CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

Update on DOE H2 Hub Initiative

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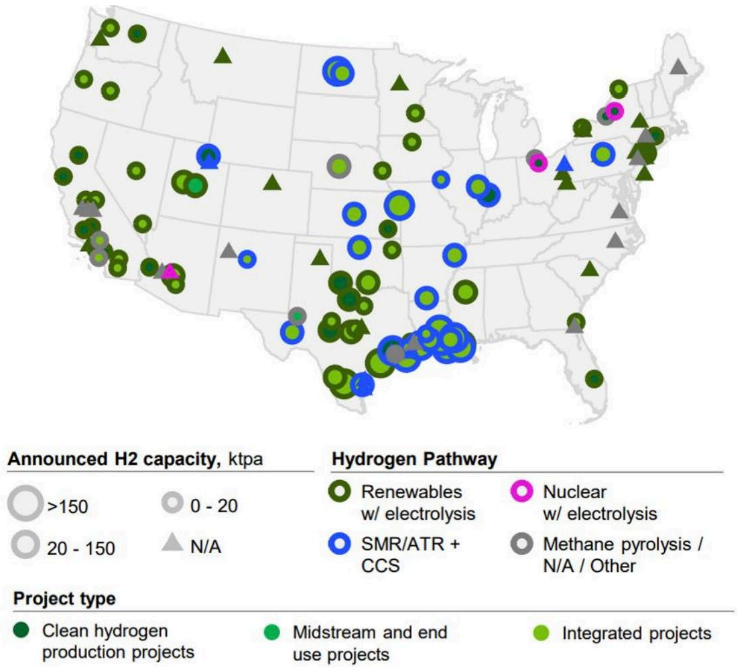
US Hydrogen Production



(a) Currently publicly announced clean hydrogen production projects as of EOY 2022, with total production potential of 12 MMT/year. (Repurposed from DOE's report, Pathways to Commercial Liftoff: Clean Hydrogen[3])

Courtesy: DOE 2023 U.S. National Clean Hydrogen Strategy and Roadmap

Hydrogen Applications

	Industrial feedstocks	Transportation	Power generation & energy storage	Buildings and hydrogen blending
Existing demands at limited current scales	• Oil refining • Ammonia • Methanol • Other (e.g. food, chemicals)	• Forklifts and other material-handling equipment • Buses • Light-duty vehicles	• Distributed generation: primary and backup power • Renewable grid integration with storage and other ancillary services	• Low percentage hydrogen blending in limited regions
Emerging demands and potential new opportunities	• Steel and cement manufacturing • Industrial heat • Bio/synthetic fuels using hydrogen	• Medium- and heavy-duty vehicles • Rail • Maritime • Aviation • Offroad equipment (mining, construction, agriculture)	• Long-duration energy storage • Hydrogen low NOx combustion • Direct/reversible fuel cells • Nuclear/hydrogen hybrids • Fossil/waste/biomass hydrogen hybrids with CCUS	• Mid to high percentage hydrogen blending in certain regions with limited alternatives • Building or district heating, including fuel cells and combined heat and power, for hard to electrify or limited options

Figure 9: Current and emerging demands for hydrogen.[50]

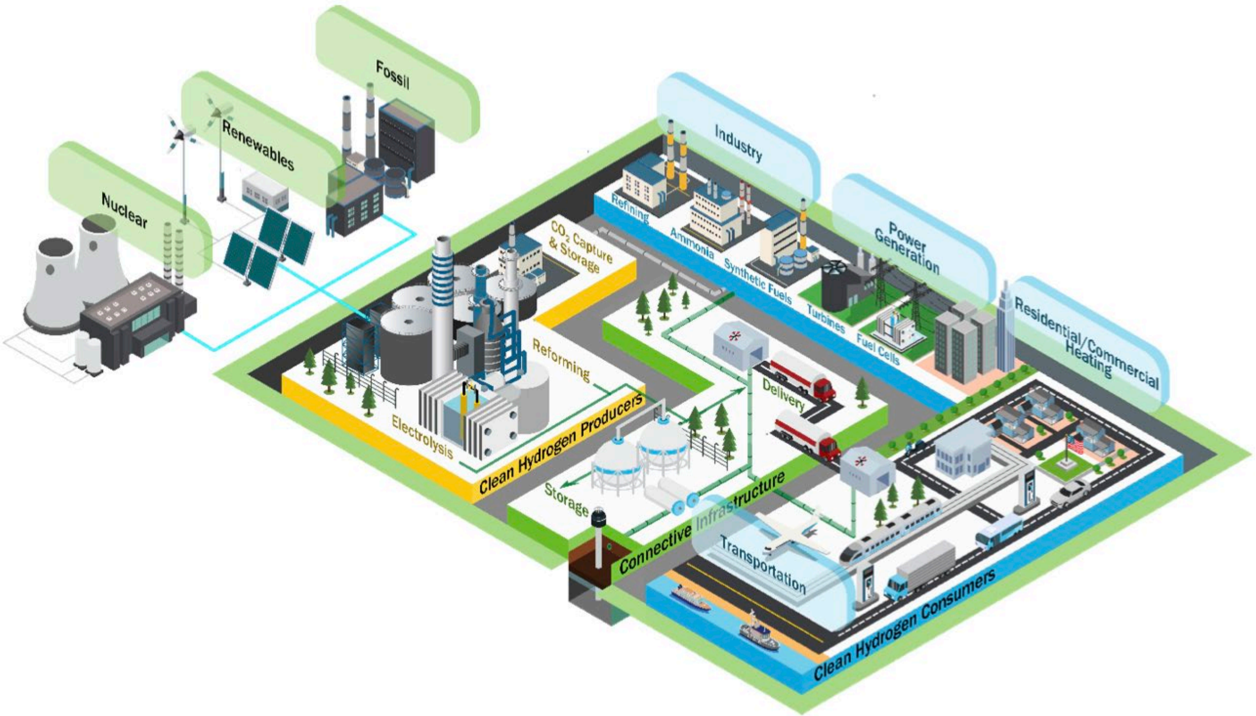
Courtesy: DOE 2023 U.S. National Clean Hydrogen Strategy and Roadmap

