferry in San Francisco
- Lift Trucks – Over 25,000 Hydrogen forklifts currently in operation in the U.S.



Increased Wind Curtailment is a growing Concern



Monthly West Texas Wind and Solar Curtailment in 2023 Base Case

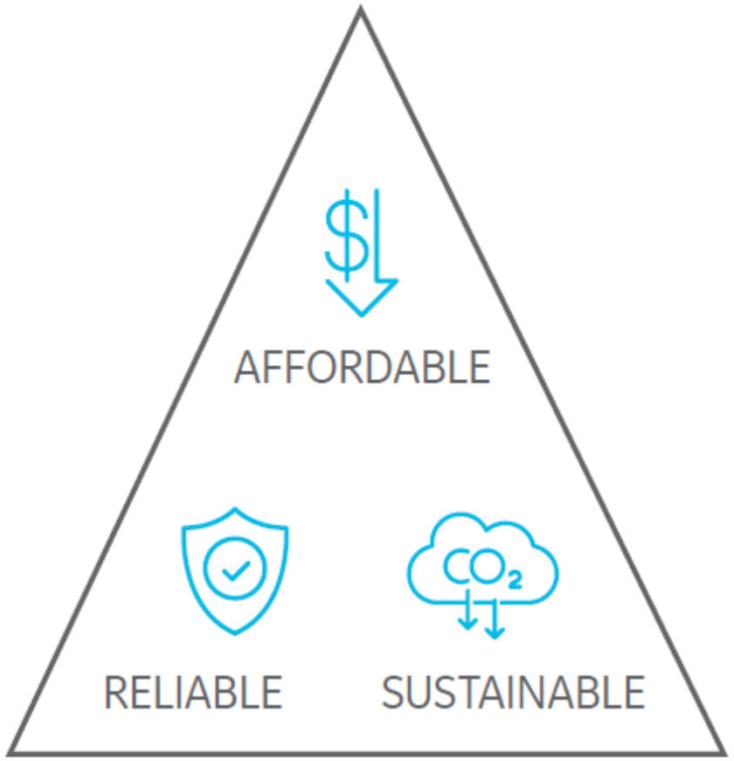


Annual Wind and Solar Output and Curtailment in West Texas

Source: Electric Reliability Council of Texas, January 2022

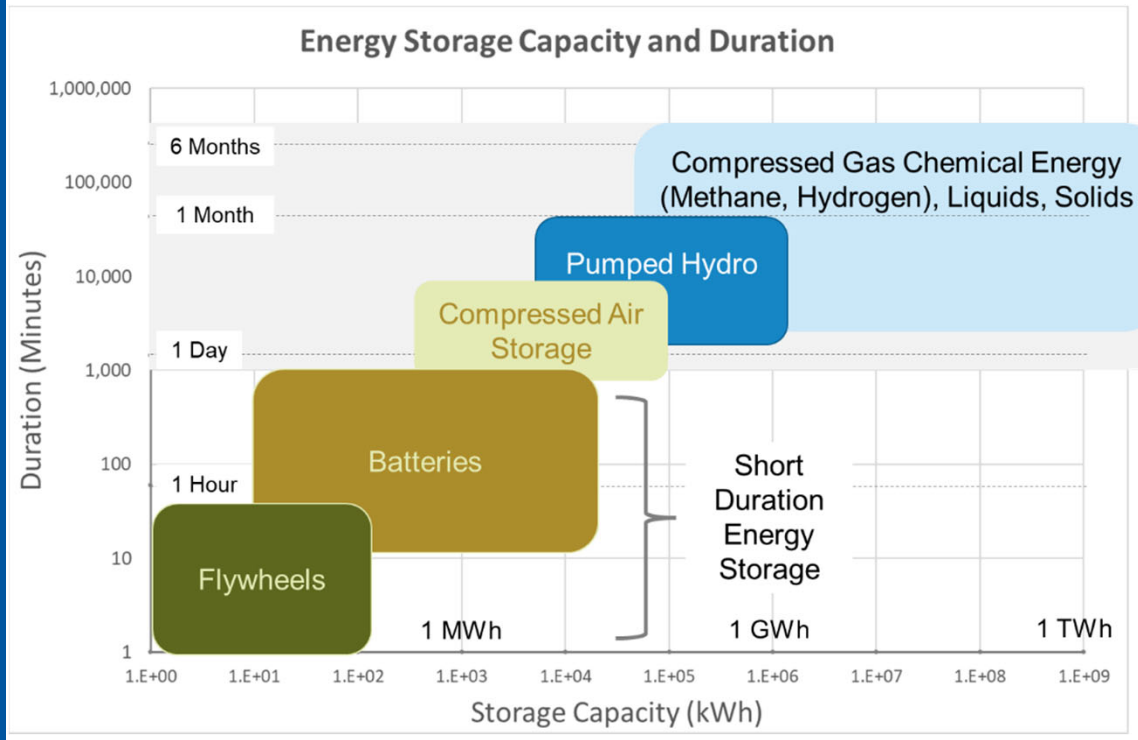
The Concerns of the Power Industry Today

