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# Hydrogen Hubs and Demonstrating the Hydrogen Energy Value Chain

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# Hydrogen Hubs and Demonstrating the Hydrogen Energy Value Chain

SUMMARY

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October 24, 2022

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Hydrogen hubs are emerging centers of activity involving hydrogen production, transport, delivery, and end use to provide modern energy services such as mobility, goods movement, heat for manufacturing processes, and other services. A future economy using hydrogen as an energy carrier and fuel could offer an alternative method to provide the many modern energy services associated with fossil fuels. In addition to providing a fuel for transportation—one of the larger applications envisaged—hydrogen can support industrial processes or building operations or can become part of the energy infrastructure by storing energy.

Congress, in the Infrastructure Investment and Jobs Act (IIJA, §40315, P.L. 117-58), authorized a program of Regional Clean Hydrogen Hubs. Congress appropriated $8 billion (Division J, Title III of the IIJA) for the U.S. Department of Energy (DOE) to make awards to support at least four demonstration projects involving networks of clean hydrogen producers and consumers and the connecting infrastructure. DOE has funded demonstration programs at small and large scale since its inception in 1977. The essential purpose is to demonstrate technological feasibility. A demonstration project also reduces risk to subsequent investors as the government assumes the role of first mover to some extent. Hydrogen demonstrations to date have ranged from single refueling stations to linked activities for realizing value propositions typical of modern energy services, such as goods movement. To give an example, the Shore-to-Store project at the Port of Los Angeles completed its initial phase in February 2022 to demonstrate the shore-side movement of goods by zero-emission vehicles.

Consumption of hydrogen is focused in a relatively concentrated set of end-users. Almost all produced hydrogen is consumed by the petroleum industry or chemical industry either on site or via delivery through dedicated pipelines from large merchant producers. The hydrogen hubs and the additional supply of hydrogen they will create will likely need to be matched to new sources of demand.

Hydrogen in its current uses has a dedicated infrastructure, but one that is small compared to other energy commodities, such as natural gas. For example, hydrogen pipelines comprise 1,600 miles in the United States compared with 300,000 miles of natural gas transmission pipelines. To service a fleet of numerous and relatively smaller hydrogen refueling stations for fuel cell electric vehicles (FCEVs), for example, will require expanded hydrogen delivery infrastructure, such as additional pipelines and delivery trucks loaded with liquid or compressed, gaseous hydrogen, or advances in onsite hydrogen production.

DOE released an initial funding opportunity announcement (FOA) in September 2022. DOE plans to select six to ten hubs with total funding of up to $6 to $7 billion. DOE is requiring a 50% cost share from nonfederal sources and anticipates projects to be executed over 8 to 12 years. Based on state legislative activity, press releases, and news articles, it appears that state governments, many in combination with private sector entities and one or more other states, have announced aspirations for over twenty hydrogen hubs. Some have stated their non-binding intention to apply for funding for Regional Clean Hydrogen Hubs. In general, the hubs must "demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen" (Section 40314 of IIJA).

DOE's 2020 Hydrogen Program Plan identified rights-of-way and permitting for hydrogen pipelines as needs and challenges for hydrogen delivery infrastructure. Key policy issues that Congress may examine include the regulation of pipeline and other infrastructure siting, including potential federal-state jurisdictional conflicts, and the regulation of pipeline rates and terms of service.

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# Introduction

Hydrogen hubs are emerging centers of activity involving hydrogen production, transport, delivery and end use to provide energy services, such as mobility, goods movement, and heat for manufacturing processes.[1] Congress, in the Infrastructure Investment and Jobs Act (IIJA, §40315, P.L. 117-58), authorized a program of Regional Clean Hydrogen Hubs. Congress appropriated $8 billion (IIJA, Division J, Title III) for the U.S. Department of Energy (DOE) to make awards to support at least four demonstration projects involving networks of clean hydrogen producers and consumers and the connecting infrastructure.[2] Congress created a new Office of Clean Energy Demonstrations (OCED) to manage these and other non-hydrogen demonstration projects. DOE's Hydrogen and Fuel Cell Technologies Office (HFTO) retains the overall lead role for coordination of DOE hydrogen programs.

A future economy using hydrogen as an energy carrier[3] and fuel could offer an alternative method to provide the many modern energy services associated with fossil fuels. In addition to providing a fuel for transportation—one of the larger applications envisaged—hydrogen could support industrial processes or building operations or become part of the energy infrastructure by storing energy. Demonstrations of hydrogen technology and value propositions based on hydrogen continue to emerge, ranging from one-off funded projects to public-private partnerships (P3s) with regional scope in the United States and abroad. Many such projects investigate uses of hydrogen as fuel for familiar services such as personal transportation/mobility or industrial heat for manufacturing. The hydrogen energy value chain spans resource extraction, production, storage, and final conversion and end use. Although demonstrations have addressed portions of this value chain, DOE's statements on the Regional Clean Hydrogen Hubs envisage the full value chain, following the prescriptions of the IIJA.

# DOE Programs and Demonstrations

## DOE Hydrogen Programs

The DOE Hydrogen Program, led by the HFTO within the Office of Energy Efficiency and Renewable Energy (EERE) and including several other DOE offices, addresses the development of applications that use hydrogen in place of other fuels and technologies. The Hydrogen Program also considers hydrogen in its role as an established chemical feedstock. The Hydrogen Program includes over 400 projects of research and development (R&D), systems integration, demonstrations, and initial deployment activities performed by universities, national laboratories, and industry.[4]

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[1] For further discussion of energy services, see A. Grubler et al., *Energy Primer*, International Institute for Applied Systems Analysis, Laxenburg, Austria, August 2015, pp. 8-14, at https://pure.iiasa.ac.at/id/eprint/11190/1/EnergyPrimer_Aug15_HiRes.pdf; M.J. Fell, "Energy Services: A Conceptual Review," *Energy Research and Social Science*, vol. 27 (May 2017), p. 129–140.

[2] For further discussion of DOE's funding of hydrogen programs, see CRS In Focus IF12163, *Department of Energy Funding for Hydrogen and Fuel Cell Technology Programs*, by Martin C. Offutt.

[3] Energy carriers are substances or physical phenomena such as electricity that have potential energy, which allows them to perform work or provide heat or light, and that can be transmitted over long distances without substantially losing their potential energy.

[4] Sunita Satyapal, Director, DOE Hydrogen and Fuel Cell Technologies Office, *2022 AMR Plenary Session*, June 6, 2022, at https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf.

# Demonstrations

## Purpose and Expectations

The essential purpose of demonstrations is to show technological feasibility.[5] A demonstration project receiving government support also reduces risk to subsequent investors as the government assumes the role of first mover to some extent.[6] Inserting a technology into a demonstration project allows testing in relative isolation so that any failures have limited consequences and do not cascade more widely, for example into an energy network such as an electric power grid.[7] Demonstration projects have been part of early deployment by selling products, such as outputs from the demonstration project.[8] DOE has stated that the Regional Clean Hydrogen Hubs authorized in IIJA will yield insights and validate the claimed benefits (environmental and otherwise) of the hydrogen economy and will identify technology needs.[9]

Hydrogen demonstration projects have addressed portions of the full hydrogen energy value chain depicted in **Figure 1**.

[5] See, for example, A. Grubler, F. Aguayo, and K. Gallagher, "Chapter 24—Policies for the Energy Technology Innovation System," in *Global Energy Assessment—Toward a Sustainable Future* (New York and Laxenburg: Cambridge University Press, 2012), p. 1673; L.R. Cohen and R.G. Noll, *The Technology Pork Barrel* (Washington, DC: The Brookings Institution, 1991), p. 39.

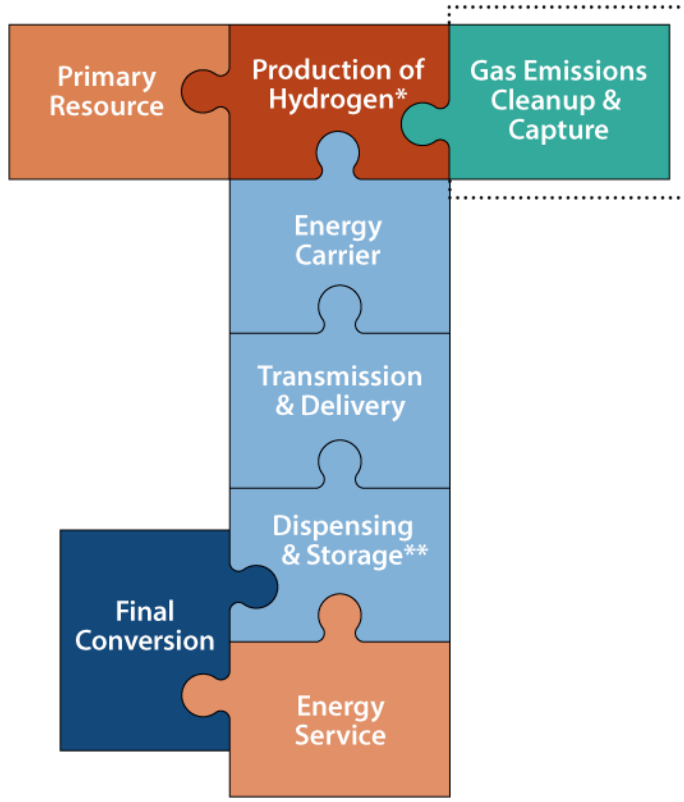
[6] D.M. Hart, "Beyond the Technology Pork Barrel? An Assessment of the Obama Administration's Energy Demonstration Projects," *Energy Policy*, vol. 119 (2018), pp. 367-376.

[7] Ibid.

[8] For discussion of sales of synthetic fuel from a demonstration project, see U.S. Government Accountability Office, *SYNTHETIC FUELS: Status of the Great Plains Coal Gasification Project—August 1, 1985*, RCED-86-36, December 1985, p. 19, at https://www.gao.gov/assets/rced-86-36.pdf.

[9] Testimony of Sunita Satyapal, Director, Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy, during U.S. Congress, Senate Energy and Natural Resources, *Clean Hydrogen*, hearing, 117th Cong., 2nd sess., February 10, 2022.

**Figure 1. Hydrogen Energy Value Chain**




**Source:** CRS.

**Notes:** Hydrogen may be sourced from numerous primary resources (amber, top left). The hydrogen production step (red) can occur in ways specific to the resource and is packaged and moved as the energy carrier (light blue) over long distances (transmission & delivery, light blue) and, as appropriate, converted to hydrogen and stored near the point of use (e.g., at the scale of a refueling station, light blue). The end-use technology such as the vehicle fuel cell will then convert the carrier into useful energy (dark blue) to provide the energy service (amber, lower right). Depending on the method of hydrogen production, there may be an additional step involving gas emissions cleanup and capture (green, enclosed in dotted lines) to remove pollutants. This description is based on hydrogen as the energy carrier. However, the sequence in the figure can also use other energy carriers as intermediaries where indicated by the asterisks:

(*) energy carrier created in production step (red) could instead be ammonia, electricity, or other.

(**) within the dispensing and storage step (light blue), a non-hydrogen energy carrier would be converted to hydrogen.

## Brief History of Demonstrations

DOE has funded demonstration programs and projects at small and large scale since its inception in 1977, many of which have included hydrogen production. Congress authorized these programs for explicit purposes and provided DOE with both annual and one-time supplemental appropriations including from the IIJA and the American Recovery and Reinvestment Act of 2009 (ARRA, P.L. 111-5). The Regional Clean Hydrogen Hubs funded in the IIJA continue this sort of demonstration activity at a conceptual level.

The Energy Conservation and Production Act of 1976 (P.L. 94-385) established a demonstration program for buildings energy conservation "to test the feasibility and effectiveness" of financial assistance for the adoption of energy conservation measures.[10] The early DOE demonstrations ranged in scope and scale from over 30 small rooftop solar photo-voltaic generation projects to larger, single demonstrations such as synthetic fuels plants. One such plant, the Great Plains coal gasification plant, attempted to demonstrate the conversion of coal into raw gas containing hydrogen and other constituents for synthesis of ammonia and other gases.[11]

DOE curtailed the number of demonstration plants in the 1980s.[12] Nonetheless, later that decade, nine clean coal demonstrations were established to burn or otherwise use coal in a way that reduces release of pollutants.[13] Later plans for large-scale demonstrations included FutureGen, an effort proposed by DOE in 2003 to build a coal-fired power plant with hydrogen production and carbon capture and storage.[14] The plant was to be based on coal gasification and was supported by outlays both from annual appropriations and $1 billion awarded from ARRA, with roughly $200 million of the latter being spent. The project was re-conceptualized and then ended in 2015.[15]

The Energy Policy Act of 2005 (EPAct05, P.L. 109-58) authorized the Next Generation Nuclear Plant (42 U.S.C. §16021), a prototype plant based on the Generation IV Nuclear Energy Systems Initiative (42 U.S.C. §16272), to generate electricity, hydrogen, or both. Congress appropriated over $500 million for Phase I of the project, including research and development, design engineering, licensing, and project management.[16] DOE decided not to proceed with Phase II in 2011 following a review by its Nuclear Energy Advisory Committee.[17]

In 2021, the IIJA consolidated demonstration programs under one office, OCED, and appropriated $21.5 billion to support large-scale demonstration projects, including the $8 billion for the Regional Clean Hydrogen Hubs.[18]

[10] 12 U.S.C. §1701z-8.

[11] National Research Council, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, Washington, DC, 2001, p. 175.

[12] National Research Council, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, Washington, DC, 2001.

[13] L.R. Cohen and R.G. Noll, *The Technology Pork Barrel* (Washington, DC: The Brookings Institution, 1991), p. 31; National Research Council, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, Washington, DC, 2001, p. 216.

[14] U.S. Department of Energy, "Abraham and Dobriansky Announce 'FutureGen,'" press release, February 27, 2003, at https://www.energy.gov/management/february-27-2003-abraham-and-dobriansky-announce-futuregen.

[15] Manuel Quinones, "Lawmakers Likely to Scrutinize DOE Closeout of FutureGen Project," *Environment & Energy Daily*, February 4, 2015, at http://www.eenews.net/eedaily/stories/1060012838/.

[16] U.S. Department of Energy, Office of Nuclear Energy, *Next Generation Nuclear Plant: A Report to Congress*, April 2010, p. 7.

[17] U.S. Government Accountability Office, *Advanced Reactor Research: DOE Supports Multiple Technologies but Actions Needed to Ensure a Prototype Is Built*, 14-545, June 2014, p. 11.

[18] M. Klembara, U.S. Department of Energy, "Office of Clean Energy Demonstrations," April 15, 2022, at https://energyresearch.ucf.edu/wp-content/uploads/2022/04/Klembara-OCED_20220415.pdf.

**The U.S. Synthetic Fuels Corporation and the Great Plains Coal Gasification Plant**

In 1980, the Energy Security Act (P.L. 96-294) established the U.S. Synthetic Fuels Corporation (SFC). Congress used $2.8 billion of the Energy Security Reserve, established and funded first in fiscal year 1980 by the Interior and Related Agencies Appropriations Act (P.L. 96-126), to fund the Great Plains coal gasification plant in North Dakota and the Parachute Creek Oil Shale project in Colorado. Five projects entered the construction phase in total and were the beneficiaries of loan and price guarantees. Congress abolished the SFC in 1986 (P.L. 99-190) and rescinded its remaining budget authority, although the projects continued.[19]

Following the August 1985 loan default at the Great Plains plant, DOE purchased the plant for $1 billion in 1986 and sold it to the Basin Electric Power Cooperative in 1988.[20] In 2021, Bakken Energy agreed to purchase the plant and announced it will partner with Mitsubishi Power Americas to develop the plant into a hydrogen production facility with carbon capture and storage.[21]

# Status of Hydrogen Hubs

## DOE's Regional Clean Hydrogen Hub Program

DOE launched an initial funding opportunity announcement (FOA) in September 2022.[22] DOE plans to select six to ten Regional Clean Hydrogen Hubs with combined total funding of up to $6 to $7 billion, with a "preferred maximum" of $1.25 billion per hub. DOE states that the balance of the $8 billion appropriated for the hubs in the IIJA may be reserved for additional hubs or other supporting activities. DOE is requiring a minimum 50% cost share from nonfederal sources and anticipates projects to be executed over 8 to 12 years.[23]

When issuing the FOA, DOE said that concept papers will be due on November 7, 2022, and full funding applications will be due by April 7, 2023.[24] DOE had conducted initial consultations including a Request for Information (RFI) on February 16, 2022.[25] DOE received more than 120 responses to the RFI comprising over 1,300 pages.[26]

Based on state legislative activity, press releases, and news articles, it appears that state governments, many in combination with private sector entities and one or more other states, have

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[19] M. Holt, *Energy Policy: Is the U.S. Ready for the 1990s? Energy Security Laws of the 1970s*, Environmental and Energy Study Conference, U.S. Congress, April 18, 1988, pp. 14-15.

[20] National Energy Technology Laboratory, *Gasifipedia: 7.5.1. Great Plains Synfuels Plant*, at https://www.netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/great-plains; T. W. Lippman, "Huge Synthetic Fuel Plant Now Operating at a Profit," *Washington Post*, February 18, 1990.

[21] S. Ali, "Bakken Energy Plans North Dakota Hydrogen Hub," *H2 Bulletin*, August 17, 2021; Bakken Energy, "Clean Hydrogen: Bakken Energy Is Currently Focused on the Development of Clean Hydrogen Production, Transportation, Storage and Applications," press release, 2022; J. McPherson, "Companies Aim to Build 'Clean Hydrogen' Hub," *Associated Press*, June 4, 2021.

[22] U.S. Department of Energy, *Bipartisan Infrastructure Law: Additional Clean Hydrogen Programs (Section 40314): Regional Clean Hydrogen Hubs Funding Opportunity Announcement*, DE-FOA-0002779, September 22, 2022, at https://oced-exchange.energy.gov/FileContent.aspx?FileID=e159ff1f-5572-437e-b02d-b68acb461893.

[23] Ibid., p. 17.

[24] U.S. Department of Energy, "Biden-Harris Administration Announces Historic $7 Billion Funding Opportunity to Jump-Start America's Clean Hydrogen Economy," press release, September 22, 2022, at https://www.energy.gov/articles/biden-harris-administration-announces-historic-7-billion-funding-opportunity-jump-start.

[25] 87 *Federal Register* 8828, February 16, 2022.

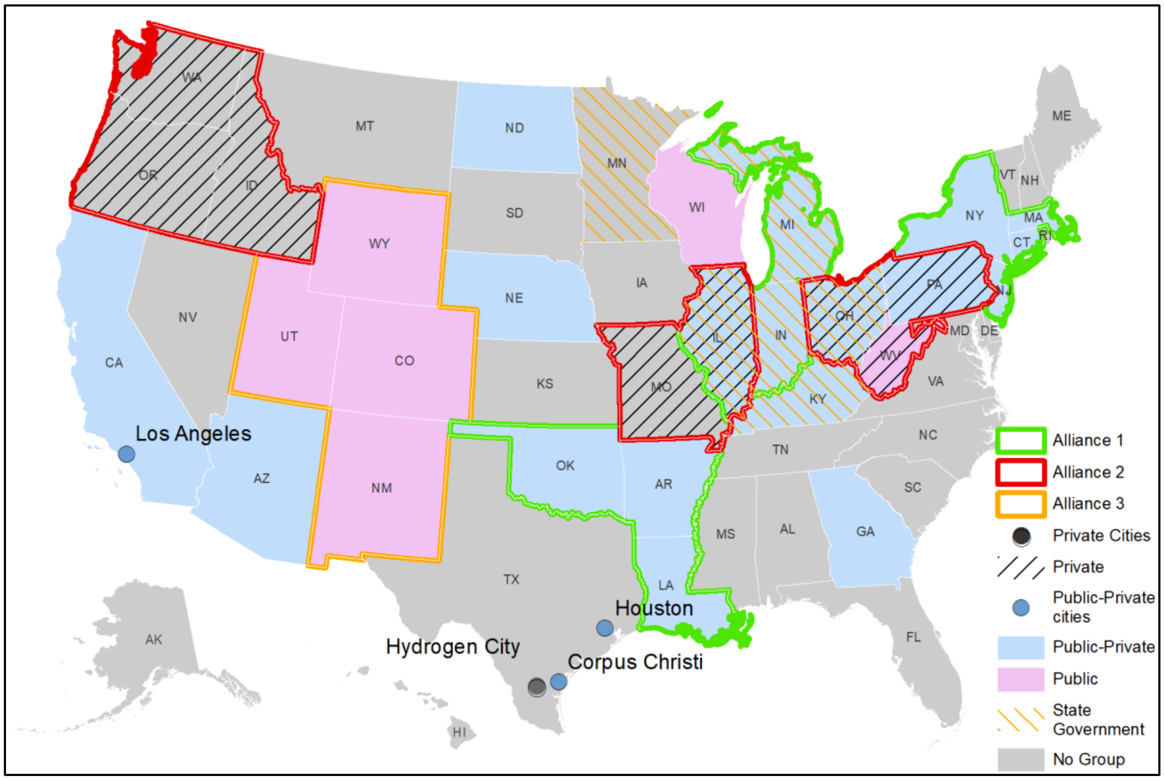
[26] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *Hydrogen and Fuel Cell Technologies Office Funding Opportunities*, at https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office-funding-opportunities.

announced interest in over twenty hydrogen hubs and stated their non-binding intention to apply for funding for Regional Clean Hydrogen Hubs. At least four private alliances have also declared interest in pursuing the Regional Clean Hydrogen Hubs. **Figure 2** depicts states with entities that appear to have expressed interest in IIJA funding for hydrogen hubs.

CRS found hydrogen hub activities in various stages of planning, with some groups having a declared geography and others not specifying a location. Groups also are soliciting additional participants.

**Figure 2. Regions, States, and Localities Expressing Interest in Hydrogen Hub Development**

Not all have declared they will apply for DOE funding




**Source:** CRS figure based on legislation, press announcements and news articles as of September 19, 2022.

**Notes:** Multi-state public-private partnerships (P3s, Type 1) are outlined in green, private only (Type 2) in red, public only (Type 3) in orange. Los Angeles includes one P3 hub and one hub declared by the city council. Alliances are groups involving governments and/or private entities in more than one state.

## Requirements

Congress required the Regional Clean Hydrogen Hubs must "demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen."[27] The IIJA revised Section 813 of EPAct05 to require the Secretary of Energy to use certain criteria in selecting among proposals for the Regional Clean Hydrogen Hubs. The DOE describes these criteria as:[28]

[27] 42 U.S.C. §16161a.

[28] The criteria are DOE's paraphrasing of 42 U.S.C. §16161a, quoted from *DOE Hydrogen Program, Request for*

- "Feedstock diversity—at least one hub shall demonstrate the production of clean hydrogen from fossil fuels, one hub from renewable energy, and one hub from nuclear energy.
- End-use diversity—at least one hub shall demonstrate the end-use of clean hydrogen in the electric power generation sector, one in the industrial sector, one in the residential and commercial heating sector, and one in the transportation sector.
- Geographic diversity—each regional clean hydrogen hub shall be located in a different region of the United States and shall use energy resources that are abundant in that region.
- Hubs in natural gas-producing regions—at least two regional clean hydrogen hubs shall be located in the regions of the United States with the greatest natural gas resources.
- Employment—DOE shall give priority to regional clean hydrogen hubs that are likely to create opportunities for skilled training and long-term employment to the greatest number of residents in the region.
- Additional Criteria—DOE may take into consideration other criteria that are necessary or appropriate to carry out the regional clean hydrogen hubs program."

# Experience with Hydrogen Projects

## Early Deployment

Industrial processes that use hydrogen already occur at large scale, such as petroleum refining or production of ammonia to make urea for fertilizer.[29] Demonstrations of additional industrial uses of hydrogen are being developed in cement, ceramics, and glass manufacturing—substituting hydrogen for operations that currently use other fuels.[30]

The customer-facing hydrogen technologies now available to retail consumers include hydrogen refueling stations and fuel cell electric vehicle (FCEV) cars. Honda, Hyundai, and Toyota have manufactured FCEV cars to buy or lease in North America. There are over 50 public, retail refueling stations—one in Hawaii and the rest in California.[31] Car makers had sold over 14,000 light-duty vehicles in the United States, cumulative through September 30, 2022,[32] with over 12,000 of these on the road at the end of 2021.[33] The sales of FCEV cars is small compared to cars of all types sold in the United States, which comprised 3.4 million sales in 2020 alone.[34]

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*Information # DE-FOA-0002664.0002: Regional Clean Hydrogen Hubs Implementation Strategy*, pp. 4-5, at https://eere-exchange.energy.gov/Default.aspx?foaId=5d96172f-e9b6-48ff-94ac-5579c3531526.

[29] International Energy Agency (IEA), *The Future of Hydrogen: Seizing Today's Opportunities*, Paris, June 2019, p. 32.

[30] International Energy Agency, *Global Hydrogen Review 2021*, Paris, October 2021, p. 6.

[31] U.S. Department of Energy, Alternative Fuels Data Center, *Hydrogen Fueling Station Locations*, at https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY.

[32]; California Fuel Cell Partnership, *By the Numbers: FCEV Sales, FCEB, and Hydrogen Station Data*, September, 2022, at https://cafcp.org/by_the_numbers.

[33] R.C. Samsun et al., "Deployment of Fuel Cell Vehicles and Hydrogen Refueling Station Infrastructure: A Global Overview and Perspectives," *Energies*, vol. 15, no. 4975 (July 7, 2022), p. 5.

[34] S.C. Davis and R.G. Boundy, *Transportation Energy Data Book, Edition 39*, Oak Ridge National Laboratory,

Overall, FCEV cars comprised slightly fewer than 1 in every 20,000 cars in the United States at the end of 2021.[35]

DOE has identified other applications in early deployment. These include over 50,000 fork lifts used for logistical operations—known as material handling equipment (MHE)—and hydrogen back-up power devices totaling over 500 megawatts (MW) capacity.[36] The two applications together received roughly $40 million from the American Recovery and Reinvestment Act (P.L. 111-5).[37]

DOE identified several technology cost advantages of hydrogen versus battery-electric MHE, beginning with lower total cost of ownership[38] for the hydrogen version.[39] Hydrogen MHE require refueling less often than battery-electric MHE require recharging, possibly avoiding work stoppages. DOE has noted that its own funding of purchase of fork lifts has been small relative to that of industry. 524 units were purchased according to a DOE-industry cost-sharing arrangement cost from the ARRA funding noted above and another 189 from DOE annual appropriations. DOE found that through the end of 2017, a further 21,000 units were in service at the sole expense of industry with users including large "big box" retail, food suppliers and retailers, car makers, and freight movers.[40] By 2020, DOE estimated there were 35,000 such units,[41] and, by 2022, over 50,000.[42]

Though early in the project execution phase, Advanced Clean Energy Storage, a hydrogen and energy storage facility, received a DOE loan guarantee in June 2022.[43] The guarantee was for a $504 million loan[44] to construct 220 MW of electrolyzers[45] in Delta, UT, paired with underground caverns to store the hydrogen. The estimated storage capacity is 150 gigawatt-hours (GWh). The off-taker (i.e., end-user) for the stored hydrogen plans to use a hydrogen-capable gas turbine supplied by project partner Mitsubishi Power Americas to generate electricity.[46]

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ORNL/TM-2020/1770, Oak Ridge, TN, April 2021, p. 3-9.

[35] Samsun et al, p. 23.

[36] Sunita Satyapal, Director, DOE Hydrogen and Fuel Cell Technologies Office, *2022 AMR Plenary Session*, June 6, 2022, at https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf.

[37] U.S. Department of Energy, *DOE National Clean Hydrogen Strategy and Roadmap*, September 2022, p. 27, at https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.

[38] Total cost of ownership refers to the sum of the initial cost plus any operation and maintenance costs including fuel consumption over the lifetime of the equipment.

[39] DOE Office of Energy Efficiency and Renewable Energy, *Early Markets: Fuel Cells for Material Handling Equipment*, DOE/EE-0751, February 2014, at https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/early_markets_mhe_fact_sheet.pdf.

[40] P. Devlin and G. Moreland, *Industry Deployed Fuel Cell Powered Lift Trucks*, Record # 18002, May 23, 2018, at https://www.hydrogen.energy.gov/pdfs/18002_industry_deployed_fc_powered_lift_trucks.pdf.

[41] U.S. Department of Energy, *Hydrogen Program Plan*, DOE/EE-2128, Washington, DC, November 2020, p. 28.

[42] Sunita Satyapal, Director, DOE Hydrogen and Fuel Cell Technologies Office, *2022 AMR Plenary Session*, June 6, pp. 5 and 49, 2022, at https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf.

[43] U.S. Department of Energy, *DOE Announces First Loan Guarantee for a Clean Energy Project in Nearly a Decade*, June 8, 2022, at https://www.energy.gov/articles/doe-announces-first-loan-guarantee-clean-energy-project-nearly-decade.

[44] Title XVII of the Energy Policy Act of 2005, P.L. 109-58, authorizes DOE to issue loan guarantees.

[45] An electrolyzer is an electrochemical device, powered by electricity, that decomposes water into hydrogen and oxygen.

[46] Mitsubishi Power Americas, "World's Largest Renewable Energy Storage Project Announced in Utah," press release, May 30, 2019, at https://power.mhi.com/regions/amer/news/190530.html.

## Hydrogen Demonstration Projects

Hydrogen demonstration projects have ranged from single refueling stations to linked activities for realizing broader value propositions.[47] As one example, the Shore-to-Store project at the Port of Los Angeles, completed its initial phase in February 2022 to demonstrate the shore-side movement of goods by zero-emission vehicles. Shell Oil Products US built and operated two hydrogen refueling stations. Kenworth, a truck manufacturer group within vehicle and parts maker PACCAR, provided 10 vehicles—the hydrogen fuel cell version of its T680, a class 8 tractor, with Toyota's fuel cell electric system.[48] Project partners contributed $41.4 million and the California Air Resources Board (CARB) contributed $41.1 million.[49]

The buildings sector includes demonstrations of hydrogen technologies and hydrogen fuel applications, though there is almost no evidence of retail use of hydrogen.[50] A number of demonstration projects are underway aimed at so-called hydrogen injection into existing natural gas distribution assets; these include projects in France, the United Kingdom (UK), and elsewhere and serve one hundred or more dwellings per project.[51]

## Barriers to Early Deployment

DOE's informal survey of stakeholders identified a number of perceived barriers to hydrogen market adoption, including the cost to the end-user of hydrogen technologies; need for sufficient hydrogen infrastructure; and public awareness and understanding.[52] Addressing this perceived need for sufficient infrastructure, and the cost involved, the California Air Resources Board modeled a year-by-year build-out of hydrogen refueling stations and estimated that 1,000 refueling stations would be needed for an assumed 1 million FCEVs,[53] at an estimated cost of $1.9 million (in 2016 dollars) per station based on early experience.[54]

In the RFI DOE published for comment on the hydrogen hubs, they noted that "one key pathway to achieving large-scale, commercially viable deployment of clean hydrogen is through matching the scale up of clean hydrogen supplies with a concomitant and growing regional demand." DOE has taken steps to ensure that suppliers and users of hydrogen can connect with one another by

[47] However, there is not one agreed-upon data set of all such projects; see, for example, European Commission, Clean Hydrogen Partnership, *Demo Projects Hub*, at https://www.clean-hydrogen.europa.eu/get-involved/regions-hub/demo-projects-hub_en.

[48] "Kenworth: Port of Los Angeles Rolls Out Hydrogen Fuel Cell Electric Freight Demonstration," *Automotive World*, June 7, 2021, at https://www.automotiveworld.com/news-releases/electric-mobility-news-releases/kenworth-port-of-los-angeles-rolls-out-hydrogen-fuel-cell-electric-freight-demonstration/.

[49] "Port of Los Angeles, Partners Launch Zero-Emission Project," *Transport Topics*, June 11, 2021.

[50] International Energy Agency, *Global Hydrogen Review 2021*, Paris, October 2021, pp. 90, 97.

[51] For information on specific projects, see ENGIE, *GRHYD: Rouvelons nos energies: Présentation*, at https://grhyd.fr/presentation/. HyDeploy, "Pioneering the Safe Use of Blended Hydrogen in Gas Networks to Reduce Carbon Emissions," press release, 2022, at https://hydeploy.co.uk/; Jacob Dijkstra, *Ameland: Frontrunner in the Energy Transition*, Duurzaam Ameland, Brussels, October 11, 2017, at http://www.pace-energy.eu/wp-content/uploads/2017/10/Jacob-Dijkstra_The-exemplary-role-of-local-communities-in-the-energy-transition_The-Ameland-island-story.pdf.

[52] Sunita Satyapal, Director, DOE Hydrogen and Fuel Cell Technologies Office, *2022 AMR Plenary Session*, June 6, 2022, p. 33, at https://www.energy.gov/sites/default/files/2022-06/hfto-amr-plenary-satyapal-2022-1.pdf.

[53] California Fuel Cell Partnership, *The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities*, July 2018, p. 14, at https://cafcp.org/sites/default/files/CAFCR.pdf.

[54] The estimate is based on vendor quotes for the first 111 stations planned or built. M. Koleva and M. Melaina, *DOE Hydrogen Program Record: Hydrogen Fueling Stations Cost*, U.S. Department of Energy, Record 21002, November 2, 2020, at https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf.

creating an online information resource called Hydrogen Matchmaker.[55] DOE does not identify specific challenges, but notes that "[t]o be considered for Phase 2 funding, H2Hub projects must successfully complete all Phase 1 planning activities and analysis." These activities and analyses include the availability of hydrogen infrastructure, workforce training, and minimization of environmental impacts.[56]

## International Experience

Demonstration and early deployment of the hydrogen value chain outside the United States includes planned and nascent activities similar to Regional Clean Hydrogen Hubs. A European Commission (EC)-sponsored project conducts global surveillance of selected hydrogen activities in deployment phase that are large in scale, have a clear geographic center, cover multiple steps in the value chain, and provide supply to multiple end uses—calling these "hydrogen valleys."[57] The hydrogen valleys are a similar idea to the IIJA's Regional Clean Hydrogen Hubs. The EC project surveys 33 hydrogen valleys worldwide, including two in the United States, in various stages of planning and initiation.[58]

The EC-sponsored project identified permitting as the number one policy barrier during a survey of participants.[59] Respondents to the survey noted that local permitting authorities were not familiar with hydrogen. The survey included 28 locations, though the majority were outside the United States. These site were either planning (90%) or have implemented (10%) large scale, full hydrogen value-chain systems with multiple end-uses in a defined geography.