Key Transportation Challenges

- **Commercially Available FCEV Options:**
  - *Investment in vehicle demonstrations*
- **Supply/Available Refueling Infrastructure:**
  - *Investment in refueling infrastructure to support larger vehicle deployments*
- **Technology Readiness:**
  - *Further improvements to range, high speed/grade performance*
- **High TCO:**
  - *Scaling vehicle, fuel production*

DOE $8B Regional H2Hubs Overview

- **6 to 10 Regional Hubs:** $400M to $1.25B
- **50% Cost Share**
- **Minimum H2 Production:** 50 to 100 tons/day
- **FOA** released 9/22/22
- **Concept Papers** due 11/7/22
- **Applications** due 4/7/23
- **Execution:** 8 to 12 years



Key Considerations from DOE

- Commercially Sustainable Technology
- TRL 6 or higher to achieve TRL 8+
- American Jobs
- Local Workforce Benefits/Community Impact
- Benefits to Disadvantaged Communities/Justice40

Fall 2023 – Fall 2024
Phase 1: Detailed Plan

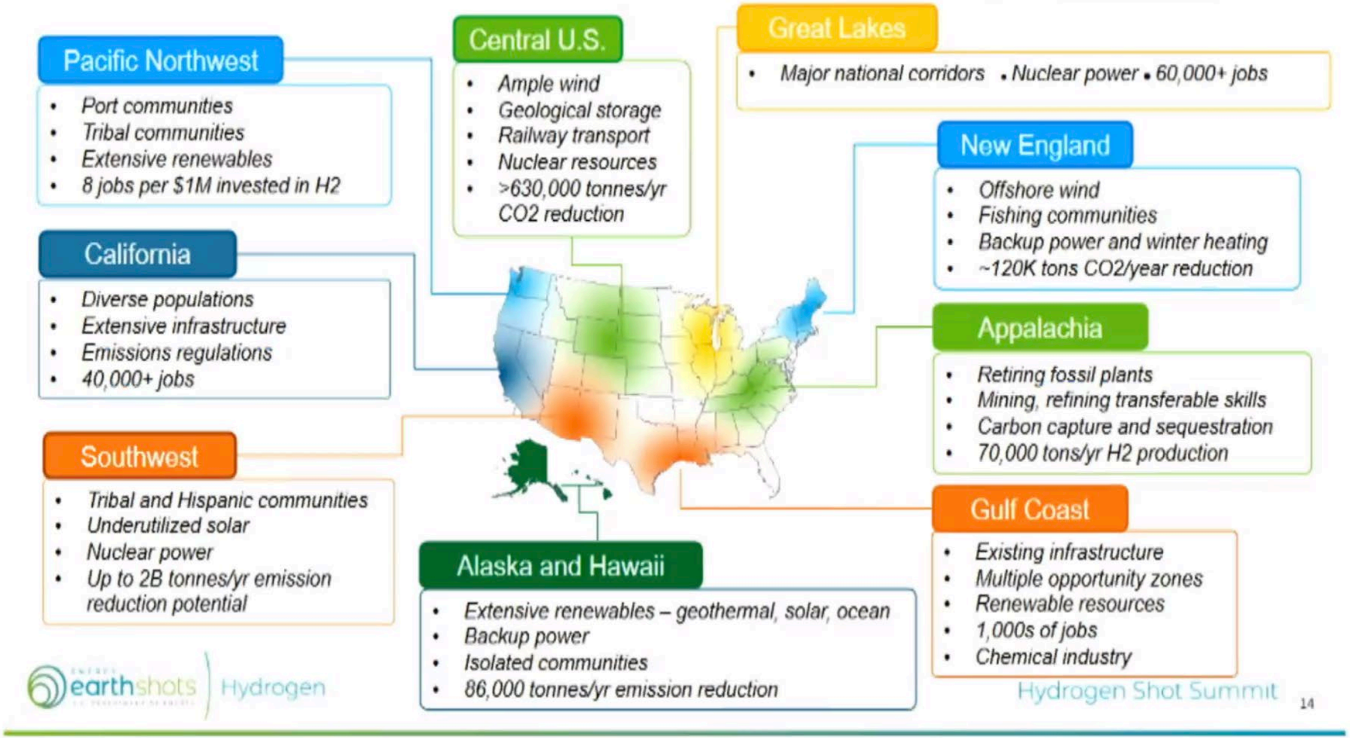
Fall 2024 – Fall 2027
Phase 2: Develop, Permit, Finance

