Zero Carbon Fuels – A Global perspective with Contemporary North American insights

Andrew Place | July 20, 2022

CLEAN AIR TASK FORCE

CATF

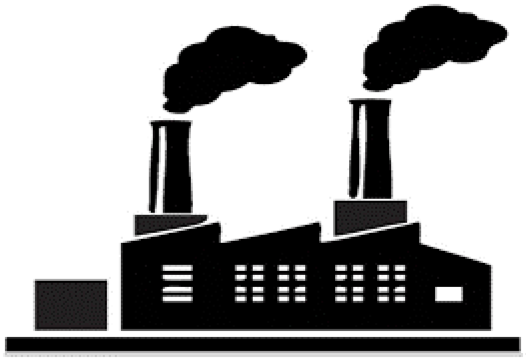
Mission: Lead the way to an affordable, zero carbon energy system by advocating for pragmatic policies, new business strategies, and advanced technologies.

Steam Methane Reforming

(95% of H_2 production today)

Carbon Intensive

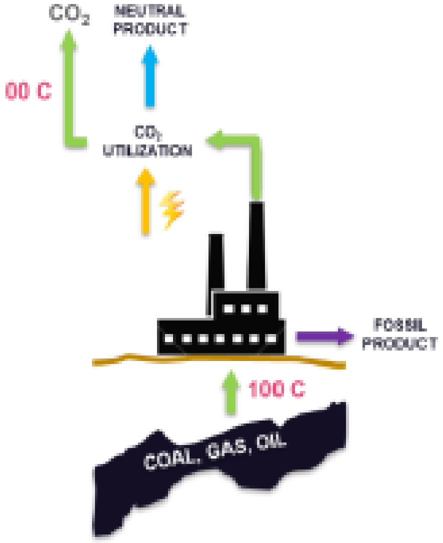
H_2 produced at oil refineries = 10.5 tons CO_2 per ton of H_2



Oil, Coal, Natural Gas

Steam Methane Reforming + CCUS

Low Carbon, but more expensive

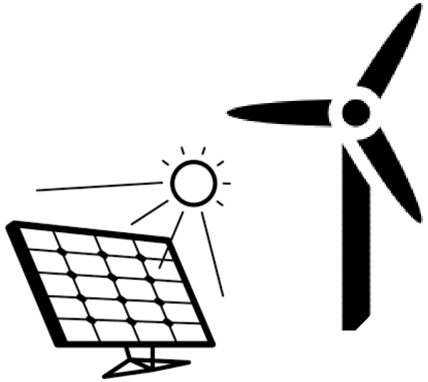


Electrolysis + Zero-Carbon Source

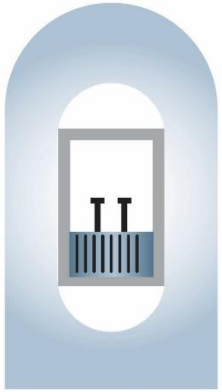
Zero Carbon, but currently more expensive

Geographic Limitations

Zero Carbon, can be economically competitive due to baseload production + H2 production efficiencies