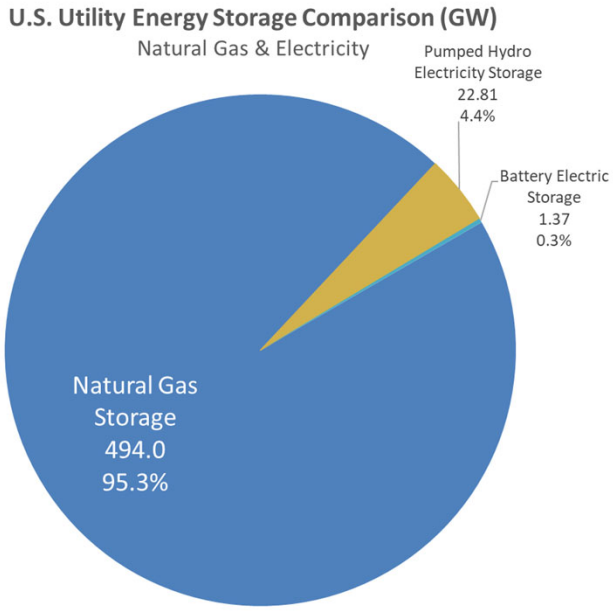
- The Climate Objective of the US Power Industry is to Reach Zero Carbon Output
- With Existing Technology and Regulatory Constraints, Tradeoffs are Looming
- The Reality is that the Electric Industry Need to Satisfy this ENTIRE Triangle



Increased Renewables NEED Reliable Energy Storage

Gases are excellent energy storage solutions at large scale



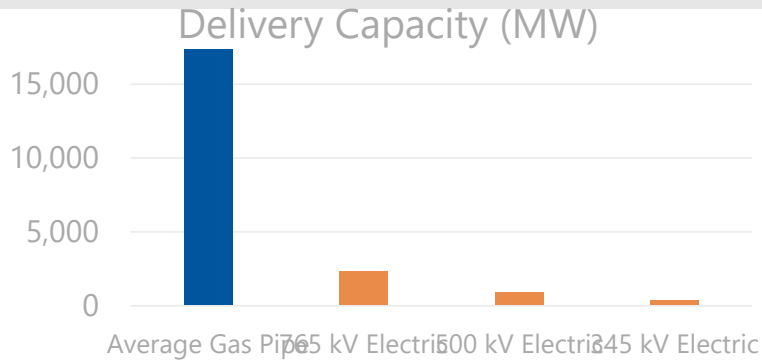


Natural gas underground storage comprises >95% of U.S. utility energy storage capacity.

Source: DOE-EIA

Comparison of Large-Scale Energy Delivery Systems
Natural Gas Transmission Pipelines and Electric Transmission Lines

- Chemical energy delivery systems, like gas pipelines, have much greater energy delivery capability than electric power lines (10-50+ times higher)
- Gas pipelines are more cost effective, feature improved aesthetics (out of sight), and less vulnerable to weather impacts



350 U.S. Gas Transmission Pipelines	Delivery Capacity, MW
Average Gas Pipeline	17,386

Electric Transmission	Nominal Capacity, MW
765 kV Line	2,300
500 kV Line	900
345 kV Line	400

Source: DOE EIA (top 80% of interstate gas pipelines).
http://web.ecs.baylor.edu/faculty/grady/_13_EE392J_2_Spring11_AEP_Transmission_Facts.pdf

"Green Hydrogen", a.k.a. Power-to-Gas

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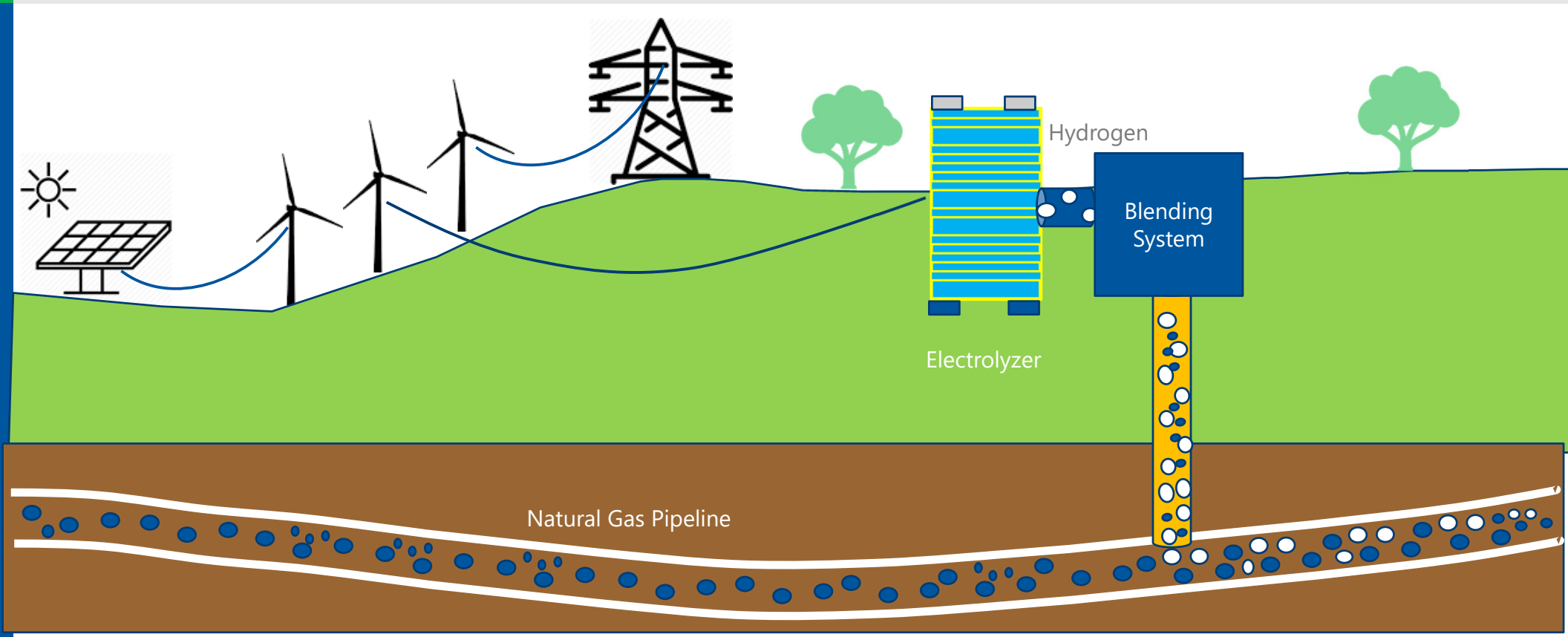
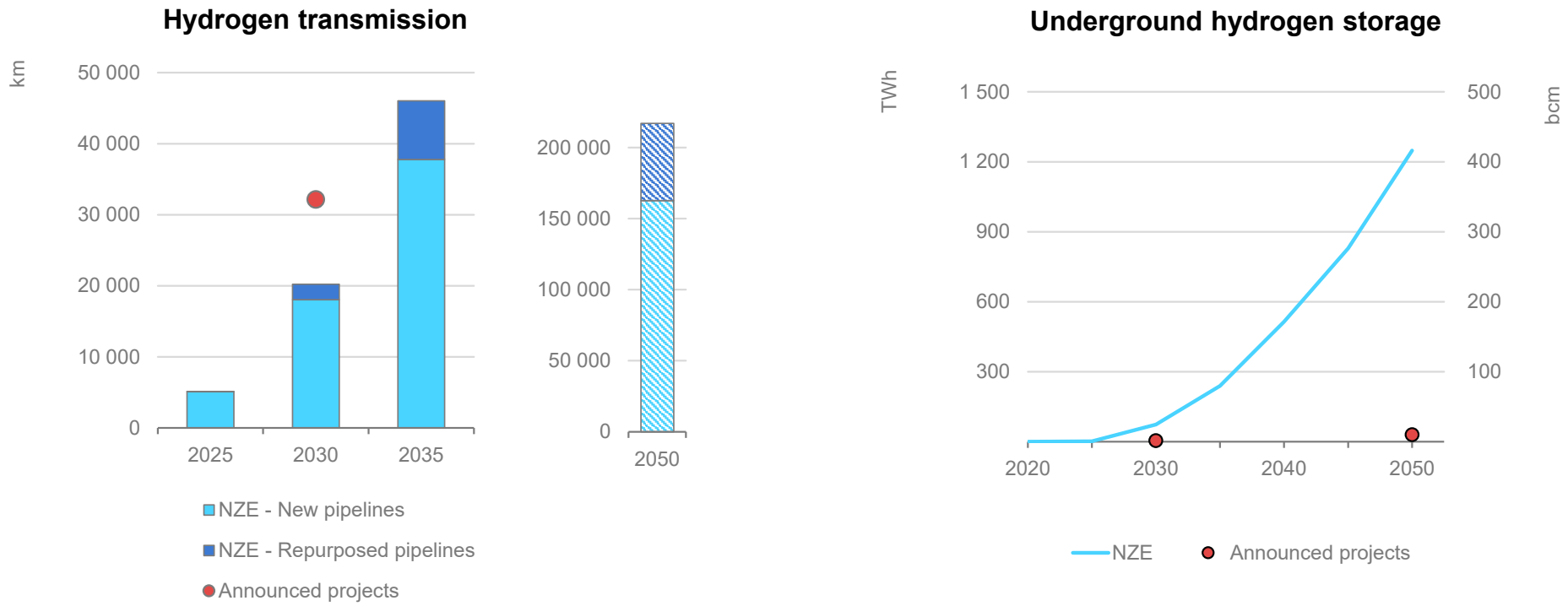


The rise of infrastructure for hydrogen transport and storage

Global hydrogen transmission pipeline length and underground storage capacity in the NZE Scenario, 2020-2050



The long lead times associated with infrastructure projects mean that while the announced length of hydrogen pipelines is in line with needs, underground storage requires urgent and accelerated action

Source: IEA

Why Hydrogen: Decarbonization at Scale

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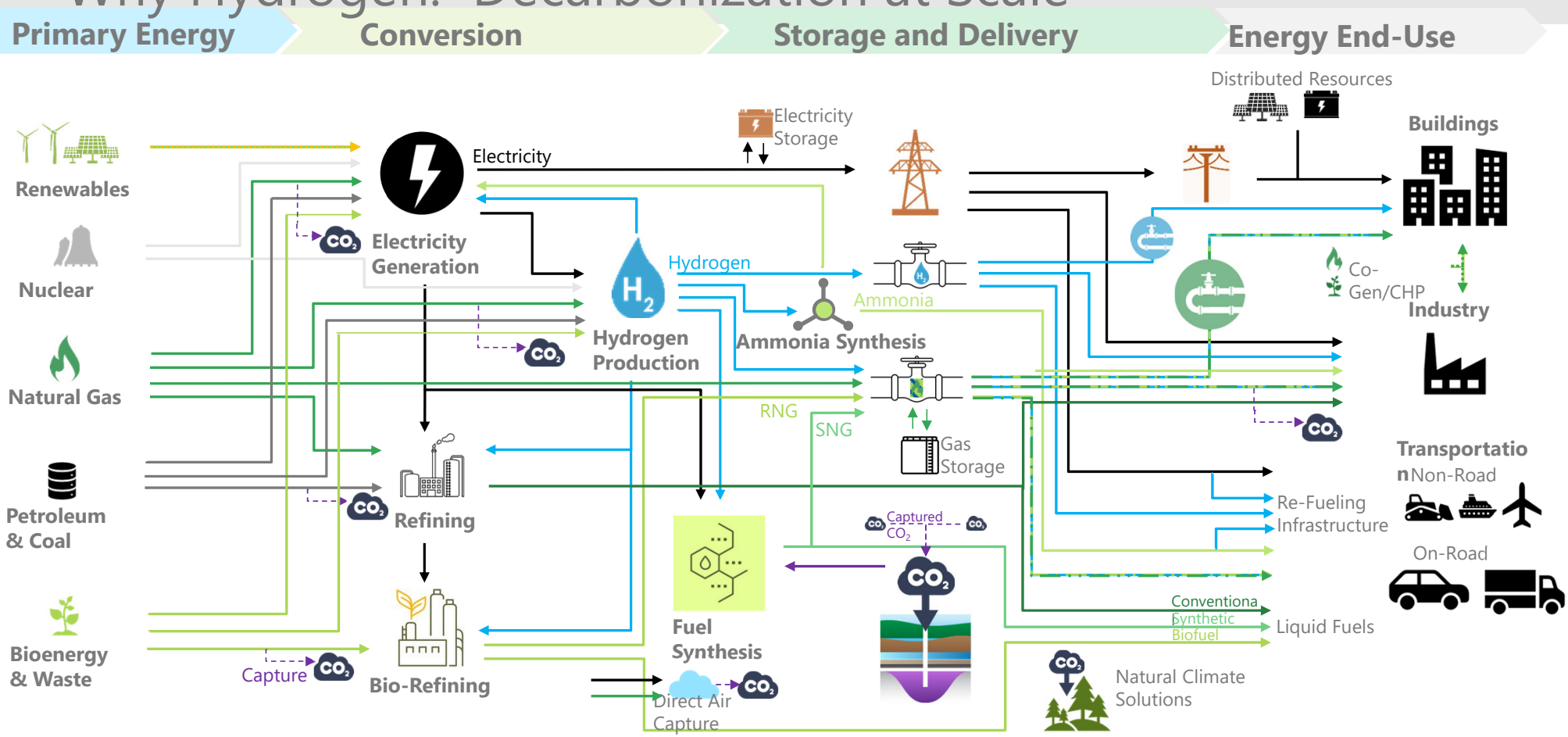


The Gulf Coast's Regional Hydrogen Advantages

Gulf Coast's Energy Assets

Broad base of industrial energy customers across multiple demand segments

Welcoming environment for infrastructure development

33% of U.S. hydrogen production capacity

Highly skilled energy workforce (11% of U.S. energy jobs)

Large concentration of academic and industry-driven energy innovation: major research universities and a new innovation campus

Largest energy manufacturing cluster (7000+ establishments)

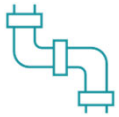
Production capacity

Largest renewable energy market in the nation (36 GW wind, 15 GW solar)

2.4 billion tons of CO_2 storage capacity (10,000x Houston's current CO_2 emissions)

Access to abundant low-cost natural gas (11.2 Tcf natural gas produced in 2022)

Transportation and storage



1000+ miles of hydrogen pipeline – largest networks in the nation

3 of the 6 hydrogen storage caverns in the world

Source: McKinsey and CHF Gulf Coast Hydrogen Roadmap , 2022 US DOE Energy and Employment Report

There are over 50 publicly declared clean hydrogen projects

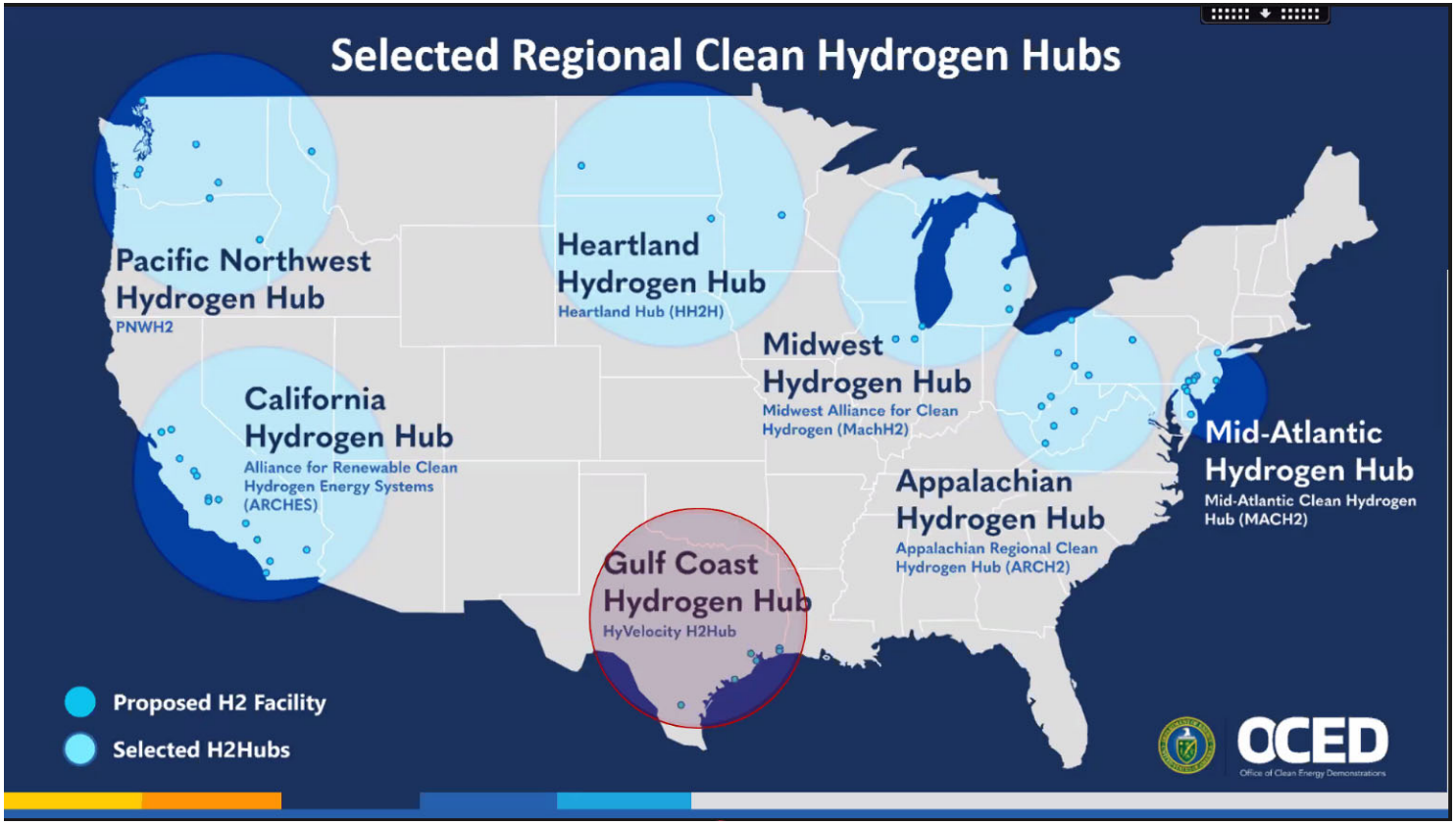
Announced Clean Hydrogen Projects in Texas and Louisiana

And many more not yet made public…

Source: Center for Houston's Future

Regional Clean Hydrogen Hubs Selected by DOE

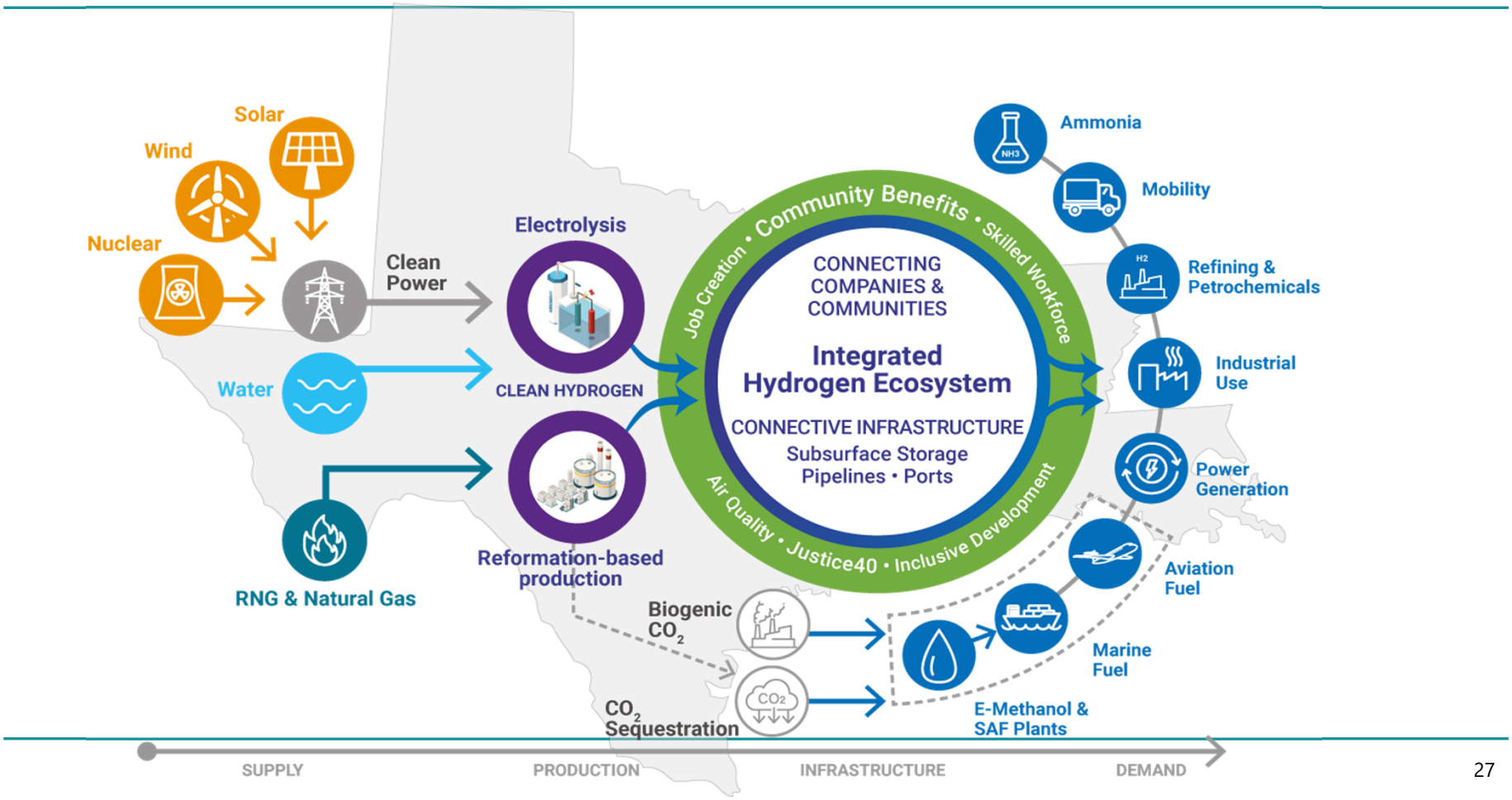
Bi-Partisan Infrastructure Bill (BIL)



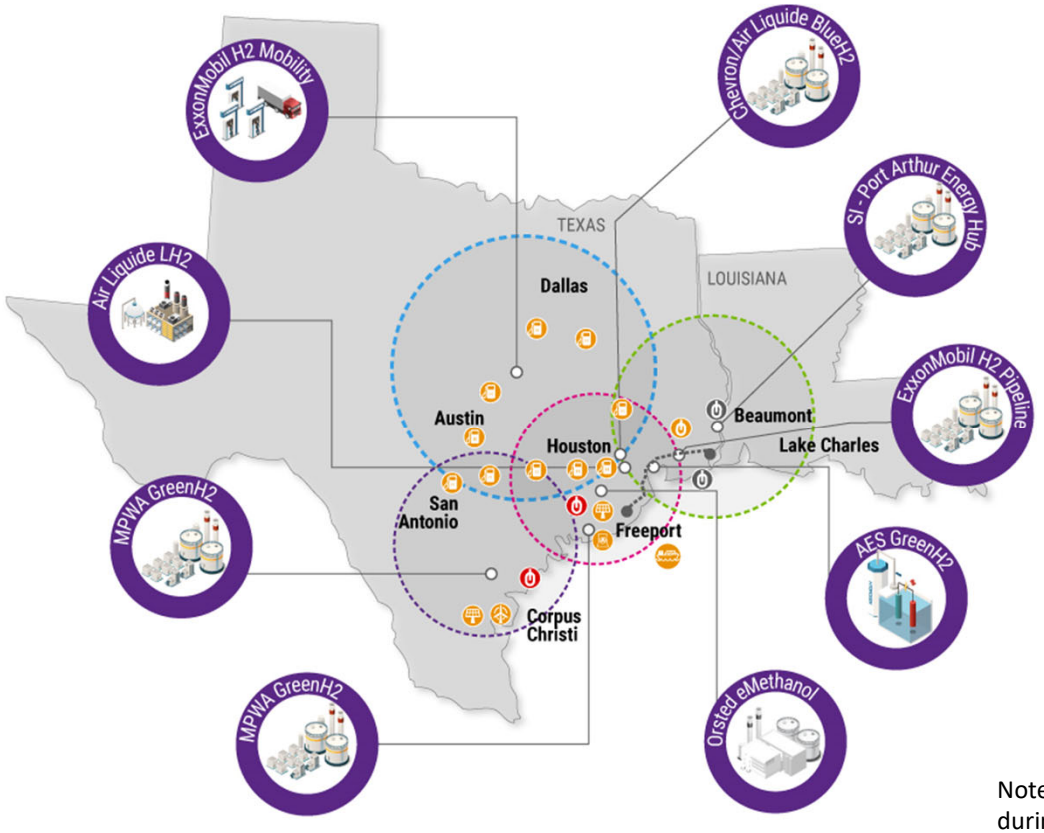
Inflation Reduction Act (IRA)

