U.S. Department of Energy
Advanced Research Projects Agency-Energy (ARPA-E)

Request for Information
DE-FOA-0003494
on Geologic Hydrogen Resource Exploration

Introduction:

The purpose of this RFI is to solicit input for a potential Advanced Research Projects Agency-Energy (ARPA-E) program focused on evaluating novel approaches to: 1) explore for naturally occurring subsurface hydrogen resources or geologic targets for hydrogen stimulation, and 2) develop methodologies to determine the recoverable reserves of hydrogen from natural accumulation or available through stimulation. These approaches will accelerate the discovery and economic evaluation of these resources and inform management steps needed to harness them.

Areas not of Interest for Response to this RFI:

A potential ARPA-E program would focus on technological solutions for expediting the discovery of naturally occurring geologic hydrogen resources and associated production methods. Approaches not of interest include:

- Discovery or quantification of deposits of fossil fuel resources (e.g., coal, natural gas, oil) that may be converted to hydrogen;
- Identification of subsurface resources that may be only relevant for industrial production of hydrogen through electrolysis, methane pyrolysis, or any other process; and
- Funding for conventional drilling projects (e.g., "wildcat drilling" in locations that are not established oil fields).

RFI Guidelines:

CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Note that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS RFI DOES NOT CONSTITUTE A FUNDING OPPORTUNITY. NO FUNDING OPPORTUNITY EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E's consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential**.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on December 2, 2024.** Emails should conform to the following guidelines:

- Insert "<your organization name> - Response to RFI on Geologic Hydrogen Resource Exploration" in the email subject line.
- In the body of your email, include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center [FFRDC], government-owned/government-operated [GOGO]), email address, telephone number, and area of expertise.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential materials, designs, or processes.

Background:

To fulfill the expectations of the global energy transition, demand for hydrogen is forecast to increase 500% by 2050.[1] Current methods of production release carbon dioxide (CO_2) during the conversion of fossil resources (e.g., methane or coal) to hydrogen. In order to reduce the potential greenhouse gas (GHG) impacts of increased hydrogen demand on the global clean energy transition, the industry must move beyond conventional production methods. The Inflation Reduction Act, passed in 2022, provides the maximum incentives for the production of hydrogen with associated GHG emissions of less than 0.45 kilograms (kg) of CO_2 equivalents (CO_2e) per kg of hydrogen (CO_2e/kg H_2).[2] Additionally, the Department of Energy (DOE) has set an "Energy Earthshot" target for clean hydrogen to cost $1/kg or less within a decade.[3]

To meet these targets (less than $1/kg and less than 0.45 kg CO_2e/kg H_2) the DOE is establishing a network of Hydrogen Hubs that rely heavily on industrial means to create "green" hydrogen (through the electrolysis of water) and "blue" hydrogen (through methane conversion with carbon capture and sequestration), and a system of tax credits to reduce costs associated with these processes.[4] However, there are concerns that these energy-intensive blue and green hydrogen production methods cannot meet the targets due to the higher cost of, high demand for, and limited availability of sufficient clean electricity in the right locations to power these processes while emitting fewer GHGs than fossil fuels.[5]

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[1] International Energy Agency. "Global Average Levelised Cost of Hydrogen Production by Energy Source and Technology, 2019 and 2050." IEA. Accessed October 17, 2024. https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050

[2] U.S. DOE. "Financial incentives for hydrogen and fuel cell projects." Accessed October 17, 2024. https://www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects

[3] U.S. DOE. "Hydrogen Shot." Accessed October 17, 2024. https://www.energy.gov/eere/fuelcells/hydrogen-shot

[4] Text - H.R.5376 - 117th Congress (2021-2022): Inflation reduction act of 2022 | congress.gov | library of Congress. Accessed October 17, 2024. https://www.congress.gov/bill/117th-congress/house-bill/5376/text

[5] Greenwald, Julia E., Mervin Zhao, and Douglas A. Wicks. "Critical Mineral Demands May Limit Scaling of Green Hydrogen Production." Frontiers in Geochemistry 1 (January 16, 2024). https://doi.org/10.3389/fgeoc.2023.1328384

Naturally occurring geologic hydrogen is produced from rocks composed of iron-bearing minerals in a reduced state through a process known as serpentinization (in some limited cases, geologic hydrogen results from naturally occurring nuclear radiolysis of water).[6] Geologic hydrogen may come from naturally accumulating hydrogen reserves or from stimulation of target formations to produce hydrogen. The resource potential varies considerably, but most estimates point towards potential production in the billions of tonnes per year with a projected cost of less than $1/kg H_2 and associated GHG emissions of less than 0.45 kg CO_2e/kg H_2.[7,8] While geologic hydrogen has traditionally been overlooked, the past few years have seen a rapid increase (from one organization to more than 100) in the number of public and private organizations exploring for hydrogen worldwide.