Renewables



Nuclear

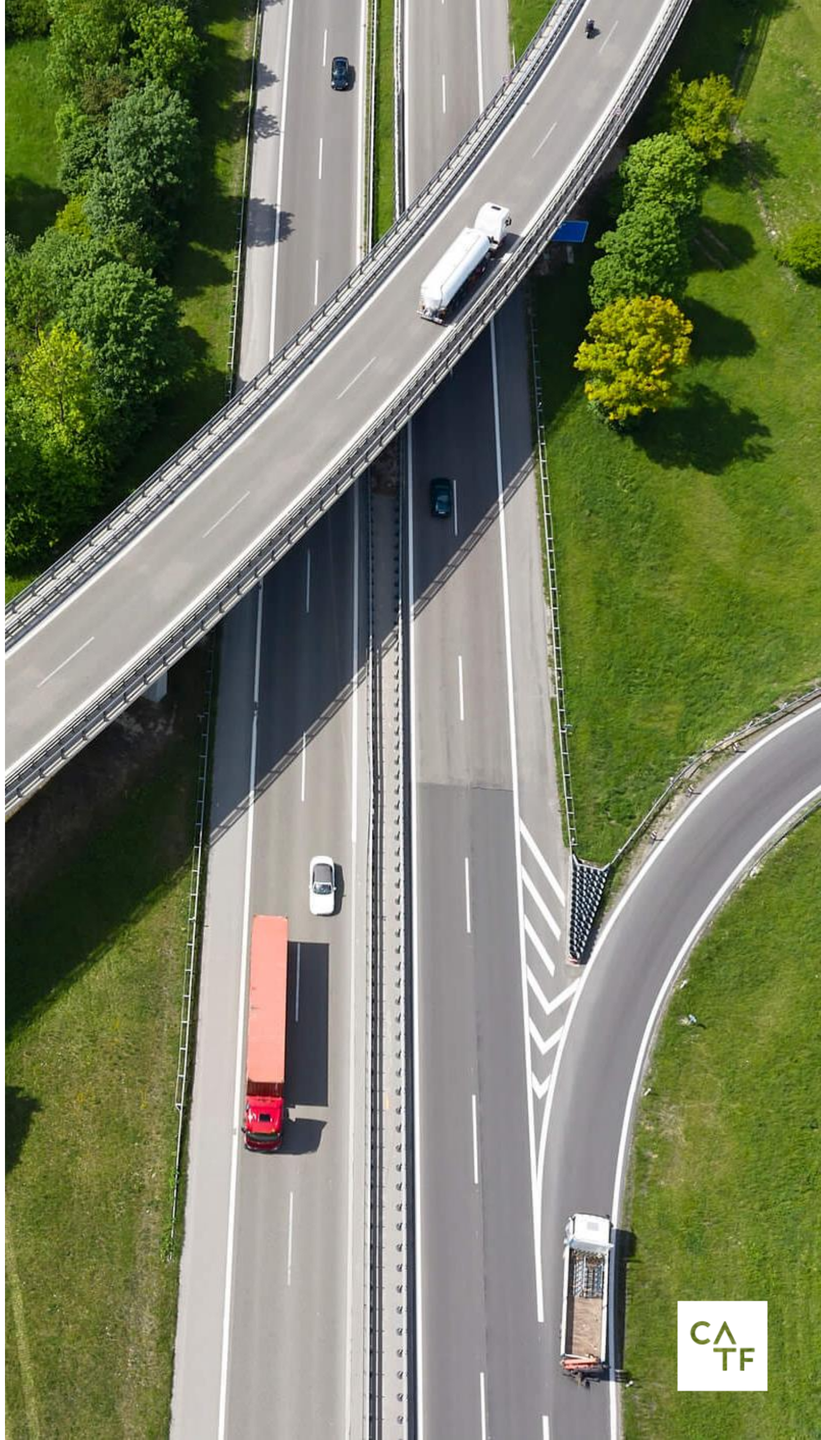
Zero-carbon fuels production pathways

We refer to fuels that are not only zero- carbon at the point of use, but that are also produced in ways that aim to minimize greenhouse gas emissions, resulting in very low CO2-equivalent emissions across the value chain.

Clean hydrogen can be produced in multiple ways, through electrolysis using zero-carbon electricity, methane reforming using natural gas with carbon capture and upstream methane control, etc.

Clean hydrogen is the whole point. What constitutes “clean” depends on context and should evolve over time, but at a minimum:

- Gas-based production must feature very high level of carbon capture for reformers, extremely low methane loss rates upstream, low CO2 intensity of process electricity
- Electrolytic production must utilize electricity that is renewable or clean



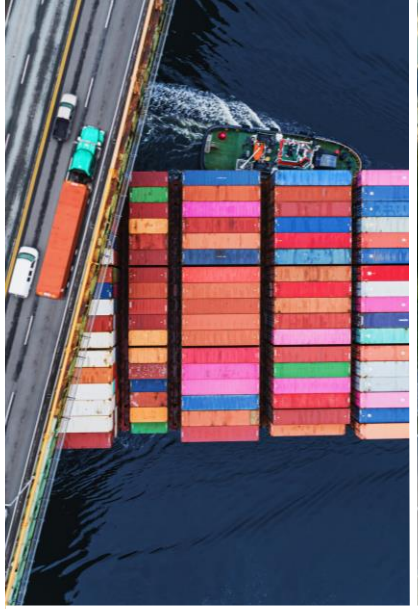
Zero-Carbon Fuels (ZCF)

80% of end-use energy is currently provided by fuel molecules like coal, natural gas and gasoline.

In the future, **many fuel end users will convert that consumption into electricity.**

Despite critical efforts to expand electrification, **there are many sectors of the economy where electrification is not a viable alternative to molecules.**
This is because the energy demand is so high, that it cannot be commercially delivered through electrification alone. For these sectors, replacement fuels are required that do not emit carbon when consumed.

Zero-carbon fuels—specifically hydrogen and ammonia—are fuels that do not emit carbon dioxide when consumed and can replace existing high-emitting fuels.