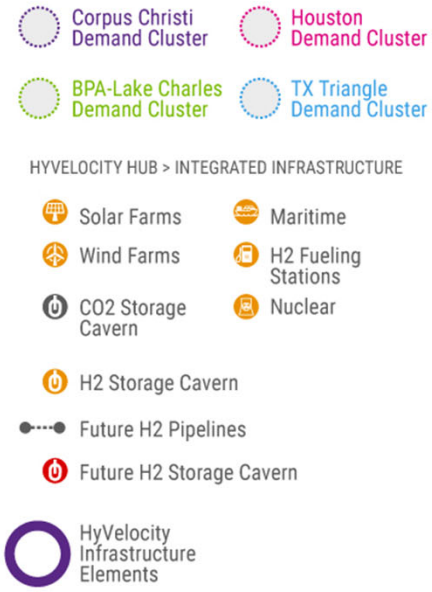
45Q , 45V

HyVelocity: Envisioned Clean Hydrogen Ecosystem



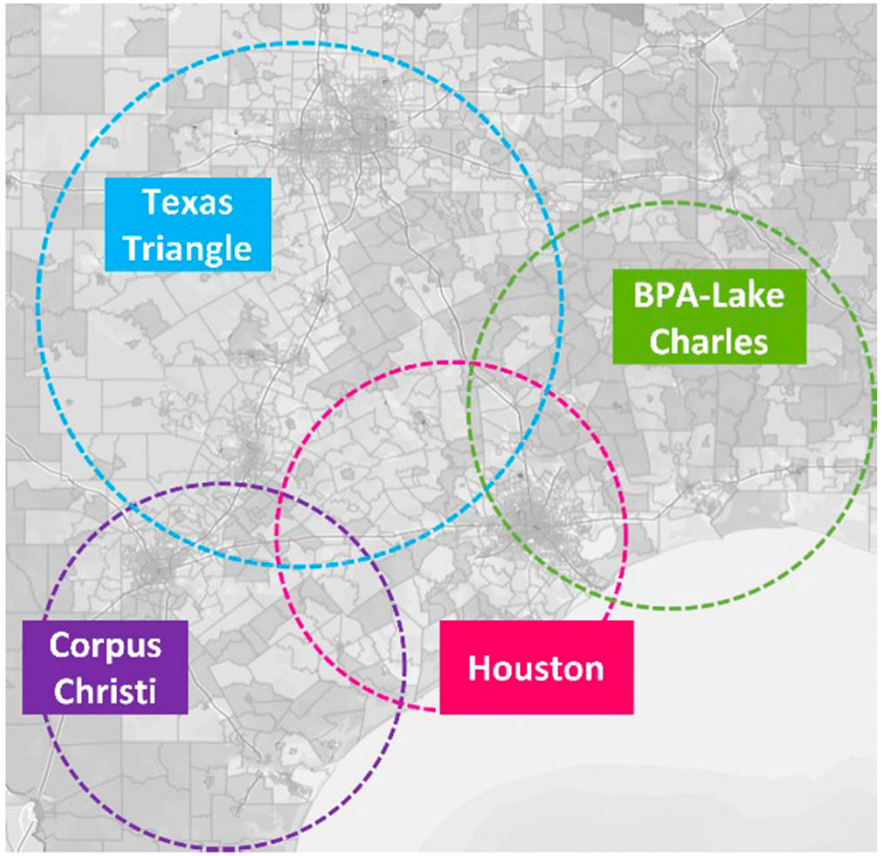
HyVelocity Envisioned Projects





Note: Map shows general preliminary project locations and are subject to change during future negotiations and site planning

HyV Community Engagement



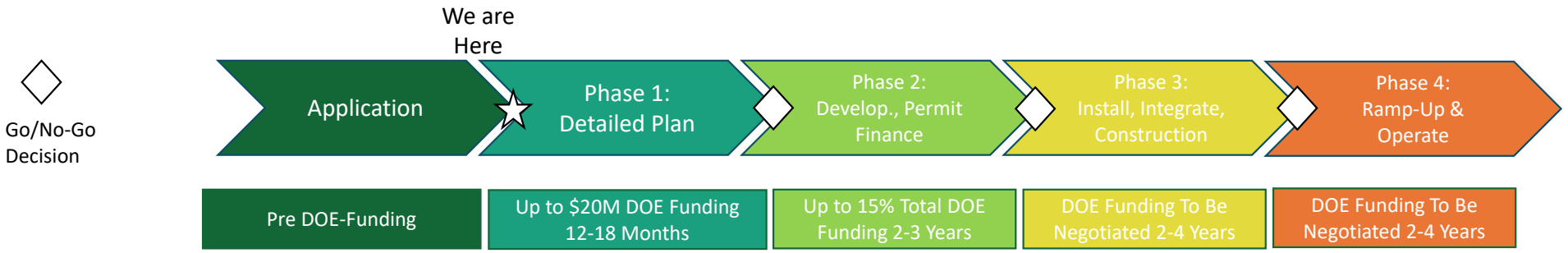
Community Benefits:

- Anticipated Community Benefits Plan Funding – $120 million.
- Meaningful engagement with stakeholder organizations to ensure disadvantaged and impacted communities benefit from this hub.
- Potential for reductions in Scope 3 emissions for industries purchasing hydrogen.
- Reduction in local air pollution for parts of the region most impacted, including disadvantaged communities.

Job Creation:

- Potential for ***up to*** 45,000 direct jobs
  - Up to 35,000 construction jobs
  - Up to 10,000 permanent jobs

Regional Clean Hydrogen Hub Project Phases



Business Development and Management
Engineering, Procurement, Construction, and Operations
Safety, Security, & Regulatory Compliance
Risk Analysis & Mitigation
Technical Data & Analysis
Community Benefits: Job Quality & Equity

2024 is a significant year for hydrogen policy

- Hydrogen Pipeline Federal Jurisdiction under consideration
- Hydrogen Incentives via 45V final guidelines developed by Treasury Dept.
- EPA Notice of Proposed Rulemaking on GHG emissions from power plants (implementation begins 2032).
- PHMSA Notice of Proposed Rulemaking on hydrogen pipeline leak detection and repair
- PHMSA R&D Forum focus on CO2 pipelines
- Various state incentives and hydrogen strategy legislation (Texas RRC and TCEQ)
- National Petroleum Council Hydrogen Report