Fall 2027 – Fall 2031
Phase 3: Install, Integrate, Construct

Fall 2031 – 2035
Phase 4: Ramp Up and Operate

DOE H2 Hubs Regional Clusters

LAUNCH ALASKA



https://www.energy.gov/sites/default/files/2021-12/h2iq-12082021.pdf, slide #14

Hubs Encouraged

States Involved + Project Name	Project Partners
Louisiana, Arkansas and Oklahoma: **HALO**	Shell, TC Energy, Williams Halliburton, GE, Plug Power, Total Energies, Oak Ridge National Lab
Colorado, New Mexico, Utah and Wyoming: **Western Interstate Hydrogen Hub**	Atkins, Xcel Energy, Avangrid, Dominion Energy Utah, Los Alamos National Laboratory, DOE’s NREL, Sandia National Laboratories
Houston and University of Texas: **HyVelocity Hub**	Chevron, ENGIE, ExxonMobil, Fortescue Future Industries, Phillips66, Sempra Infrastructure, Shell, Siemens, the Port of Houston
New York Connecticut, New Jersey, Massachusetts, Rhode Island and Maine	NYSERDA, Con Edison, Eversource, National Grid, Nucor Steel, Plug Power, Avangrid, EPD Renewables, Equinor, GE, Invenergy and Pratt and Whitney
California: **Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)**	AECOM and Wood, PGE, Toyota Corp., Plug Power, Hyundai, Michelin, BOSCH, Bloom Energy, Avantus and others
Texas: **Trans Permian H2Hub**	MMEX Resources, Siemens Energy and a number of cities in the Permian region
Pennsylvania, Ohio, and West Virginia: **Decarbonization Network of Appalachia**	Shell, Equinor, U.S. Steel
Washington, Oregon: **Pacific Northwest Hydrogen Association**	Consortium for Hydrogen and Renewably Generated E-Fuels Network, the Renewable Hydrogen alliance, Washington Green Hydrogen Alliance, Washington State University, Pacific Northwest National Laboratories
Oregon: **Obsidian Pacific NW Hydrogen Hub**	Obsidian Renewables
Midwest Alliance for Clean Hydrogen	ADL Ventures, Air Liquide, Ameren Illinois, American Center for Mobility, ArcelorMittal, Argonne National Laboratory, Atlas Agro, Avina Clean Hydrogen Inc., BayoTech, Big Rivers, Bloom Energy and others
Hawaii, **Hawaii Pacific Hydrogen Hub**	Hawaii Gas, Cyrq Energy, Dibshawaii, 174 Power Global and others

California: 1,000 Bus Initiative

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cte

Project Scope / Overview

Over an eight year period from 2024 to 2031, the 1,000 Bus Initiative will deliver to California based transit agencies:

- 1,081 fuel cell electric buses (FCEBs)
- 13 Hydrogen Refueling Stations
- Upgrades to 9 Hydrogen Refueling Stations
- Upgrades to 16 Maintenance Facilities

CTE Supports ARCHES: California Hydrogen Hub

Press Releases May 15, 2023

FOR IMMEDIATE RELEASE

May 15, 2023

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CTE Supports ARCHES: California's Hydrogen Hub

The Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), with the support of the Center for Transportation and the Environment (CTE), has submitted a proposal to the United States Department of Energy (DOE) for federal funding to establish a regional Hydrogen Hub in the state of California.

Appendix: DOE TRL Levels

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Appendix B – DOE Technology Readiness Level Scale

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	TRL 9	Actual system operated over the full range of expected conditions	Actual operation of the technology is in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	Prototype full scale system. Represents a major step up from TRL 6, requiring demonstration of an actual prototype system in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Representative engineering scale model or prototype system, which is well beyond the lab scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
	TRL 4	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	TRL 1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties.