American Energy Innovation Council

HIGH HOPES FOR HYDROGEN HUBS: ACCELERATING CLEAN HYDROGEN INNOVATION THROUGH REGIONAL HUBS

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EXECUTIVE SUMMARY

As part of the bipartisan Infrastructure Investment and Jobs Act of 2022, Congress authorized a historic federal investment of $8 billion over the next five years to develop clean hydrogen hubs in different regions of the United States. The new Regional Clean Hydrogen Hubs (H2Hubs) program, which will be administered by the Department of Energy's Office of Clean Energy Demonstrations, aims to jumpstart innovation in an industry that could play a vital role in achieving domestic and international climate goals over the next several decades. Clean hydrogen is a leading candidate to address hard-to-decarbonize energy end uses in transportation and industry; it can also help assure grid stability in a net-zero emissions future by providing a means to store energy from intermittent renewable resources such as wind and solar. Clustering projects in regional hubs will facilitate connections between hydrogen producers and users, enabling them to take advantage of connective infrastructure and creating the economies of scale needed to lower the risk of investment in clean hydrogen solutions.

The release of the first H2Hubs program funding opportunity announcement in September 2022 represents a significant first step toward implementing this critical new program. However, important program design and implementation decisions still lie ahead. This report offers specific recommendations for the Department of Energy to maximize clean hydrogen innovation and the program's chances of success in achieving its objectives. The American Energy Innovation Council's recommendations for program implementation are summarized below; the full report provides additional detail for each recommendation, together with more background and context about the need for investment in clean hydrogen and the role of regional clusters in accelerating clean hydrogen innovation.

Recommendations	
Drive innovation and investment for diverse modes of clean hydrogen production and utilization.	1. The H2Hubs program should facilitate and foster strong partnerships with start-ups and innovative entrepreneurs. 2. The H2Hubs program should prioritize projects with diversified utilization and secured revenue streams. 3. Support clean hydrogen demand challenges using funding set aside for additional activities. 4. The H2Hubs program should select different hub ownership and operation models and track their comparative success.

	Recommendations continued
Leverage synergies between H2Hubs program with other decarbonization efforts across DOE.	5. Optimize resources and infrastructure by co-locating clean hydrogen hubs with other relevant energy infrastructure, where possible and advantageous. 6. The H2Hubs program should establish new technical performance targets that are informed by hub projects' technical achievements.
Support partnerships and community engagement practices that promote local buy-in for clean hydrogen projects.	7. Prioritize H2Hubs teams that include diverse participants, including individuals and organizations with technical, business, workforce, and community backgrounds and expertise. 8. Prioritize proposals that site hubs in locations where there is strong community interest and local enthusiasm for hub development. 9. Encourage project developers to use well-established stakeholder engagement practices and apply metrics for evaluating community engagement efforts throughout hub deployment.
Manage projects from entry to exit to maximize learning and help scale clean hydrogen.	10. Facilitate knowledge sharing throughout the hub deployment process to enable clean hydrogen production and utilization at scale. 11. For projects that do not move forward, collaboratively work with project leads to develop an exit plan. 12. Provide clarity and transparency to all stakeholders in the decision-making process for project termination. 13. Avoid binary definitions of "success" and "failure" and evaluate project performance from multiple perspectives.

INTRODUCTION

The American Energy Innovation Council (AEIC) has been working together since 2010 to advance policies aimed at strengthening America's innovation capabilities in clean energy technology. As an essential decarbonization tool, the development, scaling, and deployment of clean hydrogen technologies is a key interest. With the historic establishment of the Regional Clean Hydrogen Hubs (H2Hubs) program through the bipartisan Infrastructure Investment and Jobs Act of 2021, AEIC came together to develop program design and implementation recommendations for the Department of Energy (DOE) to maximize clean hydrogen innovation and ensure program success.

WHY IS CLEAN HYDROGEN IMPORTANT?

With growing recognition of the need for rapid reductions in global greenhouse gas (GHG) emissions, clean hydrogen is emerging as a critical enabling technology for achieving the full decarbonization of energy systems in the United States and around the world. Clean hydrogen is important for several reasons. First, it can serve as a low- or zero-carbon fuel in certain end-uses and sectors, such as long-haul, heavy transport or high-heat industrial processes, that will be difficult to decarbonize through electrification or by other means. Second, clean hydrogen can be used as a climate-friendly industrial feedstock, including in the production of chemicals, iron, and steel. Finally, hydrogen offers a way to store excess electricity generated during periods of high resource availability for use at a later time. This energy storage function could be extremely helpful in increasing the utilization of intermittent renewables such as wind and solar, while also providing valuable benefits in terms of load-balancing and grid stability.

As an energy carrier, hydrogen offers several important advantages: it emits no carbon dioxide (CO_2) at the point of use; it has very high energy density by weight, and it is versatile and can be used in a variety of applications. Hydrogen can also be produced in a variety of ways, from a variety of sources, and it can be transported and stored using known technologies. In fact, hydrogen is already being used and distributed in large quantities for various non-energy purposes—as a feedstock in fertilizer production and in other industrial processes, including in petroleum refining and in the manufacture of cement, glass, metals, and pharmaceuticals.[1] Worldwide demand for hydrogen in these applications has grown rapidly in recent years, to more than 900 million metric tons in 2021, with the United States and China leading global production at present.[1] Expanding the use of hydrogen as part of a comprehensive decarbonization strategy could greatly boost demand by several fold over current levels, according to some studies.[2,3,4]

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1 International Energy Agency (IEA). (2022). *Global Hydrogen Review 2022.* Retrieved from https://www.iea.org/reports/global-hydrogen-review-2022

2 McKinsey and Company. (December 2020). *Net-zero Europe*. Retrieved from https://www.mckinsey.com/capabilities/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost

3 DNV. (June 2022). *Hydrogen Forecast to 2050*. Retrieved from https://www.dnv.com/news/hydrogen-at-risk-of-being-the-great-missed-opportunity-of-the-energy-transition-226628

4 U.S. Department of Energy (DOE). (2022). Draft: DOE National Clean Hydrogen Strategy and Roadmap. Retrieved from https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf

The methods used to produce hydrogen today, however, are carbon intensive: the most common—called steam methane reforming (SMR)—involves reacting natural gas with high-temperature steam in the presence of a catalyst. Other conventional hydrogen production methods, such as gasifying coal or another hydrocarbon feedstock are likewise carbon intensive, emitting as much as nine kilograms of CO_2 for every one kilogram of hydrogen produced.[5] In fact, CO_2 emissions from hydrogen production in the United States alone currently exceed 100 million metric tons per year.[4] Worldwide hydrogen production emissions exceed 900 million metric tons per year, surpassing a quarter of all GHG emissions of the European Union in 2021.[1]

Hydrogen can be made in a low-carbon manner by adding technologies for carbon capture and storage (CCS) to SMR and other conventional, fossil-fuel-based production methods. Hydrogen can also be produced by "splitting" water molecules with an electrical current—this process, called electrolysis, can be carbon free if it uses electricity generated in a zero-carbon manner, such as electricity from renewable resources (wind or solar), nuclear power, or fossil fuel generators with CCS. At present, however, electrolysis is substantially more expensive than SMR and accounts for only a very small fraction (approximately 0.03% worldwide and 1% in the United States) of all hydrogen production.[1,6]

Realizing the promise of clean hydrogen will require overcoming several key innovation challenges. A first priority is to rapidly improve and scale the technologies available for producing hydrogen with low- or zero-GHG emissions, including technologies for capturing CO_2 emissions from SMR or gasification facilities and technologies for renewably powered electrolysis.[7] Significant technology and infrastructure challenges also exist at other points in the hydrogen value chain, including infrastructure to enable the large-scale storage, transportation, distribution, and utilization of clean hydrogen in energy and industrial applications for which hydrogen has not been historically used.[8] These challenges are not small, but they do present the United States—which is rich in both natural gas and renewable energy resources—with an opportunity to build a leadership position in an energy technology with growing global demand.[4] According to one recent analysis, a large-scale, clean hydrogen industry in the United States could support 700,000 jobs and generate $140 billion in annual revenue by 2030.[9] As part of a net-zero emissions economic scenario, hydrogen is estimated to meet

5 Global Carbon Capture and Storage (CCS) Institute. (2021). *Blue Hydrogen*. Retrieved from https://www.globalccsinstitute.com/wp-content/uploads/2021/04/CCE-Blue-Hydrogen.pdf

6 U.S. Department of Energy (DOE). (2020) *Hydrogen Strategy; Enabling A Low-Carbon Economy*. Retrieved from https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

7 Energy Futures Initiative. (2021). *The Future of Clean Hydrogen in the United States*. Retrieved from https://energyfuturesinitiative.org/reports/the-future-of-clean-hydrogen-in-the-united-states/

8 Pure hydrogen exists as a gas at ambient pressures and temperatures. This means that hydrogen, even though it is more energy dense than conventional fossil fuels on a *mass* basis, is far less dense on a volume basis. Compressed hydrogen can be moved in large quantities via pipeline, including via existing natural gas pipelines. Hydrogen can also be liquefied for transport by truck or ship, but this requires compressing and cooling the hydrogen to a very low temperature and specialized cryogenic equipment through the transport process. Alternatively, hydrogen can be converted to another, less demanding, liquid carrier such as ammonia for transport. But this approach likewise comes with additional energy, technology, and infrastructure requirements.

9 Fuel Cell and Hydrogen Energy Association. (2021). *Road Map to a US Hydrogen Economy*. Retrieved from: https://www.fchea.org/us-hydrogen-study

up to 14% of U.S. energy demand by mid-century, provide GHG emission reductions up to 16% from 2005 levels, and generate an estimated 3.4 million jobs by 2050.[4,9]

ACCELERATING CLEAN HYDROGEN INNOVATION THROUGH REGIONAL HUBS

The concept of a technology "hub" is to accelerate the process of discovery, demonstration, and commercialization by targeting investments in a particular geographic area such that project developers can take advantage of shared infrastructure and resources. A clean hydrogen hub would bring hydrogen production, processing, delivery, storage, and end-use projects together with a network of producers, consumers, and connective infrastructure—all in relative proximity.

Governments around the world have begun applying the hub approach to accelerate clean hydrogen development. In the United Kingdom, the HumberZero industrial hub received funding in 2021 to produce hydrogen from offshore wind and SMR with CCS to supply hydrogen, power, and heat to nearby industrial facilities and residential communities.[10] In 2022, Spain committed 150 million in funding for the Puertollano hydrogen hub to build a solar-energy driven hydrogen production facility for green fertilizer production.[11] In China, the Datong Hydrogen Hub has been using solar energy to produce hydrogen for public and urban transportation since 2019.[12]

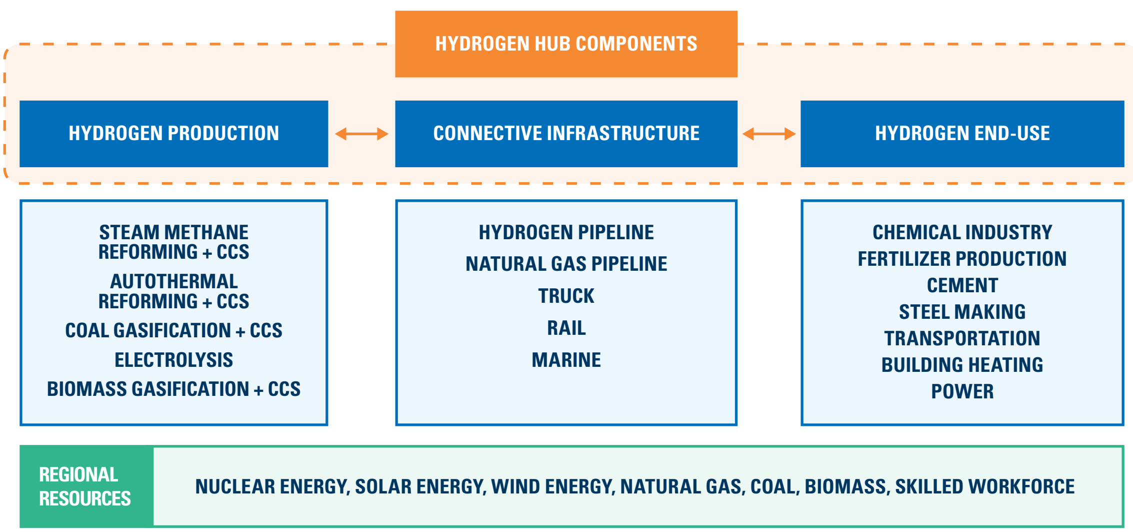

FIGURE 1: COMPONENTS OF A REGIONAL HYDROGEN HUB – UTILIZING REGIONAL RESOURCES AND BRINGING TOGETHER A NETWORK OF PRODUCERS, END-USERS AND NEEDED CONNECTIVE INFRASTRUCTURE IN RELATIVE PROXIMITY.

10 Humber Zero. Retrieved from: https://www.humberzero.co.uk/

11 Iberdrola. Puertollano Green Hydrogen Plant. Retrieved from: https://www.iberdrola.com/about-us/lines-business/flagship-projects/puertollano-green-hydrogen-plant

12 Accenture and World Economic Forum. (2022). Industrial clusters; Working together to achieve net zero. Retrieved from: https://www.accenture.com/_acnmedia/PDF-147/Accenture-WEF-Industrial-Clusters-Report.pdf#zoom=40

With passage of the Infrastructure Investment and Jobs Act (IIJA) in 2021, the United States is joining other countries that are launching hubs for clean hydrogen development. The IIJA authorizes $8 billion of federal investment over five years in the H2 Hubs program, which will be run by DOE's new Office of Clean Energy Demonstrations (OCED).[13]

In seeking to develop clean hydrogen hubs in different regions of the country, the H2Hubs program can provide multiple benefits including:[14]

- Accelerate the scaling of clean hydrogen production technologies.
- Develop the infrastructure needed to support a clean energy transition.
- Enable the decarbonization of supply chains in multiple sectors including heavy industry, transportation, power generation, and critical chemicals like fertilizers.
- De-risk and reduce the cost of clean hydrogen and carbon capture and storage technologies.
- Leverage existing regional resources, infrastructure, and workforce skills to ease the impacts of the clean energy transition, create jobs, and strengthen local economies.

OTHER FEDERAL POLICIES AND PROGRAMS THAT ENABLE CLEAN HYDROGEN INNOVATION

The H2Hubs program is part of a broader set of policies and programs aimed at spurring the technology innovations that will be needed to achieve economy-wide net-zero emissions by 2050.[15] The Energy Act of 2020, for example, authorized $500 million in federal investments to develop emission reduction options, including hydrogen, for hard-to-abate industries.[16] Several other DOE initiatives and research programs, spanning multiple DOE offices, specifically target clean hydrogen. The H2@Scale program, for example, funds cooperative clean hydrogen projects at the National Laboratories; a related initiative, Hydrogen Shot, focuses on developing and scaling lower-cost technologies for producing clean hydrogen. The goal of Hydrogen Shot, which is part of DOE's broader set of Energy Earthshots initiatives, is to reduce production costs for clean hydrogen to $1 per kilogram in under a decade (by comparison, estimates of current production costs for clean hydrogen range from $2 to $8 per kilogram).[4] Collectively, DOE's offices of Energy Efficiency and Renewable Energy, Fossil Energy and Carbon Management, Science, and Nuclear Energy provided more than $316 million for hydrogen-related research and development in

13 Public Law 117 - 58

14 Columbia University. (2021). *Evaluating Net-Zero Industrial Hubs in the United States: A Case Study of Houston*. Retrieved from: https://www.energypolicy.columbia.edu/research/report/evaluating-net-zero-industrial-hubs-united-states-case-study-houston

15 Executive Order (EO) 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability

16 Holland and Knight. (2021). *Energy Policy Act Signals Inclusive, Innovation-Focused Future for DOE*. Retrieved from: https://www.hklaw.com/en/insights/publications/2021/01/energy-policy-act-signals-inclusive-innovation-focused-future-for-doe

fiscal year 2023.[17] In another DOE effort, the H2Matchmaker tool was launched in 2021 to connect clean hydrogen suppliers with end-users. And in March 2022, DOE's Loan Programs Office announced a first-ever loan-guarantee—totaling more than $500 million—for a hydrogen storage project in Utah.[18]

Funding for several existing hydrogen-related programs at DOE were increased in the IIJA, which also established, in addition to the H2Hubs program, a new Clean Hydrogen Electrolysis program and a Clean Hydrogen Manufacturing and Recycling program.[13] Several tax provisions included in the more recent Inflation Reduction Act of 2022—including federal tax credits for hydrogen production, clean energy investment, CCS, and clean vehicles—are designed to provide further incentives for clean hydrogen investments. The Inflation Reduction Act also provided for federal investments in fuel delivery infrastructure, a cap on methane leaks from natural gas production and distribution infrastructure, and support for the adoption of hydrogen technology in industrial applications.[19]

DESIGN AND IMPLEMENTATION OF THE REGIONAL CLEAN HYDROGEN PROGRAM

The H2Hubs program is required by statute to launch at least four regional hubs that: (1) demonstrably aid the achievement of the clean hydrogen production standard; (2) demonstrate technologies for producing, processing, delivering, and storing hydrogen, as well as end-use technologies for utilizing hydrogen; and (3) provide a foundation for developing a national clean hydrogen network that can sustain a clean hydrogen economy. IIJA statute also defines the term "clean hydrogen" to mean hydrogen produced with a carbon intensity equal to or less than two kilograms of CO_2-equivalent emissions per kilogram of hydrogen produced at the site of production (approximately an 80% reduction in CO_2 intensity compared to conventional hydrogen production pathways).

A funding opportunity announcement (FOA) released by DOE in September 2022 outlines three main elements of future hydrogen hubs:[20]

- **Clean hydrogen supply:** The H2Hubs program aims to support a range of technologies and processes for producing clean hydrogen, including renewable- or nuclear-powered electrolysis, SMR with CCS, and gasification or thermal conversion of biomass, among others. Under the IIJA, DOE is required to fund projects that utilize diverse feedstocks, with at least one hub focused on clean hydrogen production

17 Public Law 117-328

18 U.S. Department of Energy; Loan Program Office. (2022). *Advanced Clean Energy Storage*. Retrieved from: https://www.energy.gov/lpo/advanced-clean-energy-storage

19 Bipartisan Policy Center. (2022). *Inflation Reduction Act Summary of Energy and Climate Provisions*. Retrieved from: https://bipartisanpolicy.org/blog/inflation-reduction-act-summary-energy-climate-provisions/

20 Office of Clean Energy Demonstrations Funding Opportunity Exchange. *DE-FOA-0002779: Bipartisan Infrastructure Law: Additional Clean Hydrogen Programs (Section 40314): Regional Clean Hydrogen Hubs Funding Opportunity Announcement*. Retrieved from: https://oced-exchange.energy.gov/Default.aspx#FoaId4dbbd966-7524-4830-b883-450933661811

using fossil fuels and at least two other hubs focused on production using renewable energy and nuclear energy, respectively.

- **Clean hydrogen end-uses:** H2Hubs aims to demonstrate multiple end-uses for clean hydrogen. At a minimum, the IIJA requires that the program demonstrate at least one existing or new end-use in the following sectors: power generation, industry, residential buildings, and transportation.[13]
- **Connective infrastructure:** Connective transportation and delivery infrastructure is essential to link supplies of clean hydrogen with end users. Applicants for federal funding under the H2Hubs program are encouraged to leverage existing facilities and infrastructure for storing and delivering clean hydrogen (this direction also applies to the infrastructure needed to implement CCS, where applicable, including pipelines for bringing captured CO_2 from clean hydrogen production facilities to geologic storage sites).

Besides identifying key hub elements, the H2Hubs program articulates several regional resource and workforce objectives. To promote investments in helping local workforces transition to a clean energy economy, at least two hubs must be located in regions that have a high concentration of fossil-fuel resources.[13] In addition, the IIJA requires DOE to prioritize projects that can be expected to create opportunities for skills training and long-term employment for local residents.

FUNDING OPPORTUNITY STRUCTURE AND TIMELINE

DOE has structured the H2Hubs program to provide $6–$7 billion in initial funding to launch anywhere from six to ten hubs around the country. The remaining $1–$2 billion of funding authorized under the IIJA will be reserved for future hub launches, supporting activities, or other program needs. DOE began reviewing concept papers for proposed hubs, as a prelude to full applications, in November 2022. The concept papers are intended to provide basic information on hub proposals, as such they are expected to identify the hub project team; define a preliminary scope, plan, and timeline; and include an expression of interest in submitting a full application. If concept papers align with the objectives of the FOA, applicants are encouraged to move forward and submit full applications, due to DOE in April 2023. DOE expects to complete the process of reviewing applications, providing comments, reviewing responses to comments, and conducting pre-selection interviews for purposes of making final project selections by the end of 2023.[20]

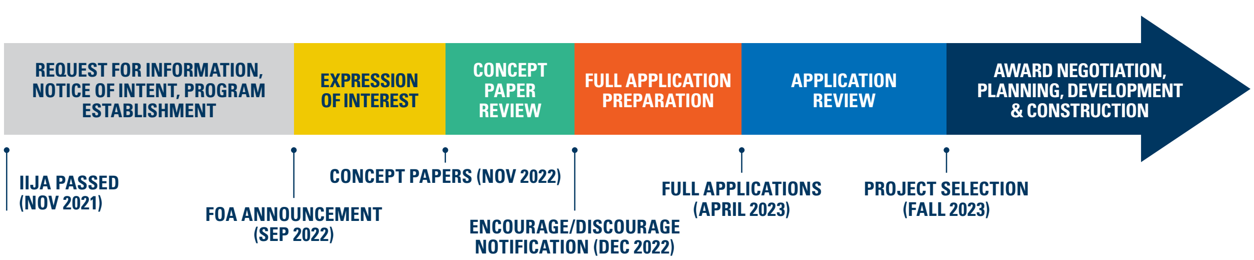

FIGURE 2: THE REGIONAL CLEAN HYDROGEN HUBS(H2HUBS) PROGRAM AND FUNDING OPPORTUNITY TIMELINE

For approved hub proposals, DOE envisions that deployment will occur over four phases spanning 8–12 years.[20]

- **Phase One** is expected to take one to one-and-a-half years. In this phase, project teams will undertake detailed planning and analysis to develop a hub design, identify technology needs, develop a business case, and engage relevant local stakeholders.
- **Phase Two** is set in motion only after the successful completion of phase one and is expected to span two to three years. In this phase DOE would provide funding for needs related to engineering designs and business development, securing site access, labor agreements, permitting, offtake agreements, and community engagement activities.
- **Phase Three** covers the installation, integration, and construction phases. It is expected to span a period of two to four years, depending on the project.
- **Phase Four**, the final phase, is expected to last two to four years. The focus in this phase is on demonstrating hub operation and collecting data on technical performance and financial viability.

At the end of each phase, and within phases, H2Hubs program administrators will evaluate project performance and make related funding decisions, including whether to continue or withdraw federal support, and whether project adjustments or changes are warranted. The program will fund projects through cooperative agreements, with a maximum federal cost share of 50% over the lifetime of the award and in each development phase.[20]

AEIC'S RECOMMENDATIONS FOR HUB SELECTION AND PROGRAM IMPLEMENTATION

Successful implementation of the H2Hubs program is critical to set the United States on a path to producing 10 million metric tons of clean hydrogen annually by 2030, which is the target articulated in DOE's National Clean Hydrogen Strategy and Roadmap.[4] AEIC provides the recommendations for the H2Hubs program to advance four core objectives outlined below:

- Drive innovation and investment in a range of technologies that allow for diverse modes of clean hydrogen production and utilization.
- Leverage synergies between clean hydrogen projects and other clean energy projects and align H2Hubs program goals with other decarbonization efforts.
- Support partnerships and community engagement practices that promote local buy-in for clean hydrogen projects.
- Manage projects from entry to exit in a manner that maximizes learning, both about technical issues and project management practices, to help scale clean hydrogen.

RECOMMENDATIONS TO DRIVE INNOVATION AND INVESTMENT IN CLEAN HYDROGEN TECHNOLOGIES

Recommendation 1: The H2Hubs program should facilitate and foster strong partnerships with start-ups and innovative entrepreneurs. Technologies for producing clean hydrogen are at an early stage of deployment globally and in the United States.[3] Additionally, almost all advanced hydrogen production pathways have yet to meet desired system performance, cost, and lifecycle-emission targets.[4] Although new pilot and demonstration projects continue to be announced, further innovation in clean hydrogen production, delivery, and end-use technologies is needed.[21] The H2Hubs program can promote innovation by working closely with start-ups and entrepreneurs. DOE is already well equipped to stimulate innovation through its H-prize competition and Regional Technology and Innovation Hub program, as well as through its Office of Technology Transfer; DOE and other federal agencies also participate in the Small Business Innovation Research and Small Business Technology Transfer programs. These programs already work with entrepreneurs and small businesses on a wide range of technologies at different stages of development.[22] Early research and development should continue to be supported through other program funds. However, more formal integration with these programs would enable the H2Hubs program to connect with regional innovators, accelerators, and small businesses and build a robust pipeline of innovation for a national clean hydrogen economy.

21 S&P Global. (2021). US hydrogen pilot projects build up as gas utilities seek low-carbon future. Retrieved from: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-hydrogen-pilot-projects-build-up-as-gas-utilities-seek-low-carbon-future-65570349

22 Climate Tech VC (2022). *Founders Guide to the DOE; DOE 123s for climate RDD&D*. Retrieved from: https://www.ctvc.co/founders-guide-to-the-doe/

Recommendation 2: The H2Hubs program should prioritize projects with diversified utilization and secured revenue streams. Investments in clean hydrogen production require a degree of confidence that there will be customers for the hydrogen. To reduce the risk that demand will fall short of expectations, hubs should ideally support multiple hydrogen end-uses. Past DOE demonstration programs have shown that high-risk projects that are reliant on a single revenue stream can be significantly impacted by market changes.[23] Thus, DOE should prioritize hub designs and business plans that include multiple end-users and security of revenue that enables long-term hub sustainability.

Recommendation 3: Support clean hydrogen demand challenges using funding set-aside for additional activities. Support for clean hydrogen end-users is an essential aspect of building a national clean hydrogen economy and the H2Hubs program. Faster adoption of clean hydrogen utilization across multiple sectors of our economy can ensure hubs that receive DOE funding will have a sustainable business model long after federal support is withdrawn. The H2Hubs program should use a portion of the $1-2 billion reserved for later activities to provide demand-targeted incentives/efforts.

Recommendation 4: The H2Hubs program should select different hub ownership and operation models and track their comparative success. In the long-term, hydrogen hubs should be self-sustaining, well-integrated, large-scale economic clusters. In support of this objective, the H2Hubs program should experiment with different hub ownership structures and operational models. For instance, a natural gas producer, project management experts, and energy consultants may come together to lead a hub, while enabling external entities like materials and technology providers, hydrogen end users, and academic institutions to participate in varied capacities. Other hub teams may use similar arrangements or use alternative organization structures such as an industry alliance, integration into public utility operators, limited liability partnership, or consortium (incorporated or unincorporated) to jointly plan, build, and operate a hub. Teams may also choose to pursue different finance structures or combinations of structures to fund hub projects.[12] DOE should use lessons learned from experimenting with a variety of ownership, risk management, and financing models to inform future funding decisions. DOE should also facilitate knowledge and experience sharing among hub participants and the broader public.

RECOMMENDATIONS TO HARMONIZE H2HUBS PROGRAM WITH OTHER DECARBONIZATION EFFORTS

Recommendation 5: Optimize resources and infrastructure by co-locating clean hydrogen hubs with other relevant energy infrastructure where possible and advantageous. Co-locating hydrogen projects in proximity to renewable power and heat generators, geological carbon dioxide storage, and industrial end-users can help create a circular clean-energy economy. Although not possible in every scenario, nor necessary for every project, co-locating projects can also deliver significant benefits in terms of energy and water use efficiency and GHG reductions in some scenarios.[12] Therefore, the H2Hubs FOA encouragement of hub applicants to leverage existing facilities, infrastructure, and rights-of-way and coordinate/co-locate hub projects with other existing or planned energy infrastructure projects is a welcomed feature.

23 Clean Air Task Force. (2020). *Petra Nova: De-risking Carbon Capture Business Models with Saline Storage*. Retrieved from: https://www.catf.us/2020/08/petra-nova-de-risking-carbon-capture-business-models-with-saline-storage/

Recommendation 6: The H2Hubs program should establish new technical performance targets that are informed by hub projects' technical achievements. DOE's Hydrogen and Fuel Cell Technologies Office publishes multi-year technical performance targets that are periodically updated to reflect technological progress and new developments. The office's current targets are not up to date, however; in addition, they are limited to specific applications and production pathways, and are not informed by experience with clean hydrogen production at scale.[24] The H2Hubs FOA, for example, calls for hub proposals that can demonstrate clean hydrogen production on a commercial scale of 50–100 metric tons per day; to date, only one project meets or exceeds this rate of production.[25] Large-scale demonstration facilities can provide valuable insights about materials and equipment performance, monitoring and safety control tools, durability, energy and water use, efficiency and waste management opportunities, and economies of scale in transport and storage that can inform future research and investment decisions. As DOE selects and supports hub projects it will be critical to ensure that knowledge and experience gained in the process is both widely shared and reflected in future program metrics and performance targets. Additionally, coordinating with other complementary efforts, such as the Hydrogen Shot program, through an intra-agency working group will be essential to the H2Hubs overall success.

RECOMMENDATIONS TO SUPPORT LOCAL PARTNERSHIPS AND MEANINGFUL COMMUNITY ENGAGEMENT

Recommendation 7: Prioritize H2Hubs teams that include diverse participants, including individuals and organizations with technical, business, workforce, and community backgrounds and expertise. Diverse project teams will be in a better position to build and sustain political support and local buy-in. The FOA therefore encourages applicants to create diverse, committed, and capable teams that can demonstrate the hub's technical and financial viability and sustainability. The FOA also encourages applicants to obtain statements of support from organized labor and engage in close consultation with local authorities and communities to ensure that hub development aligns with local interests and delivers lasting regional benefits even after federal funding ends. Thus, the selection process should favor hub teams and coalitions that include government, labor, local organizations, and community representatives in addition to technical experts, academics, and corporate and local business stakeholders.

Recommendation 8: Prioritize proposals that site hubs in locations where there is strong community interest and local enthusiasm for hub development. Projects deployed with strong community support and participation in decision making are more likely to succeed and maximize the local and regional benefits from federal investment. Community-invited proposals and approaches can help avoid resistance to clean energy development and ensure that projects are deployed in locations where there is strong local interest and support.

Recommendation 9: Encourage project developers to use well-established stakeholder engagement practices and apply metrics for evaluating community engagement efforts throughout hub deployment. Thoughtful

24 U.S. Department of Energy, Hydrogen and Fuel Cell Technologies Office. (2014). *DOE Hydrogen and Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan*. Retrieved from: https://www.energy.gov/eere/fuelcells/articles/hydrogen-and-fuel-cell-technologies-office-multi-year-research-development

25 Clean Air Task Force. U.S. Carbon Capture Project Map. Retrieved from: https://www.catf.us/ccsmapus/

consultation and involvement of local stakeholders and communities is needed, both to address environmental concerns and enable lasting adoption of climate solutions. The H2Hubs FOA therefore requires applicants to include a detailed plan for community engagement. In addition, DOE should make resources for community engagement available to hub developers, including best practice documents and tools for community education, consultation, and decision-making (such as guidelines, principles, survey, and education kits).[26,27,28,29] As projects are selected and go through planning, design, construction, and operating phases, the H2Hubs program should encourage project leads to engage relevant stakeholders throughout. The program should also develop a set of community engagement practices and characteristics that will be used to evaluate and guide projects. The table below lists relevant practices and characteristics for successful stakeholder and community engagement. A scale for rating projects on the quality of their engagement efforts can be developed using published best practices along with input from practitioners, guidance from local communities, and information about project specifics.

SUCCESSFUL COMMUNITY ENGAGEMENT PRACTICES AND CHARACTERISTICS[30,31]

- ✓ Conducted early engagement
- ✓ Communicated local project benefits and perceived risks through public presentations
- ✓ Tailored outreach materials to different audiences and employed varied formal and informal engagement strategies
- ✓ Demonstrated knowledge about relevant stakeholders (who is/is not at the table) and had effective characterization of local opinions prior to project development
- ✓ Demonstrated clarity about the role of engagement in decision making (informing, consulting, involving, collaborating, and empowering)
- ✓ Involved local stakeholders and community members in initial project planning
- ✓ Gained local political support
- ✓ Addressed key concerns of the community
- ✓ Provided multiple tools, opportunities or strategies to inform community about on-going activity

26 Forbes S, Almendra F, Ziegler M. (2010). *Guidelines for Community Engagement in Carbon Dioxide Capture, Transport, and Storage Projects*. World Resources Institute, Washington DC.

27 IFC (2007). *Stakeholder engagement: A good practice handbook for companies doing business in emerging markets*. Retrieved from IFC engagement handbook.

28 U.S. Department of Energy, National Energy Technology Laboratory. (2017). *Best practices for: Public outreach and education for carbon storage projects* (DOE/NETL/1845).

29 Hund, G. E., Engel-Cox, J. A. (2002). Two-way responsibility: The role of industry and its stakeholders in working towards sustainable development. In J. Andriof, S. Waddock, B. Husted, & S. S. Rahman (Eds.), *Unfolding stakeholder thinking* (pp. 217-231). Sheffield, UK: Greenleaf.