Most current exploration campaigns focus on drilling wells at sites with promising geology. These efforts, in limited instances, also involve geophysical surveying aimed at imaging the subsurface in a non-invasive manner.[9] While these efforts have produced successes, this process is hindered primarily by a limited understanding of the geologic processes responsible for producing hydrogen within the Earth's interior. This lack of knowledge results in drilling operations based on untested geologic models that lead to underwhelming results. Surveying technology has advanced significantly within the past 100 years for mining and oil and gas exploration, but these methods tend to focus on porous sedimentary rock and are not necessarily relevant for hydrogen (which may be located anywhere and produced in deeper crystalline igneous or metamorphic rock). The use of surveying methodologies unsuited for hydrogen resource discovery may lead to false negatives that turn prospectors away from promising sites, resulting in untapped resources.

Beyond resource discovery, the requirements to produce hydrogen from these resources by tapping into naturally occurring hydrogen gas streams or stimulating the production of hydrogen are not well understood. The state of the art for natural hydrogen exploration involves considerable guesswork and uncertainty that requires innovation in the emerging field of resource characterization.

ARPA-E is soliciting information for how the agency can foster innovation in technologies and methodologies that can accomplish the following goals:

1. Produce a suite of exploration technologies specific to detecting either naturally occurring subsurface hydrogen concentrations or viable formations for hydrogen stimulation on land and offshore;
2. Increase the accuracy and precision of detection for either naturally occurring subsurface hydrogen concentrations or viable formations for hydrogen stimulation;
3. Reduce the cost of exploration efforts for either naturally occurring subsurface hydrogen concentrations or viable formations for hydrogen stimulation;

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[6] Hand, Eric. "Hidden Hydrogen: Does Earth Hold Vast Stores of a Renewable, Carbon-Free Fuel?" 2023. https://www.science.org/content/article/hidden-hydrogen-earth-may-hold-vast-stores-renewable-carbon-free-fuel

[7] Klein, Frieder, Jesse D. Tarnas, and Wolfgang Bach. "Abiotic Sources of Molecular Hydrogen on Earth." Elements 16, no. 1 (February 1, 2020): 19–24. https://doi.org/10.2138/gselements.16.1.19

[8] Zgonnik, Viacheslav. "The occurrence and geoscience of natural hydrogen: A comprehensive review." Earth-Science Reviews 203 (April 2020). https://doi.org/10.1016/j.earscirev.2020.103140

[9] Zhang, Mengli, and Yaoguo Li. "The Role of Geophysics in Geologic Hydrogen Resources." Journal of Geophysics and Engineering 21, no. 4 (May 20, 2024): 1242–53. https://doi.org/10.1093/jge/gxae056

4. Accelerate the discovery process of either naturally occurring subsurface hydrogen concentrations or viable formations for hydrogen stimulation;
5. Define the geologic processes surrounding production of naturally occurring subsurface hydrogen through either serpentinization or radiolysis of water;
6. Quantify the recharge of hydrogen reservoirs from hydrogen generative processes of naturally occurring subsurface hydrogen through either serpentinization or radiolysis of water; and
7. Inform resource prediction, site management, economic returns, subsurface engineering efforts, environmental impact and mitigation actions through better characterization and monitoring.

RFI Questions:

ARPA-E encourages responses that address any subset of the following topics. The questions present a variety of topics as examples, but respondents are not restricted to responses to these topics and innovative ideas are encouraged. **ARPA-E does not expect any one respondent to answer all, or even many, of the questions in this RFI. Please answer only the sections and questions relevant to your interest and experience.** In your response, indicate the question number(s) you are responding to (e.g., Response to RFI Question 1.a). Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies that are not outlined below, except for those that fall under the "Areas Not of Interest for Responses to this RFI" described above.

Section 1: Exploration Strategies

The current subsurface exploration strategy for naturally occurring hydrogen or geologic formations with stimulation potential is a derivative of strategies implemented in the mining and oil and gas industries. New subsurface exploration strategies are needed for hydrogen to improve success rates and control upfront costs.

a. What are exploration strategies for identifying new naturally occurring subsurface hydrogen resource plays? What criteria should determine an effective strategy?
b. How can prospective geologic blocks be selected from reconnaissance areas? What criteria should be followed in evaluating prospective geologic blocks?
c. What drilling strategy is necessary for exploring for naturally occurring subsurface hydrogen or formations ideal for stimulation within a prospective block?
d. What criteria should define the quality of hydrogen reservoirs or hydrogen source rocks? How can these be implemented in exploration strategies?
e. What criteria should determine drilling locations in prospective blocks and the prioritization of wells for drilling?
f. How can non-invasive geophysical exploration and subsurface methods be used to determine optimal well locations?
g. What are the strategies and criteria to assess the success or failure of the first drilled well? How can such failures be used to calibrate or mitigate initial failures to intersect resources?
h. What are the key drilling operation factors and how can operational factors be de-risked proactively?
i. Are there unique environmental impacts and potential mitigation strategies associated with exploration for hydrogen?

Section 2: Geologic Hydrogen Systems

The current understanding of the naturally occurring geologic processes that lead to hydrogen production within the subsurface is insufficient. The understanding of production rates, kinetics, and other driving factors is still in its infancy.

a. What geologic hydrogen generation rate would constitute the lower bound of economic hydrogen source rock? Can technologies or methods to determine such lower bounds be developed?
b. What geologic hydrogen consumption rate would set the upper bound of economic hydrogen accumulation that can occur?
c. What is the maximum migration distance between source rocks and reservoir based on the above knowledge, assuming other idealized conditions?
d. Are there dynamic subsurface conditions that may potentially reduce the accuracy of resource evaluation methods over time?

Section 3: Mapping

Current resource surveying utilizes equipment and methodologies pioneered by the mining and oil and gas industries. To minimize costs and improve resource characterization success rates, specific surveying approaches to identify naturally occurring subsurface hydrogen should be developed. Technological innovations focused on natural hydrogen exploration may include but are not limited to: large-scale mapping using space or aerial-based surveying methods; artificial intelligence and machine learning (AI/ML) integration; adaptation of established exploration methodologies from oil, natural gas, and mining industries; detection of atmospheric gas anomalies; surface topology identification; and extant data integration/interpretation.

a. What surface exploration methods can be used to decide the reconnaissance area and what technological gaps are there in the available methodologies?
b. Can surface exploration methods alone decide the prospecting blocks and siting within the target blocks?
c. Can surface exploration methods decide which well locations to drill? What other information would be needed?
d. In addition to the focus on midcontinent rift regions, what are other prospective geologic hydrogen regions in North America? Provide data or prior tests to support your response.
e. What are the challenges in using sampling of surface gas and geochemistry to infer subsurface geologic hydrogen potential, and what auxiliary data points are needed?

Section 4: Subsurface Geophysical Exploration

Non-invasive imaging and borehole logging are the mainstays of contemporary resource exploration, especially within the mining and oil and gas industries. New methodologies and technologies (e.g., sensors) are needed to improve accuracy, limit upfront costs, and increase the number and scale of natural hydrogen exploration campaigns. These innovations may include but are not limited to: large scale volumetric subsurface imaging using 2D/3D/4D tomography; space and aerial-based subsurface imaging; AI/ML data interpretation; adaptation of established non-invasive imaging methods from the oil, natural gas, and mining industries; and borehole logging.

a. What non-invasive exploration methods can be applied to hydrogen to determine reconnaissance areas?
b. Which commonly used methods are likely not relevant for geophysical surveying of naturally occurring subsurface hydrogen or for locating formations viable for stimulation through enhanced serpentinization?
c. Can non-invasive exploration methods determine the prospecting area, and what is the required efficiency of these methods in terms of cost and time?
d. How can the hydrogen reserve potential be estimated within the prospecting area (i.e., upper bound) without drilling? What are the technology gaps?
e. Can non-invasive exploration help decide the drilling well locations? If so, what would be the effect on time, cost, and the success rate in identifying subsurface hydrogen resources?
f. How can potential reservoirs that could host hydrogen accumulations be imaged?
g. How can the accumulating structures relevant to naturally occurring hydrogen be evaluated?
h. What are the technology gaps in imaging the lateral variations and discontinuities in hydrogen accumulations?
i. How can one identify the hydrogen reservoir depth and thickness in preparation for drilling?
j. What are the challenges associated with hydrogen reservoirs compared to natural gas, especially with thin hydrogen reservoirs?
k. What are the pros and cons of different geophysical methods for exploring for hydrogen source rocks, reservoirs and their changes over time? How can the advantages be utilized while avoiding the disadvantages?
l. Are there indirect indicators to the presence of potential hydrogen reservoirs such that these indicators can be used in exploration?
m. Is there a need to develop new petrophysical relationships between naturally occurring physiochemical phenomena associated with a hydrogen system and geophysical measurement parameters?
n. Can geological environments with reduced (or suppressed) hydrogen consumption be identified using geophysics?
o. What are some advantages or disadvantages in using borehole logging for exploring for and developing hydrogen reserves?
p. Is there a need to innovate new borehole logging methodologies, or are conventional methodologies acceptable?