Another study reported on emerging "hydrogen clusters," not unlike hydrogen hubs, in the Netherlands, Chile, Spain, and the United Kingdom. In the Netherlands, for example, the study identified three ports with plans for green and blue hydrogen[60] aided by proximity to demand from existing refineries and ammonia and steel plants. These locations allow for integration; for example, the oxygen by-product from electrolysis of water is being repurposed for use in basic oxygen furnaces for steelmaking.[61] The study identified further opportunities for clusters to include activities at transport hubs and ports.

[55] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *H2 Matchmaker*, at https://www.energy.gov/eere/fuelcells/h2-matchmaker.

[56] DOE Hydrogen Program, Request for Information # DE-FOA-0002664.0002: Regional Clean Hydrogen Hubs Implementation Strategy, pp. 8-9, at https://eere-exchange.energy.gov/Default.aspx?foaId=5d96172f-e9b6-48ff-94ac-5579c3531526.

[57] Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), *Hydrogen Valleys as a Stepping Stone Towards the New Hydrogen Economy*, Luxembourg, 2021, p. 13, at https://h2v.eu/analysis/reports.

[58] Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU), *Hydrogen Valleys*, at https://h2v.eu/hydrogen-valleys.

[59] Uwe Weichenhain et al., *Hydrogen Valleys: Insights into the Emerging Hydrogen Economies Around the World*, Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), Luxembourg, 2021.

[60] Hydrogen produced via electrolyzers is generally referred to as "green hydrogen" if the source of electricity is renewable. "Blue hydrogen" results when the carbon released from steam reforming of natural gas is captured and stored (i.e., carbon capture, utilization and storage (CCUS)), either for reuse in another industrial process or sequestered underground in mines or caverns. Blue hydrogen is sometimes referred to as "carbon neutral" as the emissions are not dispersed in the atmosphere. See CRS Report R46436, *Hydrogen in Electricity's Future*, by Richard J. Campbell.

[61] Energy Transitions Commission, *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy*, Version 1.2, April 2021, p. 67.

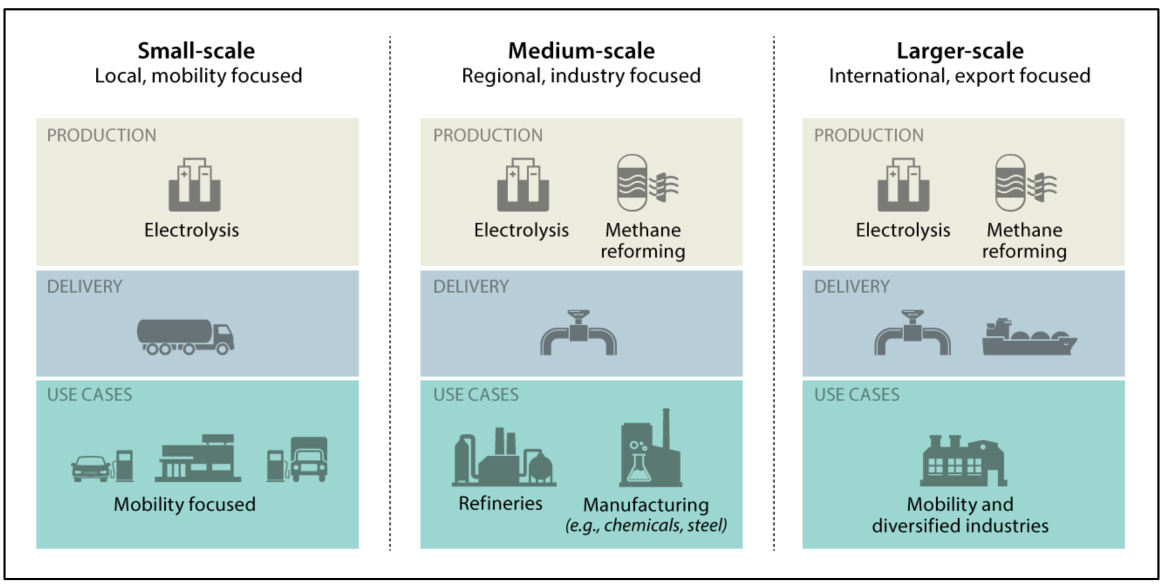
# Size, Scope, and Scale of Future Hydrogen Hubs

Studies have speculated on the size, scope, and scale of future hydrogen hubs. One study noted the advantages and economies of co-location of various industries, as this might allow integration between energy requirements and chemical byproducts, and suggested this might be a driver for the formation of hydrogen hubs.[62] The study considered four characteristic scenarios for hydrogen hubs, constructed around the following demand centers: a city; a port; fertilizer manufacture and petroleum refining; and steelmaking.

Another study surveyed existing and emerging hydrogen hubs in an international context and determined these and future hubs might evolve from existing facilities or plans for existing facilities. These hubs are illustrated in **Figure 3**. The scale of production increases, left-to-right, in the figure; the geographic orientation ranges from local to regional to international, left-to-right. The left-most hub concept, mobility, is envisaged as a public-private partnership, while the other two hub concepts are envisaged as wholly private sector. The studies do not exhaust all possibilities.

Other concepts for hydrogen hubs might combine different applications, scales of production, and off-takers. For example, DOE's Hydrogen Shot program—which supports making hydrogen commercially available at a cost of $1 for 1 kilogram in 1 decade—noted emerging "clusters" in the United States based on other industries and geographies.[63] DOE differentiated the clusters according to resources; influences such as population, policy, or pollution; and end-uses.

**Figure 3. Possible Layouts of Hydrogen Hubs**




**Source:** Adapted from Uwe Weichenhain et al., *Hydrogen Valleys: Insights into the Emerging Hydrogen Economies Around the World*, Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), Luxembourg, 2021.

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[62] Energy Transitions Commission, *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy*, Version 1.2, April 2021, p. 67.

[63] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *DOE Update on Hydrogen Shot, RFI Results, and Summary of Hydrogen Provisions in the Bipartisan Infrastructure Law*, December 9, 2021, at https://www.energy.gov/eere/fuelcells/articles/doe-update-hydrogen-shot-rfi-results-and-summary-hydrogen-provisions. The DOE launched Hydrogen Shot in June 2021.

**Notes:** Delivery is by truck with hydrogen liquid or pressurized gas, by pipeline, or by ocean-going tanker.

# Issues for Congress

## Sufficient Off-Takers to Consume Hydrogen

Consumption of hydrogen today is focused in a relatively concentrated set of end-users. Almost all is consumed by the oil industry or chemical industry either after onsite production or via delivery through dedicated pipelines from large merchant producers.[64] The hydrogen hubs and the additional supply of hydrogen they aim to create will need to be matched to new sources of demand in order to be economically feasible. DOE specifically addresses this problem in its February 2022 RFI and developed Hydrogen Matchmaker to connect hydrogen supplies with users.[65] Global experience with hydrogen hubs underscores the urgency for finding off-takers, with one EU-funded project identifying it as one of the largest financial barriers to realizing such projects.[66] At a February 2022 hearing of the Senate Energy and Natural Resources Committee, Chairman Manchin noted that, if new hydrogen demand were to arise from converting today's end-use applications to hydrogen, it would require large investment from both public and private sectors.[67] Congress may wish to monitor the deployment of hydrogen hubs to see if the demand for the newly created hydrogen supply is sufficient and stable.

## Appropriate Regulation of Hydrogen Pipelines

DOE's 2020 Hydrogen Program Plan identified rights-of-way and permitting for hydrogen pipelines as two of the challenges to overcome for hydrogen delivery infrastructure.[68] Key policy issues that Congress may examine include the regulation of pipeline siting, including potential federal-state jurisdictional conflicts, and the regulation of pipeline rates and terms of service.[69] For example, some hydrogen proponents have suggested that Congress establish federal siting authority for interstate hydrogen pipelines analogous to the Federal Energy Regulatory Commission natural gas siting authority under the Natural Gas Act.[70] Preempting state authority

[64] U.S. Department of Energy, Office of Fossil Energy, *Hydrogen Strategy: Enabling a Low-Carbon Economy*, Washington, DC, July 2020, p. 9, at https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf.

[65] U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *H2 Matchmaker*, at https://www.energy.gov/eere/fuelcells/h2-matchmaker.

[66] Uwe Weichenhain et al., *Hydrogen Valleys: Insights into the Emerging Hydrogen Economies Around the World*, Fuel Cells and Hydrogen 2 Joint Undertaking, Luxembourg, 2021, p. 39.

[67] Chairman Manchin's Opening Statement, during U.S. Congress, Senate Energy and Natural Resources, *Clean Hydrogen*, hearing, 117th Cong., 2nd sess., February 10, 2022.

[68] U.S. Department of Energy, *Hydrogen Program Plan*, DOE/EE-2128, Washington, DC, November 2020, p. 6.

[69] Regulation of hydrogen pipeline siting, commercial service, security, and safety is divided among federal agencies and the states. Federal jurisdiction resides variously with the Surface Transportation Board (STB), the Federal Energy Regulatory Commission (FERC), the Transportation Security Administration (TSA), and the Pipeline and Hazardous Materials Safety Administration (PHMSA). For more information see CRS Report R46700, *Pipeline Transportation of Hydrogen: Regulation, Research, and Policy*, by Paul W. Parfomak.

[70] James Bowe and William Rice, "Building the Hydrogen Sector Will Require New Laws, Regs," *Law360*, January 13, 2021.

in this way could simplify the siting process; however, it would not necessarily ensure such pipelines would be constructed and might raise concerns from affected states.[71]

## Sufficient Transmission, Distribution, and Delivery Infrastructure

Hydrogen in its current uses has a dedicated infrastructure, but one that is small compared to natural gas. Hydrogen pipelines comprise 1,600 miles in the United States compared with 300,000 miles of natural gas transmission pipelines.[72] The layout of these pipelines provides service to a relatively concentrated set of end-users, with most hydrogen pipelines owned by merchant hydrogen producers who sell their hydrogen to industry in bulk.[73] To service a fleet of numerous and relatively small hydrogen refueling stations for FCEVs, for example, will require a different hydrogen delivery infrastructure. This might include additional pipelines and delivery trucks loaded with liquid or compressed hydrogen gas, or onsite hydrogen production from electricity or natural gas. During the legislative activity on the IIJA, the House Committee on Transportation and Infrastructure noted, "The committee believes that robust private sector involvement is necessary to maximize investment in and widespread availability of electric vehicle charging and hydrogen fueling infrastructure."[74] Congress may wish to monitor the build-out of fueling stations and the network of pipelines and trucks and consider whether federal financial incentives would correct any shortfalls or whether such costs should be borne by the private sector.

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[71] For more information see CRS Report R46700, *Pipeline Transportation of Hydrogen: Regulation, Research, and Policy*, by Paul W. Parfomak.

[72] U.S. Department of Transportation: Pipeline and Hazardous Materials Safety Administration, *Annual Report Mileage for Natural Gas Transmission & Gathering Systems*, May 2, 2022. Over 90%, by mile of pipeline, are in Texas and Louisiana with 10 other states having fewer than 35 miles each. U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office, *Hydrogen Pipelines*, at https://www.energy.gov/eere/fuelcells/hydrogen-pipelines. Hydrogen Tools, *Hydrogen Pipelines*, at https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines.

[73] International Energy Agency, *Global Hydrogen Review*, Paris, 2021, at https://www.iea.org/reports/global-hydrogen-review-2021, p. 44.

[74] U.S. Congress, House Committee on Transportation and Infrastructure, *Investing in a New Vision for the Transportation in America Act*, Report of the Committee on Transportation and Infrastructure to Accompany H.R. 3684, 117th Cong., 1st sess., June 22, 2021, H.Rept. 117-70 (Washington: GPO, 2021), p. 537.

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