NASEO
National Association of State Energy Officials

Clean Hydrogen End Uses and Considerations Webinar for State Energy Offices

March 30, 2023

Welcome and Zoom 101

Speakers

- Dr. Sunita Satyapal, Director, U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office
- Maria DiBiase Eisemann, Policy Advisor, Special Projects, Colorado Energy Office
- Tessa Weiss, Senior Associate, Climate-Aligned Industries, RMI
- David Edwards, Director and Advocate for Hydrogen Energy, Air Liquide

Additional Resources

- NASEO, Hydrogen: Critical Decarbonization Element for the Grid, Manufacturing, and Transportation (2021)
- Gerhardt, N., J. Bard, R. Schmitz, M. Beil, M. Pfennig, T. Kneiske, Fraunhofer Institute for Energy Economics and Energy System Technology, Hydrogen in the Energy System of the Future: Focus on Heat in Buildings (2020)
- Energy Transitions Commission, Making the Hydrogen Economy Possible (2021)
- Michael Liebreich, Bloomberg BNEF, Separating Hype from Hydrogen – Part Two: The Demand Side (2020)
- Tess Weiss, Thomas Koch Blank, RMI, Hydrogen Reality Check: We Need Hydrogen — But Not for Everything (2022)
- Patrick Ploetz, Nature Electronics, Hydrogen technology is unlikely to play a major role in sustainable road transport (2022)

DOE Hydrogen and Fuel Cell Remarks

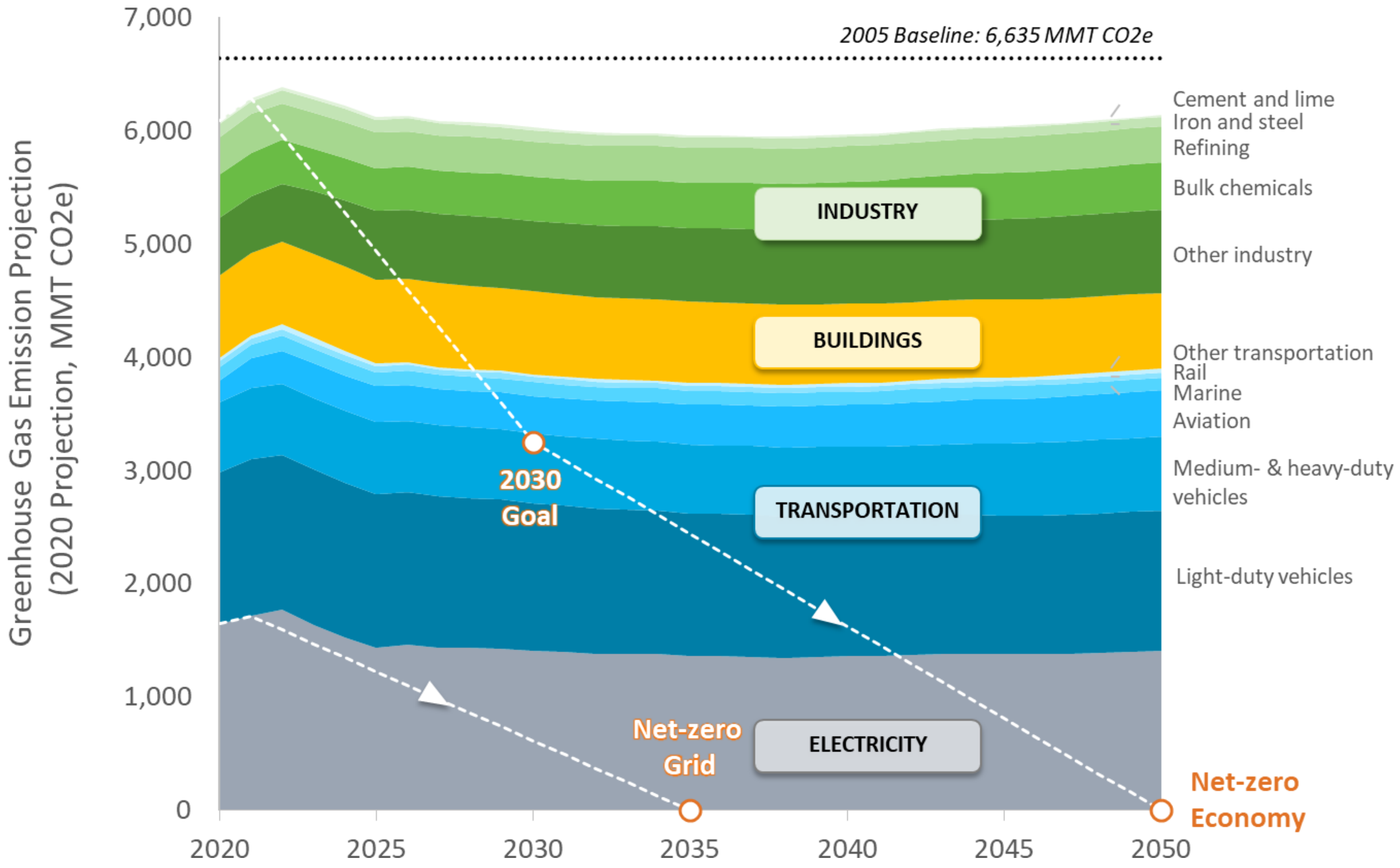
Dr. Sunita Satyapal, Director, Hydrogen and Fuel Cell Technologies Office and DOE Hydrogen Program Coordinator
U.S. Department of Energy

NASEO Meeting

March 30, 2023



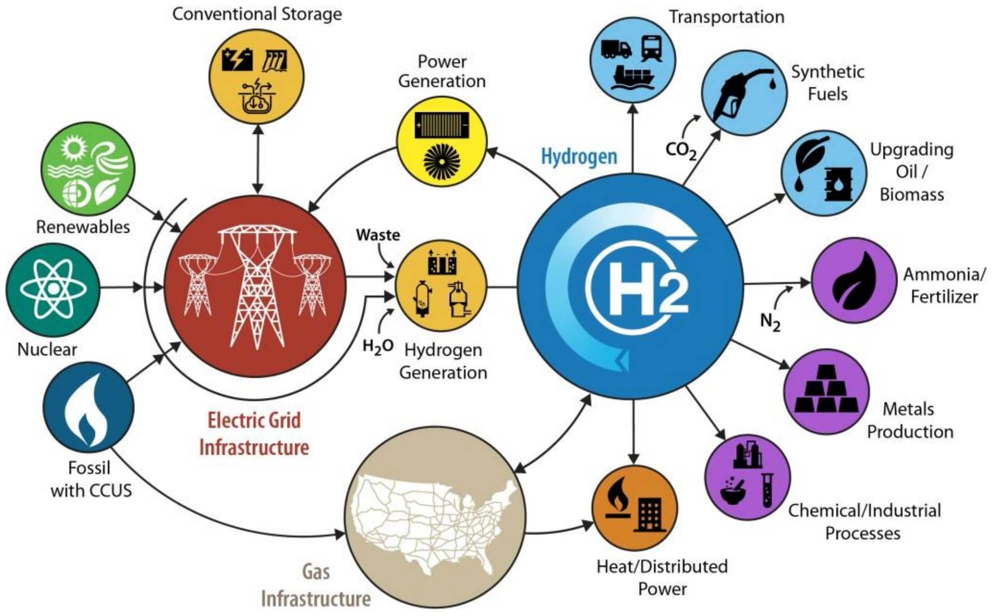

Carbon Dioxide Emissions by Sector

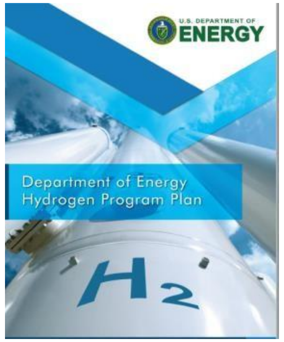


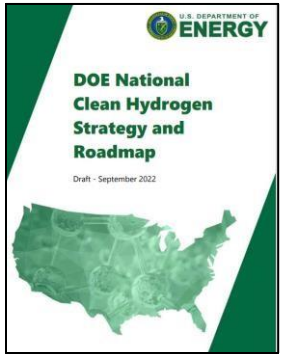
Source: Annual Energy Outlook 2021, DOE National Clean Hydrogen Strategy and Roadmap

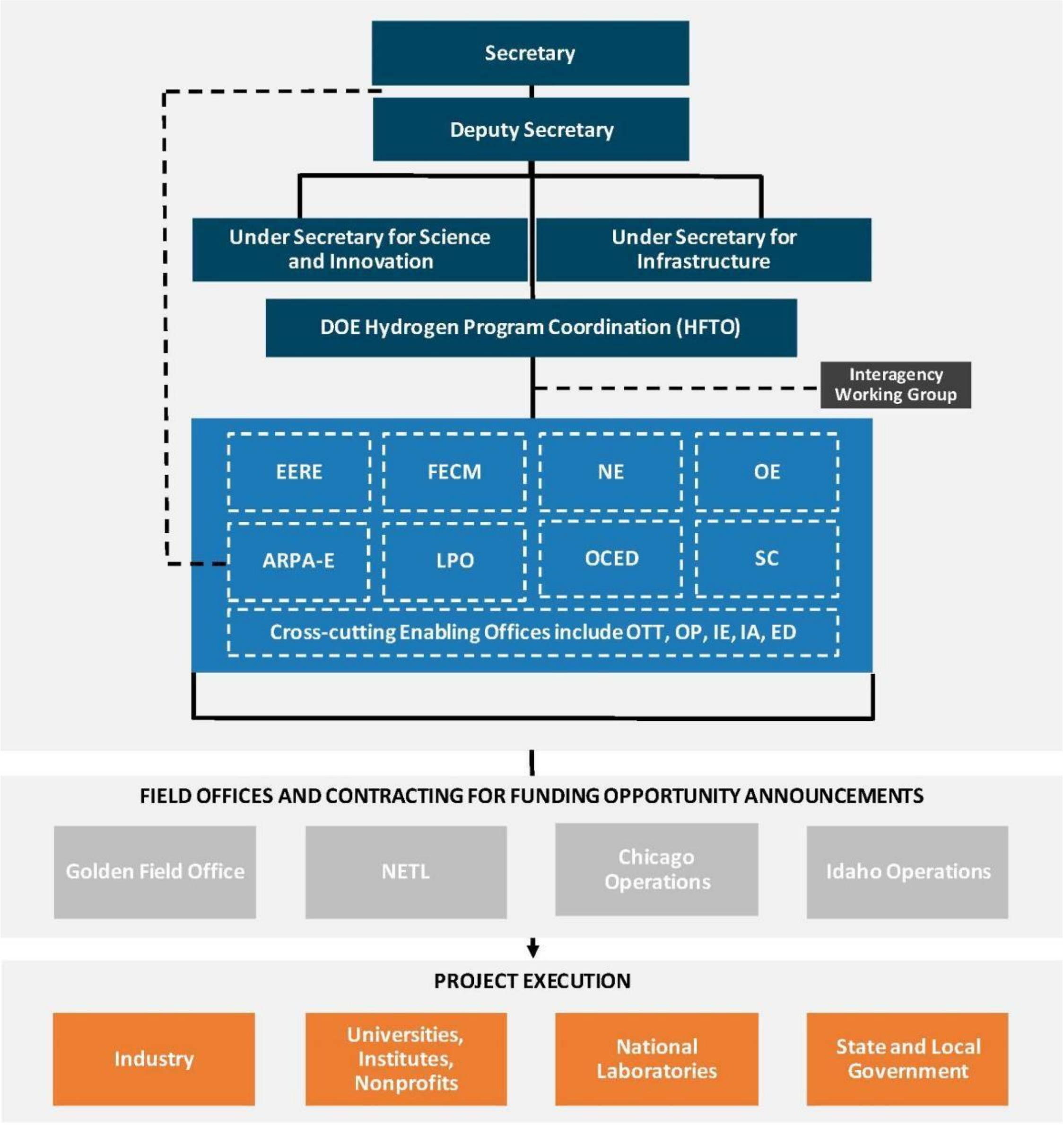
U.S. DOE Hydrogen Program

Hydrogen is one part of a broad portfolio of activities
Includes multiple offices and the entire RDD&D value chain from production through end use









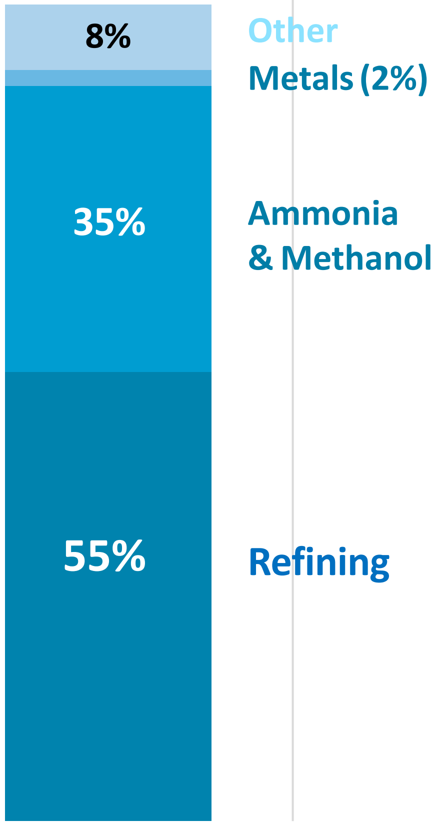
www.hydrogen.energy.gov

Coordinated across Offices by DOE Hydrogen and Fuel Cell Technologies Office (HFTO)