Section 5: Drilling and Core Analysis

Drilling is an important, albeit expensive, aspect of any subsurface resource exploration campaign. Drilling is also dependent on equipment availability and logistics, often competing with other efforts (e.g., oil and gas exploration). Core sampling and analysis are typically used to corroborate large geophysical datasets and improve resource economic predictions. New drilling methods (e.g., measuring while drilling, geosteering, mud analysis) and core analysis workflows may be needed to enhance hydrogen exploration efforts.

a. What technologies can guide horizontal drilling for hydrogen reservoirs?
b. Do new drilling methods need to be developed to improve exploratory drilling operations?
c. What would be the value of vertical wells versus horizontal wells in geologic hydrogen drilling, and what are the relative strengths and weaknesses of each?

d. What core analysis methods are most relevant to resource estimation and modeling for naturally occurring hydrogen or stimulated production through serpentinization?
e. Are there gaps in existing core analysis and laboratory analysis capabilities that need to be addressed?
f. Are there sampling and sample treatment needs that are specific to core analysis for hydrogen?
g. Is there a need to develop new sampling methodologies or are current core sampling methods sufficient for hydrogen exploration?
h. Is new mud-logging analysis needed for the purpose of hydrogen exploration?

Section 6: Monitoring and Characterization for Hydrogen Reservoir Management and Production

The methods for producing hydrogen through tapping into naturally occurring subsurface hydrogen gas flows or through stimulation are quite new. Moving from laboratory studies to the field will require the collection of actionable data to support subsurface engineering efforts and site development. Investment and subsequent production rely on being able to quantify the economic viability by estimating potential economic output (i.e., total potential and production rates), capital expenditures, and operational expenditures. Only when these quantities are more reliably estimated will hydrogen be valued as a natural resource, or a "reserve".

An understanding of unique environmental impacts associated with hydrogen resource extraction, and potential strategies to mitigate those impacts, is also needed. While hydrogen exploration and potential extraction can reduce emissions, environmental impacts go beyond GHGs. An understanding of such impacts is needed to ensure compliance with environmental laws and regulations. Due to the novelty of the geology associated with naturally occurring hydrogen or the stimulation of hydrogen production, new methods will likely need to be developed to assist with reservoir extraction.

a. What is the value of vertical versus horizontal wells for hydrogen production?
b. Is there a need to innovate on drilling production wells?
c. Can artificial fracturing be effectively used to produce naturally occurring subsurface hydrogen?
d. Are new fracturing techniques needed to support hydrogen production by tapping into existing reservoirs or through stimulation by enhanced serpentinization?
e. How would one monitor and evaluate the effectiveness of fracturing?
f. Is there a need for innovation in surveying methodologies to image fracture networks in crystalline rock?
g. Is there a need for innovation in how fractures are imaged within crystalline rock (e.g., ultramafic, mafic) formations?
h. Are there pore scale processes that are critical for the production hydrogen (e.g., mass transfer, multi-phase flow, sorption processes) that need to be considered?
i. What monitoring challenges exist for the safe production of natural hydrogen?
j. Do we need to innovate new methods to allow us to monitor regional or localized hydrogen leakage from reservoirs, volume expansion, and associated induced seismicity?

Section 7: Offshore Exploration

Offshore hydrogen resources, like oil and gas reserves found within continental shelf environments, require special consideration for exploration and production. Operating in this environment requires more significant capital expenditures to effectively discover and predict the economic viability of these resources. Exploring the continental shelf and beyond for hydrogen resources requires methods that may differ significantly from those used in terrestrial environments.

a. Do continental shelf methodologies for oil and gas resource exploration translate to hydrogen exploration?
b. Is there a need to innovate new waterborne resource assessment modalities specific for hydrogen exploration within the continental shelf regions?
c. Are oil and gas offshore seismic survey designs suitable for hydrogen discovery?
d. Is there a need to develop new geophysical or remote chemical sensors specific to surveying continental shelf environments for hydrogen accumulations or stimulation targets?
e. Are there topological signatures characteristic with subsurface hydrogen production specific to offshore environments?
f. Do topological signatures characteristic with subsurface hydrogen differ from topological features characteristic of hydrogen production on land?
g. How can one perform a cost-effective search for topological signatures characteristic with hydrogen production on the ocean floor?
h. Are there biological signatures that may indicate the presence of shallow geologic hydrogen deposits?
i. Is there a need to develop underwater or seafloor exploration methods specific for hydrogen exploration within continental shelves? How would these methods have capabilities that differ from technologies available today?
j. What previous data could be relevant for offshore hydrogen exploration? Are there current sources of this data, and if so, who has custody of this data?
k. Do continental shelf exploration drilling methods need to be developed for the purpose of drilling for hydrogen accumulations in offshore environments?
l. What are the potential environmental concerns associated with both the resource evaluation and extraction of hydrogen from offshore reservoirs, and how may they be mitigated?
m. Is there a rationale to extend exploratory interest for hydrogen beyond the shelf break?