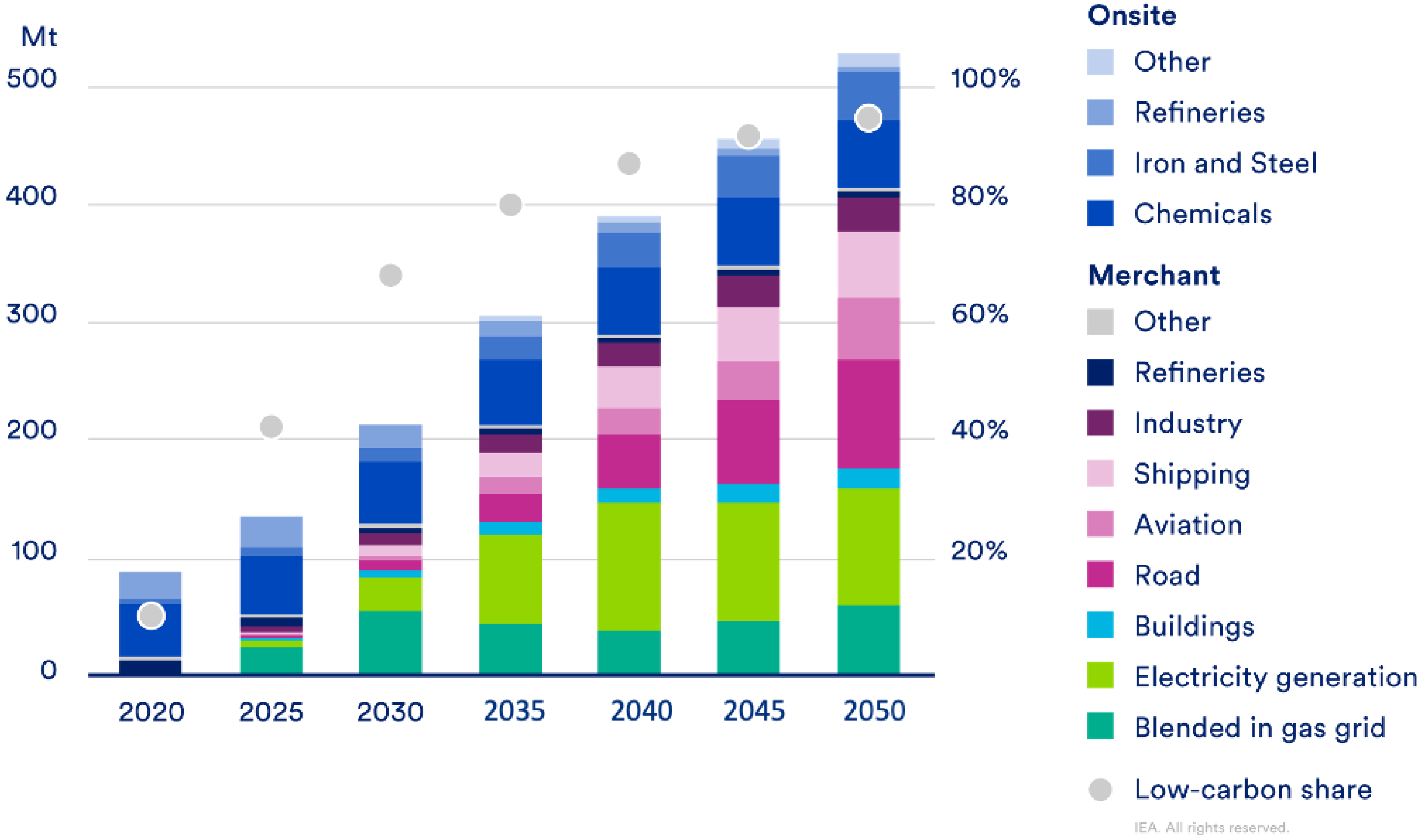


ZCFs' Role

IEA Predicts that global hydrogen demand will increase form 90 Mt/y to **530 Mt/y by 2050**

- 46% of hydrogen produced by 2030 is low-carbon
- By 2050, 38% of hydrogen is fossil-based with CCS.

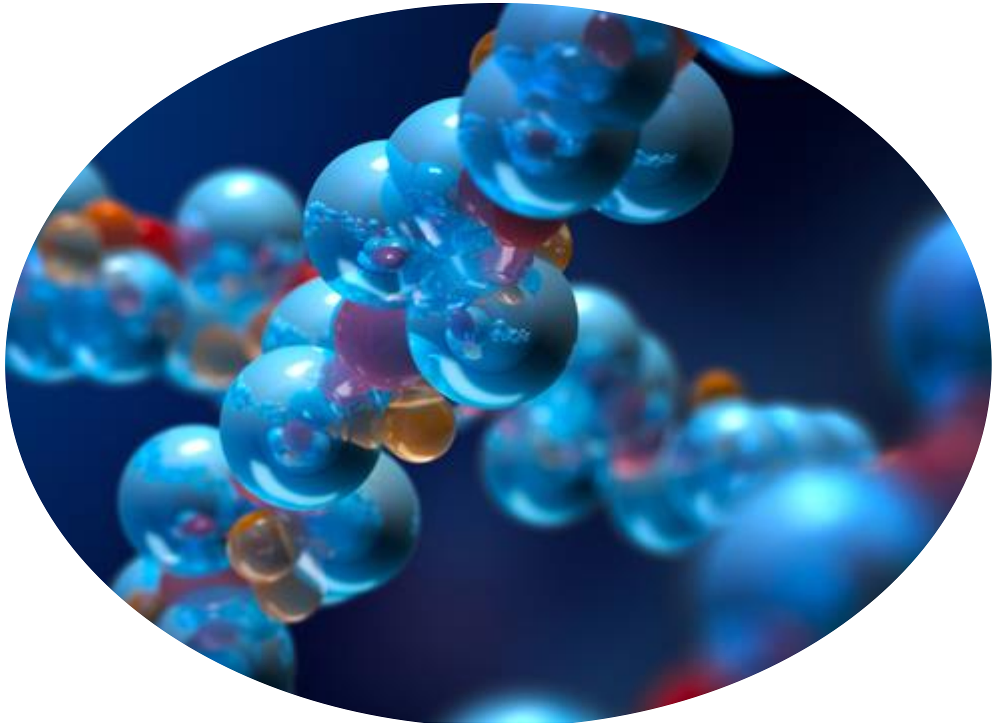
Global hydrogen and hydrogen-based fuels in IEA NZE 2021



Hydrogen Market Potential

Hypothetically, meeting replacing of the energy (~372 EJ) currently provided by fuels with hydrogen would require:

- 186 EJ of H2
- 1.3 billion metric tonnes H2
- 68000 TWh of electricity (with today's low-temperature electrolysis)
- 8.6 TW of electric capacity (if 90% capacity factor)

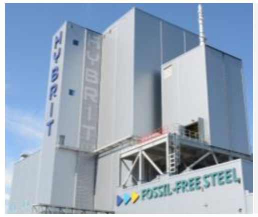


Hydrogen’s eventual role in full economy-wide decarbonization may be limited in scope, but it probably won’t be a niche role

Marine Vessels
1 B tpy CO_2
6 EJ H_2 @ 50%

Balancing
~ 1 B tpy CO_2
18 EJ H2 @ 10%

Heavy Trucking
~ 2 B tpy CO_2
13 EJ H_2 @ 50%



Ironmaking
~ 2 B tpy CO_2
6 EJ H_2 @ 50%

Aviation
~ 1 B tpy CO_2
6 EJ H_2 @ 40%

Process Heat
~ 2 B tpy CO_2
10 EJ H_2 @ 25%

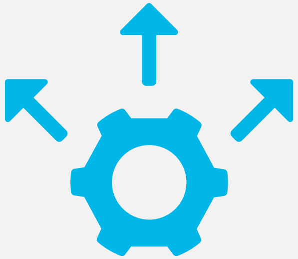
NOTES ON HYDROGEN DEMAND: Except for power system balancing, CO2 values represent approximate current total global emissions from the indicated activity and EJ values illustrate potential H2 demand assuming the stated % of current demand is replaced with hydrogen. Power system balancing CO2 represents potential CO2 if assumed balancing energy was provide by natural gas. Total potential demand total ~70 EJ including ~5 EJ from building heating (~10% today’s demand) and ~5 EJ from ammonia fertilizer production. Marine fraction reflects bulker and containership fraction of current marine fuel consumption. Trucking fraction reflects current fuel consumed in US on trips more than 300 km from base. Aviation fraction reflects half of fuel currently consumed on trips more than1500 km. Process heat fraction assumes electrification and CCS apply to 75% of fuel consumption. Ironmaking fraction assumes CCS and hydrogen split current market size. 1.5%/yr growth suggests >100 EJ/yr could be needed by 2050. All values intended for illustration only.

Zero-Carbon Fuels Challenges

- The key challenges for zero-carbon fuels are costs, infrastructure development and markets.
- Costs are currently too high to compete with incumbent high-emitting fuels without public policy support.
- Reductions in costs will require large-scale deployment through markets that recognize the greenhouse gas benefits of these fuels.
- Other challenges include the lack of an attractive ecosystem for financing and investing in zero-carbon fuels projects.
- Fuel switching for industrial players will come with significant cost challenges just for energy inputs.
- Low-carbon fuel adoption represents a substantial increase in fuel price compared to natural gas, ultimately increasing production costs. Electricity, however, appears to be even higher cost.

Zero-Carbon Fuels

Reduced Cost



Wide Deployment

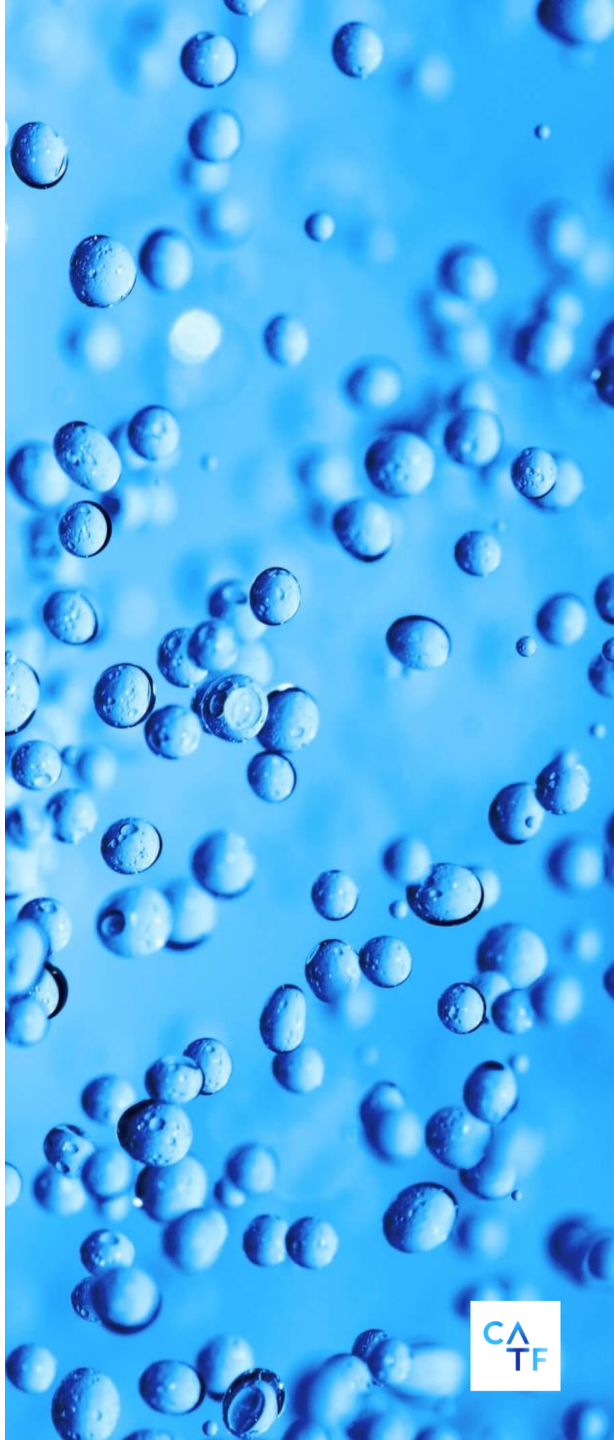
Meeting Hydrogen Demand Requires
Coordinated Public- and Private-Sector Action

We need lots of zero/low-carbon hydrogen if we want to fully decarbonize the global economy, we need it soon, and we need it to be competitively priced.

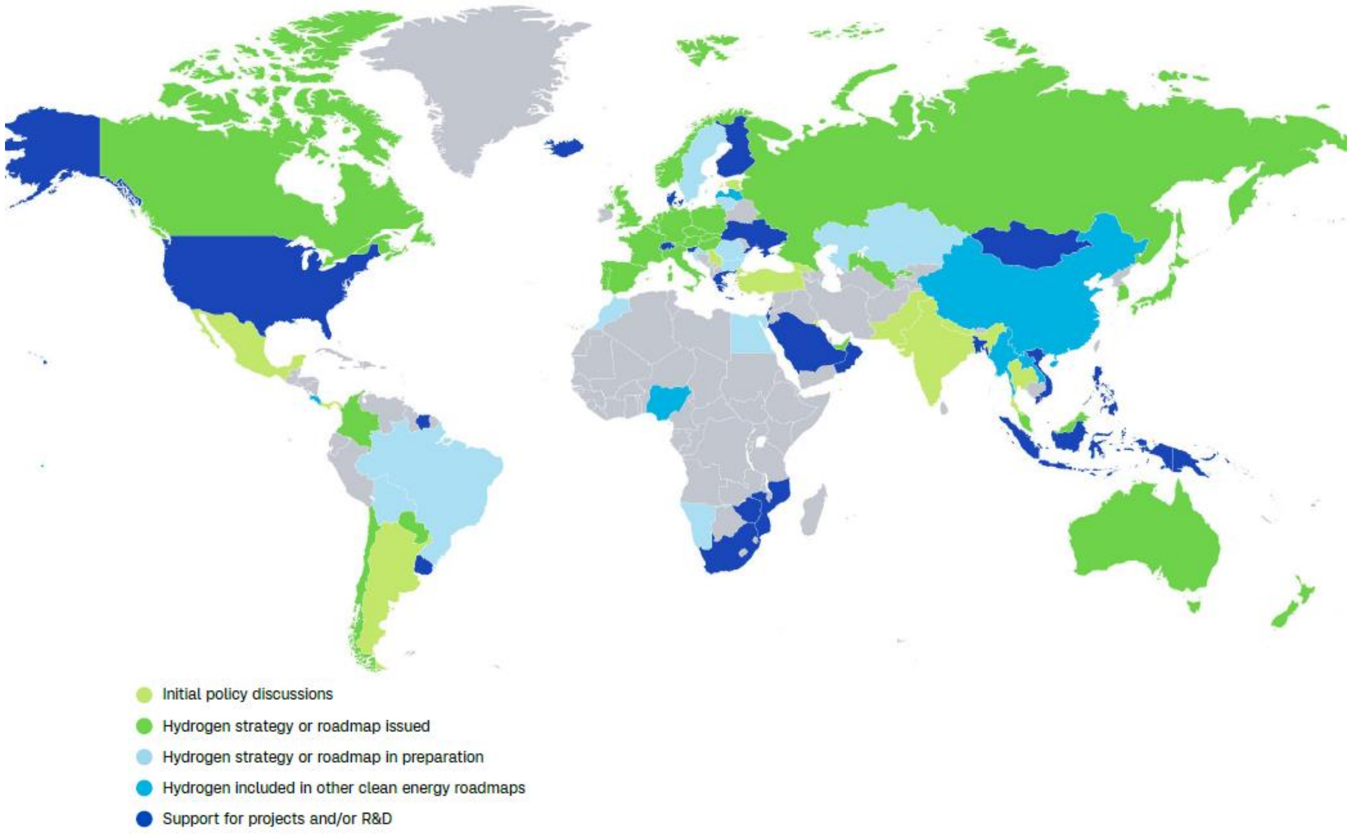
Achieving all that requires public- and private-sector investment in:

- **A range of decarbonized production technologies** including renewable- and nuclear-based electrolysis and natural gas reforming with carbon capture and storage systems.
- Pipelines and other c**onnective infrastructure.**
- **Fueling infrastructure** like hydrogen truck fueling depots and ammonia bunkering.
- **Zero-emission end-use applications** like fuel-cells, ammonia-fueled engines, and hydrogen-fueled turbines and process heaters.

Developing and deploying a sufficient volume of clean and affordable hydrogen fuels will also require leadership, oversight, and resources from the public sector.



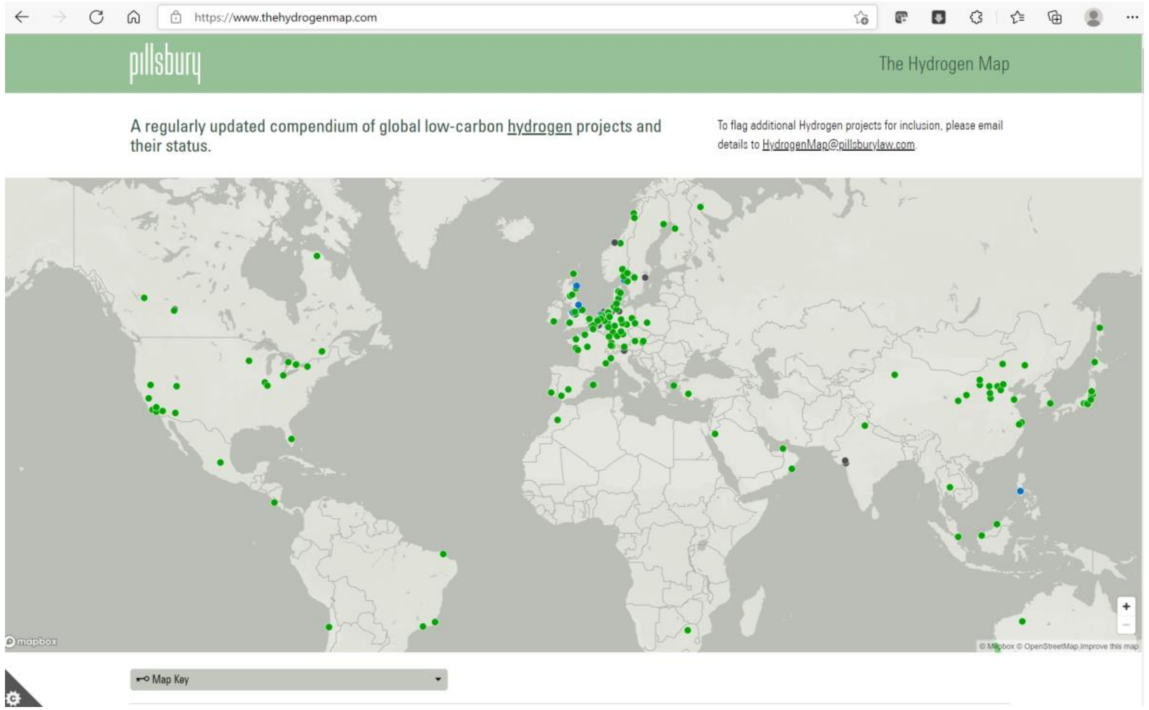
Nuclear Hydrogen - Policy Drives Projects