30 U.S. Government Accountability Office. (2022). *Decarbonization: Status, Challenges, and Policy Options for Carbon Capture, Utilization, and Storage*. Retrieved from: https://www.gao.gov/products/gao-22-105274

31 Bipartisan Policy Center. (2023). *Case Study: The federal role in stakeholder engagement for a carbon capture and storage demonstration project*. https://bipartisanpolicy.org/report/engaging-stakeholders-ccs-demo-projects/

RECOMMENDATIONS TO PROMOTE KNOWLEDGE GAINS FROM PROJECT ENTRY TO EXIT

Recommendation 10: Facilitate knowledge sharing throughout the hub deployment process to enable clean hydrogen production and utilization at scale. Hub projects will leverage large, long-term public investments to develop a range of options for producing and utilizing clean hydrogen at scale. To continue accelerating the commercialization of clean hydrogen technologies throughout this period of federal support, DOE should promote the sharing of non-proprietary information and knowledge across hubs and with the broader public. Knowledge sharing performed through DOE's own National Energy Technology Laboratory (NETL) Carbon Storage program and its Regional Sequestration Partnerships can serve as a great example. As part of the Carbon Storage program, NETL developed, managed, and distributed best practice manuals, online tools and databases, and training and outreach resources to address various challenges among stakeholders working in this area.[32] DOE can do the same for the H2Hubs program to facilitate learning about the technical, financial, infrastructure, and social aspects of deploying hydrogen hubs. DOE can also provide separate forums or platforms for knowledge sharing with hubs teams and other relevant technical stakeholders, and the public.

Recommendation 11: For projects that do not move forward, collaboratively work with project leads to develop an exit plan. After initial project selection, projects will face at least three decision points concerning funding continuation (or discontinuation) under DOE's four-phased hub funding structure. Details of these go/no-go decision points and milestones will be negotiated between DOE and project leads. As part of these negotiations, DOE and project developers should agree on a project-specific transition or exit management plan, in the event that the next round of funding is not awarded.

Recommendation 12: Provide clarity and transparency to all stakeholders in the decision-making process for project termination. In the past, DOE has sometimes terminated or redirected planned projects well into the deployment phase. In some cases, major changes in terms of project characteristics and site have been made with short public notice.[31,33] Such opaque decision making can negatively impact project developers, relationships with communities, and public perceptions of DOE.[31,34] Therefore, DOE should be more transparent about its decision-making processes and should provide adequate notice to project developers and affected communities about major decisions, including decisions to make major changes or terminate projects, prior to public announcement.

Recommendation 13: Avoid binary definitions of "success" and "failure" and evaluate project performance from multiple perspectives. The definition of "success" in DOE demonstration programs has historically been too focused on whether a final project operates and meets budget targets. However, evaluating projects from portfolio perspective can provide valuable insights even from projects that fail to "turn on". The H2Hubs

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32 Litynskia, John, Andrea McNemara, Traci Rodostaa, Dawn Deela, Derek Vikarab, Rameshwar D. Srivastavab, Larry Myerc, and Robert Kanec. (2013). *U.S. DOE's Efforts to Promote Knowledge Sharing Opportunities from R&D Efforts: Development of the U.S. Carbon Utilization and Storage Atlas and Best Practices Manuals*. https://www.sciencedirect.com/science/article/pii/S1876610213007832?ref=cra_js_challenge&fr=RR-1

33 Gill, Elizabeth, Hallisey, Mary, Baranowski, Ruth, Preziuso, Danielle. (2022). *Equitable Demonstration and Deployment Roundtable Report*. Retrieved from: https://www.nrel.gov/docs/fy22osti/81593.pdf

34 U.S. Government Accountability Office. (2021) *Carbon Capture and Storage: Actions Needed to Improve DOE Management of Demonstration Projects*. Retrieved from: https://www.gao.gov/assets/gao-22-105111.pdf

program should therefore avoid binary declarations of “success” or “failure” and focus instead on ensuring that even those projects that don’t move forward add to the knowledge base for scaling clean hydrogen technologies. DOE should develop additional success evaluation criteria throughout go/no-go checkpoints beyond budget and timeline. Third-party evaluations of DOE-funded projects that account for project experience and lessons learned from multiple perspectives have provided useful insights in the past.[33] For projects terminated after the second phase, DOE should solicit a third party to retrospectively evaluate hub management and develop a publicly accessible report on lessons learned.

CONCLUSION

If executed successfully, the Regional Clean H2Hubs program can accelerate clean hydrogen innovation and deployment at scale. Leveraging the regionally targeted investment, H2hubs can tangibly bring together clean hydrogen supply, demand, and infrastructure to decarbonize multiple sectors, produce economic benefits, and put the United States on the path to net-zero emissions by 2050. Tasked with the implementation of the H2Hubs program, DOE can make several design and program execution choices to create four or more H2Hubs across the country by 2026. This report provides tangible recommendations from AEIC’s experienced clean energy leaders to drive innovation and investment in a diverse set of technologies, synergize efforts and project objectives across other DOE efforts, promote local buy-in for clean hydrogen projects, and utilize knowledge sharing practices that maximize public learning of clean hydrogen scale-up and acceleration processes.

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