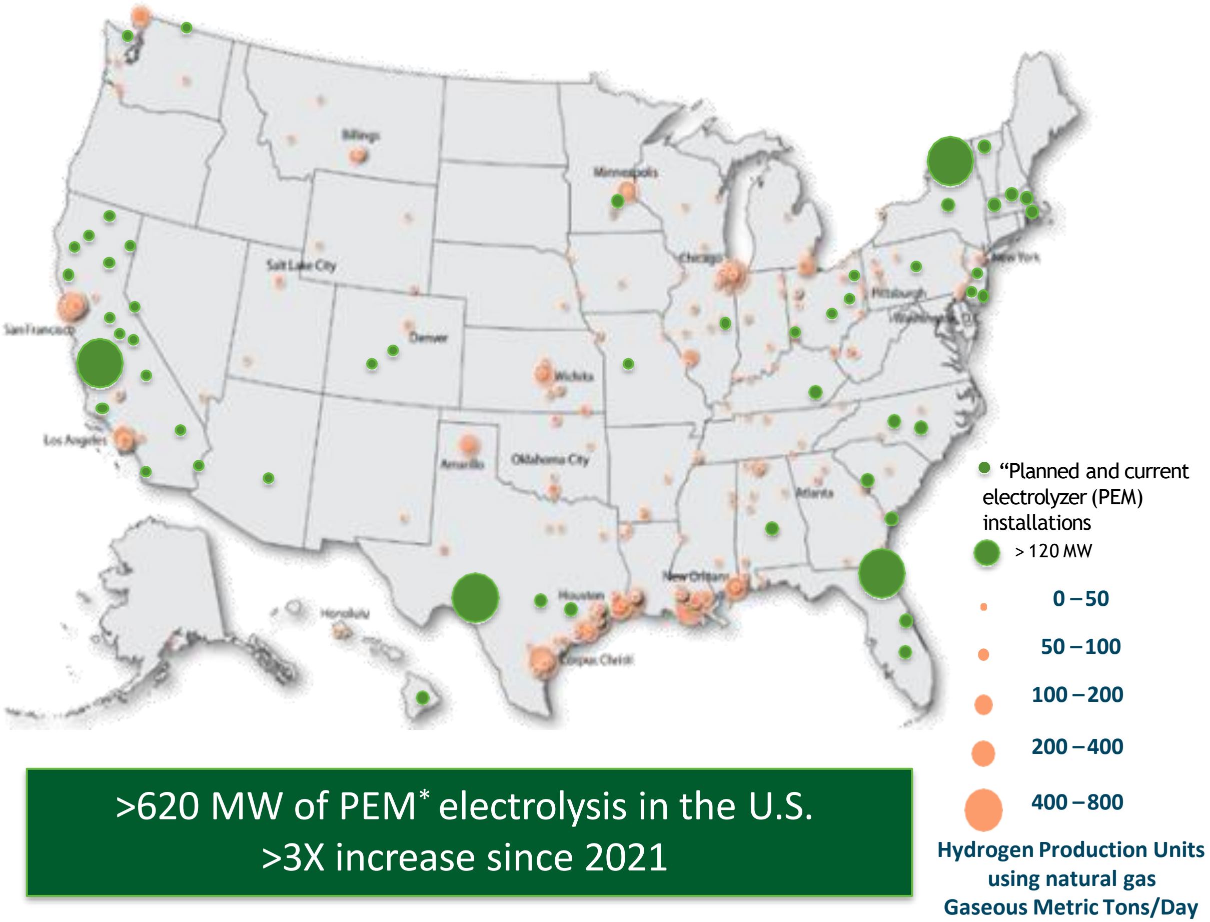
Snapshot of Hydrogen and Fuel Cells in the U.S.

- 10 million metric tons produced annually
- More than 1,600 miles of H_2 pipeline
- World's largest H_2 storage cavern

Use of Hydrogen in the U.S. Today



Examples of Hydrogen Production Locations



>620 MW of PEM* electrolysis in the U.S.
>3X increase since 2021

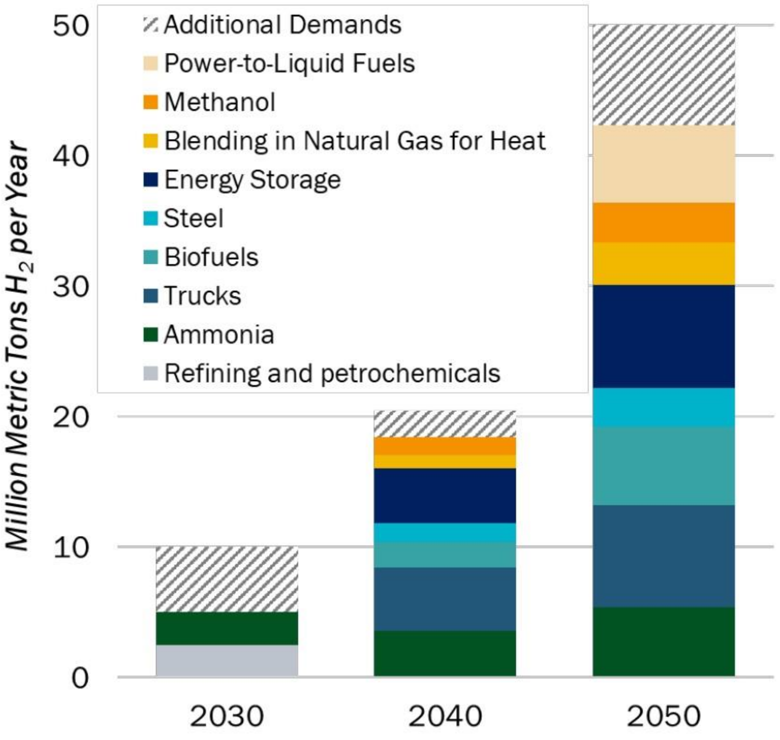
Examples of Deployments

- **>500MW** Backup Power
- **>50,000** Forklifts
- **>620 MW** PEM* Electrolyzers
- **>80** Fuel Cell Buses
- **~50** H_2 Retail Stations
- **>15,000** Fuel Cell Cars

*Proton exchange membrane

National Clean Hydrogen Strategy – The Opportunity for Clean Hydrogen

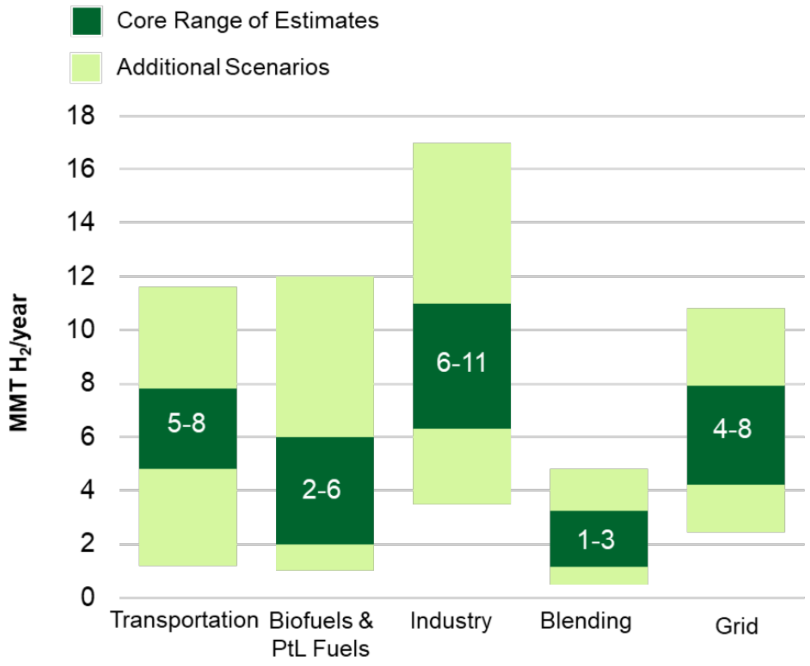
Opportunities for Clean Hydrogen Across Applications



Clean Hydrogen Use Scenarios

- Catalyze clean H_2 use in existing industries (ammonia, refineries), initiate new use (e.g., sustainable aviation fuels (SAFs), steel, potential exports)
- Scale up for heavy-duty transport, industry, and energy storage
- Market expansion across sectors for strategic, high-impact uses

Range of Potential Demand for Clean Hydrogen by 2050



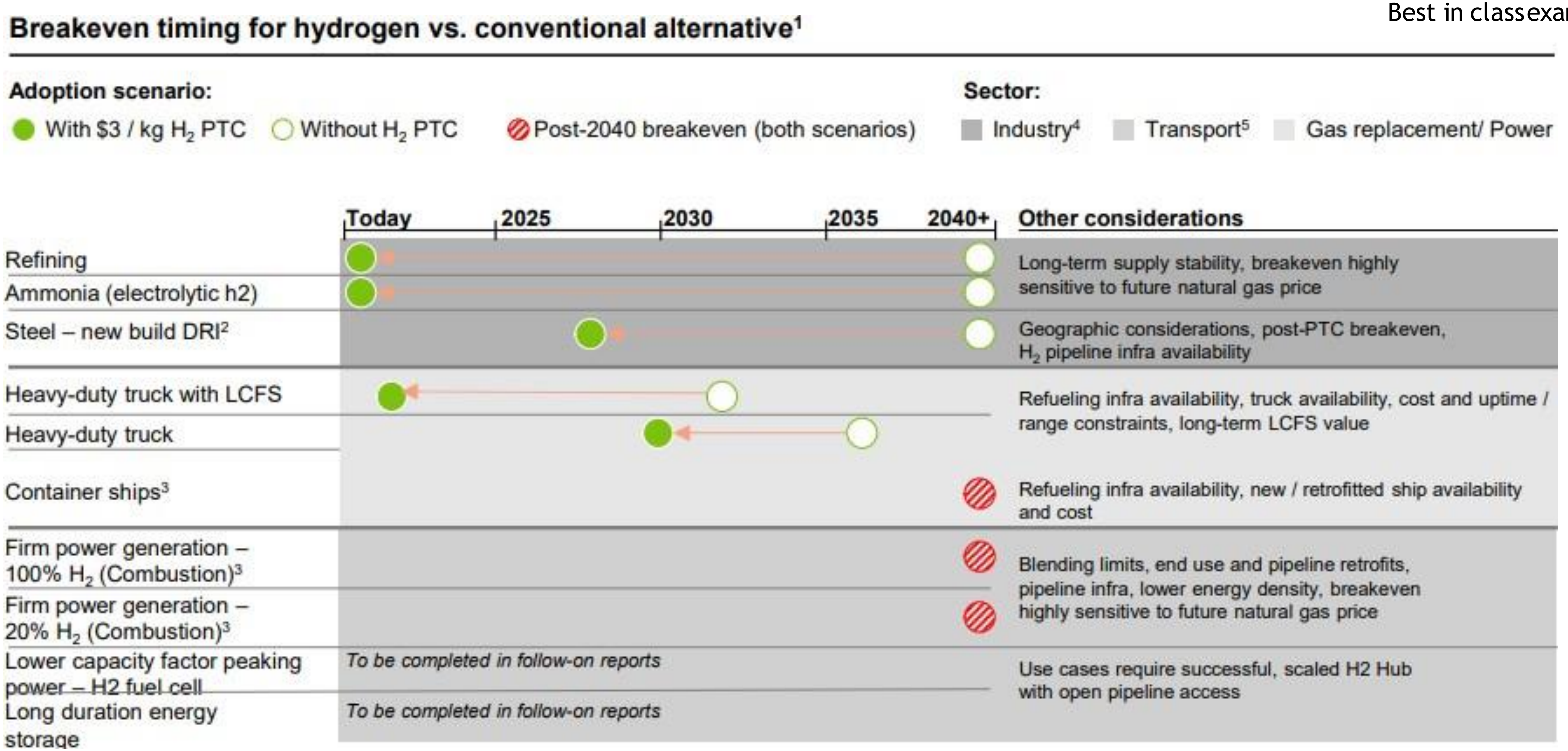
- **Core range: ~ 18–36 MMT H_2**
- **Higher range: ~ 36–56 MMT H_2**

U.S. Opportunity:
10MMT/yr by 2030, 20 MMT/yr by 2040, 50 MMT/yr by 2050

Refs: 1. NREL MDHD analysis using TEMPO model; 2. Analysis of biofuel pathways from NREL; 3. Synfuels analysis based off H2@Scale ; 4. Steel and ammonia demand estimates based off DOE Industrial Decarbonization Roadmap and H2@Scale. Methanol demands based off IRENA and IEA estimates; 5. Preliminary Analysis, NREL 100% Clean Grid Study; 6. DOE Solar Futures Study; 7. Princeton Net Zero America Study

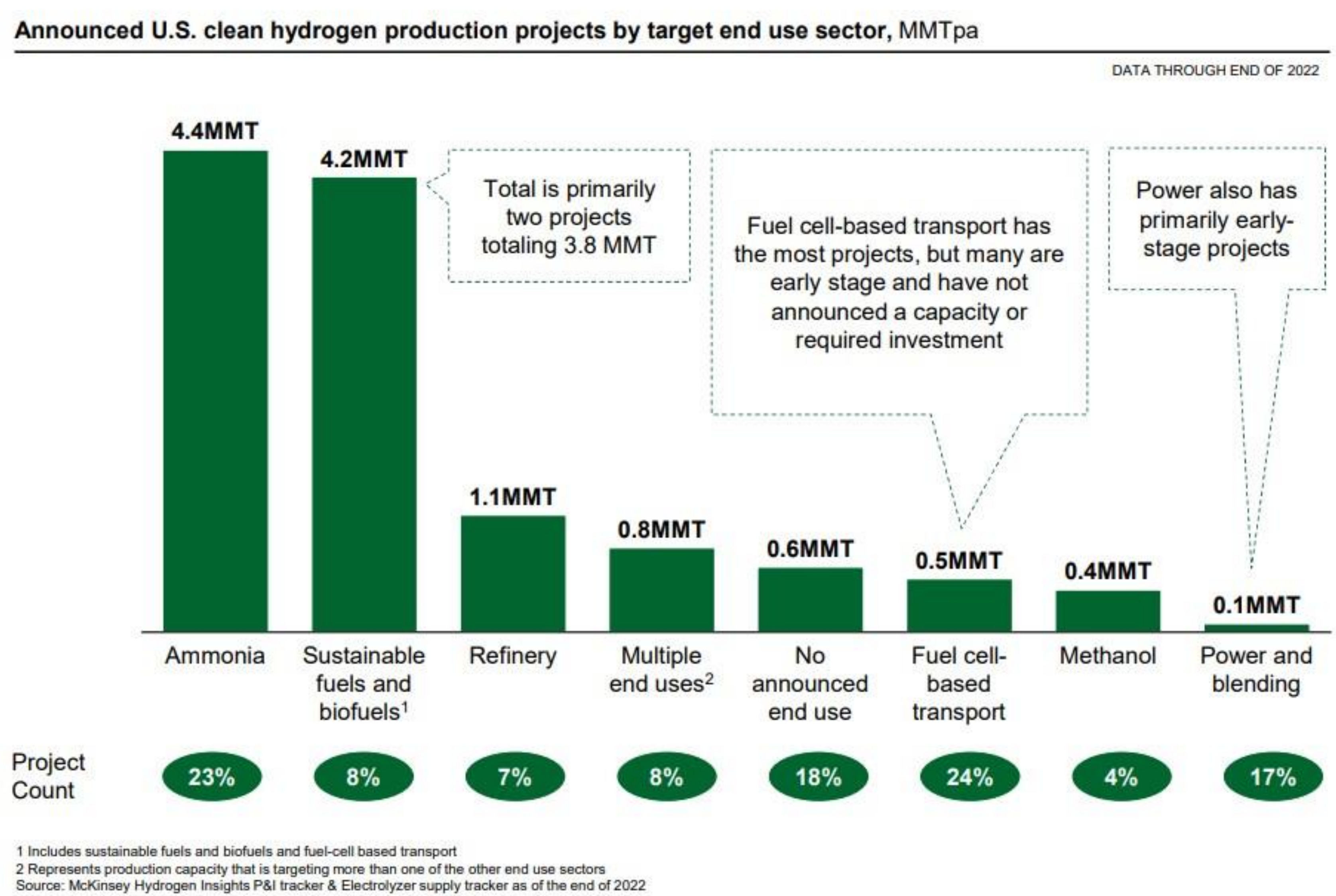
Commercial Lift Off Report Analyses- Examples to be Periodically Updated

Best in class examples



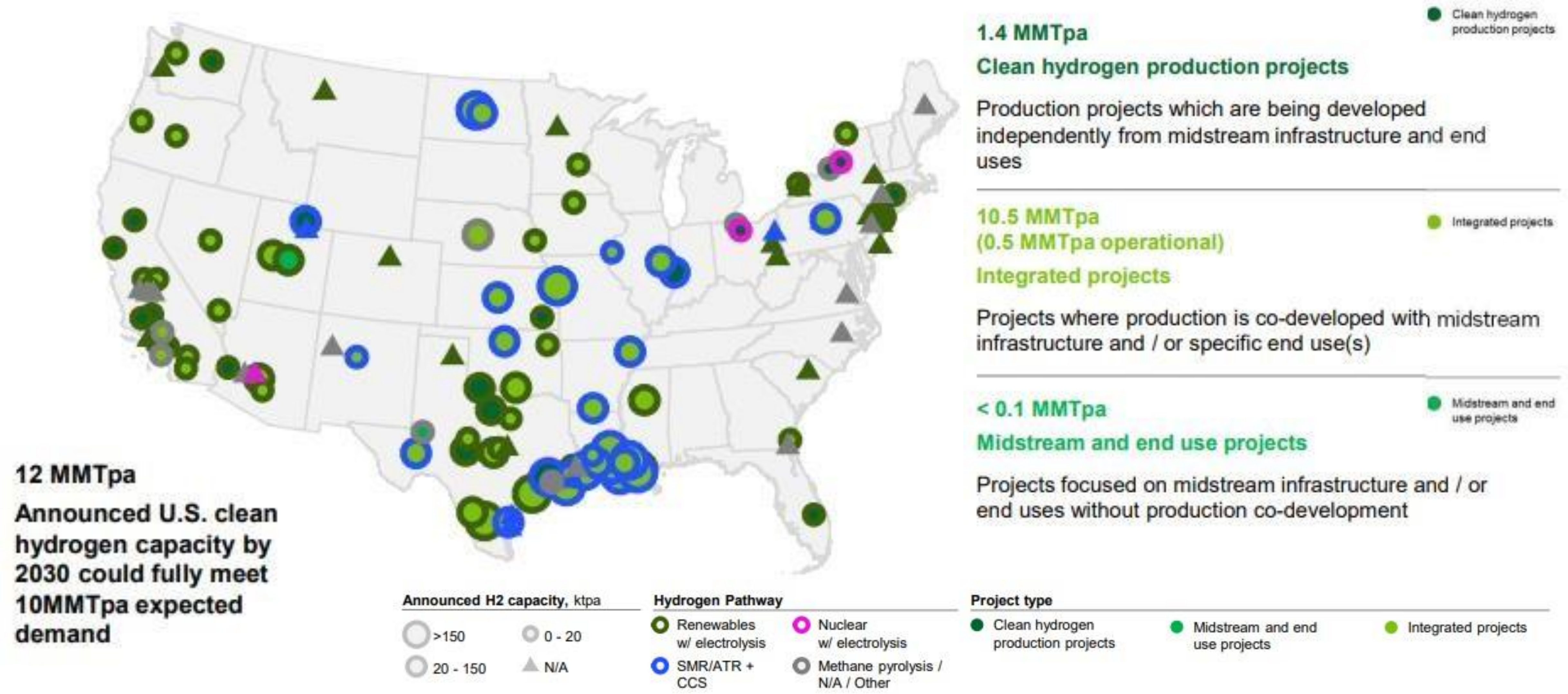
Source: DOE- https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB-0329-update.pdf, OTT, OCED, LPO, et al

Commercial Lift Off Report Analyses- Snapshot of Projects by End Use



Source: DOE- https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB-0329-update.pdf, OTT, OCED, LPO, et al

Commercial Lift Off Report Analyses- Snapshot of Announcements



Source: DOE- https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB-0329-update.pdf, OTT, OCED, LPO, et al

Resource Availability

A: Hydrogen production potential from onshore wind resources, by county land area

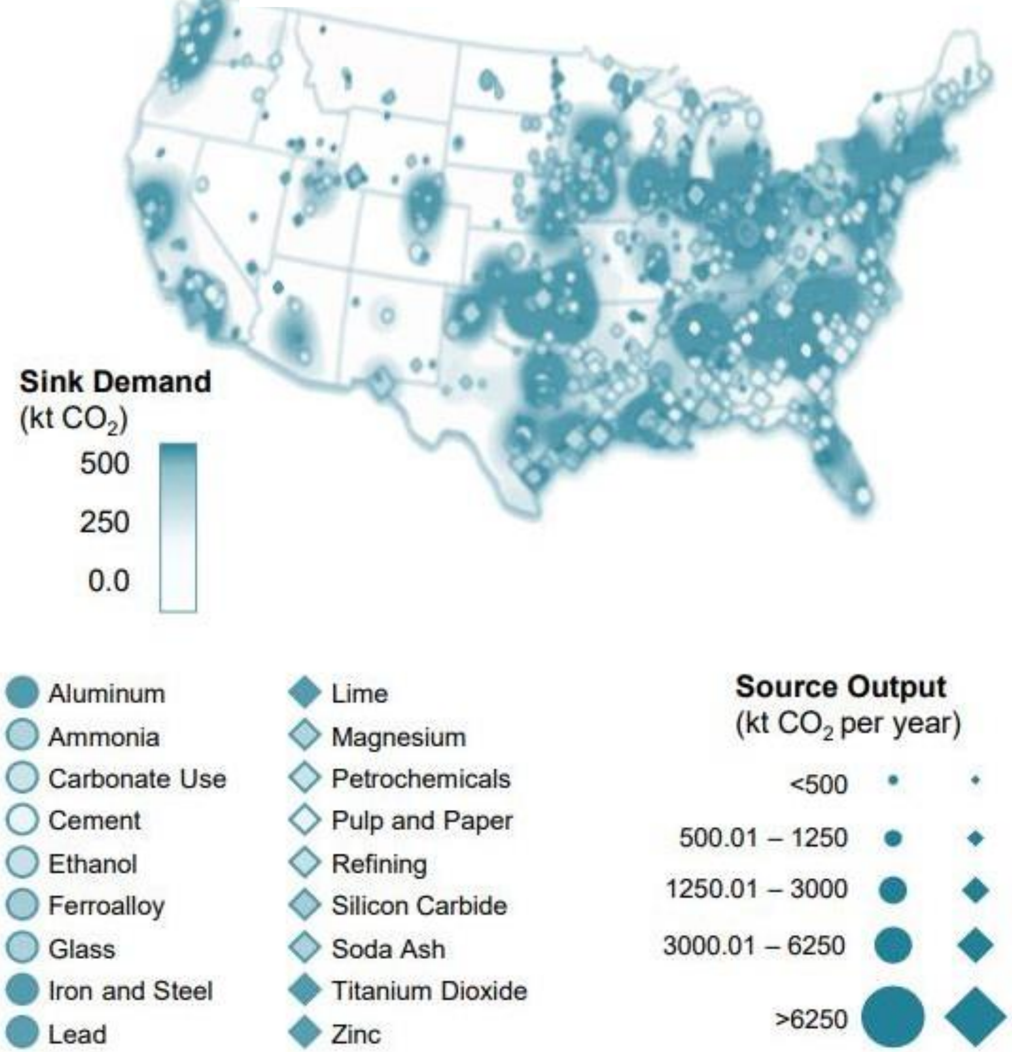
B: Hydrogen production potential from utility-scale PV, by county land area

C: Hydrogen production potential from concentrated solar power, by country
land area

D: Hydrogen production potential from solid biomass resources, by county land area

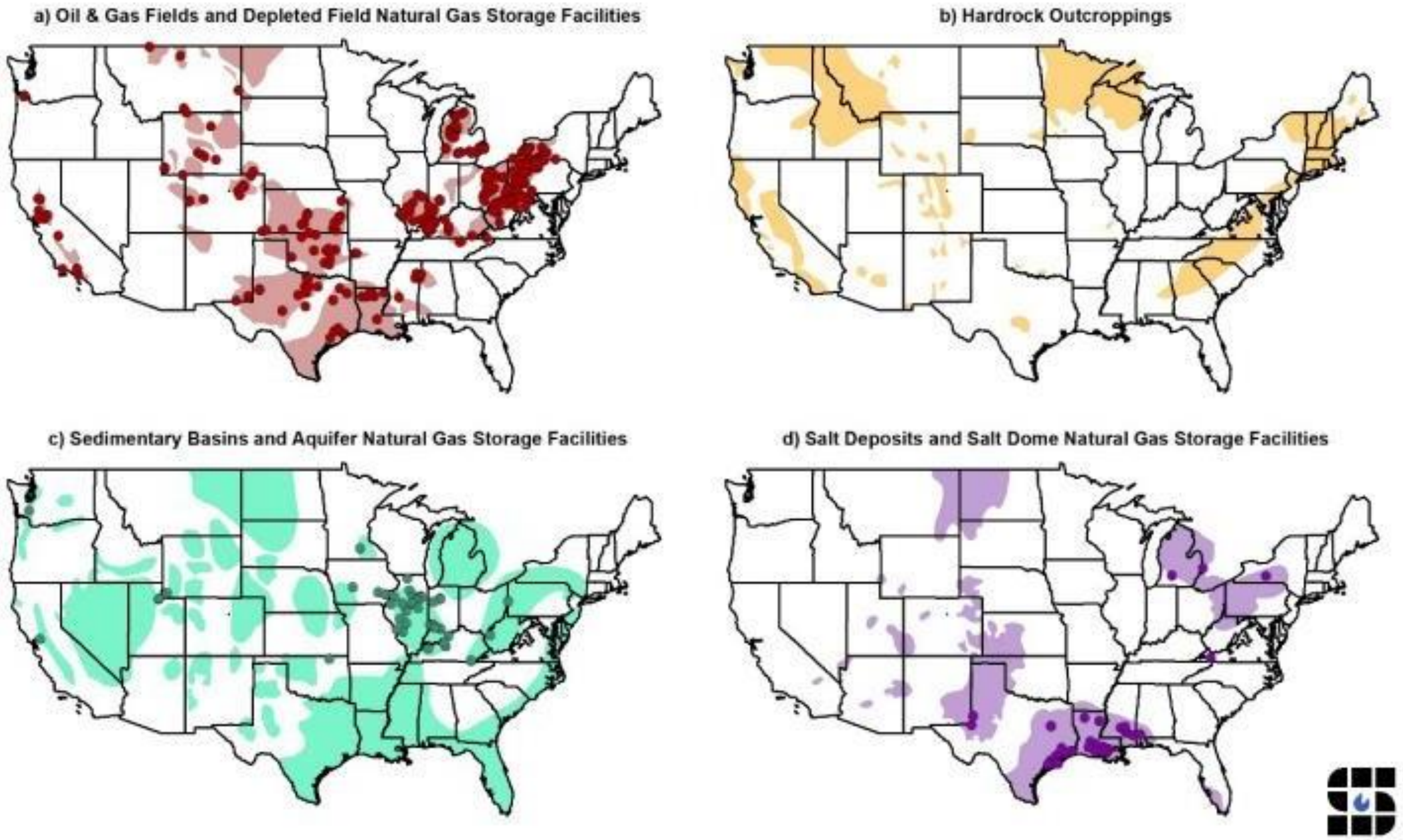
E: Hydrogen production potential from offshore wind resources, by county land area

Industrial clusters in the United States create potential regions for decarbonization hubs



Source: US DOE National Clean Hydrogen Strategy and Roadmap Draft, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf and references therein

Analysis of Potential Underground Storage Opportunities

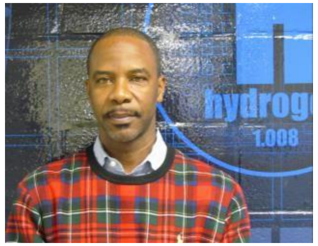


Source: US DOE National Clean Hydrogen Strategy and Roadmap Draft, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf; National Energy Technology Laboratory, Pacific Northwest National Laboratory, and Lawrence Livermore National Laboratory, Subsurface Hydrogen and Natural Gas Storage: State of Knowledge and Research Recommendations Report, DOE/NETL2022/3236, NETL Technical Report Series, U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2022; p. 6. https://www.netl.doe.gov/projects/files/SubsurfaceHydrogenandNaturalGasStorageStateofKnowledgeandResearchRecommendati onsReport_041122.pdf.

Collaboration
Diversity, Equity, Inclusion, and Accessibility

Advancing Diversity, Equity, Inclusion, Accessibility (DEIA) - Examples

Labs, Universities, and Industry Engagement and Initiatives



Minority Serving Institution Partnership Program (MSIPP) at LANL. Mentored >100 minority students, enabling fuel cell jobs

Funding for MSIs and HBCUs

DOE Announces $1.5 Million to Train the Next-Generation Hydrogen Workforce | Department of Energy

IPHE Early Career Network with over 38 countries (www.iphe.net)

Workforce and STEM focused initiatives

ORISE and GEM Fellowships, webinars including Tribal engagement, and stakeholder outreach

Example of HFTO Projects in Disadvantaged Communities and Industry Engagement

15 fuel cell trucks in disadvantaged community.
Reduces:
- 285 metric tons of CO_{2e},
- 280 kg of criteria pollutants,
- 56,000 gallons of diesel

Connecting communities across continents

INCREASE YOUR H2IQ
hydrogen.energy.gov

H2IQ Hour webinars to learn more

Industry Days (Pajarito)

Resources and Opportunities for Engagement

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

Save the date!

2023 DOE Annual Merit Review and Peer Evaluation Meeting
June 5-8, 2023

Hydrogen and Fuel Cells Day October 8

- Held on hydrogen's very own atomic weight-day

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INCREASE YOUR H2IQ hydrogen.energy.gov

Join Monthly
H2IQ Hour Webinars

Download
H2IQ For Free

Visit H2tools.Org For Hydrogen Safety And Lessons Learned

https://h2tools.org/

CENTER FOR Hydrogen SAFETY
Connecting a Global Community
www.aiche.org/CHS

Sign up to receive hydrogen and fuel cell updates

www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

Learn more at: energy.gov/eere/fuelcells AND www.hydrogen.energy.gov

Thank You

Dr. Sunita Satyapal
Director, Hydrogen and Fuel Cell Technologies Office
and DOE Hydrogen Program Coordinator
Sunita.Satyapal@ee.doe.gov
U.S. Department of Energy

www.energy.gov/fuelcells

www.hydrogen.energy.gov

Example of Stakeholder Feedback - Opportunities for Regional Clusters

Pacific Northwest

- *Port communities*
- *Tribal communities*
- *Extensive renewables*
- *8 jobs per \$1M invested in H_2*

California

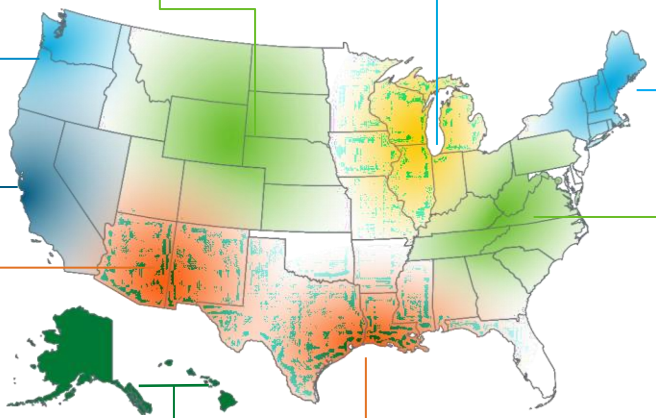
- *Diverse populations*
- *Extensive infrastructure*
- *Emissions regulations*
- *40,000+ jobs*

Southwest

- *Tribal and Hispanic communities*
- *Underutilized solar*
- *Nuclear power*
- *Up to 2B tonnes/yr emission reduction potential*

Central U.S.

- *Ample wind*
- *Geological storage*
- *Railway transport*
- *Nuclear resources*
- *>630,000 tonnes/yr CO_2 reduction*



Alaska and Hawaii

- *Extensive renewables – geothermal, solar, ocean*
- *Backup power*
- *Isolated communities*
- *86,000 tonnes/yr emission reduction*

Great Lakes

- *Major national corridors • Nuclear power • 60,000+ jobs*

New England

- *Offshore wind*
- *Fishing communities*
- *Backup power and winter heating*
- *~120K tons CO_2/year reduction*

Appalachia

- *Retiring fossil plants*
- *Mining, refining transferable skills*
- *Carbon capture and sequestration*
- *70,000 tons/yr H_2 production*

Gulf Coast

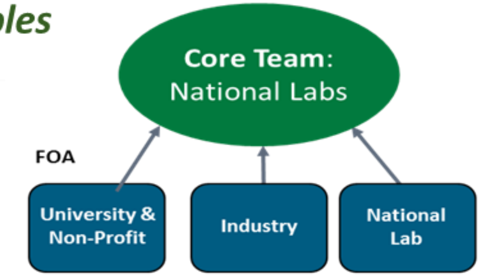
- *Existing infrastructure*
- *Multiple opportunity zones*
- *Renewable resources*
- *1,000s of jobs*
- *Chemical industry*

DOE Hydrogen Activities across RDD&D – Examples

Research and Development

Basic and applied research through individual projects and consortia

Consortia Examples



HydroGEN Advanced Water Splitting Materials

H2NEW U.S. DEPARTMENT OF ENERGY

H-Mat

ElectroCat Electrocatalysis Consortium

HyMARC

M2FCT MILLION MILE FUEL CELL TRUCK

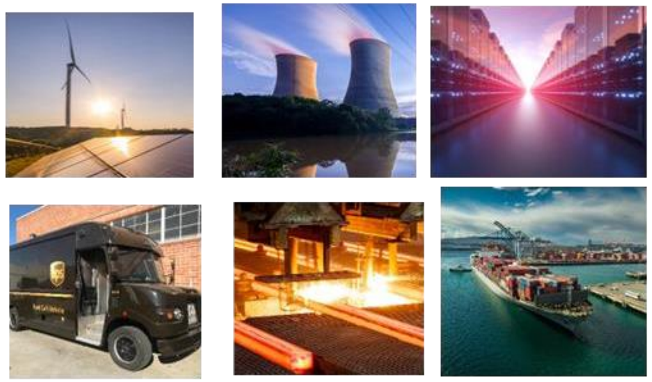
SHASTA Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

Basic science user facilities, theory, modeling

Technology Integration, Validation, Demos

1st of a kind demonstrations and systems integration to de-risk deployments

Examples:



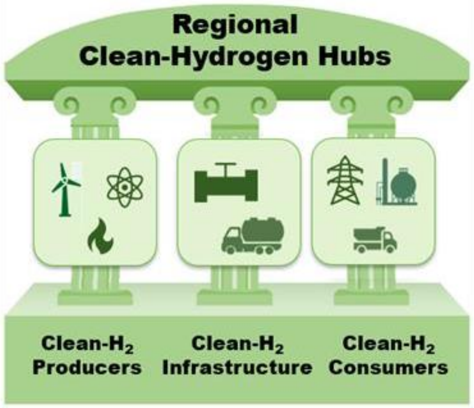
Renewables and nuclear to H_2, 15 delivery trucks in disadvantaged area, 3 Super Truck projects, data center, fueling for passenger ferry, energy storage, H_2 for steel

Deployment and Financing

H2 Hubs, loan guarantee program, workforce development

Example:

$8 billion for at least 4 hubs: Renewables, fossil w/CCS, nuclear; multiple end-uses



2 new loan guarantee projects ($1.5B total) on pyrolysis and large-scale electrolysis, H_2 energy storage and power generation

Enabling Activities

- Analysis and tools
- Safety, codes & standards
- Manufacturing
- Workforce development

H2EDGE Hydrogen Education for a Decarbonized Global Economy

CENTER FOR Hydrogen SAFETY Connecting a Global Community

HyBlend U.S. DEPARTMENT OF ENERGY

H2 Matchmaker

NASEO Webinar Colorado Low-Carbon Hydrogen Roadmap

March 2023

COLORADO
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CO POLICIES AND ACTIONS SET STAGE

- House Bill 19-1261-*Climate Action Plan to Reduce Pollution* with targets for reducing statewide GHG pollution 26% by 2025, 50% by 2030 and 90% by 2050 from 2005 levels;

- Development of a Colorado GHG Roadmap to ensure progress towards these targets which found that low-carbon fuels such as clean hydrogen are essential after 2030 and need to start ramping up between 2025 and 2030;

- Development of the *Opportunities of Low-Carbon Hydrogen in Colorado Roadmap* which identified the actions the state could take to develop a hydrogen economy.

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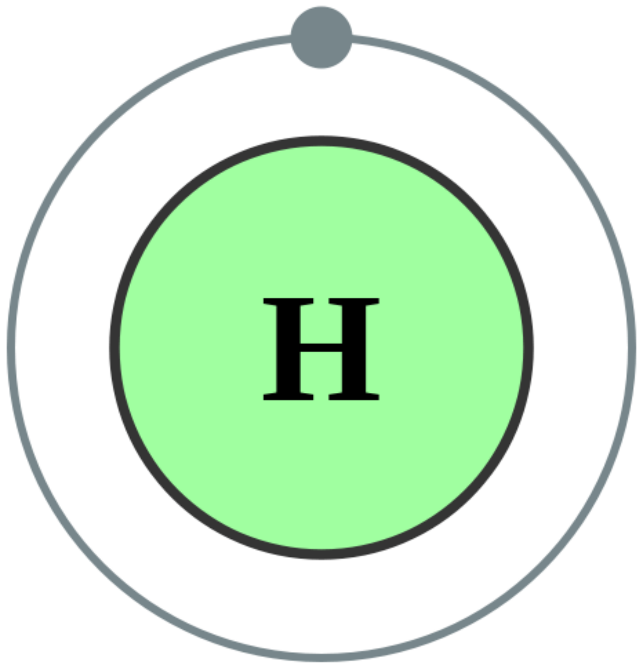
Colorado Low-Carbon Hydrogen Roadmap

Project Objective: a Colorado Low-Carbon Hydrogen Roadmap that is based upon:

- Definition of low-carbon hydrogen for Colorado;
- State of the hydrogen market in world, US and Colorado;
- Opportunities for hydrogen in Colorado;
- Steps Colorado could take to overcome barriers to build a hydrogen economy and;
- Economic potential of a Colorado hydrogen economy.

Final deliverable: Roadmap for the next 15-year period with:

- Key Success Factors
- Recommended Actions
- Production and Investment Targets



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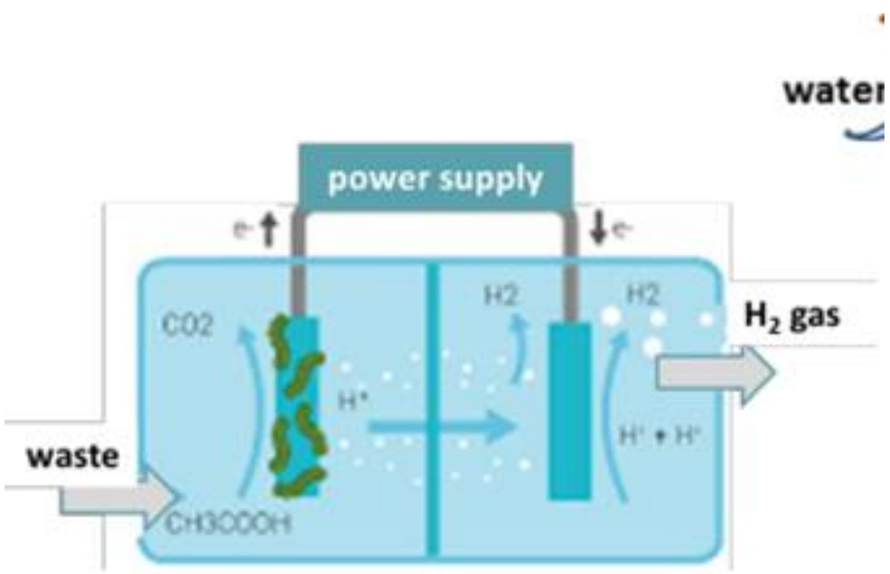
What is Low-Carbon Hydrogen?

Defined in the roadmap as:

- Hydrogen produced with significantly reduced life-cycle GHG emission compared to existing hydrogen production and encompasses both:
- Green hydrogen from renewable electricity and,
- Blue hydrogen produced from fossil-based source with Carbon Capture and Storage



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What Makes H2 Advantageous for CO

Defining low-carbon hydrogen in the context of Colorado: What makes Colorado unique?

Good wind & solar resources

Favoring the production of renewable hydrogen from electrolysis

Cold climate

Requiring the need for low-carbon heating sources to supply winter peak

Long traveling distances & elevation

Requiring the need for extended vehicle range

Large presence of Oil and Gas Industry

Potentially playing a role in production & distribution

Under-ground storage network

Providing opportunities for hydrogen storage in depleted hydrocarbon fields

Strong hydrogen interest

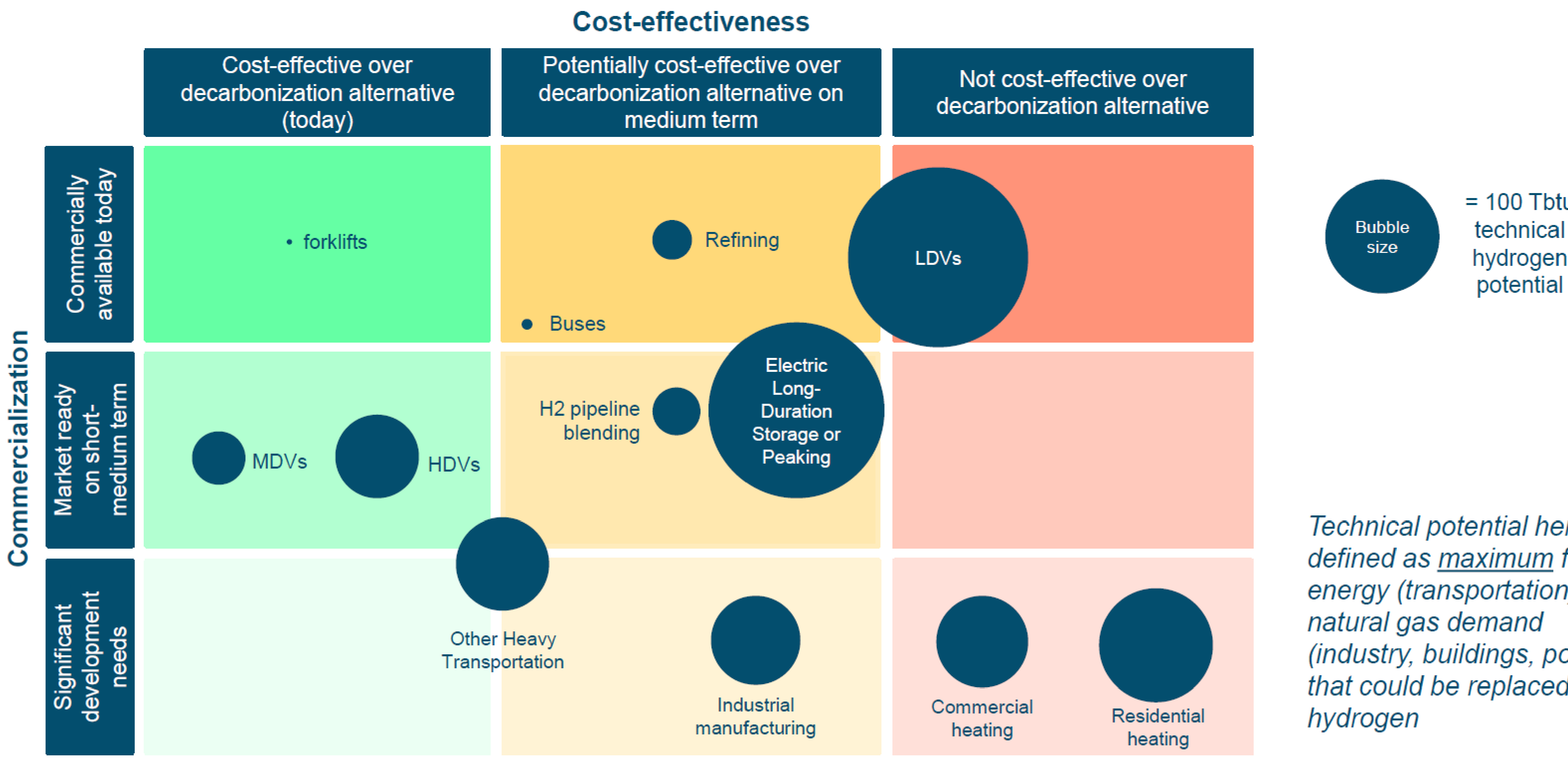
Resulting in opportunities for accelerated take-off

Large body of research & market parties

Enabling R&D and development of hydrogen in the region

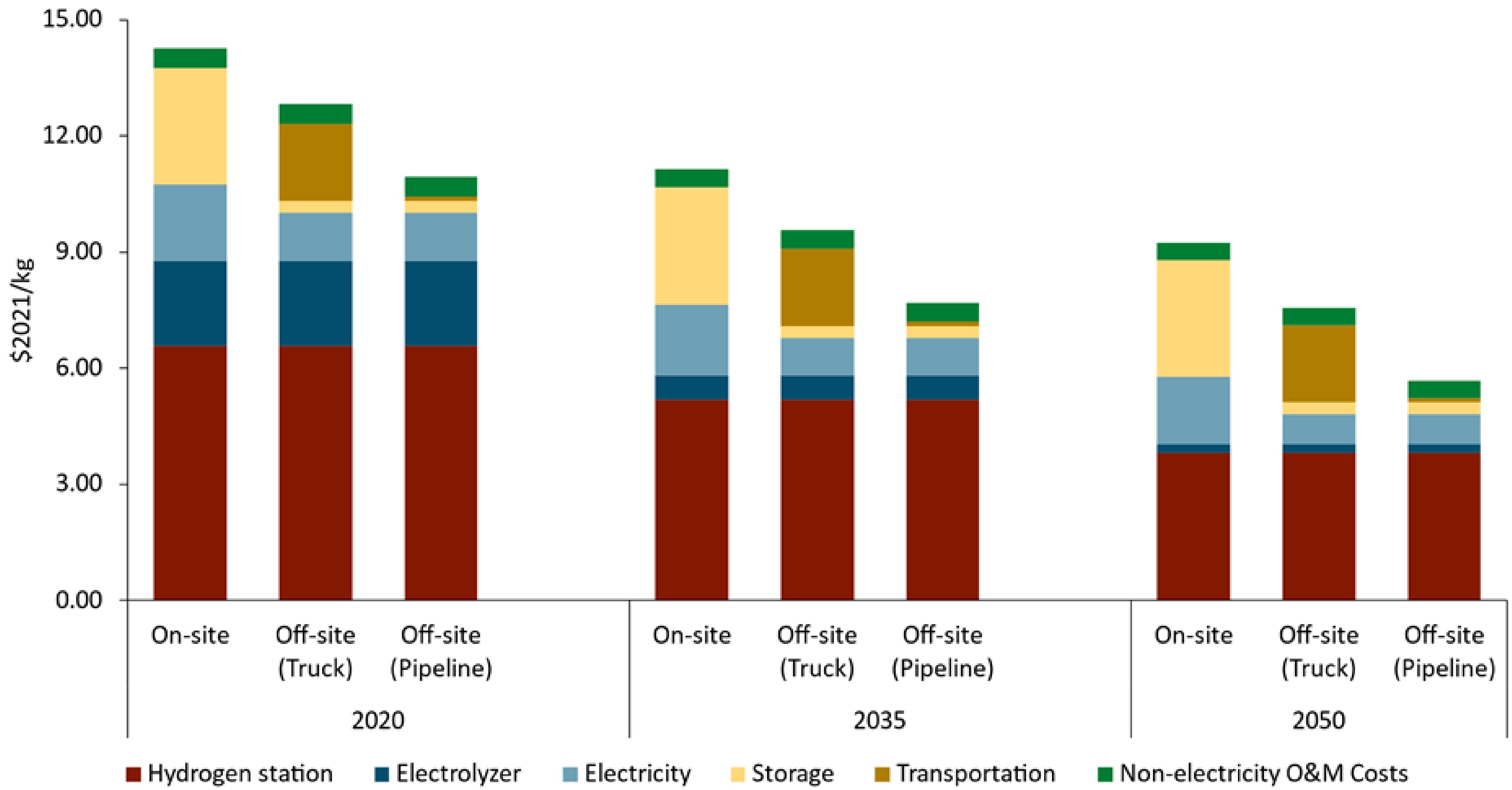
Opportunities for hydrogen by end-use application

Conceptual overview of mid-term (2030) hydrogen potential in Colorado



Technical potential here defined as maximum final energy (transportation) or natural gas demand (industry, buildings, power) that could be replaced by hydrogen

Estimated hydrogen refueling costs in CO



By 2030 the study finds H2 would need to be $6-8/kg to be cost competitive with diesel

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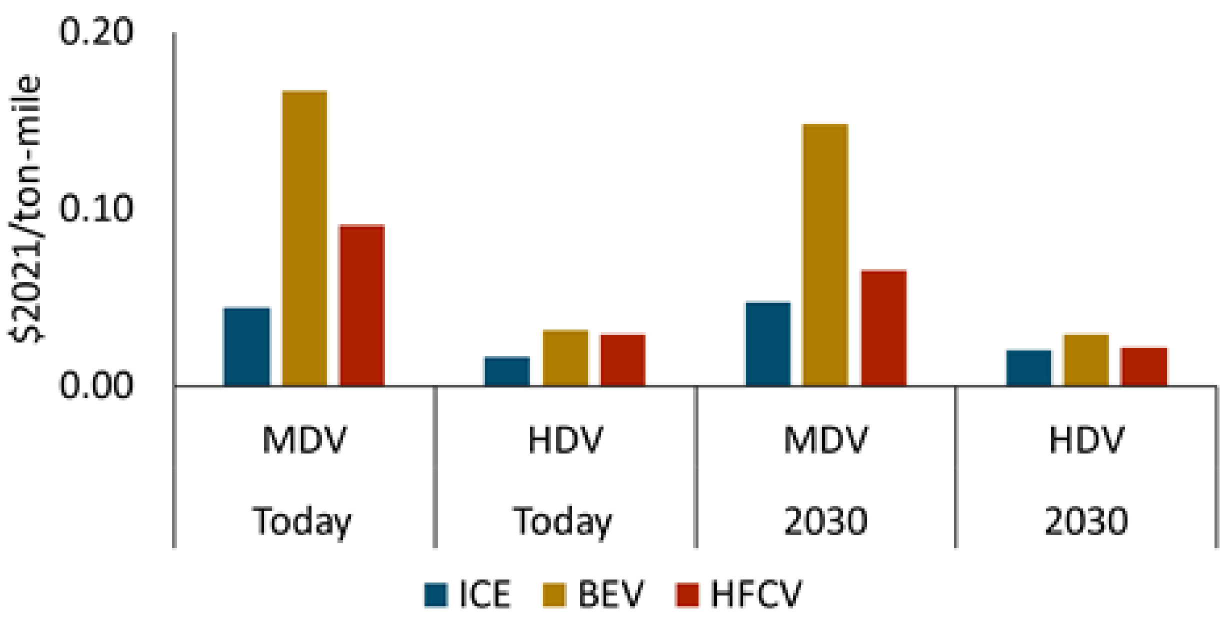
-Pump prices using off-site hydrogen production remain the more cost-effective option compared to on-site production, both now and in the future,

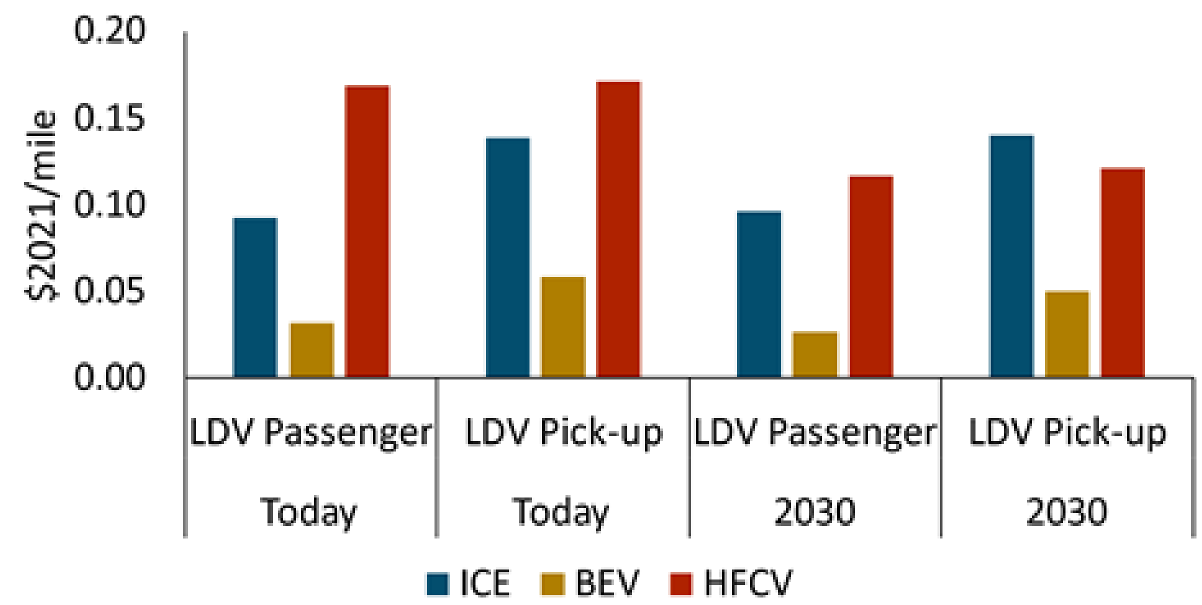
-Because, electrolyzers using electricity from the grid may have higher electricity prices than using off-grid electricity (like excess solar and wind)

-However, off-site production, especially by pipeline, requires more advanced infrastructure that is likely to become viable only at scale.

-Pump prices across all scenarios are expected to decline as electrolyzer costs decline and station cost economics improve with scale and higher utilization rates.

Operational Costs for HFCEV vs alternatives





-In the HDV segment, hydrogen is shown to be a cost-effective solution compared to electric vehicles, both now and in the future, on a per weight basis.

-Because, HD-EVs are projected to have a significantly lower carrying capacity than a diesel or HFCEV. Most public roadways have an 80,000lb weight limit for vehicles, the greater unladen weight of electric trucks, due to onboard batteries, is a competitive disadvantage because it results in lower cargo capacity and therefore higher costs per ton of cargo shipped.

- In the LDV segment, the study estimates that BEVs will remain a more operationally cost-effective option both today and in the next decade as a result of significantly better fuel economies and lower fuel costs than equivalent LDV FCEVs.

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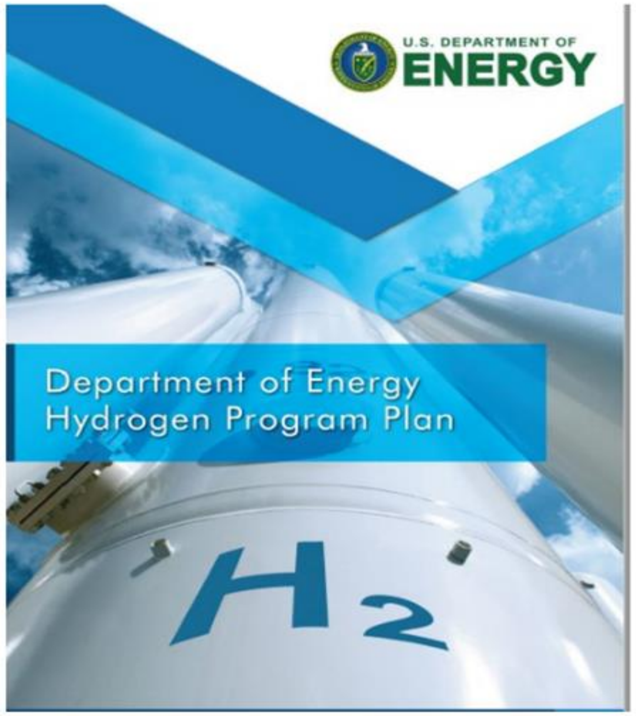
Recommended Actions

The Roadmap suggests the following actions:

- Develop a hydrogen plan that includes:
  - A renewable hydrogen production target
  - A target for development of vehicle refueling stations potentially in centralized areas or hubs
- Investigate market interest and feasibility of regional early-development hydrogen hubs
- Develop pilot projects on the use of hydrogen in the power sector
- Develop pilots related to blending of hydrogen in existing gas infrastructure
- Issue a Request for Information to potential hydrogen market participants to assess the feasibility of developing pilots and/or geographically-based hydrogen hubs in the state

Hubs in 2021 Infrastructure Investment and Jobs Act (IIJA)

- Released just after release of the CO H2 Roadmap
- Allocates $8 billion for four or more regional clean hydrogen hubs
- Colorado found itself very well-positioned to seriously consider this opportunity due to the very recent completion of it's Low Carbon Hydrogen Roadmap
- Decided to pursue this opportunity in a regional collaboration rather than develop a Colorado focused plan as the roadmap suggested- our findings aligned with IIJA



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Western Inter-States Hydrogen Hub (WISHH)

- In February of 2022, the states of Colorado, New Mexico, Utah and Wyoming signed an Memorandum of Understanding (MOU) to exclusively work together to compete for a portion of the IIJA $8 billion DOE Regional Clean Hydrogen Hub program- Western Interstates Hydrogen Hub (WISHH)

- WISHH hired a prime contractor, Atkins, and under their direction collaborated with the research institutions and industry partners on a Concept Paper in response to the DOE Clean Hydrogen Hub Funding Opportunity Announcement (FOA)

- Concept paper was encouraged by DOE!

- Full proposals are due April 7, 2023

- WISHH aspects in CO very closely align with recommendations from our Roadmap

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How can you stay informed?

The Colorado Energy Office has created an website to share information and updates, including our concept paper: https://energyoffice.colorado.gov/climate-energy/western-inter-states-hydrogen-hub

Link to *Opportunities for Low-Carbon Hydrogen in Colorado: A Roadmap:* *https://drive.google.com/file/d/1wV2Xq1COF0BY77X_OSvkNSMKgPNeMfcU/view*

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Thank you!

Maria DiBiase Eisemann
Policy Advisor, Special Projects
Colorado Energy Office
Maria.eisemann@state.co.us

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Hydrogen End-Use Prioritization

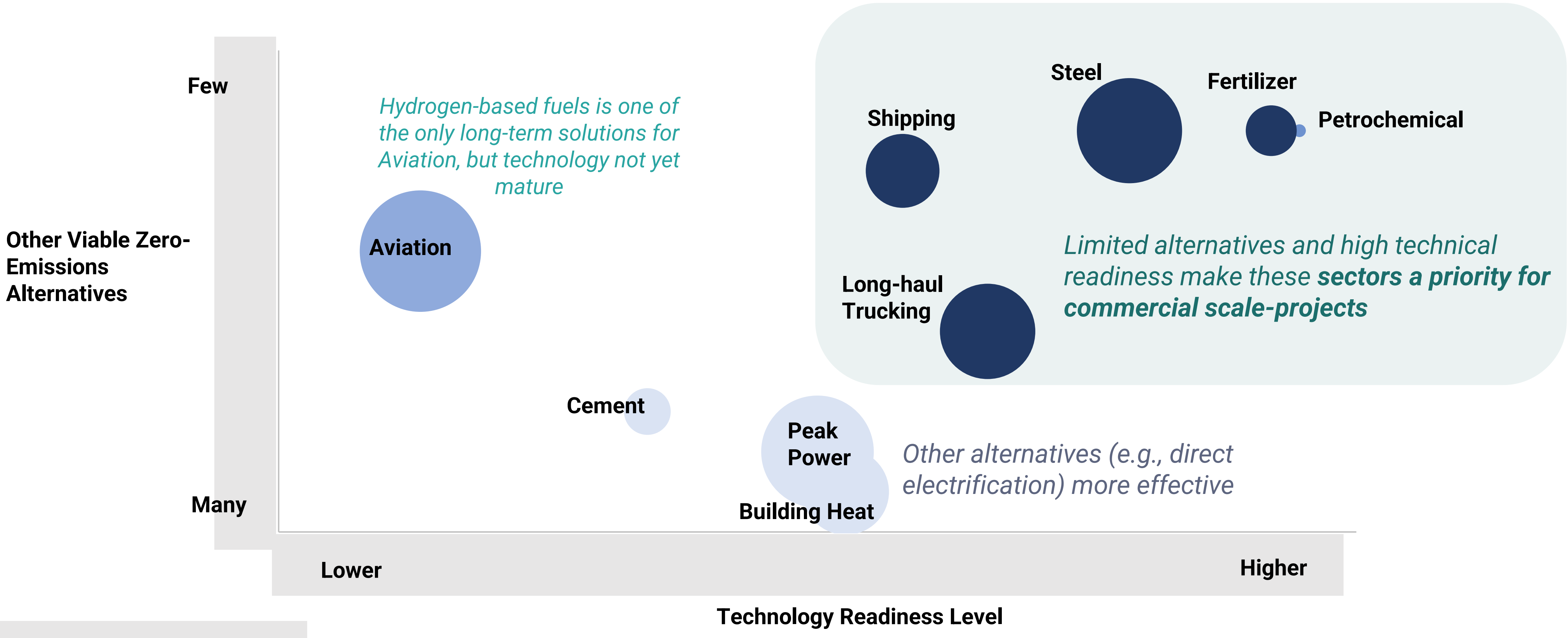
Tessa Weiss

March 2023

Hydrogen is the only viable decarbonization solution for several hard-to-abate sectors

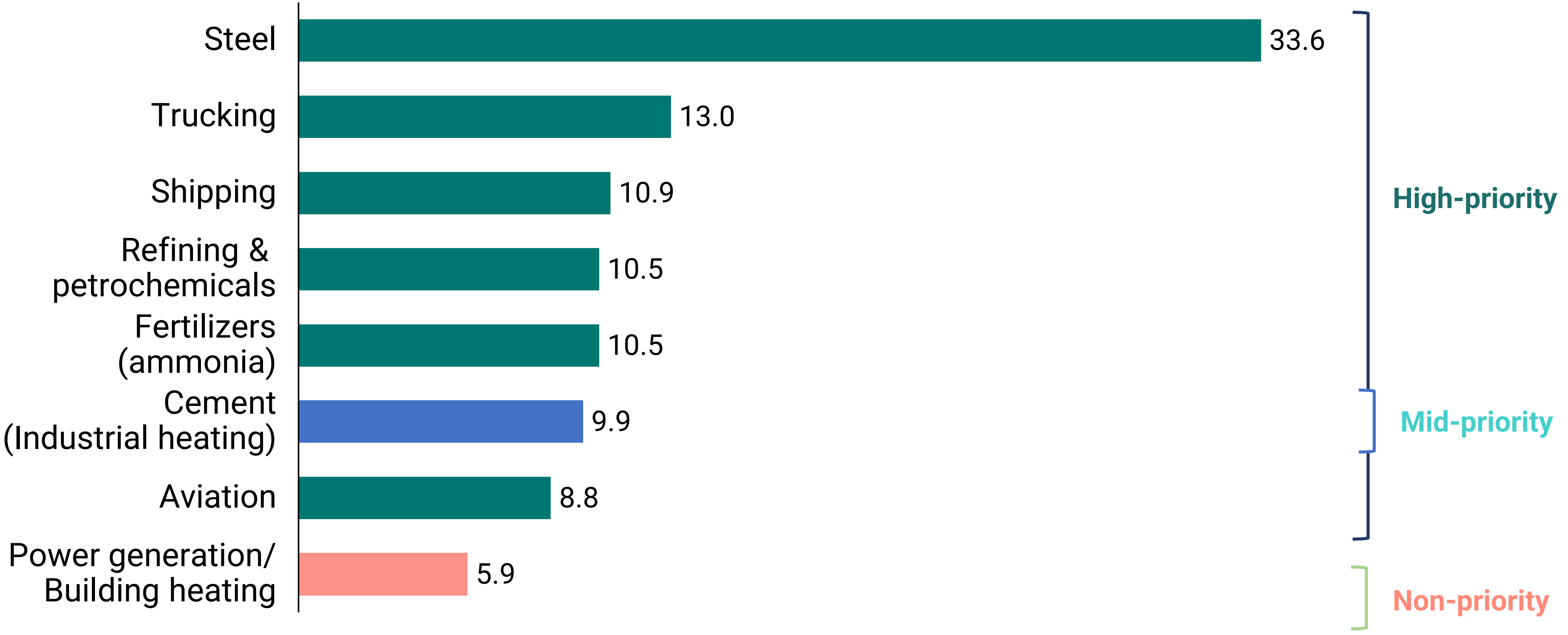
Prioritization of Hydrogen for the U.S.

Bubble size indicates potential CO_2 emissions reduction (MMt/yr)



Emissions impact of sector prioritization

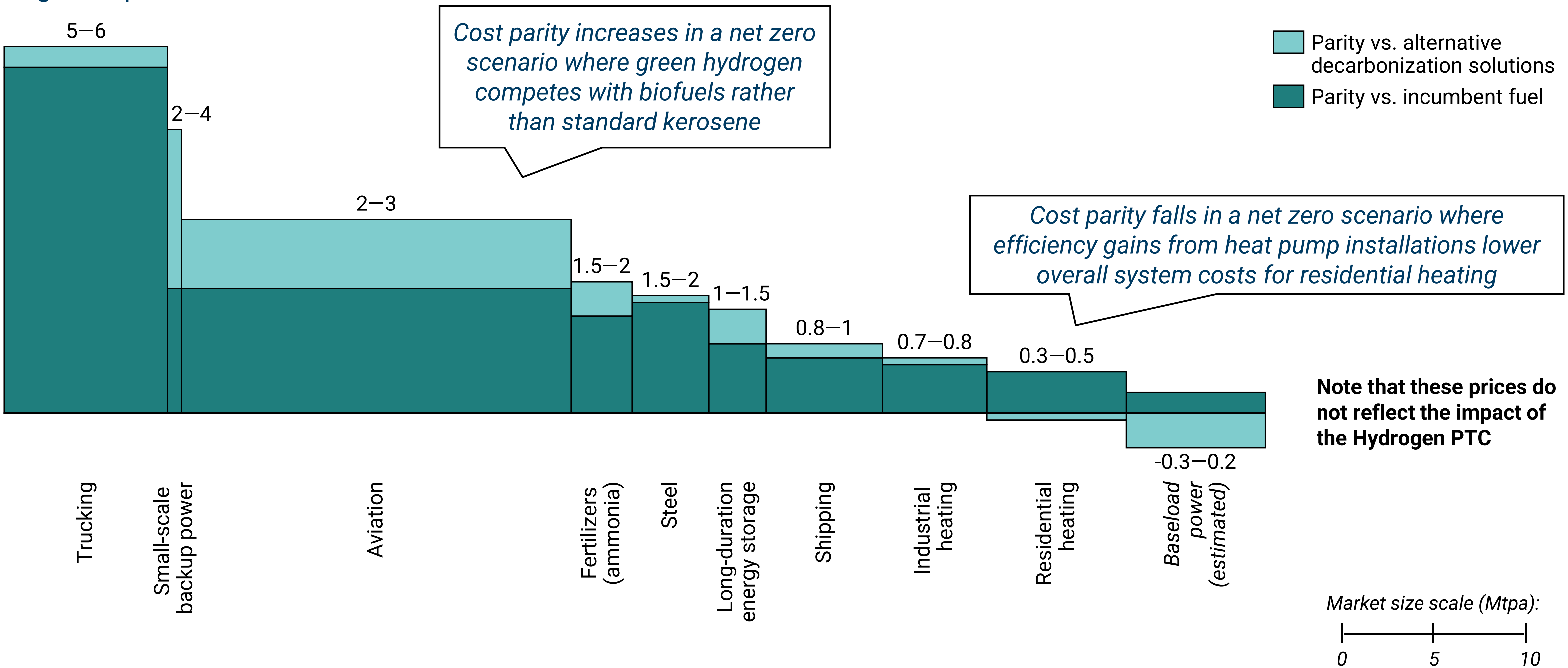
Sectoral abatement potential of hydrogen fuel-switching
kg CO_2/kg H_2



Producers can serve larger markets at higher prices by distributing green hydrogen to priority end-use sectors like trucking, aviation, and steel making instead of power generation

Competitive prices for hydrogen compared to alternative fuels vs. addressable market sizes in the US

$/kg vs. Mtpa sectoral market



Note that these prices do not reflect the impact of the Hydrogen PTC

*Parity price covers production and distribution, driving up the price in heavy duty trucking where distribution costs are high

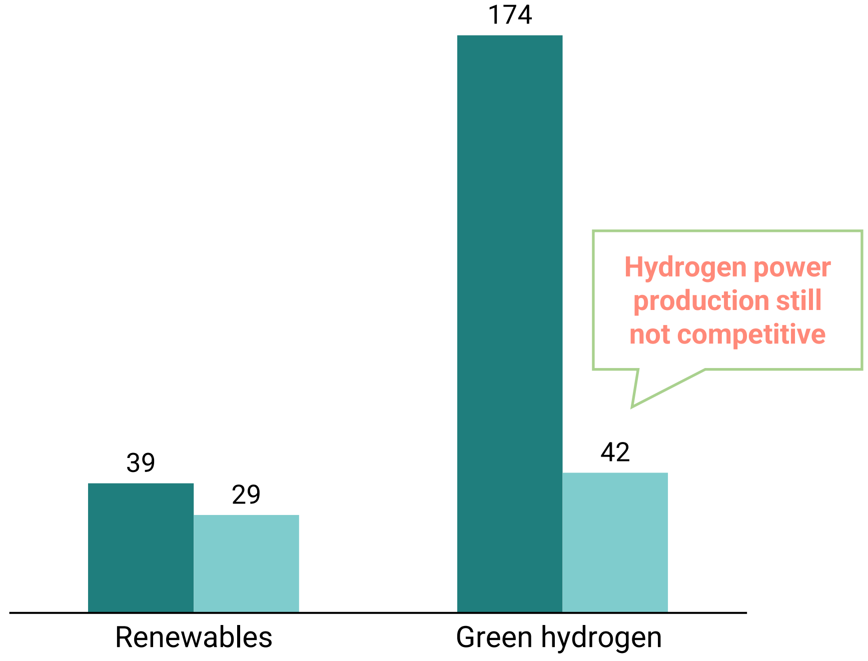
Sources: US DOE National Clean Hydrogen Strategy and Roadmap (2022), Mission Possible Partnership Action Sector briefings, RMI analysis and expert input

Production tax credits could help justify business cases for hydrogen power generation even though without subsidies, it's 3—4x more expensive than solely renewable power generation

***Scenario analysis*: Via simple optimizations, green H_2 production and storage levels can be calibrated to maximize subsidy benefits for power plants with different renewable profiles**

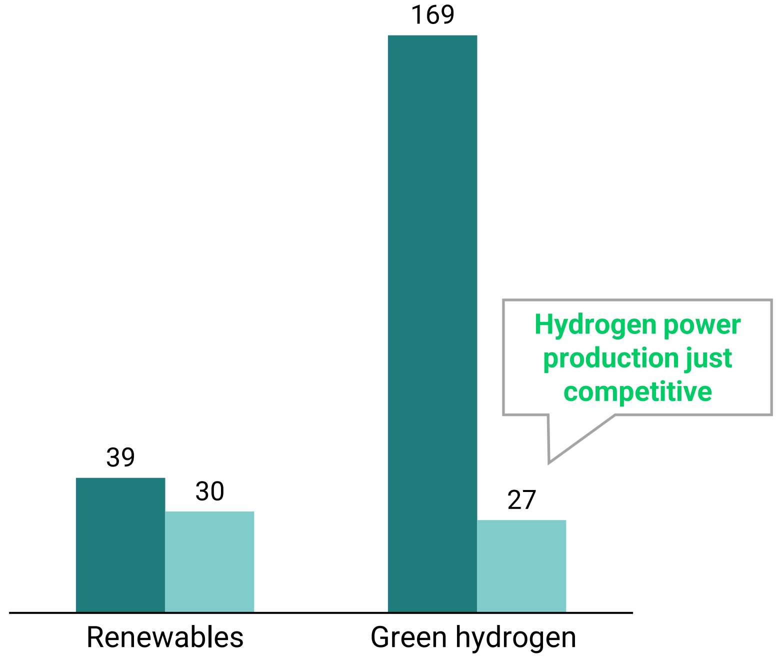
Case 1: Solar PV > green H_2 > gas turbine

Plant LCOE by power source
$/MWh



Case 1 system parameters
- 1 MW Solar PV with a 24% effective capacity factor
- 830 kW Electrolyzer with a 68% efficiency
- 90 kW CCGT retrofitted and used to combust green hydrogen

Case 2: Onshore wind > green H_2 > gas turbine



Case 2 system parameters
- 1 MW Onshore Wind with a 44% effective capacity factor
- 700 kW Electrolyzer with a 68% efficiency
- 150 kW CCGT retrofitted and used to combust green hydrogen

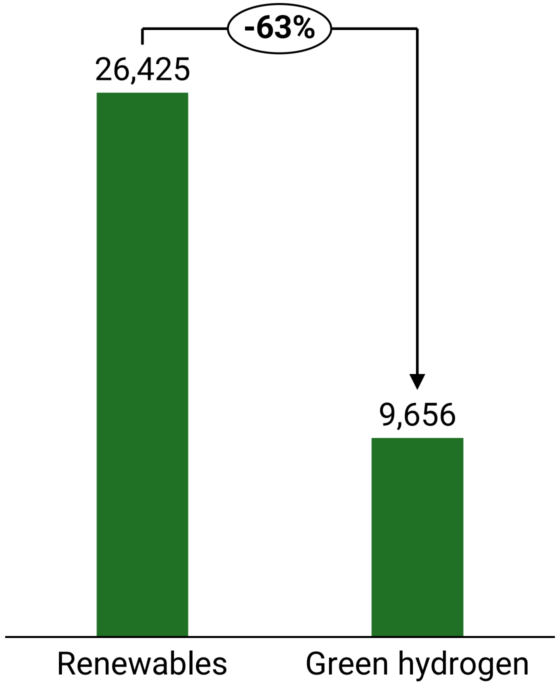
In plants with optimal renewable profiles and storage facilities, the hydrogen production tax credit can create an economic incentive for hydrogen power production

But hydrogen power generation will reduce the amount of green electricity available for decarbonizing the US grid in the short-term and cause power assets to strand in the long-term

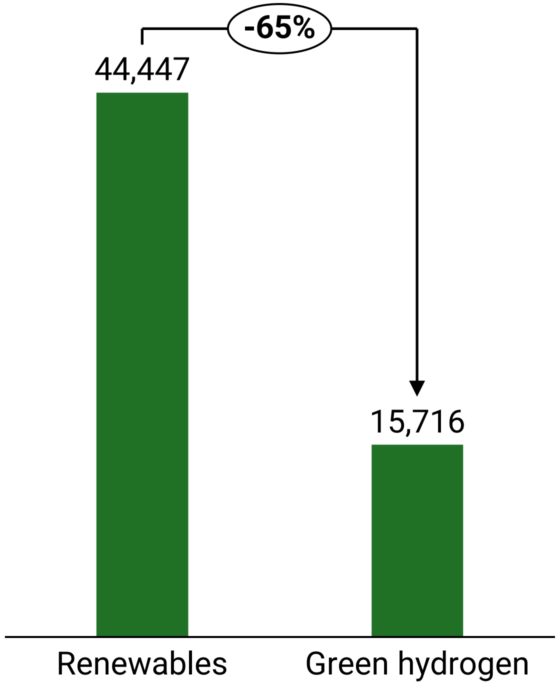
Scenario analysis: Net electricity generated over plant lifetimes decreases by >60% in scenarios that prioritize hydrogen generation over solely renewable generation

Case 1: Solar PV > green H_2 > gas turbine

Lifetime (20-year) electricity generation
MWh



Case 2: Onshore wind > green H_2 > gas turbine



- Enforcing a strict additionality principle could help keep power plants from exploiting production tax credits and incentivize solely renewable-based electricity generation
- This would free up more than 2x as much green electricity to decarbonize the US grid
- This would also prevent vital power generation assets from stranding once tax credits are phased out

Clean Hydrogen End Uses and Considerations for State Energy Offices

An Industry Perspective on H2

Dave Edwards, PhD
Air Liquide Hydrogen Energy

March 2023

2019 Key Figures

Air Liquide

~67,000
EMPLOYEES

PRESENT IN
80 COUNTRIES

MORE THAN
3.7 MILLION
CUSTOMERS & PATIENTS

REVENUE
€21.9bn

NET PROFIT
(GROUP SHARE)
€2.24bn

INVESTMENT DECISIONS
€3.7bn

O_2 OXYGEN

N_2 NITROGEN

Ar ARGON AND RARE GASES

H_2 HYDROGEN

He HELIUM

CO_2 CARBON DIOXIDE

CO CARBON MONOXIDE

Air Liquide

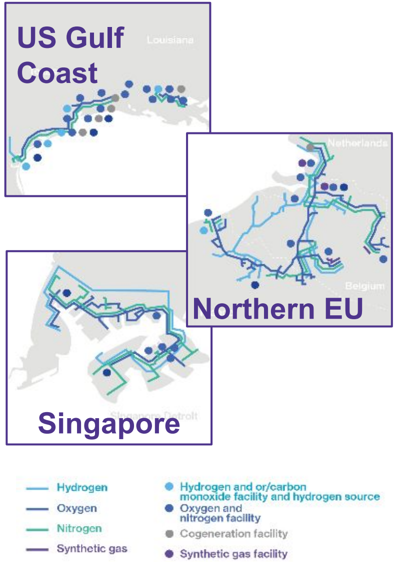
Air Liquide has nearly 50 years of hydrogen development for industries

Production & Supply chain

Production

Supply chain

Distribution Networks



Markets Segments

Process industries

Oil & Gas

Steel, Glass

Electronics

Transportation

Space

Key Figures

14 Bm^3/yr

1,850 km H_2 pipeline

46 large H_2/CO plants

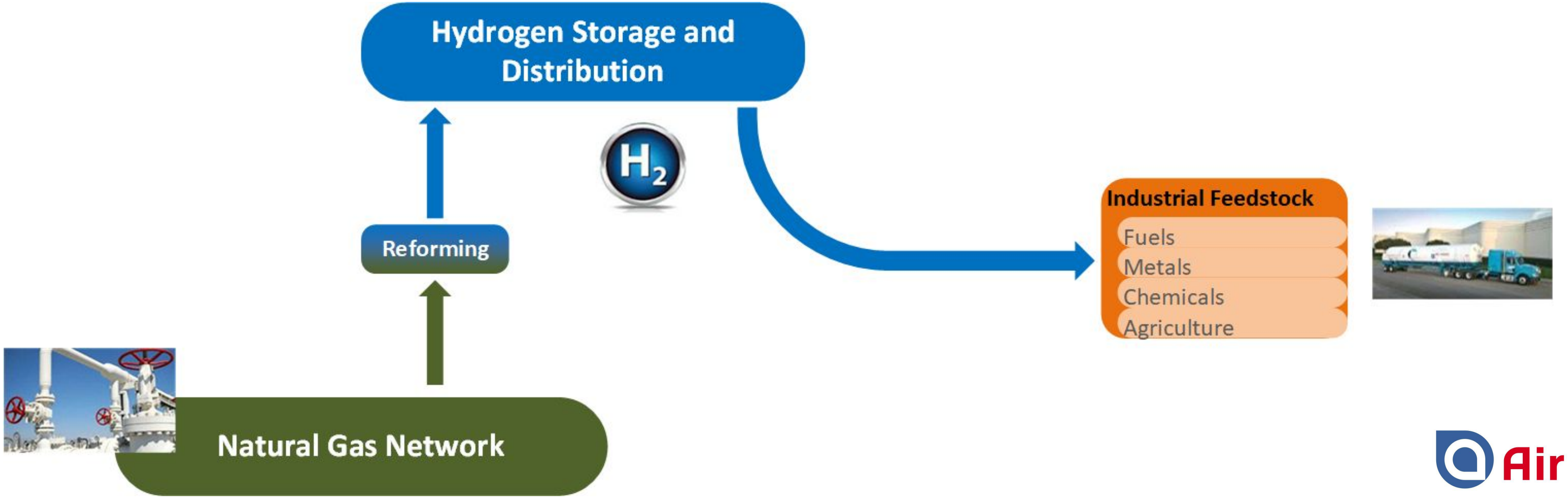
40 electrolyzers in operation

2 B€ sales

Hydrogen and the Energy Transition

Air Liquide

Hydrogen Today - Industrial Processes



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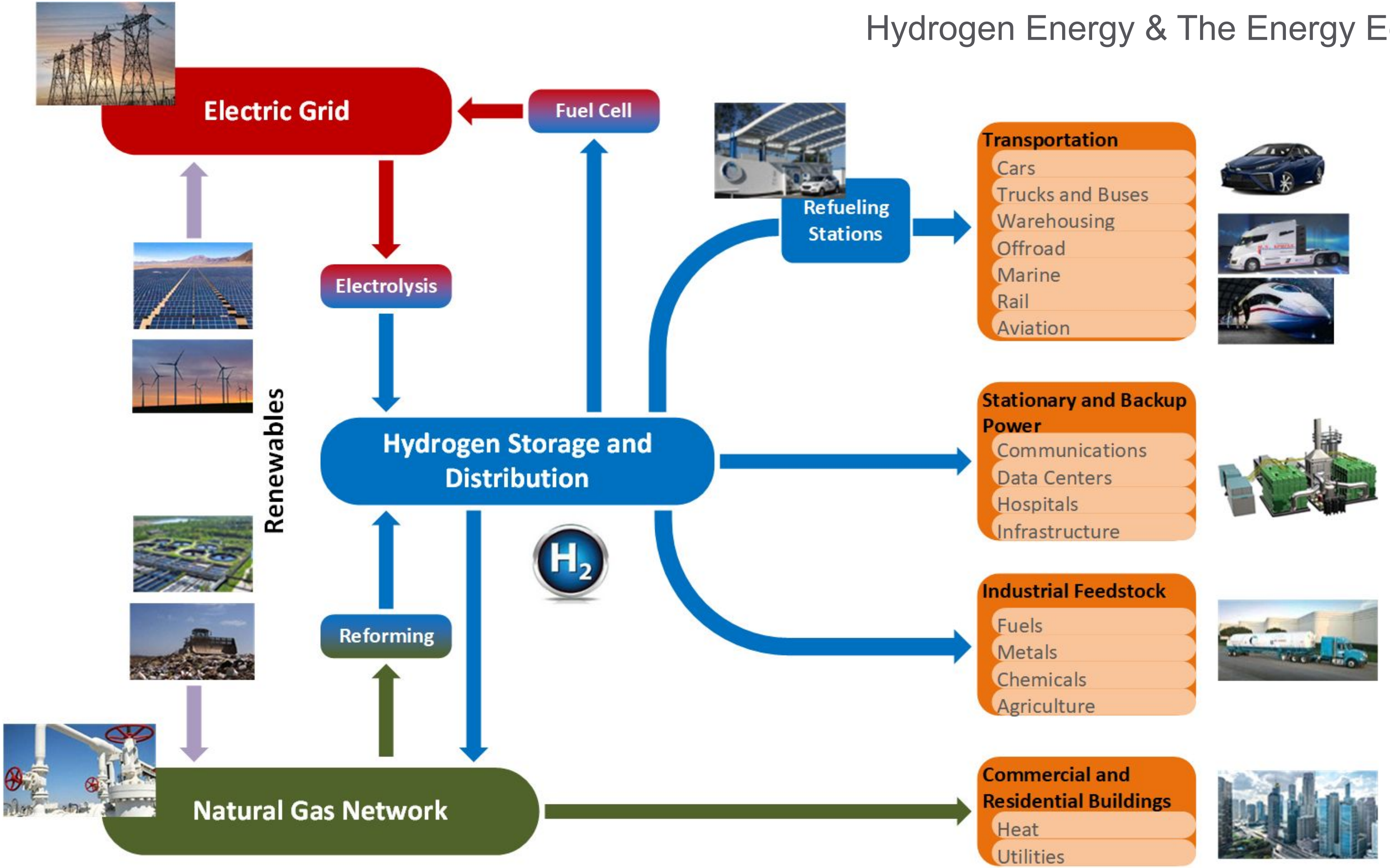
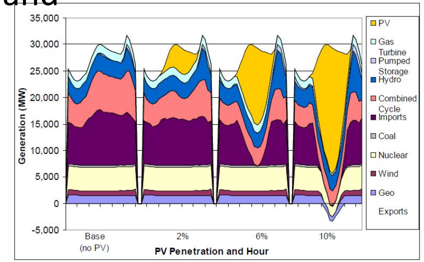
Hydrogen Energy & The Energy Ecosystem



Hydrogen – enabling the renewable grid

Renewables on the Grid…

…can lead to unbalanced supply & demand



Water Electrolysis → **Hydrogen Storage**

Texas Wind Energy

- 29 gigawatts (GW) of wind in the state with potential for up to 1300 GW
- #1 in US for both installed and under construction wind capacity
- Only 4 countries have more wind power than Texas.
- 25,000 wind-related jobs

29 GW could produce enough hydrogen to fuel every car in TX

The introduction of hydrogen production and storage enables renewables for both the power and transportation sectors

Air Liquide investments in North America

Nevada

1st large scale **renewable liquid hydrogen** production plant dedicated to the Hydrogen energy markets

- Investment: **$250M**
- Capacity: **30 tons per day** (40,000 FCEVs in the West Coast)
- Location: **North Las Vegas, Nevada**
- Construction: **Began in 2020; operations & delivery in 2022**

World's Largest PEM Electrolyzer to supply **~100% low-carbon hydrogen** for Canada and the East Coast Markets

- Investment: **$40M** (additional investment to existing site with liquefier)
- Capacity: **>8 tons per day (20 MW PEM electrolyzer)**
- Location: **Bécancour, Québec**
- Construction: **Began in 2019; operations & delivery started 2021**

Bécancour

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Hydrogen and the Energy Transition

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The Role of Policy - Drive Markets to Scale

<u>Policies need to balance the priorities of the populace</u>

Environmental

- GHG - net CO_2 reduction
- Health effects - particulates and criteria pollutant reductions

Economic

- Affordable, available, reliable energy
- Domestic energy, local investments

Societal

- Disadvantaged communities impact

All of these require solutions at SCALE

SCALE requires PRIVATE INVESTMENT (balanced and encouraged by policies)

PRIVATE INVESTMENT requires a MARKET (open, stable, competitive)

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The Role of Policy - Four Elements

<u>Policies that enable a sector to Transition to Hydrogen - Three Elements</u>

Fuel (Hydrogen Production)

- Prioritize outcomes (carbon intensity, criteria pollutants), not specific pathways
- Leverage all available resources - wind, solar, nuclear, RNG, CCUS
- Examples: IRA 45V, IRA 45Q, LCFS

Distribution (Infrastructure)

- Balance between public infrastructure and private ownership
- Onroad distribution, Pipelines, Bulk (cavern) storage, refueling stations
- Infrastructure <u>must</u> precede End Use

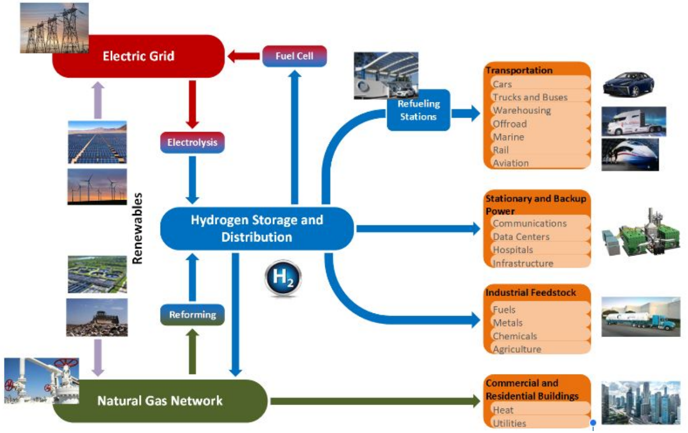
End Use (Transportation, Industry, Power Generation…)

- Ports (air, sea, land), warehousing districts, data centers
- Vehicle adoption costs - vehicle regulation, incentives
- Examples: CA ZEV Portfolio (Clean Cars, ACT/ACF, ICT)

<u>Fourth Element - cross sector H2 markets</u>

Utilize the same Production and Infrastructure

Enables SCALE



Summary

Hydrogen has the potential to enable an Energy Transition

Driving scale will enable the economic, environmental, and societal outcomes

Policies which encourage outcomes best enable markets

H2 adoption at scale must enable investments in

- Fuel production
- Distribution infrastructure
- End Users

Cross sector growth further enables scale

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Thank You!

david.edwards@airliquide.com

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