National Hydrogen Strategies as of June 2022:
https://nuclear-hydrogen.org/

Over 200 low and zero carbon H2 projects globally under development

https://www.thehydrogenmap.com



Highlights and Policies in the United States

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Emerging U.S. Hydrogen Hub Regions

Northeast
New York, New Jersey, Massachusetts, Connecticut

WISHH (Mountain Region)
New Mexico, Wyoming, Utah, Colorado

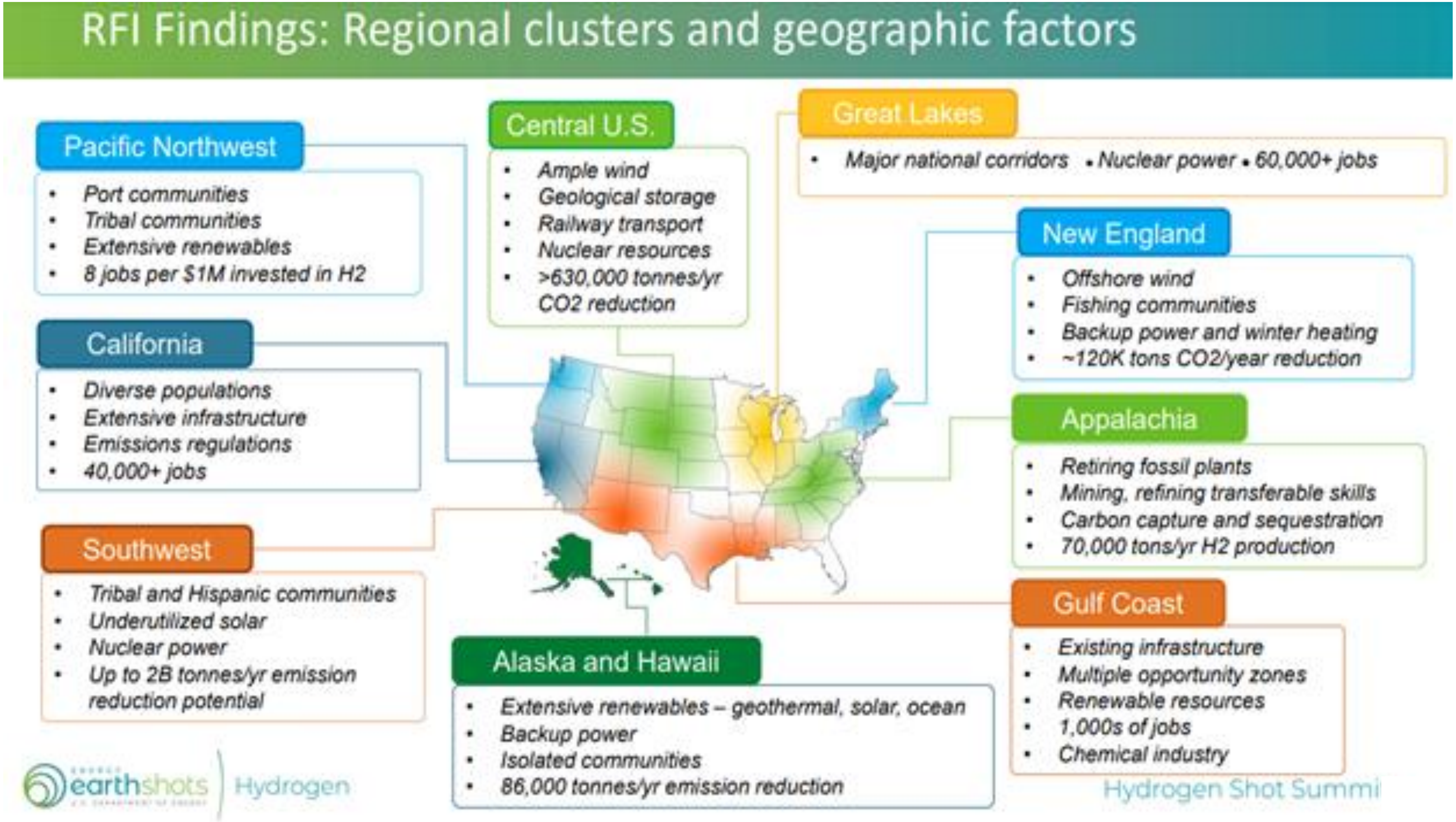
Appalachian Region
Pennsylvania, Ohio, West Virginia

North & South Carolina

Los Angeles, California

Houston, Texas

Southern & Gulf Coast Region - HALO
Louisiana, Oklahoma, Arkansas


RFI Findings: Regional clusters and geographic factors
Pacific Northwest
Port communities
Tribal communities
Extensive renewables
8 jobs per $1M invested in H2
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 CO2 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 CO2/year reduction
Appalachia
Retiring fossil plants
Mining, refining transferable skills
Carbon capture and sequestration
70,000 tons/yr H2 production
Gulf Coast
Existing infrastructure
Multiple opportunity zones
Renewable resources
1,000s of jobs
Chemical industry
earthshots
Hydrogen
Hydrogen Shot Summi

