DOE Regional Clean Hydrogen Hubs Program (H2Hubs)

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Brattle

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Regional Clean Hydrogen Hubs (H2Hubs)

Department of Energy (DOE) Regional Clean Hydrogen Program (H2Hubs)

In 2021, Congress approved the Bipartisan Infrastructure Law, which appropriated $8 billion in funding to the DOE for awards to between six and 10 Hydrogen Hubs that will contribute to a decarbonized and sustainable economy.

Overview:

- Hydrogen Hubs are intended to create capabilities for all stages of a H_2 supply chain, including production, processing, delivery, storage, and end use
- Awards are intended for networks of clean H_2 producers and consumers, and the infrastructure connecting the two

Requirements:

- DOE was required by law to select hubs such that, together, meet the following requirements:
  1. Produce hydrogen from renewable, fossil fuels with carbon capture and storage (CCS), and nuclear
  2. Serve power generation, industrial, heating, and transportation end users
  3. Have geographic diversity
  4. At least two hubs must be located in natural gas producing regions
  5. Create employment opportunities

Timeline:

- Projects were selected in Fall 2023
- DOE expects project execution over 8–12 years

Applicant Hubs:

- **Northeast:** CT, NY, NJ, ME, RI, VT, and MA to compete jointly for a $1.25 billion of DOE funding. Hub will focus on clean electrolytic production for hard to decarbonize sectors – i.e., transportation and heavy industry
- **California:** State-wide hub application led by the Alliance for Renewable Clean Hydrogen Energy Systems
- **Texas:** Three hub proposals – Gulf Coast Hydrogen Transition Hub, HyVelocity Hub, Corpus Christi Horizons Clean Hydrogen Hub
- 21 projects total, including the five above, were encouraged to and submitted full applications to the DOE

Selected Clean Hydrogen Hubs

On October 13, 2023 the US government announced the decision to allocate $7 billion in DOE funds to seven Clean Hydrogen Hubs, plus $1 billion for hydrogen demand-side initiatives within the hubs. $40 billion in private funds will increase total H2Hubs investments to almost **$50 billion**.

Selected Hydrogen Hubs are:

1. Appalachian Hydrogen Hub (West Virginia, Ohio, Pennsylvania)
2. California Hydrogen Hub (California)
3. Gulf Coast Hydrogen Hub (Texas, Southwest Louisiana)
4. Heartland Hydrogen Hub (Minnesota, North Dakota, South Dakota, Wisconsin)
5. Mid-Atlantic Hydrogen Hub (Pennsylvania, Delaware, New Jersey)
6. Midwest Hydrogen Hub (Illinois, Indiana, Michigan)
7. Pacific Northwest Hydrogen Hub (Washington, Oregon, Montana)

The hubs involve a mix of **green** (solar, wind), **blue** (natural gas + carbon capture), and **pink** (nuclear) hydrogen and target a wide range of end-use sectors.

Selected Regional Clean Hydrogen Hubs

Source: US Energy Dept., Office of Clean Energy Demonstrations.

Note: Individual Hydrogen Hub applications were not made publicly available. The information in this presentation is based on details disclosed by DOE and the selected hubs thus far. The amount and type of available information varies by hub.

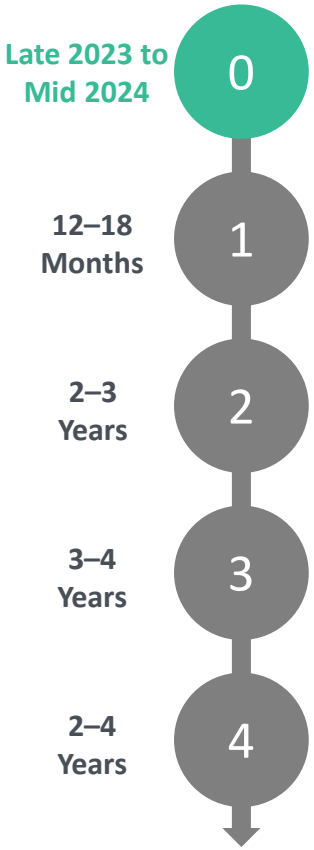
Overview of Selected Hubs

DOE Project Name	Selectee Name	States	Type of H_2	DOE Funds	Target Sectors
Appalachian Hydrogen Hub	Appalachian Regional Clean Hydrogen Hub (ARCH2)	WV, OH, PA	Green, Blue, Biohydrogen	$925 million	Ammonia, chemicals, industrial, heavy-duty transport, mining, data centers, distribution centers, Sustainable aviation fuel (SAF), gas utility blending, residential fuel cells
California Hydrogen Hub	Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)	CA	Green, Biohydrogen	$1.2 billion	Heavy duty-transport, power generation, port operations
Gulf Coast Hydrogen Hub	HyVelocity H2 Hub	TX, LA	Green, Pink, Blue	$1.2 billion	Ammonia, refining and petrochemicals, industrial, heavy-duty transport, transit authorities, ports, SAF, marine fuel (eMethanol), power generation
Heartland Hydrogen Hub	Heartland Hydrogen Hub (HH2H)	MT, ND, SD, MN, WI	Green, Pink, Blue	$925 million	Fertilizer, industrial, SAF, power generation, gas LDC blending
Mid-Atlantic Hydrogen Hub	Mid-Atlantic Clean Hydrogen Hub (MACH2)	PA, DE, NJ	Green, Pink, Blue	$750 million	Industrial, refineries, heavy-duty transportation, transit authorities
Midwest Hydrogen Hub	Midwest Alliance for Clean Hydrogen (MachH2)	IL, IN, MI	Green, Pink, Blue	$1 billion	Agriculture, industrial, manufacturing, heavy-duty transportation, SAF, gas utility blending
Pacific Northwest Hydrogen Hub	Pacific Northwest Hydrogen Hub (PNWH2 Hub)	WA, OR, MT	Green	$1 billion	Fertilizer, refiners, industrial, heavy-duty transport, SAF, marine fuel, long-duration energy storage

Notes: States based on information provided by selectee hubs.

H2Hubs Development Phases

After the selected hubs complete their negotiations with the Department of Energy, each Hydrogen Hub will undergo a four stage process to achieve full operations. Initially, DOE will only authorize funds through Phase 1. Funding for each additional phase is contingent upon meeting deliverables in each phase.



Selected hubs and DOE begin negotiations on funding agreements

Initial planning and analysis activities to ensure that the overall H2Hub concept is technologically and financially viable, with input from local stakeholders

Finalize engineering designs and business development, site access, labor agreements, permitting, offtake agreements, and community engagement activities

Implementation activities necessary to begin installation, integration, and construction activities

Ramp-up hubs to full operations, including data collaboration to analyze each hub's operations, performance, and financial viability

Source: DOE

H2Hubs Community Benefits Plans

Each Hydrogen Hub was required to submit a Community Benefits Plan that lays out strategies to achieve four core policy priorities:

- Engage communities and labor
- Invest in America's workforce
- Advance diversity, equity, inclusion, and accessibility (DEIA)
- Flow 40% of the benefits from projects to disadvantaged communities (Justice40 Initiative)

The Community Benefits Plans must:

- Demonstrate actionable goals, outcomes, and implementation steps supported by adequate money, people, and time resources
- Include mechanisms for accountability and transparency with impacted community
- Propose clear metrics to measure success
- Robustly address four core policy priorities
- Minimize and mitigate negative impacts and harm, especially to overburdened communities
- Create quality jobs, equitable access, and investment in workforce development
- Evolve to incorporate community and worker feedback
- Build towards lasting and enforceable community and labor agreements

Source: DOE OCED, Guidance for Creating a Community Benefits Plan for the Regional Clean Hydrogen Hubs, October 2022.

Key Observations (1/3)

1

What is the expected timeline for H2Hub development?

- H2Hubs will take over a decade to fully develop and the exact pace will depend on each hub meeting yet-to-be-disclosed milestones
- Hubs with existing H_2 infrastructure and operational experience (e.g., Gulf Coast and Mid-Atlantic) will likely develop first

2

How much hydrogen are these hubs expected to produce?

- Based on disclosed production estimates, H2Hubs will increase US H_2 production from 10 million metric tons per year (mtpy) to over 30 million mtpy by 2045
- California Hydrogen Hub is expected to be the largest H_2 hub with a forecasted production of 17 million mtpy of green H_2 by 2045. We estimate this will require approx. 291 GW of renewable generation to achieve.[1] In comparison, California's current installed generation capacity of 84.6 GW, of which 24.3 GW is solar or wind

3

What types of hydrogen are these hubs expected to produce?

- The hubs will produce a mix of electrolytic H_2 from solar, wind (on and offshore), nuclear, and hydro power as well as reformation-based H_2 with carbon capture from natural gas and RNG
- Pink hydrogen will be produced at nuclear plants in the Mid-Atlantic (Salem, Oyster Creek [small modular reactor]), Heartland (Monticello), Midwest (Braidwood), and Gulf Coast (not specified) hubs. The identified nuclear plants have an average remaining operating license of about 17 years; Mid-Atlantic hub indicated H_2 production volumes are too small to materially impact future extension decisions

1: Assumes a projected electrolyzer efficiency of 45 kWh/kg of H_2 and a 30% load factor. Current electrolyzers consume approximately 50% more power.

Key Observations (2/3)

4

Will these H2Hubs build new pipeline infrastructure?

- Hubs aim to build new pure H_2 pipeline backbones using existing right-of-ways to minimize community impacts and reduce cost of delivered H_2. Clarification on state and federal regulation of H_2 pipelines will be required
- Hubs producing blue H_2 (Appalachia, Gulf Coast, Heartland, Mid-Atlantic, and Midwest) will require new CO_2 pipelines to sequester carbon in geological formations; opportunities to use existing CO_2 pipelines may exist

5

How do the hubs plan to store excess hydrogen?

- Appalachian and Gulf Coast hubs will leverage valuable salt dome caverns, which can store large volumes of H_2 and provide flexible cycling capabilities
- Other hubs need to rely on other storage technologies, like small-scale short-duration storage tanks (California) or linepack (Mid-Atlantic). Advances in H_2 storage technologies may unlock additional opportunities

6

Which end-use sectors do these H2Hubs target?

- Nearly all disclosed H_2 projects are focused on hard-to-abate industries, such as heavy-duty transport, industrial demand, chemicals, sustainable aviation fuel (SAF), and marine (port operations, eMethanol fuels)
- Despite legal requirement of the H2Hub initiative, H_2 blending into gas distribution systems only featured in Appalachian (Hope Gas), Midwest (Nicor Gas), and Heartland (Xcel Energy). Other hubs (Mid-Atlantic, Pacific Northwest) state distribution blending is not an area of focus. In contrast, about 30 gas utilities have announced H_2 blending pilots separate from DOE's H2Hubs initiative

Key Observations (3/3)

7

What emission reductions are these hubs expected to provide?

- While the debate about emissions accounting rules for H_2 production is ongoing, the DOE requires each hub to pass a lifecycle analysis for carbon emissions and criteria pollutants (e.g., NO_X, SO_X)
- Together, the H2Hubs are expected to reduce GHG emissions by 25 million mtpy, an amount roughly equivalent to combined annual emissions of 5.5 million gasoline-powered cars. This is also equivalent to 0.4% of US emissions in 2021 (5,586 million metric tons CO_2e)

8

What other community benefits will the hubs provide?

- Selected hubs are investing nearly $50 billion to develop hubs in selected regions
- H2Hubs are expected to create approximately 221,000 temporary jobs and 112,000 permanent jobs
- The hubs are investing in education and job training programs, partnering with labor, universities, K-12, and tribal communities

Overview of Selected Hubs

Appalachian Hydrogen Hub

Overview

Appalachian Hydrogen Hub (ARCH2), centered in the nation's second-largest natural gas-producing region, was awarded up to up to **$925 million** of federal funding.

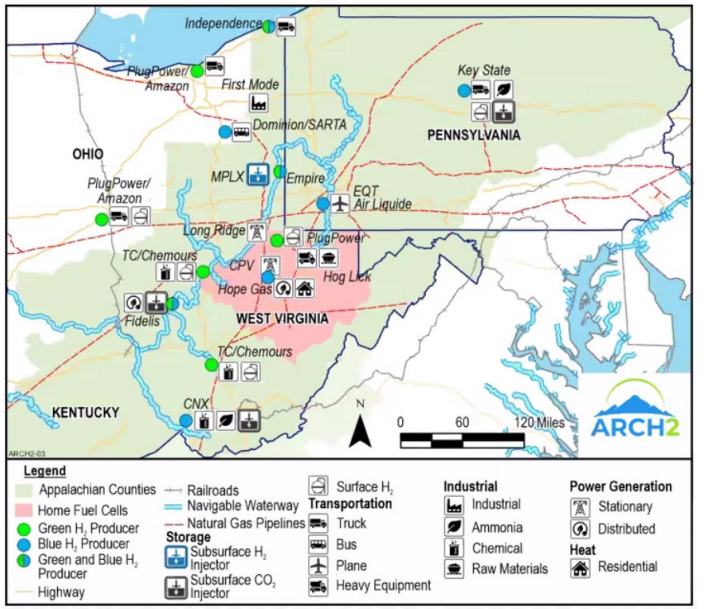
H_2 Production

The hub will take advantage of the states' access to renewable power and natural gas supplies to produce:

- **Green hydrogen**
- **Blue hydrogen** using auto thermal reformation. CO_2 will be permanently stored locally
- Biohydrogen (from anaerobically digested food waste)

H_2 Infrastructure

- Hydrogen will be transported within the hub via dedicated pipelines
- MPLX is building a hydrogen storage facility (underground salt cavern) in eastern Ohio
- Minimal CO_2 pipeline infrastructure, sequestration caverns located close to source



Source: ARCH2

End-Use Sectors

The hub has 15 identified projects targeting:

- NH_3 production for fertilizer
- Sustainable aviation fuel (SAF) production
- Boilers at chemical production facilities
- Hydrogen-powered mining trucks and heavy duty vehicles
- Powering data centers, material handling, and distribution centers
- Gas distribution system blending (Hope Gas)
- Residential fuel cells

Benefits

ARCH2 is committed to:

- Reduce emissions by 9 million $MTCO_2$ per year
- Create 18,000 jobs in construction and 3,000 permanent jobs
- Partner with labor, business development/ industry organizations, community/ environment nonprofits, academia, and government

California Hydrogen Hub

Overview

California Hydrogen Hub (ARCHES) – a statewide public-private partnership to build the framework for California's renewable clean hydrogen hub – was awarded up to **$1.2 billion** of federal funding.

H_2 Production

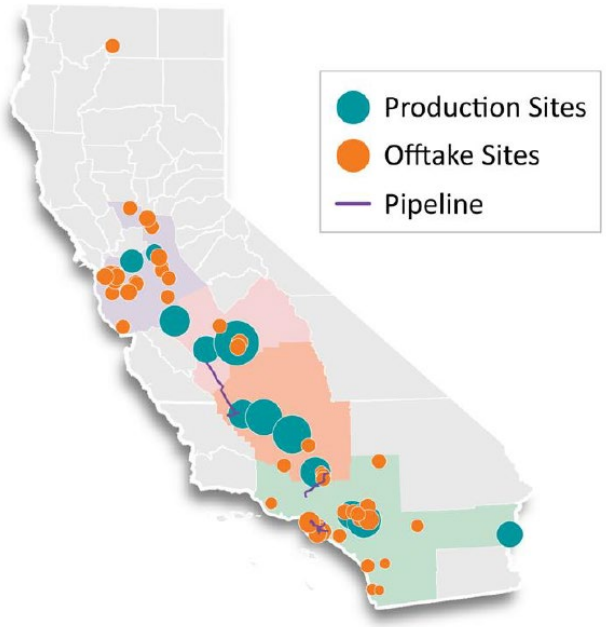
The hub will produce:

- **Green hydrogen** from solar, wind, and hydro
- Biohydrogen from biogenic sources (woody biomass, municipal waste, etc.)

Hub will produce 6,820 mtpy in 2023, primarily in the Central Valley, with a goal of ramping to 17 million mtpy by 2045.

H_2 Infrastructure

- The hub will transport hydrogen via 165 miles of pure hydrogen pipelines and liquid hydrogen trucks (powered with fuel cells)
- The hub will also develop short-term, small-scale storage facilities



Source: ARCHES

End-Use Sectors

The hub identified 39 Tier 1 projects that are included in DOE proposal targeting hard-to-abate sectors. 31 Tier 2 projects will be developed without DOE funding. ARCHES is targeting:

- Heavy-duty trucking (252 mtpy)
- Power (200 mtpy)
- Port operations (63 mtpy)

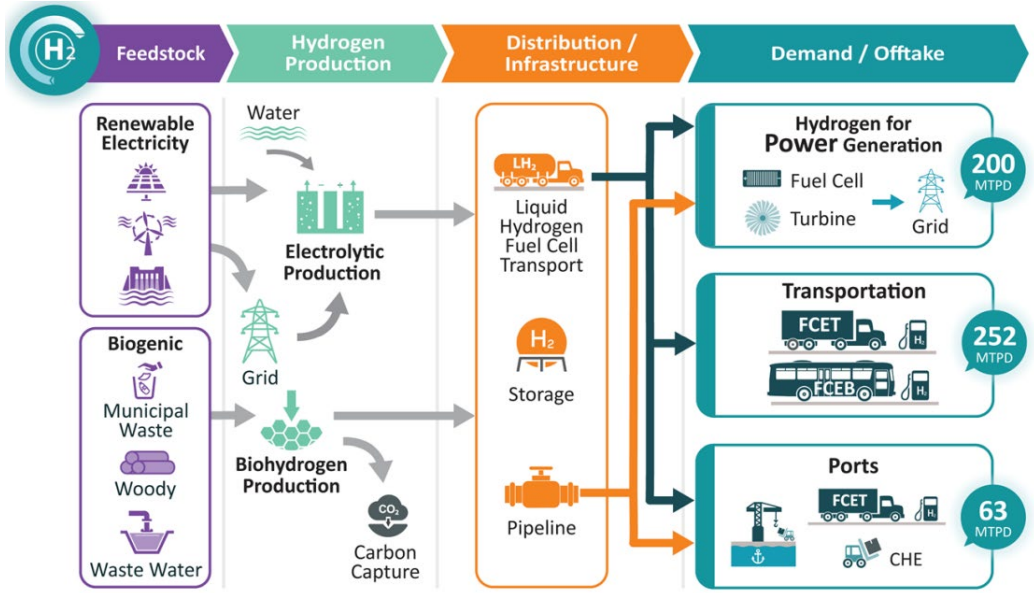
Offtake sites primarily located in central and southern California.

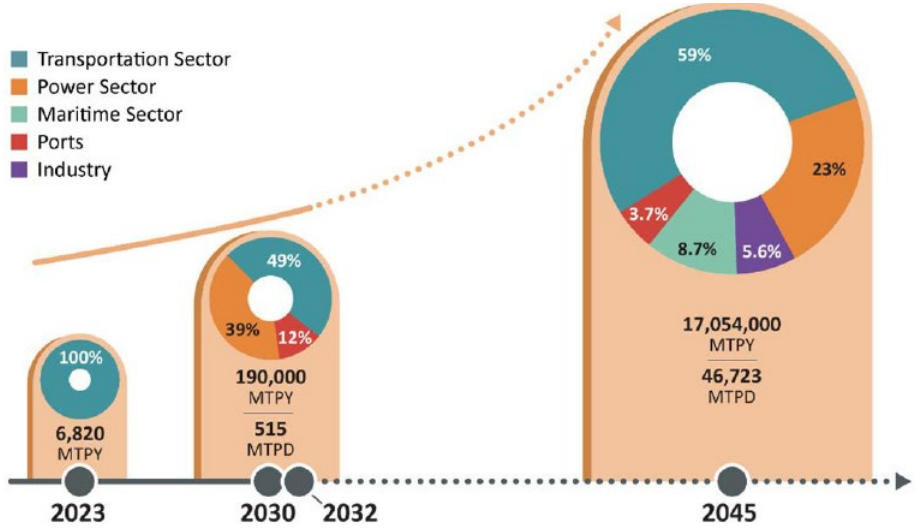
Benefits

ARCHES is committed to:

- Reduce emissions by 2 million $MTCO_2$ per year
- $2.95 billion per year in economic value from health benefits
- Create 222,400 jobs, including 130,000 in construction and 90,000 permanent jobs
- $380 million invested in community benefits and workforce development

California Hydrogen Hub By the Numbers





COMMUNITY

▲ $2.95 billion	Economic value of increased health* and associated health costs savings per year
▲ 222,400	Number of jobs created
▼ 2,097	Fewer hospitalizations for respiratory & cardiac illness per year
▼ 13,292	Fewer work loss days per year
▼ 6,900	Nitrogen oxide net emissions avoided MTPY
▼ 239	Sulfer dioxide net emissions avoided MTPY
▼ 326 PM 2.5, 10	Particulate matter net emissions avoided MTPY
▼ 48	Fewer premature deaths per year
▲ $380 million	Invested in community benefits & workforce development

** Reduced premature death, asthma, cancer risk, missed work days*

DEPLOYMENT

Average delivered H_2 cost to end use kg

$7.65 w/o any PTC — $5.04 with PTC & LCFS

165	Miles of new H_2 pipeline (30 existing)
~5,500 FCET	Class 6 & 8 trucks
-0.15 $kgCO_2/KgH_2$	Average life-cycle carbon intensity
1,080 FCEB	Transit buses
Heavy-duty HRS: 66 Public / 24 Private/ Transit	
232	Port cargo handling equipment

Source: ARCHES

Gulf Coast Hydrogen Hub

Overview

The Gulf Coast Hydrogen Hub (HyVelocity H2Hub) will leverage the existing hydrogen infrastructure along the Gulf Coast, which currently accounts for 33% of current US hydrogen production. The hub was awarded up to **$1.2 billion** of federal funding.

HyVelocity has an additional **$10 billion** in private funding.

End-Use Sectors

Nine projects are spread out across four target areas (Texas Triangle, Beaumont/ Lake Charles, Houston, and Corpus Christi), serving:

- Ammonia production
- Transport (heavy-duty vehicles, ports, transit agencies)
- Refining and petrochemicals
- Industrial demand
- Power generation
- Aviation (SAF) and marine (eMethanol) fuel

H_2 Production

The hub will take advantage of the region's energy supplies to produce:

- **Green hydrogen** using solar, onshore and offshore wind
- **Pink hydrogen** using nuclear power
- **Blue hydrogen** using RNG and natural gas

Production is expected to reach 5,000 mtpd.

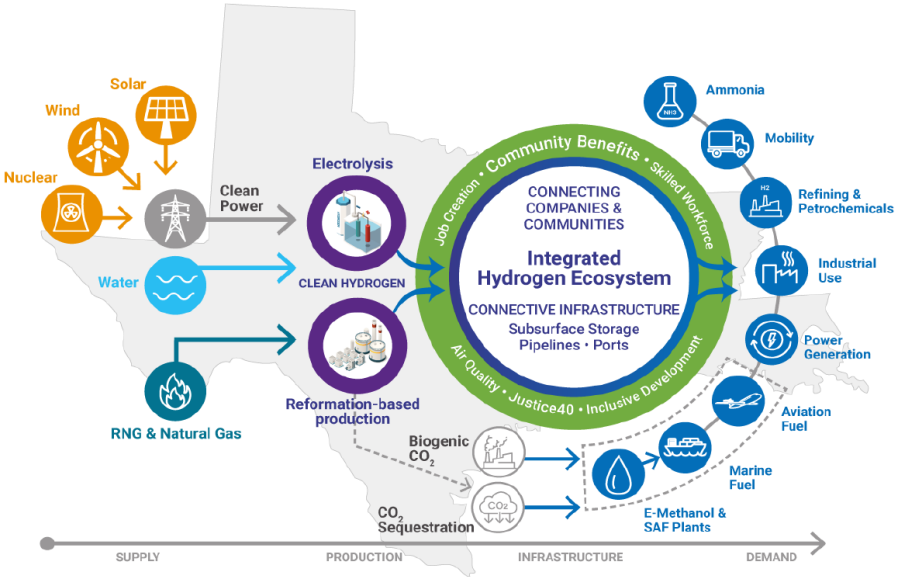
Benefits

HyVelocity H2Hub expects to:

- Reduce emissions by 7 million $MTCO_2$ per year
- Create 45,000 jobs, including 35,000 in construction and 10,000 permanent jobs
- Provide $120 million in Community Benefits Plan funding

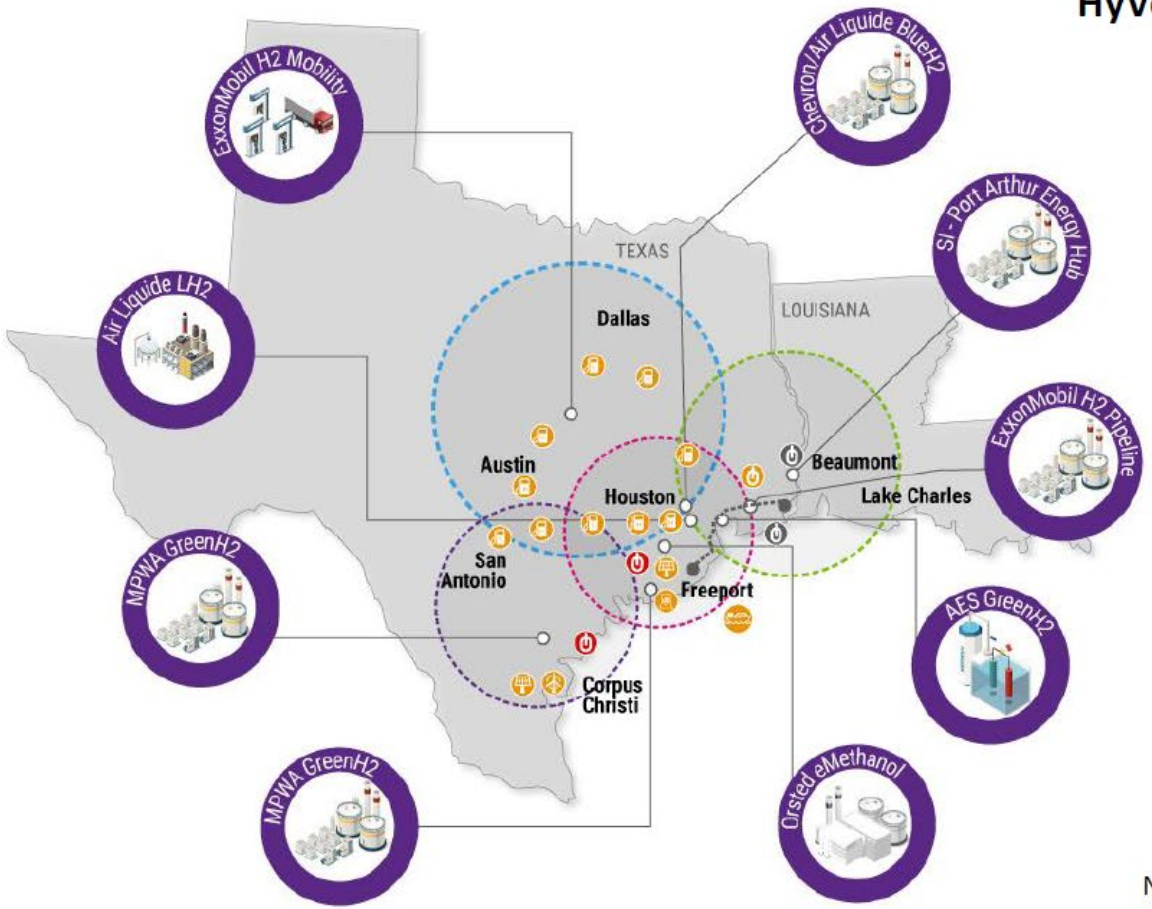
H_2 Infrastructure

- The hub will leverage the Gulf Coast's existing infrastructure: 1,000+ miles of H_2 pipelines and three of the six H_2 storage caverns in the world
- ExxonMobil will build an open-access H_2 pipeline from production near Port Arthur to end users near Freeport, TX



Source: HyVelocity H2 Hub

Gulf Coast Hydrogen Hub Identified Projects



HyVelocity Clean H2 Production Capacity: >5,000 mtpd

- Corpus Christi Demand Cluster
- Houston Demand Cluster
- BPA-Lake Charles Demand Cluster
- TX Triangle Demand Cluster

HYVELOCITY HUB > INTEGRATED INFRASTRUCTURE

- Solar Farms
- Maritime
- Wind Farms
- H2 Fueling Stations
- CO2 Storage Cavern
- Nuclear
- H2 Storage Cavern
- Future H2 Pipelines
- Future H2 Storage Cavern
- HyVelocity Infrastructure Elements

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

Source: HyVelocity H2 Hub

Heartland Hydrogen Hub

Overview

The Heartland Hydrogen Hub (HH2H), which includes support from MT, ND, SD, MN, and WI, was awarded up to **$925 million** of federal funding.

Xcel will invest **$2 billion** of its own money over the next decade for the project.

End-Use Sectors

The hub is composed of three projects:

- **Prairie Horizon Energy Solutions** (Marathon and TC Energy): Produce green and blue H_2 for industrial end uses and low-carbon fertilizer production
- **Clean Energy H_2** (Xcel Energy): Produce green and pink H_2 for industrial demand, gas utility blending, power generation, and SAF
- **Wind to Ammonia** (Xcel Energy): Green H_2 used to produce ammonia, which will be mixed with biogenic CO_2 to produce fertilizer

H_2 Production

Heartland will produce:

- **Green hydrogen** using wind and solar
- **Pink hydrogen** using power from Xcel Energy's 600 MW Monticello Nuclear Plant
- **Blue hydrogen** using natural gas and RNG with carbon capture and sequestration

No specific production volumes provided.

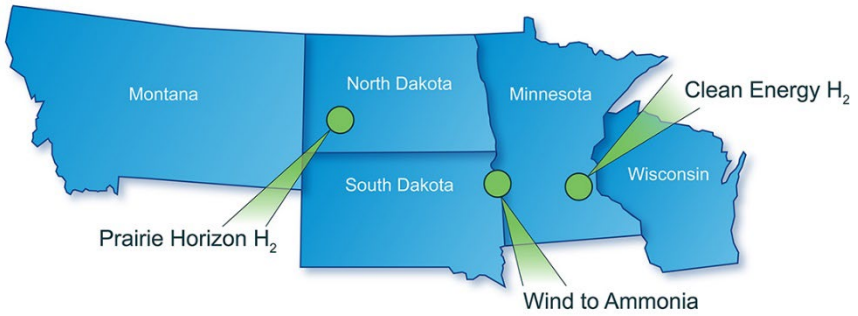
Benefits

HH2H is committed to:

- Reduce emissions by 1 million $MTCO_2$ per year
- Create 3,800 jobs
- Investments for education consortium, including K-12 education, community colleges, universities, and tribal colleges

H_2 Infrastructure

- HH2H will use local geological formations to store sequestered carbon
- The hub has not released information about hydrogen or ammonia pipeline and storage infrastructure



Source: HH2H

Mid-Atlantic Hydrogen Hub

Overview

The Mid-Atlantic Hydrogen Hub (MACH2) is designed to leverage the existing oil infrastructure and rights-of-way of the region to spur hydrogen development. The hub was awarded up to **$750 million** in federal funding.

End-Use Sectors

The hub is targeting existing hard-to-decarbonize demand in the region:

- Industrial demand (chemical, steel, cement, logistics)
- Refineries
- Heavy-duty transport and transit authorities

H_2 Production

The hub will produce:

- **Green hydrogen** using solar, onshore and offshore wind using a variety of electrolysis technologies
- **Pink hydrogen** using existing nuclear (Salem and Oyster Creek [SMR]) and proposed small modular reactor
- **Blue hydrogen** using methane from waster water facility

By 2032, production will reach 271 mtpd.

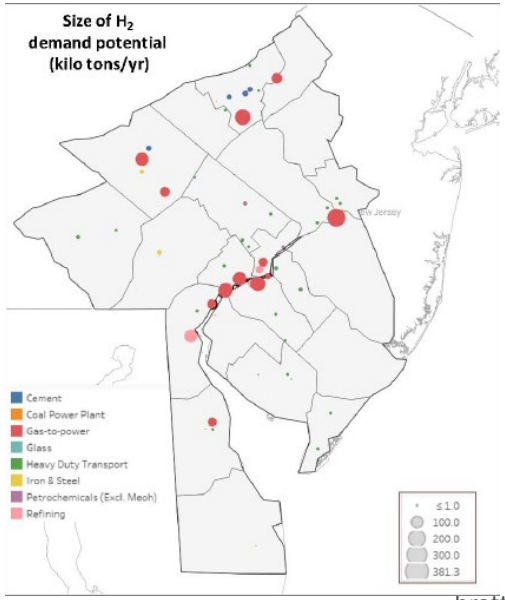
Benefits

MACH2 is committed to:

- Reduce emissions by 1 million $MTCO_2$ per year
- Create 20,800 jobs with 13,400 construction jobs
- $1.2 to $1.5 billion of project spending will take place in disadvantaged communities
- $24 million committed to workforce development

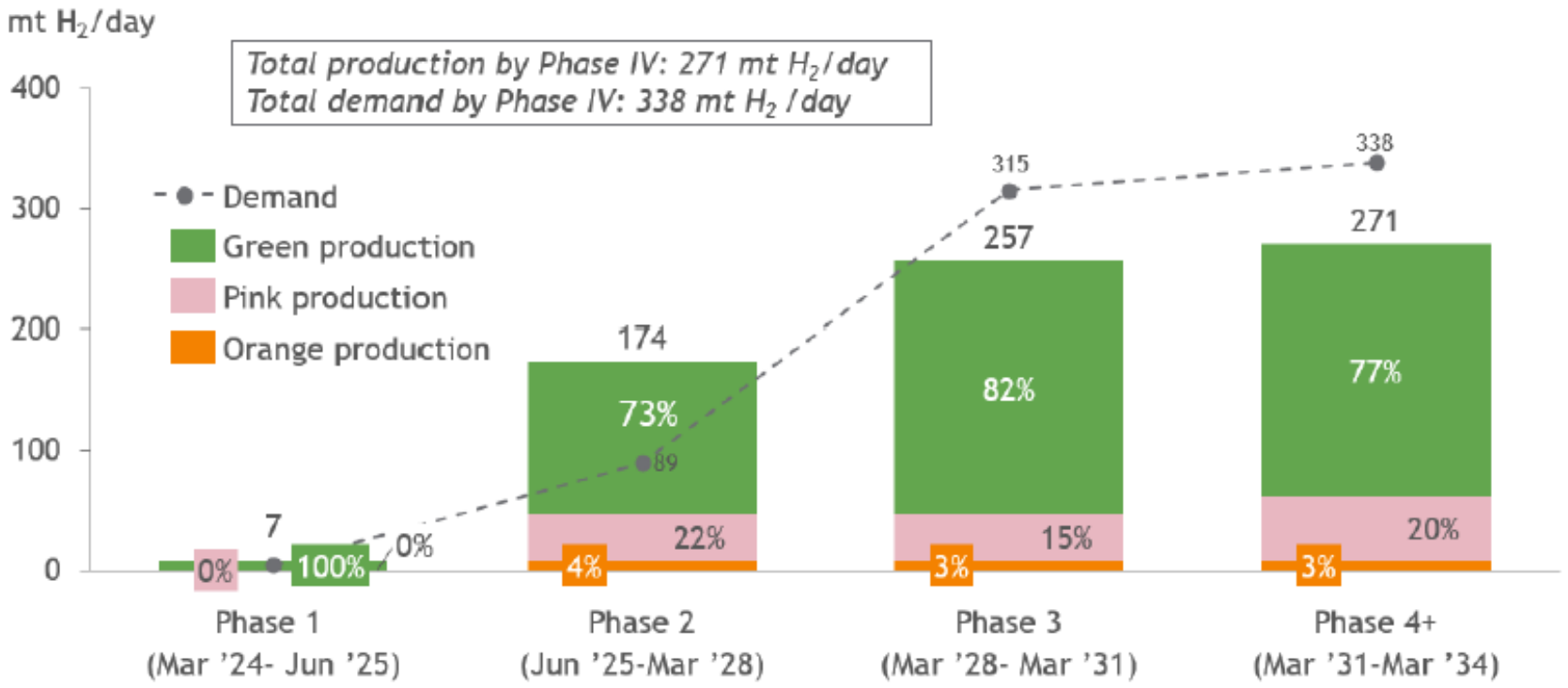
H_2 Infrastructure

- MACH2 will leveraging an existing hydrogen pipeline that moves gray H_2 between refineries
- The hub will repurpose existing oil pipelines by replacing them or sleeving an H_2 pipe inside to minimize right of way impacts and reduce cost of delivered H_2
- The hub will develop storage facilities as part of the delivery network



Source: MACH2

Mid-Atlantic Hydrogen Hub by the Numbers



Source: MACH2. According to the hub, Orange H_2 is produced from methane from wastewater treatment facilities using steam methane reformation and carbon capture.

Midwest Hydrogen Hub

Overview

The Midwest Hydrogen Hub (MachH2) aims to take advantage of the region's energy sources to produce H_2 from all three methods required by DOE. The hub was awarded up to **$1 billion** of federal funding.

End-Use Sectors

Hydrogen produced in the hub will be used to serve:

- Heavy-duty transportation and transit authorities
- Agriculture
- Industrial (steel, glass, and cement)
- Aviation (SAF)
- Gas distribution end users (Nicor Gas)

H_2 Production

The hub will produce:

- **Green hydrogen** via renewables at two project sites
- **Pink hydrogen** using nuclear at Constellation's 2,386 MW Braidwood Generating Station
- **Blue hydrogen** using natural gas with carbon capture and sequestration

No specific hydrogen volumes provided.

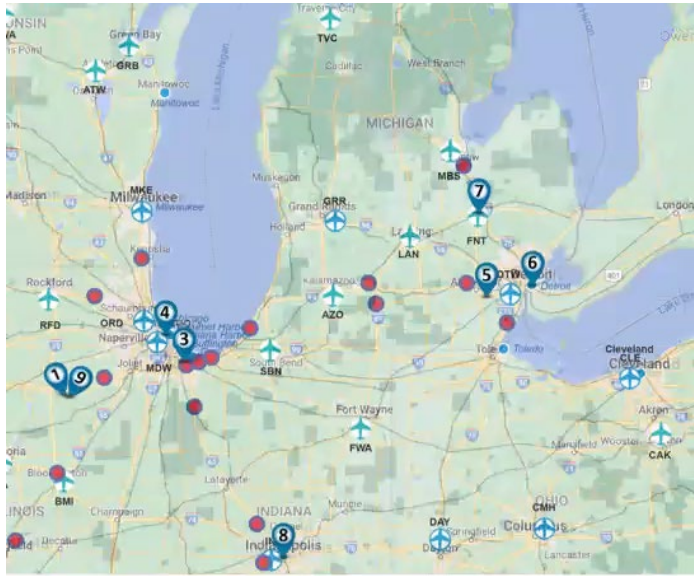
Benefits

MachH2 is committed to:

- Reduce emissions by 3.9 million $MTCO_2$ per year
- Create 13,600 jobs, including 1,500 permanent jobs and $15 million in job training initiatives
- Provide $30 million for H_2 startups

H_2 Infrastructure

- The hub will build new H_2 and CO_2 pipelines within the hub. Nicor Gas is investigating blending H_2 into its distribution system
- The hub is evaluating other methods to transport H_2, including truck, barge, and rail



Source: MachH2

Pacific Northwest Hydrogen Hub

Overview

The Pacific Northwest Hydrogen Hub (PNWH2 Hub), which spans WA, OR, and MT, was awarded up to **$1 billion** of federal funding.

Washington Governor Inslee directed the state to respond to DOE H2Hubs program. The Washington legislature passed SB5910 to support production and storage of H_2 to meet the state's energy and climate goals.

End-Use Sectors

The hub is centered around eight nodes, each with an anchor project and downstream projects. The hub is targeting:

- Long-duration energy storage
- Refiners
- Heavy-duty transport and transit authorities
- Aviation and marine fuel
- Industrial demand
- Fertilizer production

H_2 Production

The hub will produce:

- **Green hydrogen** exclusively from solar, wind, and hydro

No specific volume estimates provided.

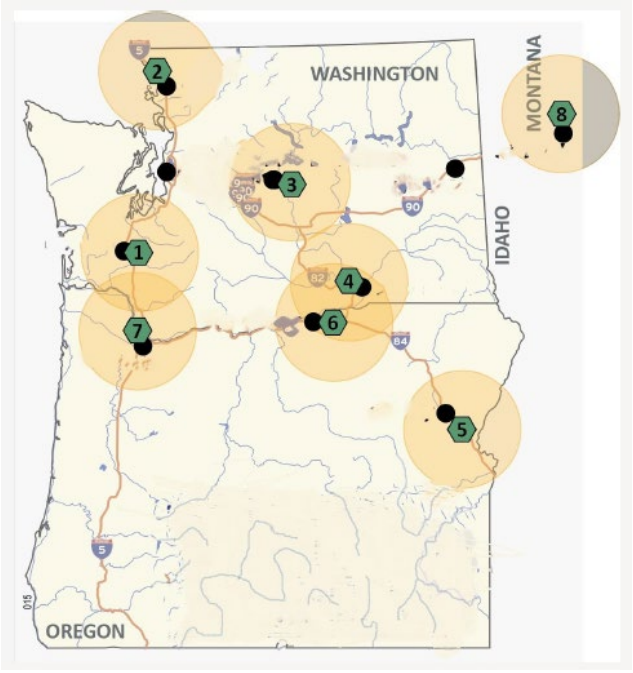
Benefits

PNWH2 Hub is committed to:

- Reduce emissions by 1.6 million $MTCO_2$ per year
- Engage tribal communities in the PNW
- Create 70,000 jobs in the region by 2030

H_2 Infrastructure

- The hub has not provided any details about pipeline or storage infrastructure



Source: Pacific Northwest Hydrogen Hub

Brattle's Hydrogen Expertise

Emissions

- Lifecycle emissions assessment
- Emissions accounting standards
- Impact of H_2 hubs on state/regional emissions

Technological

- Impacts on power system from electrolyzer demand (flexible/ fixed)
- The value of H_2 as a clean firm, dispatchable generation resource
- Analyzing optimal hydrogen operations

Regulatory

- H_2 pipeline and storage siting and safety regulations
- H_2 procurement and risk management reviews
- Rate base and customer bill impacts
- Regulatory due diligence

Economics

- Impact of Inflation Reduction Act tax incentives (and their planned sunset in early 2030s)
- Regional H_2 market dynamics
- Economics of potential end-use pathways
- Economic impact assessments

Contracting

- Structure of H_2 offtake contracts

Markets

- Evolution of hydrogen markets – location, demand, type

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- Electricity Litigation & Regulatory Disputes
- Electricity Wholesale Markets & Planning
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- Financial Institutions
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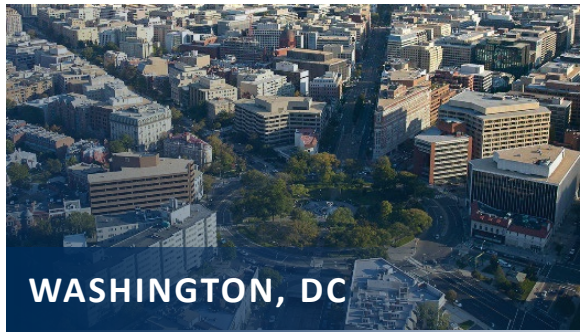

Brattle

Clarity in the face of complexity

Brattle