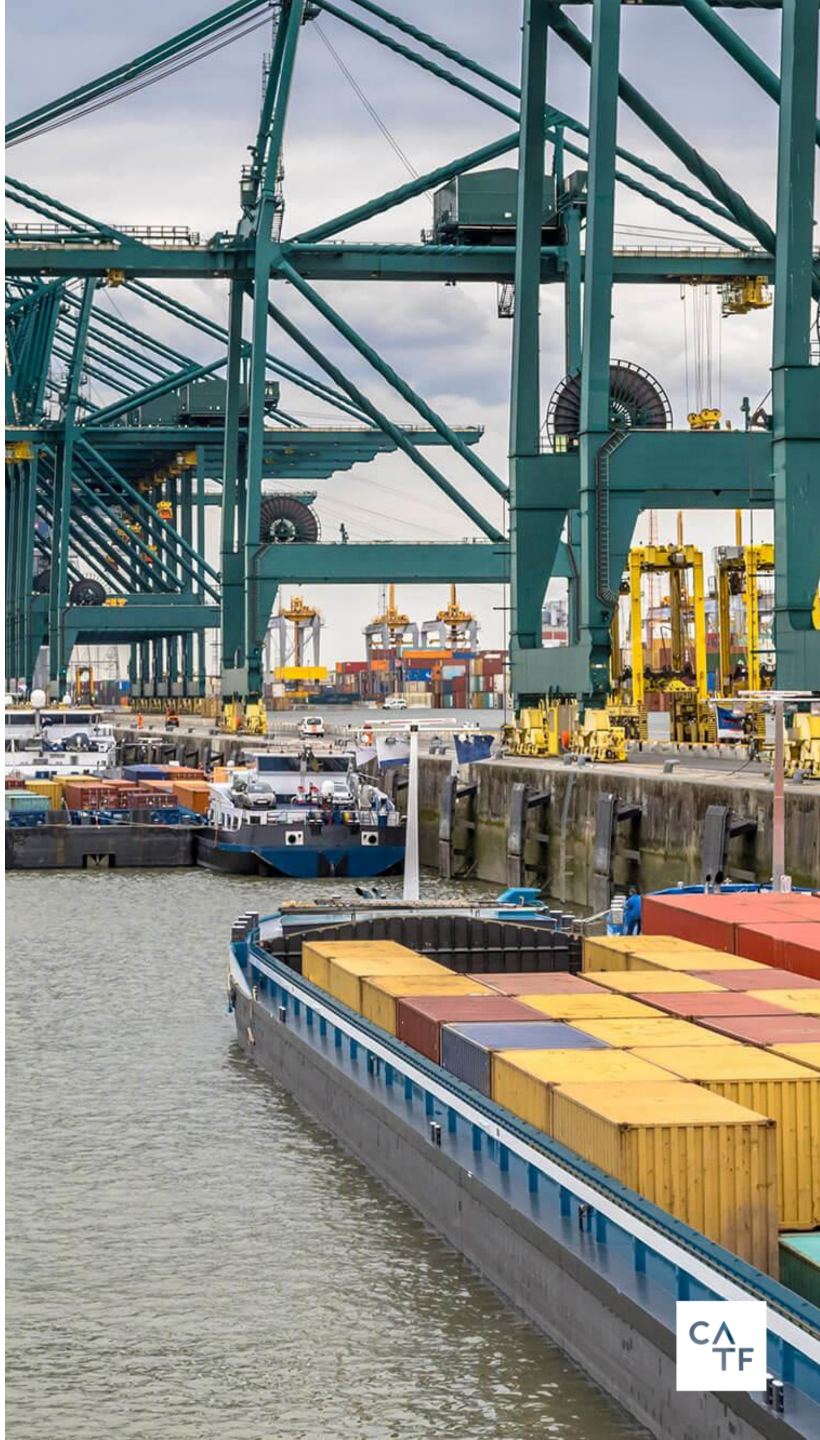
Transportation as a Key End-Use Sector

The global transportation decarbonization challenge

25% **Roughly 25% of global warming pollution comes from vehicles.**

Electrification can eliminate much of that pollution, but **many vehicles will be difficult or impossible to power with batteries**—including marine vessels, aircraft, and long-haul freight trucks that could account for approximately one-quarter of future transportation sector energy demand.

Unless zero-carbon fuels are produced at massive scale and ZCF-powered vehicles are developed and deployed around the world in massive numbers, we cannot fully eliminate GHG emissions from the transportation sector.



Thank you

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